

Multi-Higgs or Flavour with symmetries

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The Standard Model is very successful but...

- Neutrinos have masses (ν SM)
- Dark matter (no viable explanation) - MH? FS?
- Matter / antimatter asymmetry (no viable explanation) - MH? FS?
- Hierarchy problem (fine-tuning between parameters)
- Strong CP problem (fine-tuning between parameters)
- Gauge couplings (additional free parameters) - GUT?
- Flavour problem (many additional free parameters) - FS?

BSM solutions involve additional fields and symmetries, like MH and FS.

The Standard Model

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Chiral spin 1/2 fermions (left and right)

Quarks: colour triplets of $SU(3)_C$

Left fermions are doublets of $SU(2)_L$

Spin 0 scalar, doublet of $SU(2)_L$

The Standard Model (1 generation)

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks (Q , u_R , d_R): colour triplets of $SU(3)_C$

LH fields (Q and L): doublets of $SU(2)_L$

e_R just $U(1)_Y$

(ν SM: add ν_R , complete singlet)

Scalar H also doublet of $SU(2)_L$

$\langle H \rangle$ breaks $SU(2)_L \times U(1)_Y \rightarrow U(1)_{em}$

Mass terms: $m_f F_\alpha f_R$ not invariant under $SU(2)_L$

But $y_f (\epsilon^{\alpha\beta} H_\alpha F_\beta) f_R$ is...

$y_f \langle H \rangle F f_R \rightarrow m_f F f_R$ with $m_f = y_f \langle H \rangle$

Multi-Higgs models

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks (Q, u_R, d_R): colour triplets of $SU(3)_C$

LH fields (Q and L): doublets of $SU(2)_L$

e_R just $U(1)_Y$

(ν SM: add ν_R , complete singlet)

Scalars H_i , doublets of $SU(2)_L$

Potential $V(H_i)$, Yukawa couplings, with **each** H_i ...

Proliferation of parameters? Symmetries!

The Standard Model (3 generations)

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks (Q^i, u_R^j, d_R^k): colour triplets of $SU(3)_C$

LH fields (Q^i and L^i): doublets of $SU(2)_L$

e_R^j just $U(1)_Y$

(ν SM: add ν_R^k , complete singlet)

Scalar H also doublet of $SU(2)_L$

$\langle H \rangle$ breaks $SU(2)_L \times U(1)_Y \rightarrow U(1)_{em}$

Mass terms: $M_{ij} F_\alpha^i f_R^j$ not invariant under $SU(2)_L$

But $Y_{ij} (\epsilon^{\alpha\beta} H_\alpha F_\beta^i) f_R^j$ is...

$Y_{ij} \langle H \rangle F^i f_R^j \rightarrow M_{ij} F^i f_R^j$

Proliferation of parameters? Symmetries!

Papers with PhD student Miguel Levy

Exploring multi-Higgs models with softly broken large discrete symmetry groups #1

Ivo de Medeiros Varzielas (Lisbon, CFTP), Igor P. Ivanov (Zhongshan U., Zhuhai), Miguel Levy (Lisbon, CFTP) (Jul 17, 2021)

Published in: *Eur.Phys.J.C* 81 (2021) 10, 918 • e-Print: 2107.08227 [hep-ph]




 pdf  DOI  cite

 4 citations

Symmetries and stabilisers in modular invariant flavour models #2

Ivo de Medeiros Varzielas (Lisbon, CFTP), Miguel Levy (Lisbon, CFTP), Ye-Ling Zhou (Southampton U.) (Aug 12, 2020)

Published in: *JHEP* 11 (2020) 085 • e-Print: 2008.05329 [hep-ph]




 pdf  DOI  cite

 27 citations

Effective alignments and the landscape of S_4 flavour models #3

Ivo De Medeiros Varzielas (Lisbon, CFTP), Miguel Levy (Lisbon, CFTP), Ye-Ling Zhou (Southampton U.) (Mar 25, 2019)

Published in: *Phys.Rev.D* 100 (2019) 3, 035027 • e-Print: 1903.10506 [hep-ph]

 pdf  DOI  cite

 8 citations

Papers with Master student Diogo Ivo

Regular Article - Theoretical Physics | [Open Access](#) | [Published: 07 May 2022](#)

Softly-broken A_4 or S_4 3HDMs with stable states

[Ivo de Medeiros Varzielas](#)  & [Diogo Ivo](#)

[The European Physical Journal C](#) **82**, Article number: 415 (2022) | [Cite this article](#)

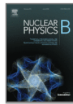
Papers with Master student João Lourenço



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Two A4 modular symmetries for Tri-Maximal 2 mixing

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Conclusion

- Models with Multi-Higgs and symmetries are a very natural extension of the Standard Model
- Models with Family Symmetry are a very natural extension of the Standard Model
- Viable research opportunities for interested students