SEARCHING FOR BSM PHYSICS IN HIGGS COUPLINGS TO FERMIONS AND FLAVOUR SYMMETRIES

Based on:

- J. Alonso-Gonzales, L. Merlo and SP, JHEP 06(2021) 166
- J.Alonso-Gonzales, A. di Giorgi, L.Merlo and SP, to appear

SM: $$y_{h\bar{\psi}\psi} = \frac{\sqrt{2}}{v} m_\psi$$

MOTIVATION(GENERAL)

FLAVOUR IS ESSENTIALLY A BEYOND THE SM CONCEPT AND THE NEW PHYSICS SCALE BEHIND THE FLAVOUR PARADIGM MAY BE DIFFERENT FROM THE ELECTROWEAK SCALE, USUALLY LINKED TO THE HIERARCHY PROBLEM

MOTIVATION (SPECIFIC)

ELECTROWEAK BARYOGENESIS NEEDS NEW SOURCES OF

CP VIOLATION (BEYOND THE CKM MATRIX)

THE MOST NATURAL SCENARIO (IF NOT THE ONLY ONE?) IS THAT YUKAWA COUPLINGS HAVE A CP VIOLATING COMPONENT.

CP VIOLATING INTERACTIONS ACROSS THE EXPANDING WALLS OF THE

BUBBLES OF THE VEVs OF THE HIGGS FIELD WOULD CREATE A CHIRAL ASYMMETRY,

THEN CONVERTED TO A BARYON ASYMMETRY BY THE WEAK SPHALERON PROCESS.

(VERY RICH LITERATURE ON THIS SUBJECT:
most recent E. FUCHS, M.Losada, Y. Nir and Y. VIERNIK)

MOTIVATION cont

SEVERAL SOURCES OF INFORMATION ON THE BSM PHYSICS IN YUKAWAS:

- HIGGS BOSON PRODUCTION AND DECAYS, DIRECTLY DEPENDENT ON THE YUKAWA COUPLINGS (COLLIDERS)

- VERY HIGH PRECISION LOW ENERGY FLAVOUR OBSERVABLES, INCLUDING MAGNETIC AND ELECTRIC DIPOLE MOMENTS AND A VARIETY OF FCNC PROCESSES, DEPENDENT ON THE YUKAWA COUPLINGS VIA HIGGS EXCHANGE CONTRIBUTIONS TO THEIR AMPLITUDES

COMPLEMENTARITY OF DIFFERENT EXPERIMENTS IN
THEIR SENSITIVITY TO THE BSM PHYSICS IN YUKAWA COUPLINGS?
ITS DEPENDENCE ON THE FLAVOUR STRUCTURE OF THE BSM PHYSICS?

HAS THE BSM PHYSICS IN THE HIGGS COUPLINGS ANY FLAVOUR STRUCTURE ?

WHAT CAN WE EXPECT FOR IT ?

IN THE SMEFT FRAMEWORK, INCLUDING DIM 6 OPERATORS, THERE IS ONLY ONE OPERATOR CONTRIBUTING TO YUKAWA COUPLINGS:

$$L = -\bar{Q}_L^J \bar{H} Y_u'^{JK} u_R^K - \bar{Q}_L^J H Y_d'^{JK} d_R^K - \bar{L}_L^J H Y_e'^{JK} e_R^K$$

$$-(\bar{Q}_L^J \bar{H} C_u'^{JK} u_R^K - \bar{Q}_L^J H C_d'^{JK} d_R^K - \bar{L}_L^J H C_e'^{JK} e_R^K) \frac{H^\dagger H}{\Lambda^2} + h.c$$

Y, C' ARE 3x3 COMPLEX MATRICES IN THE FLAVOUR SPACE

TWO INTERESTING HYPOTHESIS FOR FLAVOUR PARADIGM IN THE BSM PHYSICS: MINIMAL FLAVOUR VIOLATION OR IT RESPECTS A FLAVOUR SYMMETRY OFTEN INVOKED TO EXPLAIN FERMION MASSES AND MIXINGS.

IN BOTH CASES THE YUKAWA MATRICES AND THE WILSON COEFFICIENT MATRICES ARE RELATED TO EACH OTHER.

STRONG IMPLICATIONS FOR THE EMERGING PICTURE OF POTENTIAL DEVIATIONS FROM THE SM PREDICTIONS,
MUCH DIFFERENT FROM WHAT COULD BE IF THE WILSON COEFFICIENTS HAVE NO FLAVOUR STRUCTURE.

TWO EXAMPLES:

IMPLICATIONS FOR ELECTROWEAK BARYOGENESIS

LOWER BOUNDS ON THE SCALE OF NEW PHYSICS FROM FLAVOUR DATA WITH AND WITHOUT FLAVOUR SYMMETRIES

IN THE PRESENCE OF DIM 6 OPERATORS THE FERMION MASSES AND THE FERMION COUPLINGS TO THE HIGGS, IN THE MASS EIGENSTATE, READ

$$L = -\bar{u}_L Y_u u_R \frac{v}{\sqrt{2}} - \bar{d}_L Y_d d_R \frac{v}{\sqrt{2}} - \bar{e}_L Y_e e_R \frac{v}{\sqrt{2}}$$

$$-[\bar{u}_L (Y_u + \frac{v^2}{\Lambda^2} C_u) u_R + \bar{d}_L (Y_d + \frac{v^2}{\Lambda^2} C_d) d_R + \bar{e}_L (Y_e + \frac{v^2}{\Lambda^2} C_e) e_R] \frac{h}{\sqrt{2}} + h.c$$

$$Y_u = \sqrt{2}/v(m_u, m_c, m_t) \qquad Y_d = \sqrt{2}/v(m_d, m_s, m_b) \qquad Y_e = \sqrt{2}/v(m_e, m_\mu, m_\tau)$$

$$C_F = V_F^\dagger C' U_F$$

V_F, U_F ARE THE MATRICES WHICH DIAGONALIZE THE MASS TERMS

DEFINING, FOR DIAGONAL YUKAWAS

$$\mathcal{L}_{eff} = -\frac{m_f}{v}(\kappa_f \bar{f} f + i\tilde{\kappa}_f \bar{f}\gamma_5 f)h$$

THE MATCHING WITH THE EFFECTIVE YUKAWAS $\kappa_f, \tilde{\kappa}_f$ GIVES, E.G

$$K_u = diag(\kappa_u, \kappa_c, \kappa_t)$$

$$YK = Y + \frac{v^2}{\Lambda^2} diag(ReC), \qquad Y\tilde{K} = \frac{v^2}{\Lambda^2} diag(ImC)$$

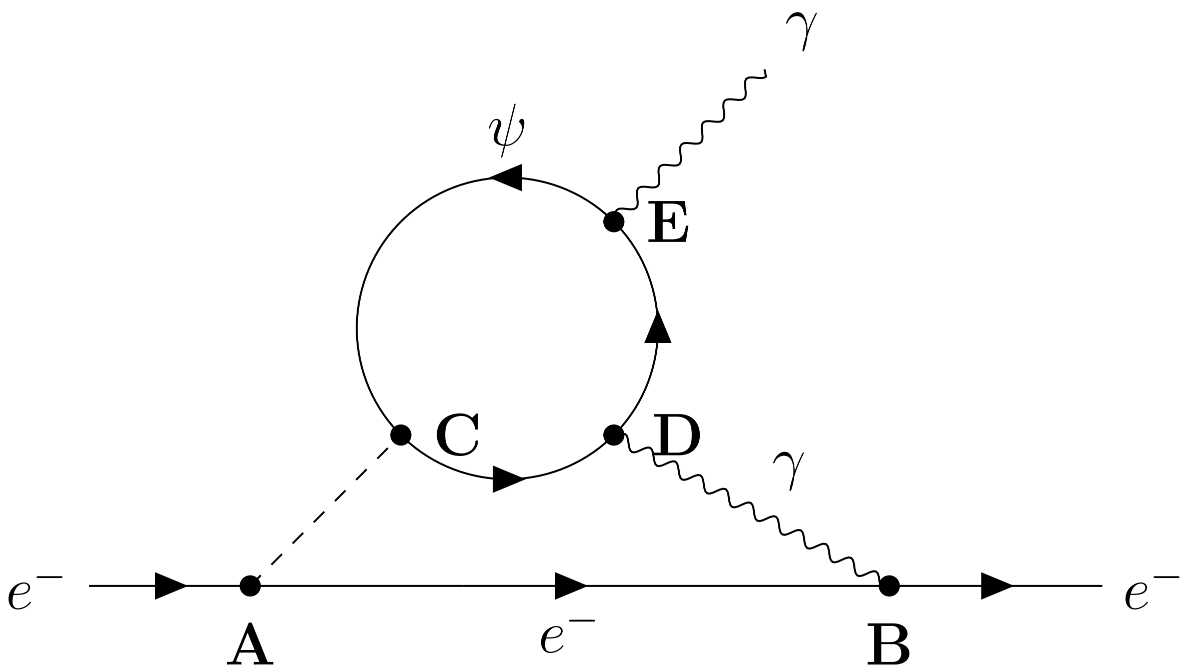
AND THE NON_DIAGONAL COUPLINGS (IF PRESENT) ARE GIVEN BY THE NON-DIAGONAL ENTRIES IN THE MATRICES C

ELECTROWEAK BARYOGENESIS: TO EXPLAIN THE BARYON ASYMMETRY OF THE UNIVERSE WITH A SINGLE COMPLEX YUKAWA COUPLING ONE NEEDS (FUCHS ET AL)

$$|\tilde{\kappa}_t| \approx 0.06 \qquad |\tilde{\kappa}_b| \approx 3 \qquad |\tilde{\kappa}_\tau| \approx 0.12$$

HOWEVER, THERE ARE EXPERIMENTAL BOUNDS ON $|\tilde{\kappa}|$

THEY COME FROM THE ELECTRON EDM, WHICH IS GIVEN BY THE TWO-LOOP BARR-ZEE DIAGRAM



γ
ψ
E
C
D
γ
e^-
A
e^-
B
e^-

BARR-ZEE DIAGRAM CONTRIBUTION TO THE ELECTRON EDM:

$$\frac{d_e}{e} \sim [\kappa_e \tilde{\kappa}_f f_1(x) + \tilde{\kappa}_e \kappa_f f_2(x)] \qquad x = \frac{m_f^2}{m_h^2}$$

$$|d_e| < 1.1 \times 10^{-29} e\ cm$$

ASSUMING ONLY ONE THIRD GENERATION FERMION RUNNING IN THE LOOP ONE GETS THE BOUNDS

$$|\tilde{\kappa}_t| \leq 0.0012 \qquad |\tilde{\kappa}_b| \leq 0.27 \qquad |\tilde{\kappa}_\tau| \leq 0.3$$

$$\tilde{\kappa}_e \leq 0.0017$$

ONLY THE IMAGINARY PART OF THE TAU YUKAWA COUPLING CAN SAVE BAU BUT….

$$\tilde{\kappa}_e = \frac{v^2}{\Lambda^2}\frac{ImC_{11}}{y_e} \qquad \tilde{\kappa}_\tau = \frac{v^2}{\Lambda^2}\frac{ImC_{33}}{y_\tau}$$

WITH THE BOUND $\tilde{\kappa}_e \leq 0.0017$ ONE GETS

$$\tilde{\kappa_\tau} < 0.0017\frac{m_e}{m_\tau}\frac{ImC_{33}}{ImC_{11}}$$

MINIMAL FLAVOUR VIOLATION

$C' = c'Y'$ WHERE C' is a flavour blind complex number

HENCE WE GET $\tilde{\kappa}_\tau < 0.0017$

FROGGATT-NIELSEN MODELS- FLAVOUR U(1) SYMMETRY- AS A GENERIC EXAMPLE

$$\tilde{\kappa}_\tau < \mathcal{O}(1)0.0017$$

IN SUCH TYPICAL FLAVOUR SCENARIOS, THE ELECTRON EDM BOUNDS EXCLUDE SUCCESSFUL ELECTROWEAK BARYOGENESSIS

SEARCHING FOR CP VIOLATION IN

$$h \to \tau\tau$$

IS CRUCIAL FOR TESTING THE VIABILITY OF THE ELECTROWEAK BARYOGENESISIS

ANOTHER EXAMPLE, THIS TIME FOR THE EMERGING PICTURE FOR THE BOUNDS ON THE NP SCALES (= SENSITIVITY OF DIFFERENT OBSERVABLES TO NP)

CONSIDER BOUNDS ON NP COMING FROM ϵ_K

ADDING TO THE SM A GENERIC 4-FERMION OPERATOR

$$\frac{1}{\Lambda^2}(\bar{s_R} d_L)(\bar{s_L} d_R) \to \Lambda > \mathcal{O}(10^5) TeV$$

ADDING 4-FERMION OPERATOR GENERATED BY THREE LEVEL HIGGS EXCHANGE WITH GENERIC NONDIAGONAL COUPLINGS OBTAINED FROM THE DIM 6 OPERATOR

$$\frac{v^2}{\Lambda^2} \bar{f}_i f_j h \to \Lambda > \mathcal{O}(300) TeV$$

ADDING 4-FERMION OPERATOR GENERATED BY TREE LEVEL HIGGS EXCHANGE WITH NONDIAGONAL WILSON COEFFICIENTS OF THE DIM 6 OPERATOR CONTROLLED BY FROGGATT-NIELSEN MODELS

$$C_{ij}\frac{v^2}{\Lambda^2}\bar{f}_i f_j h \rightarrow \Lambda > \mathcal{O}(2)TeV$$

$$C_{ij} \approx \mathcal{O}(1)\epsilon^{n_{Q_i}+n_{d_j}} e^{i\theta_{ij}}$$

n_{Q_i}, n_{d_j} -FERMION CHARGES GIVING GOOD DESCRIPTION OF FERMION MASSES AND MIXING $\epsilon = 0.23 \quad (Cabibbo \quad angle)$

HIGH BOUNDS ON NP FROM SELECTED OBSERVABLES = SENSITIVITY TO HIGH SCALES OF NP IN THOSE OBERVABLES BUT VERY LIMITED ACCESSIBILITY OTHERWISE

LOW MAXIMAL BOUNDS- INTERESTING PROSPECTS FOR FUTURE EXPERIMENTS

$\Lambda > \mathcal{O}(2) TeV$

--→ DEVIATIONS UP TO O(1-2)% IN THE HIIGS COUPLINGS STILL POSSIBLE
(GOOD NEWS FOR THE FUTURE PRECISION HIGGS MEASUREMENTS IN COLLIDERS)

SUMMARY

THE SCALE OF BEYOND THE SM PHYSICS CONTRIBUTING TO THE HIGGS FERMION COUPLINGS MAY BE DIFFERENT FROM E.G. ELECTROWEAK BSM PHYSICS

IF IN THE EFT APPROACH THE WILSON COEFFICIENTS OF THE RELEVANT OPERATORS RESPECT SOME FLAVOUR STRUCTURE, LIKE MINIMAL FLAVOUR VIOLATION OR A FLAVOUR SYMMETRY RESPONSIBLE FOR THE FERMION MASSES AND MIXING, THERE ARE BAD AND GOOD NEWS:

BAD NEWS: ELECTROWEAK BARYOGENESIS LOOKS UNLIKELY

GOOD NEWS FOR COLLIDERS: A COUPLE OF PER CENT DEVIATIONS FROM THE SM PREDICTIONS IN THE HIGGS COUPLINGS TO FERMIONS ARE STILL POSSIBLE, CONSISTENTLY WITH VERY HIGH PRECISION FCNC DATA.