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Unveiling hadronic de-excitation mechanism via Lepton Flavor Violation

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arXiv:2405.01782

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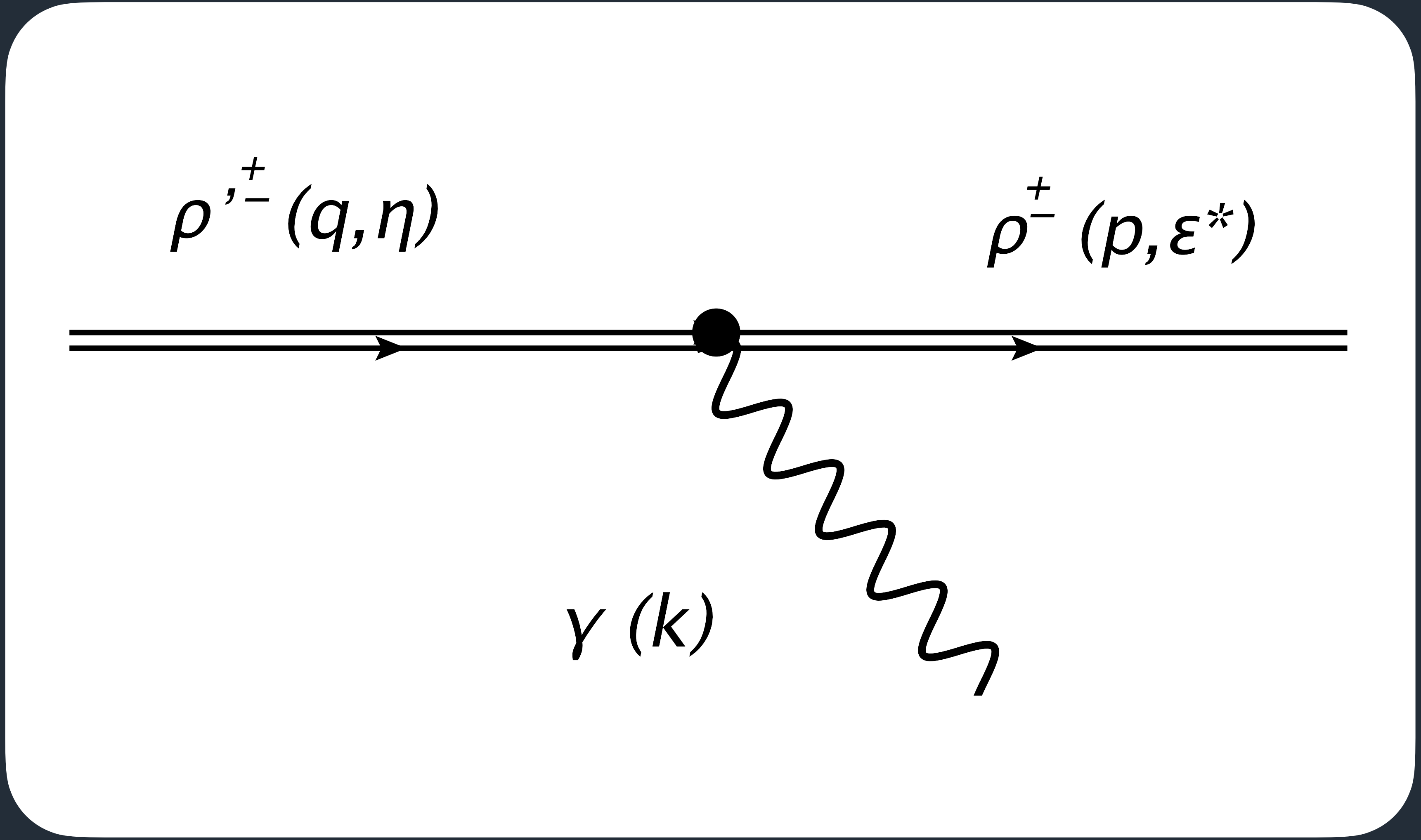
Motivation

- Typical de-excitation $V \to P\gamma$
- Lepton Flavor Violation (LFV) in Standard Model Extensions (SME).
- Previous hadronic transitions involving b → s transitions: $B_{(d\bar{b})} \to K_{(d\bar{s})}\, l_i^+\, l_i^-$.
- Hadronic de-excitations with no changing in flavor (not studied yet).

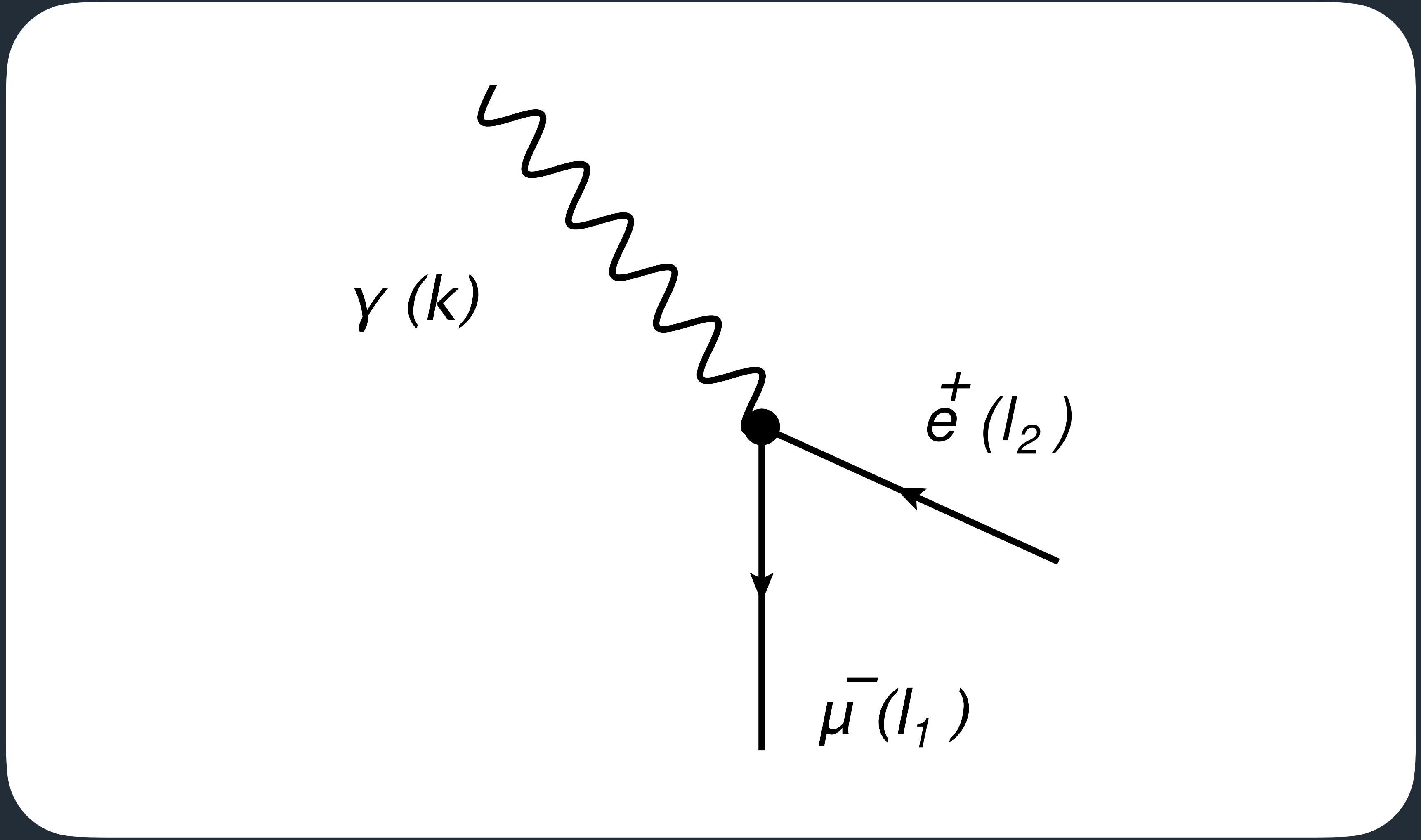
Hadronic de-excitation and LFV

Hadronic de-excitation



(same initial and final quarks)

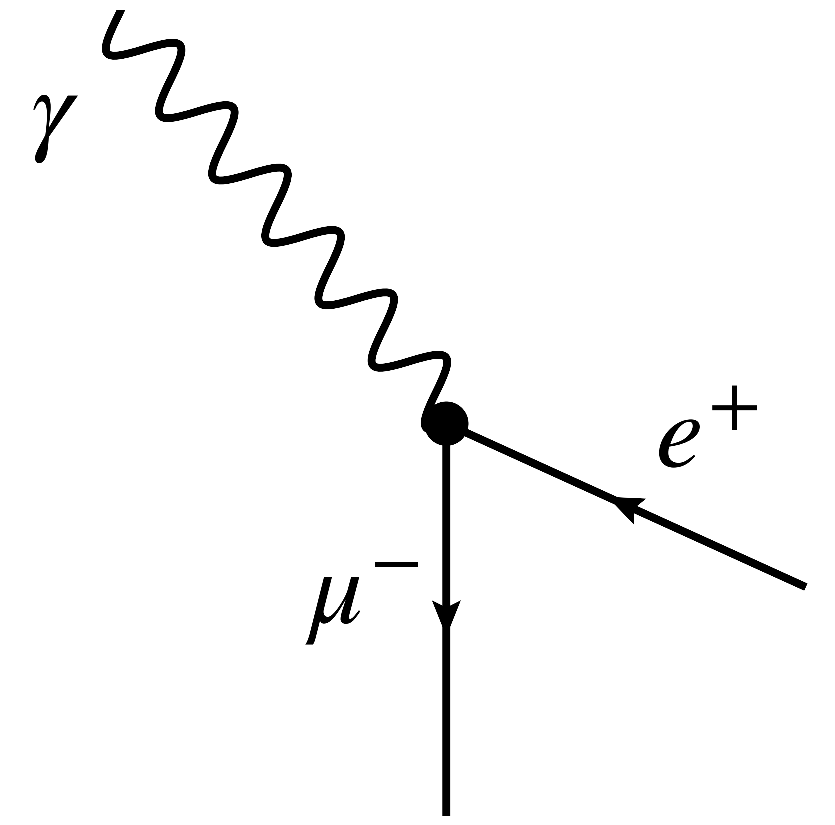
Lepton Flavor Violation (LFV)



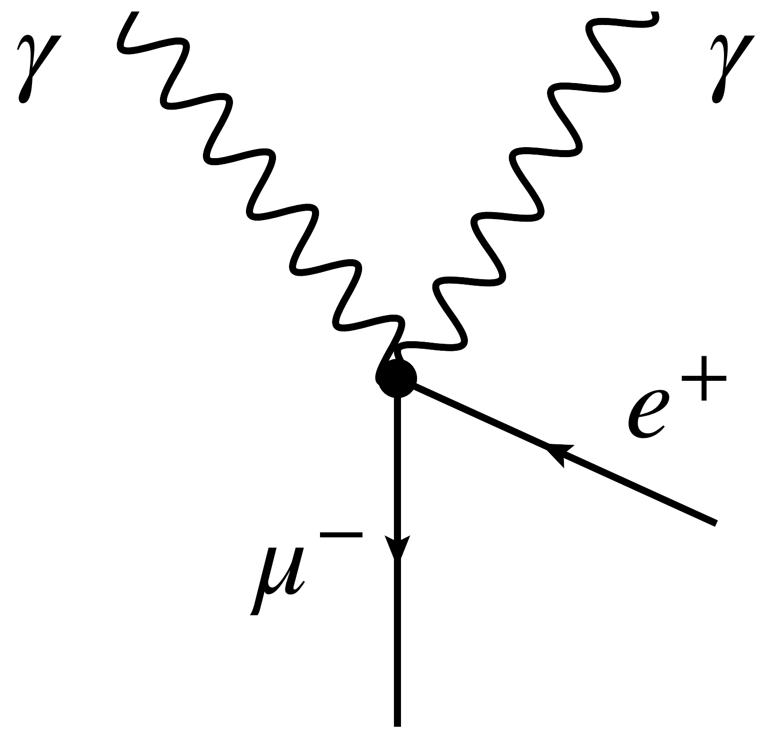
Not allowed in the SM

LFV: Effective Theory with dim-5 and dim-7 operators

$$\mathscr{L}_{dim-5} = D_R^{\mu e}\, \bar{\mu}_L \sigma_{\mu\nu} e_R F^{\mu\nu} + D_L^{\mu e}\, \bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + h.c.$$



$$\mathscr{L}_{dim-7} = (G_{SR}^{\mu e}\bar{\mu}_L e_R + G_{SL}^{\mu e}\bar{\mu}_R e_L) F_{\mu\nu} F^{\mu\nu} + (\tilde{G}_{SR}^{\mu e}\bar{\mu}_L e_R + \tilde{G}_{SL}^{\mu e}\bar{\mu}_R e_L)\tilde{F}_{\mu\nu} F^{\mu\nu} + h.c.$$

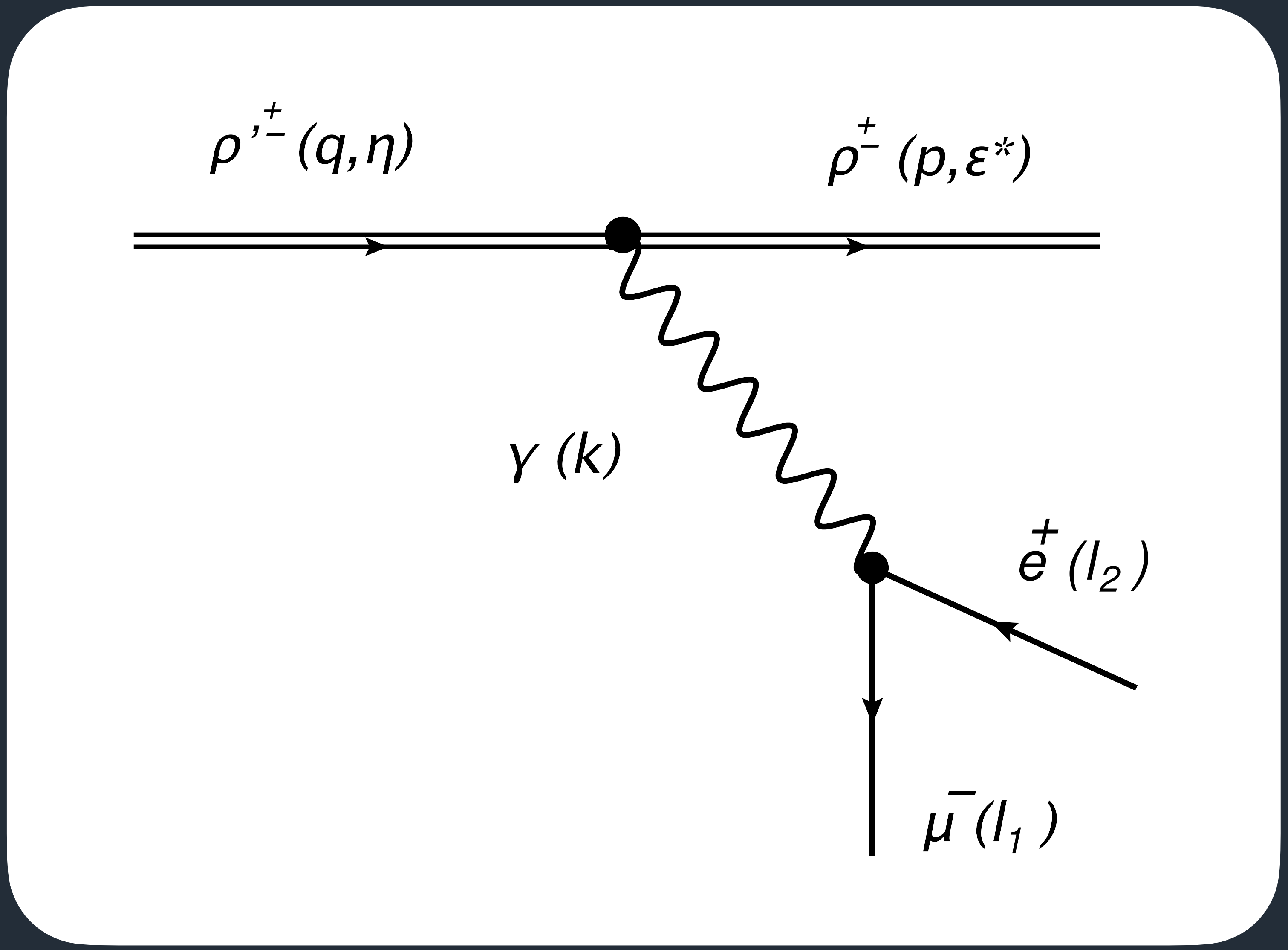


Wilson Coefficients

Coefficient	Constraint
$\lvert D^{\mu e} \rvert$	3.1×10^{-14} GeV^{-1}
$\lvert G_{\mu e} \rvert$	1.1×10^{-10} GeV^{-3}

F. Fortuna, A. Ibarra, X. Marcano, M. Marín, and P. Roig, Indirect upper limits on $l_i \to l_j \gamma\gamma$ from $l_i \to l_j \gamma$, Phys. Rev. D 107, 015027 (2023), arXiv:2210.05703

Decay $\rho' \to \rho\mu e$, dim-5 operator



$$\mathcal{M}_{\text{dim5}} = -\frac{e\, g_{\rho'\rho\gamma}}{k^2} \ell_{\mu\nu}(k^\mu g^{\nu\gamma} - k^\nu g^{\mu\lambda})\, \Gamma_{\alpha\beta\gamma}(q,k)\, \eta^\alpha \epsilon^{*\beta}$$

$$\ell_{\mu\nu} = \bar{u}_1 \sigma_{\mu\nu}(D_R^{\mu e} P_R + D_L^{\mu e} P_L) v_2$$

$$\Gamma^{\alpha\beta\gamma}(q,k) = \beta(g^{\alpha\beta}k^\gamma - g^{\gamma\alpha}k^\beta) + \frac{\gamma}{2m_{\rho'}^2}\left[(2q-k)^\gamma k^\alpha k^\beta - q\cdot k(g^{\beta\gamma}k^\alpha + g^{\gamma\alpha}k^\beta)\right]$$

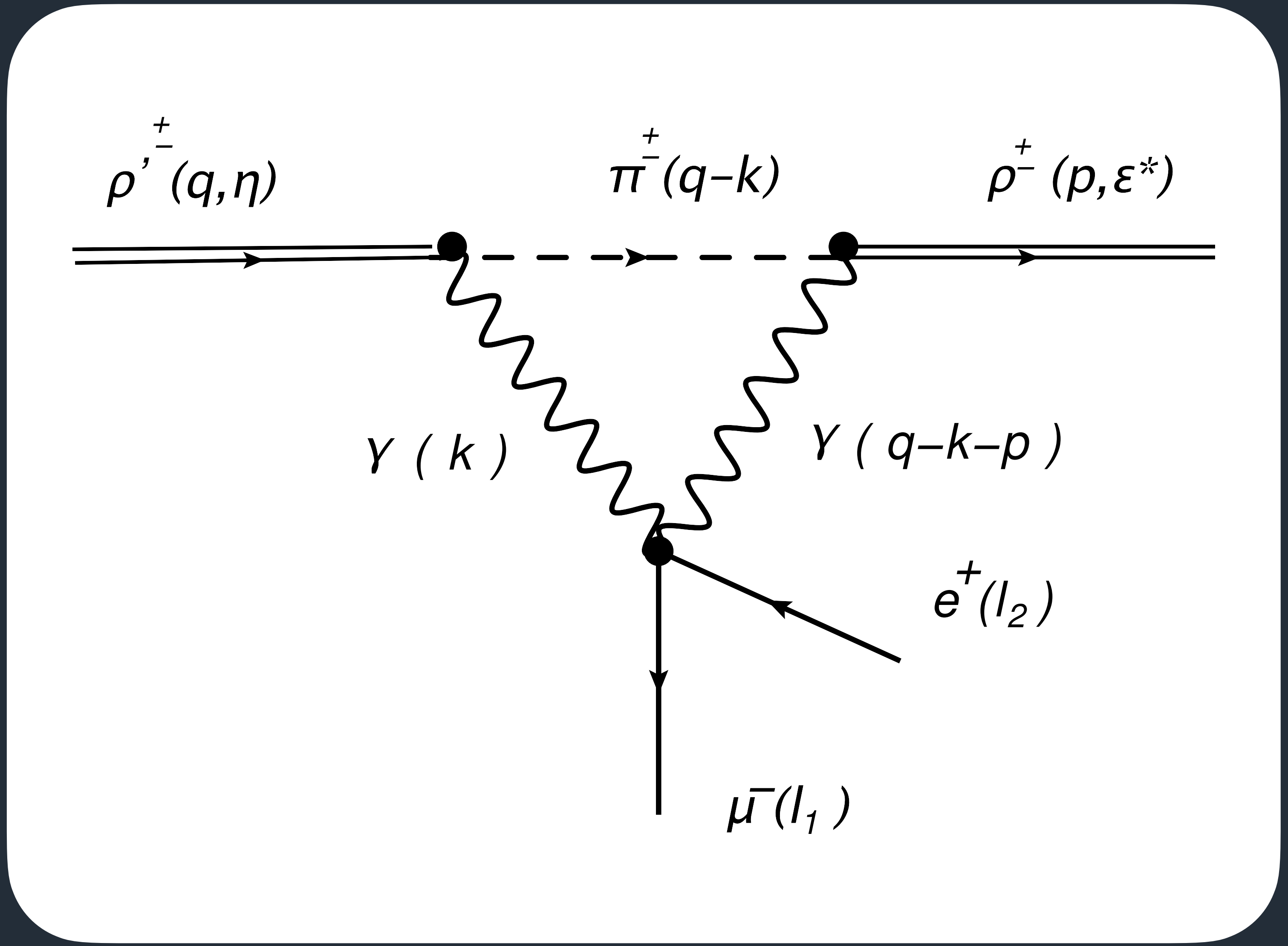
Magnetic dipole moment

$\beta = 2$

Electric quadrupole

$\gamma = 1$

Decay $\rho' \to \rho\mu e$, dim-7 operator



Effective Vector-Vector-Pseudoscalar model:

$$\mathscr{L} = g_{VP\gamma}\,\epsilon_{\alpha\beta\mu\nu}\,\partial^\alpha V^\beta \partial^\mu A^\nu P$$

$$\mathscr{M}_{dim7(F)} = 2\ell^F \Gamma^F_{\alpha\beta}\eta^\alpha \epsilon^{*\beta} \qquad \mathscr{M}_{dim7(\tilde F)} = 2\ell^{\tilde F} \Gamma^{\tilde F}_{\alpha\beta}\eta^\alpha \epsilon^{*\beta}$$

$$\ell^{\tilde F} = \bar u_1(\tilde G^{\mu e}_{SR} P_R + \tilde G^{\mu e}_{SL} P_L) v_2$$

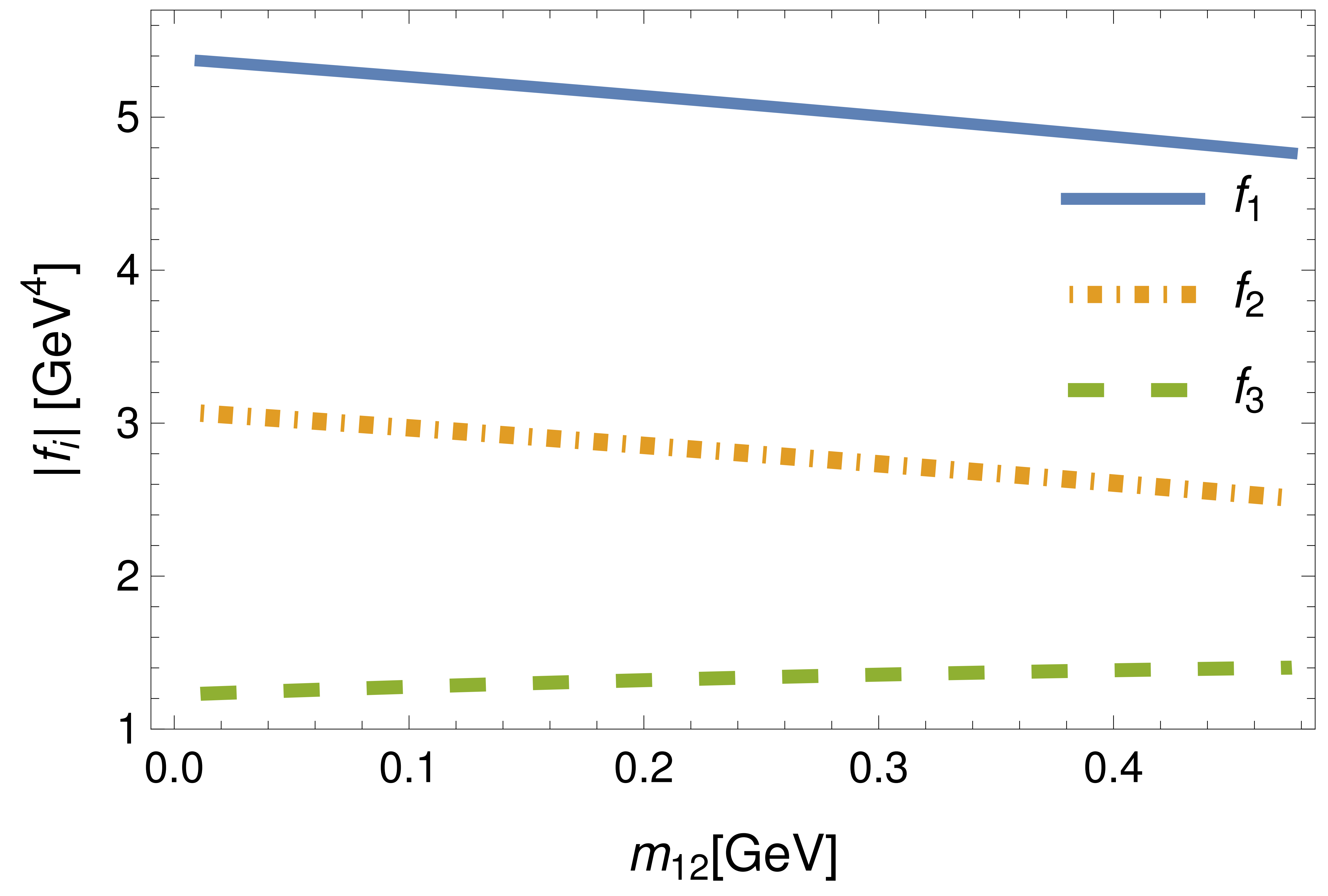
$$\Gamma^F_{\alpha\beta} = \frac{i g_{\rho'\pi\gamma}\, g_{\rho\pi\gamma}}{16\pi^2}\left\{ f_1(m^2_{12})\, p_\alpha\, q_\beta + f_2(m^2_{12})\, g_{\alpha\beta} \right\} \qquad \Gamma^{\tilde F}_{\alpha\beta} = \frac{i g_{\rho'\pi\gamma}\, g_{\rho\pi\gamma}}{16\pi^2} \epsilon_{\alpha\beta\mu\nu}\, p^\mu\, q^\nu f_3(m^2_{12})$$

$$\Gamma^{F}_{\alpha\beta} = \frac{i g_{\rho'\pi\gamma}\, g_{\rho\pi\gamma}}{16\pi^2} \left\{ f_1(m_{12}^2)\, p_\alpha\, q_\beta + f_2(m_{12}^2)\, g_{\alpha\beta} \right\}$$

$$\Gamma^{\tilde{F}}_{\alpha\beta} = \frac{i g_{\rho'\pi\gamma}\, g_{\rho\pi\gamma}}{16\pi^2} \epsilon_{\alpha\beta\mu\nu}\, p^\mu\, q^\nu\, f_3(m_{12}^2)$$

f1, f2: EM

f3: Dual EM

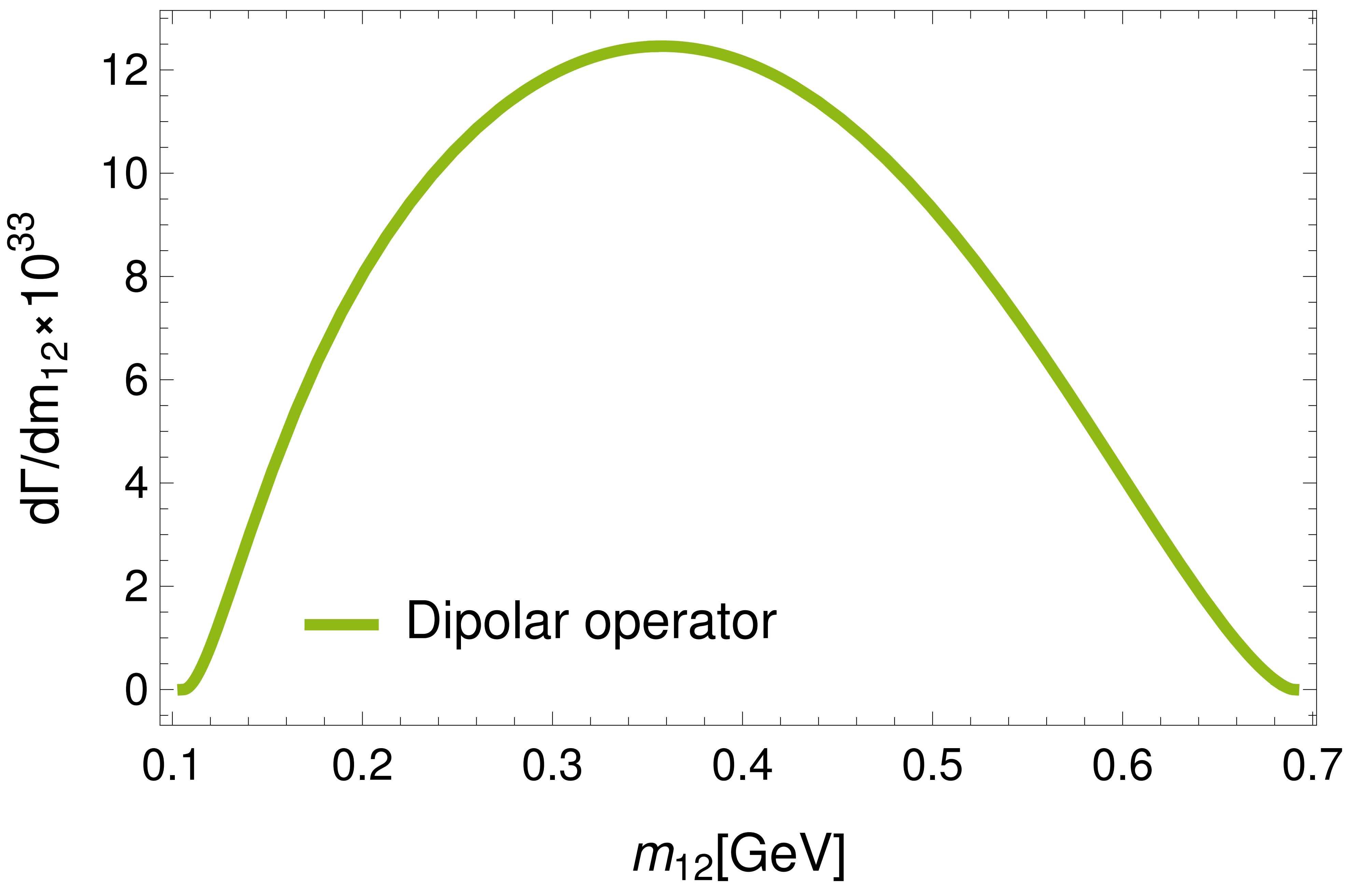


f_1 and f_3 are multiplied by $p \cdot q$ to be dimensionally consistent with f_2

Results

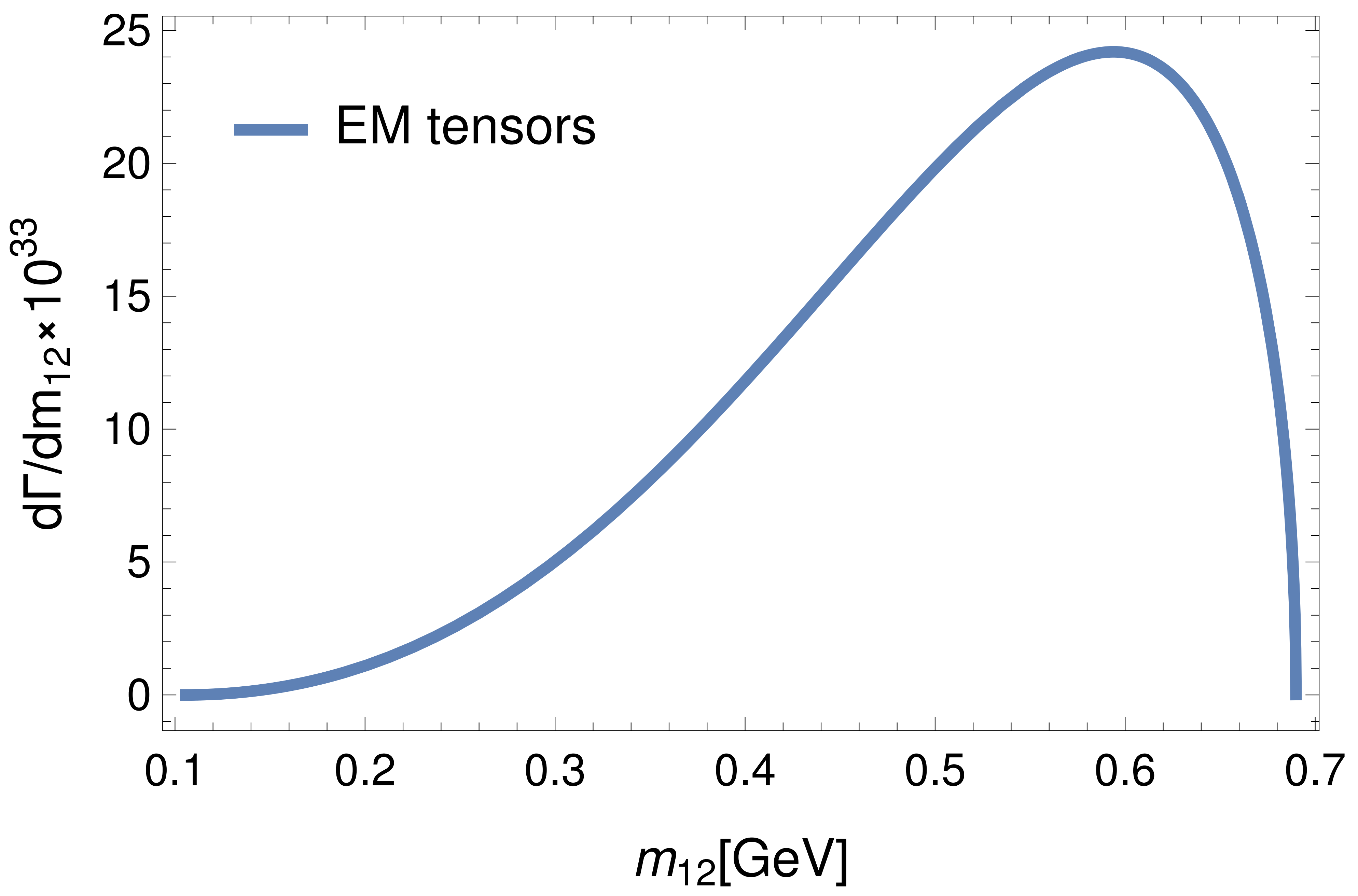
dim-5

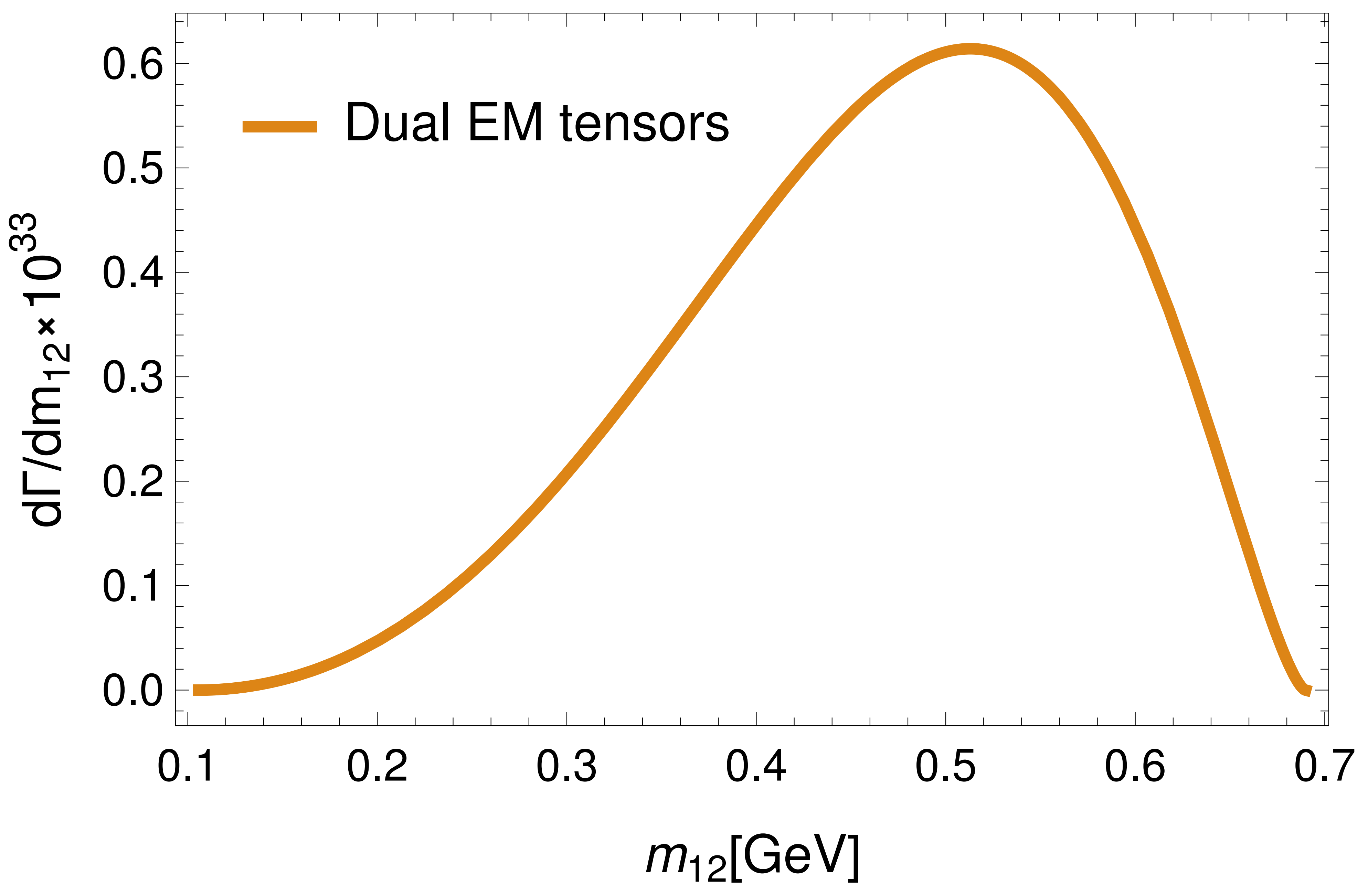
Differential decay rate $\frac{d\Gamma}{dm_{12}}$ with respect to the invariant dilepton mass $m_{12}^2 = (l_1 + l_2)^2$



dim-7

Differential decay rate $\frac{d\Gamma}{dm_{12}}$ with respect to the invariant dilepton mass $m_{12}^2 = (l_1 + l_2)^2$





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Branching Ratios

Operator	BR (ρ′ —> ρμe)
Dim-5 dipolar	$[1.7 - 77.8] \times 10^{-33}$
Dim-7 EM	1.7×10^{-32}
Dim-7 Dual EM	4.4×10^{-34}

- Highly suppressed! Orders of magnitude $10^{-32} - 10^{-34}$

Conclusions

- Possibility to distinguish the energy behavior between dim-5 and dim-7.
- For the dim-5 operator, dominant contribution comes from the dipolar magnetic interaction, with 2 orders of magnitude above the quadrupolar electric interaction.
- For the dim-7 operator, EM part is one order of magnitude greater than the dual EM part, opposite to previous results obtained with nuclei interactions (arXiv:2305.04974, Fabiola Fortuna, Xabier Marcano, Marcela Martín and Pablo Roig).

Further work:

- Consider ρ' and ρ as unstable particles (add finite decay width Γ).
- Explore other hadronic de-excitation in other scenarios such as *Quarkonium* ($q_i\,\bar{q}_i$).

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Thank you!