BCFW tree level QCD corrections to WBF Higgs production

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We explicitly compute analytic tree level amplitudes for the production of a Higgs boson via Weak Boson Fusion (WBF) with one and two additional gluon emissions in the final state. The computation for the additional emission of an arbitrary number of gluons is discussed, obtaining a general result related with the procedure of contraction of 2 Single Weak Boson (SWB) currents: the calculation of WBF amplitudes is valid by this mean for any number of gluons and the involved currents are identified and characterized. The generalization of the Britto-Cachazo-Feng-Witten (BCFW) formula to the massive case is applied successfully, obtaining compact results which agree with those calculated with the conventional approach of Feynman diagrams. We show that, in relation to the latter method, the involved BCFW amplitudes are computed through a notably more efficient process (particularly for high numbers of external particles) suggesting that successive corrections to WBF process can be obtained alike in a swift way.

BCFW On-Shell Recursion Relations at Tree Level

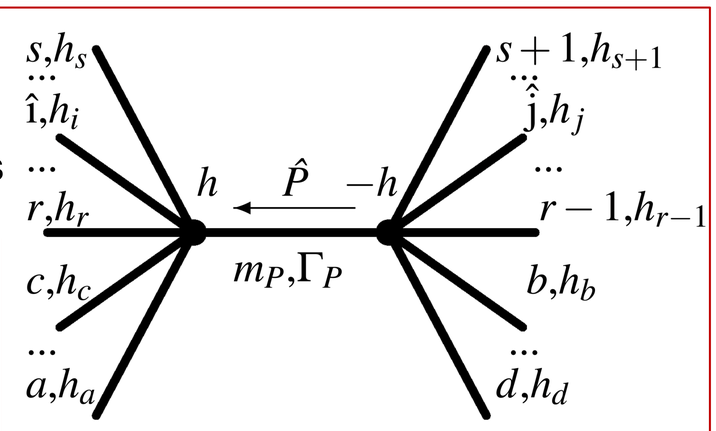
Consider a color-ordered partial amplitude (color factors stripped away) $iM\left(k_1^{h_1},\ldots,k_m^{h_m},p_1^{h_1},\ldots,p_n^{h_n}\right)$, in which the colored particles $\left(p_1^{h_1},\ldots,p_n^{h_n}\right)$ come in a definite cyclic order, and some colorless particles $\left(k_1^{h_1},\ldots,k_m^{h_m}\right)$ are produced too. Then, with the shift

$$\left|\hat{i}\right\rangle=\left|i\right\rangle \quad \left|\hat{i}\right]=\left|i\right]+z\left|j\right] \qquad \left|\hat{j}\right]=\left|j\right] \quad \left|\hat{j}\right\rangle=\left|j\right\rangle-z\left|i\right\rangle$$

$$z_{part}=-\frac{\left[P_{Left}^2-m_P^2+i\Gamma_P m_P\right]}{\left\langle i\left|\bar{P}_{Left}\right|j\right]}$$

If $\lim_{|z|\to\infty} iM(z)=0$ (dep. on i and j helicities), then

$$iM\left(k_1^{h_1},\ldots,k_m^{h_m},p_1^{h_1},\ldots,p_n^{h_n}\right)=\sum_{\substack{\text{Partitions with } i \text{ on the left,}\\ j \text{ on the right,}\\ \text{keeping Cyclic Order in Colored Particles.}}}\ \sum_{\substack{\text{Intermediate}\\ \text{State}\\ \text{Helicities}\\ \textbf{or Spins.}}}\left\{iM\left(k_a^{h_a},\ldots,k_c^{h_c},p_r^{h_r},\ldots,\hat{p}_i^{h_i},\ldots,p_s^{h_s},-\hat{P}^h\right)\times \frac{i}{P_{Left}^2-m_P^2+i\Gamma_P m_P}\times iM\left(k_b^{h_b},\ldots,k_d^{h_d},\hat{P}^{-h},p_{s+1}^{h_s},\ldots,\hat{p}_j^{h_i},\ldots,p_{r-1}^{h_{r-1}}\right)\right\}_{z=z_{part}}$$

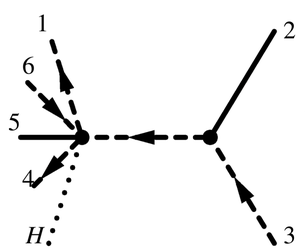


$\{a,\ldots,c\}\subset\{1,\ldots,m\}$ $\quad\{b,\ldots,d\}=\{1,\ldots,m\}-\{a,\ldots,c\}$
$\{r,\ldots,i,\ldots,s,s+1,\ldots,j,\ldots,r-1\}$ a cyclic permutation of $\{1,\ldots,n\}$

Tree level Amplitudes with BCFW: WBF + 2 Gluon Emissions

2 Fundamental Color Structures

4 Feynman Diagrams

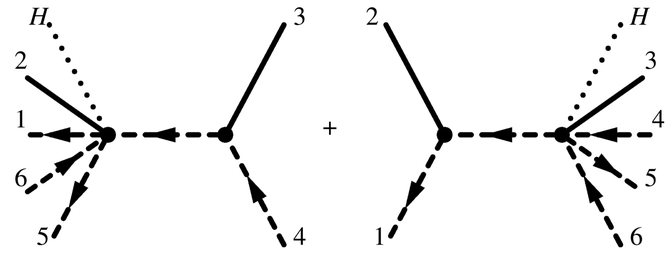


$(i,j)=(1,2)$ or $(2,1)$

$$P_V'=-p_1-p_2-p_3 \quad P_V''=-p_4-p_5-p_6$$

$$\begin{cases} iM_V\left(H,1_q^-,2_g^+,3_{\bar{q}}^+,4_q^+,5_g^-,6_{\bar{q}}^-\right)=\dfrac{-2i\left\langle 1\left|\bar{P}_V'\right|4\right]\left\langle 1\left|\bar{P}_V''\right|4\right]}{\langle 12\rangle\langle 23\rangle[45][56]}\xi_V\left(P_V',P_V''\right) \\ iM_V\left(H,1_q^+,2_g^+,3_{\bar{q}}^-,4_q^-,5_g^-,6_{\bar{q}}^+\right)=\dfrac{-2i\left\langle 3\left|\bar{P}_V'\right|6\right]\left\langle 3\left|\bar{P}_V''\right|6\right]}{\langle 12\rangle\langle 23\rangle[45][56]}\xi_V\left(P_V',P_V''\right) \end{cases}$$

$$\xi_V\left(P_V',P_V''\right)\equiv\frac{1}{\left[P_V'^2-M_V^2+i\Gamma_V M_V\right]\left[P_V''^2-M_V^2+i\Gamma_V M_V\right]}$$



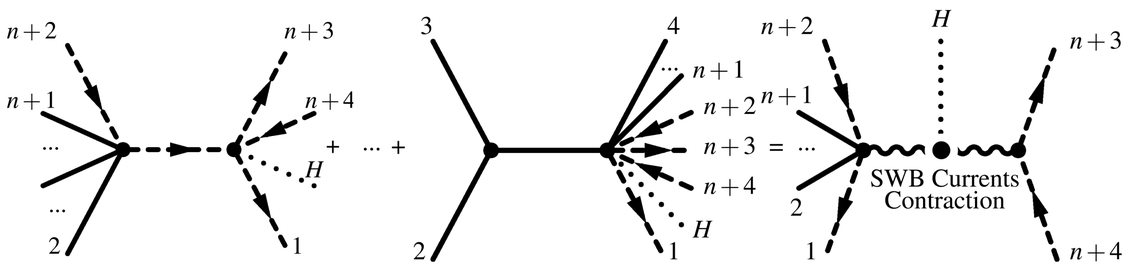
$(i,j)=(2,3)$ or $(3,2)$

5 Feynman Diagrams

$$P_V'=-p_1-p_2-p_3-p_4 \quad P_V''=-p_5-p_6$$

$$\begin{cases} iM_V\left(H,1_q^-,2_g^-,3_g^-,4_{\bar{q}}^+,5_q^-,6_{\bar{q}}^+\right)=\dfrac{-2i[46]\left\langle 5\left|\bar{P}_V'\right|4\right]}{[12][23][34]}\xi_V\left(P_V',P_V''\right) \\ iM_V\left(H,1_q^-,2_g^-,3_g^+,4_{\bar{q}}^+,5_q^-,6_{\bar{q}}^+\right)=\dfrac{2i[13]\left[3\left|(p_1+p_2)\bar{P}_V'\right|6\right]\left[3\left|(p_1+p_2)\right|5\right\rangle}{[12][23]s_{123}\left[1\left|(p_2+p_3)\right|4\right\rangle}\xi_V\left(P_V',P_V''\right) \\ -\dfrac{2i\langle 24\rangle\left\langle 2\left|(\bar{p}_3+\bar{p}_4)P_V'\right|5\right\rangle\left\langle 2\left|(\bar{p}_3+\bar{p}_4)\right|6\right]}{\langle 23\rangle\langle 34\rangle s_{234}\left[1\left|(p_2+p_3)\right|4\right\rangle}\xi_V\left(P_V',P_V''\right) \end{cases}$$

SWB Current Decomposition Theorem



Consider the tree level color-ordered partial amplitude consisting in the production of a Higgs particle through the WBF of two fermion currents (the mediator being a specific boson V and the fusion the only Weak interaction). m and n gluons are produced respectively in each fermion current. Then, this amplitude can be written as the contraction of two SWB currents.

The Complete WBF Tree Level Amplitude with the Emission of N Gluons

- Take all the possible separations of N gluons in the 2 fermion currents (i.e. $(N+1)/2$ if N is odd and $(N+2)/2$ if N is even). Find the color ordered partial amplitudes by contraction of SWB currents or directly by BCFW. Use symmetries!
- The color dependence is easily determined as products of the m and n ($N=m+n$) T operators properly contracted with the gluon and fermion indices (or an identity, if there are no gluons in the respective current). The remaining coupling factors can be written as functions of the input parameters of the amplitude.
- Finally, it is summed over all the weak channels in consideration for specific flavors, introducing combinatorial and crossing factors.

Conclusions and Prospects

Compact color-ordered amplitudes were easily obtained using the most simple blocks with the BCFW formalism. As an original approach for this process, the scheme proved to be increasingly efficient (in relation to the Feynman approach) as the number of external legs grows, reducing the algebra substantially. Successive analytical corrections to WBF can be obtained with little effort and a procedure for the N gluon emissions problem was proposed. In fact, the SWB current decomposition was proved in this general case with the use of induction and the BCFW formula. The potential in this treatment for the phenomenology of related or similar interactions is remarkable, reaching the possibility of increasing efficiency to unexpected levels. Between some of the prospects: *QCD Corrections to WBF with photon emissions*, *Inverse Soft Limit process as a solely scheme for Amplitudes Computation*, and linear combinations…

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Main Reference

A. R. Fazio and S. C. Vargas, *Helicity Spinor Methods and Tree Level QCD Corrections in Higgs Production via Weak Bosons Fusion*, Aditi Journal of Mathematical Physics **1**, 47-92 (2012), arXiv:1201.2673v1 [hep-ph].