$\tau \to \pi\eta^{(\prime)}\gamma\nu_\tau$ as background for SCC

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Background

- Trying to obtain new conservation laws, T.D. Lee and C.N. Yang introduced the operator

$$G = Ce^{i\pi I_2}$$

- For states with $N_B = 0$, $G = \pm 1$ and is the same for all components of an I–multiplet[1].

- Thus, hadronic currents with $\Delta S = \Delta C = \Delta B = 0$ will have a definite G–parity.

[1] T.D. Lee and C.N. Yang, Nuovo Cim. 3 (1956) 749

Background

- These currents can be devided into two classes

G	S	P	V	A
1^{st}	$+1$	-1	$+1$	-1
2^{nd}	-1	$+1$	-1	$+1$

- 2^{nd} class currents (SCC) have opposite G–parity to weak currents in SM.

- In QCD, G–parity is broken by u–d mass and electric charge differences.

- *eg*, $G(\eta\pi) = -1$, and $\mathcal{P}(\eta\pi) = +1 \Rightarrow$ a scalar 2^{nd} class current must generate the $\tau \to \pi\eta\nu_\tau$ decay.

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Background

- Therefore, isospin breaking currents are important background for genuine SCC.
- Search for SCC in β–decays is difficult due to the small momentum transfer and the many form factors implicated.
- However, search for these currents have been suggested[2] in semileptonic decays such as $\tau \to \pi\eta\nu_\tau$ (cleanest).
- Current experimental limits $\mathcal{B}_\eta < 10^{-4}$ and $\mathcal{B}_{\eta'} < 10^{-5}$ are close to G–parity breaking prediction.
- Belle-II may discover G–parity breaking so that we can characterize further its structure and disentangle New Physics contributions (See Michel Hernandez's talk).

[2] C. Leroy and J. Pestieau, Phys. Lett. B72 (1978) 398

Background

- Within the SM, $\tau \to \pi\eta\nu_\tau$ is suppressed due to a factor

$$\left(\left[\frac{m_{\pi^0}}{m_\eta} \cdot \frac{m_d - m_u}{m_s} \right]^2 \sim 10^{-5} \right).$$

- An important background for this process is $\tau \to \pi\eta\nu_\tau\gamma$ with γ escaping detection.

- γ does not have a definite I value $\Rightarrow$ some contributions do not have the suppression factor.

- We study the radiative process, where we estimate this suppression to compete with the one from α_{EM}.

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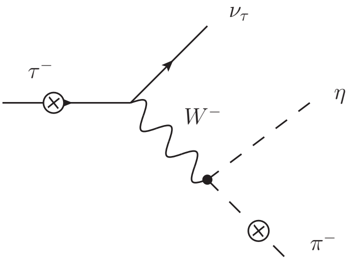
Main contributions to the amplitude

- We will try to find a photon energy E_γ cut to safely neglect this contribution in the search for SCC.



- Bremsstrahlung contributions will have both, the $\sim 10^{-5}$ factor and the α_{EM} suppression.

- Contributions involving the effective $W^*\pi\eta\gamma$ vertex will give the main contribution to the amplitude.

Main contribution to the decay amplitude

- The main contribution can be expressed as

$$\mathcal{M} = \frac{eG_F V_{ud}^*}{\sqrt{2}} \epsilon^{*\mu} (V_{\mu\nu} - A_{\mu\nu}) L_\tau^\nu$$

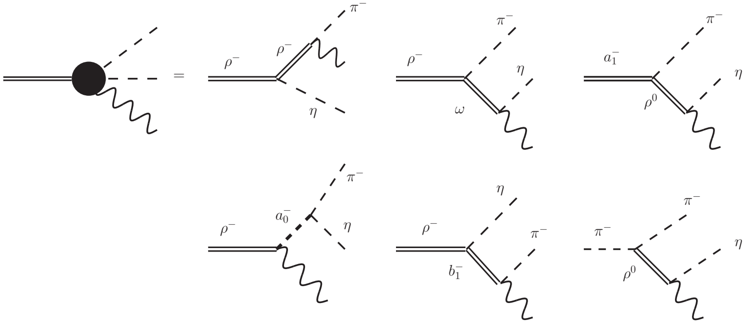
- where the hadronic tensors are parametrized as

$$V_{\mu\nu} = \boldsymbol{v_1}(p \cdot k g_{\mu\nu} - p_\mu k_\nu) + \boldsymbol{v_2}\left(g_{\mu\nu} p_0 \cdot k - p_{0\mu} k_\nu\right)$$
$$+\boldsymbol{v_3}(p_\mu p_0 \cdot k - p_{0\mu} p \cdot k) p_\nu + \boldsymbol{v_4}(p_\mu p_0 \cdot k - p_{0\mu} p \cdot k) p_{0\nu}$$

$$A_{\mu\nu} = i\varepsilon_{\mu\nu\rho\sigma}\left(\boldsymbol{a_1} p_0^\rho k^\sigma + \boldsymbol{a_2} k^\rho W^\sigma\right)$$
$$+i\varepsilon_{\mu\rho\sigma\tau} k^\rho p^\sigma p_0^\tau \left(\boldsymbol{a_3} W_\nu + \boldsymbol{a_4}(p_0 + k)_\nu\right)$$

Meson Dominance Model (MDM)

- We rely on MDM to estimate the order of magnitude of the branching fraction with the following contributions.



- Using MDM we estimated $\mathcal{B}(\tau \to \pi\eta\gamma\nu_\tau) \sim \mathcal{B}(\tau \to \pi\eta\nu_\tau)$

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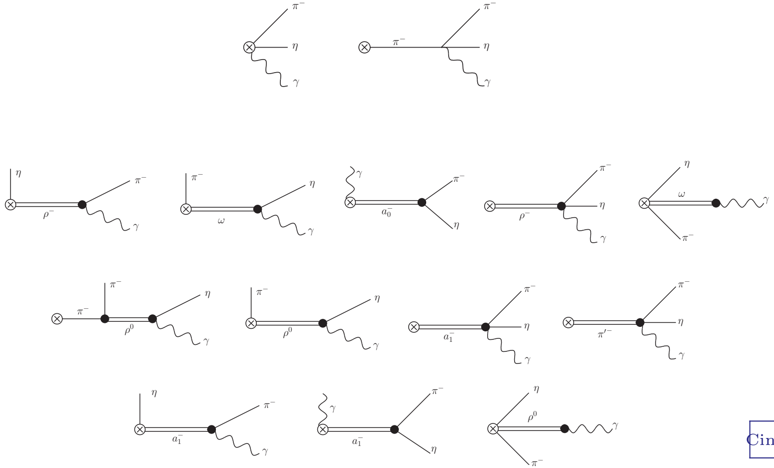
Resonance Chiral Theory (RχT)

- We then computed the branching ratio using RχT and obtained contributions from diagrams with 0 and 1 meson resonance exchange.



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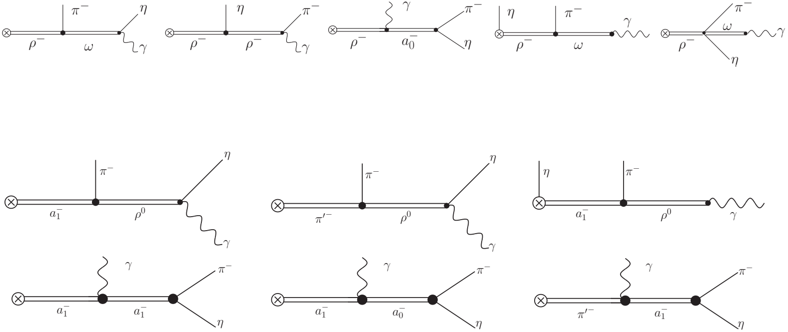
2R Contributions

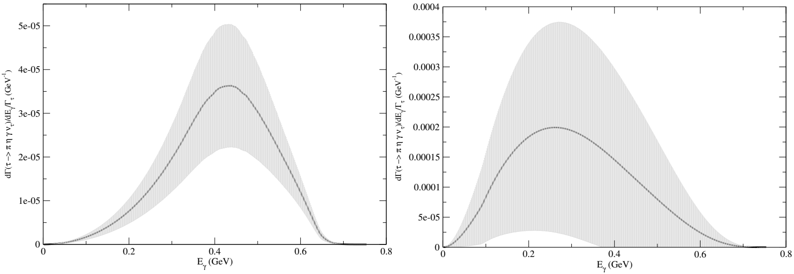
- and with two resonance exchange



- There is no *a priori* argument to neglect 2R exchange contributions, however we get that they are suppressed with respect to the 1R exchange contributions.

E_γ spectrum for $\tau \to \pi\eta\gamma\nu_\tau$

- E_γ spectrum[3] for MDM (left) and RχT (right).



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[3] AG, G. López Castro y P. Roig, Phys. Rev. D95 (2017) 054015

Results

- We compare our results to the non-radiative process[4]

Bkg	BR (no cuts)	BR ($E_\gamma^{\text{cut}} > 100$ MeV)	BR SCC signal
η	$(3.0 \pm 0.6) \cdot 10^{-5}$	$(1.2 \pm 0.6) \cdot 10^{-6}$	$\sim 1.7 \cdot 10^{-5}$
η'	$(2.2 \pm 0.4) \cdot 10^{-6}$	$(2 \pm 1) \cdot 10^{-7}$	$[10^{-7}, 10^{-6}]$

- The radiative process can be suppressed by cutting photons with energies $E_\gamma > 100$ MeV for η.

- Due to the large uncertainty in $BR(\tau \to \pi\eta'\nu_\tau)$ we cannot say the same for the η' channel

[4] R. Escribano, S. González-Solís and P. Roig, Phys. Rev. D**94** (2016)

Conclusions

- We were able to suppress the background due to the radiative process by imposing a cut on E_γ for the η channel.
- A better analysis of the non-radiative process must be done to give a conclusion for the η'.
- We found that neglecting the two resonance exchange contribution is a very good approximation.
- This will greatly simplify the Monte Carlo code for generating the form factors and reduce the computation time.

Back up

Constantes de acoplo MDM

- Los acoplamientos de MDM se obtienen haciendo los siguientes ajustes.
- Usamos el ancho

$$\Gamma(\tau^- \to \nu_\tau X^-) = \frac{G_F^2 |V_{ud}|^2}{8\pi M_\tau^3} \frac{M_X^2}{g_X^2} \left(M_\tau^2 - M_X^2\right)^2 \left(M_\tau^2 + 2M_X^2\right)$$

- para encontrar g_{a_1}, tomando (PDG) $BR(\tau^- \to a_1^- \nu_\tau) = 0.1861 \pm 0.0013$
- Para g_ρ se toma el ancho

$$\Gamma(\rho^0 \to e^+ e^-) = \frac{4\pi}{3} \left(\frac{\alpha}{g_\rho}\right)^2 \left(1 + \frac{2m_\ell^2}{M_V^2}\right) \sqrt{M_V^2 - 4m_\ell^2}\,.$$

Constantes de acoplo MDM

- El acoplamiento Vector-fotón-pseudoescalar, $g_{V\gamma P}$, se obtiene con los anchos medidos (PDG) $\Gamma(\rho/\omega \to \pi/\eta\,\gamma)$ y de la expresión para ancho

$$\Gamma(V \to P\gamma) \;=\; \frac{|g_{VP\gamma}|^2}{96\pi M_V^3}(M_V^2 - M_P^2)^3$$

- El acoplamiento $g_{\rho a_1 \pi}$ se obtiene del ancho (λ es la función de Källén)

$$\Gamma(a_1 \to \rho\pi) \;=\; \frac{|g_{\rho a_1 \pi}|^2}{96\pi M_{a_1}^3}\left[\lambda(M_{a_1}^2, M_\rho^2, m_\pi^2) + 6 M_\rho^2 M_{a_1}^2\right] \times \lambda^{1/2}(M_{a_1}^2, M_\rho^2, m_\pi^2)\,.$$

- con[5] $BR(a_1 \to \rho\pi) = 61.5\,\%$ y $\Gamma_{a_1} = (475 \pm 175)$ MeV

[5] D. M. Asner *et al.* [CLEO Collaboration], Phys. Rev. D**61** (2000) 012002.

Constantes de acoplo MDM

- Para los acoplos de a_0 se usa

$$\Gamma(a_0 \to \gamma\gamma) = \frac{|g_{a_0\gamma\gamma}|^2}{32\pi} M_{a_0}^3 \,,$$

$$\Gamma(a_0 \to \pi\eta) = \frac{|g_{a_0\pi\eta}|^2}{16\pi M_{a_0}^3} \lambda^{1/2}(M_{a_0}^2, m_\eta^2, m_\pi^2) \,,$$

- Donde se reporta (PDG)

$$\Gamma(a_0 \to \gamma\gamma) \times \frac{\Gamma(a_0 \to \pi\eta)}{\Gamma_{a_0}} = \left(0.21^{+0.08}_{-0.04}\right) \text{keV} \,.$$

- y usando[6] $\Gamma_{a_0} = \left(75.6 \pm 1.6^{+17.4}_{-10.0}\right)$ MeV

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[6] S. Uehara *et al.* [Belle Collaboration], Phys. Rev. D**80** (2009) 032001

Constantes de acoplo MDM

- Las demás constantes se obtienen de simetrías del modelo[7]

[7] Alaín Flores Tlalpa, PhD Thesis, *Modelo de dominancia de mesones para decaimientos semileptónicos de sabores pesados.* (2008) Cinvestav, México, DF

MDM

- Las reglas para los diferentes vértices vienen dadas por

$$V'^{\mu}(r) \to V^{\alpha}(s)P(t) : ig_{V'VP}\epsilon^{\mu\alpha\rho\sigma}s_{\rho}t_{\sigma} \,,$$

$$V^{\mu}(r) \to \gamma^{\alpha}(s)P(t) : ig_{VP\gamma}\epsilon^{\mu\alpha\rho\sigma}s_{\rho}t_{\sigma} \,,$$

$$A^{\mu}(r) \to V^{\alpha}(s)P(t) : ig_{VAP}(r\cdot s g^{\mu\alpha} - r^{\alpha}s^{\mu}) \,,$$

$$V^{\mu}(r) \to \gamma^{\alpha}(s)S(t) : ig_{VS\gamma}(r\cdot s g^{\mu\alpha} - r^{\alpha}s^{\mu}) \,,$$

$$S(r) \to P(s)P'(t) : ig_{SPP'} \,.$$

- Los acoplamientos se determinan de procesos independientes.

$BR(\tau \to \pi\eta\gamma\nu_\tau)$

- BR calculado con RχT

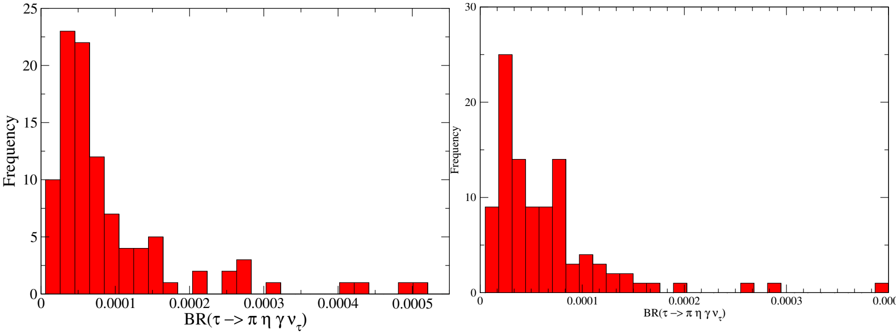
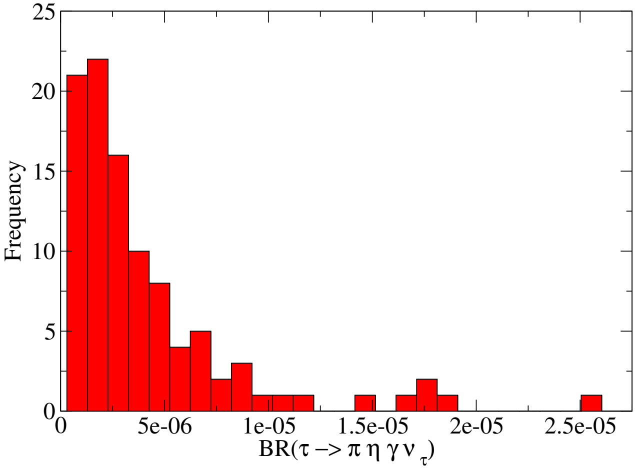


Figura: Fracción de decaimiento con todas las contribuciones (izq.) y sin intercambio de dos resonancias.

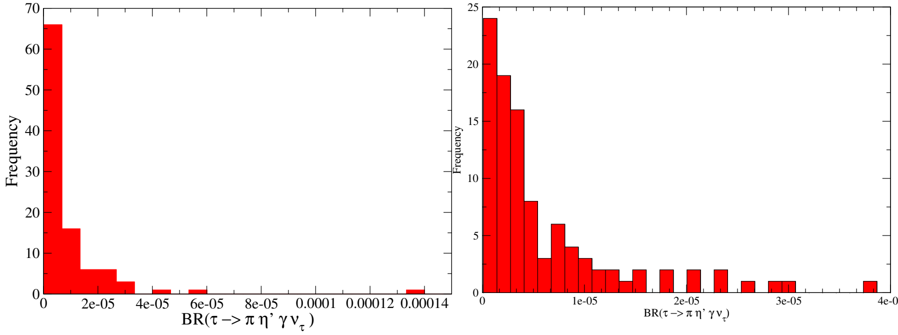
$BR(\tau \to \pi\eta\gamma\nu_\tau) \qquad E_\gamma < 100$ MeV

- BR calculado con RχT con corte en $E_\gamma = 100$ MeV



$BR(\tau \to \pi\eta'\gamma\nu_\tau)$

- BR calculado con RχT



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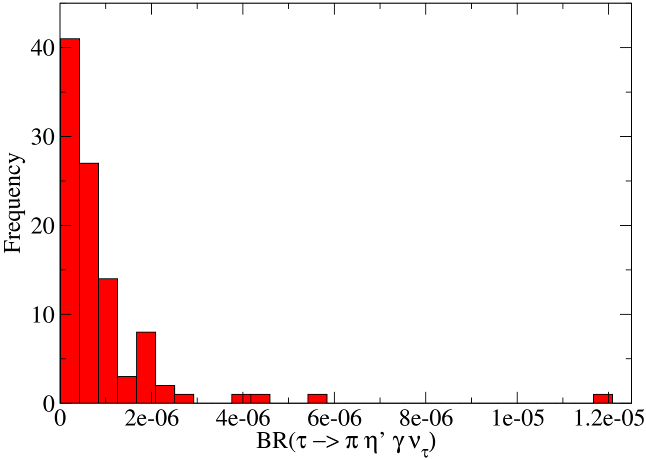
$BR(\tau \to \pi\eta'\gamma\nu_\tau) \qquad E_\gamma < 100$ MeV

- BR calculado con RχT con corte en $E_\gamma = 100$ MeV



Bremsstrahlung contribution to $\tau \to \pi\eta^{(\prime)}\gamma\nu_\tau$

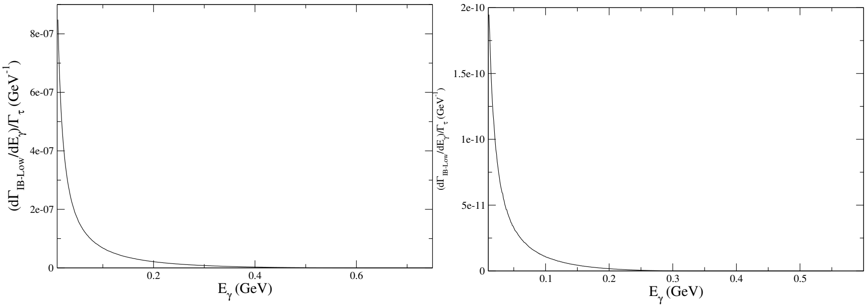


Figura: Contribution for the $\tau \to \pi\eta\gamma\nu_\tau$ (left) and for $\tau \to \pi\eta'\gamma\nu_\tau$ (right)

Spectra for $\tau \to \pi\eta\gamma\nu_\tau$ in MDM

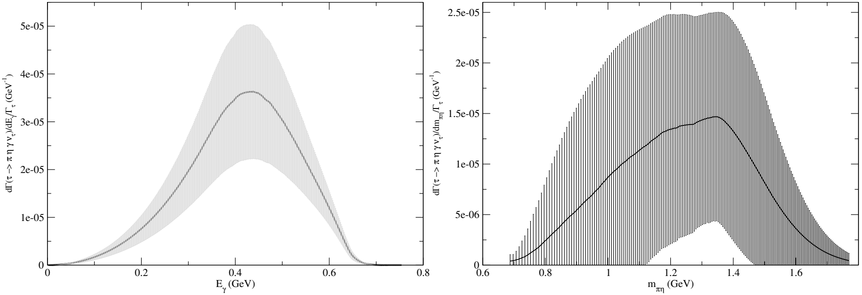


Figura: Invariant mass spectrum (right) and photon energy spectrum (left)

Spectra for $\tau \to \pi\eta'\gamma\nu_\tau$ in MDM

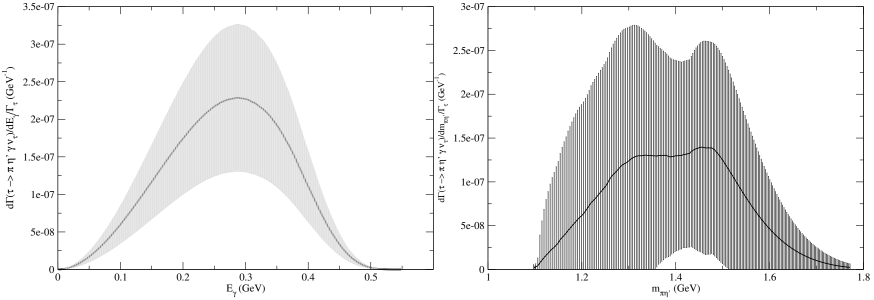


Figura: Invariant mass spectrum (right) and photon energy spectrum (left)

Spectra for $\tau \to \pi\eta\gamma\nu_\tau$ in RχT

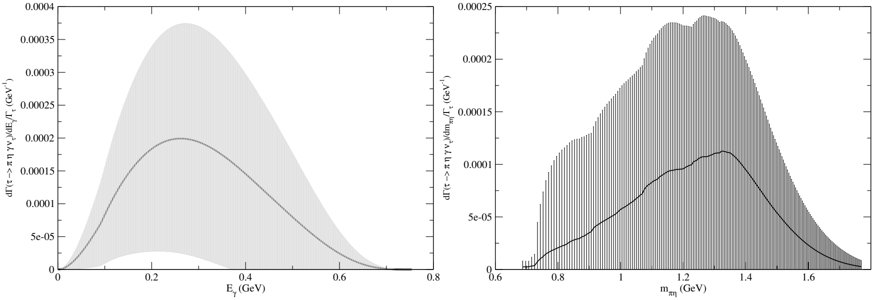


Figura: Invariant mass spectrum (right) and photon energy spectrum (left)

Spectra for $\tau \to \pi\eta'\gamma\nu_\tau$ in RχT

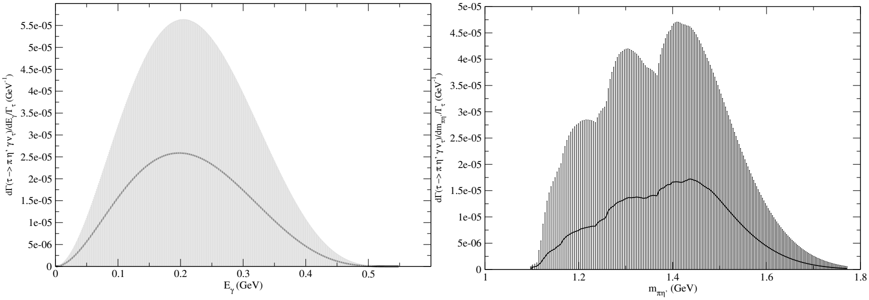


Figura: Invariant mass spectrum (right) and photon energy spectrum (left)