Probing beyond the standard model with $\Delta S=2$ hyperon decays

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Based on

X.G. He, JT, G. Valencia, 2304.02559

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- Introduction
  - Nonleptonic ΔS=2 processes
- Standard model predictions
  - Short-distance contributions
  - Long-distance contributions
- Enhancements due to new physics
  - *Z*' boson
  - Leptoquarks
- Conclusions

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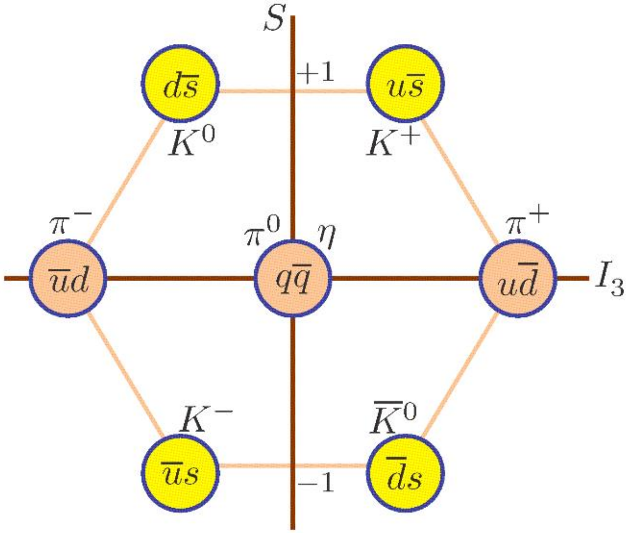
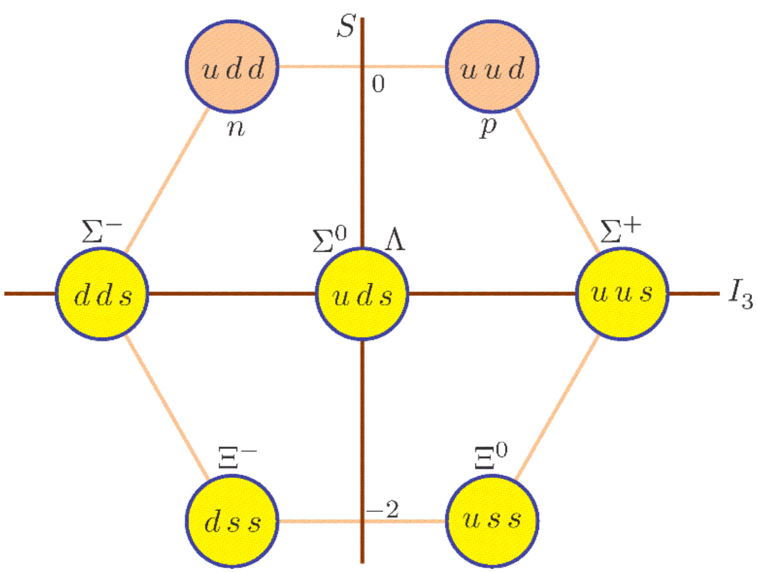
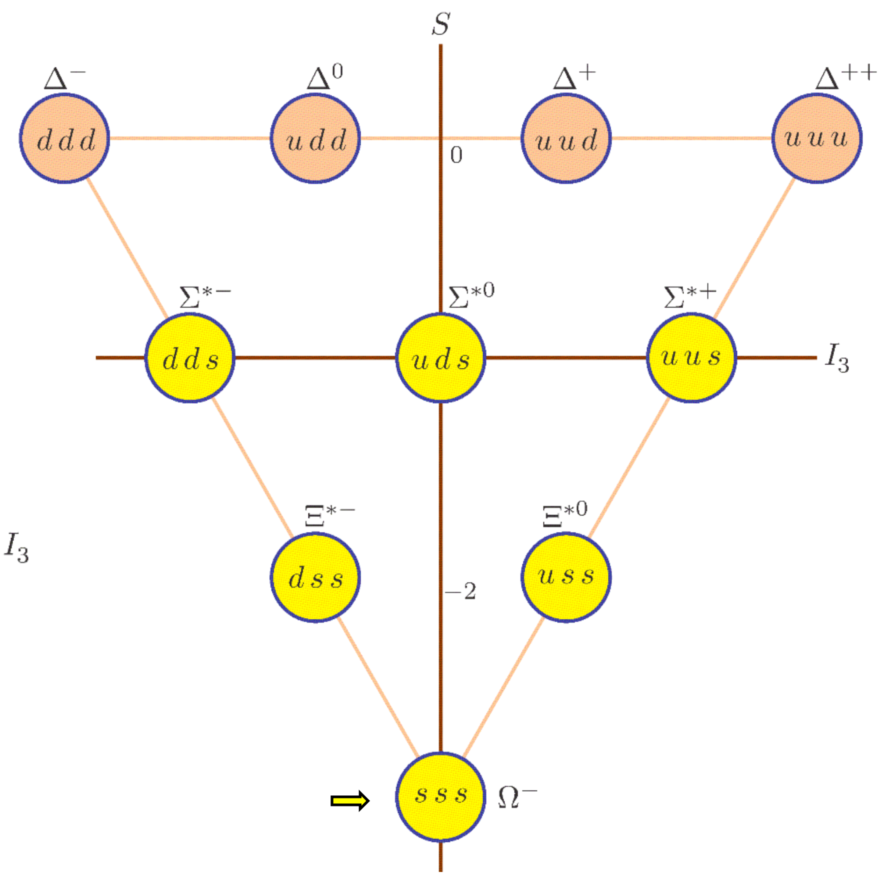
Strange hadrons among flavor-SU(3) multiplets of lightest mesons & baryons

- **Kaons**



- **Hyperons**





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- To date, there have been some searches for ΔS=2 baryon decays:

PDG 2022

Ξ^0 decay	$p\pi^-$	S2	$<$	8	$\times 10^{-6}$	90%
	$pe^-\overline{\nu}_e$	S2	$<$	1.3	$\times 10^{-3}$	
	$p\mu^-\overline{\nu}_\mu$	S2	$<$	1.3	$\times 10^{-3}$	
Ξ^- decay	$n\pi^-$	S2	$<$	1.9	$\times 10^{-5}$	90%
	$ne^-\overline{\nu}_e$	S2	$<$	3.2	$\times 10^{-3}$	90%
	$n\mu^-\overline{\nu}_\mu$	S2	$<$	1.5	%	90%
	$p\pi^-\pi^-$	S2	$<$	4	$\times 10^{-4}$	90%
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Alves Junior *et al.*, 1808.03477
HB Li

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- Further in the future, the Super Tau-Charm Factory could expectedly probe these hyperon decays better.

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- Nonleptonic Δ*S*=2 interactions at short distance (SD) in the SM arise from box diagrams involving up-type quarks and the *W* boson in the loops.

- The effective Hamiltonian at low energies

$$\mathcal{H}^{\rm SM}_{\Delta S=2} = \frac{G_{\rm F}^2}{4\pi^2}\Big[\eta_{cc}\mathrm{V}^{*2}_{cd}\mathrm{V}^{2}_{cs}\mathrm{S}(x_c) + \eta_{tt}\mathrm{V}^{*2}_{td}\mathrm{V}^{2}_{ts}\mathrm{S}(x_t) + 2\eta_{ct}\mathrm{V}^{*}_{cd}\mathrm{V}_{cs}\mathrm{V}^{*}_{td}\mathrm{V}_{ts}\mathrm{S}(x_c, x_t)\Big]\mathcal{Q}_{LL}$$

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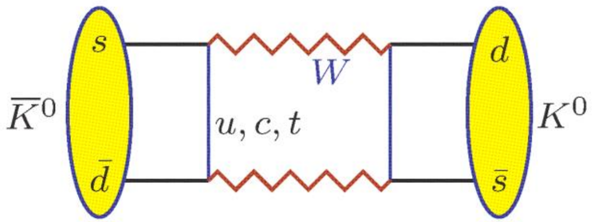

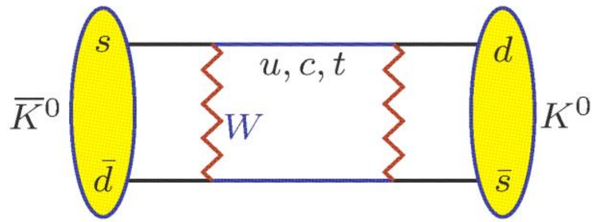

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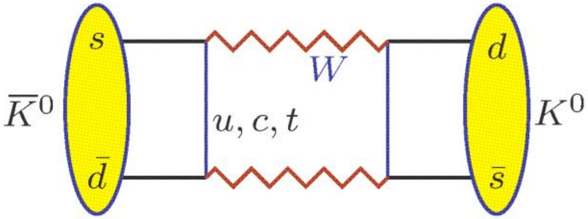
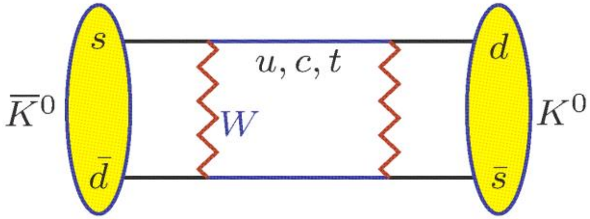
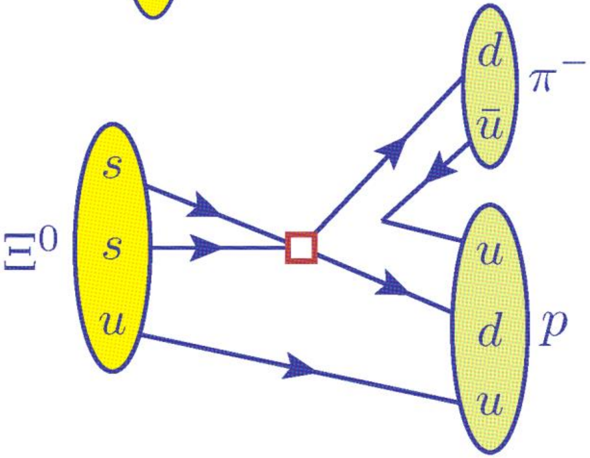




- This Hamiltonian also contributes to ΔS=2 nonleptonic hyperon decays.



* To address the hyperon decays requires the baryonic realization of $\mathcal{Q}_{LL}$, which transforms as $(\mathbf{27}_L, \mathbf{1}_R)$ under the flavor $\mathbf{SU(3)}_L\times\mathbf{SU(3)}_R$ symmetry.

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* The leading-order chiral realization of $\mathcal{Q}_{LL}$ is

$$\mathcal{O}_{LL} = \Lambda_\chi f_\pi^2 t_{kl,no}\Big[\hat{\beta}_{27}\big(\xi\overline{B}\xi^\dagger\big)_{nk}\big(\xi B\xi^\dagger\big)_{ol} + \hat{\delta}_{27}\xi_{nx}\xi_{oz}\xi^\dagger_{vk}\xi^\dagger_{wl}\big(\overline{T}_{rvw}\big)^\varsigma\big(T_{rxz}\big)_\varsigma\Big]$$

$\hat{\beta}_{27}$ and $\hat{\delta}_{27}$ are parameters to be estimated, Λ_χ is the scale of chiral-symmetry breaking, and f_π is the pion decay constant.

He & Valencia, 1997
Abd El-Hady, JT, Valencia, 1999

The baryons and mesons are collected into

$$B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & \frac{\Lambda}{\sqrt{6}} - \frac{\Sigma^0}{\sqrt{2}} & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\,\Lambda \end{pmatrix}, \quad \xi = \exp\left(\frac{i\varphi}{2f}\right), \quad \varphi = \begin{pmatrix} \pi^0 + \frac{\eta_8}{\sqrt{3}} & \sqrt{2}\,\pi^+ & \sqrt{2}\,K^+ \\ \sqrt{2}\,\pi^- & \frac{\eta_8}{\sqrt{3}} - \pi^0 & \sqrt{2}\,K^0 \\ \sqrt{2}\,K^- & \sqrt{2}\,\bar{K}^0 & \frac{-2\eta_8}{\sqrt{3}} \end{pmatrix}$$

$T_{111} = \Delta^{++}$, $T_{112} = \frac{1}{\sqrt{3}}\Delta^+$, $T_{122} = \frac{1}{\sqrt{3}}\Delta^0$, $T_{222} = \Delta^-$, $T_{113} = \frac{1}{\sqrt{3}}\Sigma^{*+}$, $T_{123} = \frac{1}{\sqrt{6}}\Sigma^{*0}$, $T_{223} = \frac{1}{\sqrt{3}}\Sigma^{*-}$, $T_{133} = \frac{1}{\sqrt{3}}\Xi^{*0}$, $T_{233} = \frac{1}{\sqrt{3}}\Xi^{*-}$, $T_{333} = \Omega^-$

Under chiral symmetry $B \to \hat{U} B \hat{U}^\dagger$, $\xi \to \hat{L}\xi\hat{U}^\dagger = \hat{U}\xi\hat{R}^\dagger$, $(T_{rvw})^\eta \to \hat{U}_{rn}\hat{U}_{vx}\hat{U}_{wz}(T_{nxz})^\eta$

$\hat{U} \in \mathrm{SU}(3)$ implicitly defined by the ξ equation, $\hat{L} \in \mathrm{SU}(3)_L$, and $\hat{R} \in \mathrm{SU}(3)_R$.

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$$\mathcal{L}_\mathrm{s} \supset \mathrm{Tr}\big(D\,\overline{B}\gamma^\varsigma\gamma_5\{\mathcal{A}_\varsigma, B\} + F\,\overline{B}\gamma^\varsigma\gamma_5[\mathcal{A}_\varsigma, B]\big) + \epsilon_{kln}\,\mathcal{C}\,\big[(\overline{T}_{nvw})^\varsigma\,(\mathcal{A}_{wl})_\varsigma\,B_{vk} + \overline{B}_{kv}\,(\mathcal{A}_{lw})_\varsigma\,(T_{nvw})^\varsigma\big]$$

Bijnens, Sonoda, Wise, 1985
Jenkins & Manohar, 1991

D, F, and $\mathcal{C}$ are constants and $\mathcal{A}_\varsigma = i(\xi\partial_\varsigma\xi^\dagger - \xi^\dagger\partial_\varsigma\xi)/2$

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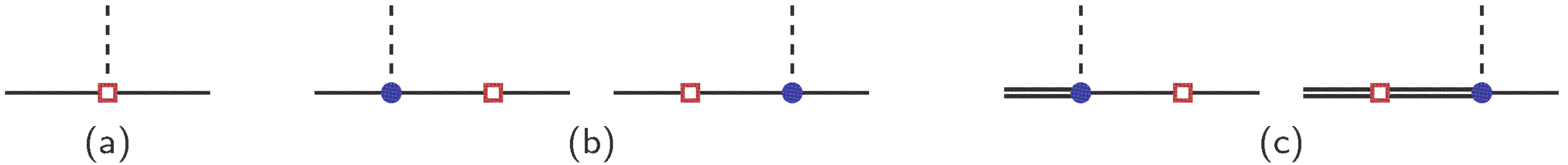
- The SD contributions to the amplitudes



Feynman diagrams for the (a) S-wave and (b) P-wave of $\Xi \to N\pi$ and (c) the P-wave of $\Omega^- \to \mathfrak{B}\phi$, each hollow square symbolizing a coupling induced by $\mathcal{H}^{\rm SM}_{\Delta S=2}$

- S-wave amplitudes

$$\mathbb{A}_{\Xi^0 p}^{(\mathrm{SM,SD})} = \mathbb{A}_{\Xi^- n}^{(\mathrm{SM,SD})} = \frac{\mathrm{C}_{\mathrm{SM}}}{\sqrt{2}}$$

$$\mathrm{C}_{\mathrm{SM}} = \eta_{cc} G_{\mathrm{F}}^2 m_c^2 \left(V_{cd}^* V_{cs}\right)^2 f_\pi^2 \hat{\beta}_{27}/\pi$$

- P-wave amplitudes

$$\mathbb{B}_{\Xi^0 p}^{(\mathrm{SM,SD})} = \frac{D+F}{\sqrt{2}} \left(\frac{m_N + m_\Xi}{m_\Xi - m_N}\right) \mathrm{C}_{\mathrm{SM}}\,, \qquad \mathbb{B}_{\Xi^- n}^{(\mathrm{SM,SD})} = \frac{D-F}{\sqrt{2}} \left(\frac{m_N + m_\Xi}{m_N - m_\Xi}\right) \mathrm{C}_{\mathrm{SM}}$$

$$\mathbb{C}_{nK^-}^{(\mathrm{SM,SD})} = \frac{\mathcal{C}}{\sqrt{2}} \left[\frac{\mathrm{C}_{\mathrm{SM}}}{m_\Xi - m_N} - \frac{\widetilde{\mathrm{C}}_{\mathrm{SM}}}{3(m_\Omega - m_{\Sigma^*})}\right],$$

$$\mathbb{C}_{\Lambda\pi^-}^{(\mathrm{SM,SD})} = \frac{\mathcal{C}\,\widetilde{\mathrm{C}}_{\mathrm{SM}}}{2\sqrt{3}\,(m_\Omega - m_{\Sigma^*})}\,, \qquad \mathbb{C}_{\Sigma^0\pi^-}^{(\mathrm{SM,SD})} = \frac{-\mathcal{C}\,\widetilde{\mathrm{C}}_{\mathrm{SM}}}{6(m_\Omega - m_{\Sigma^*})}$$

$$\widetilde{\mathrm{C}}_{\mathrm{SM}} = \eta_{cc} G_{\mathrm{F}}^2 m_c^2 \left(V_{cd}^* V_{cs}\right)^2 f_\pi^2 \hat{\delta}_{27}/\pi$$

Branching fractions

$$\mathcal{B}(\Xi^0 \to p\pi^-)^{\rm SD}_{\rm SM} = 3.0 \times 10^{-16}\,, \qquad \mathcal{B}(\Xi^0 \to n\pi^0)^{\rm SD}_{\rm SM} = 3.0 \times 10^{-16}$$

$$\mathcal{B}(\Xi^- \to n\pi^-)^{\rm SD}_{\rm SM} = 7.9 \times 10^{-17}\,.$$

$$\mathcal{B}(\Omega^- \to nK^-)^{\rm SD}_{\rm SM} = (1.4, 9.4) \times 10^{-17}\,, \qquad \mathcal{B}(\Omega^- \to \Lambda\pi^-)^{\rm SD}_{\rm SM} = 2.0 \times 10^{-17}$$

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- But there are also long-distance contributions.

- The SM also generates ΔS=1 nonleptonic interactions described by the leading-order weak chiral Lagrangian

$$\mathcal{L}_{\Delta S=1}^{\rm SM} = {\rm Tr}\big(h_D \overline{B}\{\xi^\dagger\hat{\kappa}\xi, B\} + h_F \overline{B}[\xi^\dagger\hat{\kappa}\xi, B]\big) + h_C (\overline{T}_{kln})^\varsigma (\xi^\dagger\hat{\kappa}\xi)_{no} (T_{klo})_\varsigma$$

Bijnens, Sonoda, Wise, 1985
Jenkins, 1992

transforming as $(8_L, 1_R)$ under $\mathrm{SU}(3)_L \times \mathrm{SU}(3)_R$ and containing parameters $h_{D,F,C}$ and a 3×3 matrix $\hat{\kappa}$ with elements $\hat{\kappa}_{kl} = \delta_{2k}\delta_{3l}$.

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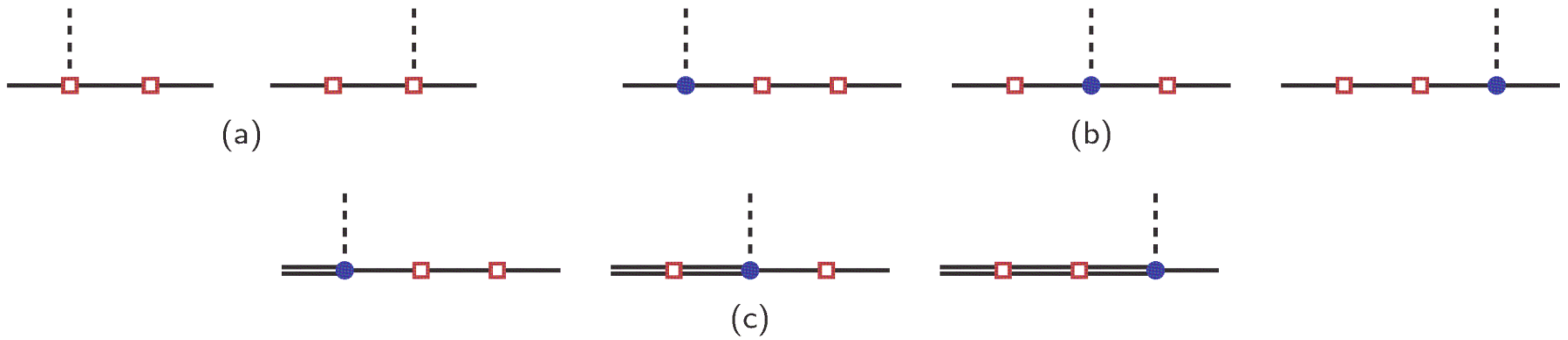
- It can act twice to produce long-distance ΔS=2 contributions:



Feynman diagrams for the long-distance contributions to the (a) S-wave and (b) P-wave of $\Xi \to N\pi$ and (c) the P-wave of $\Omega^- \to \mathfrak{B}\phi$, each hollow square symbolizing a weak coupling supplied by $\mathcal{L}^{\rm SM}_{\Delta S=1}$

- S-wave amplitudes

$$\mathbb{A}^{(\rm SM,LD)}_{\Xi^0 p} = \frac{1}{\sqrt{2}\,f_\pi}\left[\frac{h_D^2-h_F^2}{m_N-m_\Sigma}+\frac{h_D^2-h_F^2}{2(m_\Sigma-m_\Xi)}+\frac{h_D^2-9h_F^2}{6(m_\Xi-m_\Lambda)}\right]$$

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$$\mathbb{C}^{(\rm SM,LD)}_{nK^-} = \frac{\mathcal{C}\,h_C}{6\sqrt{2}\,f_\pi\,(m_\Omega-m_{\Xi^*})}\left[\frac{h_D+3h_F}{m_\Lambda-m_N}-\frac{h_D-h_F}{m_\Sigma-m_N}+\frac{4h_C}{3(m_\Omega-m_{\Sigma^*})}\right] - \frac{\mathcal{C}}{2\sqrt{2}\,f_\pi\,(m_\Xi-m_N)}\left[\frac{h_D^2-9h_F^2}{3(m_\Lambda-m_N)}+\frac{h_D^2-h_F^2}{m_\Sigma-m_N}\right],$$

$$\mathbb{C}^{(\rm SM,LD)}_{\Lambda\pi^-} = \frac{\mathcal{C}\,h_C}{6\sqrt{3}\,f_\pi\,(m_\Omega-m_{\Xi^*})}\left(\frac{h_D-3h_F}{m_\Xi-m_\Lambda}-\frac{2h_C}{m_\Omega-m_{\Sigma^*}}\right),$$

$$\mathbb{C}^{(\rm SM,LD)}_{\Sigma^0\pi^-} = \frac{\mathcal{C}\,h_C}{6f_\pi\,(m_\Omega-m_{\Xi^*})}\left[\frac{h_D+h_F}{m_\Xi-m_\Sigma}+\frac{2h_C}{3(m_\Omega-m_{\Sigma^*})}\right].$$

- The predicted rates depend on the choices for h_D, h_F, and h_C.

- If they're fixed from a fit to the data on the S-waves of octet-hyperon nonleptonic decays and the P-waves of $\Omega^- \to \mathcal{B}\phi$ decays in the ΔS=1 sector, the branching ratios (including the SD contributions) are

$$\mathcal{B}\big(\Xi^0 \to p\pi^-\big)_{\rm SM} = (2.8, 3.1) \times 10^{-15}, \qquad \mathcal{B}\big(\Xi^0 \to n\pi^0\big)_{\rm SM} = (1.6, 0.03) \times 10^{-15}$$

$$\mathcal{B}\big(\Xi^- \to n\pi^-\big)_{\rm SM} = (1.2, 1.8) \times 10^{-15}.$$

$$\mathcal{B}\big(\Omega^- \to nK^-\big)_{\rm SM} = 3.6 \times 10^{-13}, \qquad \mathcal{B}\big(\Omega^- \to \Lambda\pi^-\big)_{\rm SM} = 8.6 \times 10^{-14}$$

$$\mathcal{B}\big(\Omega^- \to \Sigma^0\pi^-\big)_{\rm SM} = 1.5 \times 10^{-14},$$

- The Ξ results are only somewhat larger than the corresponding SD ones alone, but the Ω^- numbers far exceed their SD counterparts.

- If $h_{D,F,C}$ are fixed from fitting to the P-waves of ΔS=1 octet-hyperon and Ω^- nonleptonic decays, the resulting branching ratios are instead

$$\mathcal{B}(\Xi^0 \to p\pi^-)_{\rm SM} = (2.76, 2.82) \times 10^{-13}\,, \qquad \mathcal{B}(\Xi^0 \to n\pi^0)_{\rm SM} = (0.9, 1.2) \times 10^{-14}$$
$$\mathcal{B}(\Xi^- \to n\pi^-)_{\rm SM} = (1.1, 1.2) \times 10^{-13}\,,$$

$$\mathcal{B}(\Omega^- \to nK^-)_{\rm SM} = 7.7 \times 10^{-13}\,, \qquad \mathcal{B}(\Omega^- \to \Lambda\pi^-)_{\rm SM} = 1.3 \times 10^{-13}$$
$$\mathcal{B}(\Omega^- \to \Sigma^0\pi^-)_{\rm SM} = 6.0 \times 10^{-15}\,,$$

- These are all much higher than their SD counterparts.

- Including uncertainties of the input parameters leads to

Decay mode	Branching fractions		
	SD	SD + LD ($\tilde{\mathrm{s}}$)	SD + LD ($\tilde{\mathrm{p}}$)
$\Xi^0 \to p\pi^-$	$(0.03, 1) \times 10^{-15}$	$(0.01, 2.6) \times 10^{-14}$	$(0.7, 8.2) \times 10^{-13}$
$\Xi^0 \to n\pi^0$	$(0.03, 1) \times 10^{-15}$	$(0., 0.9) \times 10^{-15}$	$(0.03, 0.4) \times 10^{-13}$
$\Xi^- \to n\pi^-$	$(0.07, 2.6) \times 10^{-16}$	$(0.01, 1.3) \times 10^{-14}$	$(0.03, 0.3) \times 10^{-12}$
$\Omega^- \to nK^-$	$(0.1, 6.5) \times 10^{-17}$	$(0.2, 0.6) \times 10^{-12}$	$(0.2, 2.1) \times 10^{-12}$
$\Omega^- \to \Lambda\pi^-$	$(0.2, 7.1) \times 10^{-17}$	$(0.4, 1.5) \times 10^{-13}$	$(0.2, 4.2) \times 10^{-13}$
$\Omega^- \to \Sigma^0\pi^-$	$(0.04, 1.7) \times 10^{-17}$	$(0.5, 3.1) \times 10^{-14}$	$(0.05, 2.2) \times 10^{-14}$

The 90%-CL intervals of branching fractions of $\Delta S = 2$ nonleptonic hyperon decays from the short-distance and complete contributions of the SM.

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The 90%-CL intervals of branching fractions of $\Delta S = 2$ nonleptonic hyperon decays from the short-distance and complete contributions of the SM.

- Evidently, the LD contributions can greatly raise the SM predictions, by up to 5 orders of magnitude.
- Still, the enhanced results do not go above the 10^{-12} level.
- Thus, it's unlikely for the SM predictions to be tested anytime soon.

- The striking dissimilarity between the two sets of SM total-predictions for $\Xi \to N\pi$

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- The smallness of the SM predictions, which are below the available experimental bounds by up to ten orders of magnitude, suggests that the window to discover new physics in these hyperon decays is still wide open.

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- We assume that a spin-1 massive boson *Z*' exists, associated with a new Abelian gauge group U(1)' and coupled to SM quarks in a family-nonuniversal manner.
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Z' model

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- The *Z'* couplings to the *d* and *s* quarks $\mathcal{L}_{dsZ'} = -\overline{d}\gamma^\beta (g_L P_L + g_R P_R) s \, Z'_\beta + \mathrm{H.c.}$

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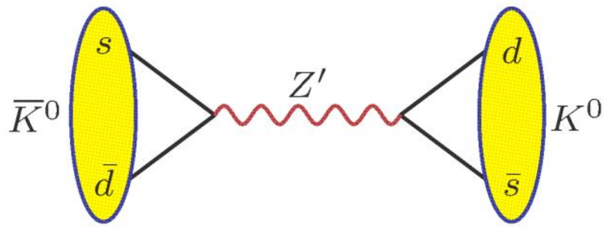
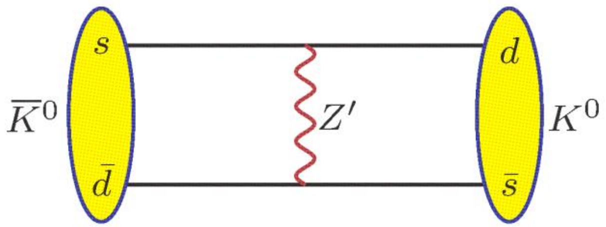
- They lead to the low-energy effective Hamiltonian

$$\mathcal{H}^{Z'}_{\Delta S=2} = \eta_{LL}\frac{g_L^2\mathcal{Q}_{LL} + g_R^2\mathcal{Q}_{RR}}{2m_{Z'}^2} + \frac{g_L g_R\left(\eta_{LR}\mathcal{Q}_{LR} + \eta'_{LR}\mathcal{Q}'_{LR}\right)}{m_{Z'}^2}$$

$$\mathcal{Q}_{RR} = \overline{d}\gamma^\alpha P_R s\,\overline{d}\gamma_\alpha P_R s\,, \qquad \mathcal{Q}_{LR} = \overline{d}\gamma^\alpha P_L s\,\overline{d}\gamma_\alpha P_R s \qquad \mathcal{Q}'_{LR} = \overline{d}P_L s\,\overline{d}P_R s$$

- It contributes to neutral-kaon mixing

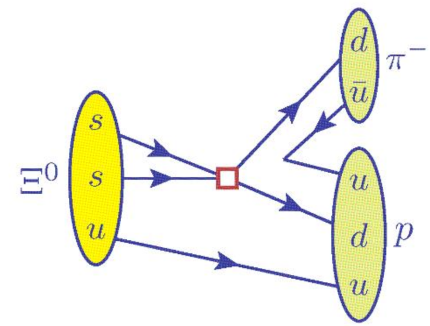




- The Hamiltonian also contributes to the nonleptonic ΔS=2 decays of hyperons.
- Their evaluation requires the baryonic realization of the 4-quark operators

$$\mathcal{O}_{RR} = \Lambda_\chi f_\pi^2 \, t_{kl,no}\Big[\hat{\beta}_{27}\,(\xi^\dagger\overline{B}\xi)_{nk}\,(\xi^\dagger B\xi)_{ol} + \hat{\delta}_{27}\,\xi^\dagger_{nx}\xi^\dagger_{oz}\xi_{vk}\xi_{wl}\,(\overline{T}_{rvw})^\eta(T_{rxz})_\eta\Big]$$

$$\mathcal{O}^{(\prime)}_{LR} = \tfrac{1}{2}\Lambda_\chi f_\pi^2 \, t_{kl,no}\Big\{\hat{\beta}^{(\prime)}_{88}\Big[(\xi\overline{B}\xi^\dagger)_{nk}\,(\xi^\dagger B\xi)_{ol} + (\xi^\dagger\overline{B}\xi)_{nk}\,(\xi B\xi^\dagger)_{ol}\Big] + \hat{\delta}^{(\prime)}_{88}\,(\xi_{nx}\xi^\dagger_{oz}\xi^\dagger_{vk}\xi_{wl} + \xi^\dagger_{nx}\xi_{oz}\xi_{vk}\xi^\dagger_{wl})\,(\overline{T}_{rvw})^\eta(T_{rxz})_\eta\Big\}$$



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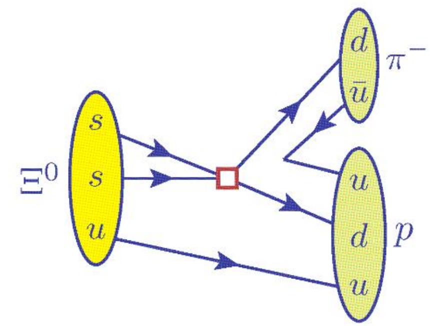

- The resulting amplitudes

$$\mathbb{A}^{(Z')}_{\Xi^0 p} = \mathbb{A}^{(Z')}_{\Xi^- n} = \frac{\mathsf{c}_{LL}-\mathsf{c}_{RR}}{2\sqrt{2}}\,,$$

$$\mathbb{B}^{(Z')}_{\Xi^0 p} = \left(\mathsf{c}_{LL}+\mathsf{c}_{RR}+2\mathsf{c}_{LR}+2\mathsf{c}'_{LR}\right)\frac{D+F}{2\sqrt{2}}\left(\frac{m_N+m_\Xi}{m_\Xi-m_N}\right)$$

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$$\mathbb{C}^{(Z')}_{nK^-} = \mathcal{C}\,\frac{\mathsf{c}_{LL}+\mathsf{c}_{RR}+2\mathsf{c}_{LR}+2\mathsf{c}'_{LR}}{2\sqrt{2}\,(m_\Xi-m_N)} - \mathcal{C}\,\frac{\tilde{\mathsf{c}}_{LL}+\tilde{\mathsf{c}}_{RR}+2\tilde{\mathsf{c}}_{LR}+2\tilde{\mathsf{c}}'_{LR}}{6\sqrt{2}\,(m_\Omega-m_{\Xi^*})}$$

$$\mathbb{C}^{(Z')}_{\Lambda\pi^-} = \mathcal{C}\,\frac{\tilde{\mathsf{c}}_{LL}+\tilde{\mathsf{c}}_{RR}+2\tilde{\mathsf{c}}_{LR}+2\tilde{\mathsf{c}}'_{LR}}{4\sqrt{3}\,(m_\Omega-m_{\Xi^*})}\,,$$

$$\mathbb{C}^{(Z')}_{\Sigma^0\pi^-} = -\mathcal{C}\,\frac{\tilde{\mathsf{c}}_{LL}+\tilde{\mathsf{c}}_{RR}+2\tilde{\mathsf{c}}_{LR}+2\tilde{\mathsf{c}}'_{LR}}{12(m_\Omega-m_{\Xi^*})}\,,$$

$$\mathsf{c}_{LL(RR)} = \frac{4\pi\,\eta_{LL}\,g^2_{L(R)}}{m^2_{Z'}}\,f_\pi^2\,\hat\beta_{27}$$

$$\mathsf{c}^{(\prime)}_{LR} = \frac{4\pi\,\eta^{(\prime)}_{LR}\,g_L g_R}{m^2_{Z'}}\,f_\pi^2\,\hat\beta^{(\prime)}_{88}$$

$$\tilde{\mathsf{c}}_{LL(RR)} = \frac{4\pi\,\eta_{LL}\,g^2_{L(R)}}{m^2_{Z'}}\,f_\pi^2\,\hat\delta_{27} \qquad \tilde{\mathsf{c}}^{(\prime)}_{LR} = \frac{4\pi\,\eta^{(\prime)}_{LR}\,g_L g_R}{m^2_{Z'}}\,f_\pi^2\,\hat\delta^{(\prime)}_{88}$$

- Kaon-mixing observables $\Delta M_K = 2\,\mathrm{Re}\,M_{K\bar{K}}$ $|\epsilon| \simeq |\mathrm{Im}\,M_{K\bar{K}}|/(\sqrt{2}\,\Delta M_K^{\rm exp})$

$$2m_{K^0} M_{K\bar{K}}^{Z'} = \langle K^0|\mathcal{H}_{\Delta S=2}^{Z'}|\bar{K}^0\rangle$$

- *Z′* contribution

$$\langle \mathcal{Q}\rangle \equiv \langle K^0|\mathcal{Q}|\bar{K}^0\rangle \qquad M_{K\bar{K}}^{Z'} = \frac{\eta_{LL}\,(g_L^2+g_R^2)\langle \mathcal{Q}_{LL}\rangle + 2g_L g_R\,(\eta_{LR}\langle \mathcal{Q}_{LR}\rangle + \eta'_{LR}\langle \mathcal{Q}'_{LR}\rangle)}{4m_{K^0}\,m_{Z'}^2}$$

- It can be suppressed but fine-tuning of the *Z′* couplings is needed.

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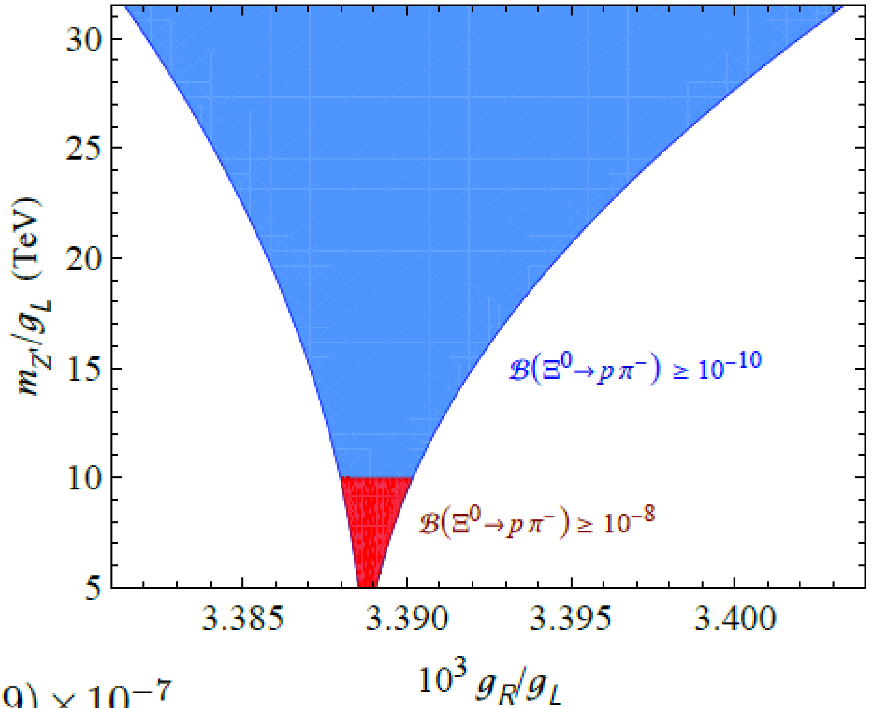
- It can be suppressed but fine-tuning of the Z' couplings is needed.

- The hyperon branching fractions can be substantially amplified relative to their SM values.



$$1.0\,(1.2)\times10^{-8} \leq \mathcal{B}\big(\Xi^0\to p\pi^-\,(n\pi^0)\big)_{Z'} \leq 1.6\,(1.9)\times10^{-7}$$

$$3.4\,(1.2)\times10^{-9} \leq \mathcal{B}\big(\Omega^-\to nK^-(\Lambda\pi^-)\big)_{Z'} \leq 5.4\,(2.0)\times10^{-8}$$

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- We assume 2 scalar leptoquarks (LQs), with their SM $(\mathrm{SU}(3)_C, \mathrm{SU}(2)_L, \mathrm{U}(1)_Y)$ group assignments: $\tilde{S}_1 \sim (\bar{3}, 1, 4/3)$ and $R_2 \sim (\bar{3}, 2, 7/6)$.

- They have renormalizable interactions with SM fermions:

$$\mathcal{L}_{\rm LQ} = \widetilde{\rm Y}^{\rm RR}_{jx}\, \overline{d^{\rm c}_j}\, e_x \tilde{S}_1 + {\rm Y}^{\rm LR}_{jx}\, \overline{q_j}\, R_2\, e_x + {\rm H.c.}$$

- The LQs generate separate contributions to nonleptonic Δ*S*=2 interactions, and the second LQ also affects charmed-meson mixing.

$$\mathcal{H}^{\rm LQ}_{\Delta S=2} = \frac{\left(\sum_x \widetilde{\rm Y}^{\rm RR*}_{1x}\, \widetilde{\rm Y}^{\rm RR}_{2x}\right)^2}{128\pi^2\, m^2_{\tilde{S}_1}}\, \mathcal{Q}_{RR} + \frac{\left(\sum_x {\rm Y}^{\rm LR}_{1x}\, {\rm Y}^{\rm LR*}_{2x}\right)^2}{128\pi^2\, m^2_{R_2}}\, \mathcal{Q}_{LL}$$

$$\mathcal{H}^{\rm LQ}_{\Delta C=2} = \frac{\left[\sum_x \left(V_{\rm CKM}{\rm Y}^{\rm LR}\right)_{1x} \left(V^*_{\rm CKM}{\rm Y}^{\rm LR*}\right)_{2x}\right]^2}{128\pi^2\, m^2_{R_2}}\, \overline{u}\gamma^\eta P_L c\, \overline{u}\gamma_\eta P_L c$$

- It turns out to be possible to arrange the elements of the Yukawa matrices of the two LQs such that the Δ*S*=2 Hamiltonian becomes purely parity-violating and consequently yields no contribution to kaon mixing.

- Example

$$m_{\tilde{S}_1} = m_{R_2} \equiv m_{\rm LQ} \qquad \widetilde{\rm Y}^{\rm RR} = \begin{pmatrix} 0 & 0 & y_{d\tau} \\ 0 & 0 & i y_{s\tau} \\ 0 & 0 & 0 \end{pmatrix} \qquad {\rm Y}^{\rm LR} = \begin{pmatrix} 0 & 0 & y_{d\tau} \\ 0 & 0 & y_{s\tau} \\ 0 & 0 & 0 \end{pmatrix}$$

- These imply

$$\big(\textstyle\sum_x \widetilde{\rm Y}^{\rm RR*}_{1x}\,\widetilde{\rm Y}^{\rm RR}_{2x}\big)^2 + \big(\textstyle\sum_x {\rm Y}^{\rm LR}_{1x}\,{\rm Y}^{\rm LR*}_{2x}\big)^2 = 0$$

$$\mathcal{H}^{\rm LQ}_{\Delta S=2} = \frac{y_{d\tau}^2\, y_{s\tau}^2}{128\pi^2\, m_{\rm LQ}^2}\big(\mathcal{Q}_{LL} - \mathcal{Q}_{RR}\big)$$

- This Hamiltonian does not affect kaon mixing and hence evades its constraints.
- But the charmed-meson constraint translates into a restriction on the size of the Yukawa matrix elements.
- Consequently

$$\mathcal{B}\big(\Xi^0 \to p\pi^-\big)_{\rm LQ} < 3.4\times 10^{-8}\,, \qquad \mathcal{B}\big(\Xi^0 \to n\pi^0\big)_{\rm LQ} < 6.9\times 10^{-8}$$

$$\mathcal{B}\big(\Xi^- \to n\pi^-\big)_{\rm LQ} < 2.0\times 10^{-8}\,,$$

- These are also much higher than their SM counterparts.

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- Hyperon nonleptonic decays that change strangeness by two units are expected to have tiny branching ratios in the SM.
- Such processes are, therefore, potentially sensitive tools in the search for new physics beyond the SM.
- Although constraints from kaon-mixing data are consequential, it is possible for new physics to boost the rates of $\Delta S=2$ nonleptonic hyperon decays to levels that can be probed in future quests by BESIII and LHCb and at the proposed Super Tau-Charm Factory.