$K^+ \to \pi^+\pi^0\gamma$ in the Standard Model and Beyond

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Young Scientists Forum (2)
Rencontres de Moriond - 05.03.12 - La Thuile

Based on : MP and Christopher Smith JHEP08 (2011)069
[arXiv:1103.5992v1]

Why should we look at $K^+ \to \pi^+\pi^0\gamma$?

FCNC proceed through Loop (GIM breaking) effects

↓

Suppressed in the SM

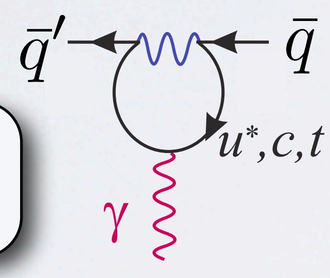
↓

Powerful tools to constrain New Physics

$b \to s\gamma$

$s \to d\gamma$

$\bar{B} \to X_s\gamma$



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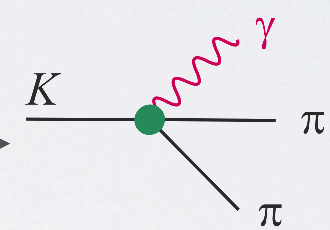


$K^+ \to \pi^+\pi^0\gamma$

$E_\gamma^{\rm exp} > 1.6$ GeV

$E_\gamma^{\rm th} < 0.2$ GeV

$\mathrm{Br}(\bar{B} \to X_s\gamma)_{\rm TH} = 3.15(23) \times 10^{-4}$ (♭)

$\mathrm{Br}(\bar{B} \to X_s\gamma)_{\rm EXP} = 3.55(26) \times 10^{-4}$ (♮)

Takes place deep within the non-perturbative regime of QCD

χPT ➡ SM prediction ?

➡ SD sensitivity ?

(♭) M. Misiak et al., PRL 98:022002, 2007.

(♮) E. Barberio et al., hep-ex/0603003v1.

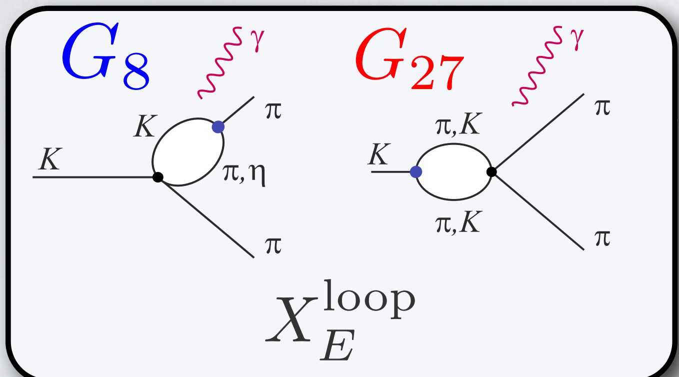
SM prediction ?

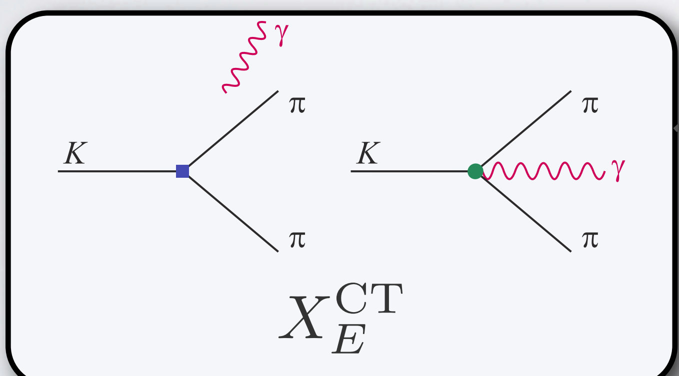
(♭) NA48/2 Collaboration, EPJ C68 (2010) 75.
(♮) G. D'Ambrosio and G. Isidori, Z. Phys. C65 (1995) 649.

Adopting the NA48/2[♭] differential branching parametrization :

$$\frac{\partial^2\Gamma^+}{\partial T_\pi^* \partial W^2} = \underbrace{\frac{\partial^2\Gamma^+_{IB}}{\partial T_\pi^* \partial W^2}}_{\text{IB}} \left[1 - \underbrace{2\cos(\delta_1^1 - \delta_0^2) m_\pi^2 m_K^2 X_E W^2}_{\text{INT}} + \underbrace{m_\pi^4 m_K^4 (X_E^2 + X_M^2) W^4}_{\text{DE}}\right]$$

the theoretical prediction reads :





$$X_E^{\mathrm{TH}} = (\overbrace{-10.2^{(♮)} - 7.4}^{X_E^{\mathrm{Loop}}} + X_E^{\mathrm{CT}}) \ \mathrm{GeV}^{-4}$$

Comparing with experiment[♭] :

$$X_E^{\mathrm{EXP}} = (-24 \pm 4 \pm 4) \ \mathrm{GeV}^{-4}$$

implies

$$X_E^{\mathrm{CT}} / X_E^{\mathrm{Loop}} = 0.37(32)$$

CT contributions are now under control

SD sensitivity ? $\longrightarrow$ DCPV charge asymmetry

NLO, CT,
$\Omega \in [-1, 0.8]$

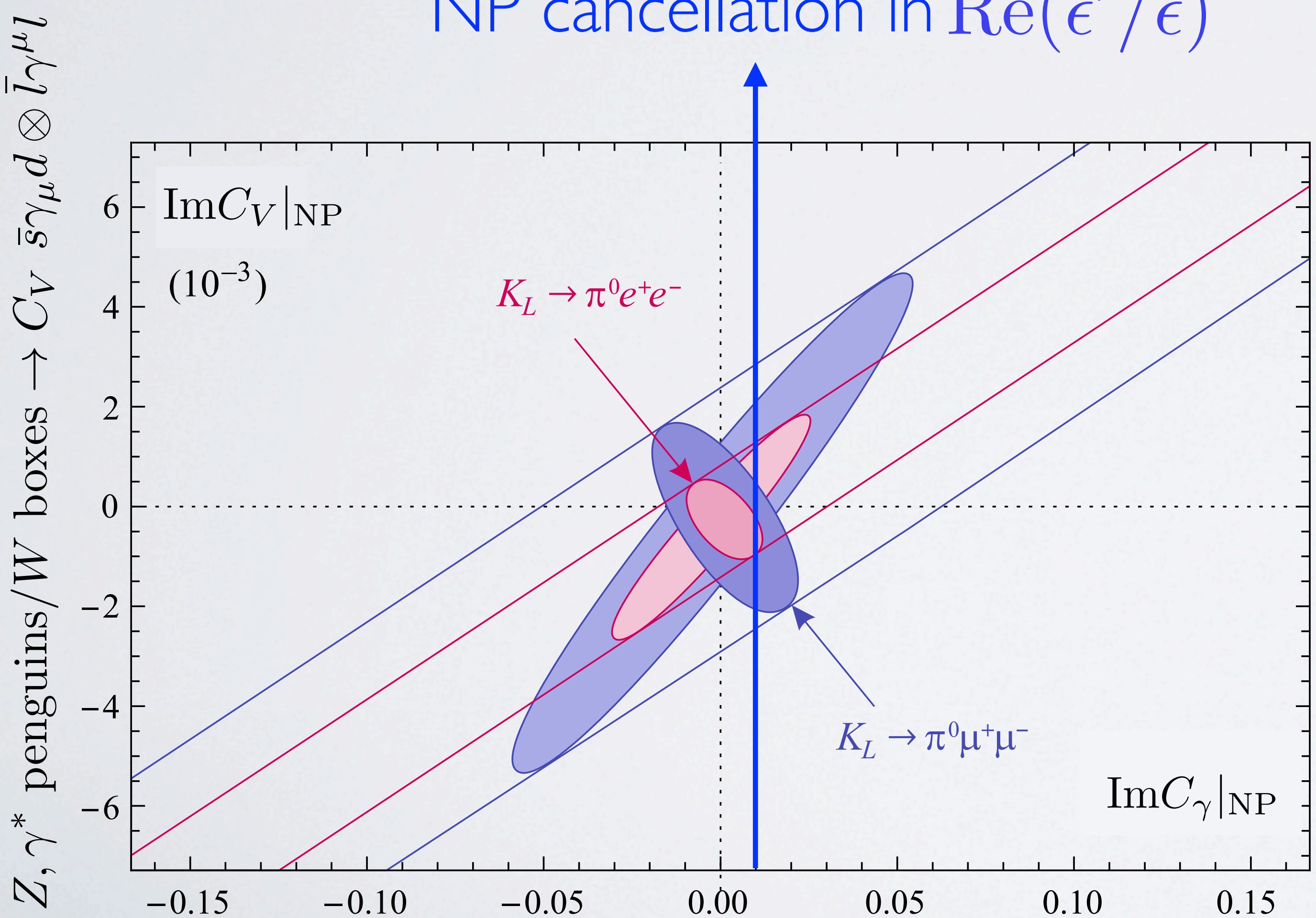
$$\epsilon'_{+0\gamma} = \frac{\mathrm{Im}A_{DE}}{\mathrm{Re}A_{DE}} - \frac{\mathrm{Im}A_{IB}}{\mathrm{Re}A_{IB}} \approx -\frac{2}{3}\frac{\sqrt{2}|\epsilon'|}{\omega}\left[1 + \frac{\Omega}{1-\Omega}\omega\right] + 3\mathrm{Im}C_\gamma$$

In the SM : $-0.6(3)\ 10^{-4}$ $+1.2(4)\ 10^{-4}$

Experiment still allows large NP effects : $\epsilon'^{\,\mathrm{exp}}_{+0\gamma} = -0.21 \pm 0.34$ NA48/2 (2010)

MSSM :

A 80 % EW-QCD NP cancellation in $\mathrm{Re}(\epsilon'/\epsilon)$ allows $\boxed{\mathrm{Im}C_\gamma|_{\mathrm{NP}} \approx 10^{-2}}$



- Close to $K_L \to \pi^0 e^+ e^-$ upper bound
- Corresponds to the maximum ϵ_K allowed value for $\mathrm{Im}\delta^{D,12}_{LR}$

See also :
- G. Colangelo et al., PLB 470 (1999) 134.
- A. J. Buras et al., NPB 566 (2000)3.

Conclusions :

As exemplified in $K^+ \to \pi^+\pi^0\gamma$:

- The $s \to d\gamma$ transition is under theoretical control.
  Crucial to complement $b \to s\gamma,\ \mu \to e\gamma, \ldots$

- The $s \to d\gamma$ transition can resolve the physics content of epsilon-prime,
  by unravelling SM or NP cancellations between EW and QCD penguins.

- So, radiative decays must be included in the physics program of futur experiments : NA62 (Cern) / K0TO (J-Parc) / ORKA (Fermilab).

Thank You.

Back Up

Details on X_E^{TH}:

$$X_E^{\mathrm{TH}} = X_E^{\mathrm{Loop}} + X_E^{\mathrm{CT}}$$

The loop contribution is expanded in multipoles : $X_E^{\mathrm{Loop}} = X_E^1 + X_E^{\mathrm{Higher}}$

All over the phase-space :

$$|X_E^{\mathrm{Higher}}/X_E^1| \leq 2.5\% \longleftrightarrow |\Delta X_E^{\mathrm{EXP}}/X_E^{\mathrm{EXP}}| \sim 23\%$$

Over the experimental phase-space X_E^1 is almost flat :

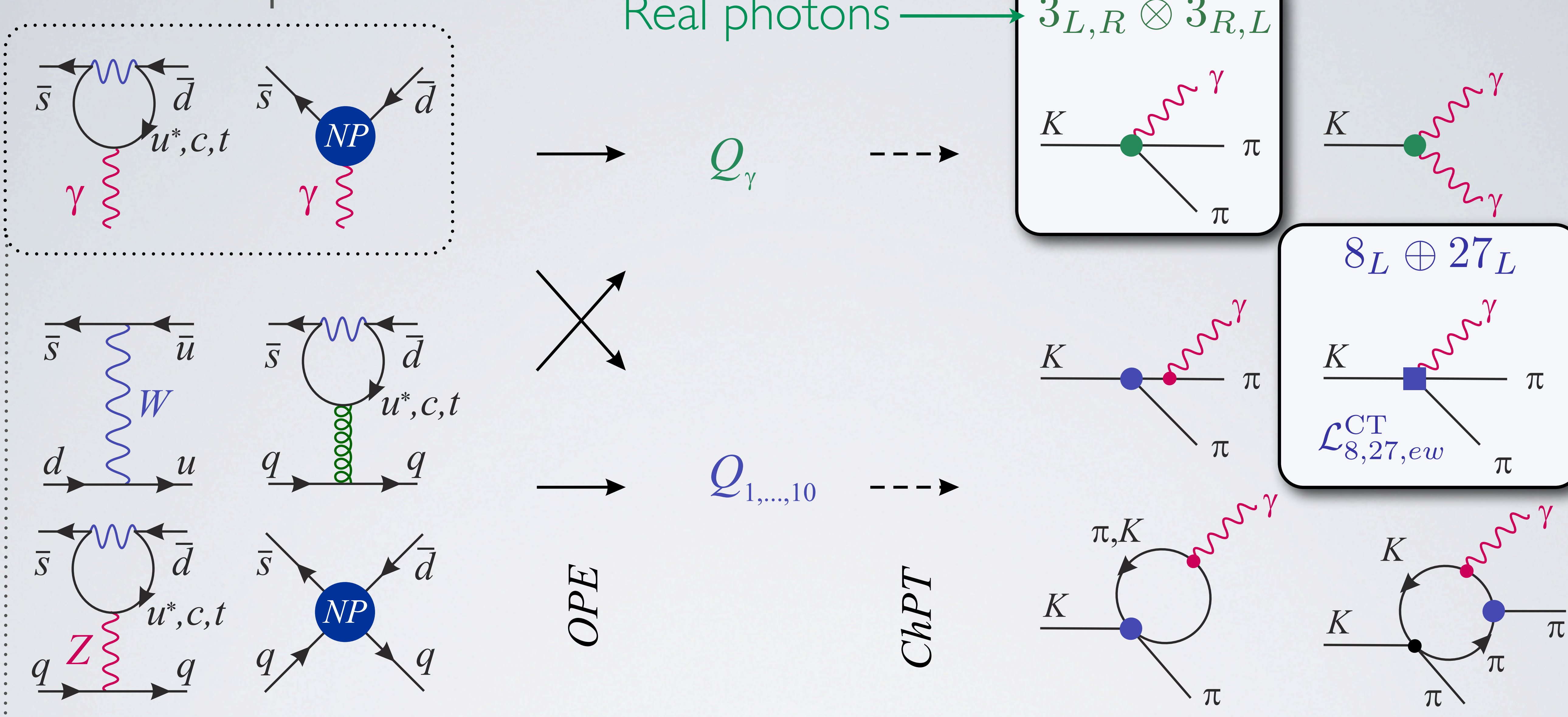
$$X_E^1 \approx \frac{3G_8/G_{27}}{40\pi^2 F_\pi^2 m_K^2}\left[-0.260 - 0.051W + 0.089\frac{T_\pi^*}{m_K}\right]$$

In order to compare with experiment we average over the experimental phase-space :

$$\boxed{X_E^{\mathrm{Loop}} \rightarrow \langle X_E^1 \rangle_{T_\pi^* \leq 80\ \mathrm{MeV}, 0.2 \leq W \leq 0.9} = -17.6\ \mathrm{GeV}^{-4}}$$

See slide 3

The full picture :



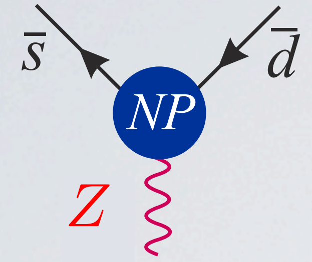
$\bullet$ $Q_{1,\ldots,10} \leftrightarrow \epsilon'/\epsilon\,|_{\exp}$

$$\mathcal{H}_{\text{eff}} = C_\gamma^{L,R}\, \bar{s}_{R,L} \sigma^{\mu\nu} d_{L,R}\ F_{\mu\nu}$$
$$+ C_{\gamma^*}^{L,R}\, \bar{s}_{L,R} \gamma^\nu d_{L,R}\ \partial^\mu F_{\mu\nu}$$

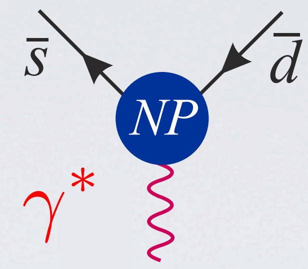
LD / SD factorized for real photons

$$Q_\gamma \notin \mathcal{L}^{\mathrm{CT}}_{8,27,ew}$$

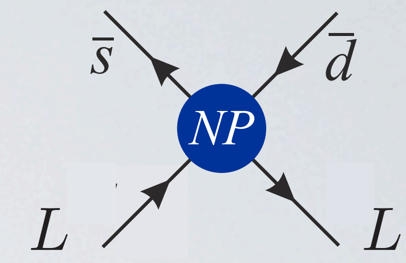
Semi-Leptonic NP operators basis :



Z penguin : Q_Z



γ^* penguin : Q_A



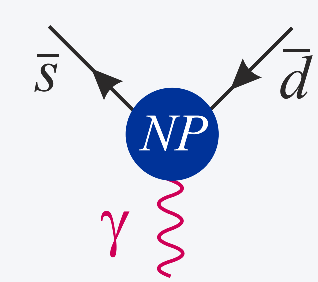
W boxes : Q_B

$$\mathcal{H}_{\mathrm{PB}} = -\frac{G_F \alpha}{\sqrt{2}}(C_Z\, Q_Z + C_A\, Q_A + C_B\, Q_B) + C_\gamma^{L,R} Q_\gamma^{L,R} + h.c.$$

$$\begin{pmatrix} C_{\nu,\ell} \\ C_{V,\ell} \\ C_{A,\ell} \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & 0 & -4 \\ 4s_W^2 - 1 & s_W^2 & 1 \\ 1 & 0 & -1 \end{pmatrix}\begin{pmatrix} C_Z \\ C_A \\ C_B \end{pmatrix} \qquad \begin{pmatrix} C_\gamma^- \\ C_\gamma^+ \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix}\begin{pmatrix} C_\gamma^R \\ C_\gamma^L \end{pmatrix}$$

$$\mathcal{H}_{\mathrm{Pheno}} = -\frac{G_F \alpha}{\sqrt{2}} \sum_{\ell = e,\mu,\tau} (C_{\nu,\ell}\, Q_{\nu,\ell} + C_{V,\ell}\, Q_{V,\ell} + C_{A,\ell}\, Q_{A,\ell}) + C_\gamma^\pm Q_\gamma^\pm + h.c.$$

$$\boxed{Q_{V,\ell} = \bar{s}\gamma^\mu d \otimes \bar{\ell}\gamma_\mu \ell} \longrightarrow K \to \pi l^+ l^- \longleftarrow$$



$$Q_\gamma^\pm = \frac{Q_d e}{16\pi^2}\left(\bar{s}_L \sigma^{\mu\nu} d_R \pm \bar{s}_R \sigma^{\mu\nu} d_L\right) F_{\mu\nu}$$

$$Q_{A,\ell} = \bar{s}\gamma^\mu d \otimes \bar{\ell}\gamma_\mu \gamma_5 \ell$$

$$Q_{\nu,\ell} = \bar{s}\gamma^\mu d \otimes \bar{\nu}_\ell \gamma_\mu (1 - \gamma_5)\nu_\ell$$