Weak Interaction Sum Rules for Polarized $t\overline{t}$ Production at LHC *

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Abstract

We consider two polarization asymmetries in the process of top-antitop production at LHC. We show that the theoretical predictions for these two quantities, at the strong and electroweak partonic one-loop level, are free of QCD and QED effects. At this perturbative level we derive two sum rules, that relate measurable quantities of top-antitop production to genuinely weak inputs. This would allow to perform two independent tests of the candidate theoretical model, with a precision that will be fixed by the future experimental accuracies of the different polarization measurements. A tentative quantitative illustration of this statement for a specific MSSM scenario is enclosed, and a generalization to include two other future realistic measurements is also proposed.

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I. INTRODUCTION

It is by now generally accepted that top-antitop production at LHC will be a potential source of very relevant theoretical information, both within the Standard Model description and within other possible new physics schemes [1]. In this spirit, the possibility of performing high precision measurements of the process has been considered with some attention in the literature. The general difficulty that one encounters in this case is that two different sources of uncertainty have to be carefully taken into account. Actually, on top of the experimental statistical and systematic errors, a not negligible theoretical uncertainty of, essentially, QCD origin usually affects the available theoretical predictions. In the case of unpolarized cross sections, the size of the theoretical QCD uncertainty is at the moment estimated to be of, approximately, a relative twelve percent [1]. This value is not much smaller than that of the corresponding overall experimental error, for which a recent preliminary estimate has derived a rather conservative upper limit of approximately twenty percent [2]. Assuming that this experimental limit will be reduced to a ten percent level by more dedicated future efforts (which appears a reasonable aim in the discussions of [1]), one expects a future situation where the experimental and the QCD uncertainties would be of, roughly, equal \sim ten percent size for the production of unpolarized top-antitop pairs.

If the theoretical model to be tested is one of supersymmetric kind, like for instance the MSSM, and the purpose of the investigation is that of measuring weak supersymmetric virtual effects at the one-loop level, assuming a preliminary direct Supersymmetry discovery, the previous discussion shows that it might be difficult to identify virtual effects if they were not beyond the ten percent limit. For special scenarios of light Supersymmetry and large tan β values one might well find the case of such large (~ twenty percent) effects, as exhaustively discussed in [2], where a particular approach was proposed, based on measurements of the slope of the final invariant mass distribution $d\sigma/dM_{t\bar{t}}$. But in a less "friendly" supersymmetric scenario, with possibly smaller virtual SUSY effects, a different search would be requested, and the size of the QCD uncertainty might add an extra difficulty to the analysis. Clearly, this difficulty would be "substantially" reduced if a different experimental quantity could be measured that turned out to be, within certain reasonable assumptions, "substantially" less sensitive to QCD effects.

The aim of this paper is precisely that of proposing the measurements of two observables of the process that would meet the previous request. Both quantities are certain polarization asymmetries, and therefore the needed measurements would be those of the final top-antitop helicities. Although the topics is not a new one, and several excellent papers exist in the literature devoted to a description of the theoretical properties of the top-antitop polarized cross sections, we shall devote the next Section 2 to a brief summary of those features that are essential for our approach. In Section 3 a tentative quantitative illustration of the possible outcomes of our proposal will be also briefly proposed.

II. POLARIZED $t\bar{t}$ PRODUCTION

We start by considering top-antitop production at the Born level, with a final invariant mass $M_{t\bar{t}}$ (that coincides, at Born level, with the initial partons c.m. energy \sqrt{s}). A very special feature of the process, not shared by any other light (u,d,s,c,b) quark pair production at the corresponding energies, is that both top and antitop can be separately produced in two different helicity states. This is a consequence of the large top mass, that generates two "unconventional" helicity pairs (i.e. not of the massless quark kind) accompanied by typical m_t^2/s factors. In our notations, that are essentially similar to those of [2], we shall label states by their chirality at high energy. Thus, the two combinations (L,L) and (R,R) would be in our notation the pairs with opposite helicities, while (L,R) and (R,L) would be those with equal helicities.

At LHC, the dominant production mechanism is due to an initial gluon-gluon pair. As already discussed in previous articles (see e.g. [3]), the two equal (LR and RL) and opposite (LL and RR) helicity pairs are in this case orthogonal, in the sense that equal helicities production dominates at low energies, opposite helicities production dominates at high energies. For an initial quark-antiquark pair, that represents the leading mechanism at Tevatron, the dominant production would be in each case that of opposite helicity pairs,less strongly at at low energies and more strongly at high energies, where it would reproduce the LHC situation. To get a more quantitative description, we have computed, at Born level, the overall LHC (LR +RL) and (LL + RR) invariant mass distributions $d\sigma_{LL}/dM_{t\bar{t}} = d\sigma_{RR}/dM_{t\bar{t}}$ and $d\sigma_{LR}/dM_{t\bar{t}} = d\sigma_{RL}/dM_{t\bar{t}}$. With this aim, we have started from the Born expressions of the differential cross sections at partonic level that are, for the initial gluon-gluon state:

$$\frac{d\sigma^{Born}(gg \to t_L \bar{t}_L)}{d\cos\vartheta} = \frac{d\sigma^{Born}(gg \to t_R \bar{t}_R)}{d\cos\vartheta} = \frac{\pi\beta^3 \alpha_s^2 \sin^2\vartheta (1+\cos^2\vartheta)(7+9\beta^2\cos^2\vartheta)}{192s(1-\beta^2\cos^2\vartheta)^2}.$$
(2.1)

$$\frac{d\sigma^{Born}(gg \to t_L \bar{t}_R)}{d\cos\vartheta} = \frac{d\sigma^{Born}(gg \to t_R \bar{t}_L)}{d\cos\vartheta} = \frac{\pi\beta\alpha_s^2 m_t^2 (1+\beta^2(1+\sin^4\vartheta))(7+9\beta^2\cos^2\vartheta)}{48s^2(1-\beta^2\cos^2\vartheta)^2}$$
(2.2)

where $\beta = \sqrt{1 - 4m_t^2/s}$.

For initial quark-antiquark state we have:

$$\frac{d\sigma^{Born}(q\overline{q} \to t_L \overline{t}_L)}{d\cos\vartheta} = \frac{d\sigma^{Born}(q\overline{q} \to t_R \overline{t}_R)}{d\cos\vartheta} = \frac{\pi\alpha_s^2\beta}{18s}(1+\cos^2\vartheta)$$
(2.3)

$$\frac{d\sigma^{Born}(q\overline{q} \to t_L \overline{t}_R)}{d\cos\vartheta} = \frac{d\sigma^{Born}(q\overline{q} \to t_R \overline{t}_L)}{d\cos\vartheta} = \frac{2\pi\alpha_s^2\beta m_t^2}{9s^2}\sin^2\vartheta \tag{2.4}$$

Starting from these expressions, and working systematically at Born level, we have next computed the distributions (a and b can be L or R)

$$\frac{d\sigma(PP \to t_a \bar{t}_b + ...)}{ds} = \frac{1}{S} \int_{\cos\vartheta_{min}}^{\cos\vartheta_{max}} d\cos\vartheta \left[\sum_{ij} L_{ij}(\tau, \cos\vartheta) \frac{d\sigma_{ij \to t_a \bar{t}_b}}{d\cos\vartheta}(s) \right]$$
(2.5)

where $\tau = \frac{s}{S}$, and (ij) represent all initial $q\bar{q}$ pairs with q = u, d, s, c, b and the initial gg pairs, with the corresponding luminosities

$$L_{ij}(\tau, \cos\vartheta) = \frac{1}{1+\delta_{ij}} \int_{\bar{y}_{min}}^{\bar{y}_{max}} d\bar{y} \left[i(x)j(\frac{\tau}{x}) + j(x)i(\frac{\tau}{x}) \right]$$
(2.6)

where S is the total proton-proton c.m. energy, and i(x) the distributions of the parton i inside the proton with a momentum fraction, $x = \sqrt{\frac{s}{S}} e^{\bar{y}}$, related to the rapidity \bar{y} of the $t\bar{t}$ system [4]. The parton distribution functions are the latest MRST set [5]. The limits of integrations for \bar{y} can be written

$$\bar{y}_{max} = \max\{0, \min\{Y - \frac{1}{2}\log\chi, Y + \frac{1}{2}\log\chi, -\log(\sqrt{\tau})\}\}$$
$$\bar{y}_{min} = -\bar{y}_{max}$$
(2.7)

where the maximal rapidity is Y = 2. The quantity χ is related to the scattering angle in the $t\bar{t}$ c.m. by the relation $\chi = (1 + \beta \cos \vartheta)/(1 - \beta \cos \vartheta)$ where $\beta = \sqrt{1 - 4m_t^2/s}$. The integration limits are $\cos \vartheta_{min,max} = \mp \sqrt{1 - 4p_{T,min}^2/s}$ expressed in terms of the chosen value for $p_{T,min} = 50$ GeV.

The resulting curves are depicted in Fig. 1. The upper limit for $M_{t\bar{t}}$ has been taken at ~ 1.2 TeV, where the recent analysis of [2] shows that one can still expect a reasonable number of events. One sees from our analysis, that reproduces correctly the Stelzer-Willenbrock curve [3] for $M_{t\bar{t}} \leq 0.8$ TeV (the limit of that calculation), that the asymptotically leading opposite helicities production starts being really more, but not "much" more, relevant exactly at that energy, becoming about three times larger than the "competitor" production at $M_{t\bar{t}} \simeq 1.2$ TeV, and being definitely depressed in the region around threshold and below ~ 500 GeV. Thus, in the overall realistic LHC energy range for top-antitop production, the "asymptotically depressed" equal helicity production must be carefully taken into account for an accurate theoretical description of the process.

Until now, our analysis has been limited to the consideration of the Born level description. For a realistic analysis, one must now move to the next one-loop level. This has to be done both for the QCD and for the electroweak virtual effects. Before making this effort, though, we want to make a remark that will turn out to be essential for our approach. This is related to the diagrams that contribute, at Born level, the different helicity productions. As already pointed out in [2], the production of (LL,RR) from a two gluon state is only due to the same t and u channel exchanges, while (LR and RL) are coming from t, u and s channel diagrams (thus canceling for $M_{t\bar{t}} \gg m_t$). Adding the small quark-antiquark contribution, that only comes from an s channel gluon exchange, one concludes that the Born diagrams for (LL) and (RR) production are the same, and are different from those that determine the (LR) and (RL) case. Moving now to the one-loop partonic level, we shall write therefore in full generality:

$$\frac{d\sigma_{ab}^{1 \text{ loop}}}{d\cos\vartheta} = \frac{d\sigma_{ab}^{\text{Born}}}{d\cos\vartheta} (1 + \alpha_s F_{ab}^{\text{QCD}} + \alpha F_{ab}^{\text{EW}})$$
(2.8)

A clear statement must be made at this point. Our treatment of the perturbative expansion is rigorously performed at the one-loop level, i.e. neglecting extra terms of order α_s^2 , α^2 , and $\alpha_s \alpha$. In particular, considering the latter ones would also imply mixed strong-electroweak effects at the two-loop level, well beyond the theoretical purposes at LHC. Having made this statement, we can now observe that the one-loop QCD corrections $F_{LL}^{\rm QCD}$ and $F_{RR}^{\rm QCD}$ are necessarily equal, since they come from gluon additions to the SAME set of Born diagrams, and the gluons do not distinguish the top or the antitop helicities. In full analogy, we conclude that $F_{LR}^{\rm QCD}$ must be equal to $F_{RL}^{\rm QCD}$. These conclusions do not apply to the electroweak functions $F_{ab}^{\rm EW}$, since weak exchanges discriminate in general L from R. In full generality, we are therefore led to the statement that

$$d\sigma_{LL}^{1 \text{ loop}} - d\sigma_{RR}^{1 \text{ loop}} = d\sigma_{LL=RR}^{\text{Born}} \alpha \left(F_{LL}^{\text{EW}} - F_{RR}^{\text{EW}} \right)$$
(2.9)

$$d\sigma_{LR}^{1 \text{ loop}} - d\sigma_{RL}^{1 \text{ loop}} = d\sigma_{LR=RL}^{\text{Born}} \alpha \left(F_{LR}^{\text{EW}} - F_{RL}^{\text{EW}} \right)$$
(2.10)

i.e. the differences of the previous cross sections are, at the one-loop level, free of QCD effects. In fact, one can be even more stringent since, for the same reasons that eliminate the virtual gluon corrections, also the virtual photon corrections are washed out in the differences. In other words, the two quantities Eqs. (2.9-2.10) are, at the one loop level, free of both QCD and QED virtual effects.

Before continuing our analysis, we feel that it is opportune at this point to make two extra remarks. The first one is that, for what concerns the "QCD-QED freedom" of the two Eqs. (2.9-2.10), our conclusion is only valid if one considers, as we did, the differences of the cross sections. For the sums of the polarized quantities, the cancellation of the QCD (and QED) virtual effects would not be obtained, so that in those cases the calculation of those terms should be rigorously performed. One might imagine to remove this difficulty by considering "conventional" polarization asymmetries, defined as the ratios of the differences (2.9-2.10) to the corresponding sums. This possibility, first proposed by Kao and Wackeroth [6] and more recently reconsidered in [2] for the (LL,RR) case, leads to the definition of invariant mass distributions of the kind :

$$A_{LL,RR}(M_{t\bar{t}}) = \frac{d\sigma_{LL} - d\sigma_{RR}}{d\sigma_{LL} + d\sigma_{RR}}$$
(2.11)

and analogously:

$$A_{LR,RL}(M_{t\bar{t}}) = \frac{d\sigma_{LR} - d\sigma_{RL}}{d\sigma_{LR} + d\sigma_{RL}}$$
(2.12)

where the various components should be computed at the pp level as in Eq. (2.5). At the one-loop level, Eqs.(2.11) and (2.12) would also actually be QCD and QED free. The reason why we believe that these asymmetries might not be the best choice for an experimental test is related to the second remark that we anticipated. This is the statement that the theoretical results of our investigation must be compared with realistic experimental measurements. In this sense, a problem that we can imagine for the measurement of the invariant mass distribution of general polarized cross sections is that a precise determination of the top (antitop) helicity usually generates a loss of precision for the value of the invariant mass distributions, the integration of the polarized cross sections, the integral being performed between a lower value and an upper value of the invariant mass to be conveniently chosen. In this spirit, we shall therefore consider from now on as potential measurable candidates the following quantities (\mathcal{L}_{int} being the integrated luminosity):

$$N_{ab}(s_1, s_2) = \mathcal{L}_{int} \int_{s_1}^{s_2} \frac{d\sigma_{ab}}{ds} ds$$
(2.13)

Note that we used for simplicity the initial parton c.m. energy \sqrt{s} , since the difference at one-loop between \sqrt{s} and $M_{t\bar{t}}$ has been estimated in detail in [2], and should anyhow be scarcely relevant if a complete integration (i.e. from threshold to the "end" point $M_{t\bar{t}} \simeq 1.2$ TeV is performed).

Eq. (2.13) defines the number of top-antitop pairs with a certain given helicity that are produced in the energy interval $(\sqrt{s_1}, \sqrt{s_2})$, ignoring the precise details of the invariant mass distributions. From these expressions we can now express the differences that would correspond to the original Eqs. (2.9-2.10), i.e.:

$$N_{LL}(s_1, s_2) - N_{RR}(s_1, s_2) =$$

$$\mathcal{L}_{int} \int_{s_1}^{s_2} ds \, \frac{1}{S} \, \int_{\cos\vartheta_{min}}^{\cos\vartheta_{max}} d\cos\vartheta \, L\left(\frac{s}{S}, \cos\vartheta\right) \, \frac{d\sigma_{LL=RR}^{\text{Born}}}{d\cos\vartheta} \, \alpha \, \left(F_{LL}^{\text{EW}} - F_{RR}^{\text{EW}}\right)$$
(2.14)

$$N_{LR}(s_1, s_2) - N_{RL}(s_1, s_2) =$$

$$\mathcal{L}_{int} \int_{s_1}^{s_2} ds \, \frac{1}{S} \, \int_{\cos\vartheta_{min}}^{\cos\vartheta_{max}} d\cos\vartheta \, L\left(\frac{s}{S}, \cos\vartheta\right) \, \frac{d\sigma_{LR=RL}^{\mathrm{Born}}}{d\cos\vartheta} \, \alpha \, \left(F_{LR}^{\mathrm{EW}} - F_{RL}^{\mathrm{EW}}\right)$$
(2.15)

One sees that now these (more realistic) sum rules are not completely free of QCD effects, since the latter are implicitly affecting the used value of the various parton distribution functions. This seems to be a price to pay to the purpose of a meaningful experimental verification of the sum rules. However, one may also assume the consistency philosophy of the paper, i.e. that the relevant parton distribution functions (in this case, the gluon-gluon ones) should be estimated at Born level, or alternatively that they will be

¹We thank Stan Bentvelsen for an illuminating discussion on this point

independently derived by other measurements. In this sense, the QCD independence of Eqs. (2.14,2.15) would be valid not only for the virtual effects of the final states diagrams, but for the overall process.

The question that should now be asked is that of whether an experimental analysis of the realistic experimental errors on the differences that appear in Eqs. (2.14,2.15) does or will exist. At the moment, we are not aware of such an investigation, that appears to us reasonably well motivated and auspicable. The only experimental measurement that appears to have been considered with sufficient details is that of a different asymmetry, originally called C in [3] and very recently reconsidered in some papers [7]. In our notation, we would define it as :

$$C(s_1, s_2) = \frac{(N_{LL} + N_{RR}) - (N_{LR} + N_{RL})}{(N_{LL} + N_{RR}) + (N_{LR} + N_{RL})}, \qquad N_{ab} \equiv N_{ab}(s_1, s_2)$$
(2.16)

For the latter quantity, a recent estimate [8] proposes the value (assuming 30 fb^{-1} statistics and integrating over the full energy range) :

$$C = 0.311^{+0.034}_{-0.035} \text{ (stat)} \pm 0.028 \text{ (syst)}$$
(2.17)

A priori, the result (2.17) cannot be directly related to our Eqs. (2.14,2.15). One sees that the proposed value for C implies a determination of the two "blocks" of opposite helicity (LL+RR) and equal helicity (LR + RL) pairs, without selecting within the blocks the fraction of left-handed (or right- handed) top components, and analogously for the equal helicity case. Waiting for a dedicated experimental analysis of our suggestion, we have tried to produce some qualitative numbers to be compared e.g. with that of Eq. (2.17). This analysis, that we consider a purely indicative one, is illustrated in the final forthcoming Section (III).

III. TENTATIVE NUMERICAL ANALYSIS

To produce some numerical results, we do not have many reliable possibilities at this stage of our theoretical investigations. In practice, the only possible example that we can propose is that of an estimate of the first of the two candidate asymmetries, i.e. Eq. (2.14). Assuming the MSSM theoretical description, we have reasons to believe, from the investigation performed in [2], that in the so called "reasonably light SUSY scenario", where all SUSY masses lie below 400 GeV, a logarithmic expansion of Sudakov kind, computed at NLO, should provide a valid description of the electroweak one-loop effects of the model, in the \sqrt{s} region from ~ 0.7 to ~ 1.3 TeV (on the contrary, we do not have at disposal a similar simple expansion for the remaining LR, RL amplitudes, that would require a complete calculation, not yet available). In this spirit, we have thus estimated the two numbers N_{LL} and N_{RR} entering the difference Eq. (2.14) with

$$\sqrt{s_1} = M_{t\bar{t},\min}, \qquad \sqrt{s_2} = 1.2 \text{ TeV}, \tag{3.1}$$

and $\mathcal{L}_{int} = 30 \text{fb}^{-1}$. The upper limit has been kept fixed. The lower limit $M_{t\bar{t},\min}$ has been varied in the analysis. For the parton distribution functions we have used the lastest MRST set [5], although we insist that in this way a part of the $\mathcal{O}(\alpha \alpha_s)$ corrections has been inserted, that could be considered as a future experimental input.

The result of our calculation are shown in Figs. (2) and (3). As one sees, the lower limit of integration has been allowed, for purely illustrative purposes, to reach the physical threshold of the process, where our assumed asymptotic expansion is very unlikely to be valid. For a reasonably meaningful interpretation of our analysis, one should consider a lower limit of $M_{t\bar{t}}$ of at least, say, 700 – 800 GeV. In this range, our results are plotted as a function of $\tan \beta$, that is the only free parameter in the assumed MSSM scenario entering the NLO logarithmic expansion (the light SUSY scale would enter at next-to next leading order). Keeping in mind the limitations of our analysis, we mention some features that seem to us to be, least to say, encouraging. First of all, when $\tan\beta$ varies in its considered range (2-50), Fig. (2) shows that the difference of the number of pairs changes sign, moving from a positive value of $\sim +1.5 \cdot 10^4$ to a negative one $\sim -3.5 \cdot 10^4$, at the assumed luminosity. This fact can be expressed in terms of the values of the integrated asymmetry, as shown in Fig. (3). Here one sees a variation of this quantity from $\sim +2\%$ percent to $\sim -5\%$ in the tan β range. Perhaps more relevant is the fact that, varying $\tan\beta$ in the large values range, from 30 to 50, the asymmetry varies from $\sim -1\%$ to $\sim -5\%$. This implies that a measurement of the integrated asymmetry performed with a hundred percent precision, leading to a central value within this range, could lead to a valuable discrimination of candidate $\tan\beta$ values, to be combined with other existing $\tan\beta$ determination proposals [9]. Clearly, a more rigorous calculation, valid in a less special scenario and extended to the remaining sum rule, would be requested. This is in fact being performed at the moment [10].

To conclude this paper, we add another short proposal. We have derived until now the two sum rules Eqs. (2.14-2.15), and one major difficulty has been represented by the lack of a dedicated experimental analysis on the proposed quantities. Since, on the contrary, an experimental estimate exists for the quantity C defined in Eq. (2.16), one might wonder whether some possible information could be obtained combining the latter Eq. (2.17) with our proposed sum rules Eqs. (2.14-2.15). We want to show that, working consistently in the one-loop approximation, this is actually the case. With this purpose, we shall make the extra assumption (that appears rather natural to us) that a precise experimental information exists also on the total number of top-antitop pairs, defined in our notations as :

$$N_T = N_{LL} + N_{RR} + N_{LR} + N_{RL}, (3.2)$$

and from now on we do not include in the notations the limits (s_1, s_2) which are the same as in our previous discussions, *i.e.* $N_{ab} \equiv N_{ab}(s_1, s_2)$. In this spirit, we write now the general expressions for the separate N_{ab}

$$N_{ab} = \mathcal{L}_{int} \int_{s_1}^{s_2} ds \, \frac{1}{S} \, \int_{\cos\vartheta_{min}}^{\cos\vartheta_{max}} d\cos\vartheta \, L\left(\frac{s}{S},\cos\vartheta\right) \, \times \qquad (3.3)$$
$$\times \quad \frac{d\sigma_{ab}^{\mathrm{Born}}}{d\cos\vartheta} \, (1 + \alpha_s \, F_{ab}^{\mathrm{QCD}} + \alpha \, F_{ab}^{\mathrm{EW}}).$$

In the four cases N_{ab} , ab = LL, LR, RL, RR, there are actually only 2 independent QCD correction factors. Note that, in fact, this is the point of our analysis, since we have shown that on general grounds the QCD correction is the same for the pair (LL, RR) or for the pair (LR, RL). Therefore, we can write Eq. (3.3) as

$$N_{LL} = N + \alpha_s \,\delta_1^{\text{QCD}} + \alpha \,\delta_{LL}^{\text{EW}},\tag{3.4}$$

$$N_{RR} = N + \alpha_s \, \delta_1^{\text{QCD}} + \alpha \, \delta_{RR}^{\text{EW}}, \qquad (3.5)$$

$$N_{LR} = N' + \alpha_s \, \delta_2^{\text{QCD}} + \alpha \, \delta_{LR}^{\text{EW}}, \tag{3.6}$$

$$N_{RL} = N' + \alpha_s \,\delta_2^{\text{QCD}} + \alpha \,\delta_{RL}^{\text{EW}},\tag{3.7}$$

where N and N' are the Born values $N_{LL}^{Born} = N_{RR}^{Born}$ and $N_{LR}^{Born} = N_{RL}^{Born}$, respectively, and $\delta_{1,2}^{\text{QCD}}$, δ_{ab}^{EW} can be derived from Eq. (3.3). Since only two QCD theoretical quantities appear, we can at this point bargain them in terms of the measured quantities C, N_T . This leads us to the following 4 equations:

$$N_{LL} = \frac{1}{4} N_T (1+C) + \frac{1}{2} \alpha \ (\delta_{LL}^{\rm EW} - \delta_{RR}^{\rm EW}), \tag{3.8}$$

$$N_{RR} = \frac{1}{4} N_T (1+C) - \frac{1}{2} \alpha \left(\delta_{LL}^{\rm EW} - \delta_{RR}^{\rm EW} \right), \tag{3.9}$$

$$N_{LR} = \frac{1}{4} N_T (1 - C) + \frac{1}{2} \alpha \left(\delta_{LR}^{\rm EW} - \delta_{RL}^{\rm EW} \right), \tag{3.10}$$

$$N_{RL} = \frac{1}{4} N_T (1 - C) - \frac{1}{2} \alpha \left(\delta_{LR}^{\rm EW} - \delta_{RL}^{\rm EW} \right), \tag{3.11}$$

One sees that the previous equations allow to express each separate possible helicity pair production in terms of N_T , C and of 4 purely weak one-loop corrections, to be estimated theoretically once the candidate model is fixed.

Eqs. (3.8-3.11) are the most general expressions of the considerations of our paper. They relate observable quantities of the process, with all possible polarization properties, to purely weak effects, and would therefore provide a clean test of the genuinely weak sector of candidate theoretical models. In our opinion, they would deserve a dedicated experimental investigation. This was in fact the main goal of our paper, and we hope that it will inspire fruitful practical consequences.

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FIG. 1. Born value of the distributions $d\sigma_{ab}/dM_{t\bar{t}}$ at hadronic level for the four possible helicity combinations LL, LR, RL, RR.



FIG. 2. Difference $N_{LL} - N_{RR}$ computed with $\mathcal{L}_{int} = 30 \text{fb}^{-1}$ and plot as a function of the lower limit $M_{t\bar{t},\min}$ in the energy integration. The various curves are associated to different $\tan \beta$ (2, 5, 10, 15, ... from top to bottom).



energy integration. FIG. 3. Asymmetry $(N_{LL} - N_{RR})/(N_{LL} + N_{RR})$ with variable lower limit $M_{t\bar{t},min}$ in the