New Strongly Coupled Sector at the Tevatron and the LHC

Gustavo Burdman,[1] Leonardo de Lima,[1] and Ricardo D. Matheus *[1]

[1]*Instituto de Física, Universidade de São Paulo, São Paulo SP 05508-900, Brazil*

We examine the possibility that a new strong interaction is accessible to the Tevatron and the LHC. In an effective theory approach, we consider a scenario with a new color-octet interaction with strong couplings to the top quark, as well as the presence of a strongly coupled fourth-generation which could be responsible for electroweak symmetry breaking. We apply several constraints, including the ones from flavor physics. We study the phenomenology of the resulting parameter space at the Tevatron, focusing on the the forward-backward asymmetry in top pair production, as well as in the production of the fourth-generation quarks. We show that if the excess in the top production asymmetry is indeed the result of this new interaction, the Tevatron could see the first hints of the strongly coupled fourth-generation quarks. Finally, we show that the LHC with $\sqrt{s} = 7$ TeV and 1 fb^{-1} integrated luminosity should observe the production of fourth-generation quarks at a level at least one order of magnitude above the QCD prediction for the production of these states.

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I. INTRODUCTION

Although the Standard Model (SM) of particle physics is a very successful description of the interactions of fermions and gauge bosons [1], the origin of electroweak symmetry breaking remains unknown. In the SM, an ad hoc scalar sector with an elementary doublet is responsible for triggering spontaneous symmetry breaking, giving masses to gauge bosons and fermions. However, there are several reasons to believe that this description is likely to be an effective one. First, the weak scale as generated by the elementary scalar Higgs sector is not stable under radiative corrections, resulting in an unnatural tuning. Perhaps most importantly, it appears more natural to have the scalar sector as a composite of a fermionic sector, given our experience with other physical systems. The only known loophole to this statement is found in supersymmetric theories, where elementary scalars are natural and the weak scale can be stabilized by the presence of super-partners. Here we assume that supersymmetry is not present at the weak scale and therefore the Higgs sector must be a fermionic composite, with the compositeness scale not far above the weak scale. In particular, we assume that the new strong interactions are spontaneously broken, and therefore the condensing fermions are not confined by it. This opens the intriguing possibility that the condensing strongly coupled fermions might belong to a sequential fourth-generation. This scenario [2] differs from technicolor theories [3] where techni-fermions are confined by an unbroken, asymptotically free interaction. Although it is relatively simple to build a renormalizable model along the lines of top-color [4, 5] in order to obtain the condensation of a fourth-generation quark, a more complete model (e.g. including mass generation for all fermions) is more elusive. For instance, recently a model embedded in AdS_5 was presented in Ref. [6, 7], where the fourth-generation is strongly coupled to the Kaluza-Klein (KK) excitations of the gauge bosons due to its localization in a compact extra dimension.

In this paper we would like to focus on the basic ingredients for this scenario: a new strong interaction at the TeV, a fourth-generation strongly coupled to it, and with enough flavor violation to generate the flavor hierarchies. The aim is to apply the minimal set of requirements to a model of fourth-generation condensation in order to fix some important aspects of its phenomenology at colliders. One important feature that must be present is flavor violation at tree level, ensuring a supercritical coupling of the fourth-generation quarks. It is then natural to assume that he third generation might also be more strongly coupled to the mass-generating interaction than the lighter two. Thus, we are inclined not just to consider the fourth-generation phenomenology in isolation, but also the signals and constraints from flavor violation involving the third generation. In particular, we study the possibility that the new interaction coupled to the top quark might result in large deviations in the top-production forward-backward asymmetry A^t_{FB} recently measured at the Tevatron. At the same time, we must consider the flavor physics bounds on flavor-violating processes.

Rather than to attempt building a full fledged theory we will take an effective field theory approach and write the most general interactions containing these ingredients and satisfying all existing constraints. This procedure will be restrictive enough so as to result in a predictive model of the new interaction, including the fourth generation quarks. In order to implement this approach, we consider a full fourth generation of chiral fermions to have an anomaly-free extension from the start. We re-

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*Current address: *Departamento de Ciências Exatas e da Terra, Universidade Federal de São Paulo, Diadema SP 09972-270, Brazil* quire a new interaction strongly coupled to at least some of the fourth-generation fermions. However, in this paper we will not be concerned with the phenomenology of the fourth-generation leptons [8], since early signals of this scenario are much more likely in the quark sector.

We further assume that the new interaction is spontaneously broken at a scale close to 1 TeV, and that it is mostly mediated by a color-octet spin-one massive state. Although this choice is not unique, it does appear in various models such as the fourth-generation version of top-color and extra dimensional theories. Finally, we demand that the interaction couples to the fourth-generation quarks strongly enough so as to induce $\langle Q_4 U_4\rangle \neq 0$ and/or $\langle Q_4 D_4\rangle \neq 0$, where Q_4, U_4 and D_4 are the doublet, up right-handed and down right-handed fourth-generation quarks respectively. If at least one of these two condensates forms, it induces electroweak symmetry breaking (EWSB) and generates a dynamical mass for the condensing quark. The requirement of super-critical coupling of the color-octet to the fourth-generation quarks is important because it greatly determines its width. In fact, as we will see later, the width of the color-octet must be rather large in all of these scenarios.

Regarding the lighter three generations, their masses will typically arise from higher dimensional operators, which are too suppressed to affect the phenomenology at colliders. On the other hand, the color-octet couplings to the SM quarks should be considerably smaller than the couplings to the fourth generation. Here we will mostly leave these couplings free, but for the constraints imposed on them by flavor-changing neutral currents (FCNC), by multijet production and by top quark observables. As a result, we will obtain the allowed parameter space for this scenario which will result in predictions for the production of fourth-generation quarks via this new interaction plus QCD both at the Tevatron and at the LHC. We first focus our attention on the potential of the Tevatron to produce the fourth-generation quarks given that it will eventually accumulate $10^{-1} fb$ per experiment. In addition, we will consider the possibility that the new color-octet interaction, if appropriately coupled to top-quarks, could be responsible for the observed deviation in the measured forward-backward asymmetry in top-quark production at the Tevatron [9] with respect to the SM prediction. Once this additional information from the Tevatron is considered, we study the LHC reach during its first physics run, with $\sqrt{s} = 7$ TeV and $1^{-1} fb$ of accumulated luminosity.

There is a large number of existing studies involving either a new interaction leading to deviations in A^t_{FB} [10] or the phenomenology of the fourth generation [12]. This is the first attempt to combine the two in one effective model. Particularly relevant to our study on A^t_{FB} is Ref. [13], where an axi-gluon model is studied. In Ref. [14] this specific axi-gluon model is excluded by flavor constraints.

In the next section we define the effective theory to be used in the rest of the paper. In Section III we fix the parameter space of the model by requiring it to satisfy FCNC constraints, as well as various direct detection observables including the observed A_{FB} in top-quark production. In Section IV, the fourth-generation quarks are introduced and the constraints on them are presented. In Section V we present our results and evaluate the reach of the Tevatron in both the color-octet and the fourth-generation masses. We also discuss the level of these signals at the LHC. We conclude in Section VI.

II. EFFECTIVE THEORY

We extend the SM by including a chiral fourth generation $Q_4, U_4, D_4, L_4, E_4, N_4$. We also assume the presence of a massive, color-octet, spin-one state G^a_μ. The relevant effective interaction with quarks is given by

$$\begin{aligned}\mathcal{L}_{\rm eff} &= g^i_L\, G^a_\mu\, \bar{Q}_i\gamma^\mu T^a Q_i \\ &+ g^i_u\, G^a_\mu\, \bar{U}_i\gamma^\mu T^a U_i \\ &+ g^i_d\, G^a_\mu\, \bar{D}_i\gamma^\mu T^a D_i\ , \end{aligned} \tag{1}$$

where T^a are the $SU(3)_c$ generators, a sum over the generation number $i = 1, 2, 3$ is understood, Q_i denotes the left-handed quark doublet and $U_i(D_i)$ the up (down) right-handed quark of the i-th generation. Although at this point the couplings g^i_L, g^i_u and g^i_d are free parameters, we will impose constraints on them, some of which come from the desired dynamics of EWSB, whereas other will be purely phenomenological in origin.

In order to focus in a scenario where EWSB is triggered by the condensation of fourth-generation quarks we ask that the fourth-generation couplings be strong enough to lead to at least one of the two quark condensates, $\langle Q_4 U_4\rangle$ and $\langle Q_4 D_4\rangle$, to be non-vanishing. The four-fermion operators of interest are induced by integrating out the color-octet and are given by

$$\begin{aligned}\mathcal{L}^4_{\rm eff} &= \frac{g^4_L g^4_u}{M^2_G}\, \bar{Q}_4\gamma_\mu T^a U_4\, \bar{U}_4\gamma^\mu T^a Q_4 \\ &+ \frac{g^4_L g^4_d}{M^2_G}\, \bar{Q}_4\gamma_\mu T^a D_4\, \bar{D}_4\gamma^\mu T^a Q_4\ .\end{aligned} \tag{2}$$

In order for one of these two terms to lead to condensation, at least one of the criticality conditions must be satisfied. That is

$$g^4_L g^4_u > \frac{8\pi^2}{3}, \qquad \text{and/or} \qquad g^4_L g^4_d > \frac{8\pi^2}{3}\ . \tag{3}$$

Thus, the scenario where at least one of the fourth-generation quarks condenses requires that the left-handed and/or the right-handed quarks be strongly coupled to the color-octet interaction. Although these couplings are required to be close to non-perturbativity, it is possible to have condensation with couplings satisfying $g^4_{L,u,d} \lesssim 2\pi$, which we take as an upper limit to the couplings we will consider here.

On the other hand, the values of g_L^i, g_u^i and g_d^i for $i = 1, 2, 3$ can be generically smaller than the corresponding couplings for the fourth generation. We will essentially consider two constraints on these couplings. First, we require that for a given color-octet mass, the G' couplings of light quarks satisfy bounds from searches for di-jet resonances at hadron colliders [15]. The bounds, for fixed values of M_G, translate on limits on g_L^q and g_R^q for the light quarks [16]. Typically, for $M_G \simeq 1$ TeV the light-quark couplings to G' are bound to be smaller than the QCD coupling, and they can be almost as large as this one (i.e. $O(1)$) for $M_G \simeq 1.5$ TeV.

A second requirement on the G' couplings to the first three generation quarks is that they do not violate flavor bounds. In principle, the color-octet interactions violate flavor at tree level since they couple to the fourth generation quarks with a larger strength. However, in order to evade strong FCNC bounds from flavor physics we will assume that the G' couplings of the first three generations are nearly universal, with the only exception of the couplings to t_R. As we will see later, this is the minimum flavor violation required in order to accommodate a significant forward-backward asymmetry in $t\bar{t}$ production at the Tevatron. This flavor violation leads to significant contributions to vertices involving the fourth and third generation quarks, such as $GQ_4 t_R$, but it does not generate dangerous FCNC contributions in low energy flavor observables. Thus, these two requirements define an effective theory of a strongly coupled fourth generation, where the new interactions are at the TeV scale, but without problems with flavor violation.

The effective theory defined above should encompass models of EWSB via fourth-generation condensation that somehow manage to avoid having large tree-level FCNC. In the next section we investigate the parameter space of these theories. In particular, we consider the possibility of large contributions to the $t\bar{t}$ forward-backward asymmetry A_{FB}^t, as well as the potential of the Tevatron to observe the production of fourth-generation quarks.

III. FIXING THE PARAMETER SPACE

In this section we reduce the size of the parameter space of the effective theory presented in the previous section by requiring that it gives a significant contribution to A_{FB}^t, while not violating FCNC bounds. The current measurement of A_{FB}^t from the CDF collaboration at Fermilab gives [9]

$$A_{FB}^t = 0.158 \pm 0.072 \pm 0.017 \ . \tag{4}$$

where we consider the forward-backward asymmetry in the $t\bar{t}$ rest frame. The SM prediction from NLO QCD using MCFM [17] results in $A_{FB}^{SM} = 0.058 \pm 0.009$, leaving then considerable room for potential contributions from new physics. First, for a given value of M_G, we require that g_L^q, g_R^q, g_R^t and g_L^t be such that the contributions of the color-octet to $t\bar{t}$ production result in

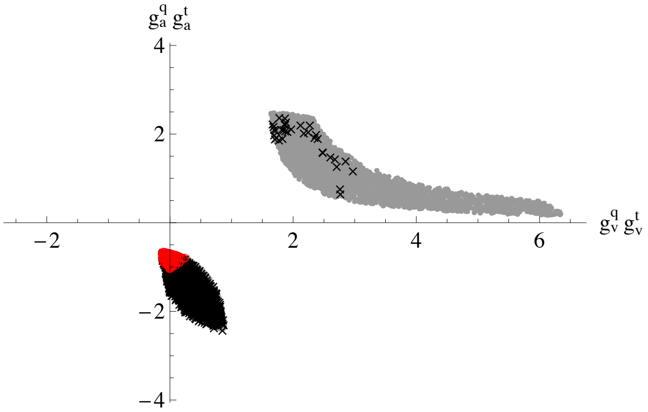

FIG. 1: Allowed region of parameter space leading to significant effects in A_{FB}^t, for $M_G = 1$ TeV (grey). The black crosses mark the region of parameter space further satisfying the dijet bounds as well as flavor universality. The (red) dots satisfy, in addition, the bounds from the invariant mass distribution of Figure 3 and the Δy_t distribution of A_{FB}^t shown in Figure 4 .

$A_{FB}^{\rm new} = 0.16 \pm 0.07$. Figure 1 shows the response of the parameter space of the effective theory to various constraints for $M_G = 1$ TeV. The shaded region of the plot shows the selected parameter space in terms of the product of the light quark and top vector couplings, $g_V^q g_V^t$, and the product of their axial couplings $g_A^q g_A^t$. This region results from imposing the A_{FB}^t constraint, plus demanding that the total $t\bar{t}$ cross section be within one sigma of [18] $\sigma_{t\bar{t}} = 7.50 \pm 0.31 \pm 0.34 \pm 0.15$. Imposing the perturbativity of the top quark coupling g_R^t, the dijet bounds, and flavor universality in all couplings with the exception of g_R^t results in the smaller regions represented by the darker crosses in the Figure. Imposing the light flavor universality leaves us with the right-handed top as the only free coupling to achieve a large asymmetry. This is shown in Figure 2, where we show solutions for A_{FB}^t for given values of g_R^t that satisfy all other constraints, and for $M_G = 1$ TeV. We see that it is possible to generate important contributions to A_{FB}^t even for moderate values of g_R^t. Furthermore, we require a good fit to the measured [19] $t\bar{t}$ invariant mass distribution, by excluding solutions which would make any one bin in the distribution fall outside a 1.5 σ band. We show the result for the invariant mass distribution in $t\bar{t}$ production in Figure 3. Finally, the resulting parameter space is used to plot the rapidity dependence of A_{FB}^t as obtained in [9], resulting in the bands of Figure 4. In both cases, the crosses represent the data points. We see that both distributions can be safely accommodated with the available parameter space. In the case of the rapidity distribution of Figure 4, the band representing the available solutions is consistent with the data even when the QCD (shown as the dashed line) is not. The region of parameter space consistent with the m_{tt} distribution and with the Δy dependence of A_{FB}^t, is shown in Figure 1 as the smaller

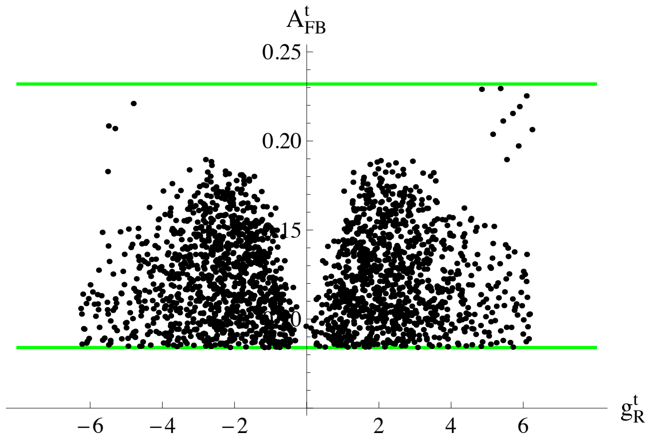

FIG. 2: A^t_{FB} vs. the right-handed top quark coupling g^t_R, for $M_G = 1$ TeV.

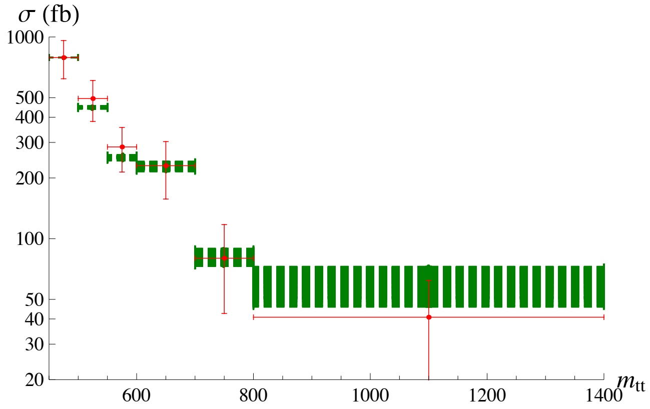

FIG. 3: The $t\bar{t}$ production cross-section as a function of the $t\bar{t}$ invariant mass m_{tt}, for $M_G = 1$ TeV. The crosses are the experimental values. The band represent the solutions of the scattered plot in Figure 1 that are within 1.5 σ of the data.

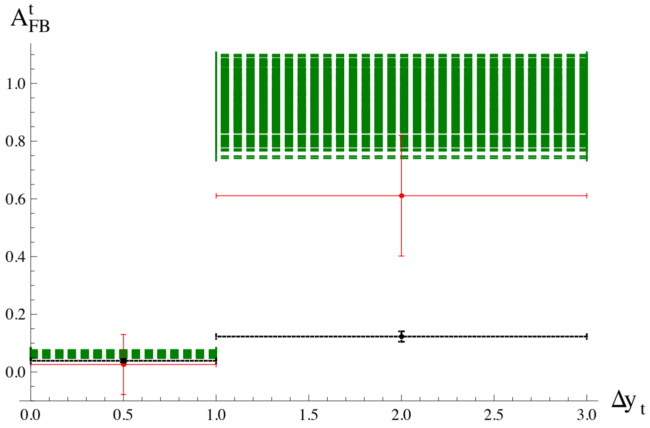

FIG. 4: The rapidity dependence of the forward-backward asymmetry in $t\bar{t}$ production. for $M_G = 1$ TeV. The crosses are the experimental values. The band represent the solutions of the scattered plot in Figure 1 that are within 1.5 σ of the data. The dashed line is the NLO QCD prediction obtained using MCFM [17].

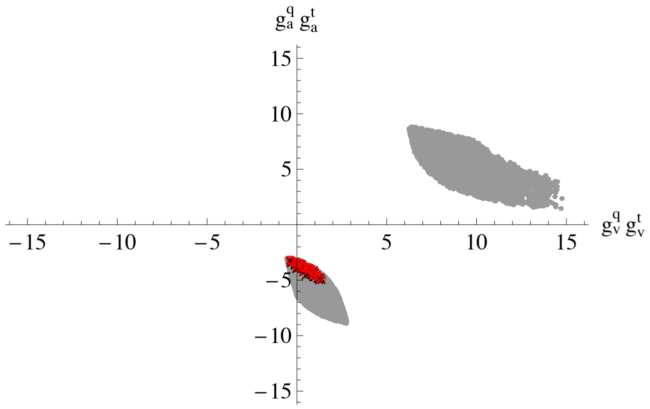

FIG. 5: Allowed region of parameter space leading to significant effects in A^t_{FB}, for $M_G = 1.5$ TeV (grey). The black crosses mark the region of parameter space further satisfying the dijet bounds as well as flavor universality. The (red) dots satisfy, in addition, the bounds from the invariant mass distribution of Figure 7 and the Δy_t distribution of A^t_{FB} shown in Figure 8.

(red) region in the lower left region, corresponding to low values of the product of the vector couplings $g^q_v g^t_v$. These solutions then, satisfy all constraints. We observe that the selected region of parameter space is "axi-gluon like", in that the product of the vector couplings of the light quarks and the top is small (is zero in axi-gluon models). It is also consistent with the choice of signs of Ref.[13], but here the solutions are more generic and are arrived at by imposing all constraints.

We repeat the exercise for $M_G = 1.5$ TeV and show the allowed regions in Figure 5. Although, in principle, the region of allowed parameter space appears to be slightly larger for $M_G = 1.5$ TeV without including the flavor conservation constraints, we see that once these are considered only one of the two regions is still allowed. This is shown as (red) dots in the lower region of Figure 5. In Figure 6 we plot the asymmetry vs. the right-handed top quark coupling to G'. Just as for the previous case, in order to get a significant effect in A^t_{FB}, the right-handed top quark must have a rather large coupling. typically $|g^t_R| \sim (2-5)$. Although the larger values of g^t_R are close to the upper bound given by perturbativity, this is not a problem since in order for the top quark to condense the left-handed coupling to G' should be of the same order. But this is not allowed by the flavor-conservation constraint. In addition, we have to allow for larger values of the light-quark couplings g^q_L and g^q_R, although for this value of M_G these remain typically just below the QCD coupling. In principle, it is possible to consider larger values of the G mass. To go above $M_G = 1.5$ TeV without significantly increasing the value of g^t_R –already at the edge of perturbativity– would require light-quark couplings above the QCD coupling. But in doing so we would run into trouble with the bounds on resonances decaying to two jets from the Tevatron data [15].

To summarize, in this section we have limited the pa-

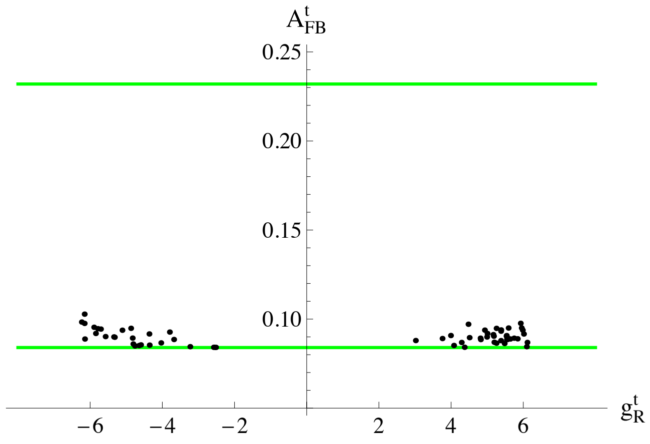

FIG. 6: A^t_{FB} vs. the right-handed top quark coupling g^t_R, for $M_G = 1.5$ TeV.

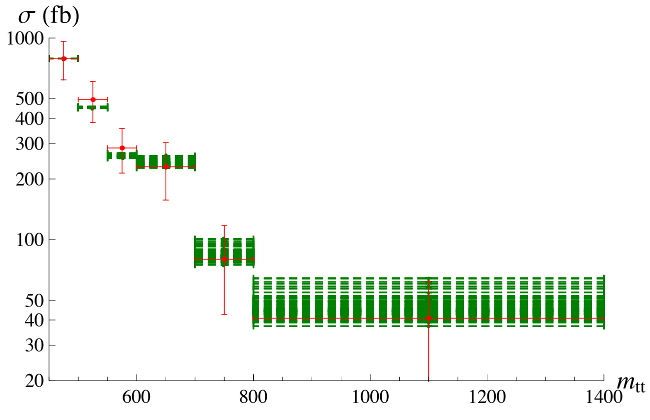

FIG. 7: The $t\bar{t}$ production cross-section as a function of the $t\bar{t}$ invariant mass m_{tt}, for $M_G = 1.5$ TeV. The crosses are the experimental values. The band represent the solutions of the scattered plot in Figure 5 that are within 1.5 σ of the data.

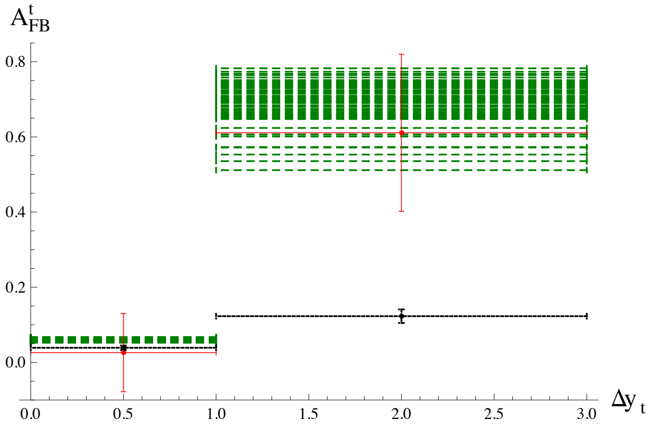

FIG. 8: The rapidity dependence of the forward-backward asymmetry in $t\bar{t}$ production. for $M_G = 1.5$ TeV. The crosses are the experimental values. The band represent the solutions of the scattered plot in Figure 5 that are within 1.5 σ of the data.

rameter space of the effective theory defined in the previous section, with the requirement that it gives a significant deviation in A^t_{FB} while not violating any known bounds, including those from flavor physics and all Tevatron top quark data. This bottom-up approach allows us to reduce the parameter space of the effective theory to the point of having a rather specific description of the new interactions of known quarks. We conclude that it is possible to generate a significant deviation from the SM in A^t_{FB} as observed at the Tevatron, while respecting all existing bounds, including the flavor constraints. This is not in contradiction with the results of Ref. [14], since in that case the axi-gluon model used (the same as in Ref. [13]), is more constrained by flavor physics since in it the freedom to have universal couplings and still have a significant deviation in A^t_{FB} is absent due to the necessary choices of the quark couplings.

In the next section, we consider the possibility that quarks of a fourth generation are strongly coupled to the new interaction. We will use the remaining parameter space of the theory, with the color-octet mass, width and couplings to light quarks constrained, in order to predict the production of fourth-generation quarks at the Tevatron as well as at the LHC.

IV. A HEAVY FOURTH GENERATION

Having limited the parameter space of our effective theory by physics observables related to the first three generations, in this Section we use the resulting model to make predictions for the production of fourth-generation quarks both at the Tevatron and at the LHC.

As mentioned in Section I, the presence of fourth-generation quarks is motivated as an alternative mechanism of EWSB. For the new strong interaction to be at around the TeV scale, a natural choice, the dynamical masses of condensing fermions should be close to $(500 - 600)$ GeV [2]. Current bounds on the masses of the fourth-generation quarks from direct searches are $m_{U_4} > 335$ GeV [20], and $m_{D_4} > 385$ GeV [21], both at 95% C.L., below the condensation model values, but not too far from them. We focus here on the most constraining bounds, which come from electroweak precision measurements. In Ref. [11] it is shown that it is possible to accommodate a heavy fourth generation with some restrictions on the mass spectrum, as well as the Higgs mass. Here, we will not assume anything about m_h, although the type of theories that result in these phenomenological models have typically larger m_h values than in SM fits, which are compatible with the findings of Ref. [11].

The most constrained parameter of a fourth-generation quark sector with this typical mass scale is the mass difference, since it affects the T parameter giving a positive contribution to it. Having a positive contribution to T is actually good since it allows for larger values of S, which is also greatly constrained by electroweak measurements. A degenerate fourth family of quarks contributes with $\delta S_q \simeq 0.2$. The $S-T$ fits allow typically for larger values of S and T as long as $S \sim T$. On the other hand, the fits disfavor values of T much larger than 0.3, even if m_h is heavy. This translates in the approximate bound [11] $|m_{U_4} - m_{D_4}| < M_W$. Somewhat larger values are still compatible with electroweak fits in some region of the parameters. However, we will consider mass differences below M_W in order to limit the amount of T from this one source. This choice has important phenomenological consequences since it suppresses intergenerational weak transitions such as $D_4 \to U_4$ by requiring a 3-body phase space. Thus, if the mass difference is significantly below M_W the 2-body weak decays to third generation quarks will be favored as long as the CKM mixing between the third and fourth generation quarks is not too small.

V. PREDICTIONS FOR THE TEVATRON AND THE LHC

Here we consider the reach of the Tevatron to observe the pair-production of fourth-generation quarks with masses of $m_4 = 500$ GeV, via the interactions described by (1). The choice of this value is mainly for concreteness, but at the same time is motivated by several arguments. As previously mentioned, in models of EWSB via fourth-generation condensation [2, 6] the dynamically generated fermion mass is typically in the range $\simeq (500-600)$ GeV when the scale of the condensing interaction is $O(1)$ TeV. Then, if the effective theory described in Section II is to emerge from this scenario, these are the typical values of the four-generation quark masses. Finally and as we will see below, the Tevatron is already beginning to be sensitive to these effective theories for quark masses around this range. Thus, although this specific value is just a straw-man choice, the actual value of the heavy quark masses should not be further than $O(100)$ GeV from it.

We first consider the $U_4\bar{U}_4$ pair-production cross section at the Tevatron. For the fixed values of m_{U_4} we are considering here, we will use values of the G' couplings to light quarks that are consistent with all bounds plus give a significant increase in A^t_{FB}. These values depend on $M_{G'}$, and can be obtained from the solutions displayed in Figures 2 and 6. Finally, we need to fix the G' coupling to U_4. Since a large fraction of the U_4 production cross-section comes from the interference with the SM s-channel gluon, and this only depends on the vector coupling $g^4_V = (g^4_L + g^4_R)/2$, we will fix the axial coupling $g^4_A = 0$ just for concreteness, and we will study the dependence of the cross-section with g^4_V. In Figure 9 we plot the production cross section of U_4 pairs from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, as a function of the U_4 vector coupling g^4_V for a color-octet mass of $M_G = 1$ TeV. The top line corresponds to $m_{U_4} = 450$ GeV, whereas the bottom one is for $m_{U_4} = 500$ GeV. The top horizontal line is an approximate value of the Tevatron sensitivity for 5 fb^{-1}, whereas the bottom horizontal line is intended as an estimate of the future reach, assuming the two-body channel $U_4 \to bW^+$ dominates. We can see that the Tevatron will have reach to observe a strongly-coupled fourth-generation up-type quark with couplings large enough to trigger condensation and EWSB. The plots reflect a particular solution for the couplings of light quarks to the color-octet that gives a large increase in the A^t_{FB} while passing all constraints. Similarly, in Figure 10 we show the results for $M_G = 1.5$ TeV, where the solution for the light quark couplings to G' is now different than in the previous example. As we can see, despite the increase in the color-octet mass, the Tevatron reach is still significant. This is due to the requirement that the light-quark couplings be large enough to give a large deviation in A^t_{FB}, which means that they have to be larger than for lighter G' masses.

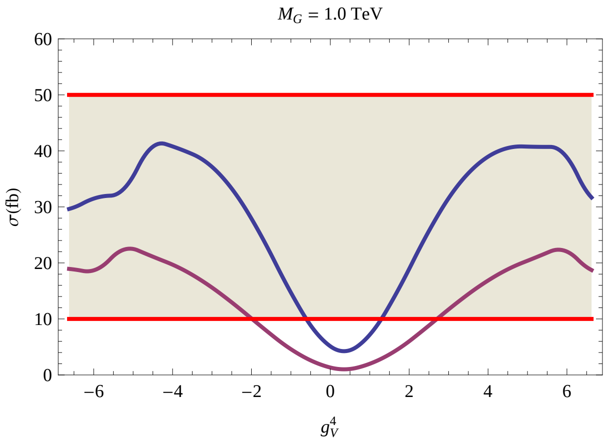

FIG. 9: U_4 pair-production cross section vs. the U_4 vector coupling g^4_V for $g^4_A = 0$, and for $M_G = 1$ TeV.

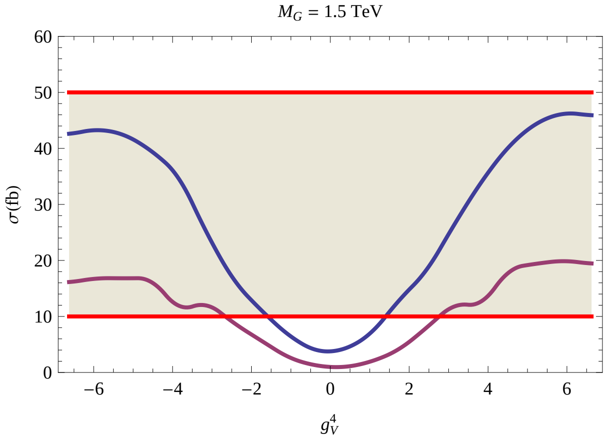

FIG. 10: U_4 pair-production cross section vs. the U_4 vector coupling g^4_V for $g^4_A = 0$, and for $M_G = 1.5$ TeV.

Analogously, we can consider the production of the down-type quark D_4 at the Tevatron with similar results.

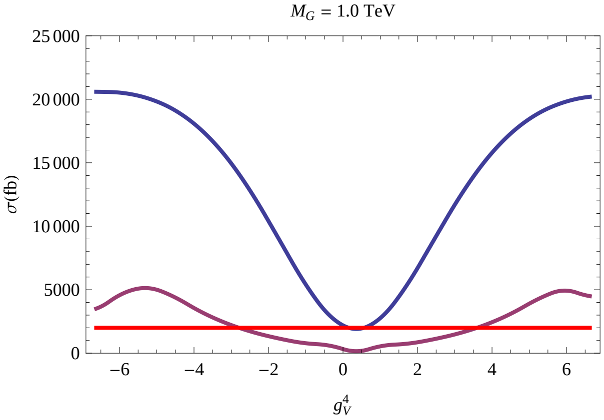

FIG. 11: U_4 pair-production cross section vs. the U_4 vector coupling g_V^4 for $g_A^4 = 0$, and for $M_G = 1$ TeV, for $\sqrt{s} = 7$ TeV. The top line is for $m_{U_4} = 450$ GeV, the second one for $m_{U_4} = 600$ GeV, whereas the horizontal line corresponds to the SM QCD production.

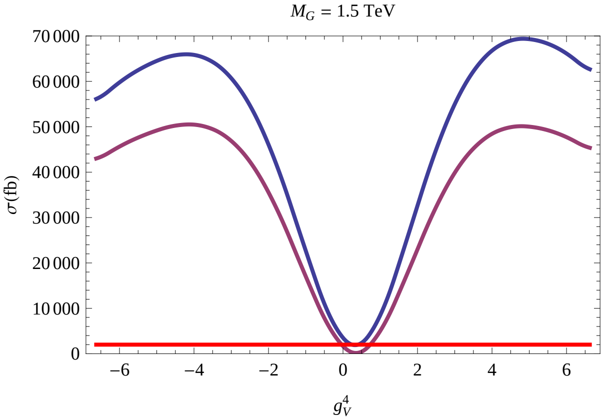

FIG. 12: U_4 pair-production cross section vs. the U_4 vector coupling g_V^4 for $g_A^4 = 0$, and for $M_G = 1.5$ TeV, for $\sqrt{s} = 7$ TeV. The top line is for $m_{U_4} = 450$ GeV, the second one for $m_{U_4} = 600$ GeV, whereas the horizontal line corresponds to the SM QCD production.

In models where only one of the two fourth-generation quarks condenses, the production of the non-condensing one is somewhat smaller than that of the condensing quark, since its couplings to the color-octet interaction are smaller. Thus, if for instance only the U_4 were to condense to break the electroweak symmetry, the D_4 production cross section could be well below the Tevatron sensitivity. On the other hand, if both are supercritically coupled to the color-octet, they will have very similar production cross sections.

We finally address the implications for the LHC. We have significantly reduced the parameter space of the effective theory described by (1). by imposing light flavor universality, asking for a deviation in A_{FB}^t, and for strong enough couplings for fourth-generation condensation while respecting limits from Tevatron. We can now make predictions for the LHC using this well-defined region of parameter space. Unlike in the AdS$_5$ model of Ref. [6], where QCD completely dominates the pair-production of fourth-generation quarks, in this case it will be dominated by the color-octet contribution. This is due in part to the relatively light masses we are considering here ($1-1.5$ TeV), but also to the strong couplings necessary to make condensation viable.

To compare to the Tevatron results above, we consider the LHC with 7 TeV center-of-mass energy. For illustration, we use the values of the light quark couplings to the color-octet G' that result in an excess in A_{FB}^t, as shown above. Once again, we use $g_A^4 = 0$ for concreteness, but the heavy-quark production cross section does not depend on this coupling significantly. The results for U_4 pair-production are shown in Figures 11 and 12, for $M_G = 1$ TeV and $M_G = 1.5$ TeV, respectively. We see that the parameter space selected from the effective theory presented in Section II in order to give an excess in A_{FB}^t consistent with observations, can potentially result in very large signals in the pair-production of fourth-generation quarks mediated by the new color-octet interaction. This, despite the fact that this very same set of parameters has not yet been excluded by the Tevatron. The LHC running at $\sqrt{s} = 7$ TeV, and accumulating 1 fb^{-1} should be able to exclude a large fraction of the relevant parameter space, as it is clearly seen in Figures 11 and 12.

VI. SUMMARY AND CONCLUSIONS

We have considered a scenario where the new physics at the TeV scale responsible for EWSB is coupled to flavor. In particular, if the new interaction is strongly coupled to heavier generations, such as the third and/or a hypothetical fourth generation, the phenomenology of this flavor dependence will be very distinct. We have taken an effective theory approach to this problem, by adding to the SM just the minimum ingredients needed for this scenario: a color-octet massive state, and a fourth generation strongly coupled to it, which presumable will lead to EWSB through the condensation of at least one of its quarks. We have shown that if we require a significant contribution to A_{FB}^t, and we impose the constraints from flavor physics, the parameter space of the effective theory is greatly reduced, making it quite predictive. This can be seen in the progression from Figure 1 to 8.

Adding the requirement that at least one of the fourth-generation quarks is strongly coupled to the new interaction, results in predictions for the Tevatron that could be falsified before the end of Run II. These predictions are summarized in Figures 9 and 10. Furthermore, we predict that this scenario can be easily observed/excluded at the LHC with $\sqrt{s} = 7$ TeV and 1 fb^{-1} of integrated luminosity, as it can be seen in Figures 11 and 12.

The bottom-up approach used here is complementary to model-building. If the deviation in A_{FB}^t is confirmed, and the LHC observes the production of fourth-generation quarks with cross-sections similar to those shown in the previous section, it would be evidence that the new interaction is coupled to flavor and that the new heavy quarks have indeed a role in EWSB. Coupled to the flavor constraints, we are left with an effective theory where the only fermion of the first three generations strongly coupled to the new interaction is the right-handed top quark t_R. Building such theory, although challenging, would be a step towards understanding EWSB and flavor.

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