

Probing anomalous interactions at the LHC

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When the M meets the P

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The SMEFT extends the SM by adding higher-dimensional operators

$$\begin{aligned}
& -\frac{1}{2}g_s^2\partial_\nu g_\mu^\nu - g_s f^{abc}\partial_\nu g_\mu^\nu g_\rho^\nu g_\sigma^\nu - \frac{1}{2}g_s^2 f^{abc}f^{ade}g_\mu^\nu g_\rho^\nu g_\sigma^\nu g_\tau^\nu + \\
& \frac{1}{2}ig_s^2(\partial_\nu^\mu\gamma^\nu g_\mu^\nu + G^\nu\partial^\mu G^\nu + g_s f^{abc}\partial_\nu G^\nu G^\nu g_\mu^\nu - \partial_\nu W_\mu^\nu\partial_\nu W_\mu^\nu - \\
& M^2 W_\mu^\nu W_\nu^\mu - \frac{1}{2}\partial_\nu Z_\mu^\nu\partial_\nu Z_\mu^\nu - \frac{1}{2}M^2 Z_\mu^\nu Z_\mu^\nu - \frac{1}{2}\partial_\nu A_\mu\partial_\nu A_\mu - \frac{1}{2}\partial_\nu H\partial_\nu H - \\
& \frac{1}{2}m_\phi^2 H^2 - \partial_\nu\phi^\nu\partial_\nu\phi^\nu - M^2\phi^\nu\phi^\nu - \frac{1}{2}\partial_\nu\phi^\nu\partial_\nu\phi^\nu - \frac{1}{2}M^2\phi^\nu\phi^\nu - \frac{1}{2}m_\phi^2\frac{2M^2}{\Lambda^2} + \\
& \frac{2M}{\Lambda}H + \frac{1}{2}(H^2 + \phi^\nu\phi^\nu + 2\phi^\nu\phi^\nu) + \frac{2M^2}{\Lambda}c_h - ig_{\nu\mu}\partial_\nu Z_\mu^\nu(W_\nu^\mu W_\nu^\mu - \\
& W_\nu^\mu W_\nu^\mu) - Z_\mu^\nu(W_\nu^\mu W_\nu^\mu - W_\nu^\mu\partial_\nu W_\nu^\mu) + Z_\mu^\nu(W_\nu^\mu\partial_\nu W_\nu^\mu - \\
& W_\nu^\mu\partial_\nu W_\nu^\mu) - ig_{\nu\mu}[\partial_\nu A_\mu(W_\nu^\mu W_\nu^\mu - W_\nu^\mu W_\nu^\mu) - A_\mu(W_\nu^\mu\partial_\nu W_\nu^\mu - \\
& W_\nu^\mu\partial_\nu W_\nu^\mu) + A_\mu(W_\nu^\mu\partial_\nu W_\nu^\mu - W_\nu^\mu W_\nu^\mu) - \frac{1}{2}g^2 W_\nu^\mu W_\nu^\mu W_\nu^\mu + \\
& \frac{1}{2}g^2 W_\nu^\mu W_\nu^\mu W_\nu^\mu + g^2 c_\gamma^2(Z_\mu^\nu W_\nu^\mu Z_\mu^\nu - Z_\mu^\nu Z_\mu^\nu W_\nu^\mu) + \\
& g^2 s_\theta^2(A_\mu A_\nu W_\nu^\mu - A_\mu A_\nu W_\nu^\mu) - 2A_\mu Z_\mu^\nu W_\nu^\mu - 2g_1 H^2 + H\phi^\nu\phi^\nu + 2H\phi^\nu\phi^\nu - \\
& \frac{1}{2}g^2 c_h[H^4 + (\phi^\nu\phi^\nu)^2 + 4(\phi^\nu\phi^\nu)^2\phi^\nu\phi^\nu + 4H^2\phi^\nu\phi^\nu + 2(\phi^\nu\phi^\nu)^2 H^2] - \\
& gM W_\mu^\nu W_\nu^\mu H - \frac{1}{2}g\frac{M^2}{\Lambda^2}Z_\mu^\nu Z_\mu^\nu H - \frac{1}{2}ig[W_\mu^\nu(\partial^\mu\phi^\nu\phi^\nu - \phi^\nu\partial_\mu\phi^\nu) - \\
& W_\mu^\nu(\partial^\mu\partial_\nu\phi^\nu - \phi^\nu\partial_\mu\phi^\nu)] + \frac{1}{2}ig[W_\mu^\nu(H\partial_\nu\phi^\nu - \phi^\nu\partial_\nu H) - W_\mu^\nu(H\partial_\nu\phi^\nu - \\
& \phi^\nu\partial_\nu H)] + \frac{1}{2}ig\frac{1}{\Lambda^2}[Z_\mu^\nu(H\partial_\nu\phi^\nu - \phi^\nu\partial_\nu H) - ig\frac{M^2}{\Lambda^2}M Z_\mu^\nu(W_\nu^\mu\phi^\nu - W_\nu^\mu\phi^\nu) + \\
& ig_{\nu\mu}M A_\nu(W_\nu^\mu\phi^\nu - W_\nu^\mu\phi^\nu) - ig\frac{1-2s_\theta^2}{2c_\theta}Z_\mu^\nu(\phi^\nu\partial_\mu\phi^\nu - \phi^\nu\partial_\mu\phi^\nu) + \\
& ig_{\nu\mu}A_\nu(\phi^\nu\partial_\mu\phi^\nu - \phi^\nu\partial_\mu\phi^\nu) - \frac{1}{2}g^2 W_\nu^\mu W_\nu^\mu (H^2 + (\phi^\nu\phi^\nu)^2 + 2\phi^\nu\phi^\nu) - \\
& \frac{1}{2}g^2\frac{1}{\Lambda^2}Z_\mu^\nu Z_\mu^\nu[H^2 + (\phi^\nu\phi^\nu)^2 + 2(2s_\theta^2 - 1)^2\phi^\nu\phi^\nu] - \frac{1}{2}g^2\frac{1}{\Lambda^2}Z_\mu^\nu\phi^\mu[W_\nu^\mu\phi^\nu + \\
& W_\nu^\mu\phi^\nu] - \frac{1}{2}ig\frac{1}{\Lambda^2}Z_\mu^\nu H(W_\nu^\mu\phi^\nu - W_\nu^\mu\phi^\nu) + \frac{1}{2}g^2 s_\theta c_\theta A_\nu\phi^\mu[W_\nu^\mu\phi^\nu + \\
& W_\nu^\mu\phi^\nu] + \frac{1}{2}ig^2 s_\theta A_\nu(W_\nu^\mu\phi^\nu - W_\nu^\mu\phi^\nu) - g^2\frac{1}{\Lambda^2}(2s_\theta^2 - 1)Z_\mu^\nu A_\nu\phi^\mu\phi^\nu - \\
& g^2 s_\theta^2 A_\nu A_\nu\phi^\mu\phi^\nu - e^2(\gamma\partial + m_\phi^2)e^{\lambda^2} - e^{\lambda^2}\gamma\partial e^{\lambda^2} - \bar{u}_i^{\lambda^2}(\gamma\partial + m_\phi^2)u_i^{\lambda^2} - \\
& d_i^{\lambda^2}(\gamma\partial + m_\phi^2)d_i^{\lambda^2} + ig_{\nu\mu}A_\nu[-(e^{\lambda^2}\gamma^\mu e^{\lambda^2}) + \frac{2}{3}(u_i^{\lambda^2}\gamma^\mu u_i^{\lambda^2}) - \frac{1}{3}(d_i^{\lambda^2}\gamma^\mu d_i^{\lambda^2})] + \\
& \frac{16}{3}e^{\lambda^2}Z_\mu^\nu[(\partial^\lambda\gamma^\mu(1 + \gamma^5))u^\lambda] + (e^{\lambda^2}\gamma^\mu(4s_\theta^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}_i^{\lambda^2}\gamma^\mu[\frac{2}{3}s_\theta^2 - \\
& 1 - \gamma^5)u_i^{\lambda^2}] + (d_i^{\lambda^2}\gamma^\mu(1 - \frac{2}{3}s_\theta^2 - \gamma^5)d_i^{\lambda^2})] + \frac{16}{3}g_s W_\mu^\nu[(\partial^\lambda\gamma^\mu(1 + \gamma^5))c^\lambda + \\
& (\bar{u}_i^{\lambda^2}\gamma^\mu(1 + \gamma^5)C_{3a}d_i^{\lambda^2})] + \frac{16}{3}g_s W_\mu^\nu[(e^{\lambda^2}\gamma^\mu(1 + \gamma^5))u^\lambda] + (d_i^{\lambda^2}C_{3a}\gamma^\mu(1 + \\
& \gamma^5)u_i^{\lambda^2})] + \frac{16}{3}g_s\frac{m_\phi}{\Lambda^2}[-\phi^\nu(\partial^\lambda(1 - \gamma^5)c^\lambda) + \phi^\nu(e^\lambda(1 + \gamma^5)u^\lambda)] - \\
& \frac{8}{3}\frac{16}{3}e^{\lambda^2}[H(e^\lambda e^\lambda) + i\phi^\mu(e^{\lambda^2}\gamma^\mu e^\lambda)] + \frac{16}{3}i\frac{1}{\Lambda^2}\phi^\mu[-m_\phi^2(d_i^{\lambda^2}C_{3a}(1 - \gamma^5)d_i^{\lambda^2}) + \\
& m_\phi^2(\bar{u}_i^{\lambda^2}C_{3a}(1 + \gamma^5)u_i^{\lambda^2})] + \frac{16}{24M\Lambda^2}\phi^\mu[m_\phi^2(d_i^{\lambda^2}C_{3a}^{\dagger}(1 + \gamma^5)u_i^{\lambda^2}) - m_\phi^2(d_i^{\lambda^2}C_{3a}^{\dagger}(1 - \\
& \gamma^5)u_i^{\lambda^2})] - \frac{8}{3}\frac{16}{3}e^{\lambda^2}H(u_i^{\lambda^2}u_i^{\lambda^2}) - \frac{8}{3}\frac{16}{3}e^{\lambda^2}H(d_i^{\lambda^2}d_i^{\lambda^2}) + \frac{8}{3}\frac{16}{3}e^{\lambda^2}\phi^\mu(\bar{u}_i^{\lambda^2}\gamma^\mu u_i^{\lambda^2}) - \\
& \frac{8}{3}\frac{16}{3}e^{\lambda^2}\phi^\mu(\bar{d}_i^{\lambda^2}\gamma^\mu d_i^{\lambda^2}) + \bar{X}^\dagger(\partial^2 - M^2)X^\dagger + \bar{X}^\dagger(\partial^2 - M^2)X^\dagger + \bar{X}^\dagger(\partial^2 - \\
& \frac{M^2}{\Lambda^2})X^\dagger + \bar{Y}\partial^\nu Y + ig_{\nu\mu}W_\mu^\nu(\partial_\nu\bar{X}^\dagger X^\dagger - \partial_\nu\bar{X}^\dagger X^\dagger) + ig_{\nu\mu}W_\mu^\nu(\partial_\nu\bar{Y}X^\dagger - \\
& \partial_\nu\bar{X}^\dagger Y) + ig_{\nu\mu}W_\mu^\nu(\partial_\nu\bar{X}^\dagger X^\dagger - \partial_\nu\bar{X}^\dagger X^\dagger) + ig_{\nu\mu}W_\mu^\nu(\partial_\nu\bar{X}^\dagger Y - \\
& \partial_\nu\bar{Y}X^\dagger) + ig_{\nu\mu}Z_\mu^\nu(\partial_\nu\bar{X}^\dagger X^\dagger - \partial_\nu\bar{X}^\dagger X^\dagger) + ig_{\nu\mu}A_\nu(\partial_\nu\bar{X}^\dagger X^\dagger - \\
& \partial_\nu\bar{X}^\dagger X^\dagger) - \frac{1}{2}igM[\bar{X}^\dagger X^\dagger H + \bar{X}^\dagger X^\dagger H + \frac{1}{2}\bar{X}^\dagger X^\dagger H] + \\
& \frac{1-2s_\theta^2}{2c_\theta}igM[\bar{X}^\dagger X^\dagger\phi^\nu - \bar{X}^\dagger X^\dagger\phi^\nu] + \frac{1}{2}igM[\bar{X}^\dagger X^\dagger\phi^\nu - \bar{X}^\dagger X^\dagger\phi^\nu] + \\
& \frac{1-2s_\theta^2}{2c_\theta}igM\bar{X}^\dagger X^\dagger\phi^\nu - \bar{X}^\dagger X^\dagger\phi^\nu + \frac{1}{2}igM[\bar{X}^\dagger X^\dagger\phi^\nu - \bar{X}^\dagger X^\dagger\phi^\nu]
\end{aligned}$$

The SMEFT extends the SM by adding higher-dimensional operators

 $\mathcal{L}_{SMEFT} =$

$$\begin{aligned}
& -\frac{1}{2}\partial_\mu g_\nu^\alpha \partial_\rho g_\sigma^\beta - g_\nu f^{\alpha\beta\gamma} \partial_\rho g_\sigma^\gamma g_\mu^\alpha g_\rho^\beta - \frac{1}{4}g_\nu^2 f^{\alpha\beta\gamma} f^{\alpha\delta\epsilon} g_\mu^\delta g_\rho^\epsilon g_\sigma^\alpha g_\nu^\beta + \\
& \frac{1}{2}ig_\nu^2 (\overline{\psi} \gamma^\mu \psi) g_\mu^\alpha + G^a \partial^\mu G^a + g_\nu f^{\alpha\beta\gamma} G^a C^a G^b g_\mu^\alpha - \partial_\mu W_\nu^+ \partial_\rho W_\mu^- - \\
& M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\mu Z_\nu^\alpha \partial_\rho Z_\mu^\beta - \frac{1}{24}M^2 Z_\mu^\alpha Z_\mu^\beta - \frac{1}{2}\partial_\mu A_\nu \partial_\rho A_\mu - \frac{1}{2}\partial_\mu H \partial_\rho H - \\
& \frac{1}{2}m_H^2 H^2 - \partial_\mu \phi^\dagger \partial_\nu \phi - M^2 \phi^\dagger \phi - \frac{1}{2}\partial_\mu \phi^\dagger \partial_\nu \phi - \frac{1}{24}M^2 \phi^\dagger \phi - \beta_3 \frac{23M^2}{12} + \\
& \frac{2M}{9}H + \frac{1}{2}(H^2 + \phi^\dagger \phi + 2\phi^\dagger \phi) + \frac{2M}{9}\alpha_\nu - igc_\nu Z_\mu^\alpha \partial_\rho Z_\mu^\beta (W_\mu^+ W_\nu^- - \\
& W_\mu^- W_\nu^+) - Z_\mu^\alpha (W_\mu^+ \partial_\nu W_\rho^- - W_\mu^- \partial_\nu W_\rho^+) + Z_\mu^\alpha (W_\mu^+ \partial_\nu W_\rho^- - \\
& W_\mu^- \partial_\nu W_\rho^+) - ig s_w [\partial_\mu A_\nu (W_\mu^+ W_\nu^- - W_\mu^- W_\nu^+) - A_\nu (W_\mu^+ \partial_\nu W_\rho^- - \\
& W_\mu^- \partial_\nu W_\rho^+) + A_\nu (W_\mu^+ \partial_\nu W_\rho^- - W_\mu^- \partial_\nu W_\rho^+)] - \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\rho^+ + \\
& \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\rho^- + g^2 c_w^2 (Z_\mu^\alpha W_\nu^+ Z_\rho^\beta W_\mu^- - Z_\mu^\alpha Z_\nu^\beta W_\mu^+ W_\rho^-) + \\
& g^2 s_w^2 (A_\mu W_\nu^+ A_\rho W_\mu^- - A_\mu A_\nu W_\mu^+ W_\rho^-) + g^2 s_w c_w [A_\nu Z_\mu^\alpha (W_\mu^+ W_\nu^- - \\
& W_\mu^- W_\nu^+) - 2A_\nu Z_\mu^\alpha W_\mu^+ W_\nu^-] - g\alpha [H^3 + H\phi^\dagger \phi + 2H\phi^\dagger \phi] - \\
& \frac{1}{2}g^2 \alpha_3 [H^4 + (\phi^\dagger)^\dagger + 4(\phi^\dagger \phi)^2 + 4(\phi^\dagger)^\dagger \phi^\dagger \phi + 4H^2 \phi^\dagger \phi + 2(\phi^\dagger)^\dagger H^2] - \\
& gM W_\mu^+ W_\nu^- H - \frac{1}{2}g \frac{M}{c_w^2} Z_\mu^\alpha Z_\nu^\beta H - \frac{1}{2}ig [W_\mu^+ (\partial^\nu \partial_\mu \phi^- - \phi^- \partial_\mu \phi^\nu) - \\
& W_\mu^- (\partial^\nu \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^\nu)] + \frac{1}{2}ig [W_\mu^+ (H \partial_\nu \phi^- - \phi^- \partial_\nu H) - W_\mu^- (H \partial_\nu \phi^+ - \\
& \phi^+ \partial_\nu H)] + \frac{1}{2}g \frac{M}{c_w^2} (Z_\mu^\alpha (H \partial_\nu \phi^\beta - \phi^\beta \partial_\nu H) - ig \frac{M}{c_w^2} Z_\mu^\alpha Z_\nu^\beta (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \\
& ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^\alpha (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) + \\
& ig s_w A_\mu (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) - \frac{1}{4}g^2 W_\mu^+ W_\nu^- [H^2 + (\phi^\dagger)^\dagger + 2\phi^\dagger \phi] - \\
& \frac{1}{4}g^2 \frac{1}{2}Z_\mu^\alpha Z_\nu^\beta [H^2 + (\phi^\dagger)^\dagger + 2(2s_w^2 - 1)^2 \phi^\dagger \phi] - \frac{1}{2}g^2 \frac{1}{2}Z_\mu^\alpha Z_\nu^\beta \phi^\dagger (W_\mu^+ \phi^- + \\
& W_\mu^- \phi^+) - \frac{1}{2}ig \frac{M}{c_w} Z_\mu^\alpha H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^\dagger (W_\mu^+ \phi^- + \\
& W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{2c_w}{c_w} (2c_w^2 - 1) Z_\mu^\alpha A_\nu \phi^\dagger \phi - \\
& g^2 s_w^2 A_\mu A_\nu \phi^\dagger \phi - e^2 (\gamma \partial + m_e^2) e^3 - e^2 \gamma \partial u^3 - \overline{u}^3 (\gamma \partial + m_u^2) u^3 - \\
& d^3 (\gamma \partial + m_d^2) d^3 + ig s_w A_\mu [-(e^3 \gamma^\mu e^3) + \frac{2}{3}(u^3 \gamma^\mu u^3) - \frac{1}{3}(d^3 \gamma^\mu d^3)] + \\
& \frac{ig}{2c_w} Z_\mu^\alpha [(\overline{u^3} \gamma^\mu (1 + \gamma^5) u^3) + (e^3 \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^3) + (\overline{u^3} \gamma^\mu (\frac{1}{3} s_w^2 - \\
& 1 - \gamma^5) u^3) + (\overline{d^3} \gamma^\mu (1 - \frac{2}{3} s_w^2 - \gamma^5) d^3)] + \frac{ig}{2\sqrt{3}} W_\mu^+ [(\overline{u^3} \gamma^\mu (1 + \gamma^5) e^3) + \\
& (\overline{u^3} \gamma^\mu (1 + \gamma^5) C_{3u} d^3)] + \frac{ig}{2\sqrt{3}} W_\mu^- [(\overline{e^3} \gamma^\mu (1 + \gamma^5) u^3) + (\overline{d^3} C_{3d} \gamma^\mu (1 + \\
& \gamma^5) u^3)] + \frac{ig}{2\sqrt{3}} \frac{M}{M} [-\phi^\dagger (\mu^3 (1 - \gamma^5) e^3) + \phi^- (e^3 (1 + \gamma^5) \mu^3)] - \\
& \frac{g}{2M} [H(e^3 e^3) + i\phi^\dagger (e^3 \gamma^5 e^3)] + \frac{ig}{23M^2} \phi^\dagger [-m_2^2 (u^3 C_{3u} (1 - \gamma^5) d^3) + \\
& m_4^2 (u^3 C_{3u} (1 + \gamma^5) d^3) + \frac{ig}{23M^2} \phi^\dagger [m_2^2 (\overline{d^3} C_{3d}^1 (1 + \gamma^5) u^3) - m_4^2 (\overline{d^3} C_{3d}^1 (1 - \\
& \gamma^5) u^3) - \frac{g}{2M} H (\overline{u^3} u^3) - \frac{g}{2M} H (\overline{d^3} d^3) + \frac{g}{2M} \phi^\dagger (\overline{u^3} \gamma^5 u^3) - \\
& \frac{ig}{2M} \phi^\dagger (\overline{d^3} \gamma^5 d^3) + \overline{X^+} (\partial^2 - M^2) X^+ + \overline{X^-} (\partial^2 - M^2) X^- + \overline{X^0} (\partial^2 - \\
& M^2) X^0 + \overline{Y} (\partial^2 Y + ig c_w W_\mu^+ (\partial_\mu \overline{X^0} X^- - \partial_\mu \overline{X^+} X^0) + ig s_w W_\mu^+ (\partial_\mu \overline{Y} X^- - \\
& \partial_\mu \overline{X^+} Y) + ig c_w W_\mu^- (\partial_\mu \overline{X^-} X^0 - \partial_\mu \overline{X^0} X^+) + ig s_w W_\mu^- (\partial_\mu \overline{X^-} Y - \\
& \partial_\mu \overline{Y} X^+) + ig c_w Z_\mu^\alpha (\partial_\mu \overline{X^+} X^+ - \partial_\mu \overline{X^-} X^-) + ig s_w A_\mu (\partial_\mu \overline{X^+} X^+ - \\
& \partial_\mu \overline{X^-} X^-) - \frac{1}{2}gM [\overline{X^+} X^+ H + \overline{X^-} X^- H + \frac{1}{c_w} \overline{X^0} X^0 H] + \\
& \frac{1-2c_w^2}{2c_w} igM [\overline{X^+} X^0 \phi^+ - \overline{X^-} X^0 \phi^-] + \frac{1}{2c_w} igM [\overline{X^0} X^0 \phi^+ - \overline{X^0} X^+ \phi^-] + \\
& igM s_w [\overline{X^0} X^0 \phi^+ - \overline{X^0} X^+ \phi^-] + \frac{1}{2}igM [\overline{X^+} X^+ \phi^0 - \overline{X^-} X^- \phi^0]
\end{aligned}$$

$$+ \sum_i \frac{C_i}{\Lambda^{d-4}} O_i^d$$



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$$\mathcal{L}_{\text{SMEFT}} =$$

$$\begin{aligned}
 & -\frac{1}{2}(\partial_\mu \phi^\dagger \partial_\mu \phi - \partial_\mu f^{\dagger a} \partial_\mu f^a) - \frac{1}{2}(\partial_\mu f^{\dagger a} \partial_\mu f^a) + \\
 & \frac{1}{2}(\partial_\mu \psi^\dagger \partial_\mu \psi) + G \psi^\dagger G + \psi^\dagger G G \psi - \partial_\mu W_\nu^\dagger \partial_\mu W_\nu - \\
 & M^2 W_\nu^\dagger W_\nu - \frac{1}{2} M^2 Z_\mu^\dagger Z_\mu - \frac{1}{2} \partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2} \partial_\mu H_0 \partial_\mu H - \\
 & \frac{1}{2} m^2 H^2 - \partial_\mu \phi^\dagger \partial_\mu \phi - M^2 \phi^\dagger \phi - \frac{1}{2} \partial_\mu \theta^\dagger \partial_\mu \theta - \frac{1}{2} M \theta^\dagger \theta - \delta_L \frac{(M^2)^2}{\Lambda^2} \\
 & \frac{1}{2} H + \frac{1}{2} (H^\dagger + \phi^\dagger \theta + 2\phi^\dagger \theta^\dagger) + \frac{M^2}{\Lambda^2} m_\phi - (g_{\phi W} \partial_\mu W_\nu^\dagger W_\nu - \\
 & W_\nu^\dagger W_\nu) - \mathcal{Z}(W_\nu^\dagger \partial_\mu W_\nu - W_\nu^\dagger \partial_\mu W_\nu) + \mathcal{Z}(W_\nu^\dagger \partial_\mu W_\nu - \\
 & W_\nu^\dagger \partial_\mu W_\nu) - (g_{\phi Z} \partial_\mu W_\nu^\dagger W_\nu - W_\nu^\dagger W_\nu) - A_\mu (W_\nu^\dagger \partial_\mu W_\nu - \\
 & W_\nu^\dagger \partial_\mu W_\nu) + A_\mu (W_\nu^\dagger \partial_\mu W_\nu - W_\nu^\dagger \partial_\mu W_\nu) - \frac{1}{2} g_{\phi W}^2 W_\nu^\dagger W_\nu W_\nu + \\
 & \frac{1}{2} g_{\phi W}^2 W_\nu^\dagger W_\nu W_\nu + \phi^2 (\mathcal{Z} W_\nu^\dagger \mathcal{Z} W_\nu - \mathcal{Z} W_\nu^\dagger \mathcal{Z} W_\nu) + \\
 & g_{\phi Z}^2 (A_\mu W_\nu^\dagger A_\mu W_\nu - A_\mu A_\mu W_\nu^\dagger W_\nu) + g_{\phi A}^2 (A_\mu \mathcal{Z}(W_\nu^\dagger W_\nu - \\
 & W_\nu^\dagger W_\nu) - 2A_\mu \mathcal{Z} W_\nu^\dagger W_\nu) - m^2 H^2 + H \phi^\dagger \phi + 2H \phi^\dagger \theta^\dagger - \\
 & \frac{1}{2} (g_{\phi H} H^\dagger + (\phi^\dagger)^\dagger + H (\phi^\dagger)^\dagger + 4(\phi^\dagger)^\dagger \phi^\dagger \phi + M^2 \phi^\dagger \phi + 2(\phi^\dagger)^\dagger H^\dagger) - \\
 & \frac{1}{2} M^2 W_\nu^\dagger W_\nu H - \frac{1}{2} g_{\phi Z}^2 \mathcal{Z} W_\nu^\dagger H - \frac{1}{2} g_{\phi W}^2 (g_{\phi W} \phi^\dagger \phi - \phi^\dagger \theta^\dagger \theta^\dagger - \\
 & W_\nu^\dagger (g_{\phi W} \phi^\dagger \phi - \phi^\dagger \theta^\dagger \theta^\dagger) + \frac{1}{2} g_{\phi W}^2 (H \partial_\mu \phi - \phi^\dagger \partial_\mu H) - W_\nu^\dagger (H \partial_\mu \phi - \\
 & \phi^\dagger \partial_\mu H) + \frac{1}{2} g_{\phi Z}^2 (Z(H \partial_\mu \phi - \phi^\dagger \partial_\mu H) - (H \partial_\mu \phi - \phi^\dagger \partial_\mu H) W_\nu^\dagger) + \\
 & g_{\phi W} M_\mu (W_\nu^\dagger \phi^\dagger \theta - W_\nu^\dagger \theta^\dagger) - \frac{1}{2} g_{\phi W}^2 \mathcal{Z}(g_{\phi W} \phi^\dagger \phi - \phi^\dagger \theta^\dagger \theta^\dagger) + \\
 & g_{\phi W} A_\mu (g_{\phi W} \phi^\dagger \phi - \phi^\dagger \theta^\dagger \theta^\dagger) - \frac{1}{2} g_{\phi W}^2 W_\nu^\dagger W_\nu (H^\dagger + (\phi^\dagger)^\dagger + 2\phi^\dagger \theta^\dagger) - \\
 & \frac{1}{2} g_{\phi Z}^2 \mathcal{Z}(H^\dagger + (\phi^\dagger)^\dagger + 2\phi^\dagger \theta^\dagger - 1) \phi^\dagger \phi^\dagger - \frac{1}{2} g_{\phi Z}^2 \mathcal{Z} \phi^\dagger W_\nu^\dagger \phi + \\
 & W_\nu^\dagger \phi^\dagger) - \frac{1}{2} g_{\phi Z}^2 \mathcal{Z} H (W_\nu^\dagger \phi^\dagger - W_\nu^\dagger \phi^\dagger) + \frac{1}{2} g_{\phi A}^2 A_\mu \theta^\dagger (W_\nu^\dagger \phi^\dagger + \\
 & W_\nu^\dagger \phi^\dagger) + \frac{1}{2} g_{\phi A}^2 A_\mu H (W_\nu^\dagger \phi^\dagger - W_\nu^\dagger \phi^\dagger) - g_{\phi A}^2 (2\phi^\dagger - 1) \mathcal{Z} A_\mu \phi^\dagger \phi - \\
 & g_{\phi A}^2 A_\mu \phi^\dagger \phi - e^2 (\eta \partial_\mu + m) \phi^\dagger - \partial_\mu^2 \phi^\dagger \phi + \frac{1}{2} (m \partial_\mu + m) (\eta \partial_\mu + \\
 & m) (\phi^\dagger \phi + m) \phi + (g_{\phi W} A_\mu - (g_{\phi W}^2)^\dagger) + [(g_{\phi W}^2)^\dagger] - \frac{1}{2} (g_{\phi W}^2)^\dagger] + \\
 & \frac{1}{2} g_{\phi W}^2 (\phi^\dagger (1 + \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 - \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 - \\
 & 1 - \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 - \gamma^\mu \gamma_5) \phi) + \frac{1}{2} g_{\phi W}^2 [(g_{\phi W}^2)^\dagger (1 + \gamma^\mu \gamma_5) \phi) + \\
 & (g_{\phi W}^2)^\dagger (1 + \gamma^\mu \gamma_5) \phi) + \frac{1}{2} g_{\phi W}^2 [(g_{\phi W}^2)^\dagger (1 + \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 + \\
 & \gamma^\mu \gamma_5) \phi) + \frac{1}{2} g_{\phi W}^2 [(g_{\phi W}^2)^\dagger (1 - \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 - \gamma^\mu \gamma_5) \phi) - \\
 & \frac{1}{2} g_{\phi W}^2 (H (\phi^\dagger)^\dagger + \theta^\dagger (\phi^\dagger)^\dagger) + \frac{1}{2} g_{\phi W}^2 [(g_{\phi W}^2)^\dagger (1 + \gamma^\mu \gamma_5) \phi) + (g_{\phi W}^2)^\dagger (1 + \\
 & \gamma^\mu \gamma_5) \phi) - \frac{1}{2} g_{\phi W}^2 (H (\theta^\dagger)^\dagger) - \frac{1}{2} g_{\phi W}^2 (H (\theta^\dagger)^\dagger) + \frac{1}{2} g_{\phi W}^2 (\theta^\dagger)^\dagger (\theta^\dagger)^\dagger) - \\
 & \frac{1}{2} g_{\phi W}^2 \theta^\dagger (\theta^\dagger)^\dagger) + X^\dagger (\theta^\dagger - M \theta) X^\dagger + X^\dagger (\theta^\dagger - M \theta) X^\dagger + X^\dagger (\theta^\dagger - \\
 & \frac{1}{2} M X^\dagger + Y \theta^\dagger Y + (g_{\phi W} W_\nu^\dagger \partial_\mu X^\dagger X^\dagger - \partial_\mu X^\dagger X^\dagger) + (g_{\phi W} W_\nu^\dagger \partial_\mu X^\dagger X^\dagger - \\
 & \partial_\mu X^\dagger X^\dagger) + (g_{\phi W} W_\nu^\dagger \partial_\mu X^\dagger X^\dagger - \partial_\mu X^\dagger X^\dagger) + (g_{\phi W} W_\nu^\dagger \partial_\mu X^\dagger X^\dagger - \\
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 & \partial_\mu X^\dagger X^\dagger) - \frac{1}{2} g_{\phi W} X^\dagger X^\dagger H + X^\dagger X^\dagger H + \frac{1}{2} X^\dagger X^\dagger H) + \\
 & \frac{1}{2} g_{\phi W} M [X^\dagger X^\dagger \phi^\dagger - X^\dagger X^\dagger \phi^\dagger] + \frac{1}{2} g_{\phi W} M [X^\dagger X^\dagger \phi^\dagger - X^\dagger X^\dagger \phi^\dagger] + \\
 & \frac{1}{2} M \kappa_\mu [X^\dagger X^\dagger \phi^\dagger - X^\dagger X^\dagger \phi^\dagger] + \frac{1}{2} g_{\phi W} [X^\dagger X^\dagger \phi^\dagger - X^\dagger X^\dagger \phi^\dagger]
 \end{aligned}$$

X^3		ψ^4 and $\psi^2 D^2$		$\psi^2 \psi^2$	
Q_G	$f^{ABC} G_a^B G_c^A G_a^C$	Q_ψ	$(\psi^\dagger \psi)^2$	$Q_{\psi\psi}$	$(\psi^\dagger \psi)(\psi^\dagger \psi)$
Q_G	$f^{ABC} G_a^B G_c^A G_a^C$	$Q_{\psi\psi}$	$(\psi^\dagger \psi)(\psi^\dagger \psi)$	$Q_{\psi\psi}$	$(\psi^\dagger \psi)(\psi^\dagger \psi)$
Q_W	$\epsilon^{IJK} W_a^I W_b^J W_c^K$	$Q_{\psi\psi}$	$(\psi^\dagger D_\mu \psi)(\psi^\dagger D_\mu \psi)$	$Q_{\psi\psi}$	$(\psi^\dagger \psi)(\psi^\dagger \psi)$
$Q_{\overline{W}}$	$\epsilon^{IJK} \overline{W}_a^I \overline{W}_b^J \overline{W}_c^K$				
$X^2 \psi^2$		$\psi^2 X \psi$		$\psi^2 \psi^2 D$	
$Q_{\psi\psi}$	$\psi^\dagger \psi G_a^A G^A a$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi W_\mu^\dagger W_\mu$	$Q_{\psi\psi}^{(1)}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi G_a^A G^A a$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi B_\mu$	$Q_{\psi\psi}^{(2)}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi W_\mu^\dagger W^{\mu a}$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi G_a^A$	$Q_{\psi\psi}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi \overline{W}_\mu^{\dagger a}$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi W_\mu^\dagger$	$Q_{\psi\psi}^{(3)}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi B_\mu B^\mu$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi B_\mu$	$Q_{\psi\psi}^{(4)}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi B_\mu B^\mu$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi G_a^A$	$Q_{\psi\psi}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi W_\mu^\dagger B^\mu$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi W_\mu^\dagger$	$Q_{\psi\psi}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$
$Q_{\psi\psi}$	$\psi^\dagger \psi \overline{W}_\mu^{\dagger a} B^\mu$	$Q_{\psi\psi}$	$(\psi^\dagger \psi) \psi^\dagger \psi B_\mu$	$Q_{\psi\psi}$	$(\psi^\dagger \overline{D}_\mu \psi)(\psi^\dagger \psi)$

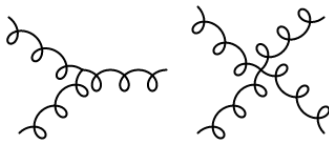
The O_G operator introduces new interactions

$$O_G = g_s f_{abc} G_\nu^{a,\mu} G_\rho^{b,\nu} G_\mu^{c,\rho}$$

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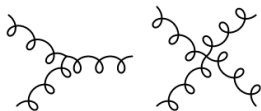
SM gluon interactions



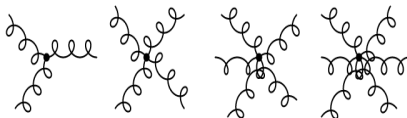
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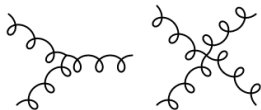
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SM gluon interactions



SMEFT gluon interactions



$$\sigma = \sigma^{SM} + \frac{C_G}{\Lambda^2} \sigma^{1/\Lambda^2} + \left(\frac{C_G}{\Lambda^2}\right)^2 \sigma^{1/\Lambda^4} + \dots$$

We concentrate on three-jet production

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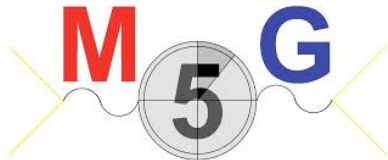
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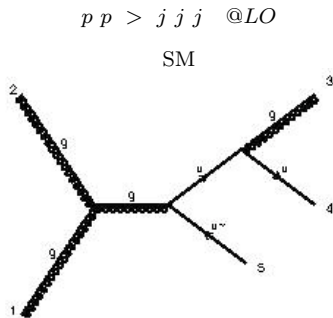
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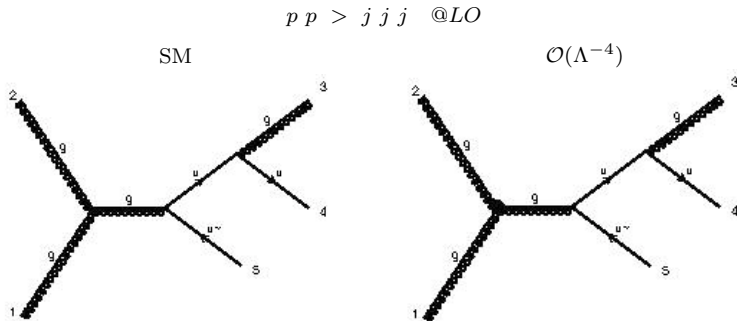
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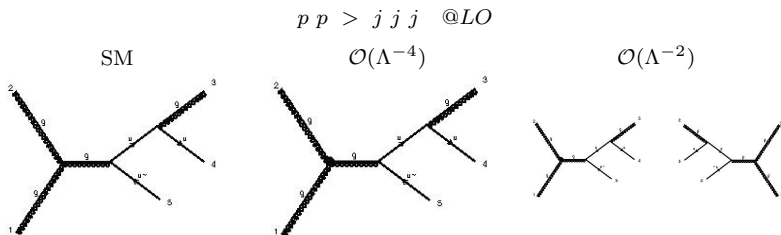
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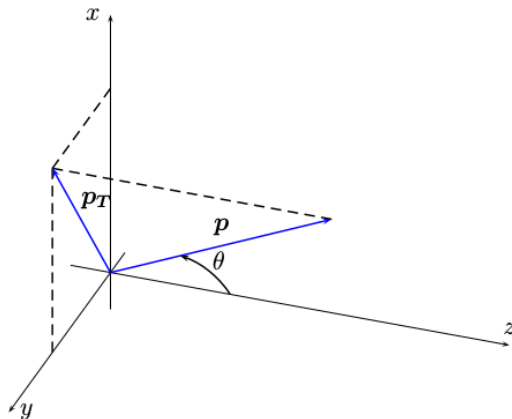
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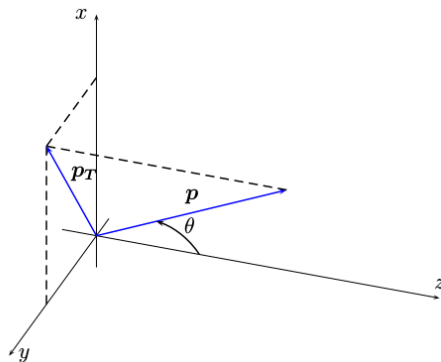
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Some quantities used in jet analysis

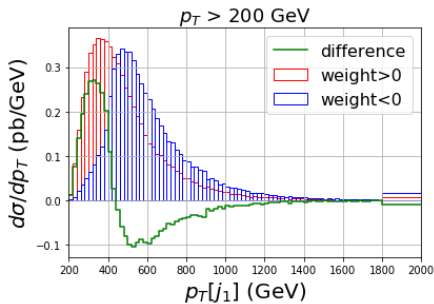


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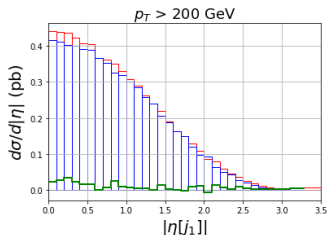
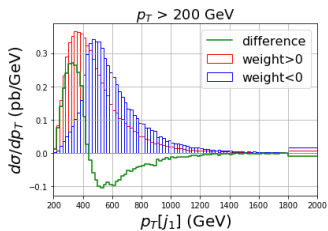


$$\eta = -\log\left(\tan\frac{\theta}{2}\right)$$

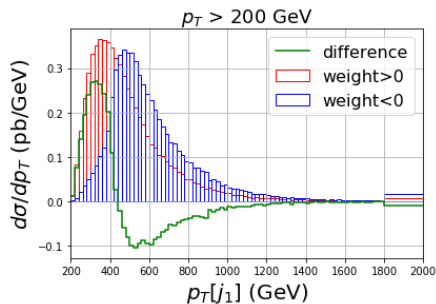
We focus on variables which separate the cross-section contributions with different sign



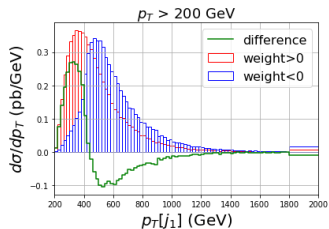
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The chi-square function sets bounds on the coefficient

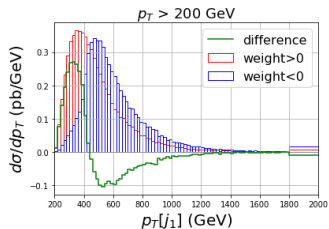


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$$\chi^2 = \sum_i \left(\frac{x_i^{exp} - x_i^{th}}{\Delta_i} \right)^2$$

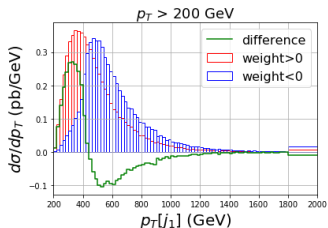
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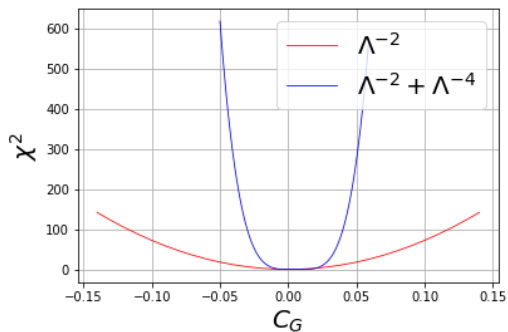
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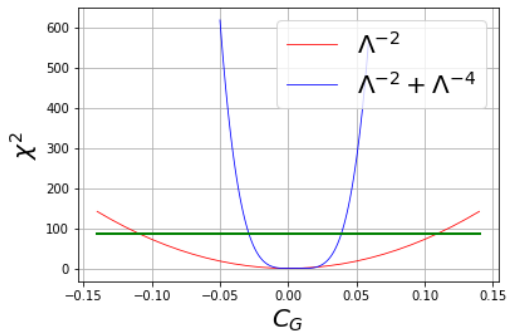
$$\begin{aligned}\chi^2 &= \sum_i \left(\frac{x_i^{exp} - x_i^{th}}{\Delta_i} \right)^2 \\ &= \sum_i \left(\frac{\frac{C_G}{\Lambda^2} \sigma_i^{1/\Lambda^2} + \left(\frac{C_G}{\Lambda^2} \right)^2 \sigma_i^{1/\Lambda^4}}{\Delta_i} \right)^2\end{aligned}$$

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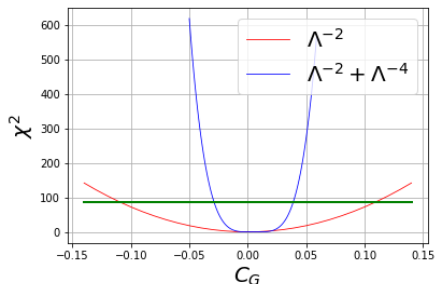
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$\Lambda = 1 \text{ TeV}$, 68% CL

- Interference contribution $\mathcal{O}(\Lambda^{-2})$

$$C_G \in [-0.136, 0.136]$$

- New Physics contribution $\mathcal{O}(\Lambda^{-4})$

$$C_G \in [-0.032, 0.041]$$

The procedure can be repeated using any distribution

$\Lambda = 1 \text{ TeV}, \quad 68\% \text{ CL}$

Distribution	Upper bound on C_G	Lower bound on C_G
$p_T[j_1]$	$1.36 \cdot 10^{-1} (4.06 \cdot 10^{-2})$	$-1.36 \cdot 10^{-1} (-3.19 \cdot 10^{-2})$
$\frac{ (\mathbf{p}_1 \times \mathbf{p}_2) \cdot \mathbf{p}_3 }{ \mathbf{p}_1 \times \mathbf{p}_2 \mathbf{p}_3 }$	$6.29 \cdot 10^{-1} (2.11 \cdot 10^{-1})$	$-6.29 \cdot 10^{-1} (-2.45 \cdot 10^{-1})$
$ \eta[j_3] $	$1.11 (2.62 \cdot 10^{-1})$	$-1.11 (-2.44 \cdot 10^{-1})$
$ \eta[j_1] $	$3.33 (2.55 \cdot 10^{-1})$	$-3.33 (2.60 \cdot 10^{-1})$

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C. Degrande, M. Maltoni, *"Reviving the interference: framework and proof-of-principle for the anomalous gluon self-interaction in the SMEFT"*, arXiv:2012.06595 [hep-ph]