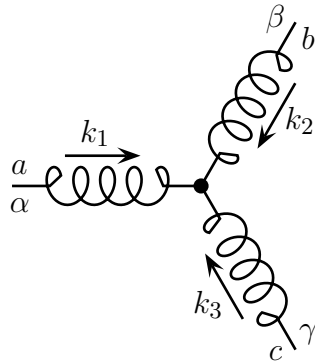




— Ghost propagator

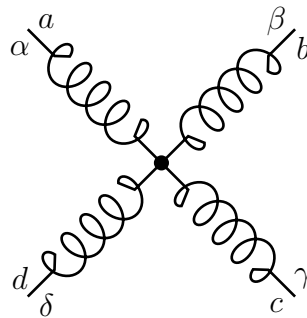
$$\begin{array}{c} a \\ \cdots \cdots \cdots \rightarrow \cdots \cdots \cdots \\ b \end{array} = \frac{i\delta^{ab}}{k^2 + i0}. \quad (5)$$

• Three-gluon vertex



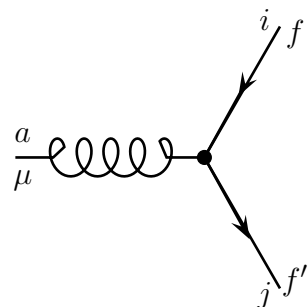
$$= -gf^{abc} \left[ g^{\alpha\beta}(k_1 - k_2)^\gamma + g^{\beta\gamma}(k_2 - k_3)^\alpha + g^{\gamma\alpha}(k_3 - k_1)^\beta \right]. \quad (6)$$

• Four-gluon vertex



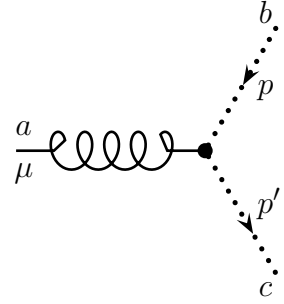
$$= -ig^2 \left[ \begin{array}{l} f^{abe} f^{cde} (g^{\alpha\gamma} g^{\beta\delta} - g^{\alpha\delta} g^{\beta\gamma}) \\ + f^{ace} f^{bde} (g^{\alpha\beta} g^{\gamma\delta} - g^{\alpha\delta} g^{\gamma\beta}) \\ + f^{ade} f^{bce} (g^{\alpha\beta} g^{\delta\gamma} - g^{\alpha\gamma} g^{\delta\beta}) \end{array} \right]. \quad (7)$$

• Quark-gluon vertex



$$= -ig\gamma^\mu \times \delta_f^{f'} \times (t^a)_i^j. \quad (8)$$

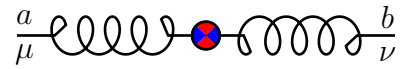
- Ghost-gluon vertex



$$= -g f^{abc} p'^{\mu}. \quad (9)$$

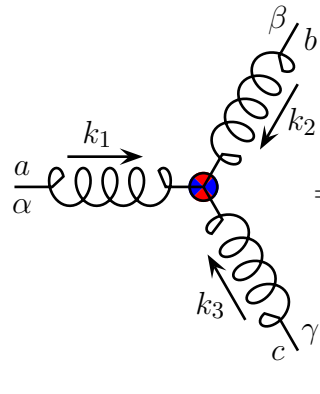
In addition, the renormalized theory has a whole bunch of the counterterm vertices:

- \* Two-gluon counterterm vertex



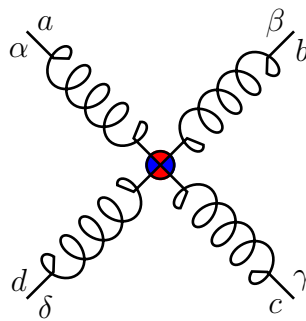
$$= -i\delta_3\delta^{ab} (k^2 g^{\mu\nu} - k^\mu k^\nu). \quad (10)$$

- \* Three-gluon counterterm vertex



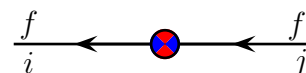
$$= -g\delta_1^{(3g)} \times f^{abc} \left[ g^{\alpha\beta} (k_1 - k_2)^\gamma + g^{\beta\gamma} (k_2 - k_3)^\alpha + g^{\gamma\alpha} (k_3 - k_1)^\beta \right]. \quad (11)$$

- Four-gluon counterterm vertex



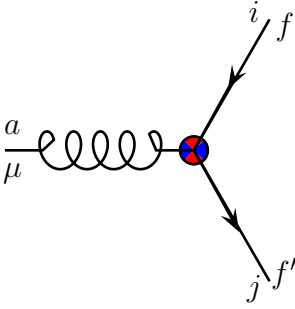
$$= -ig^2\delta_1^{(4g)} \times \begin{bmatrix} f^{abe} f^{cde} (g^{\alpha\gamma} g^{\beta\delta} - g^{\alpha\delta} g^{\beta\gamma}) \\ + f^{ace} f^{bde} (g^{\alpha\beta} g^{\gamma\delta} - g^{\alpha\delta} g^{\beta\gamma}) \\ + f^{ade} f^{bce} (g^{\alpha\beta} g^{\delta\gamma} - g^{\alpha\gamma} g^{\delta\beta}) \end{bmatrix}. \quad (12)$$

- \* Two-quark counterterm vertex



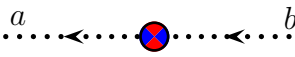
$$= \delta_f^{f'} \delta_i^j \times \left( i\delta_m^{(q_f)} - i\delta_2^{(q_f)} \times \not{p} \right). \quad (13)$$

\* Quark-gluon counterterm vertex



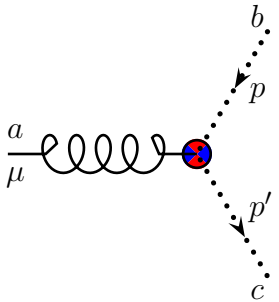
$$= -ig\delta_1^{(qf)}\delta_f^{f'} \times \gamma^\mu \times (t^a)^j_i. \quad (14)$$

\* Two ghost counterterm vertex



$$= \delta^{ab} \times i\delta_2^{(\text{gh})} \times k^2. \quad (15)$$

\* Ghost-gluon counterterm vertex



$$= -g\delta_1^{(\text{gh})} \times f^{abc}p'^\mu. \quad (16)$$

Finally, in QCD Ward-Takahashi identities are more complicated than in QED: Instead of  $\delta_1 = \delta_2$ , we have

$$\left(\frac{1 + \delta_1}{1 + \delta_2}\right)^{(qf)} = \left(\frac{1 + \delta_1}{1 + \delta_2}\right)^{(\text{gh})} = \frac{1 + \delta_1^{(3g)}}{1 + \delta_3} = \sqrt{\frac{1 + \delta_1^{(4g)}}{1 + \delta_3}} = \frac{\sqrt{1 + \delta_3} \times g_{\text{bare}}}{g_{\text{renormalized}}} \neq 1. \quad (17)$$