

# Beyond the Standard Model with low-energy precision tests

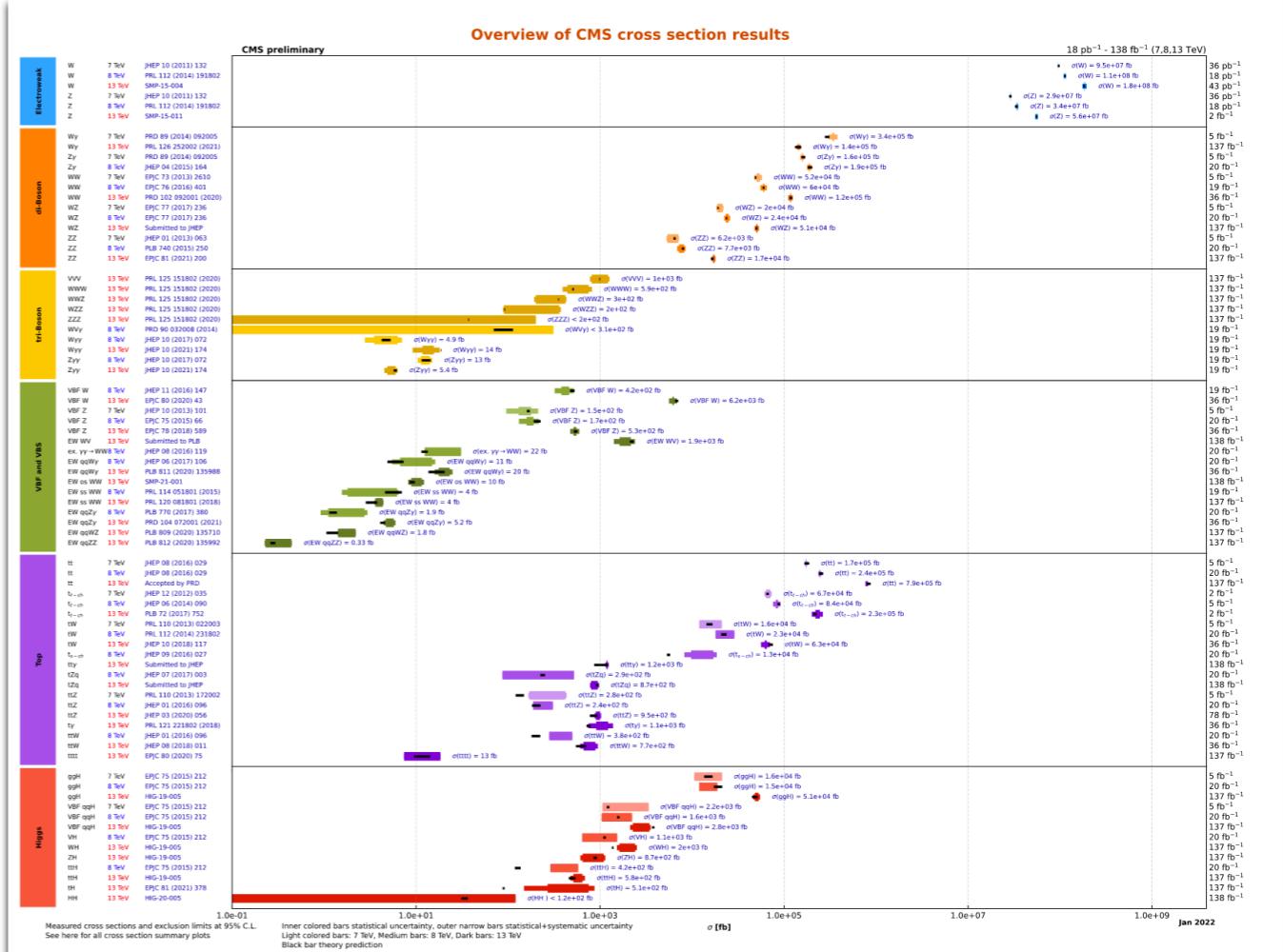
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with

T. Tong, V. Cirigliano, J. de Vries, E. Mereghetti

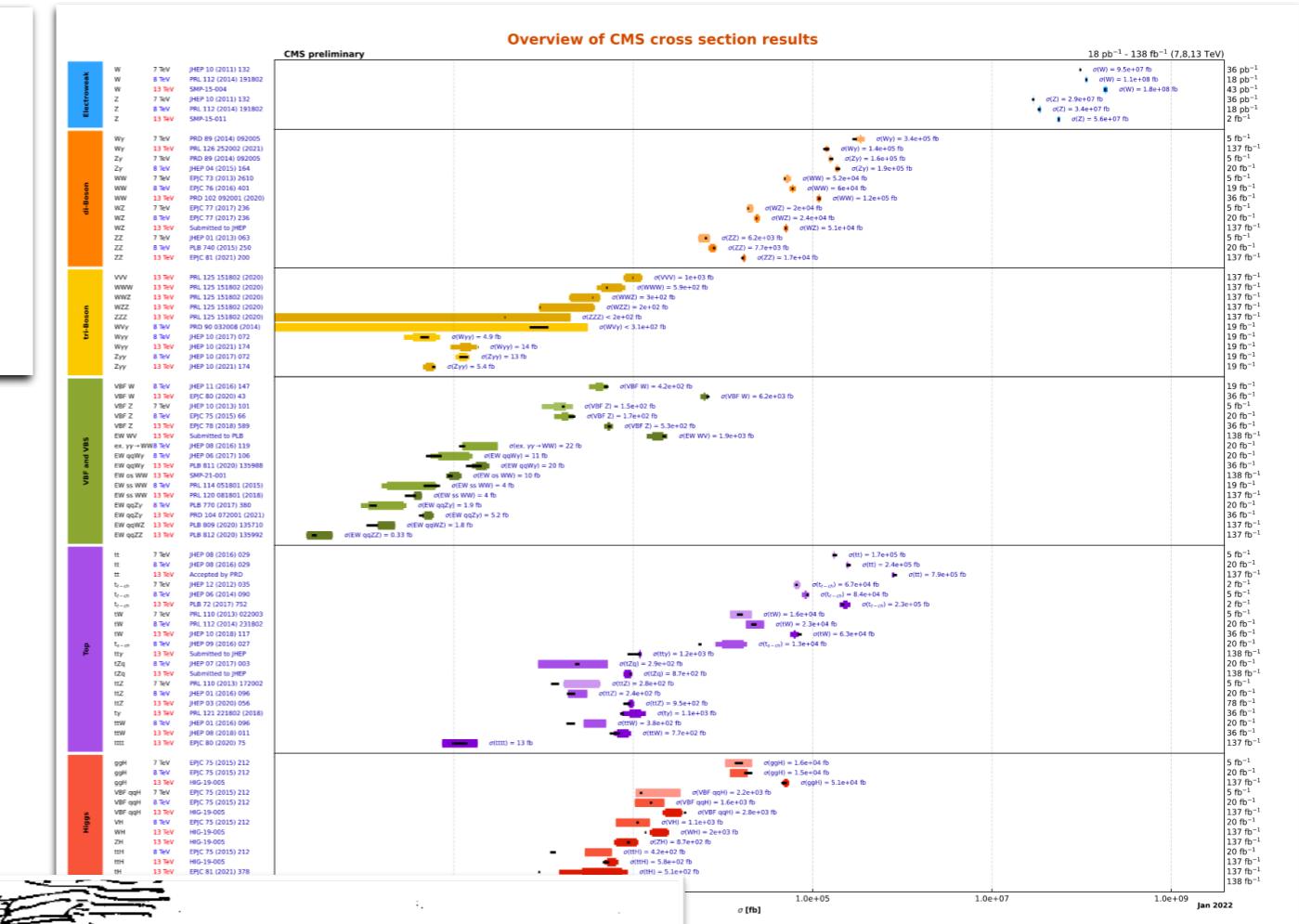
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- Standard Model is very successful
  - At the LHC
  - Low-energy precision expts.



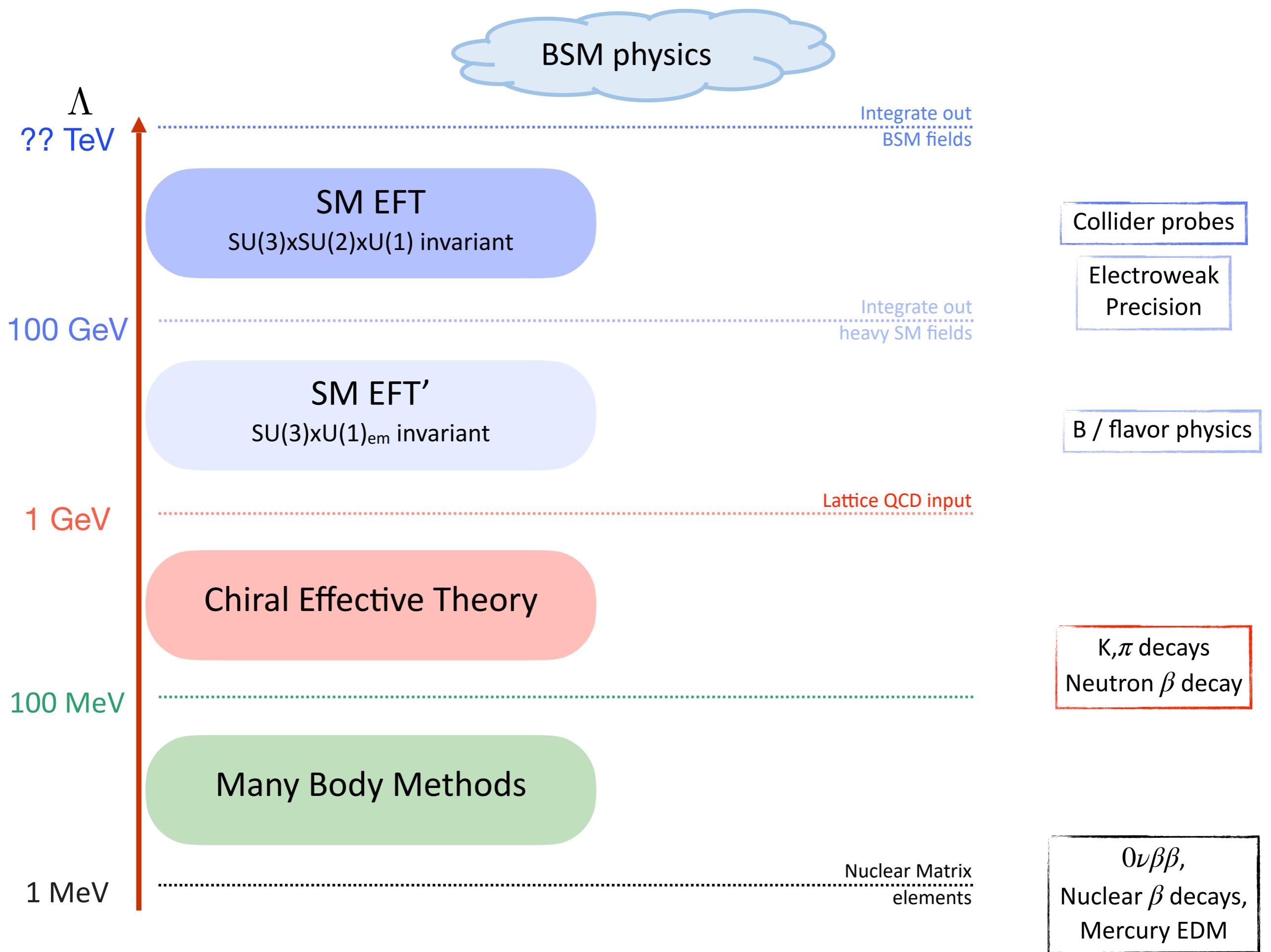
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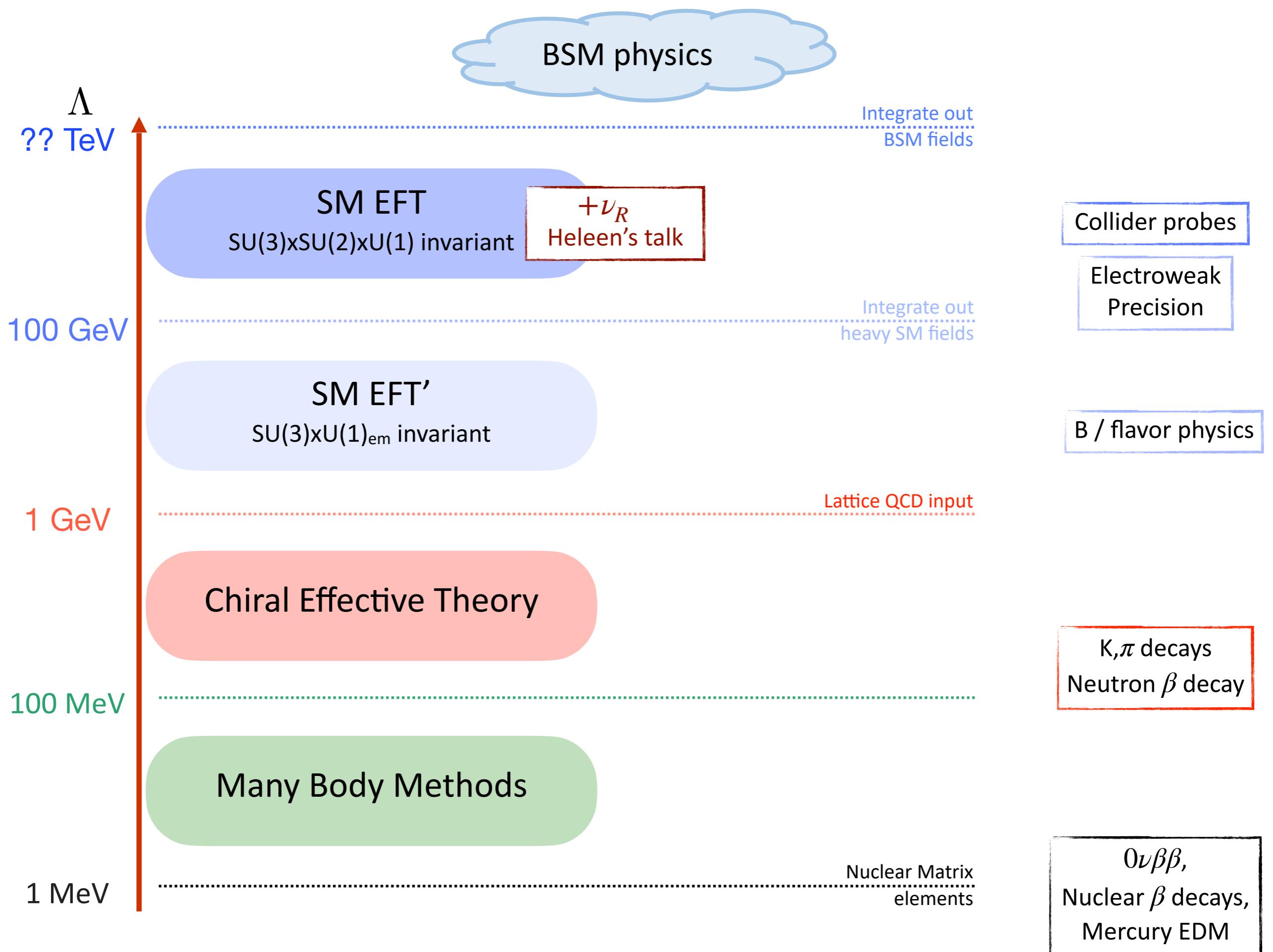
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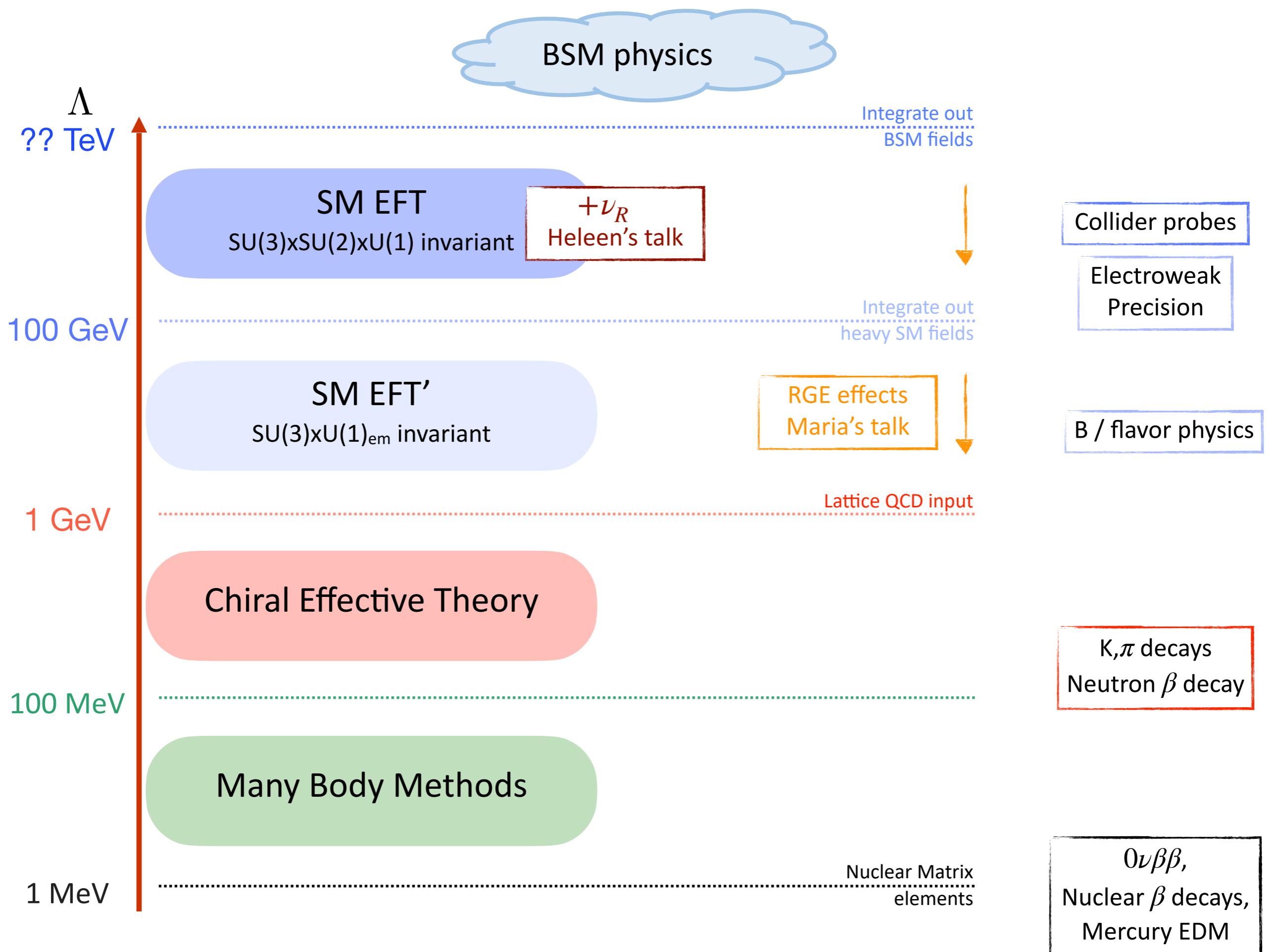


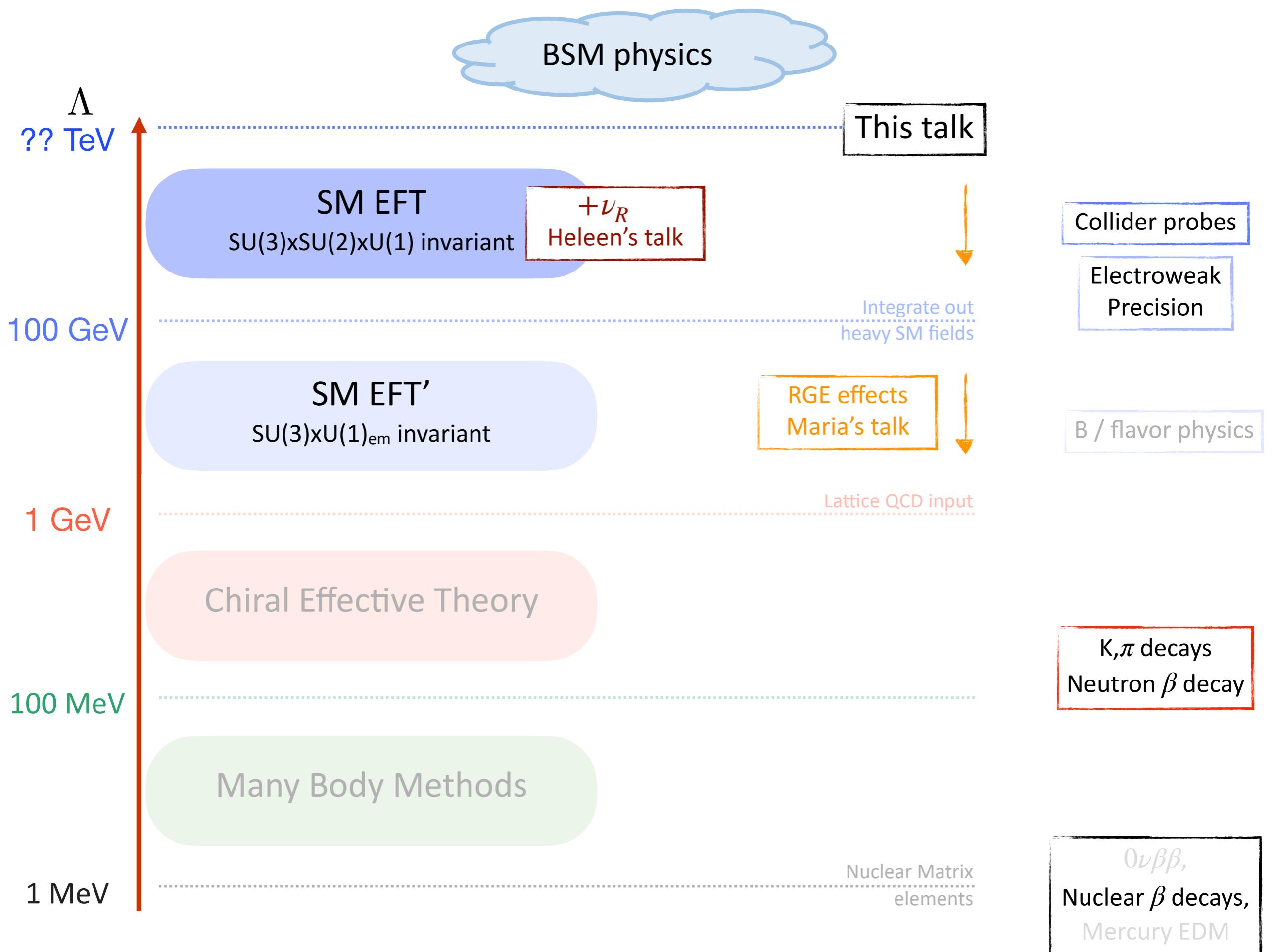
However,

- What is dark matter?
- How do neutrinos get their masses?
- Baryon asymmetry of the universe







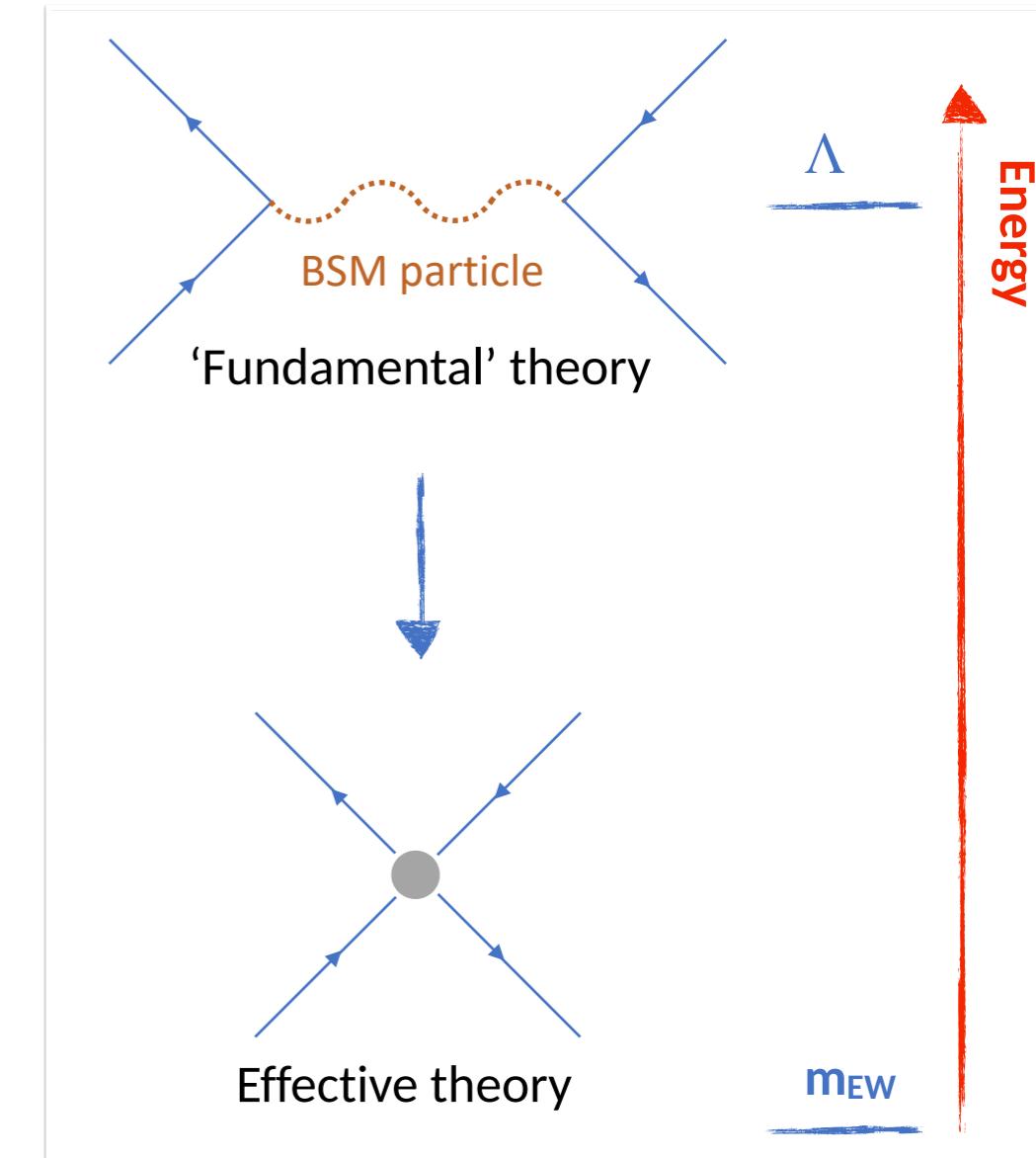


# The SM Effective Field Theory

## Describing BSM physics

### Assumptions

- No new light degrees of freedom
- BSM physics appears above the electroweak scale,  
 $\Lambda \gg v$
- $\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_5^{(i)}}{\Lambda} O_5^{(i)} + \sum_i \frac{C_6^{(i)}}{\Lambda^2} O_6^{(i)} + \dots$



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### Dimension five operators

- One term, generates Majorana neutrino masses

$$\frac{g}{M_T} (\bar{L}^c \tilde{\phi}^*) (\tilde{\phi}^\dagger L)$$

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### Dimension-six operators

$X^3$		$\varphi^6$ and $\varphi^4 D^2$		$\psi^2 \varphi^3$	
$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi \square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p u_r \tilde{\varphi})$
$Q_W$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^\star (\varphi^\dagger D_\mu \varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi \tilde{W} B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\varphi^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$	$B$ -violating
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$
$Q_{duq}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} [(d_p^\alpha)^T C u_r^\beta] [(q_s^\gamma)^T C l_t^k]$
$Q_{qqu}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(u_s^\gamma)^T C e_t]$
$Q_{qqq}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} \varepsilon_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^{\gamma m})^T C l_t^n]$
$Q_{qqq}$	$\varepsilon^{\alpha\beta\gamma} (\tau^I \varepsilon)_{jk} (\tau^I \varepsilon)_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^{\gamma m})^T C l_t^n]$
$Q_{duu}$	$\varepsilon^{\alpha\beta\gamma} [(d_p^\alpha)^T C u_r^\beta] [(u_s^\gamma)^T C e_t]$

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$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
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$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$		$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} \varepsilon_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^{\gamma m})^T C l_t^n]$	
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$		$\varepsilon^{\alpha\beta\gamma} (\tau^I \varepsilon)_{jk} (\tau^I \varepsilon)_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^{\gamma m})^T C l_t^n]$	
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$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma} (\tau^I \varepsilon)_{jk} (\tau^I \varepsilon)_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^m)^T C l_t^n]$						
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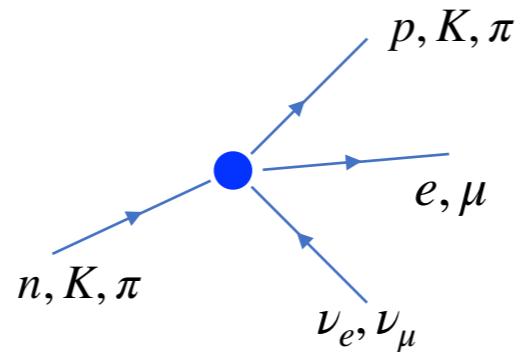
  

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$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi) (\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi) (\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi) (\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\varphi^\dagger D_\mu \varphi) (\bar{u}_p \gamma^\mu d_r)$

		$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r) (\bar{d}_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r) (\bar{u}_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r) (\bar{d}_s \gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}_s \gamma^\mu T^A d_t)$
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$B$ -violating			
$Q_{ledq}$	$(\bar{l}_p^j e_r) (\bar{d}_s q_t^j)$	$Q_{duq}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} [(d_p^\alpha)^T C u_r^\beta] [(q_s^j)^T C l_t^k]$		
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{qqu}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(u_s^\gamma)^T C e_t]$		
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\varepsilon^{\alpha\beta\gamma} \varepsilon_{jk} \varepsilon_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^m)^T C l_t^n]$		
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\varepsilon^{\alpha\beta\gamma} (\tau^I \varepsilon)_{jk} (\tau^I \varepsilon)_{mn} [(q_p^{\alpha j})^T C q_r^{\beta k}] [(q_s^m)^T C l_t^n]$		
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{duu}$	$\varepsilon^{\alpha\beta\gamma} [(d_p^\alpha)^T C u_r^\beta] [(u_s^\gamma)^T C e_t]$		

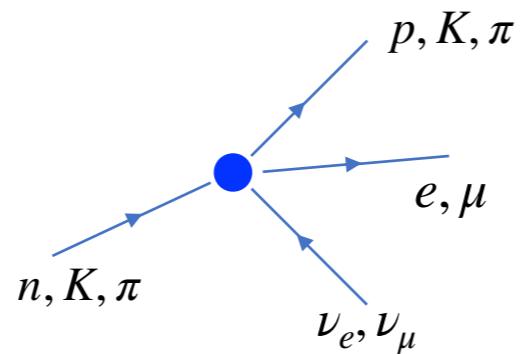
# Observables

- Low energy measurements
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  - $K \rightarrow (\pi)\ell\nu, \pi \rightarrow (\pi)\ell\nu$

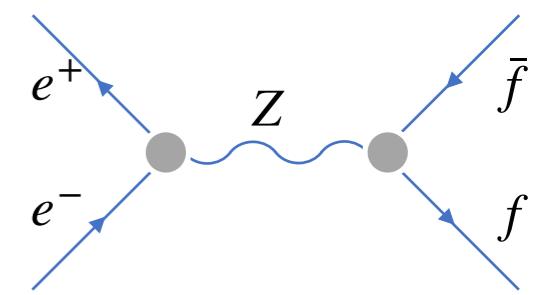


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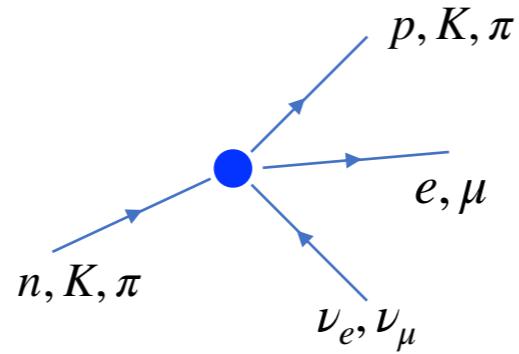


- Electroweak precision
  - Measurements at the Z pole
  - $e^+e^- \rightarrow Z \rightarrow \bar{f}f$

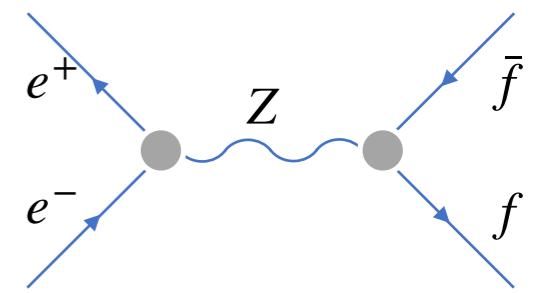


# Observables

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  - $K \rightarrow (\pi)\ell\nu, \pi \rightarrow (\pi)\ell\nu$



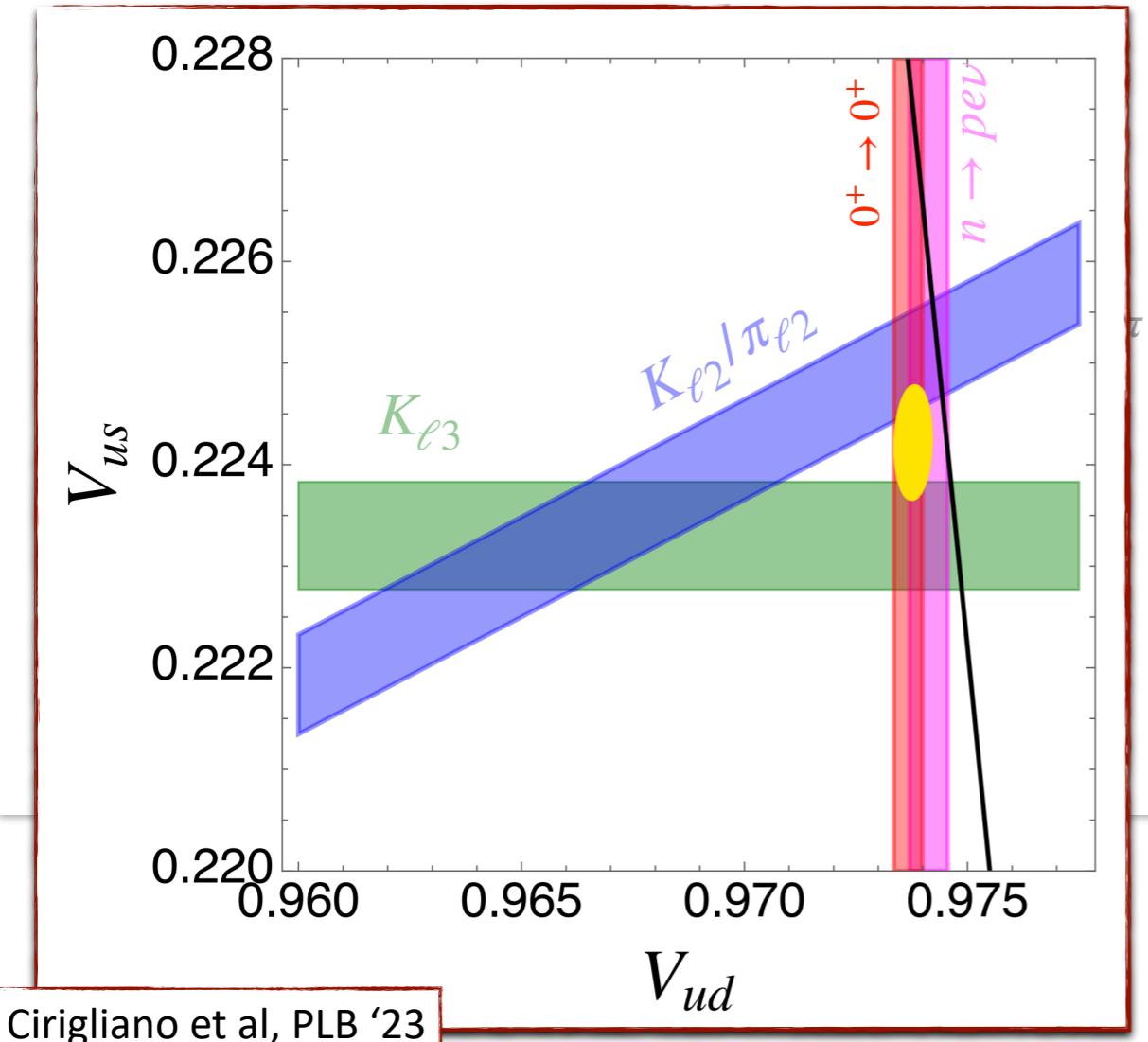
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  - Measurements at the Z pole
  - $e^+e^- \rightarrow Z \rightarrow \bar{f}f$



- Both types involve high precision measurements
  - High relative precision  $\lesssim \mathcal{O}(10^{-3})$
  - Probe high BSM scales,  $\Lambda \simeq \sqrt{10^3 v} = \mathcal{O}(10 \text{ TeV})$

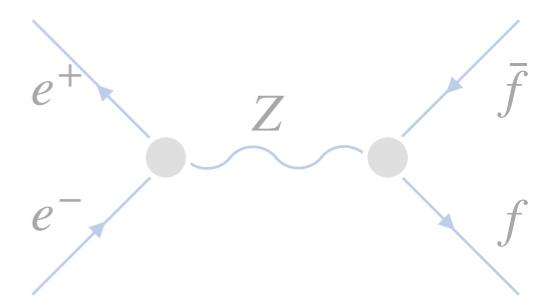
# Observables

- Low energy measurements



- Electroweak precision

- Measurements at the Z pole
- $e^+e^- \rightarrow Z \rightarrow f\bar{f}$



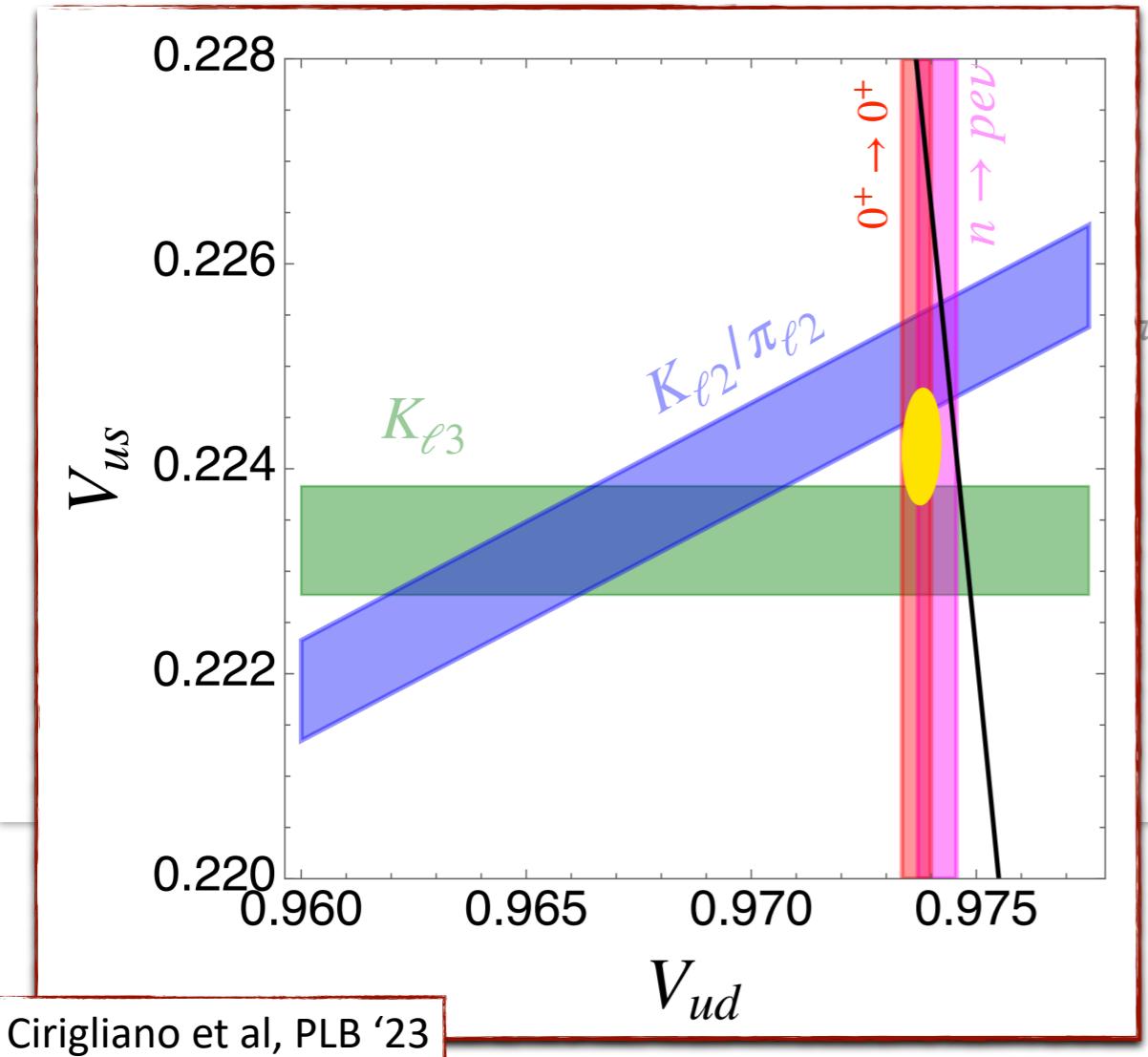
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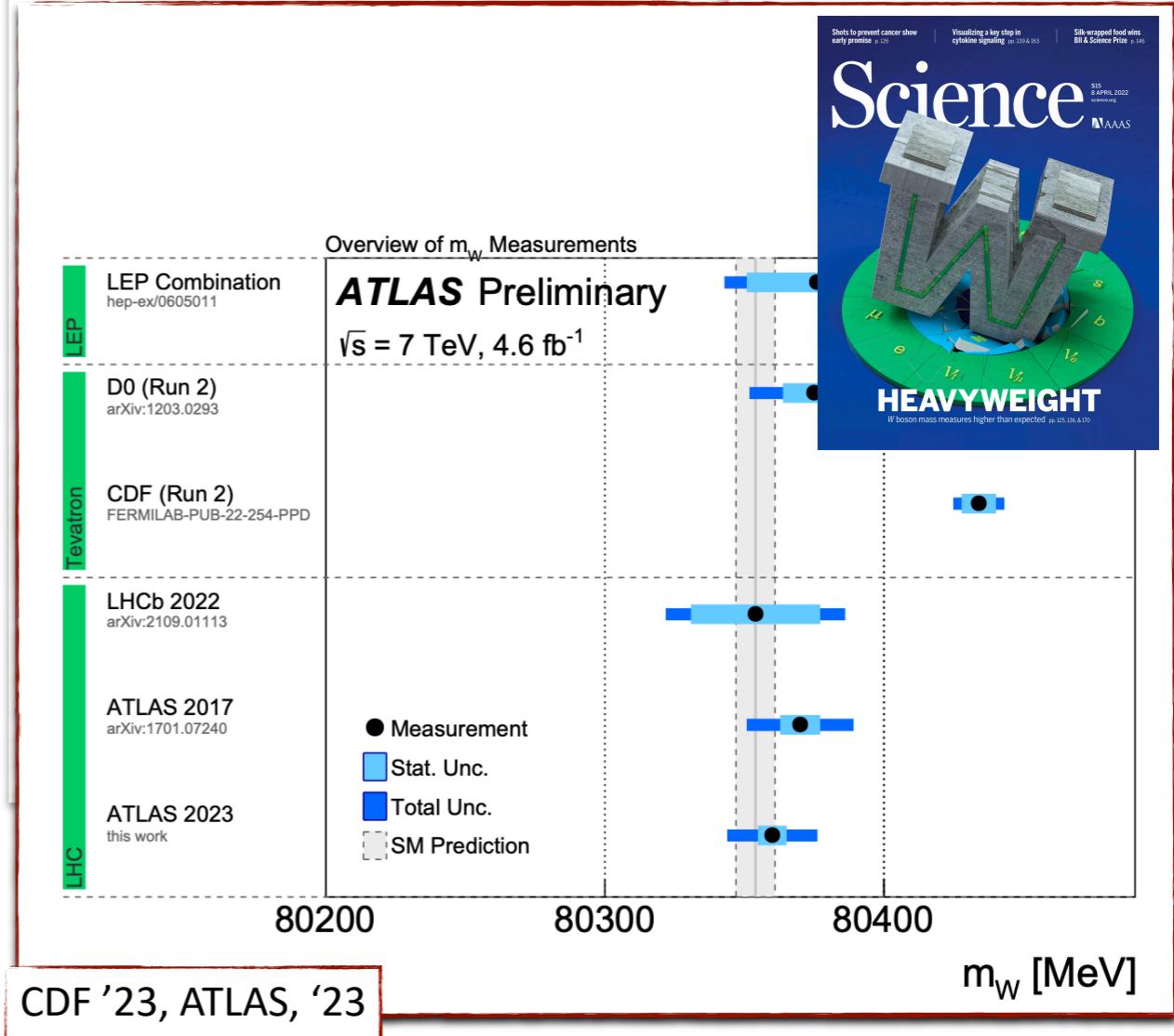
- Both involve discrepancies with the SM

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- Both types involve high precision measurements

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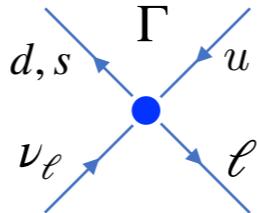
# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$	
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_W$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$		
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \widetilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi \widetilde{W}B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$

- Low energy measurements

- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
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$$\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d)(\bar{\ell} \Gamma \nu_\ell)$$



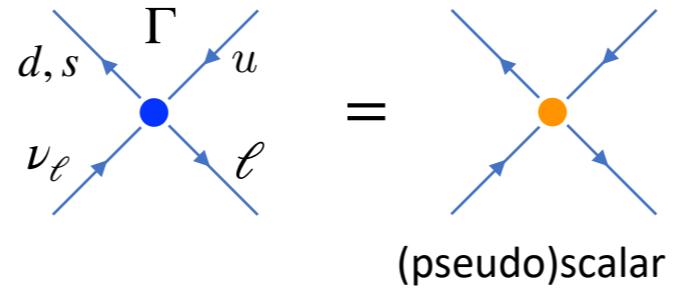
# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$	
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\varphi\Box}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi) (\bar{l}_p e_r \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_{\varphi D}$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p u_r \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$		$\varepsilon^{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p d_r \varphi)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$

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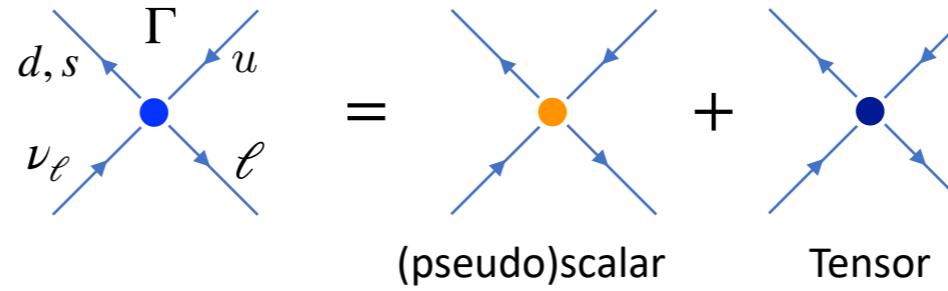
# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$	
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\varphi\Box}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi) (\bar{l}_p e_r \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_{\varphi D}$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p u_r \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$		$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p d_r \varphi)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi\tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi\tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$

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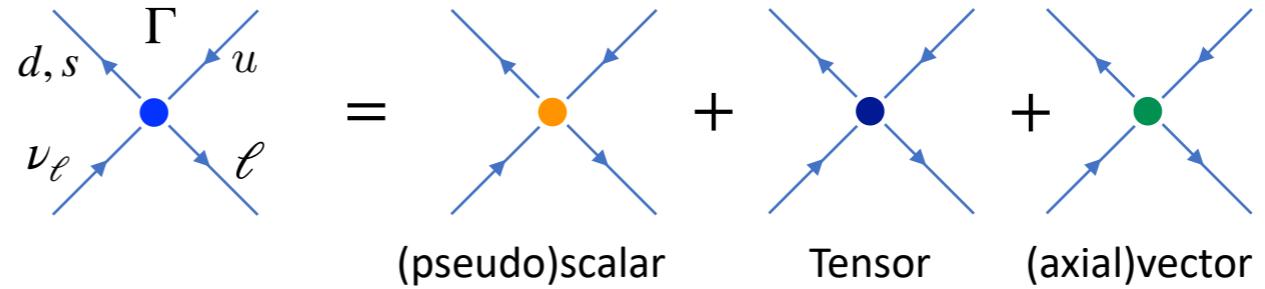
# Observables

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$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_W$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$		
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \widetilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi \widetilde{W}B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$

- Low energy measurements

- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

$$\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d)(\bar{\ell} \Gamma \nu_\ell)$$



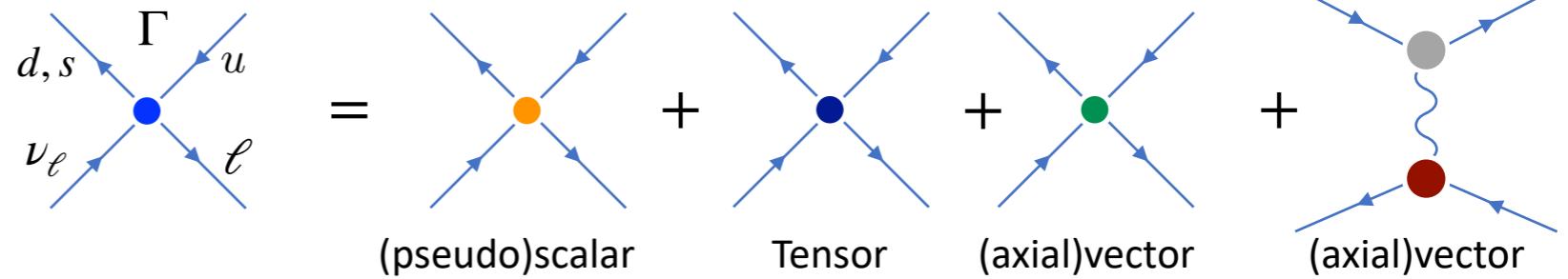
# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$	
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\varphi\Box}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi) (\bar{l}_p e_r \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_{\varphi D}$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p u_r \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$		$\varepsilon^{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi) (\bar{q}_p d_r \varphi)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$
				$Q_{\varphi ud}$	$i(\tilde{\varphi}^\dagger D_\mu \varphi) (\bar{u}_p \gamma^\mu d_r)$

- Low energy measurements

- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

$$\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d)(\bar{\ell} \Gamma \nu_\ell)$$



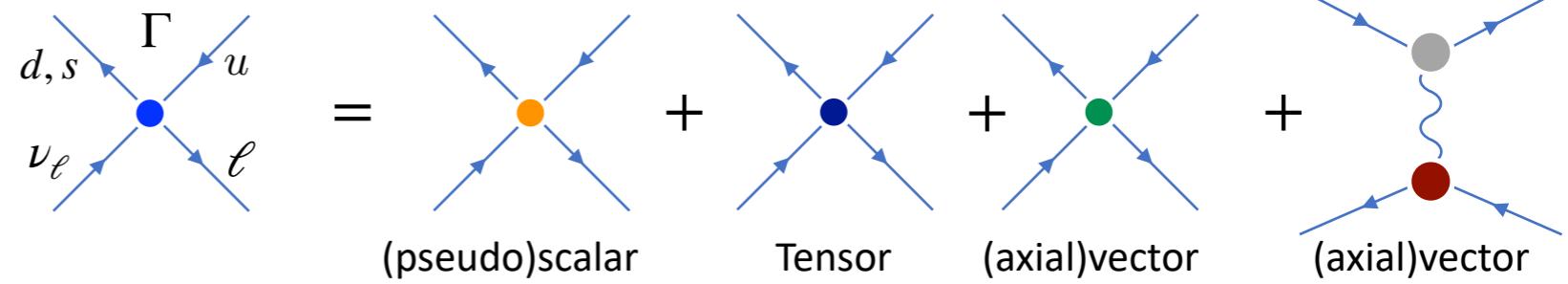
# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{e\varphi}$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$	$Q_{u\varphi}$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$	$Q_{d\varphi}$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$			
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$			
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{\varphi l}^{(1)}$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{\varphi l}^{(3)}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{\varphi e}$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{\varphi q}^{(1)}$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{\varphi q}^{(3)}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{\varphi e}$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{\varphi u}$
		$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{\varphi d}$
				$i(\tilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$
				$Q_{\varphi ud}$

- Low energy measurements

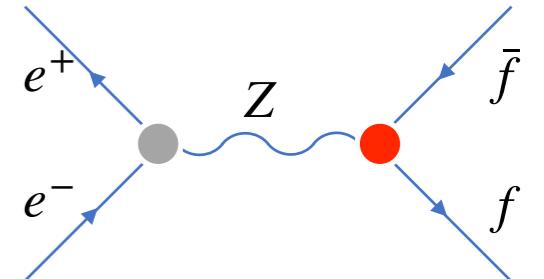
- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

$$\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d)(\bar{\ell} \Gamma \nu_\ell)$$



- Electroweak precision

- Described in SMEFT
- Affected by corrections to the Z couplings (*neutral* currents)



Berthier, Trott '15; de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

# Observables

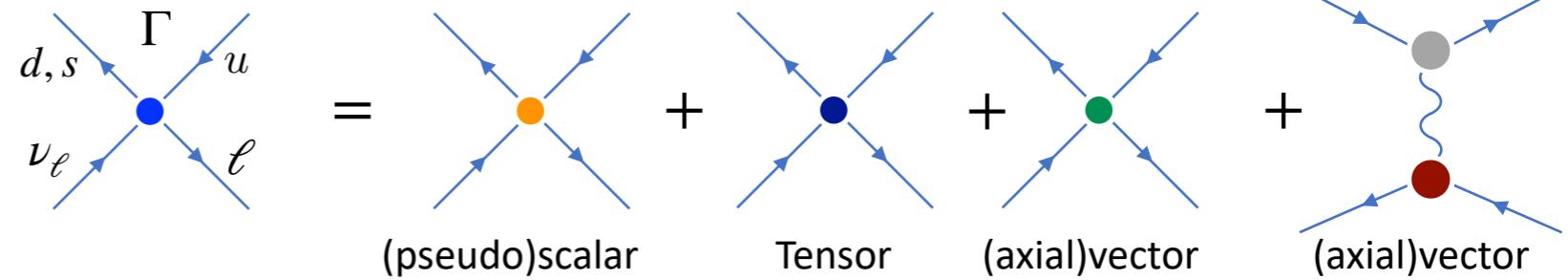
- Shifts to  $G_F$ ,  $m_Z$ ,  $\sin^2 \theta_W$

$X^3$		$\varphi^6$ and $\varphi^4 D^2$		$\psi^2 \varphi^3$	
$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p u_r \tilde{\varphi})$
$Q_W$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^*$ $(\varphi^\dagger D_\mu \varphi)$	$Q_{d\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi \widetilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu^I \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi \widetilde{W} B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

## • Low energy measurements

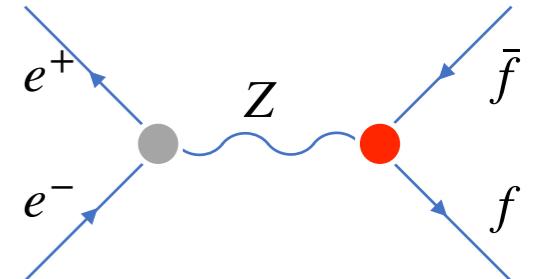
- Described by effective 4-fermion interactions in LEFT (Lee-Yang theory)
- Affected by *charged* currents

$$\mathcal{L}_{LEFT} \sim G_F \epsilon_\Gamma (\bar{u} \Gamma d)(\bar{\ell} \Gamma \nu_\ell)$$



## • Electroweak precision

- Described in SMEFT
- Affected by corrections to the Z couplings (*neutral* currents)



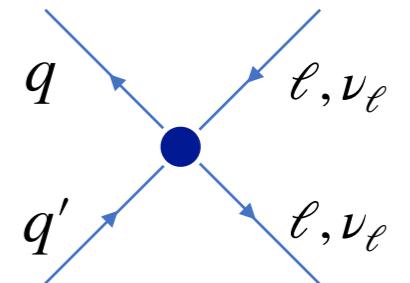
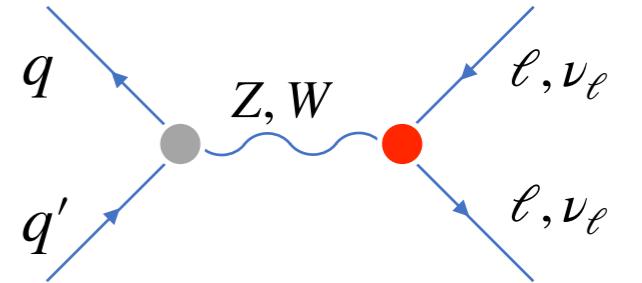
Berthier, Trott '15; de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

# Observables

$(\bar{L}L)(\bar{L}L)$		$X^3$	$\varphi^6$ and $\varphi^4 D^2$	$\psi^2 \varphi^3$	
$Q_{ll}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	$Q_G$	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_\varphi$	$(\varphi^\dagger \varphi)^3$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi) \square (\varphi^\dagger \varphi)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	$Q_W$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^* (\varphi^\dagger D_\mu \varphi)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$		
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$				
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		$X^2 \varphi^2$	$\psi^2 X \varphi$	$\psi^2 \varphi^2 D$	
$Q_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$Q_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \tilde{\varphi} G_{\mu\nu}^A$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \varepsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{\varphi \widetilde{W}}$	$\varphi^\dagger \varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	$Q_{uW}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \tilde{\varphi} W_{\mu\nu}^I$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \varepsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	$Q_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tilde{\varphi} B_{\mu\nu}$
		$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$Q_{dG}$	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$
		$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	$Q_{dW}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$
		$Q_{\varphi \widetilde{W}B}$	$\varphi^\dagger \tau^I \varphi \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	$Q_{dB}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$
				$Q_{\varphi uc}$	$i(\tilde{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$
				$Q_{\varphi ud}$	

- LHC measurements

- Described in SMEFT
- $pp \rightarrow \ell\ell, \ell\nu_\ell$  affected by *charged & neutral currents*



- Use HighPT package at dimension-six level

# Example:

## Explaining a heavy W

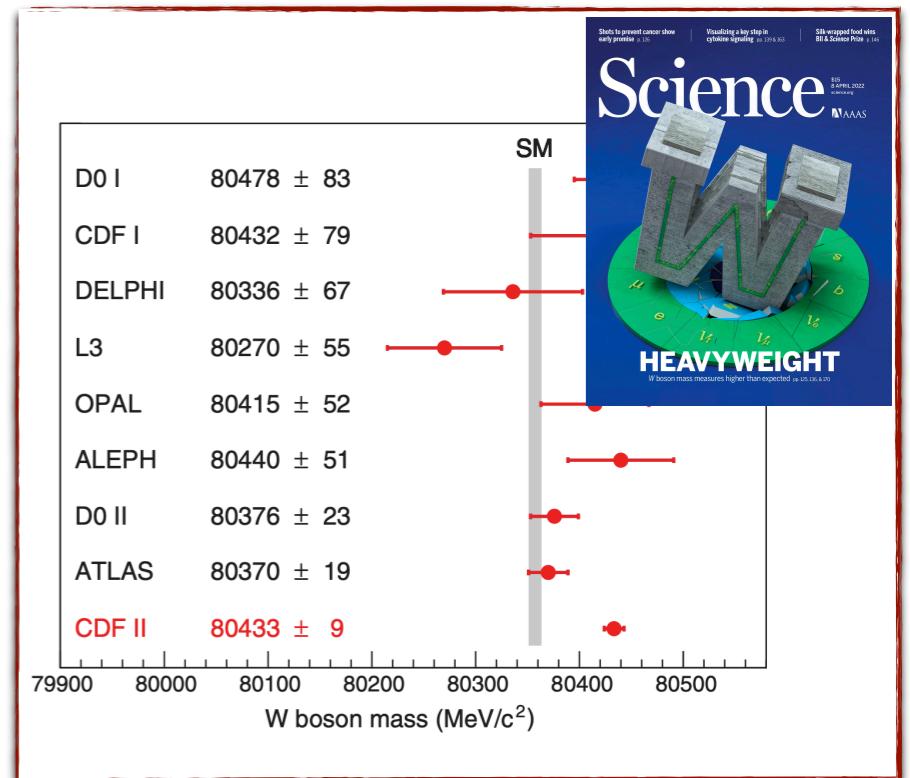
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# Explaining a heavy W

de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

- SMEFT analyses explaining  $m_W$

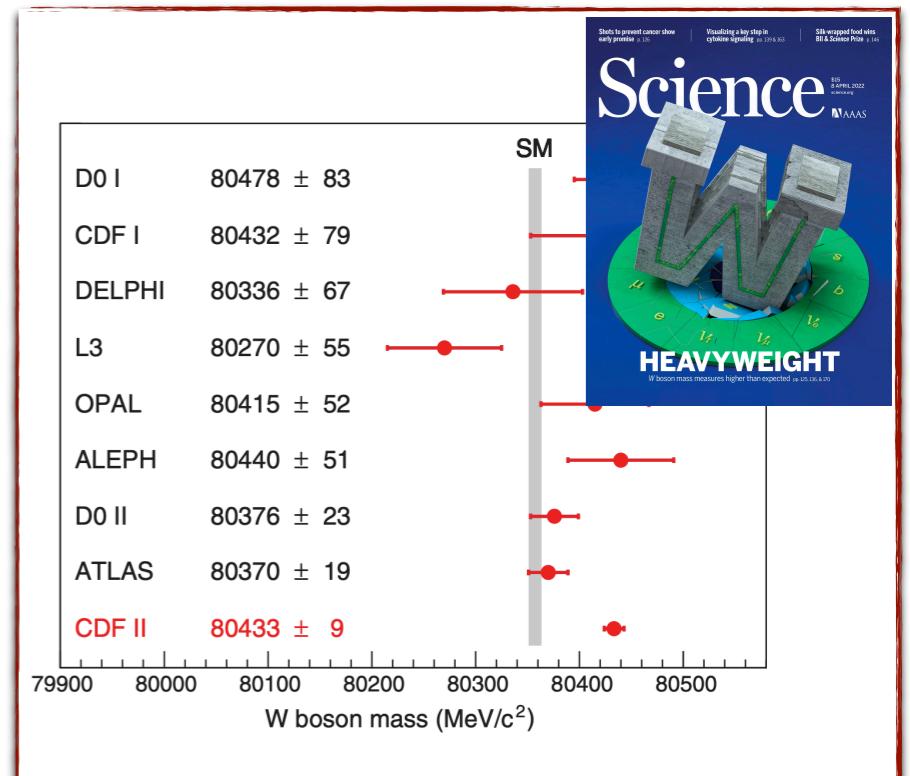
- Assume  $U(3)^5$ : 8 flavor-independent couplings
- Fit to electroweak precision data



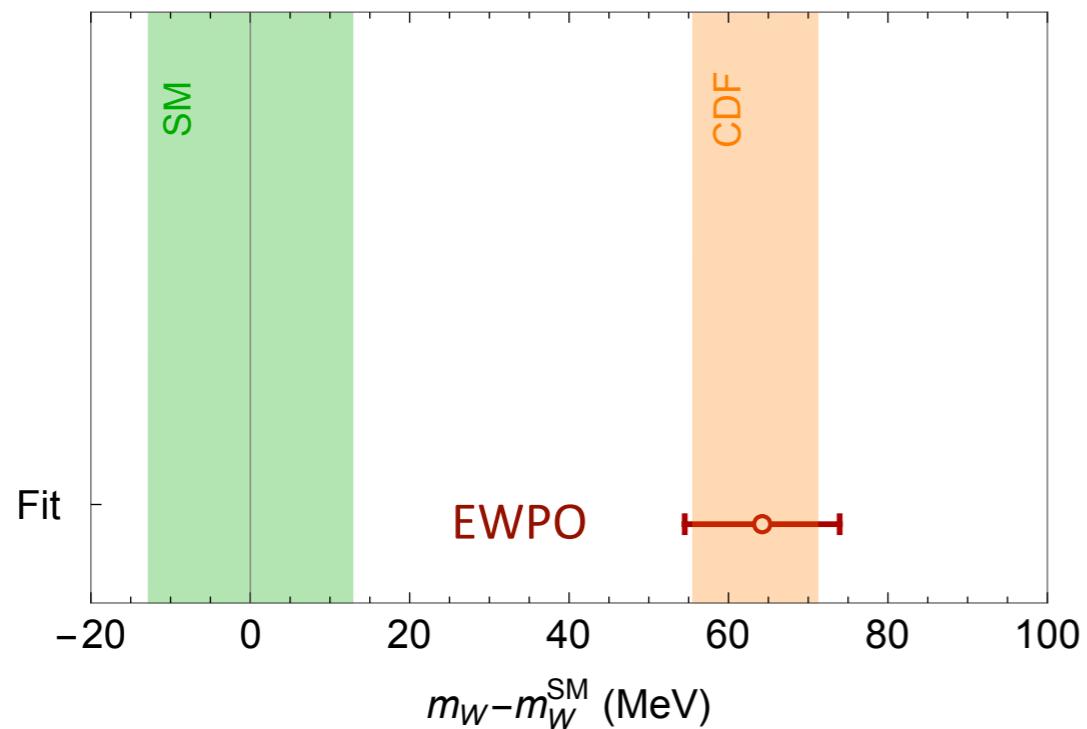
# Explaining a heavy W

de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

- SMEFT analyses explaining  $m_W$ 
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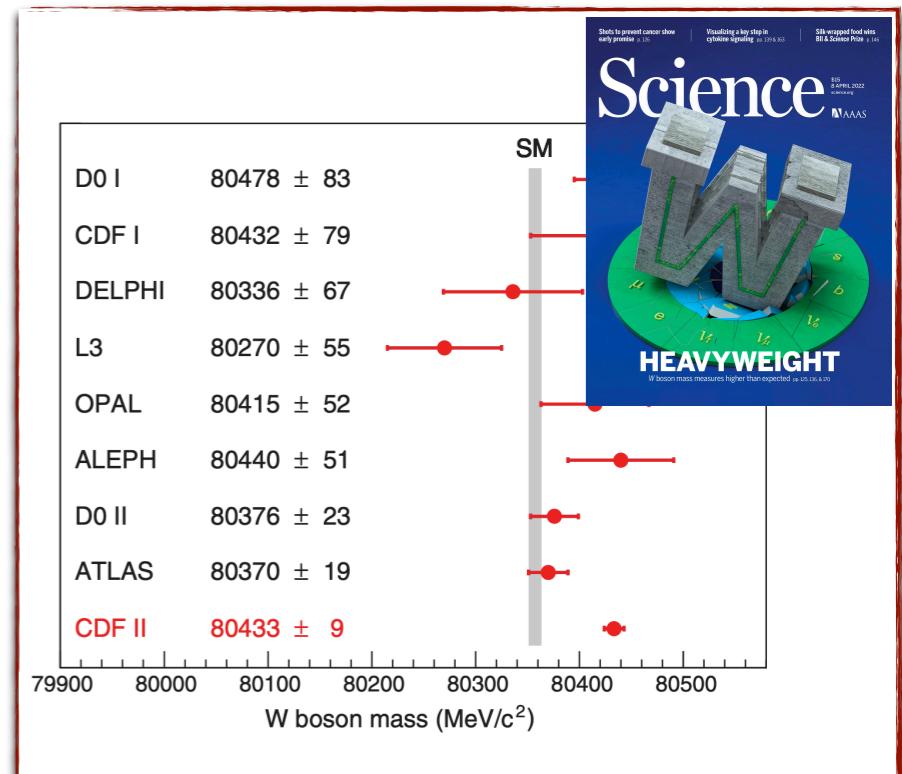
- Can resolve the CDF  $m_W$  discrepancy



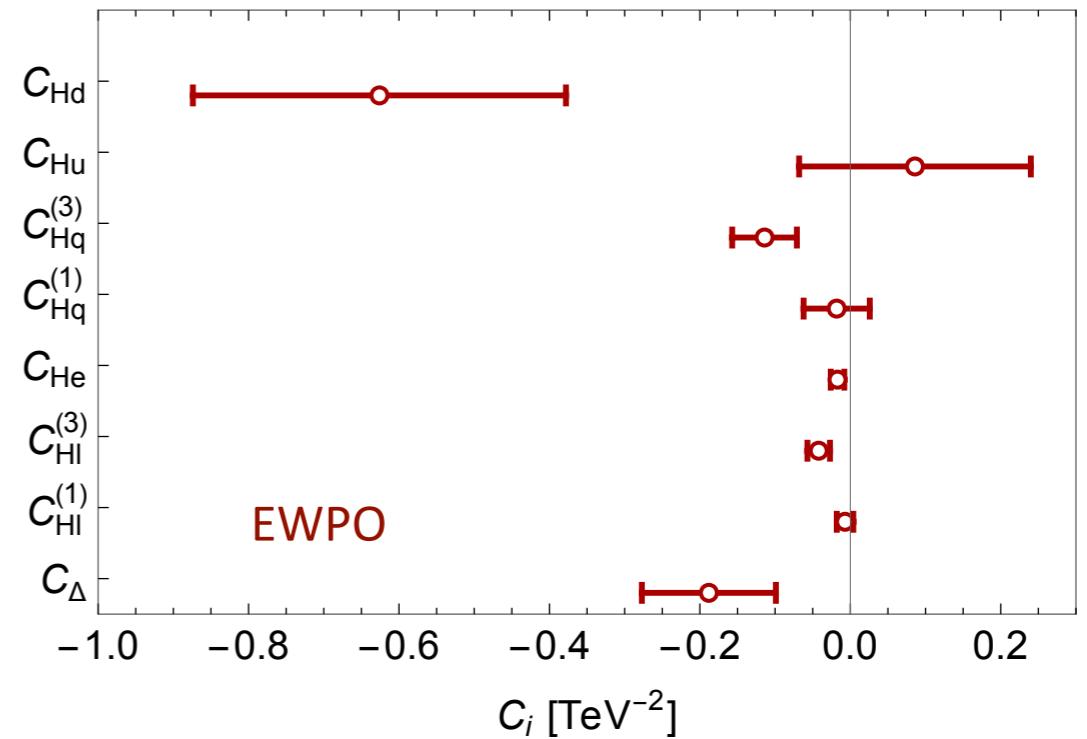
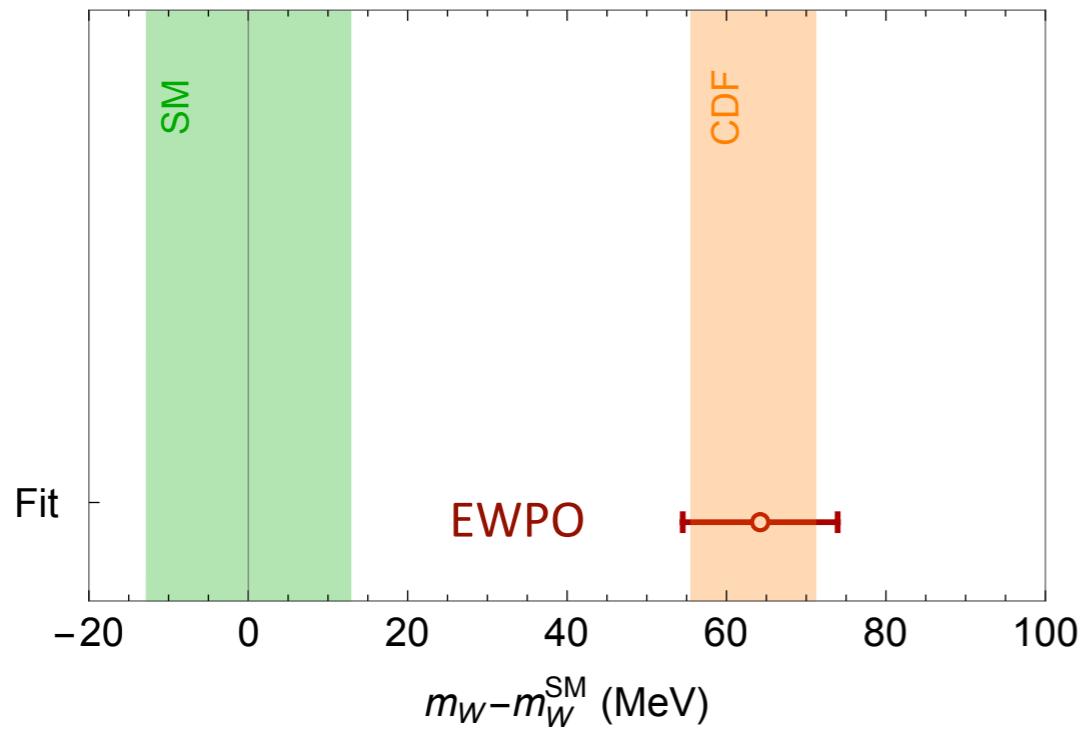
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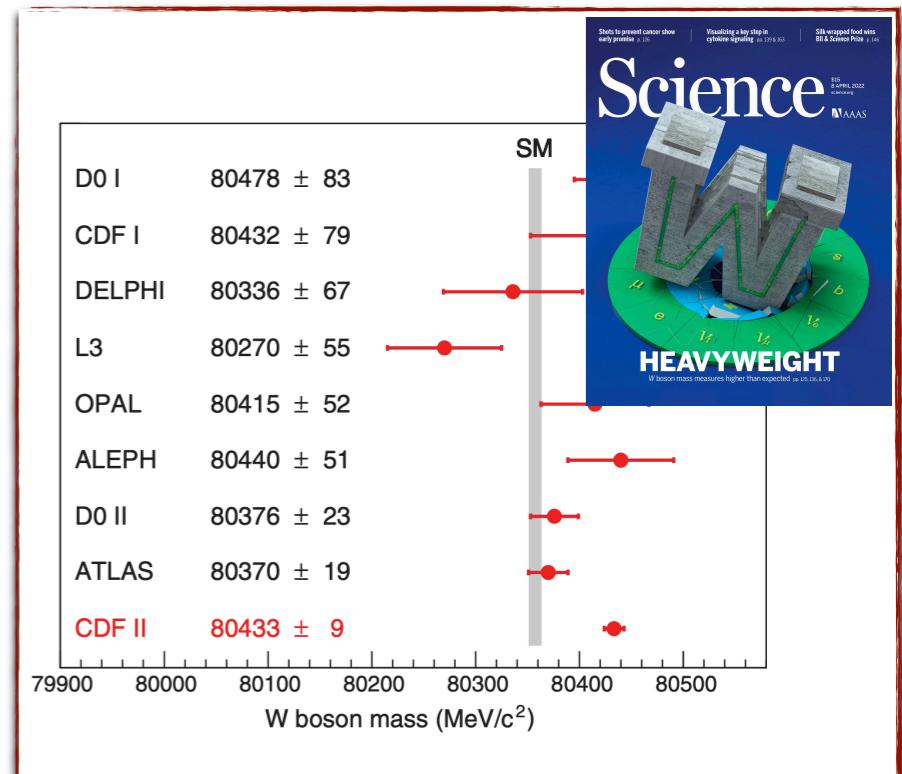
- Can resolve the CDF  $m_W$  discrepancy
  - Gives several nonzero BSM couplings



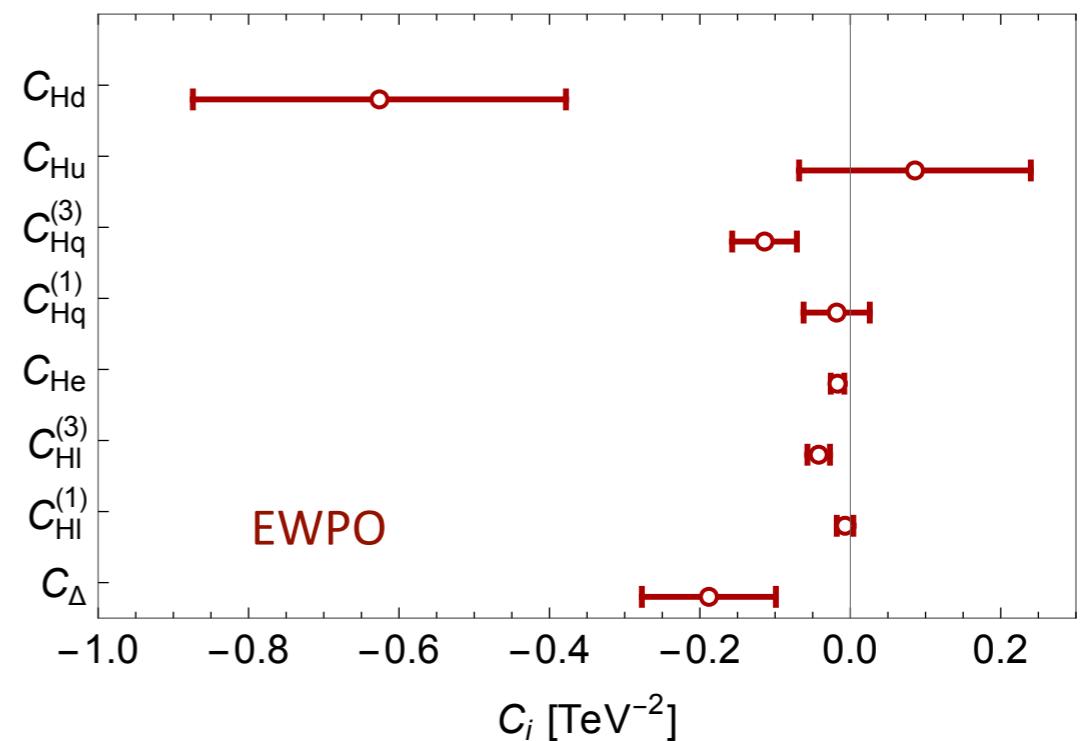
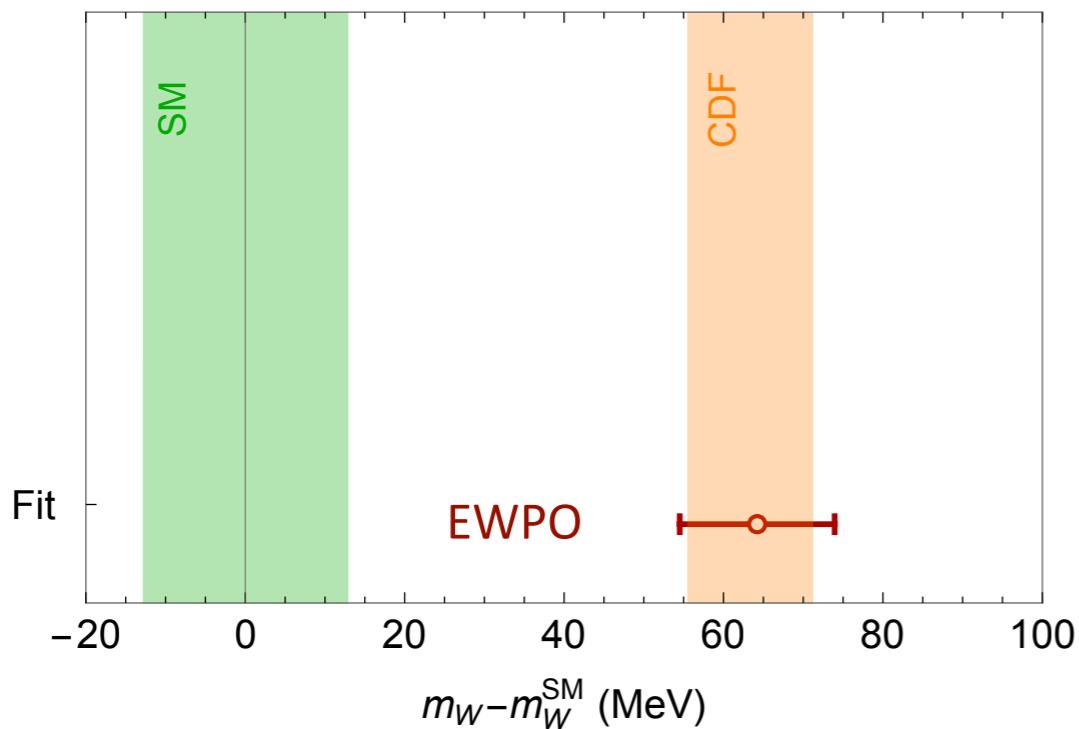
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de Blas et al '22,'21; Balkin et al '22; Bagnaschi et al '22

- SMEFT analyses explaining  $m_W$ 
  - Assume  $U(3)^5$ : 8 flavor-independent couplings
  - Fit to electroweak precision data



- Can resolve the CDF  $m_W$  discrepancy
  - Gives several nonzero BSM couplings

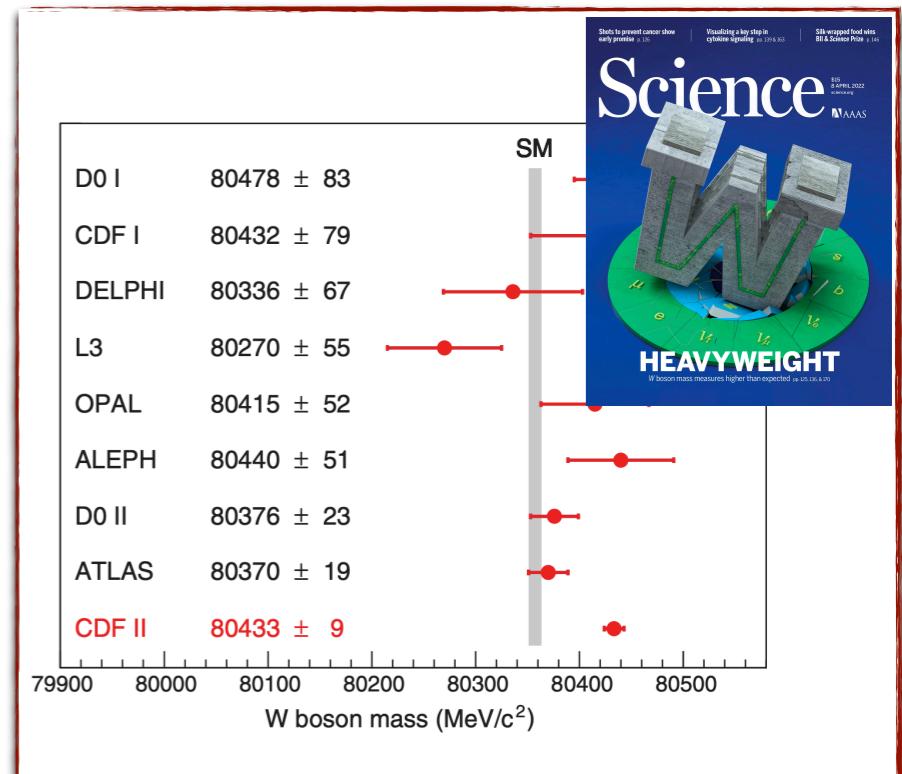


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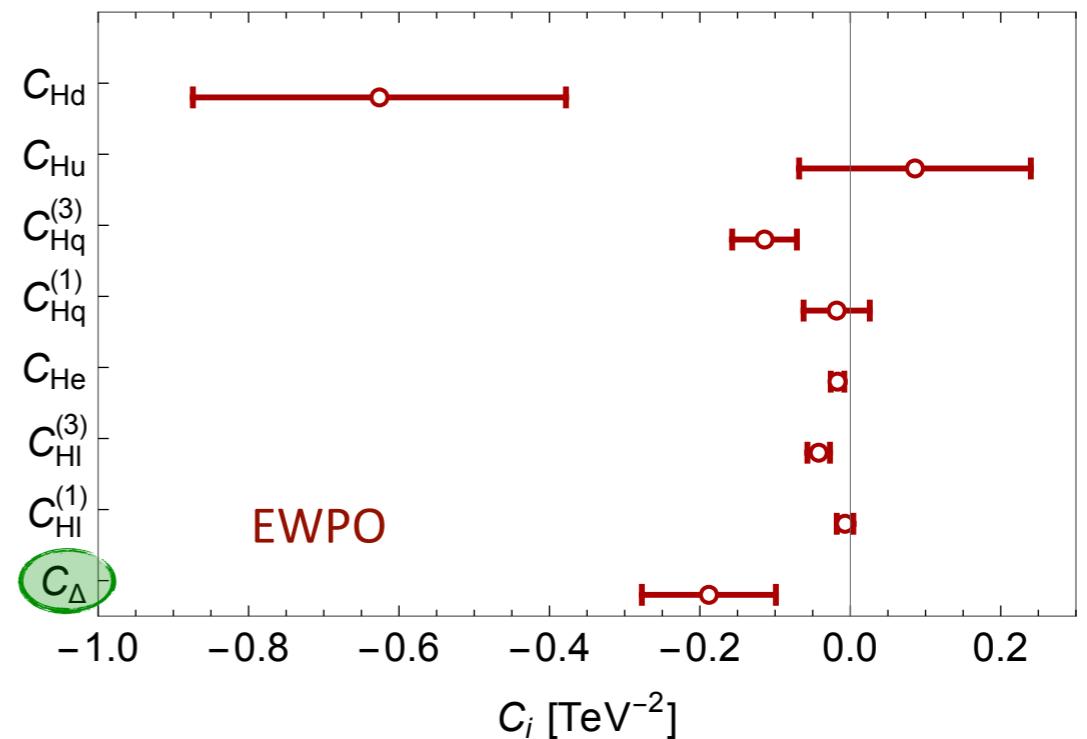
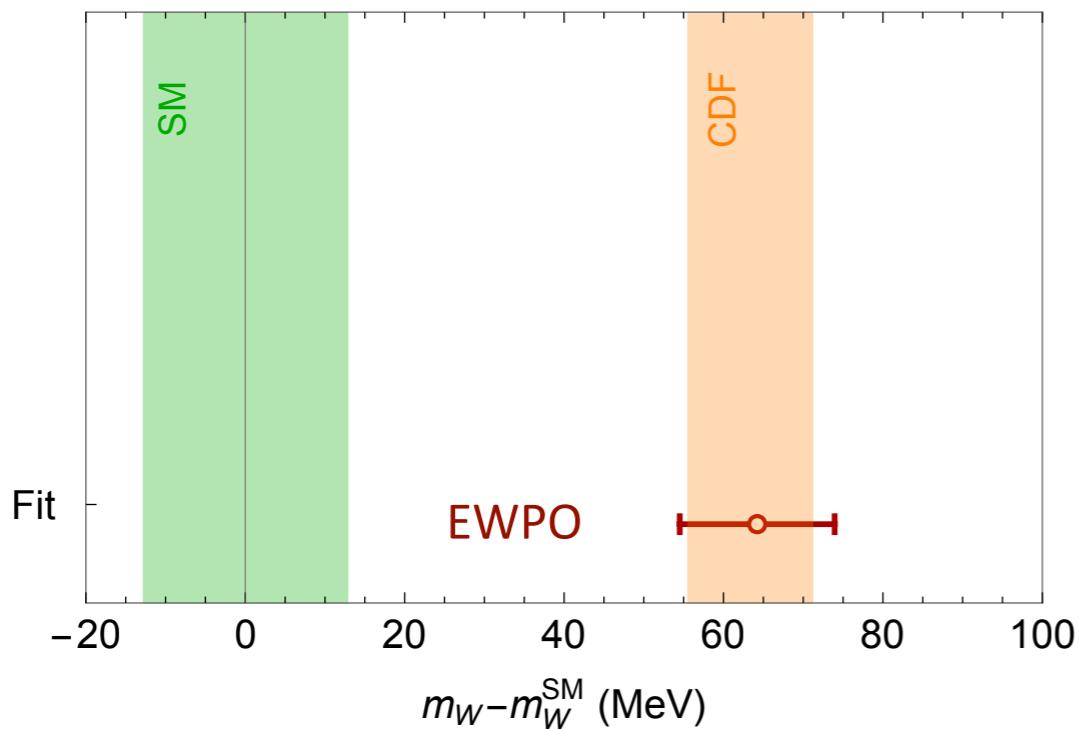
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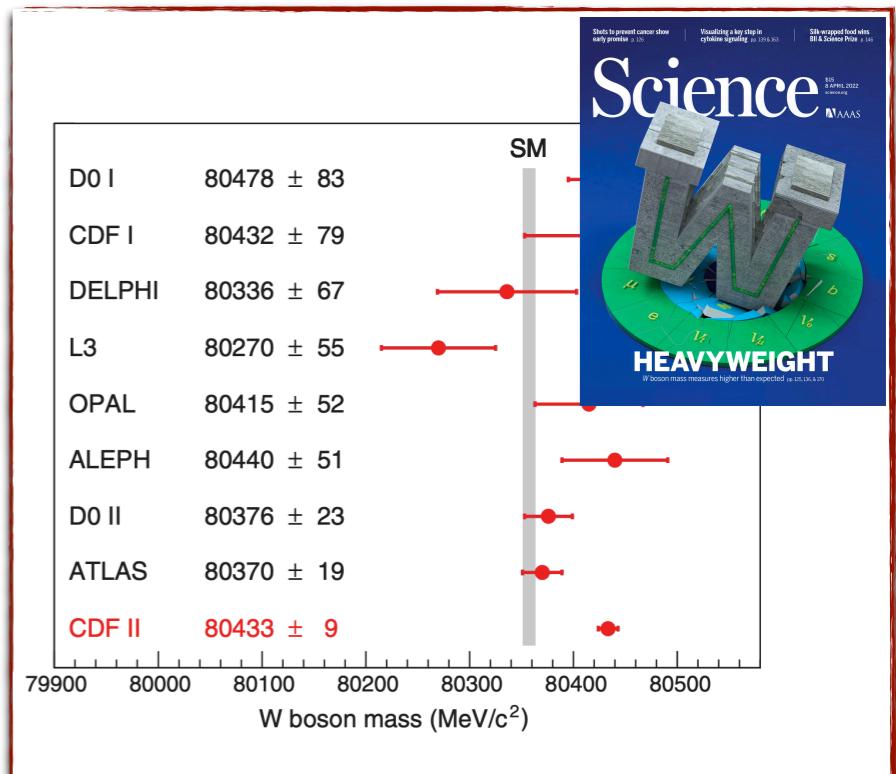


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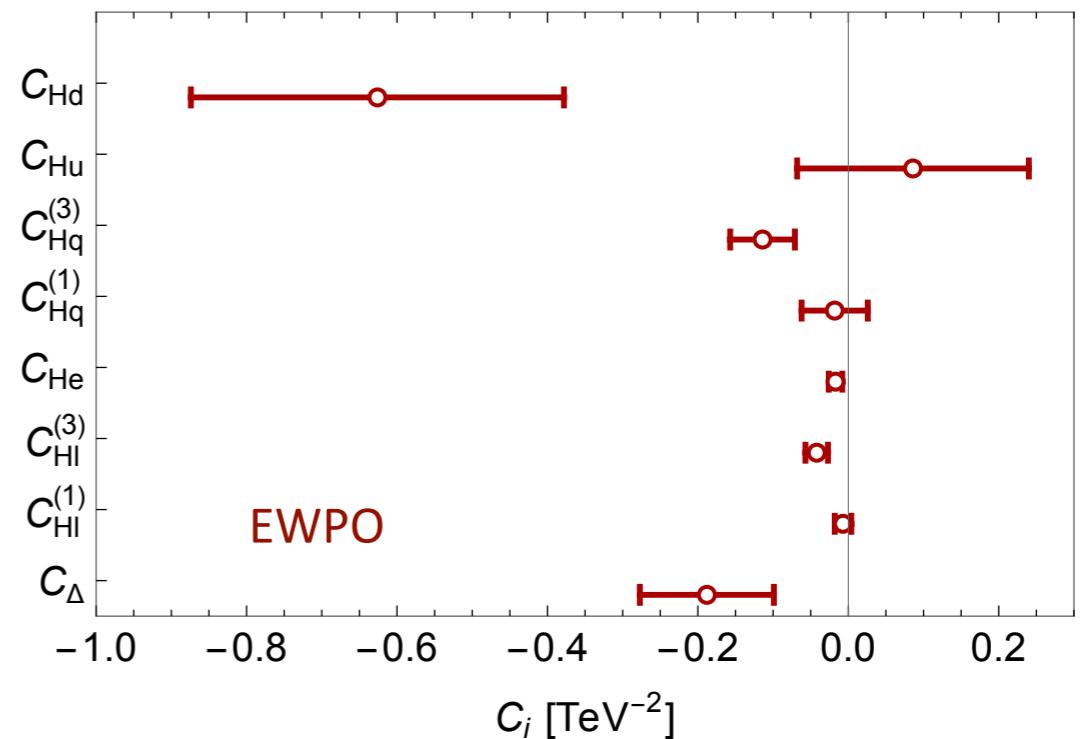
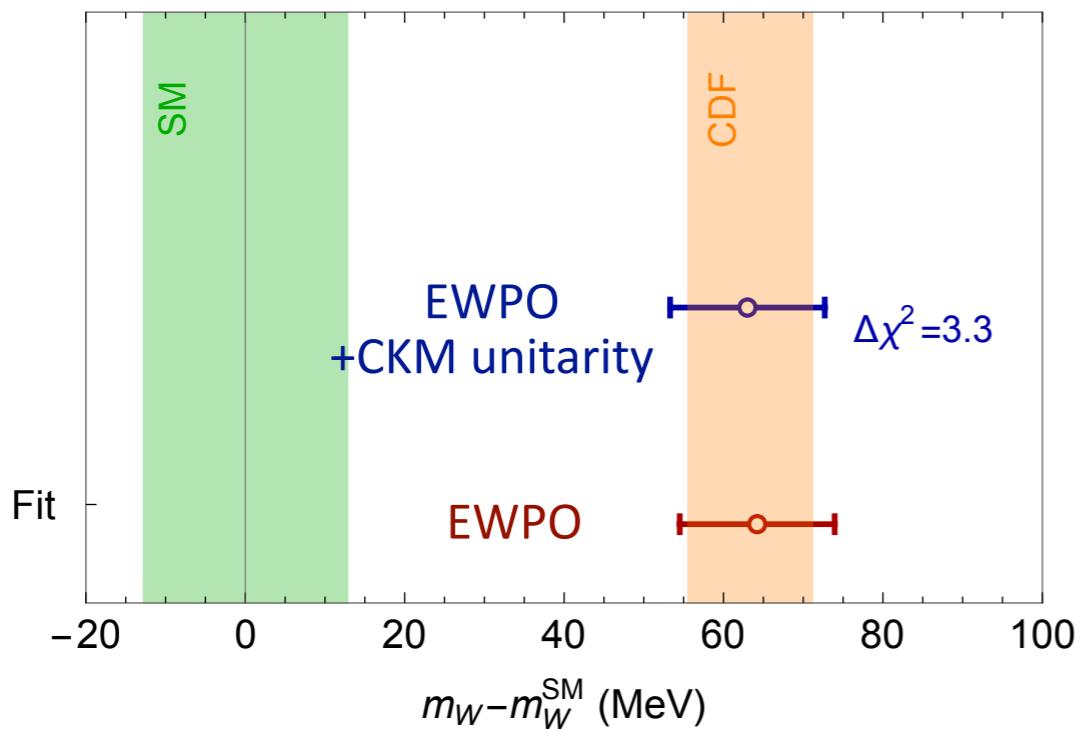
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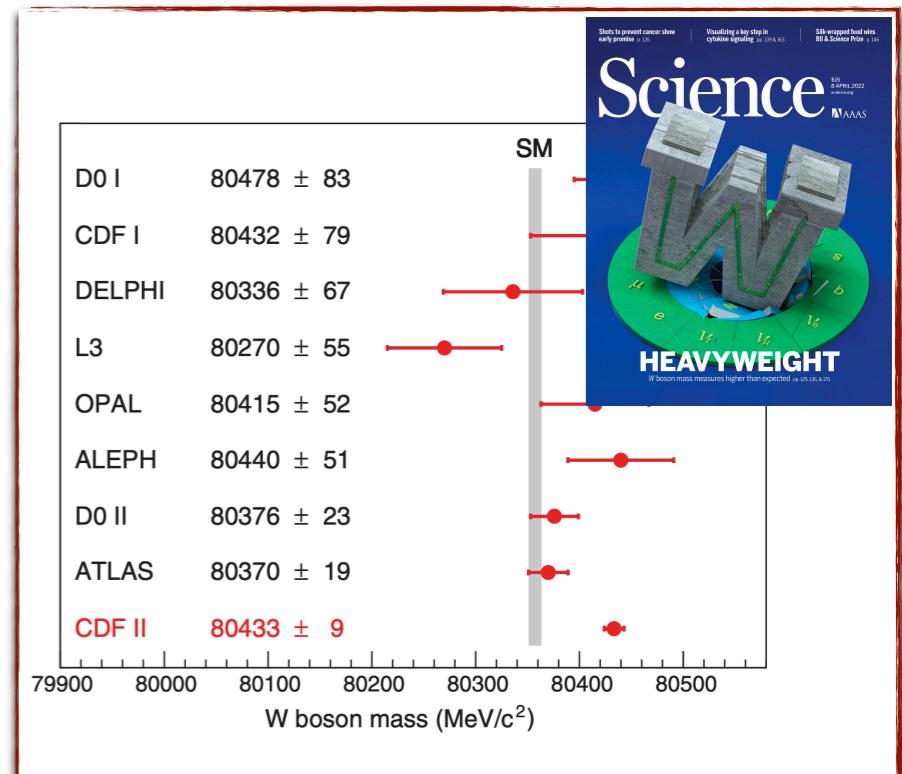


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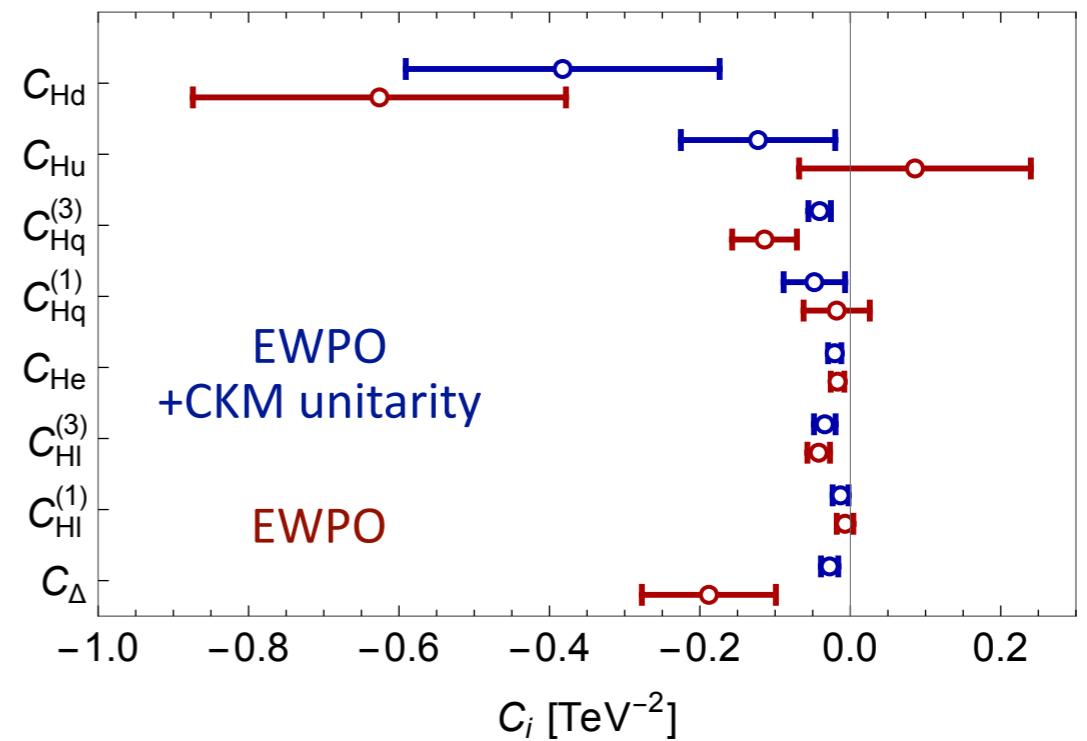
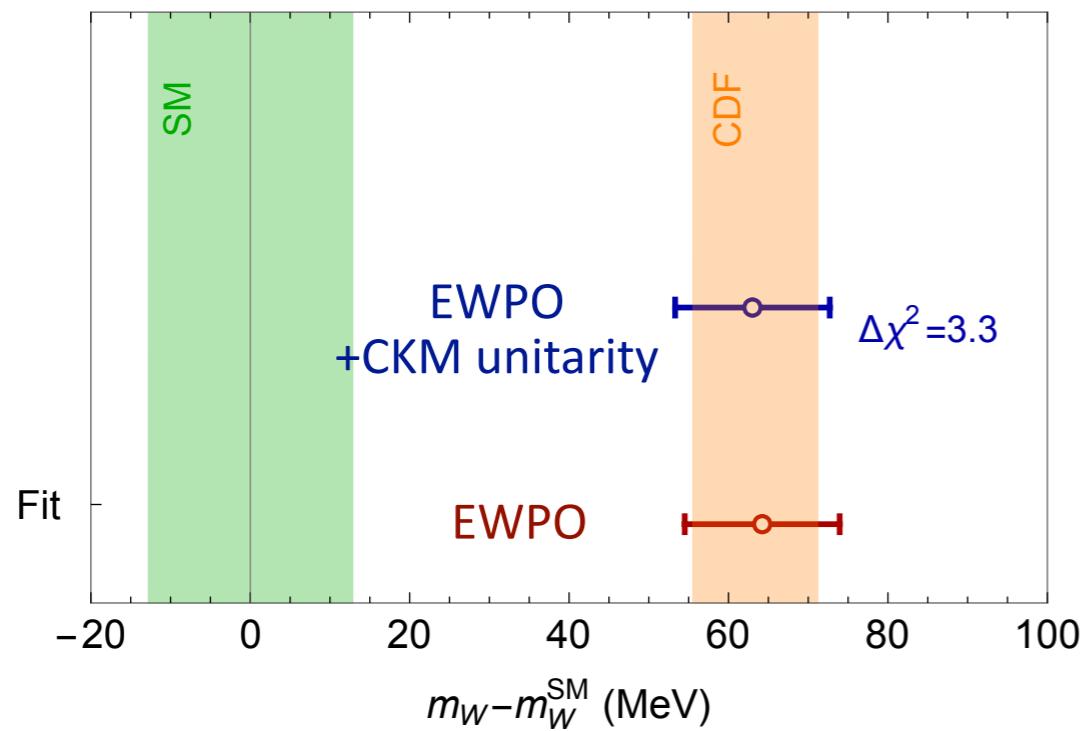
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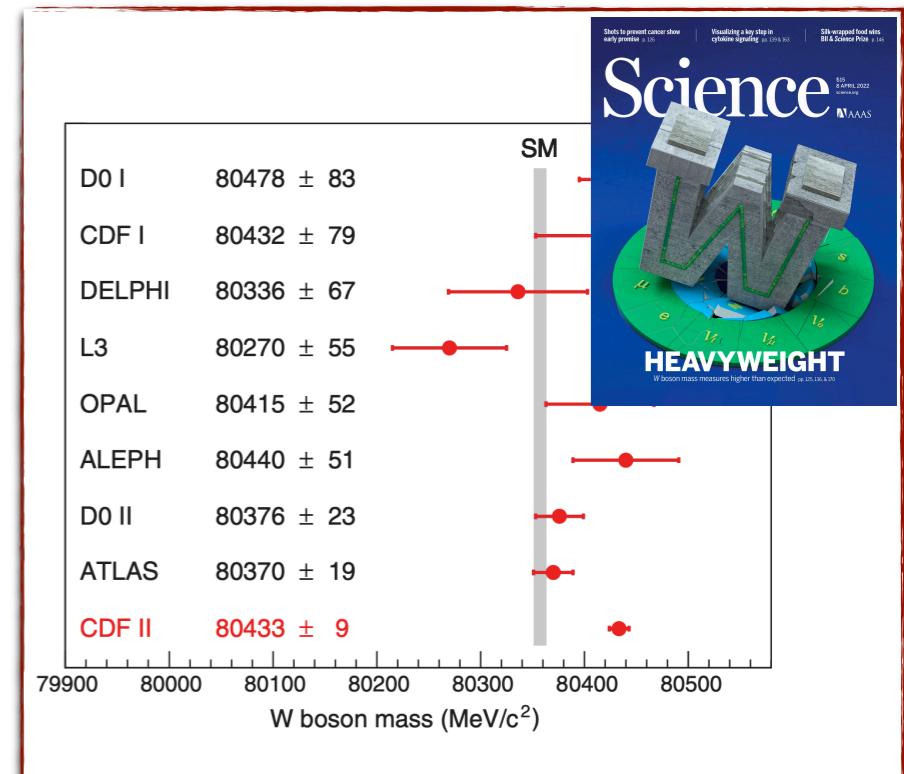
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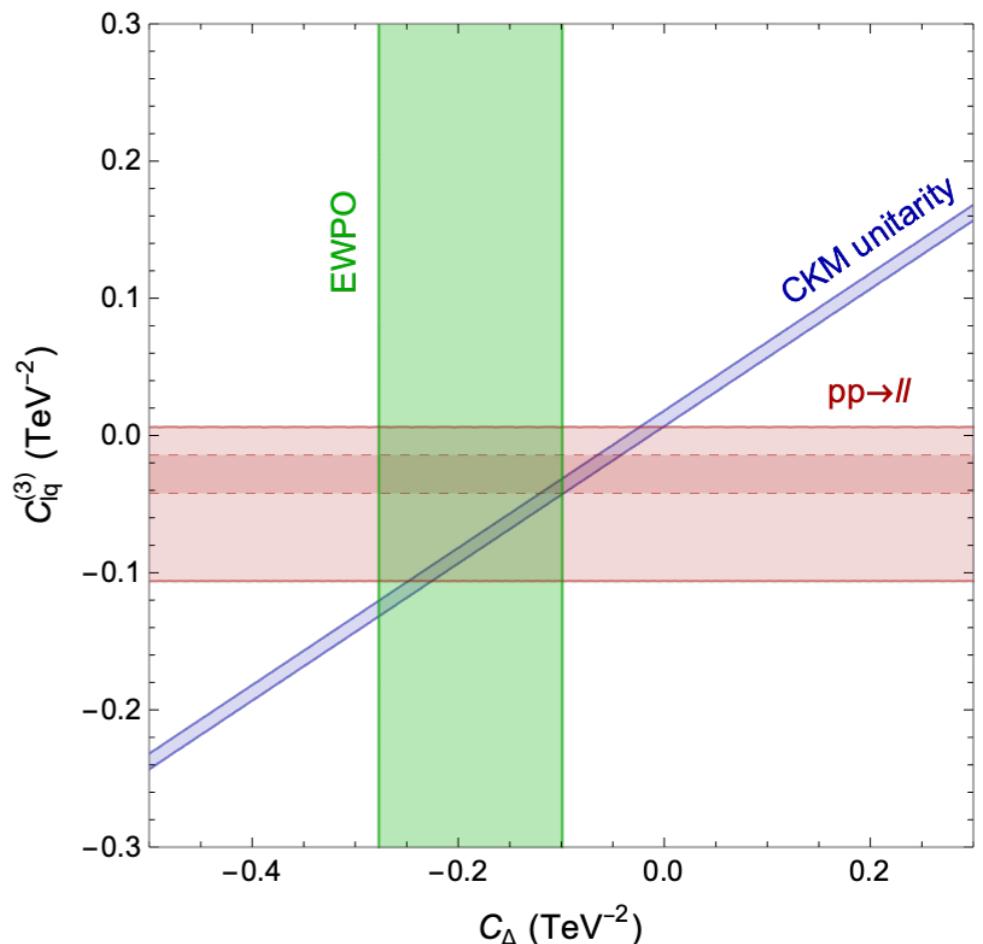
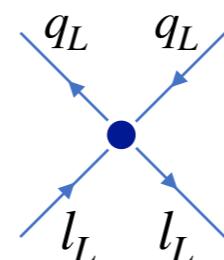
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- Can avoid impact of CKM unitarity by including  $C_{lq}^{(3)}$
- $C_{lq}^{(3)}$  constrained by LHC



- Same couplings contribute to  $|V_{ud}|^2 + |V_{us}|^2 - 1 = v^2(C_\Delta - 2C_{lq}^{(3)})$

# Explaining a heavy W

- $U(3)^5$  symmetric fit to EWPO

• Few parameters

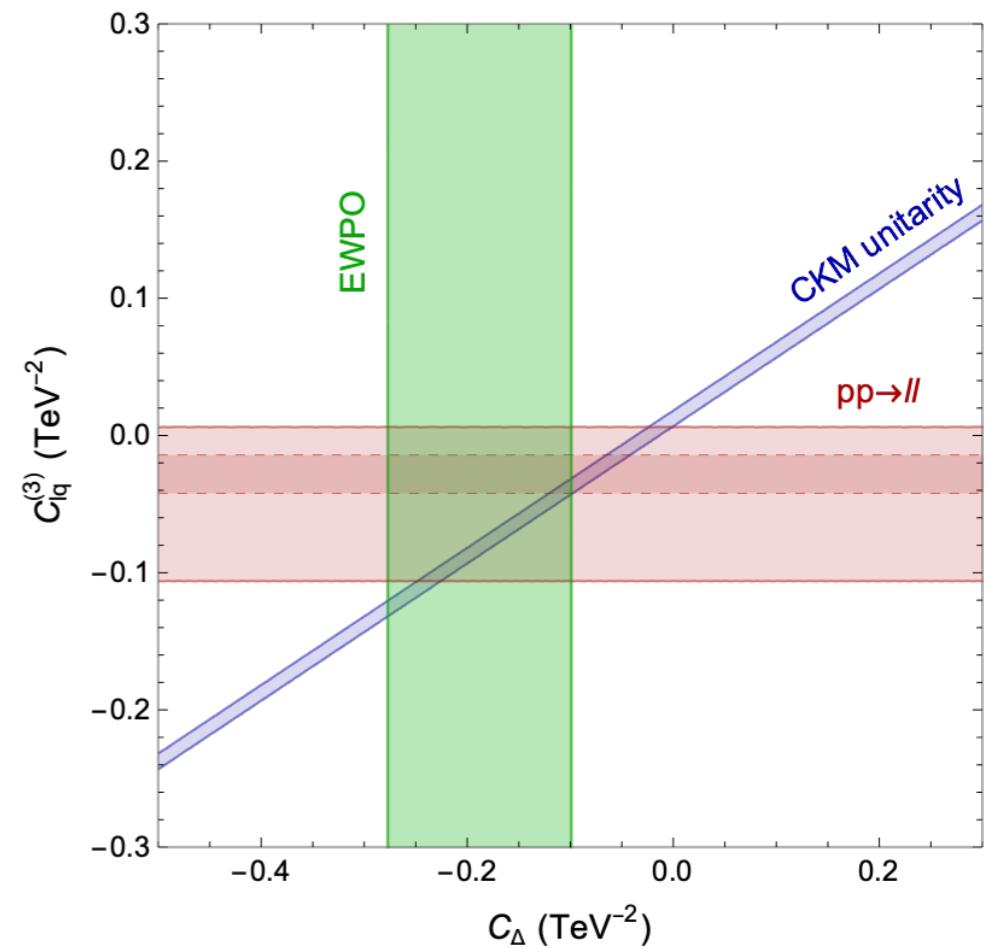
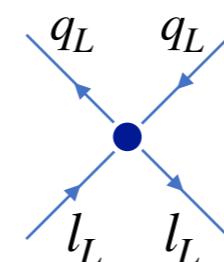
• Not self contained

• Need to include low-energy data

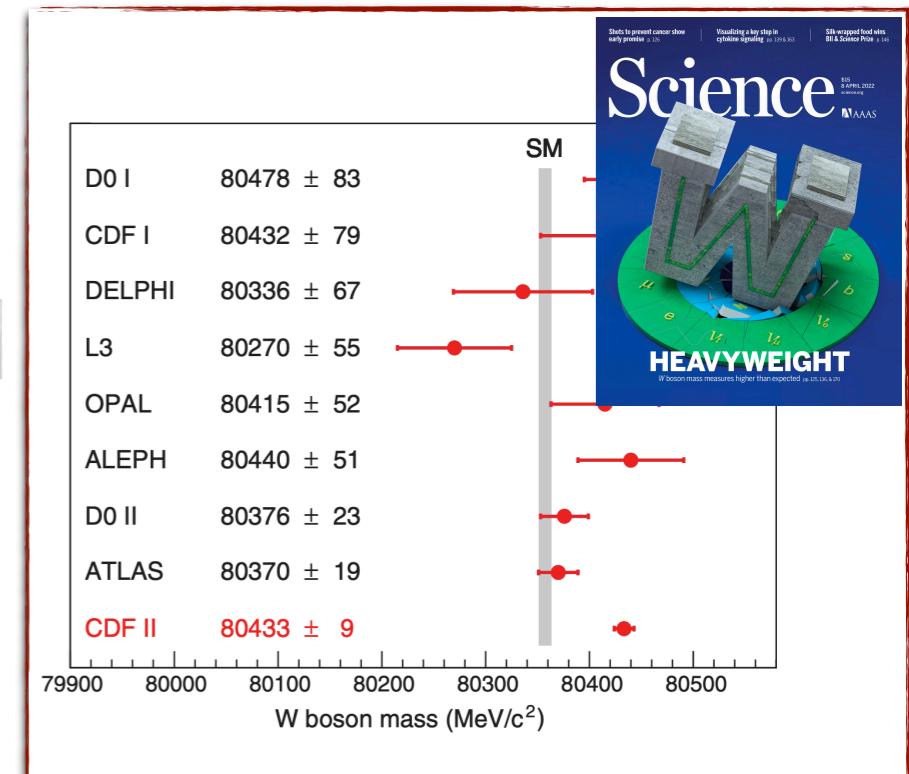
Crivellin et al, PRL '21; Blennow et al PRD '22

$lq$

'22; Bagnaschi et al '22



- Same couplings contribute to  $|V_{ud}|^2 + |V_{us}|^2 - 1 = v^2(C_\Delta - 2C_{lq}^{(3)})$



A more ‘global’  
low-energy analysis



# Towards flavor-symmetry independence

## Analysis wishlist

- Include all couplings that significantly affect EWPO and low-energy
- Should not significantly change when including more observables
  - Couplings that are very constrained by *other* measurements cannot play a role

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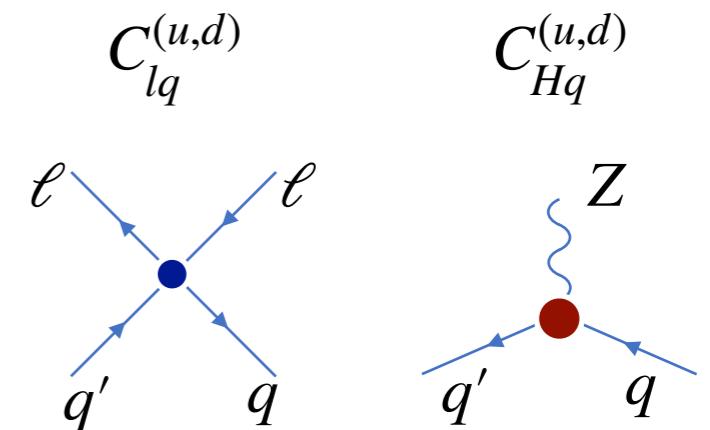
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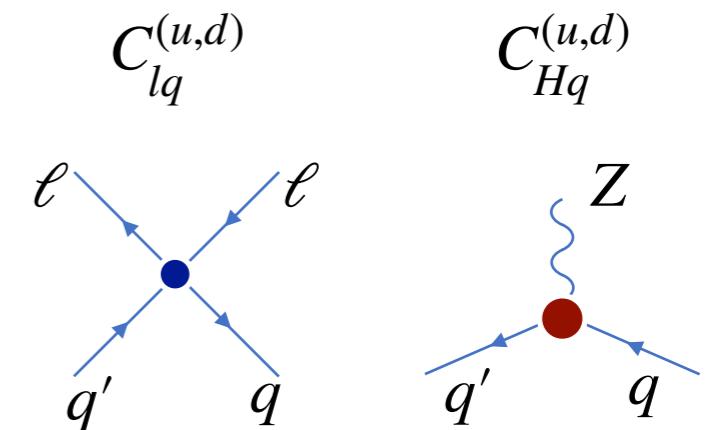
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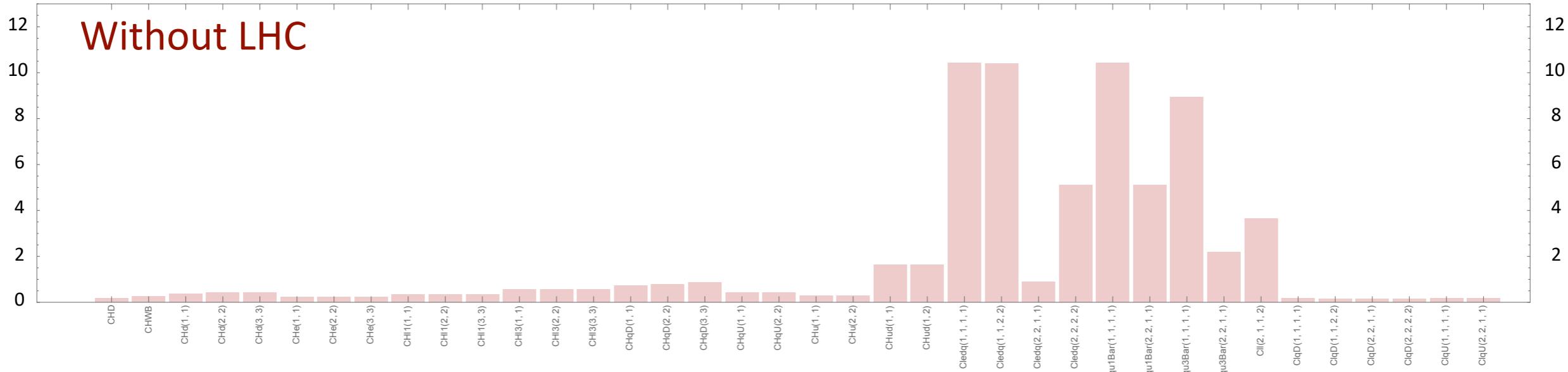
- Induced by several operators, e.g.

- Only combinations that *do not induce* FCNCs can significantly affect low-energy, EWPO
  - Keep the diagonal of

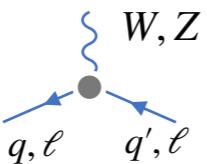
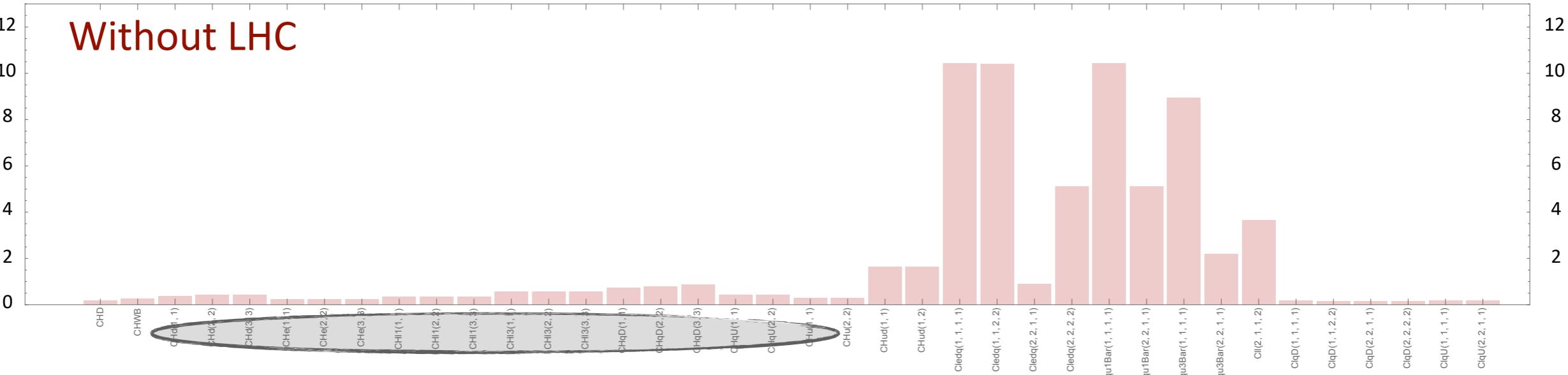
$$C_{Hq,lq}^{(d)} \equiv C_{Hq,lq}^{(1)} + C_{Hq,lq}^{(3)}$$

$$C_{Hq,lq}^{(u)} \equiv V \left[ C_{Hq,lq}^{(1)} - C_{Hq,lq}^{(3)} \right] V^\dagger$$

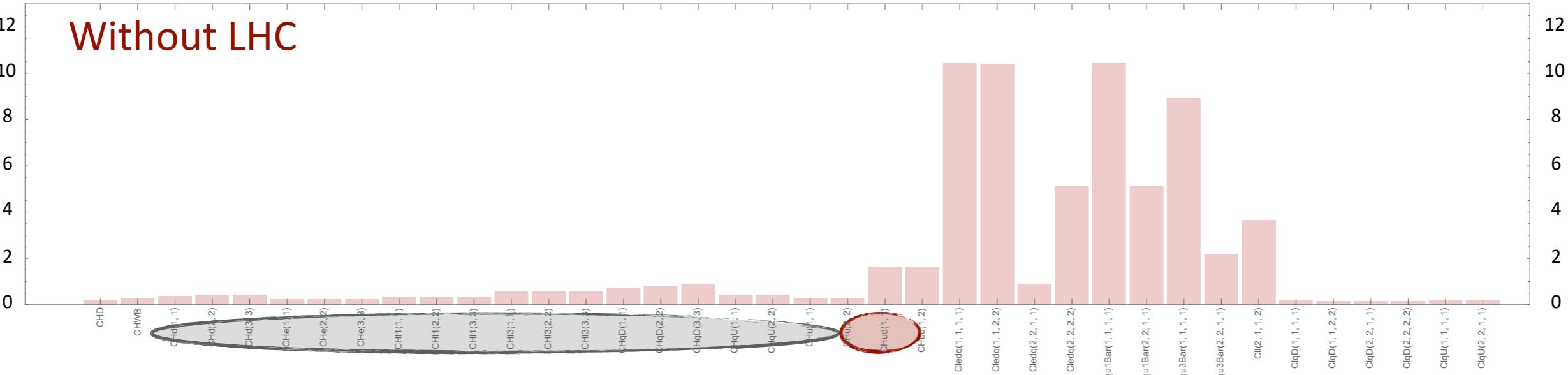
# Bounds on $\Lambda$ (TeV)



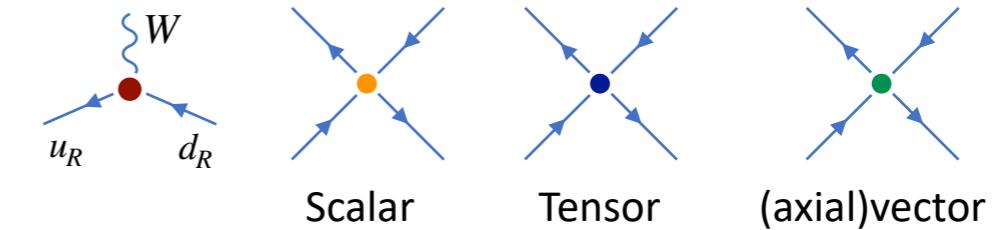
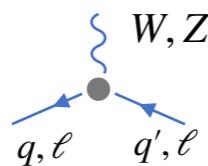
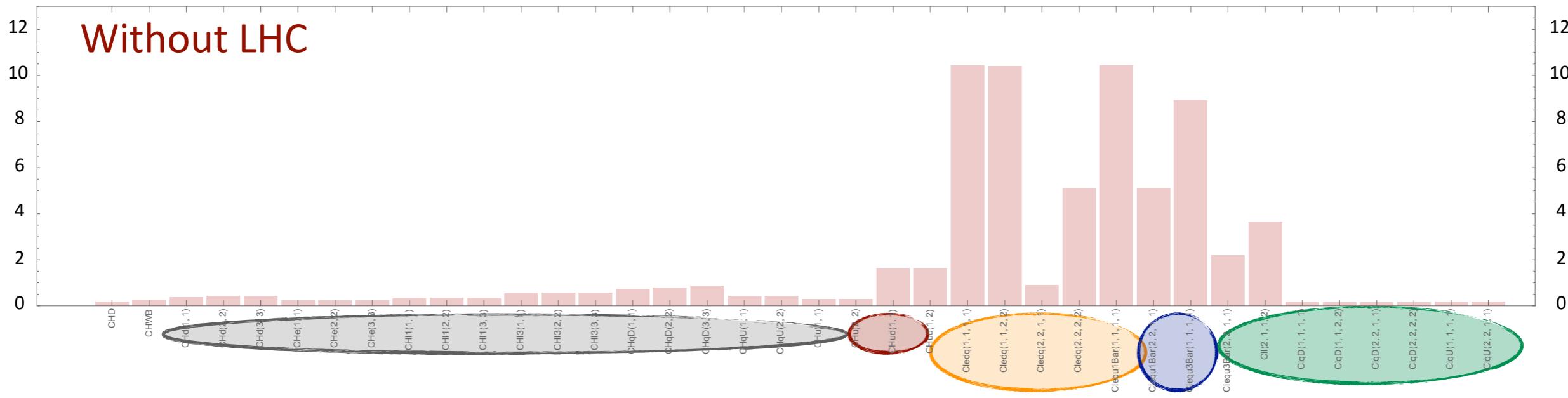
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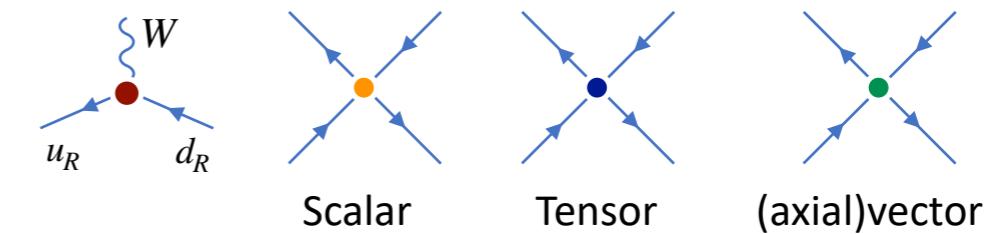
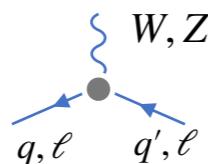
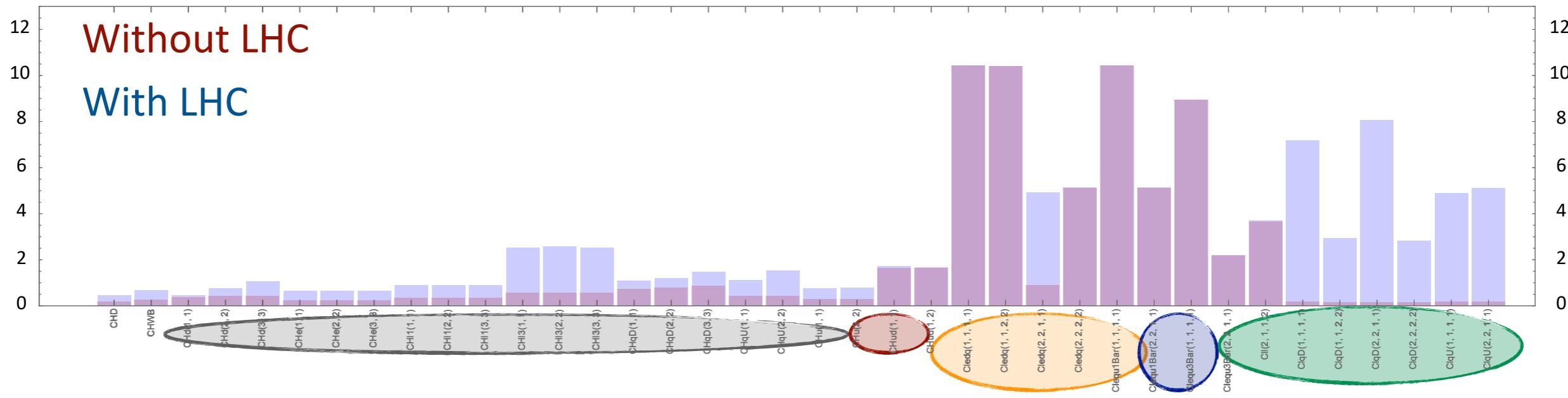
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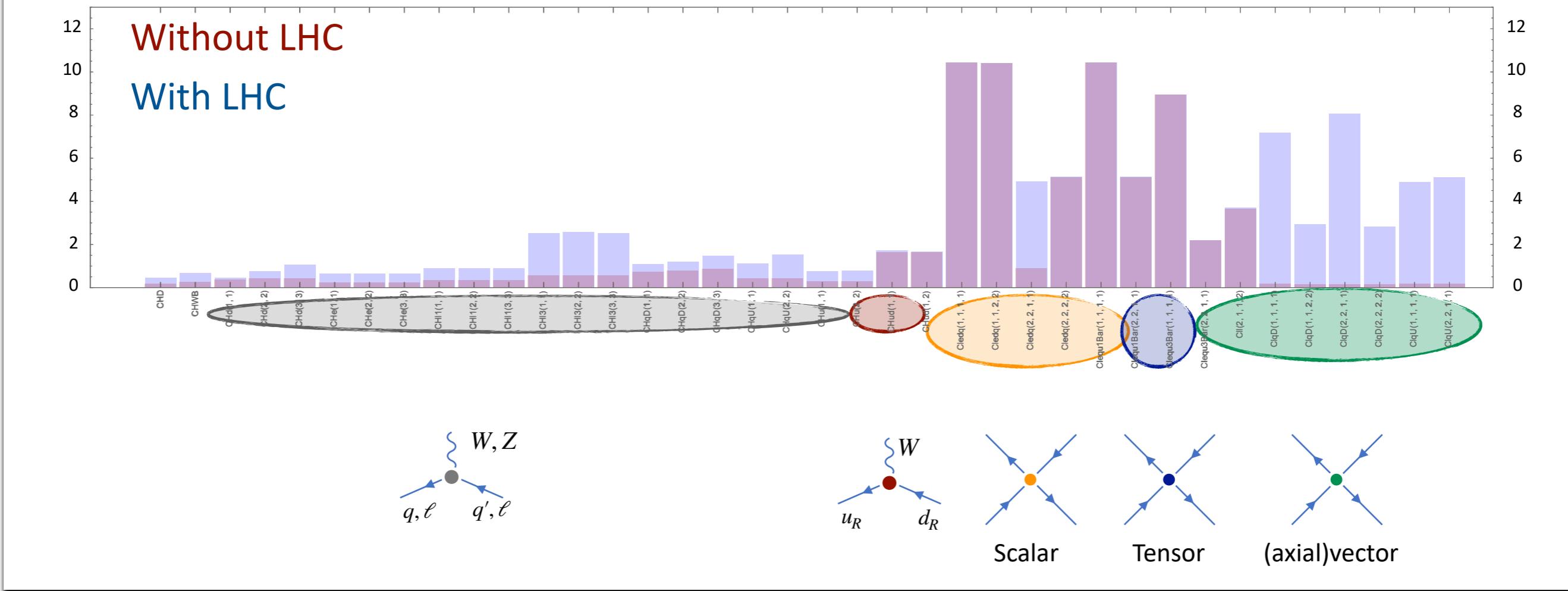
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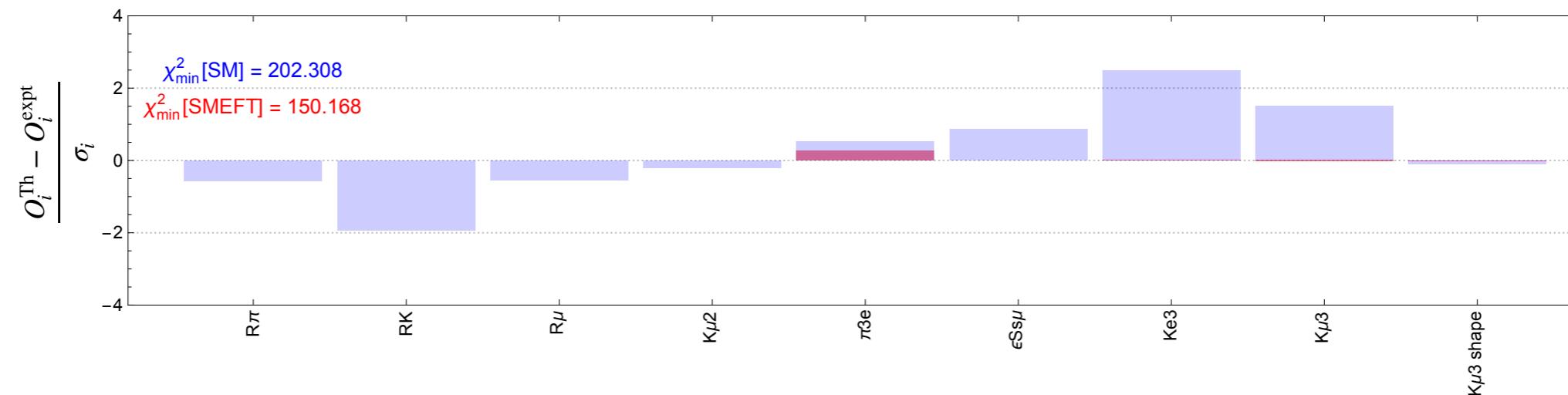
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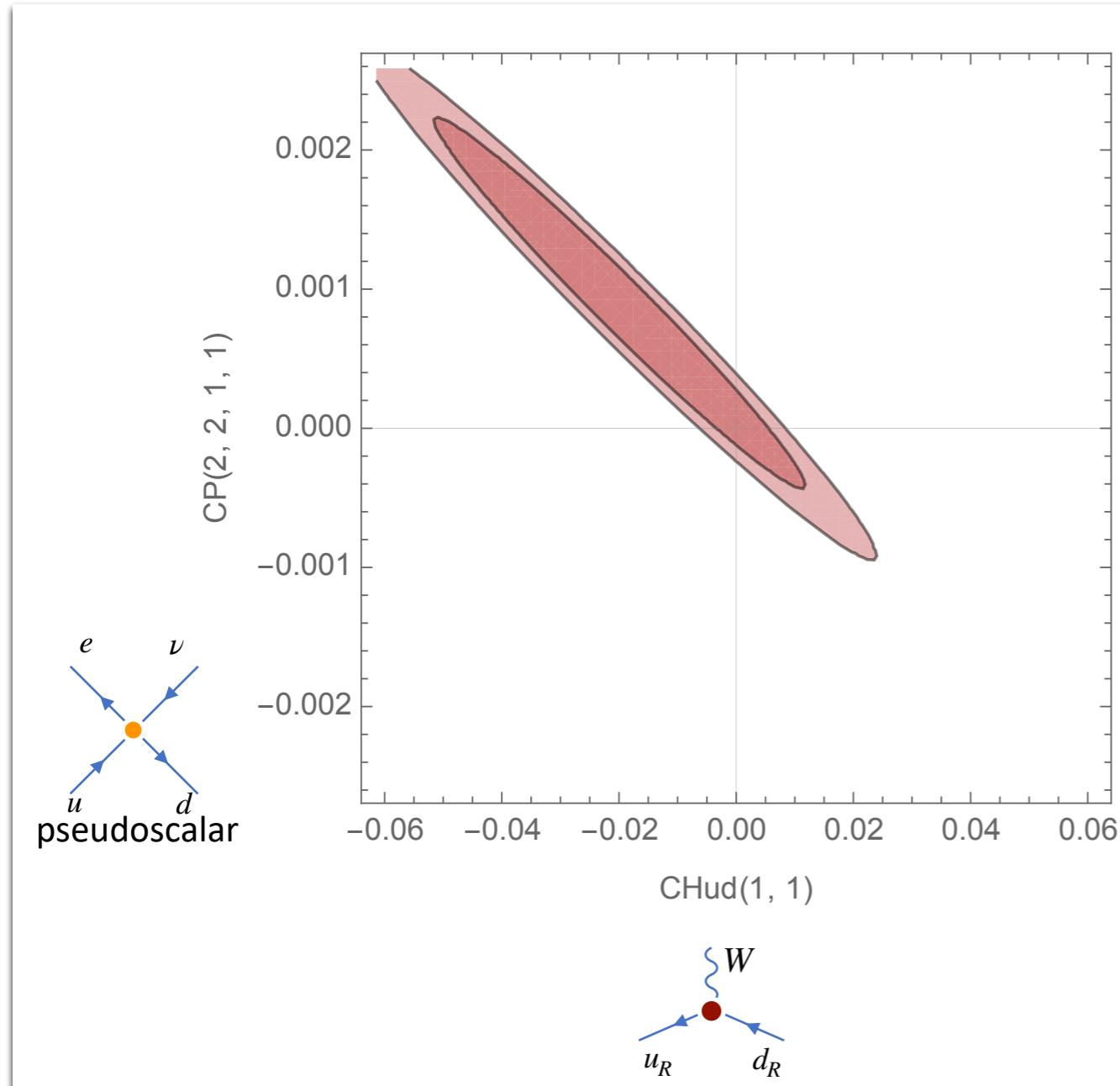
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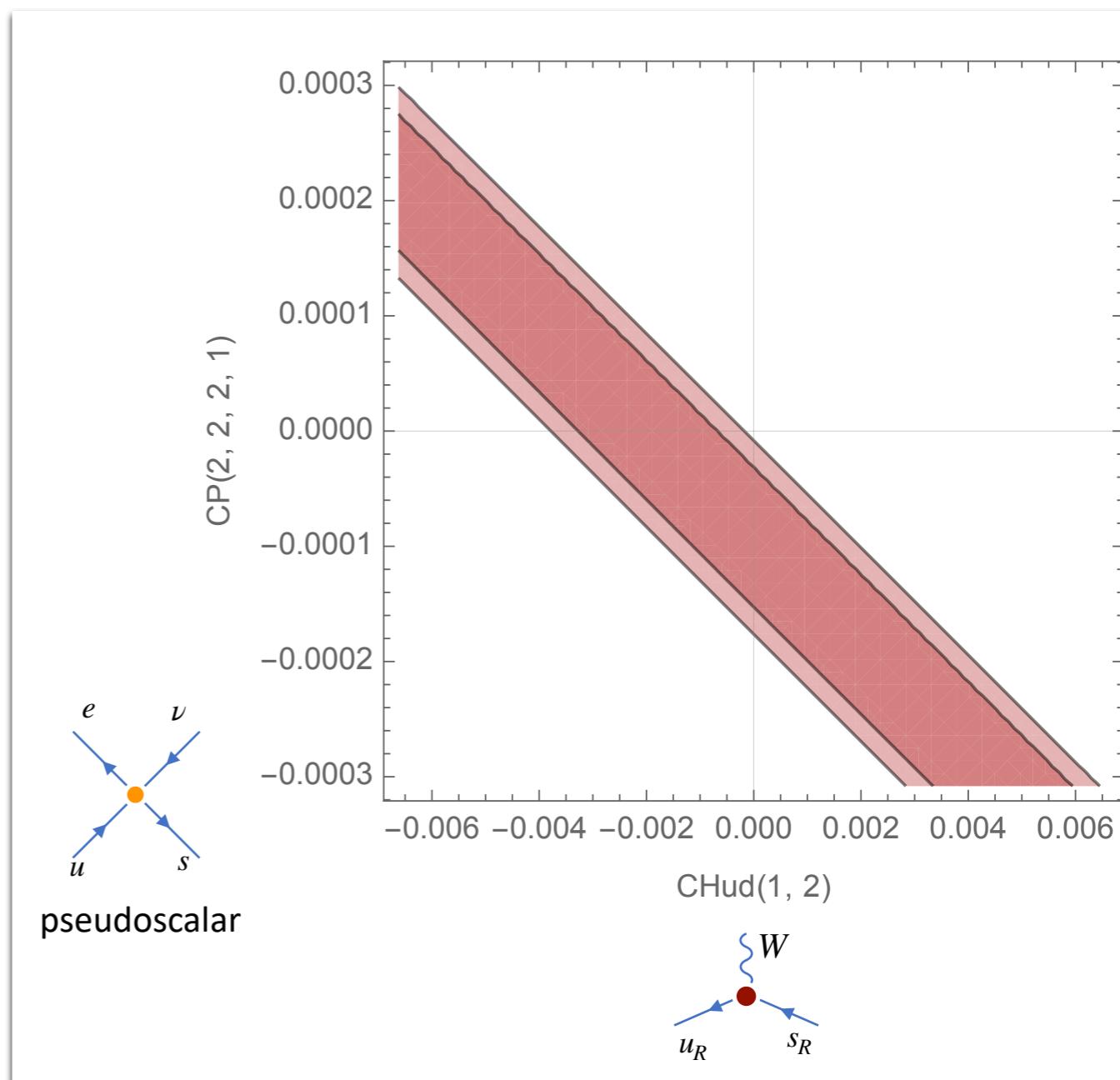
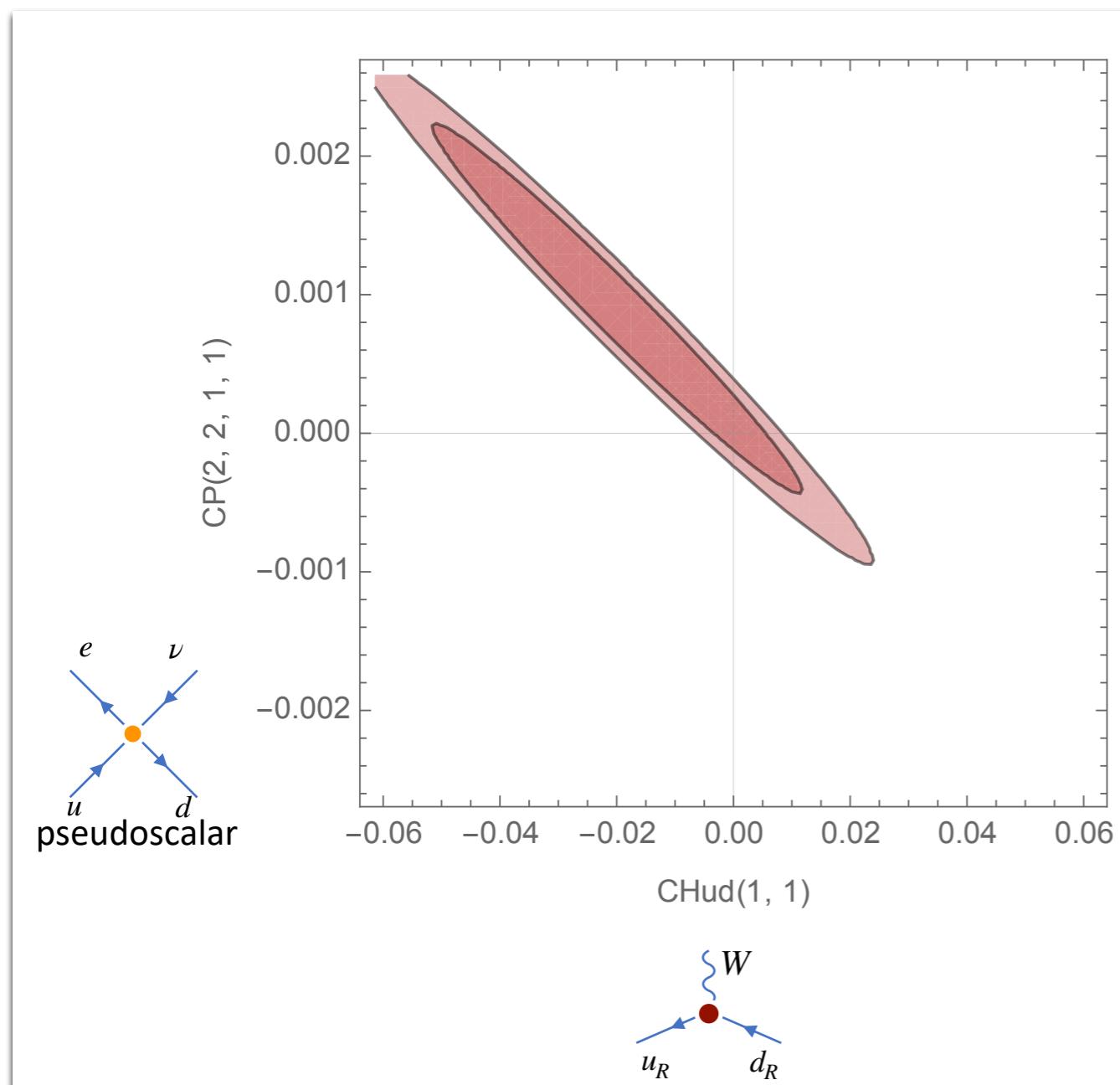
## Effect on CKM unitarity



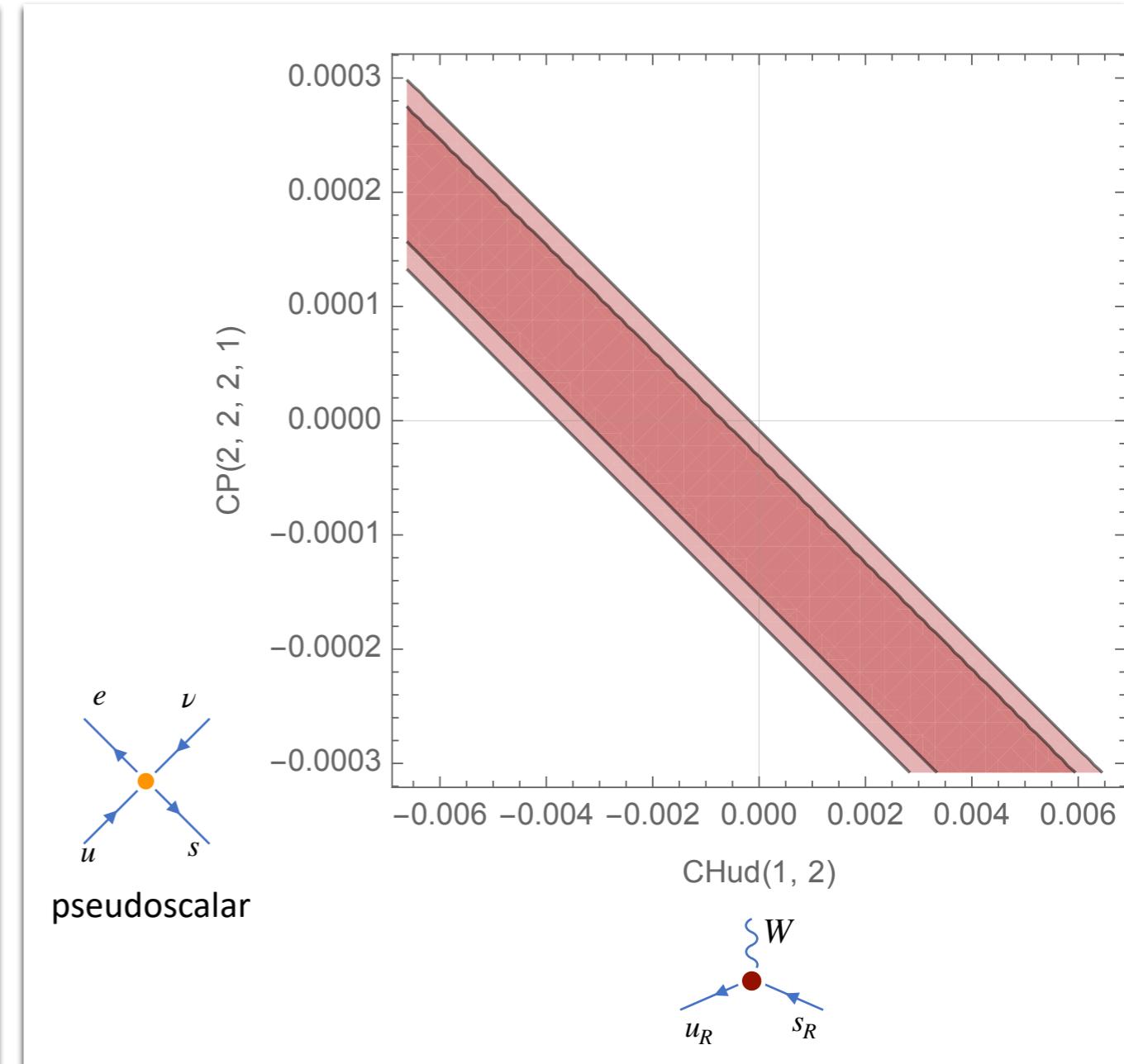
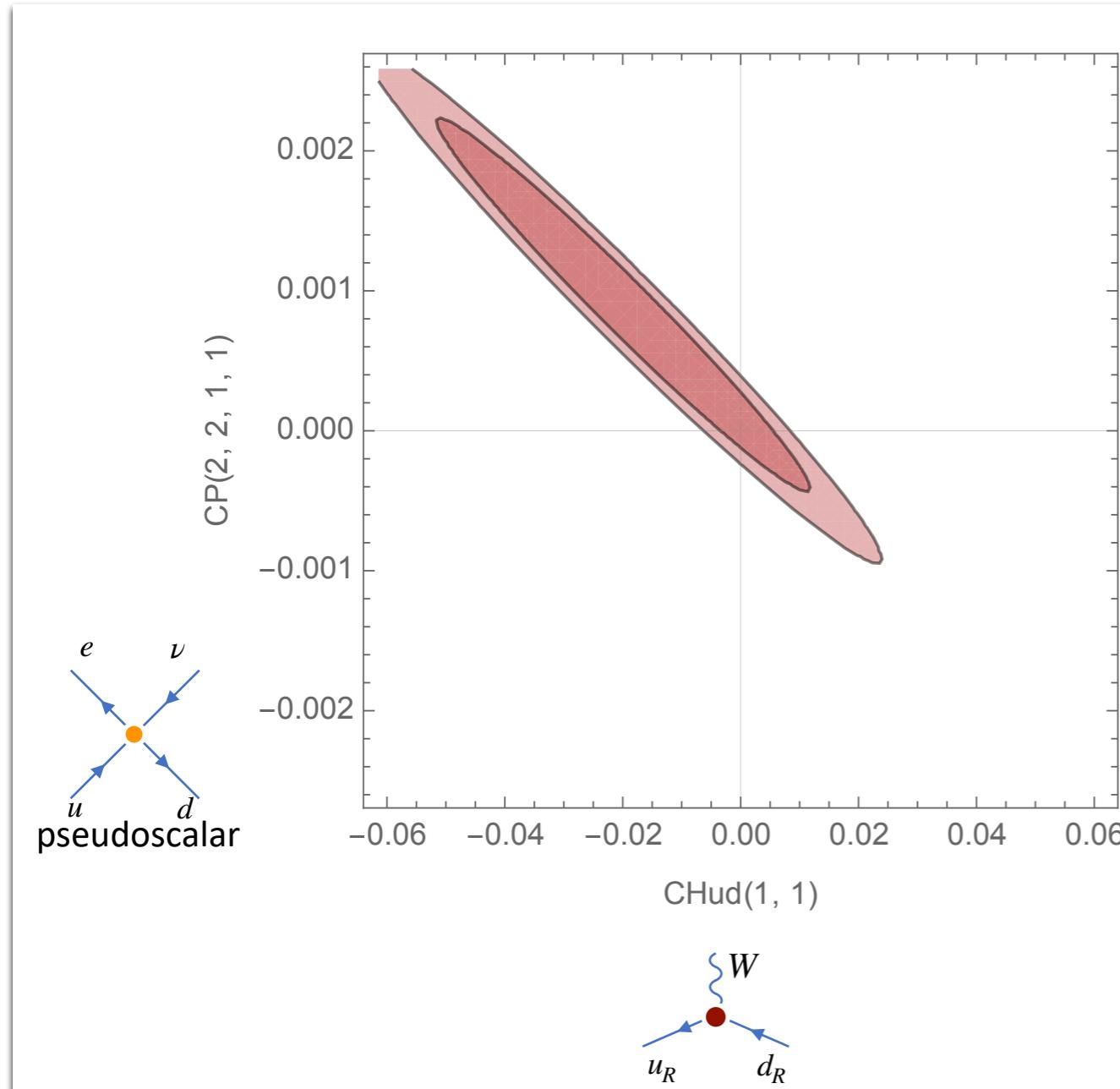
# What is improving CKM unitarity?



# What is improving CKM unitarity?



# What is improving CKM unitarity?



- Nonzero right-handed couplings preferred
  - Simple solution with only  $\epsilon_R$  survives in much more general fit
- Could be probed at the LHC in WZ production

See Heleen's talk  
 Cirigliano, Crivellin, Hoferichter, Moulson, PLB '23

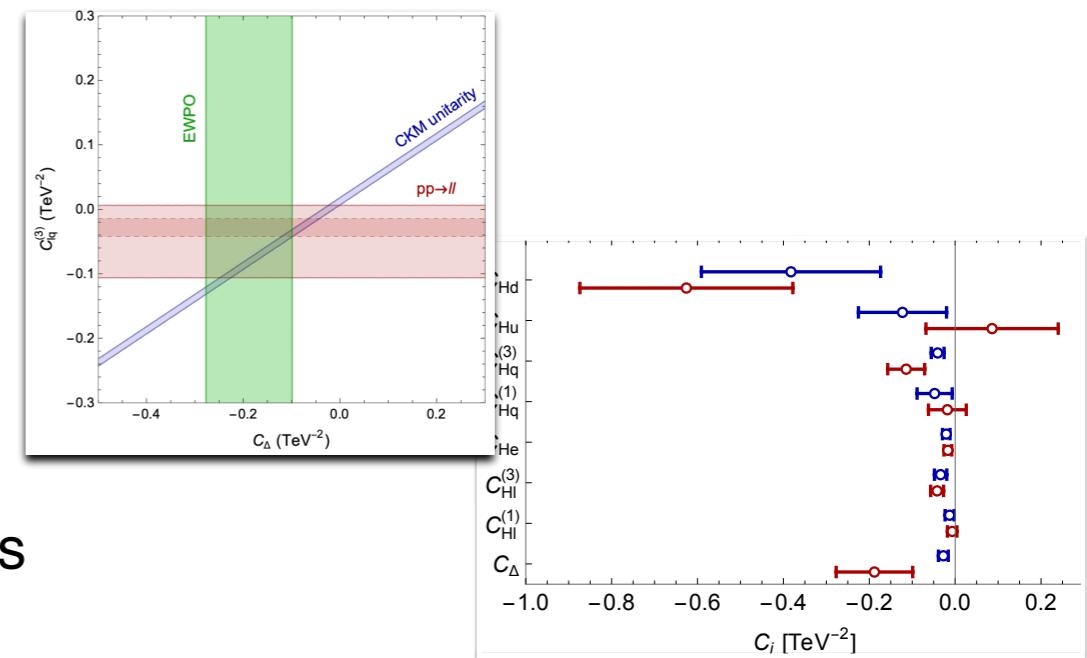
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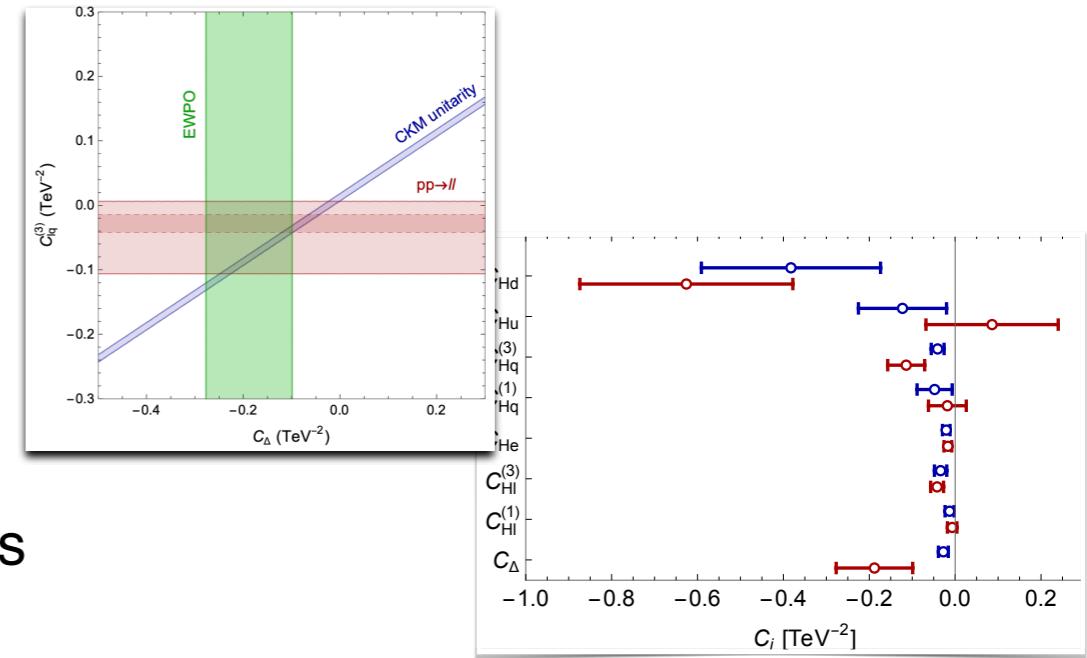
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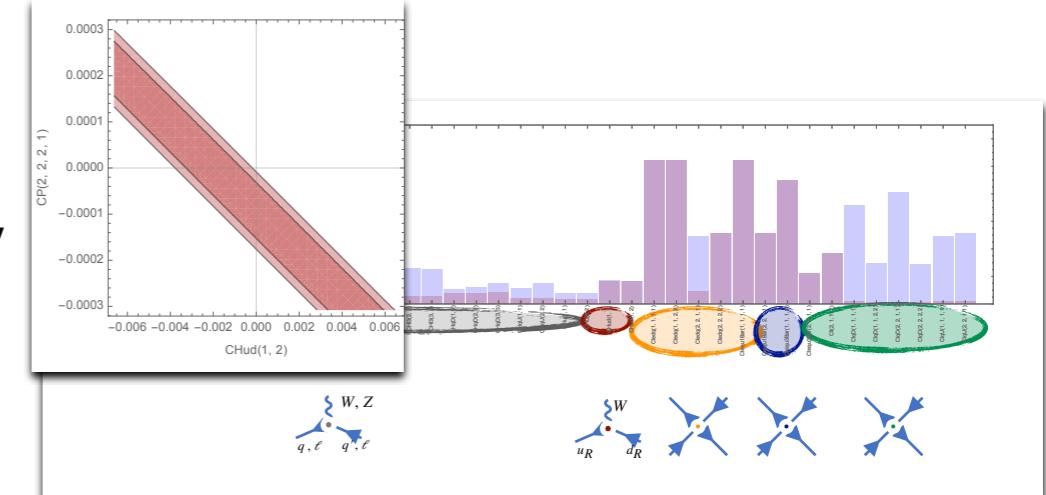
# Summary

- EFTs can systematically describe any heavy new physics
- Allow one to compare measurements from LHC, EWPO to low energies

- Can be used to investigate discrepancies
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- More general analysis involves large number of operators
- Low-energy and EWP observables still probe  $\Lambda \sim 10$  TeV
- Nonzero right-handed couplings still preferred



# Backup slides

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# $\beta$ , $\pi$ , $K$ decay input

## Meson decays

$P_{l2}$			$K_{l3}$		
Observable	value	Ref.	Observable	value	Ref.
$R_\pi$	$1.2344(30) \cdot 10^{-4}$	[53]	$ \tilde{V}_{us}^e f_+^K(0) $	$0.21626(40)$	[10]
$R_K$	$2.488(9) \cdot 10^{-5}$	[26]	$ \tilde{V}_{us}^\mu f_+^K(0) $	$0.21667(52)$	[10]
$\Gamma(K_{\mu 2})$	$5.134(10) \cdot 10^{-7} s^{-1}$	[26]	$\log C$	$0.1985(70)$	[12]
$\text{Br}(\pi_{\mu 2})$	$0.9998770(4)$	[26]	$2\epsilon_T^{s\mu} \frac{B_T(0)}{f_+(0)}$	$0.0007(71)$	[11]
$\tau_{\pi^+}$	$2.6033(5) \cdot 10^{-8} s$	[26]			

Table 15: The experimental input used for kaon and  $\pi$  decays. Note that the determinations of  $|\tilde{V}_{us}^\ell f_+^K(0)|$  involve a correlation not shown in the table.

## Nuclear decays

Parent	$J_i$	$J_f$	Type	Observable	Ref.
${}^6\text{He}$	0	1	GT/ $\beta^-$	$\tilde{a}$	[37]
${}^{32}\text{Ar}$	0	0	F/ $\beta^+$	$\tilde{a}$	[38]
${}^{38m}\text{K}$	0	0	F/ $\beta^+$	$\tilde{a}$	[39]
${}^{60}\text{Co}$	5	4	GT/ $\beta^-$	$\tilde{A}$	[40]
${}^{67}\text{Cu}$	3/2	5/2	GT/ $\beta^-$	$\tilde{A}$	[41]
${}^{114}\text{In}$	1	0	GT/ $\beta^-$	$\tilde{A}$	[42]
${}^{14}\text{O}/{}^{10}\text{C}$			F-GT/ $\beta^+$	$P_F/P_{GT}$	[43]
${}^{26}\text{Al}/{}^{30}\text{P}$			F-GT/ $\beta^+$	$P_F/P_{GT}$	[44]

Table 13: Data from correlation measurements in pure Fermi and pure Gamow-Teller decays used in the fits. Slightly simplified version of [8].

# Hadronic matrix elements

	Baryon decays		$K$ and $\pi$ decays		
$g_A$	1.246(28)	[45]	$f_+(0)$	0.9698(17)	[45]
$g_S$	1.02(10)	[45]	$\frac{f_K \pm}{f_{\pi} \pm}$	1.1932(21)	[45]
$g_T$	0.989(34)	[45]	$f_K \pm$	155.7(3) MeV	[45]
$\Delta_R^V$	0.02467(22)	[46]	$RC_\pi$	0.0332(3)	[47]
$\frac{\Delta_R^A - \Delta_R^V}{2}$	0.00013(13)	[48]	$c_1^\pi$	-2.4(5)	[49]
$g_1/f_1 \Big _{\Lambda \rightarrow p}$	0.72(7)	[9, 50]	$\Delta_{CT}$	-0.0035(80)	[51]
			$\frac{B_T(0)}{f_+(0)}$	0.68(3)	[52]

Table 14: The hadronic input that enters  $\beta$  decays. We approximate  $g_V = 1$ , which holds to high precision. Whenever appropriate the value at a renormalization scale  $\mu = 2$  GeV is given.

# Electroweak precision input

Obs.	Expt. Value	SM Prediction	Obs.	Expt. Value	SM Prediction
$\Gamma_Z$ (GeV)	2.4955(23)	[2, 29]	$m_W$ (GeV)	80.4335(94)	[30]
$\sigma_{\text{had}}^0$ (nb)	41.480(33)	[2, 29]	$\Gamma_W$ (GeV)	2.085(42)	[26]
$R_e^0$	20.804(50)	[2, 29]	$R_{Wc}$	0.49(4)	[26]
$R_\mu^0$	20.784(34)	[2, 29]	$R_\sigma$	0.998(41)	[31]
$R_\tau^0$	20.764(45)	[2, 29]	$\text{Br}(W \rightarrow e\nu)$	0.1071(16)	[26]
$A_{\text{FB}}^{0,e}$	0.0145(25)	[2, 29]	$\text{Br}(W \rightarrow \mu\nu)$	0.1063(15)	[26]
$A_{\text{FB}}^{0,\mu}$	0.0169(13)	[2, 29]	$\text{Br}(W \rightarrow \tau\nu)$	0.1138(21)	[26]
$A_{\text{FB}}^{0,\tau}$	0.0188(17)	[2, 29]	$\frac{\Gamma(W \rightarrow \mu\nu)}{\Gamma(W \rightarrow e\nu)}$	0.982(24)	[26]
$R_b^0$	0.21629(66)	[2]	$\frac{\Gamma(W \rightarrow \mu\nu)}{\Gamma(W \rightarrow e\nu)}$	1.020(19)	[26]
$R_c^0$	0.1721(30)	[2]	$\frac{\Gamma(W \rightarrow \mu\nu)}{\Gamma(W \rightarrow e\nu)}$	1.003(10)	[26]
$A_{\text{FB}}^{0,b}$	0.0996(16)	[2]	$\frac{\Gamma(W \rightarrow \tau\nu)}{\Gamma(W \rightarrow e\nu)}$	0.961(61)	[26]
$A_{\text{FB}}^{0,c}$	0.0707(35)	[2]	$\frac{\Gamma(W \rightarrow \tau\nu)}{\Gamma(W \rightarrow \mu\nu)}$	0.992(13)	[26]
$\mathcal{A}_c$	0.67(3)	[2]	$A_4(0 - 0.8)$	0.0195(15)	[32]
$\mathcal{A}_b$	0.923(20)	[2]	$A_4(0.8 - 1.6)$	0.0448(16)	[32]
$\mathcal{A}_e$	0.1516(21)	[2]	$A_4(1.6 - 2.5)$	0.0923(26)	[32]
$\mathcal{A}_\mu$	0.142(15)	[2]	$A_4(2.5 - 3.6)$	0.1445(46)	[32]
$\mathcal{A}_\tau$	0.136(15)	[2]	$g_V^{(u)}$	0.201(112)	[33]
$\mathcal{A}_e^{\tau \text{ pol}}$	0.1498(49)	[2]	$g_V^{(d)}$	-0.351(251)	[33]
$\mathcal{A}_\tau^{\tau \text{ pol}}$	0.1439(43)	[2]	$g_A^{(u)}$	0.50(11)	[33]
$\mathcal{A}_s$	0.895(91)	[35]	$g_A^{(d)}$	-0.497(165)	[33]
$R_{uc}$	0.166(9)	[26]			
$R_{uc}$	0.172220(20)	[6]			

Table 11: Input parameters and EWPOs used in the analysis. Each shaded block indicates a set of correlated observables. Entries without an explicit SM prediction share their SM value with the observable above.

# Collider measurements

Process	Experiment	Lumi.	$x_{\text{obs}}$	$x$	Ref.
$pp \rightarrow \tau^+ \tau^-$	ATLAS	$139 \text{ fb}^{-1}$	$m_T^{\text{tot}}(\tau_h^1, \tau_h^2, \cancel{E}_T)$	$m_{\tau\tau}$	[?]
$pp \rightarrow \mu^+ \mu^-$	CMS	$140 \text{ fb}^{-1}$	$m_{\mu\mu}$	$m_{\mu\mu}$	[?]
$pp \rightarrow e^+ e^-$	CMS	$137 \text{ fb}^{-1}$	$m_{ee}$	$m_{ee}$	[?]
$pp \rightarrow \tau^\pm \nu$	ATLAS	$139 \text{ fb}^{-1}$	$m_T(\tau_h, \cancel{E}_T)$	$p_T(\tau)$	[?]
$pp \rightarrow \mu^\pm \nu$	ATLAS	$139 \text{ fb}^{-1}$	$m_T(\mu, \cancel{E}_T)$	$p_T(\mu)$	[62]
$pp \rightarrow e^\pm \nu$	ATLAS	$139 \text{ fb}^{-1}$	$m_T(e, \cancel{E}_T)$	$p_T(e)$	[62]
$pp \rightarrow \tau^\pm \mu^\mp$	CMS	$138 \text{ fb}^{-1}$	$m_{\tau_h \mu}^{\text{col}}$	$m_{\tau\mu}$	[?]
$pp \rightarrow \tau^\pm e^\mp$	CMS	$138 \text{ fb}^{-1}$	$m_{\tau_h e}^{\text{col}}$	$m_{\tau e}$	[?]
$pp \rightarrow \mu^\pm e^\mp$	CMS	$138 \text{ fb}^{-1}$	$m_{\mu e}$	$m_{\mu e}$	[?]

Table 16: Experimental searches by the ATLAS and CMS collaborations that are available in HighPT.