Section 1

Conventions and notations

In this appendix, we summarize the conventions and notations used throughout the thesis. Firstly, we use the natural units with

$$c = \hbar = k_B = 1, \tag{1.1}$$

where c, $\hbar$, and k_B are the speed of light, the reduced Planck constant, and the Boltzmann constant, respectively.

Our convention of the four-dimensional Lorenzian metric is $g^{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$. We sometimes use the Pauli matrices defined as

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \tag{1.2}$$

with i being the imaginary unit. The slash on any character denotes the so-called Feynmann slash, defined as $\not{p} \equiv p^\mu \gamma_\mu$ with four-by-four gamma matrices given by

$$\gamma^0 = \begin{pmatrix} \mathbf{0} & \mathbf{1} \\ \mathbf{1} & \mathbf{0} \end{pmatrix}, \quad \gamma^i = \begin{pmatrix} \mathbf{0} & \sigma_i \\ -\sigma_i & \mathbf{0} \end{pmatrix}, \tag{1.3}$$

The unique exception of this rule is $\not{E}_T$, which is used to denote the missing transverse momentum in hadron collider experiments.

We use the notation g_1, g_2, and g_3 for the gauge coupling constant of the SM $U(1)_Y$, $SU(2)_L$, and $SU(3)_c$ gauge group. We use the so-called grand unified theory normalization of g_1; the corresponding charge assignment is different from the conventional assignment of $U(1)_Y$ (with, *e.g.*, charge $-1/2$ for the left-handed leptons) by a factor of $\sqrt{3/5}$. We also define and use the fine-structure constants

$$\alpha_1 = \frac{g_1^2}{4\pi}, \quad \alpha_2 = \frac{g_2^2}{4\pi}, \quad \alpha_s = \frac{g_3^2}{4\pi}, \tag{1.4}$$

using the low energy values of gauge coupling constants.