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Project: Courants droits faibles dans le secteur des quarks
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Project goals

The Standard Model (SM) of particle physics is a very successful theory describing quantum particles and their interactions in a regime where relativistic effects must be taken into account. As a very short taste of its power on describing nature, high energy experiments have measured a bunch of observables to high precision and accuracy, and all of them are consistently described by a small number of parameters ([Gfitter] – another example is the global fit of the CKM matrix, going be discussed below). However, many aspects of the SM are poorly understood: The masses of the three generations of quarks are distributed over a factor of 100,000; comparatively, the neutrinos are almost massless; the two chiralities are seen differently by the weak interactions (e.g. parity is maximally violated by the charged vector boson $W^{\pm}$); charges are assigned arbitrarily (e.g. electric charge quantification); the violation of CP (Charge-conjugation–Parity) by strong interactions must be extremely small or null (strong-CP problem), among other issues.

Left-Right (LR) symmetric models address the question of parity by introducing right-handed currents interacting via a new, still not detected force. They assert that one of the reasons why right and left are so different is due to the spontaneous break of parity in nature, thus implying that left and right-handed currents interact differently.

The main goal of this project is to analyze whether this is a compelling scenario, i.e. whether a better description of nature is achieved by a LR model. More precisely, we are looking for a sizable improvement of the global fit of the flavor observables and electroweak precision tests described below. We also aim to estimate the parameters of a LR model, setting constraints on them from a global fit and determining whether a direct production at the LHC is possible. A product of such a study is going to be a set of packages for the CKMfitter collaboration rendering possible further analysis of LR models after the project is accomplished.

The CKMfitter group provides an efficient frequentist (plus a *Range fit* treatment of theoretical uncertainties [CKMfitter]) framework for the simultaneous statistical analysis of many different constraints. Its analysis is organized modularly, in different packages. It can be used not only to determine the structure of the CKM matrix, but also to look for New Physics (NP) manifestations in flavor observables and beyond.

Description of work achieved

Left-Right Symmetric Model

Historically, people have explored and investigated LR models by introducing triplets of scalars in order to break parity spontaneously; let us further refer to this scenario as LR-T. It has the advantage of potentially introducing a mechanism where the tiny masses of the (left-handed) neutrinos are described by heavy (right-handed) counterparts, a mechanism called seesaw. Though it may address the puzzle of the small masses of the observed neutrinos in an extremely attractive way (by associating this issue to the spontaneous violation of parity), while containing triplets its simplest formulation lacks of observability: Combined constraints coming from meson oscillations among other observables tend to push the scale of the new scalar particles up to 10-20 TeV[1] [Mohapatra 2007, Buras 2012], rendering the model less attractive from the point of view of its phenomenology, i.e. the possible observation of its effects in the near future. Much effort has been done in order to avoid these constraints, but very stringent lower bounds on the masses of the new particles persist [Basecq 1985, Langacker 1989, Buras 2012].

Moreover, the triplet case is very constrained by its predictions for neutrino masses [Deshpande 1991] and the requirement to recover the ρ-parameter[2] from Electro-Weak Precision Observables (EWPO). Our aim is to reconsider an alternative breaking of left-right symmetry[3], via doublet rather than triplet fields, a scenario

[1] By perturbativity reasons, the new vector particles must not be far away from this scale.
[2] The ρ-parameter is defined to be $\rho \equiv M_W^2/(\cos^2(\theta_W)M_Z^2)$.
[3] The gauge group of LR models is $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, while the gauge group of the SM is $SU(3)_c \times SU(2)_L \times U(1)_Y$, where B is the baryon number, L is the lepton number, and Y is the hypercharge.

further referred here as LR-D.

A first proof of the attractiveness of LR-D was to show that it does not suffer from worse fine-tuning problems when compared to LR-T [Barenboim 2002]. Indeed, this was done through the analysis of the equations found at the minimum of the Higgs potential, when asking for a certain pattern of symmetry breaking.[4] Another issue was whether LR-D can afford for one light, SM-like Higgs particle, and many heavier scalars. We have calculated explicitly the spectrum and observed that the natural masses of these new scalars (i.e. three CP-even, two CP-odd, and four charged Higgses) are at the same scale as the masses of the new vector bosons, Z'^0 and $W'^{\pm}$, i.e. they are naturally heavy.

We have then investigated the precise scale of the masses of these new heavy particles through EWPO, see [Yuan 2010]. These are observables at the pole of the Z boson – Left-Right asymmetries $A_{\ell,c,b}$, Forward-Backward asymmetries $A_{FB}^{0,\ell,c,b}$, ratios of decay rates $R^0_{\ell,c,b}$, etc. –, as well as low energy observables – e.g. Atomic Parity Violation (APV) –, which were precisely and accurately measured.

For computing these observables, the task consisted on the use of [Zfitter] for calculating the SM contributions, and then the calculation of the first corrections introduced by LR-D (i.e. contact interactions in an Effective Field Theory, similarly to what happens in the Fermi theory).

Our preliminary results imply that, when considering a lower bound of 2 TeV for the $W'^{\pm}$, the scale of LR breaking should be roughly 50 times at least larger than the breaking of the SM, if the LR-D is the correct theory. The global fit favors a pattern where the breaking of the SM gauge group is mostly due to a left-handed scalar doublet and there is no sensitivity to the value of the right-handed gauge coupling constant (though we verified that a safe perturbative value for this coupling is favored). The fit of these EWPO was done using a CKMfitter package written by us, and a sub-product of this study was an EWPO package for further analysis in the SM framework.

Besides improving our EWPO analysis, we are at the time being investigating meson oscillations. In particular, the oscillations in the kaon system $K\overline{K}$ were of major importance in the formulation of the SM: The calculation of the mixing led Glashow, Iliopoulos, and Maiani to the introduction of the charm quark; the analysis of a particular channel of decay of this system then led to the first observation of CP violation. Meson oscillations play as well a central role in the formulation of LR models. The new contributions to the SM box diagram $W^{\pm} - W^{\pm}$ are well known in the LR-T model (e.g. [Ecker 1985]): (a) Since there is a new charged vector boson, there are new boxes $W^{\pm} - W'^{\pm}$ and $W'^{\pm} - W'^{\pm}$; (b) the scalar sector introduces a hybrid charged scalar–SM gauge boson box, $H^{\pm} - W^{\pm}$; and (c) the new neutral scalars have FCNC (Flavor Changing Neutral Currents) couplings, thus introducing two tree-level diagrams – indeed, this is the reason that constraints coming from meson oscillations are so stringent.

When asking for LR-D contributions as large as the experimental uncertainties, our preliminary results show that much less stringent bounds are found in the scalar sector, roughly 2 TeV instead of the 10-20 TeV found for LR-T. For the time being, we aim to better understand QCD corrections affecting the oscillation of mesons (see [Buras 1996]), to consider sub-leading one-loop diagrams and to implement our results into a CKMfitter package, thus performing a global fit containing both EWPO and meson oscillations ($K\overline{K}$ and $B_q\overline{B}_q$).

Other constraints are going to be integrated into our global fit analysis and we have already briefly analysed them: (1) The rare decay $b \to \gamma s$, for whom we have identified the new contribution coming from LR-D compared to LR-T (another charged Higgs fluctuation); and (2) the observed spectrum of fermions and the Cabibbo-Kobayashi-Maskawa (CKM) mixing angles (or the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) mixing angles in the leptonic sector), which set constraints on the Yukawa matrices introduced by the model [Kiers 2002].

Additional activities within the CKMfitter collaboration

As a member of the CKMfitter group, I was in charge of the latest update of the CKM global fit, that can be found in our official website:

http://CKMfitter.in2p3.fr/www/results/plots_ moriond14/ckm_ res_ moriond14.html

My work consisted on generating a large part of the plots, using updated inputs provided by other collaborators. A correct analysis of the CKM mixing structure is of crucial importance in flavor physics since large tensions coming from a global fit could indicate the existence of Beyond Standard Model (BSM) physics, as for example a fourth generation of quarks – an easy-to-understand example of how New Physics (NP) may imply a

[4] The LR gauge group $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ is first break down into $SU(3)_c \times SU(2)_L \times U(1)_Y$ at a very high energy scale and then into $SU(3)_c \times U(1)_{QED}$ at the Electro-Weak (EW) scale.

non-unitary 3x3 CKM matrix. It could also claim for LR corrections. So far, we observe a consistent description given by the SM of many different classes of observables, i.e. loop and three-level observables, CP violating and CP conserving processes, or inclusive and exclusive extractions of matrix elements.

Some references

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Publications and talks

I have discussed some of these issues in a short talk given at a summer school in Cargese. The interested reader can search for my talk in the following address:

https://indico.cern.ch/event/282015/other-view?view=standard# 20140714.detailed

We expect to publish our findings by the end of 2014-beginning of 2015.

Relevance of the project within P2IO

The thematics of the project is clearly inserted into the P2IO program, because it aims to push our theoretical knowledge up to energy scales (much) larger than those probed till now. Since our model deals with many fundamental questions in flavor physics and in the utmost symmetries of nature (hence clearly in agreement with one of the four scientific thematics of the “explorer” mission), it is of evident interest to other researches in particle physics, as those in the parisian network. On this topic, my project is particularly interesting, as it gathers two researchers of different laboratories of the P2IO labex, my two PhD advisors.

Depending on its evolution, and due to its phenomenological connections, the project may also trigger discussions and work with members of the LHCb collaboration in LAL (for flavour aspects) as well as with the P2IO teams involved in ATLAS and CMS (for direct searches of gauge bosons related to the right sector).