Gamma Ray Spectrum from Mediators

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In this document, we will explore the gamma-ray spectra produced from the decay of scalar and vector mediators. We will consider the cases where the mediator can decay into either charged fermions or scalars. The spectra can be computed using the following:

$$\frac{dN}{dE_\gamma} = \frac{1}{\Gamma(M \to \bar{X}X)} \frac{d\Gamma(M \to \bar{X}X\gamma)}{dE_\gamma} \tag{0.1}$$

where $\Gamma(M \to \bar{X}X)$ is the partial decay width of the mediator M to the final state $\bar{X}X$ and $\Gamma(M \to \bar{X}X\gamma)$ is the corresponding radiative decay. We will take the following toy model Lagrangian:

$$\mathcal{L} = \mathcal{L}_{\text{kin}} + \mathcal{L}_{\text{int}} \tag{0.2}$$

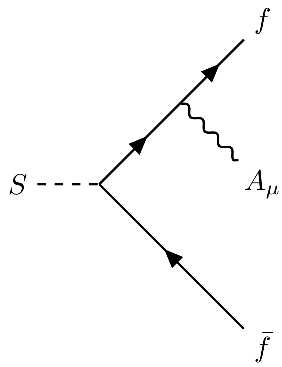
$$\begin{aligned}\mathcal{L}_{\text{kin}} &= -\frac{1}{2}S(\Box + m_S^2)S - \phi^\dagger(D_\mu D^\mu + m_\phi^2)\phi + \bar{f}(i\not{D} - m_f)f \\ &\quad - \frac{1}{4}V_{\mu\nu}V^{\mu\nu} - \frac{1}{2}m_V^2 V_\mu V^\mu - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}\end{aligned} \tag{0.3}$$

$$\begin{aligned}\mathcal{L}_{\text{int}} &= -S\Big[\mathcal{C}_{Sf}\bar{f}f + \mathcal{C}_{s\phi}^{(1)}\phi^\dagger\phi + \mathcal{C}_{s\phi}^{(2)}(D_\mu\phi)^\dagger(D_\mu\phi)\Big] \\ &\quad + V_\mu\Big(\mathcal{C}_{Vf}\bar{f}\gamma^\mu f + i\mathcal{C}_{V\phi}\Big[\phi^\dagger D^\mu\phi - (D^\mu\phi)^\dagger\phi\Big]\Big)\end{aligned} \tag{0.4}$$

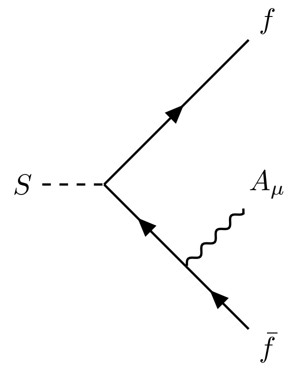
In the above, S and V are uncharged scalar and vector mediators, respectively, f is a charged fermion and ϕ is a charged scalar. $F_{\mu\nu}$ is the field strength tensor for the photon and D_μ is the covariant derivative, given by:

$$D_\mu = \partial_\mu - ieA_\mu \tag{0.5}$$

We note that the use of the covariant derivatives in the interaction terms is to ensure gauge-invariance.



(a)



(b)

Figure 1

1 Scalar Mediator

1.1 Fermions

Amplitude:

$$i\mathcal{M} = \tag{1.1}$$

1.2 Scalars

2 Vector Mediator

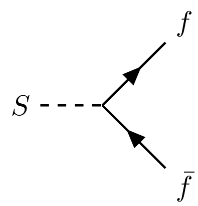
2.1 Fermions

2.2 Scalars

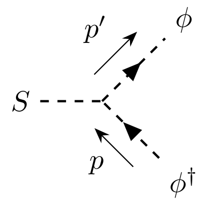
3 Appendix

3.1 Feynman Rules

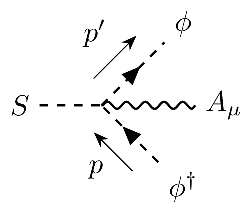
Scalar Couplings



$$= \quad -i\mathcal{C}_{Sf} \tag{3.1}$$

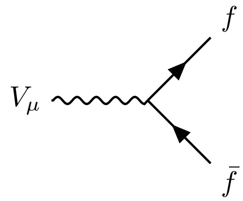


$$= \quad i\Big(\mathcal{C}^{(1)}_{S\phi} + \mathcal{C}^{(2)}_{S\phi} p \cdot p'\Big) \tag{3.2}$$

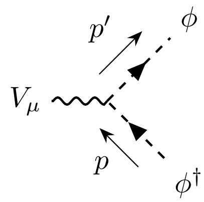


$$= \quad ie\mathcal{C}^{(2)}_{S\phi}\big(p_\mu + p'_\mu\big) \tag{3.3}$$

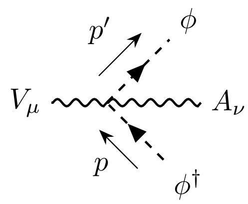
Vector Couplings



$$= \quad i\mathcal{C}_{Vf}\gamma^\mu \tag{3.4}$$

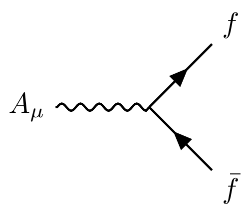


$$= \quad -i\mathcal{C}_{V\phi}\big(p_\mu + p'_\mu\big) \tag{3.5}$$

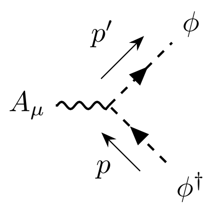


$$= \quad -2ie\eta_{\mu\nu}\mathcal{C}_{V\phi} \tag{3.6}$$

Photon Couplings



$$= \quad ie\gamma^\mu \tag{3.7}$$



$$= \quad -ie\big(p_\mu + p'_\mu\big) \tag{3.8}$$