Momentum Dependence in BSM Higgs Couplings

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Abstract

The presence of heavy new physics generally alters the Standard Model (SM) Higgs couplings predictions. In many models, we expect that momentum effects decouple as the new heavy states are integrated out. However, these effects can be important in situations of significant off-shellness at collider experiments. We study the momentum dependence of different beyond the SM scenarios, using form factors to encode the p^2 effect on the Higgs couplings. Our focus is on the effects of new strongly interacting sectors, like composite Higgs models with general scalar, vector-like fermions or vectorial resonances. We show a significant enhancement of order p^2/Λ^2 over the expected v^2/Λ^2 predictions for the BSM scenarios studied. These effects are competitive with the momentum independent coupling modifications, changing the predictions of the models. Additionally, the use of form factors modifies the shapes of the kinematic distributions, providing new opportunities for LHC signals.

Introduction

A general prediction of many beyond the standard model (BSM) models is the modification of the Higgs couplings. We verify this in explicit examples like in composite Higgs models (CHMs), and models with extra scalars [1, 2]. Assuming an energy gap at the TeVs, the modifications are of order v^2/Λ^2, where Λ is the cutoff scale.

When computing the low energy theory, we often assume that the momentum effects of the heavy new states decouple as we integrate them out. However, in the case of channels with significant off-shellness, this might not be the case.

The purpose of our work is to characterize the momentum effects induced in the Higgs interactions by BSM physics, which can be done with form factors [3, 4]. We compute the form factors to describe the non-local, momentum dependent, Higgs vertices and study the collider signals in different channels.

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Higgs Form Factors

The Higgs form factors are non-local functions of the external momentum of a given n-point-function.

- **2-point-function**: Spectral Decomposition.

$$\Pi(p^2) = \int_0^\infty d\mu^2 \frac{\rho(\mu^2)}{p^2 - \mu^2} \quad (1)$$

- **3-point-function**: Not known in general.

$$\Gamma(p_1^\mu, p_2^\nu, p_3^\alpha) = \Gamma(p_1^2, p_2^2, p_1 \cdot p_2) \quad (2)$$

The lack of a general prescription for the 3PF implies that we need to assume the Higgs BSM interactions.

We study the form factors induced by generic vector-like fermions, vectorial and scalar resonances in the context of a new strongly interacting sector.

- **CHMs** $\begin{cases} \to \text{Partial Compositeness} \\ \to \text{Hidden Local Symmetry} \end{cases}$
- **Heavy Scalars** $\to$ Bilinear Couplings

We show the form factors in figure 1. These are proportional to the resonance propagators following the interaction vertices of the new sector.
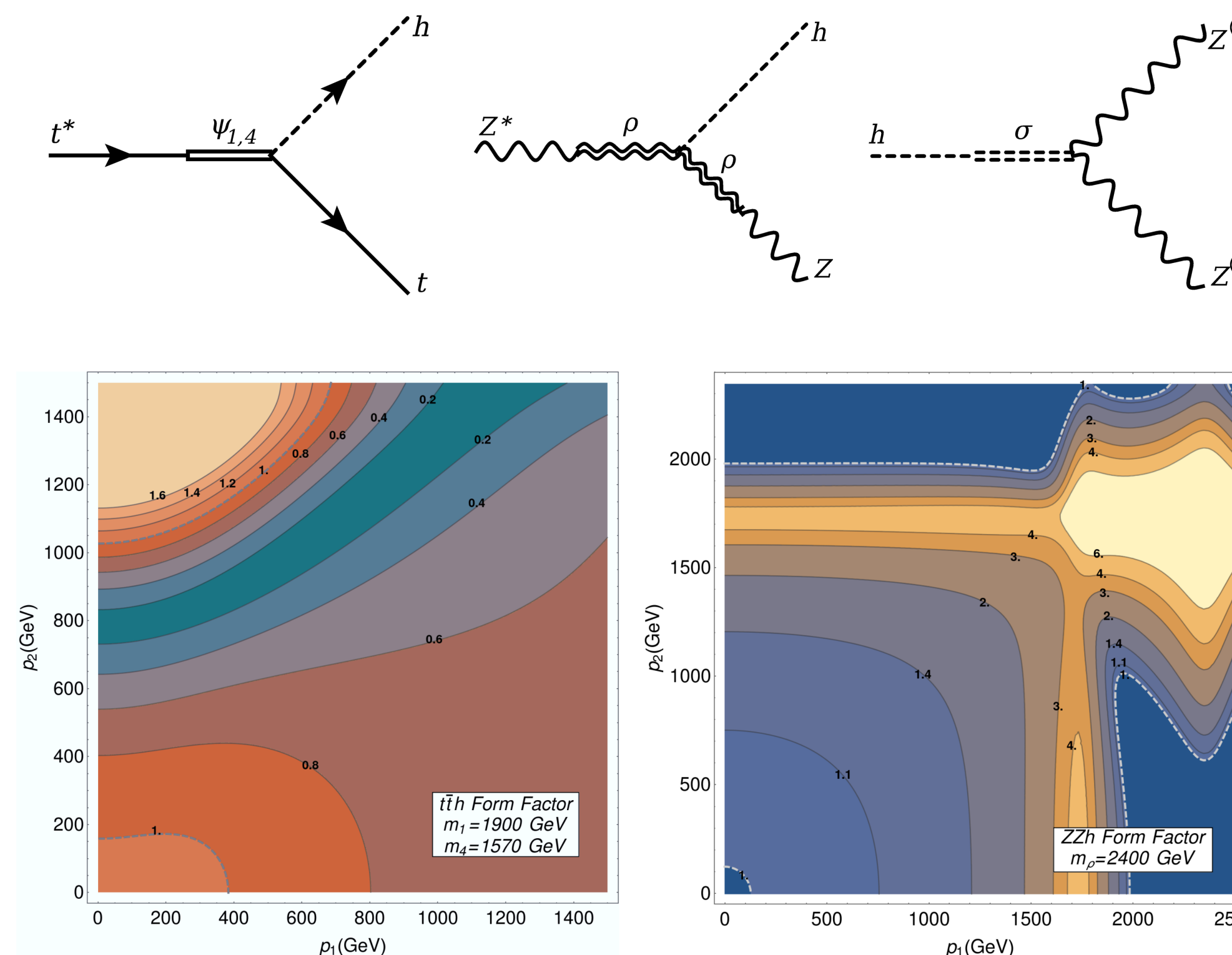

Figure 1: Countour plot of the absolute value of the $t\bar{t}h$ and ZZh form factors as function of the top and Z momenta.

Results

We implement the form factors expressions for the MCHM$_5$ with its fermion and vector resonances and a generic scalar. The form factors are proportional to the propagators of the resonances, which lead to an enhancement effect as shown in figures 2 and 3.
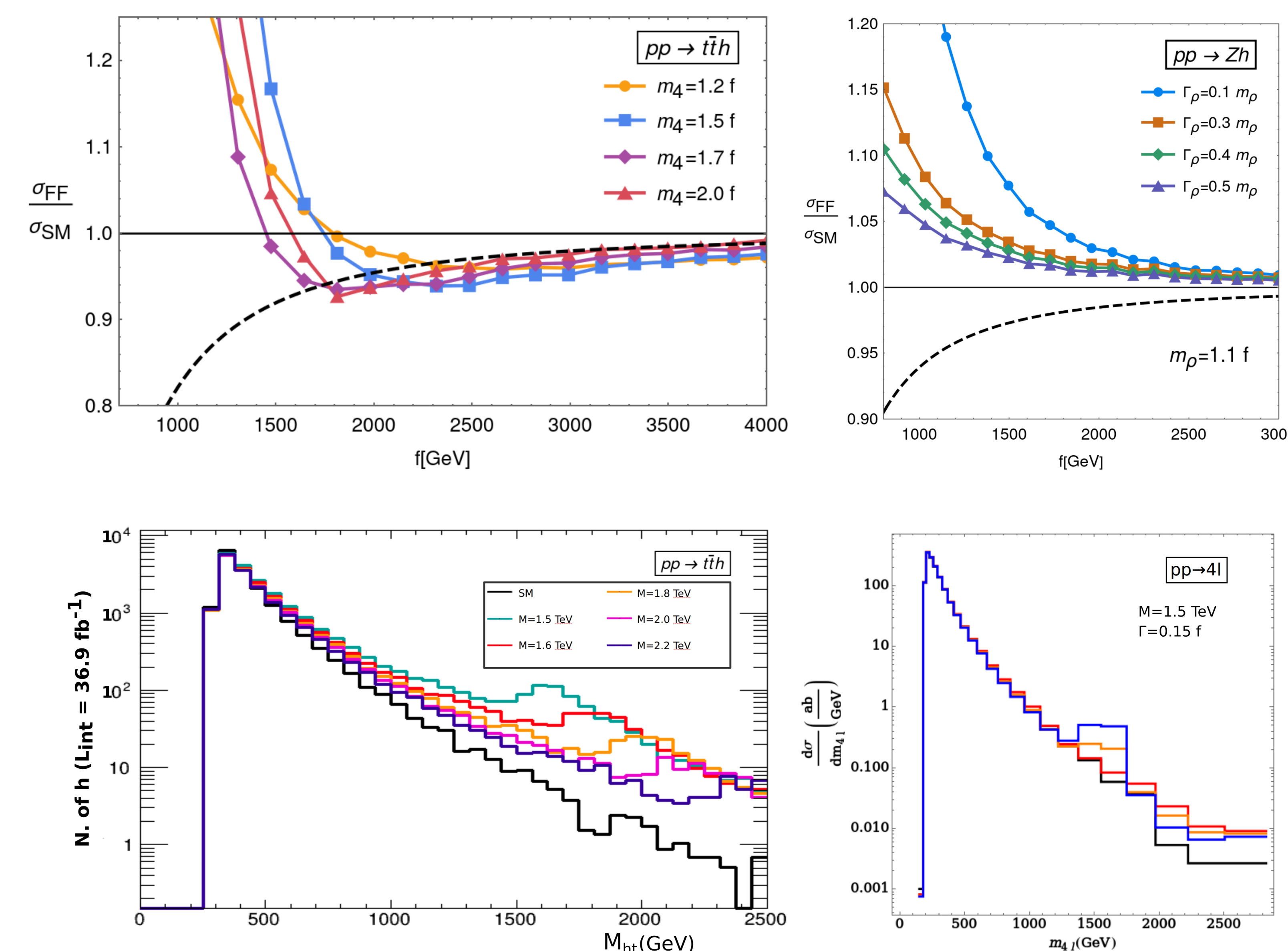

Figure 2: Cross-sections of the MCHM5 with form factors. We simulate the parton level signal with modified UFOs to include form factor vertices. The dashed lines represent the CHM suppression and the coloured ones the momentum enhancement effect.

Figure 3: Invariant mass distributions for the $t\bar{t}h$ process with MCHM5 form factors and off-shell Higgs to 4 leptons channel with the scalar resonance form factor.

Local EFT

To recover a local EFT description, we can expand the form factor in powers of p^2/Λ^2.

$$\Pi(p_1, p_2, p_3) = \Pi(0) + c_1 \frac{p_1^2}{\Lambda^2} + c_2 \frac{p_2^2}{\Lambda^2} + c_{12} \frac{p_1 \cdot p_2}{\Lambda^2} \quad (3)$$

The expansion of (3) will lead to $d = 6$ effective operators. In Figure 1, we show the momentum enhancement effect induced by the local operators.
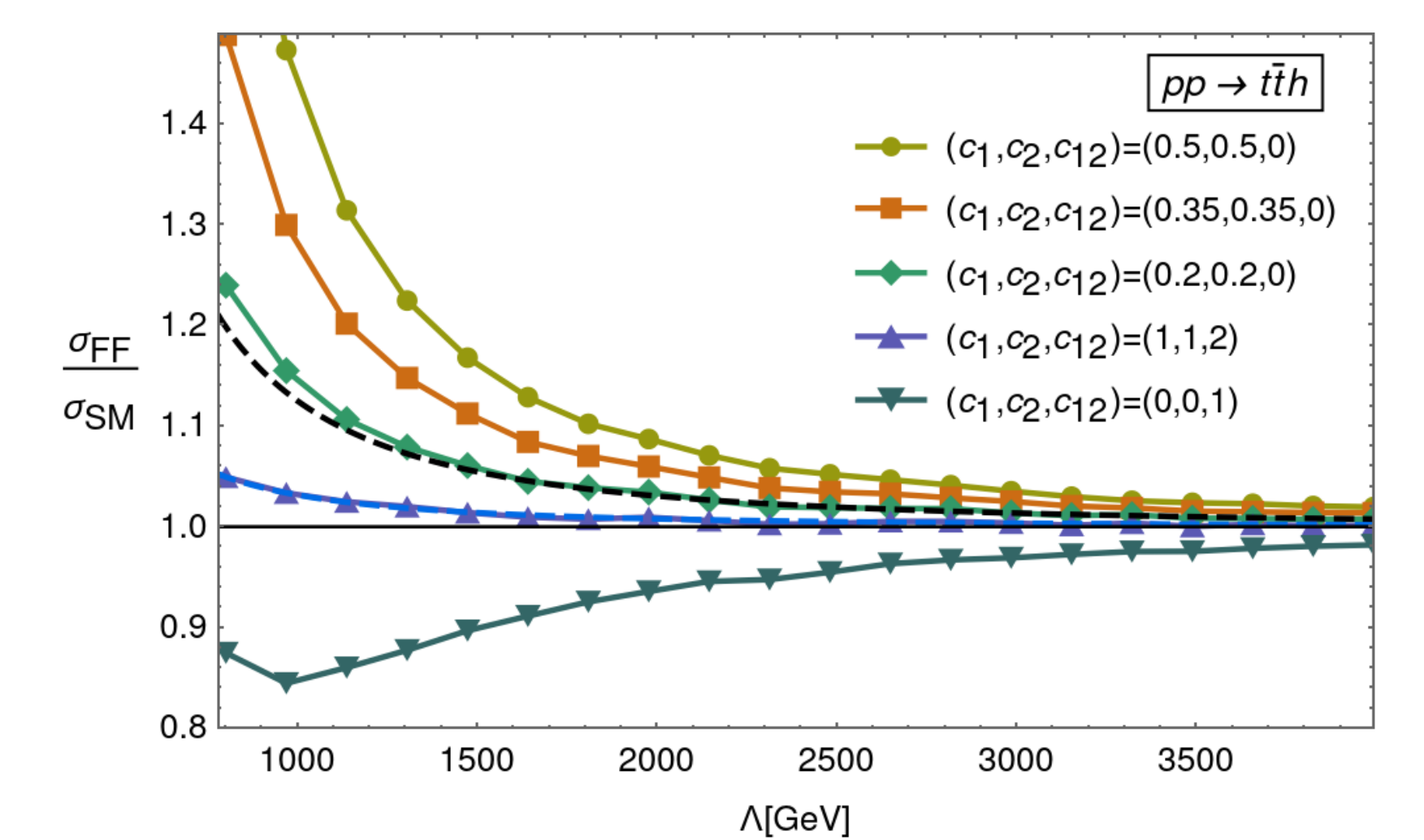

Figure 4: Cross-section momentum enhancement induced by the $d = 6$ operators from the form factor EFT expansion.

Conclusions

We explored the signals induced by the momentum-dependent Higgs form factors in the LHC channels. Our main results are:

- Form factor effects are competitive with the usual coupling modification in CHMs.
- Change of kinematic distribution shapes.
- Model independent view of momentum effects.

References

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