Deviations from Unitarity of the CKM Matrix and Vector-Like Quarks

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PhD Programme: Higgs and Flavour Beyond the Standard Model

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2021: MSc in Engineering Physics

MSc Thesis:
Scalar Mixing in New Physics Models

Supervisor:
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MSc Thesis (MEFT)

Highlighted Publications:

- **Oblique corrections from triplet quarks** F. Albergaria, J. F. Bastos, B. Belfatto, G. C. Branco, J. T. Penedo, A. Rodríguez-Sánchez, J. I. Silva-Marcos
Published in: JHEP 08 (2025) 061
- **CP-odd and CP-even weak-basis invariants in the presence of vector-like quarks** F. Albergaria, G. C. Branco, J. F. Bastos, J. I. Silva-Marcos
Published in: J.Phys.G 50 (2023) 5
- **The oblique parameters from arbitrary new fermions** F. Albergaria, D. Jurčiukonis, L. Lavoura
Published in: JHEP 05 (2024) 190

Some Talks at International Conferences

- **PLANCK'24** (IST, Lisbon)
- **Workshop on the Standard Model and Beyond** (Corfu)

Full Publication List

The **Standard Model (SM)** was first proposed more than 50 years ago and it is still one of the most successful theories in science. However, there are some phenomena that the SM cannot explain.

The SM can be extended through the addition of Vector-Like Quarks

Vector-Like Quarks (VLQs) are fermions whose left- and right-handed components transform in the same way under $SU(2)_L$.

They appear in some **Grand Unified Theories (GUTs)**, such as E_6, and they also appear in some **Extra Dimension models**, such as the Randall and Sundrum warped geometry models.

VLQs may give new sources of **CP violation** and may explain a deviations from unitarity of the **Cabibbo-Kobayashi-Maskawa (CKM) matrix**, namely of its first row, which has an experimental significance of around 3σ, and which is known as **CKM unitarity problem**.

Explaining the Deviations from Unitarity of the CKM Matrix using VLQ singlets

$$V_{\text{CKM}}^{\text{SM}} = \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix}$$

In the SM, the CKM matrix is a 3 x 3 unitary matrix. However, experimental results hint at $|V_{11}|^2 + |V_{12}|^2 + |V_{13}|^2 < 1$.

$$V_{\text{CKM}}^{\text{SM+VLQ}} = \begin{pmatrix} V_{11} & V_{12} & V_{13} & V_{14} \\ V_{21} & V_{22} & V_{23} & V_{24} \\ V_{31} & V_{32} & V_{33} & V_{34} \\ V_{41} & V_{42} & V_{43} & V_{44} \end{pmatrix}$$

In the presence of one VLQ singlet, the entries which correspond to the 3 x 3 CKM matrix of the SM are now embedded in a larger 4 x 4 unitary matrix. As such, the 3 x 3 block will no longer be unitary in models with VLQs, being the elements in the fourth row and column of this matrix responsible for the deviations from unitarity of that 3 x 3 block.

By adding **more than one VLQ** singlet, the entries of the 3 x 3 CKM matrix of the SM will then be embedded in **larger unitary matrices**.

These larger matrices, together with the masses of the VLQs, must obey constraints imposed by **electroweak precision measurements**, such as the ones coming from experimental results on **rare top decays** ($t \to Z(H)q$), **D^0 - $\overline{D^0}$ mixing**, **K^0 - $\overline{K^0}$ mixing** or **B_q - $\overline{B_q}$ mixing**.

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