BSM PHYSICS IN YUKAWA COUPLINGS AND FLAVOUR SYMMETRIES

Introduction: we are in a turning point in particle physics.
After the decades of research with clear guiding principles (driven by the experimental data and requirements of consistency with the basic theoretical principles such as e.g. unitarity) we have discovered the stunningly successful Standard Model.

AND, IN SOME SENSE, WE GOT LOST (PANIC?)

- ON THE ONE HAND, THE SM CANNOT BE THE THEORY OF EVERYTHING.

- BUT IT IS A RENORMALIZABLE QFT, SO….

RENORMALISABILITY IS A BLESSING:

ONE COULD FORMULATE QED (E~1 GeV) WITHOUT UNDERSTANDING THE SM (E~100 GeV)

RENORMALISABILITY IS A CURSE:

TO FIND LAWS OF PHYSICS BEYOND A RENORMALISABLE EFFECTIVE THEORY VALID AT E ONE NEEDS ENERGY OF ORDER OF THE NEW MASS SCALE M OR PRECISION OF ORDER E^2/M^2

BUT WHERE IS THE NEW SCALE?
CONTRARY TO THE PAST, WE DO NOT HAVE ANY STRONG HINTS

THE FERMI FOUR-FERMION THEORY FOR

THE NEUTRON $\beta-$ DECAY HAS

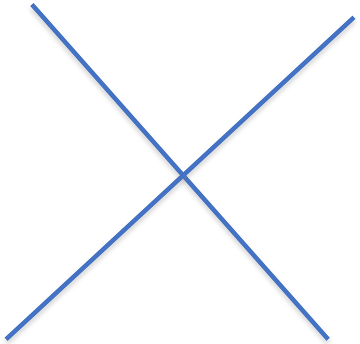
INTRODUCED A NEW MASS SCALE INTO

PARTICLE PHYSICS AND A GUARANTEE

OF NEW DISCOVERIEs

$$\mathcal{L}_F \approx G_F \bar{\Psi}^p_L \gamma_\mu \Psi^n_L \bar{\Psi}^e_L \gamma^\mu \Psi^\nu_L$$

$$G_F \approx 1/10^5 GeV^2$$



$$G_F E^2 \approx \frac{E^2}{(100\ GeV)^2}$$

2+2→2+2 SCATTERING AMPLITUDE

(e.g. N+positron→P+antyneutrino)

EVENTUALLY VIOLATES UNITARITY AND „SOMETHING NEW" MUST HAPPEN TO RESTORE IT!

THE HIGGS DISCOVERY

THE GUARANTEE THAT „SOMETHING" MUST HAVE HAPPENED TO UNITARIZE THE WW SCATTERING AMPLITUDE)

HIERARCHY PROBLEM? TOO WEAK A HINT, AT LEAST AT A QUANTITATIVE LEVEL…

BUT DONT PANIC, JUST EXPLORE…

BSM PHYSICS IN YUKAWA COUPLINGS AND FLAVOUR SYMMETRIES

F. Koutroulis, J.Alonso-Gonzales, A. de Giorgi, L.Merlo and SP,
JHEP 06(2021) 166

JHEP 05(2022) 041

MOTIVATION(GENERAL)

FLAVOUR IS ESSENTIALLY A BEYOND THE SM CONCEPT AND THE NEW PHYSICS SCALE BEHIND THE FLAVOUR PARADIGM MAY BE DIFFERENT FROM THE SCALE OF THE BSM PHYSICS LINKED TO THE BROUT-ENGLERT-HIGGS MECHANISM IN THE SM AND ITS HIERARCHY PROBLEM

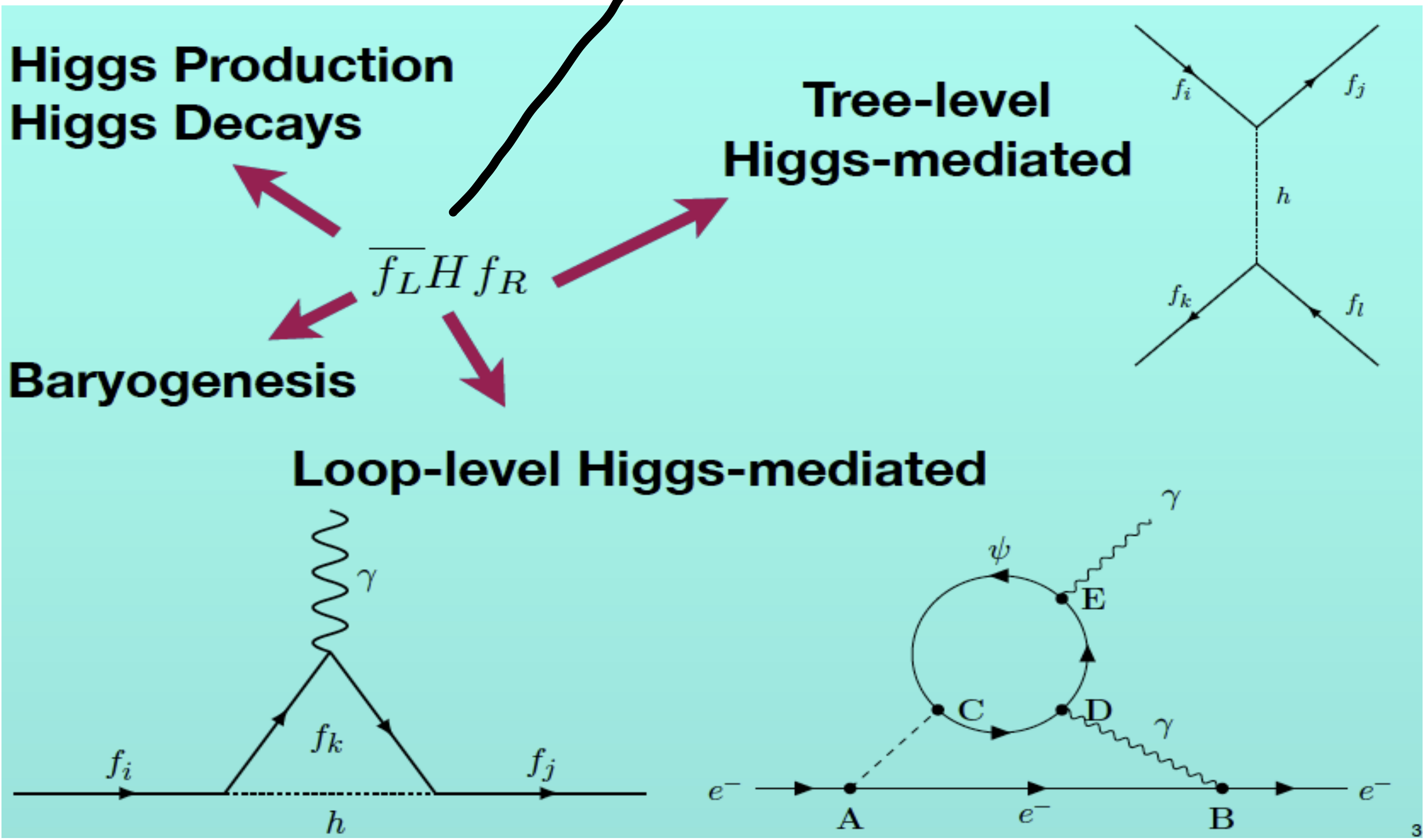
IS THERE ANY THEORY OF FLAVOUR?

IS THERE ANY SYMMETRY BEHIND THE FLAVOUR PHYSICS?

LET’s ASSUME “YES”

IN THE SM, FLAVOUR PHYSICS = YUKAWA COUPLINGS

FERMION MASSES AND MIXINGS



Flavour Symmetries

$\mathcal{G}_F$ rules the fermion interactions:

→ Allows to describe masses and mixings

→ Rules Yukawa interactions

→ Rules the fermion interactions in any d>4 ops.

IN THE EFT APPROACH

IF A SYMMETRY IS PRESENT, DIFFERENT OBSERVABLES ARE STRONGLY LINKED TO EACH OTHER

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

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

$$L = -\bar{L}_L^J H Y_e'^{JK} e_R^K - \bar{L}_L^J H C_e'^{JK} e_R^K \frac{H^\dagger H}{\Lambda^2} + h.c$$

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

(AND SIMILARLY FOR THE UP AND DOWN FERMIONS)

TWO INTERESTING HYPOTHESES FOR THE FLAVOUR STRUCTURE OF THE WILSON COEFFICIENTS:

MINIMAL FLAVOUR VIOLATION OR THEY RESPECT A FLAVOUR SYMMETRY OFTEN INVOKED TO EXPLAIN FERMION MASSES AND MIXINGS (U(1) SYMMETRY FROGGATT-NIELSEN MODELS ARE TAKEN AS EXAMPLES)

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

STRONG IMPLICATIONS FOR THE EMERGING PICTURE OF BOUNDS ON THE BSM PHYSICS IN THE HIGGS COUPLINGS

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

TWO KINDS OF PREDICTIONS:

1) NEW MASS SCALE INDEPENDENT CORRELATIONS BETWEEN DIFFERENT OBSERVABLES, E.G. CORRELATIONS BETWEEN ELECTRON AND TAUON OBSERVABLES

BOUNDS ON CP VIOLATION IN YUKAWAS

2) NEW BOUNDS ON THE BSM MASS SCALES; DIRECT LHC BOUNDS FROM HIGGS PRODUCTION AND DECAYS COMPARED TO FCNC BOUNDS

ELECTROWEAK BARYOGENESIS NEEDS NEW SOURCES OF

CP VIOLATION (BEYOND THE CKM MATRIX)

THE MOST NATURAL SCENARIO (ALTHOUGH 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.

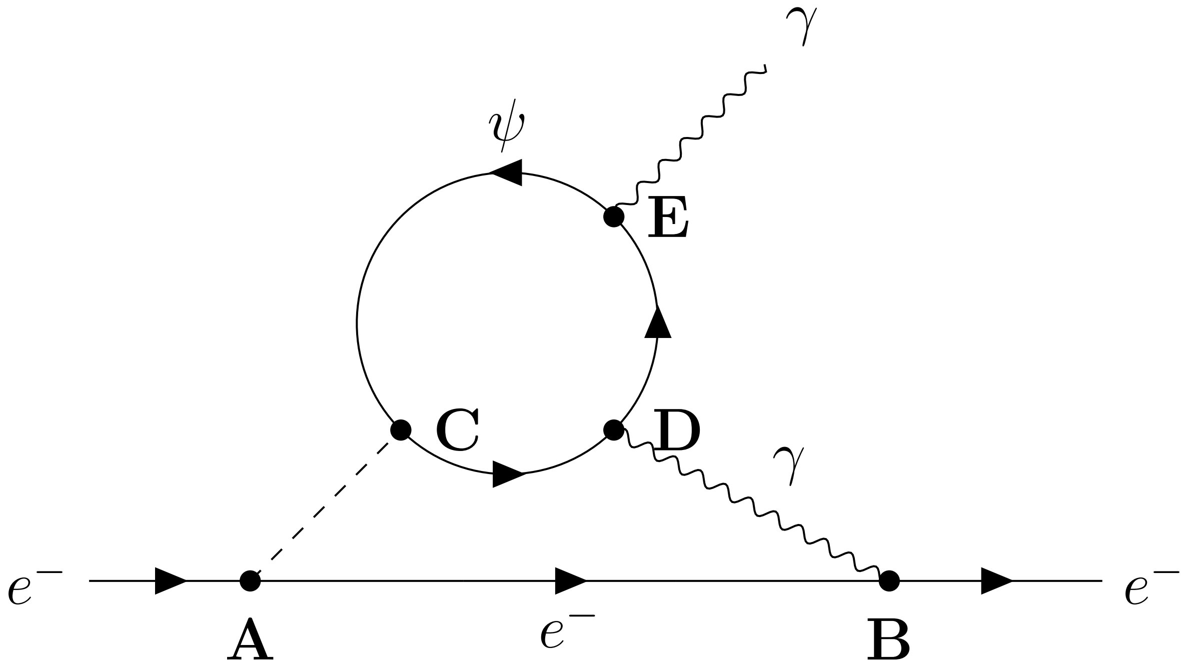
(VERY RICH LITERATURE ON THIS SUBJECT:
most recent E. FUCHS, M.Losada, Y. Nir and Y. VIERNIK)

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^-

Assuming the presence of $\mathcal{G}_F$:

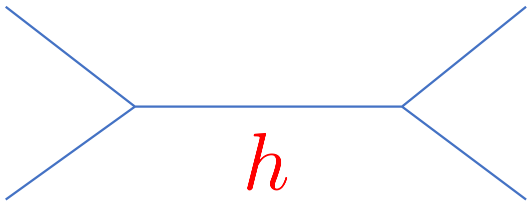
$\tilde{\kappa}_e \approx \tilde{\kappa}_\mu \approx \tilde{\kappa}_\tau$ $\tilde{\kappa}_u \approx \tilde{\kappa}_c \approx \tilde{\kappa}_t$ $\tilde{\kappa}_d \approx \tilde{\kappa}_s \approx \tilde{\kappa}_b$

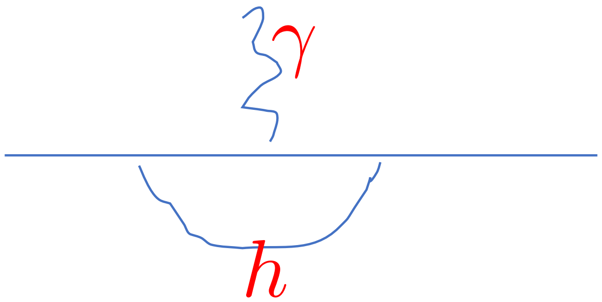
Direct bounds:		Indirect bounds:
$\lvert\tilde{\kappa}_e\rvert \lesssim 0.0017$ $\lvert\tilde{\kappa}_\mu\rvert \lesssim 31$ $\lvert\tilde{\kappa}_\tau\rvert \lesssim 0.29$	→	$\tilde{\kappa}_{e,\mu,\tau} \lesssim 0.0017$
$\lvert\tilde{\kappa}_c\rvert \lesssim 0.37$ $\lvert\tilde{\kappa}_t\rvert \lesssim 0.0012$	→	$\tilde{\kappa}_{u,c,t} \lesssim 0.0012$
$\lvert\tilde{\kappa}_b\rvert \lesssim 0.24$	→	$\tilde{\kappa}_{d,s,b} \lesssim 0.24$

LHC VS FCNC DISCOVERY POTENTIAL

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

- VERY HIGH PRECISION LOW ENERGY FLAVOUR OBSERVABLES (A VARIETY OF FCNC PROCESSES, DEPENDENT ON THE YUKAWA COUPLINGS VIA HIGGS EXCHANGE CONTRIBUTIONS TO THEIR AMPLITUDES)





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

$$C_{ij}\frac{v^2}{\Lambda^2}\bar{f}_i f_j h \to \Lambda > \mathcal{O}(1) TeV$$

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

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

LOW FCNC BOUNDS- INTERESTING PROSPECTS FOR FUTURE LHC EXPERIMENTS

$\Lambda > \mathcal{O}(1) TeV$

--→ DEVIATIONS UP TO 6 % IN THE HIIGS COUPLINGS STILL POSSIBLE
(GOOD NEWS FOR THE FUTURE PRECISION HIGGS MEASUREMENTS IN COLLIDERS)

SUMMARY

CONTRARY TO THE PAST, NO STRONG HINTS WHERE THE SCALE OF NEW PHYSICS IS

THE SCALE OF BEYOND THE SM PHYSICS CONTRIBUTING TO THE HIGGS FERMION COUPLINGS MAY BE DIFFERENT FROM E.G. BROUT-ENGLERT-HIGGS MECHANISM BSM PHYSICS

IF IN THE EFT APPROACH THE WILSON COEFFICIENTS 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 LESS LIKELY

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

Norway grants

NATIONAL SCIENCE CENTRE
POLAND

The research leading to the results presented in this talk has received funding from the Norwegian Financial Mechanism for years 2014-2021, grant nr 2019/34/H/ST2/00707

Understanding the Early Universe:
interplay of theory and collider experiments

Joint research project between the University of Warsaw & University of Bergen

THE EFFECTIVE COUPLING MATRICES

$$\hat{Y_F} = Y_F + \frac{v^2}{\Lambda^2} C_F$$

MFV: $C'_F = c'_F Y'_F \qquad |c'_F| = \mathcal{O}(1) \qquad C_F = c'_F Y_F$

NO NON-DIAGONAL COUPLINGS

FN: $C_{F,ii} = \mathcal{O}(Y_{F,ii}) e^{i\theta_{F,ii}} \quad C_{F,ij} = \mathcal{O}(1) \epsilon^{n_{Q_i} + n_{Fj}} e^{i\theta_{F,ii}}$

G. D'Ambrosio, G.F. Giudice, G. Isidori, A. Strumia (0207036)

A Flavour Model (1/2)

Minimal Flavour Violation

The Model

- **SM**: accidental symmetry $U(3)^5 = U(3)_q^3$ x $U(3)_l^2$ broken solely by Yukawas
- **MFV**: the only source of flavour and CP-violation in the SM comes from the Yukawas

- The Yukawas are promoted to **spurion fields** transforming as bi-triplets of the flavour symmetry

$\Longrightarrow$ **all** higher dimensional flavour-violating operators must be **controlled by Yukawas**!

Consequences

$$\mathcal{L} \subset - \bar{F}'_L C'_f \overset{(\sim)}{H} f'_R \frac{H^\dagger H}{\Lambda_f^2} + \text{h.c.} \qquad C'_f = c'_f Y'_f \longrightarrow$$

No flavour-violating terms!
Only one c'_f for each fermion sector!

C.D.Froggatt, H.B.Nielsen (1979)

A Flavour Model (2/2)

Froggatt-Nielsen

The Model

- New $U(1)$ **symmetry** and **SM-*singlet* scalar field** ϕ (conventionally, with charge $n_\phi = -1$)
- **Fermions** and ϕ **transform** under the new symmetry and the Yukawa terms are made invariant adding powers of ϕ/Λ_F

$$\mathcal{L} \subset -\left[y'_{f,ij}\bar{F}'_{i,L}\overset{(\sim)}{H}f'_{j,R} + c'_{f,ij}\bar{F}'_L\overset{(\sim)}{H}f'_R\frac{H^\dagger H}{\Lambda_f^2}\right]\left(\frac{\phi}{\Lambda_F}\right)^{n_{F_i}+n_{f_j}} + \text{h.c.}$$

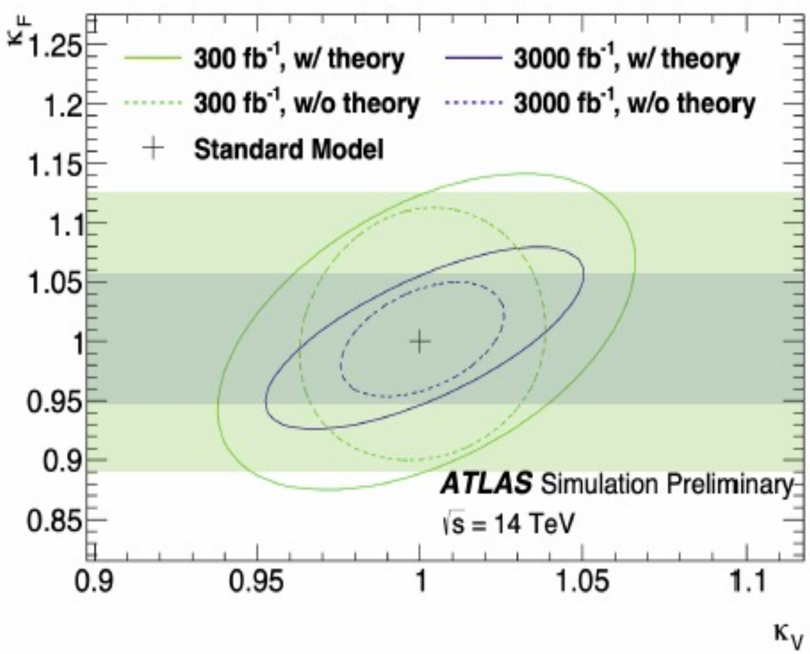
Consequences

- Once the ϕ takes **VEV**, each term is **suppressed** by powers of $\epsilon \equiv \langle\phi\rangle/\Lambda_F$

$$Y_f = \text{diag}\left(y_{f_1}\epsilon^{n_{F_1}+n_{f_1}}, y_{f_2}\epsilon^{n_{F_2}+n_{f_2}}, y_{f_3}\epsilon^{n_{F_3}+n_{f_3}}\right) \qquad C_{f,ij} \approx \mathcal{O}(1)\epsilon^{n_{F_i}+n_{f_j}}e^{i\theta_{f,ij}}$$

Waiting for HL-LHC - Run III

ATLAS Collaboration, ATL-PHYS-PUB-2014-016



Flavour Observables + **Higgs Physics**

$\Lambda_q \gtrsim 1$ TeV

$\Lambda_\ell \gtrsim 4$ TeV

$0.88 \lesssim r_q^2 \lesssim 1.12$

$0.99 \lesssim r_\ell^2 \lesssim 1.01$

VS

$\Lambda_q \gtrsim 0.8$ TeV

$\Lambda_\ell \gtrsim 0.5$ TeV

$0.82 \lesssim r^2_{t,c,u} \lesssim 1.61$

$0.67 \lesssim r^2_{b,s,d} \lesssim 1.52$

$0.49 \lesssim r^2_{\tau,\mu,e} \lesssim 1.51$

$$\frac{\Delta\kappa_q}{\kappa_q} \approx 6\% \qquad \frac{\Delta\kappa_l}{\kappa_l} \approx 0.5\%$$

Coupling	300 fb^{-1} Theory unc.:			3000 fb^{-1} Theory unc.:		
	All	Half	None	All	Half	None
$\kappa_V = \kappa_Z = \kappa_W$	4.3%	3.0%	2.5%	3.3%	2.2%	1.7%
$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_\mu$	8.8%	7.5%	7.1%	5.1%	3.8%	3.2%

Coupling	300 fb^{-1} Theory unc.:			3000 fb^{-1} Theory unc.:		
	All	Half	None	All	Half	None
κ_V	4.3%	3.1%	2.5%	3.3%	2.2%	1.7%
κ_q	11%	8.7%	7.8%	6.6%	4.5%	3.6%
κ_l	10%	9.6%	9.3%	6.0%	5.3%	5.1%

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

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

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

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

$$\frac{d_e}{e} = 4\,\frac{\alpha_{\rm em}}{(4\pi)^3}\,\sqrt{2}\,G_F\,m_e \times \tilde{\kappa}^{\rm eff}$$

$$\tilde{\kappa}^{eff} = [2.68\tilde{\kappa}_e + 3.83\tilde{\kappa}_t + 0.018\tilde{\kappa}_b + 0.015\tilde{\kappa}_\tau]$$

Experimentally: $\tilde{\kappa}^{eff} < 0.0045$

In order to relax the bounds found on $\tilde{\kappa}_{e,t}$, there should be a cancellation between the first two terms!

In the absence of any cancellation,

$$\tilde{\kappa}_{e,\mu,\tau} \lesssim 0.0017$$

is completely general.

- Assuming NP can be described within the **SMEFT**, there is just one type of **dimension-6 operator** contributing to the modification of the **Yukawa interactions:**

$$\mathcal{L} \subset -\bar{F}'_L Y'_f \overset{(\sim)}{H} f'_R - \bar{F}'_L C'_f \overset{(\sim)}{H} f'_R \frac{H^\dagger H}{\Lambda_f^2} + \text{h.c.} \quad \xrightarrow[\text{+ Mass Basis}]{\text{EWSB}} \quad \mathcal{L} \subset -\bar{f}_L Y_f f_R \frac{v}{\sqrt{2}} - \bar{f}_L \left(Y_f + \frac{v^2}{\Lambda_f^2} C_f \right) f_R \frac{h}{\sqrt{2}} + \text{h.c.}$$

Notice that in principle the **NP scale** Λ can be **different** in the quark and lepton sector!

- Parametrize **deviations:**

Effective Yukawa:

$$\hat{Y}_f \equiv Y_f + \frac{v^2}{\Lambda^2} C_f$$

Phenomenological Lagrangian:

$$\mathcal{L}_{\text{eff.}} = \frac{y_{ffh}^{\text{SM}}}{\sqrt{2}} \left(\kappa_f \bar{f} f + \tilde{\kappa} \bar{f} i \gamma_5 f \right) h \qquad \text{SM: } \kappa_f = 1 \,,\ \tilde{\kappa}_f = 0$$

Deviation Parameter:

$$r_f^2 = \frac{|\hat{y}_{ffh}|^2}{\ldots} = \frac{v^2 |\hat{y}_{ffh}|^2}{\ldots} = \kappa_f^2 + \tilde{\kappa}_f^2$$

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

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

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

IN THE FERMION MASS EIGENSTATE BASIS THE FERMION-HIGGS COUPLINGS READ

$$L = -[\bar{u}_L(Y_u + \frac{v^2}{\Lambda^2}C_u)u_R + \bar{d}_L(Y_d + \frac{v^2}{\Lambda^2}C_d)d_R$$

$$+\bar{e}_L(Y_e + \frac{v^2}{\Lambda^2}C_e)e_R]\frac{h}{\sqrt{2}} + h.c$$

$$Y_u = \sqrt{2}/v \; diag(m_u, m_c, m_t) \;\; and \;\; similarly \;\; for \;\; Y_d, Y_e$$

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

V_F, U_F ARE THE MATRICES WHICH DIAGONALIZE THE MASS TERMS

MORE COMMON NOTATION FOR DIAGONAL COUPLINGS

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

THE MATCHING WITH THE EFFECTIVE $\kappa_f, \tilde{\kappa}_f$ 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

BARR-ZEE DIAGRAM CONTRIBUTION TO THE ELECTRON EDM:

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

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

WITHOUT ANY FLAVOUR STRUCTURE, FOR THE THIRD GENERATION FERMIONS RUNNING IN THE LOOP ONE GETS THE BOUNDS (E. FUCHS, M. LOSADA, Y. NIR, Y. VIERNIK, arXiv:2003.00099)

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

ONE CAN ALSO FIND THAT $\tilde{\kappa}_e \leq 0.0017$

SINCE IN GENERAL

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

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

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

HENCE, WITH FLAVOUR STRUCTURE

MFV: $\tilde{\kappa}_\tau \leq 0.0017$ FN: $\tilde{\kappa}_\tau \leq \mathcal{O}(1) \times 0.0017$