Overview of the CSM concept and its tests.

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Abstract

We recall the motivations for the Compositeness Standard Model (CSM) concept, its precise description, the procedures for its applications and the particular constraints that it requires. We present its most spectacular predictions for typical processes observable at present and future colliders. To the previous results we add the treatment of the inclusive processes $e^+e^- \rightarrow H, Z, W$ or $t + \text{anything}$.

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1 INTRODUCTION

In spite of its success the SM is not totally satisfactory. Various BSM possibilities have been proposed including SM extensions, supersymmetry, additional strong sectors,... In most of these proposals the number of free parameters, of basic states and interactions increases in some cases enormously. No experimental indication for some direction of search has been found up to now. Maybe the corresponding new physics scale lies beyond the experimental reach. In any case introducing a large number of new states and interactions would generate an increasing number of questions about their origin.

Why compositeness?

We would prefer that new physics develops towards simplicity. Traditionally compositeness may be such a way with constituents named preons, subquarks,..., see for example [1]. There is however no special experimental indication for this possibility, maybe again due to a very high substructure scale?

Although no dynamical model with computational possibilities is available yet we want to believe that compositeness is still conceivable.

The heavy top quark has been a new motivation for full or partial top compositeness [2] and for the addition of Higgs compositeness [3, 4, 5]. Other states could still be elementary or partially composite with a very small mixing effect.

Why CSM?

In spite of its lack, SM has important and efficient structures in the gauge and Higgs sectors that one may want to maintain (structures of the gauge and Higgs couplings, Goldstone equivalence with longitudinal W,Z components). The Composite Standard Model (CSM) concept consists in assuming that the compositeness picture preserves these SM structures. We have yet no precise model to propose from which one may compute the observables and check these properties. We assume that these SM structures are reproduced in an effective way at low energies and that the first consequence of compositeness (spatial extension) will be the occurrence of form factors affecting the concerned basic couplings.

In this paper we review the results of preliminary works concerning CSM and we add some new studies (in particular for inclusive processes) which compare CSM conserving and CSM violating predictions for various processes in $e^+e^-$, $\gamma\gamma$ and hadronic collisions.

Contents: In Sect.2 we recall the basis of a CSM description. In Sect.3 we develop the 3-step strategy with (1) the detection of the presence of form factors, (2) the check that they satisfy the CSM constraints, (3) its confirmation with more involved processes. The summary and the possibility of future developments are presented in Sect.4.
2 CSM description

We have established an effective description of substructure effects with what we call the CSM concept. It consists in assuming that the pure SM is preserved at low energy with its usual set of basic couplings. We have no precise model allowing a direct computation of the CSM observable effects. But with this concept no anomalous coupling creating immediate deviation from SM should appear. The spatial extension due to compositeness would only generate an energy dependence of the point-like couplings which means a form factor affecting them, but being close to 1 at low energy, and controlled at high energy by a new physics scale related to the binding of the constituents.

An example of such form factor that we will use in our illustrations is:

\[ F(s) = \frac{s_0 + M^2}{s + M^2} \]  \hspace{1cm} (1)

with the new physics scale \( M \) taken for example in the few TeV range.

It will be applied to the top quark (\( t_L \) and/or \( t_R \)), to the Higgs boson and to the complete Higgs doublet with the Goldstone equivalence with \( W_L, Z_L \).

The preservation of the SM structure will require some relation, that we call a CSM constraint, between the form factors affecting the different basic couplings. A typical case is given by the famous cancellations ensuring a good high energy behaviour of the amplitudes involving longitudinal gauge bosons which is preserved when the involved form factors satisfy the CSM constraint.

The strategy for establishing a CSM analysis should then proceed as follows:
1) detect the presence of compositeness form factors,
2) check if they satisfy CSM constraints in basic processes,
3) confirm the expected consequences for more involved processes.

3 Three step strategy

3.1 1st step: detect the presence of form factors

In this first step we are looking for the presence of form factors in Higgs boson couplings and in top quark couplings.

a) Higgs form factor

There are no basic \( \gamma HH \) nor \( ZHH \) coupling allowing to define a pure Higgs boson form factor. The simplest place concerning a pure \( H \) form factor would be the \( HHH \) coupling, not for looking for anomalous components, but for an \( s \)-dependence when one \( H \) line is off-shell; this is difficult to measure, see [6].
One can then look for the existence of a $ZZH$ form factor, see [7]. However if compositeness preserves the whole SM Higgs doublet structure then form factors may affect the $ZG^{0}H, W^{\pm}G^{\pm}G^{0}, W^{\pm}G^{\pm}H, HG^{\pm}G^{\pm}, ZG^{\pm}G^{\pm}, \gamma G^{\pm}G^{\pm}$ couplings and, if the equivalence is preserved as assumed by CSM, the corresponding form factors when $G^{\pm,0}$ are replaced by $W^{\pm}_{L}, Z_{L}$. So one can check the SU(2)$^{*}$U(1) structure of these form factors, which means to check if the presence of a Higgs form factor can be generalized to a set of $G^{\pm,0}$ form factors transmitted to $W^{\pm}_{L}, Z_{L}$.

The first study could be the observation of a $ZZ_{L}H$ form factor equivalent to a $ZG^{0}H$ one in the $e^{+}e^{-} \rightarrow ZH$ process, see [7]. In Fig.1 we have illustrated the consequences for the $e^{+}e^{-} \rightarrow ZH$ cross section of the presence of such form factor in the case of pure $Z_{L}$ and of unpolarized $Z$ production. A direct measurement of this form factor can indeed easily be done in this channel.

In principle a second study could consist in checking the presence of $\gamma W W, \gamma \gamma W W$ form factors in the $\gamma \gamma \rightarrow W W$ process which is simpler than $e^{+}e^{-} \rightarrow W W$ that we will consider later on below because here no special $W_{L}$ cancellation occurs.

In Fig.2 one sees that in order to get a clear signal from the measurement of the $\gamma \gamma \rightarrow W W$ cross section (dominated by $W^{T}_{+}W^{T}_{-}$ production if no form factor affects the transverse $W_{T}$ states) one should detect and restrict the analysis to the pure $W^{+}_{L}W^{-}_{L}$ final state.

b) Top quark form factor

The simplest process for looking for the presence of left and right top quark form factors is $e^{+}e^{-} \rightarrow t \bar{t}$. One can obviously detect the presence of $\gamma t_{L,R}t_{L,R}$ and $Zt_{L,R}t_{L,R}$ form factors with the options of both $t_{L,R}$ or of only $t_{R}$ compositeness.

The modification of the energy dependence of the cross section would directly measure the size of the corresponding form factors.

See [8, 9] for illustrations in particular in the case of pure $t_{R}$ compositeness. It is also shown how the processes $gg \rightarrow t \bar{t}$ and $\gamma \gamma \rightarrow t \bar{t}$ should confirm these informations.

3.2 2nd step: CSM constraints

We first consider the case of pure Higgs compositeness and then the case where both the Higgs boson and the top quark are composite.

CSM constraint in the pure gauge-Higgs sector and Goldstone equivalence

One wants to check if the form factors of the Higgs sector satisfy the CSM properties related to the gauge structure and the Goldstone equivalence.
The process $e^+e^- \rightarrow W^+W^-$ provides a basic case for testing these properties due to the presence of important cancellations among different parts of its amplitudes.

At Born level it is described with 2 types of diagrams, neutrino exchange with $W\nu$ coupling and $\gamma, Z$ exchange with $\gamma, Z\rightarrow WW$ coupling. The well-known SM gauge feature is the cancellation of these 2 types of contributions for the $e^+_R e^-_L \rightarrow W^+_L W^-_L$ amplitude which would otherwise increase with energy and violate unitarity. Another SM aspect is the equivalence with $e^+e^- \rightarrow G^+G^-$ whose energy dependence is automatically well behaved.

We have checked that the introduction of an (even minor) form factor in the $\gamma, Z\rightarrow W^+_L W^-_L$ coupling immediately destroys this cancellation and leads to an unacceptable increase of the $e^+_R e^-_L \rightarrow W^+_L W^-_L$ amplitude (see ref.[7]). If the equivalence with $e^+_R e^-_L \rightarrow G^+_L G^-_L$ is maintained, as assumed by CSM, the introduction of the same form factor for the $\gamma, Z\rightarrow G^+G^-$ coupling leads to a well-behaved acceptable amplitude (see [7]).

On another hand there is no such problem for the $e^+_L e^-_R \rightarrow W^+_L W^-_L$ amplitude which receives no contribution from neutrino exchange and is well-behaved as long as the $e^+_L e^-_R \rightarrow \gamma \rightarrow W^+_L W^-_L$ and $e^+_L e^-_R \rightarrow Z \rightarrow W^+_L W^-_L$ contributions combine properly as in the SM case, which means the same form factor effects in the $\gamma\rightarrow W^+_L W^-_L$ and $Z\rightarrow W^+_L W^-_L$ couplings. Also one can check that the equivalence with the $e^+_L e^-_R \rightarrow \gamma, Z \rightarrow G^+G^-$ amplitude is quickly satisfied at high energy when the same form factor is applied (see [7]).

In a first study one may assume that Goldstone equivalence is preserved in some effective manner by CSM. We will call this possibility as CSMG.

So we will compare two different situations, one without the equivalence requirement (CSMFF) with arbitrary form factors affecting longitudinal gauge bosons and one assuming that the Goldstone equivalence is preserved by the CSM picture (CSMGFF) in some effective manner and that similar arbitrary form factors affect the corresponding Goldstone bosons couplings.

This ensures a good high energy behaviour (even with new effects) such that the presence of form factors produces immediately a decreasing effect.

This assumption is applied to $e^+e^- \rightarrow W^+W^-$ in Fig. 3. The upper panel concerns the unpolarized $e^+e^-$ case with either a crude $W_L$ form factor (LFF) which violate the CSM constraint and generates a strong effect because of the violation of the usual SM cancellation, or with the assumption of CSM Goldstone equivalence (CSMGFF) which keeps the cancellation and leads to a normal decrease. In the lower panel, one makes the comparison with the cases of $e^-_R$ polarization and again either a crude $W_L$ form factor (LFF) or with the CSM Goldstone equivalence(CSMGFF), which are now both acceptable because no (preserved or violated) cancellation is present.

One can pursue this type of study with other processes involving Higgs bosons and/or longitudinal gauge bosons and/or top quarks.

A first set corresponds to the famous WW, WZ, ZZ scattering occuring through gauge and Higgs bosons exchanges. Introducing form factors for $H$, $W_L$ and $Z_L$ couplings, the
cancellation would also require that they have a common \( F(s) \) shape. This is the crudest situation, but assuming that CSM will provide in some effective way the equivalence such that one can replace \( W^+_L, Z_L \) by \( G^{\pm,0} \) and then apply the form factors (CSMG picture) will give immediately a correct behaviour.

**CSM constraint for both Higgs and top compositeness**

We can apply this discussion to any \( W_L^- \) production process, for example obviously to \( e^+e^- \rightarrow WWH, ZZH \), but also to other processes involving the top quark. In any \( W^- \) production process, because of the presence of different types of diagrams, the complicated procedure of cancellation of the strongly increasing and unitarity violating \( W_L^- \) component plays an important role in the resulting effects of the form factors. For example the fact that the top quark may be composite and have a form factor whereas the bottom quark remains elementary without form factor creates an important lack of cancellation. The sizes of the effects are then specific to each process because on the one hand form factors lead to a decrease with the energy whereas on the other hand the lack of cancellation leads to an increase. So we will again compare for each process the two different situations, CSM without the equivalence requirement and arbitrary form factors affecting longitudinal gauge bosons and CSMG with the Goldstone equivalence and similar arbitrary form factors affecting the corresponding Goldstone bosons couplings.

For \( W_L^- \) production processes involving also the top quark we will show the differences between CSMtLR and CSMGtLR in the case of both \( t_{L,R} \) compositeness and those between CSMtR and CSMGtR assumptions in the case of pure \( t_R \) compositeness.

On another hand one may want to check if possible top quark form factors are in some way related to the ones of the Higgs sector; this could be natural if the top quark and the Higgs boson have the same subconstituents. In fact we have seen that such relations may be imposed by the energy behaviour of the \( ZH \) one loop production amplitudes in \( gg \) and \( \gamma\gamma \) collisions. In [10,11] we have remarked that the \( gg \rightarrow ZH \) and \( \gamma\gamma \rightarrow ZH \) processes are particularly sensitive to the presence of form factors because they could destroy a peculiar SM cancellation between diagrams involving Higgs boson and top quark couplings, top loops and \( G^0 \) exchange in the s-channel.

But we have also shown that this cancellation can be preserved provided a special relation between form factors is satisfied. We considered this relation as a specific CSM property. Introducing five arbitrary effective form factors chosen as \( F_{G^0ZLH}(s) = F_{ZZLH}(s), F_{Hu}(s), F_{Gtt}(s), F_{tR}(s), F_{tL}(s) \) this preservation occurs provided the following CSM constraint is satisfied:

\[
F_{G^0ZLH}(s)F_{Gtt}(s)(g_{tr}^Z - g_{tL}^Z) = F_{Hu}(s)(g_{tr}^ZF_{tR}(s) - g_{tL}^ZF_{tL}(s))
\] (2)

The same constraint can be inferred by looking directly at the high energy behaviour of the \( tt \rightarrow Z_LH \) amplitudes.
The above procedure can be generalized to $t\bar{t}$ production amplitudes in $ZZ$ and $WW$ collisions [12], especially with longitudinal $Z$ and $W$ which could be composite and nevertheless preserve the Goldstone equivalence.

First the $Z_L Z_L \to t\bar{t}$ process gives the constraint

$$- \frac{1}{2} g_{HZZ} g_{Htt} F_{HZZ}(s) F_{Htt}(s) = m_t((g_{tR} F_{tR}(s) - g_{tL} F_{tL}(s))^2$$

and the $W_L W_L \to t\bar{t}$ processes requires

$$F_{HWW}(s) F_{Htt}(s) = F_{tL}^2(s) = F_{VWW}(s) F_{tL}(s)$$

In this second case in order to recover the SM structure one needs to require that the $\gamma tt$ and $Ztt$ form factors are similar as well as the $F_{\gamma WW}(s)$ and $F_{ZWW}(s)$ form factors. Finally the two above constraints require that all the involved form factors have a common $F(s)$ shape.

**An effective top mass?**

Instead of requiring this crude property of unique form factor there is another way of preserving CSM. As mentioned in [8], in some processes where, after the cancellation of the increasing contributions, the resulting SM amplitudes appear to be proportional to the top mass $m_t$, the alternative possibility consists in introducing a (decreasing) effective mass $m_t(s)$, depending on the compositeness scale, which would finally ensure a good high energy behaviour.

This may be also considered as consistent with the CSM concept as it preserves the SM structure.

We will illustrate the effects of this choice as compared to the other CSM and CSMv cases in the following studies and in the next Section.

**Application to $gg, \gamma \gamma \to ZH$**

Details about the behaviour of the various helicity amplitudes can be found in [10, 11] for both processes and the 4 choices of form factor types, those which violate CSM, with only Higgs form factor (CSMvH), with both Higgs and top form factors (CSMvt), those which preserve the above CSM constraint with both $t_L$ and $t_R$ form factors (CSMtLR) or with only a $t_R$ form factor (CSMtR).

Explicitly, in the illustrations that we will present we will use the $F(s)$ form factor of eq.(1) and we will make comparisons between the 4 or 6 following choices:

CSMtLR and CSMGtLR: $F_{tR}(s) = F_{tL}(s) = F(s)$ and $F_G(s) = F_H(s) = F(s)$ keeping the top mass at its bare value,
CSMtR and CSMGtR: $F_{tL}(s) = 1$, $F_{tR}(s) = F(s)$ and $F_G(s) = F_H(s) = F(s)$, with the effective top mass $m_t(s) = m_t F(s)$, 

CSMvt: different form factors for $t_L$ (ex; $M = 10$ TeV) and for $t_R$ (ex; $M = 15$ TeV), and $F_G(s) = F_H(s) = F(s)$, with a bare top mass, 

CSMvH: no top form factor but $F_G(s) = F_H(s) = F(s)$ and the bare top mass.

In Fig.4 we illustrate the differences between 4 choices for the ratios of new cross sections over the SM one in the case of the $gg \rightarrow ZH$ process. The $\gamma \gamma \rightarrow ZH$ process would give complementary results in particular when polarized photon beams can be used, see [11].

3.3 3rd step: Confirmation of the CSM constraints

Careful analyses of each of the above processes should determine the detailed properties of the $H$ and top quark compositeness and in particular to see if the modifications of the SM predictions correspond to CSM conservation or to CSM violation in each of these sectors.

The next step may consist in studying other processes in order to check these properties. More involved processes like $t\bar{t}H$, $t\bar{t}Z$ and $t\bar{b}W$ production in $e^+e^-$ or in hadronic collisions and inclusive distributions like $e^+e^- \rightarrow H, Z, W, t + ....$ should be very productive because they directly involve both the Higgs boson and the top quark sectors.

In ref.[13, 14] we have studied the processes $e^+e^-, gg, \gamma \gamma \rightarrow t\bar{t}H, t\bar{t}Z, t\bar{b}W^-$. Large and specific effects of Higgs and top quark form factors have been found. The most spectacular ones appear (as expected from the special longitudinal cancellations) in the $t\bar{b}W^-$ case. We show them for the 3 processes $e^+e^-, gg, \gamma \gamma \rightarrow t\bar{b}W^-$ in Fig.5,6,7 with the 6 options of form factors. Strong effects appear from CSM violating cases. When the Goldstone equivalence is imposed (in CSM... cases) a reasonable form factor effect is recovered.

We now look at the inclusive distributions $e^+e^- \rightarrow H, Z, W, t + ....$ which should cumulate the various effects. The illustrations are shown for the reduced momentum $x = \frac{2p}{\sqrt{s}}$ at a center of mass energy of 4 TeV and an angle of $\frac{\pi}{3}$.

Inclusive distribution $e^+e^- \rightarrow H + ....$.

In SM the main leading channels contributing are $Hff$ (essentially $Htt$), $HHZ$, $HZZ$, $HZ\gamma$, $H\gamma\gamma$, $HWW$. The resulting $x$ distribution is shown in Fig.8, showing the sensitivity to $Htt$, $Vtt$, and bosonic $H$ couplings. With the usual 4 choices of form factors, only $t_R$ compositeness leads to small effects, whereas larger ones appear from $H$ compositeness.
Inclusive distribution $e^+e^- \rightarrow Z + ....$

The SM channels are $Zff$ (all quarks and leptons), $ZHH, ZHZ, ZZ\gamma, ZZ\gamma$, $ZWW$ leading to the distributions shown in Fig.9a and Fig.9b for longitudinally polarized $Z_L$ and unpolarized $Z$. The $ZWW$ contribution is particularly important due to its special SM cancellations which can be perturbed by arbitrary form factors, especially in the $Z_L$ case.

Large effect are found when these cancellations are violated (CSMtLR, CSMvH, CSMvt); they are smaller for CSMGtLR, CSMtR, CSLGtR where no violation occurs. The effects are slightly less observable in the unpolarized $Z$ case.

Inclusive distribution $e^+e^- \rightarrow W + ....$

The SM channels are now $Wff'$ (quarks and leptons), $WWH, WWZ, WW\gamma$ and shown in Fig.10a and Fig.10b for $W_L$ and unpolarized $W$.

The analysis and the effects are similar to the ones in the inclusive $Z$ case and, with the usual 6 choices, one finds even more pronounced effects.

Inclusive distribution $e^+e^- \rightarrow t + ....$

The SM channels are $ttH, ttZ, ttg, tbW$. We consider the 3 cases with $t_L, t_R$ or unpolarized $t$ for the 6 choices of form factors; the results are shown in Fig.11a, Fig.11b and Fig.11c respectively.

In the $t_L$ and unpolarized $t$ cases one can see large effects for CSMtLR, CSMvH, CSMvt; medium ones for CSMGtLR; and small ones for CSMtR, CSMGtR.

The $t_R$ distribution can reveal different specific effects of $t_R$ compositeness although the size of the effects may be weaker.

3.4 The steps after....

After having looked at all the above processes, if some form factor effect is revealed, the point will be to see all of its characteristics, in particular if it seems to correspond to some CSM, CSMG or CSMv type. The complete set of couplings should be tested. This will require an amplitude analysis of all concerned processes with measurements of angular distributions, polarization distributions, subenergy dependences of the various cross sections.

The possibilities can be estimated by looking for example for $e^+e^-$ collisions at [15], [16], [17], [18], for hadronic collisions at [19], [20] and for photon-photon collisions at [21].

Other processes, for example those involving the bottom quark, should be studied in order
to check if they are more or less affected by compositeness. All these results may then suggest some theoretical modelization of the underlying dynamics.

4 Summary

In this paper we have reviewed what we call the CSM concept, which assumes that Higgs boson and top quark compositeness may preserve the basic SM structure, including the Goldstone equivalence. Describing such compositeness effects by form factors affected to each Higgs boson and top quark coupling we have compared the observable consequences of CSM conserving and of CSM violating choices. We have proposed a 3-step strategy for analyzing possible departures from SM predictions in the concerned processes.

Step 1: detect form factors in $e^+e^- \rightarrow ZH$, in $\gamma\gamma \rightarrow WW$ and in $e^+e^- \rightarrow t\bar{t}$.

Step 2: check if special CSM constraints in $e^+e^- \rightarrow W^+W^-$ and in $gg, \gamma\gamma \rightarrow ZH$ are preserved.

Step 3: Confirm the validity of the CSM constraints in $ttH$, $ttZ$ and $t\bar{b}W$ production in $e^+e^-$, $\gamma\gamma$ and hadronic collisions and in inclusive processes like $e^+e^- \rightarrow H, Z, W, t + anything$.

Depending on the nature of the results further phenomenological and theoretical developments may be required on the one hand for analyzing complete sets of observables and on the other hand for establishing a dynamical description of the effective form factors. We would like to particularly mention the occurrence of an effective top mass. This compositeness property may suggest new ways for discussing the whole fermion spectrum.
References

[1] H. Terazawa, Y. Chikashige and K. Akama, Phys. Rev. D15, 480 (1977); for other references see H. Terazawa and M. Yasue, Nonlin.Pheno.m.Complex Syst. 19,1(2016); J. Mod. Phys. 5, 205 (2014).

[2] R. Contino, T. Kramer, M. Son and R. Sundrum, J. High Energy Physics 05(2007)074.

[3] D.B. Kaplan and H. Georgi, Phys. Lett. 136B, 183 (1984).

[4] K. Agashe, R. Contino and A. Pomarol, Nucl. Phys. B719, 165 (2005); hep/ph 0412089.

[5] G. Panico and A. Wulzer, Lect.Notes Phys. 913,1(2016).

[6] G.J. Gounaris and F.M. Renard, Phys.Rev. D93 (2016) 093018, arXiv:1601.04142.

[7] F.M. Renard, arXiv: 1701.04571.

[8] G.J. Gounaris and F.M. Renard, arXiv: 1611.02426.

[9] F.M. Renard, arXiv: 1701.03382.

[10] F.M. Renard, arXiv: 1702.08853.

[11] F.M. Renard, arXiv: 1703.04989.

[12] G.J. Gounaris and F.M. Renard, Phys. Rev. D94, 053009 (2016); arXiv: 1606.08507.

[13] F.M. Renard, arXiv: 1704.07985.

[14] F.M. Renard, arXiv: 1706.04484.

[15] G. Moortgat-Pick et al, Eur. Phys. J. C75, 371 (2015), arXiv: 1504.01726.

[16] D. d’Enterria, arXiv: 1701.02663.

[17] N. Craig, arXiv: 1703.06079.

[18] C. Englert and M. Russel, arXiv: 1704.01782.

[19] R. Contino et al, arXiv: 1606.09408.

[20] F. Richard, arXiv: 1703.05046.

[21] V.I. Telnov, Nucl.Part.Phys.Proc. 273,219(2016).
Figure 1: Energy dependence (upper panel for $\theta = \pi/2$) and angular distribution (lower panel for $\sqrt{s} = 4$ TeV) of the $e^+e^- \rightarrow ZH$ cross section. SM refers to the standard unpolarized case, SML to the standard longitudinal $Z$ production, FF and LFF to the corresponding cases including the form factor effect.
Figure 2: Ratio of $\gamma\gamma \rightarrow W^+W^-$ cross section with form factor over the standard one in unpolarized case and in $W^+_L W^-_L$ case.
Figure 3: Ratios for $e^+e^- \to W^+W^-$ production; upper panel for unpolarized $e^+e^-$ with either a crude $W_L$ form factor (LFF) or with CSM Goldstone equivalence (CSMGFF); lower panel, comparison of the above CSMGFF with the case of $e_L^+e_R^-$ polarization and again either a crude $W_L$ form factor (LFF) or with CSM Goldstone equivalence (CSMGFF).
Figure 4: Ratio of $gg \rightarrow ZH$ cross section with form factor over the standard one.
Figure 5: Ratio of $e^+e^- \rightarrow t\bar{b}W^-$ cross section with form factor over the standard one.
Figure 6: Ratio of $gg \rightarrow tbW$ cross section with form factor over the standard one.
Figure 7: Ratio of $\gamma\gamma \rightarrow tbW^-$ cross section with form factor over the standard one.
Figure 8: Ratio of $e^+e^- \rightarrow H + \text{anything}$ with form factor over the standard one.
Figure 9: Ratio of $e^+e^- \to Z + anything$ with form factor over the standard one in the longitudinal and in the unpolarized cases.
Figure 10: Ratio of $e^+ e^- \rightarrow W^- + \text{anything}$ with form factor over the standard one in the longitudinal and in the unpolarized cases.
Figure 11: Ratio of $e^+e^- \rightarrow t_L + \text{anything}$, $e^+e^- \rightarrow t_R + \text{anything}$ and $e^+e^- \rightarrow t + \text{anything}$ with form factors over the corresponding standard ones.