Oblique Parameters in General New Physics Frameworks

Francisco Albergaria

CFTP/IST, U. Lisboa

francisco.albergaria@tecnico.ulisboa.pt

In collaboration with: D. Jurčiukonis (Vilnius), L. Lavoura (Lisboa), J. C. Romão (Lisboa)

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Bibliography

This presentation is based on these three papers:

[1] F. Albergaria, L. Lavoura, and J. C. Romão, *Oblique corrections from triplet quarks*. *J. High Energ. Phys.* **03**, 031 (2023).

[2] F. Albergaria, D. Jurčiukonis and L. Lavoura, *The oblique parameters from arbitrary new fermions*. *J. High Energ. Phys.* **05**, 190 (2024).

[3] F. Albergaria and L. Lavoura, *Oblique corrections from leptoquarks*. *J. High Energ. Phys.* **09**, 080 (2023).

Introduction

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

Thus, particle physicists propose New Physics (NP) models which complement the SM, explaining some phenomena that the SM cannot.

When these NP models satisfy the following criteria:

- The electroweak gauge group is $SU(2) \times U(1)$;
- The NP particles have suppressed couplings to the light fermions with which experiments are performed and couple mainly to the SM gauge bosons;
- The relevant measurements are those made at energy scales $q^2 \approx 0$, $q^2 = m_Z^2$ and $q^2 = m_W^2$ (*i.e.* LEP physics);

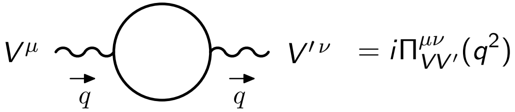
then, the NP effects can be parameterized by the oblique parameters.

Definition of the Oblique Parameters

We can write the vacuum-polarization tensors as

$$\Pi^{\mu\nu}_{VV'}(q) = g^{\mu\nu} A_{VV'}(q^2) + q^\mu q^\nu B_{VV'}(q^2),$$

where q is the four-momentum of the external gauge bosons and VV' may be either $\gamma\gamma$, γZ, ZZ or WW.



We define $\delta A_{VV'}(q^2)$ as

$$\delta A_{VV'}(q^2) \equiv A_{VV'}(q^2)|_{NP} - A_{VV'}(q^2)|_{SM},$$

where $A_{VV'}(q^2)|_{NP}$ is the function $A_{VV'}(q^2)$ computed in a NP model and $A_{VV'}(q^2)|_{SM}$ the function $A_{VV'}(q^2)$ computed in the SM.

Definition of the Oblique Parameters

Then, the oblique parameters S, T and U, as defined by Peskin and Takeuchi (1990) are given by

$$T = \frac{1}{\alpha m_Z^2}\left[\frac{\delta A_{WW}(0)}{c_W^2} - \delta A_{ZZ}(0)\right],$$

$$S = \frac{4 s_W^2 c_W^2}{\alpha}\left[\left.\frac{\partial\,\delta A_{ZZ}(q^2)}{\partial q^2}\right|_{q^2=0} - \left.\frac{\partial\,\delta A_{\gamma\gamma}(q^2)}{\partial q^2}\right|_{q^2=0} + \frac{c_W^2 - s_W^2}{c_W s_W}\left.\frac{\partial\,\delta A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0}\right],$$

$$U = \frac{4 s_W^2}{\alpha}\left[\left.\frac{\partial\,\delta A_{WW}(q^2)}{\partial q^2}\right|_{q^2=0} - c_W^2\left.\frac{\partial\,\delta A_{ZZ}(q^2)}{\partial q^2}\right|_{q^2=0}\right.$$

$$\left. - s_W^2\left.\frac{\partial\,\delta A_{\gamma\gamma}(q^2)}{\partial q^2}\right|_{q^2=0} + 2 c_W s_W\left.\frac{\partial\,\delta A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0}\right].$$

Definition of the Oblique Parameters

Maksymyk, Burgess and London (1994) defined the additional oblique parameters V, W and X as

$$
\begin{aligned}
V =& \frac{1}{\alpha}\left[\left.\frac{\partial\,\delta A_{ZZ}(q^2)}{\partial q^2}\right|_{q^2=m_Z^2} - \frac{\delta A_{ZZ}(m_Z^2)-\delta A_{ZZ}(0)}{m_Z^2}\right],\\
W =& \frac{1}{\alpha}\left[\left.\frac{\partial\,\delta A_{WW}(q^2)}{\partial q^2}\right|_{q^2=m_W^2} - \frac{\delta A_{WW}(m_W^2)-\delta A_{WW}(0)}{m_W^2}\right],\\
X =& \frac{c_W s_W}{\alpha}\left[\left.\frac{\partial\,\delta A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0} - \frac{\delta A_{\gamma Z}(m_Z^2)-\delta A_{\gamma Z}(0)}{m_Z^2}\right].
\end{aligned}
$$

Oblique Corrections from Triplet Quarks

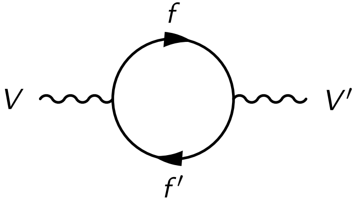
In a NP model whose scalar sector only includes $SU(2)$ doublets, vector-like quarks coupling to these scalar doublets can only appear in seven types of gauge-covariant multiplets:

- $SU(2)$ singlets with weak hypercharge $2/3$;
- $SU(2)$ singlets with weak hypercharge $-1/3$;
- $SU(2)$ doublets with weak hypercharge $7/6$;
- $SU(2)$ doublets with weak hypercharge $1/6$;
- $SU(2)$ doublets with weak hypercharge $-5/6$;
- $SU(2)$ triplets with weak hypercharge $2/3$;
- $SU(2)$ triplets with weak hypercharge $-1/3$.

Oblique Corrections from Triplet Quarks

In [1], we have computed the oblique parameters in a general model with an arbitrary number of $SU(2)$ multiplets from the types presented in the previous slide.

In this model, the Feynman diagrams that contribute at one-loop level to the vacuum-polarization are of this form:



Our results for the oblique parameters are given in terms of the Passarino-Veltman (PV) functions and in this paper we also present analytic formulas for the PV functions used.

The Oblique Parameters from Arbitrary New Fermions

Later, in [2], we have generalized the results from [1], by computing the oblique parameters in a general model with arbitrary numbers of fermions in arbitrary representations of $SU(2) \times U(1)$.

In this paper, we have also numerically computed the oblique parameters in some specific scenarios.

The Oblique Parameters from Arbitrary New Fermions

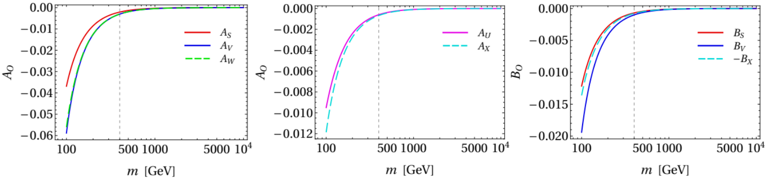
One Vector-Like Multiplet

In a NP model with one vector-like multiplet, the oblique parameter T vanishes and for the remaining oblique parameters $O = S, U, V, W, X$, we have

$$O = \frac{2J+1}{\pi}\left(\frac{4}{3}A_O(m^2)J(J+1) + B_O(m^2)Y^2\right),$$

where J is the isospin and Y is the hypercharge of the NP multiplet and m is the bare mass of the multiplet.

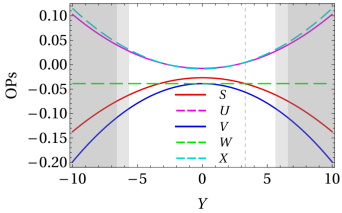
In this figure we see the functions A_O and B_O plotted as a function of m:



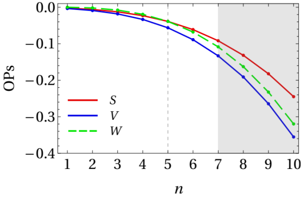
The Oblique Parameters from Arbitrary New Fermions

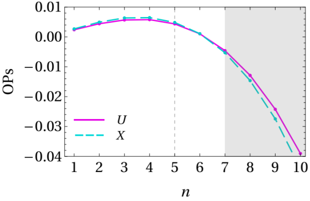
One Vector-Like Multiplet

In this figure we have a plot of the oblique parameters as a function of Y for $J = 2$ and $m = 400$ GeV:



In this figure we have a plot of the oblique parameters as a function of $n = 2J + 1$ for $Y = 3.3$ and $m = 400$ GeV:



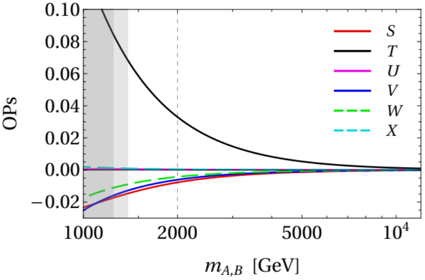


The Oblique Parameters from Arbitrary New Fermions

Two Vector-Like Multiplets

We also considered a model with two vector-like multiplets, one of them (A) with isospin J and hypercharge Y and the other one (B) with isospin $J + 1/2$ and hypercharge $Y + 1/2$.

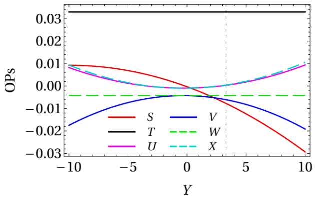
In the figure below, we see the oblique parameters from this model plotted as a function of the bare masses of the multiplets, m_A and m_B, which were imposed to be equal. In this plot we consider $J = 2$ and $Y = 3.3$.



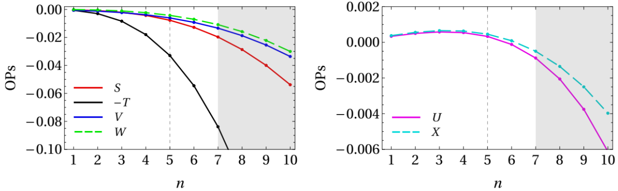
The Oblique Parameters from Arbitrary New Fermions

Two Vector-Like Multiplets

In this figure we have a plot of the oblique parameters as a function of Y for $J = 2$ and $m_A = m_B = 2000$ GeV:



In this figure we have a plot of the oblique parameters as a function of $n = 2J + 1$ for $Y = 3.3$ and $m_A = m_B = 2000$ GeV:



Oblique Corrections from Leptoquarks

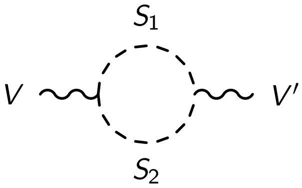
There are 5 possible scalar leptoquark representations, all of them in the triplet representation of $SU(3)$:

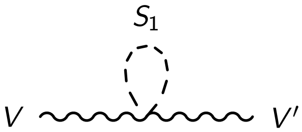
- $SU(2)$ singlets with weak hypercharge $-1/3$;
- $SU(2)$ singlets with weak hypercharge $-4/3$;
- $SU(2)$ doublets with weak hypercharge $7/6$;
- $SU(2)$ doublets with weak hypercharge $1/6$;
- $SU(2)$ triplets with weak hypercharge $-1/3$.

In [3], we have computed the oblique parameters in a model with arbitrary numbers of scalar leptoquarks in these representations.

Oblique Corrections from Leptoquarks

In this model, the Feynman diagrams that contribute at one-loop level to the vacuum-polarization are of this form:





Oblique Corrections from Leptoquarks

In [3], we computed the oblique parameters in three different specific scenarios:

- A model with one scalar singlet with weak hypercharge $-1/3$ and one scalar doublet with weak hypercharge $1/6$;
- A model with one scalar doublet with weak hypercharge $1/6$ and one scalar doublet with weak hypercharge $7/6$;
- A model with one scalar doublet with weak hypercharge $7/6$ and one scalar triplet with weak hypercharge $-1/3$.

We have also generalized our results to a general model with scalars in arbitrary representations of the gauge group that are allowed to freely mix among themselves but not to mix with the scalar doublet of the SM neither to acquire vacuum expectation values.

Conclusions

Despite being such a successful theory, we know that the SM is not complete.

Several extensions to the SM have been proposed through the years.

The oblique parameters can be used to constrain SM extensions which have $SU(2) \times U(1)$ as electroweak gauge group.

We have computed the oblique parameters in different general scenarios (with extra fermions and extra scalars), such that our results can be used to constrain a wide variety of specific models.