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Potential in probes of new physics: rare hyperon decays vs. kaon decays

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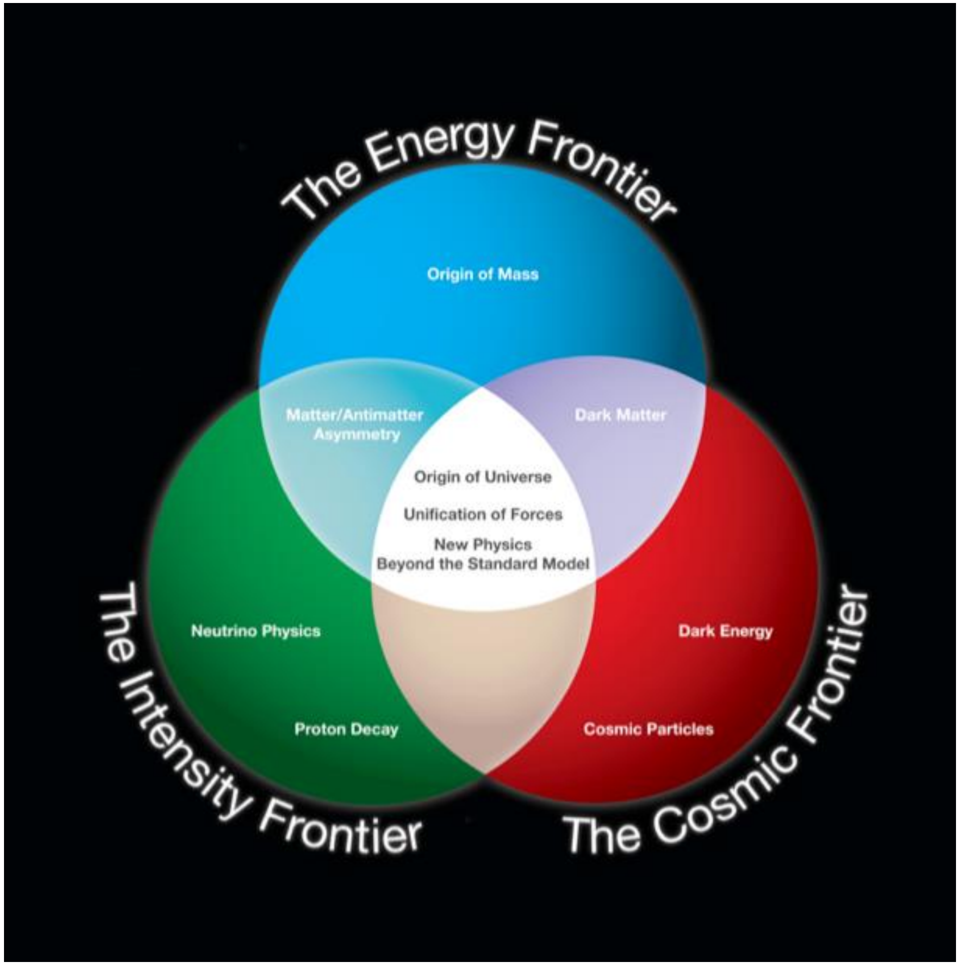
- **Background & purpose**
  - $s \to d\nu\bar{\nu}$ & $s \to d\ell^+\ell^-$
  - **Kaons vs. hyperons**
- **Theoretical framework**
- **Results and Discussions**
- **Summary and outlook**

Frontiers in high energy physics



- **CMS&ATLAS:**
  Higgs
  Supersymmetric particles
  New interactions
  …

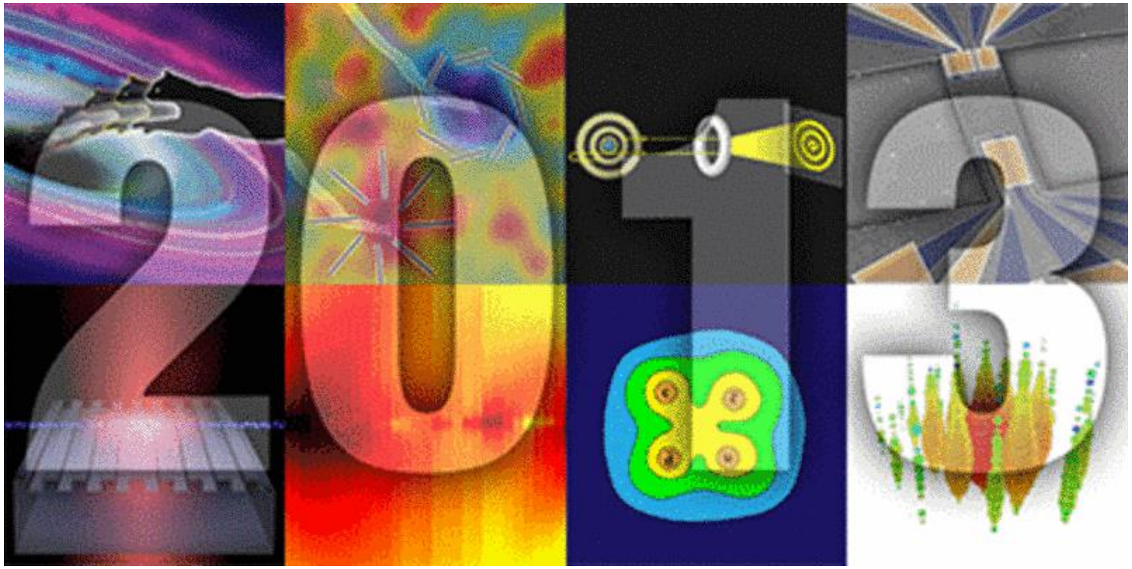
- **LCHb&BelleII&BESIII:**
  (Heavy) flavor physics
  New hadronic states
  …

Indirect detection of NP via rare decays is one of the hottest topics

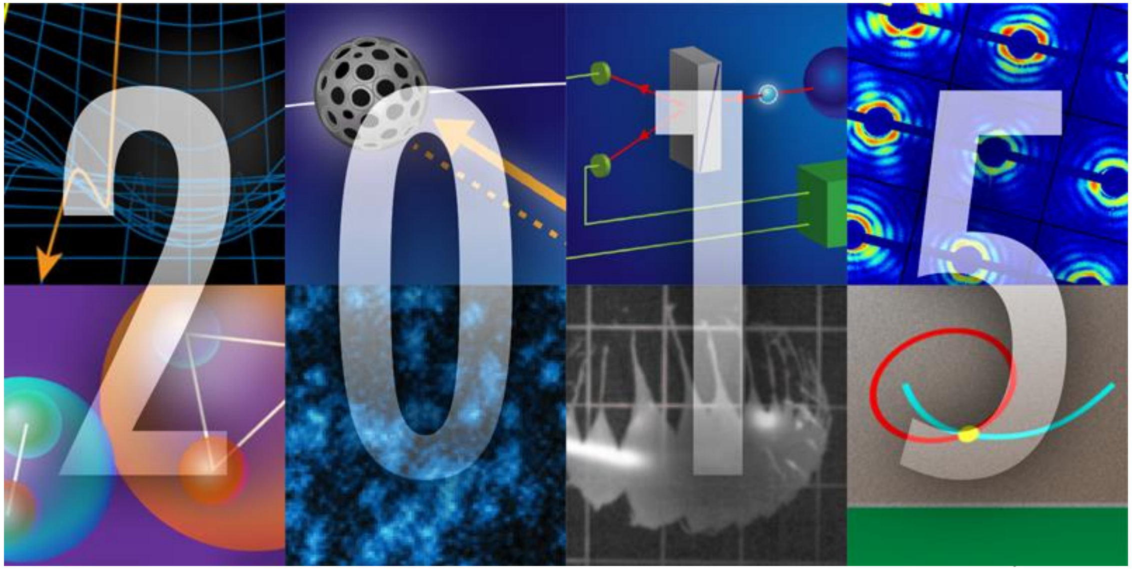
US Particle Physics Scientific Opportunities: A Strategic Plan for the Next 10 Years

Highlights of the year

the research covered in Physics that **really made waves in and beyond the physics community.**



Four-Quark Matter/BESIII

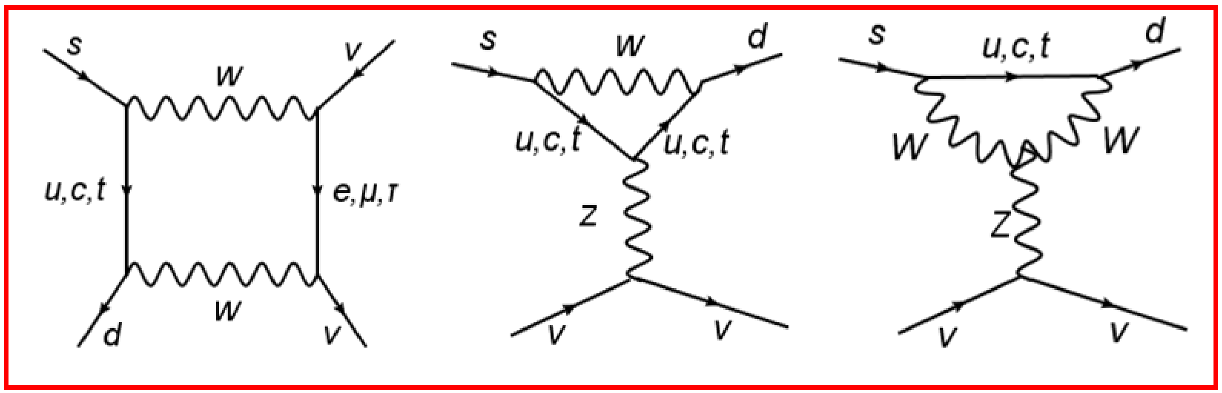


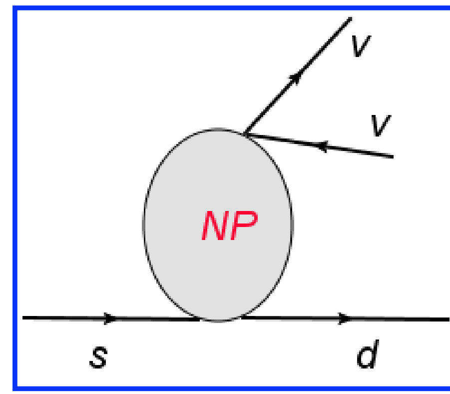
Particle High Five/LHCb

$s \to d$ transitions

- $s \to d$ **transitions are highly suppressed in the SM**

the strongest suppression factor

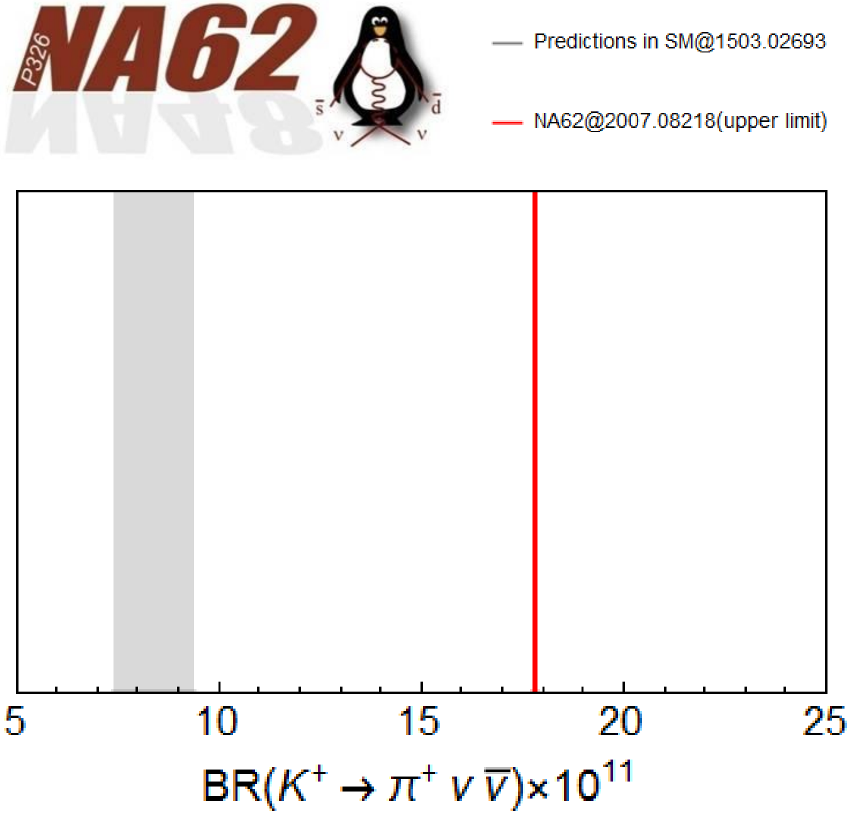


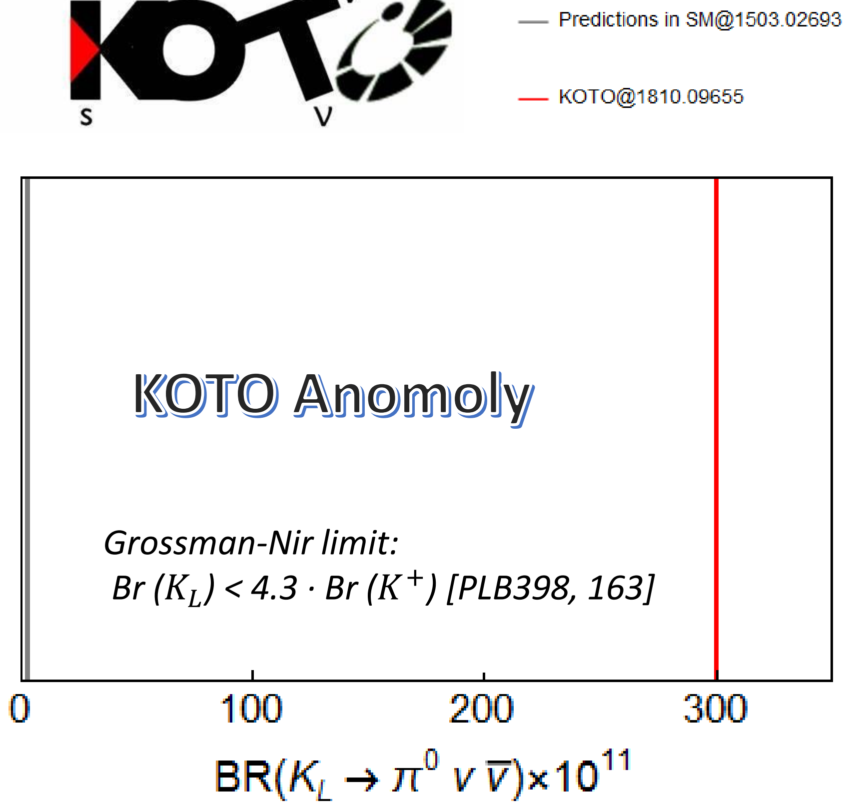


- **As such, they are ideal for tests of the SM and searches for BSM**
  - *G. Buchalla and A. J. Buras, hep-ph/9901288*
  - *V. Cirigliano et al., 1107.6001*
  - *Hai-Bo Li, 1612.01775*
  - *A. A. Alves Junior et al., 1808.03477*

$K \to \pi\nu\bar{\nu}$

- **Latest experimental results**

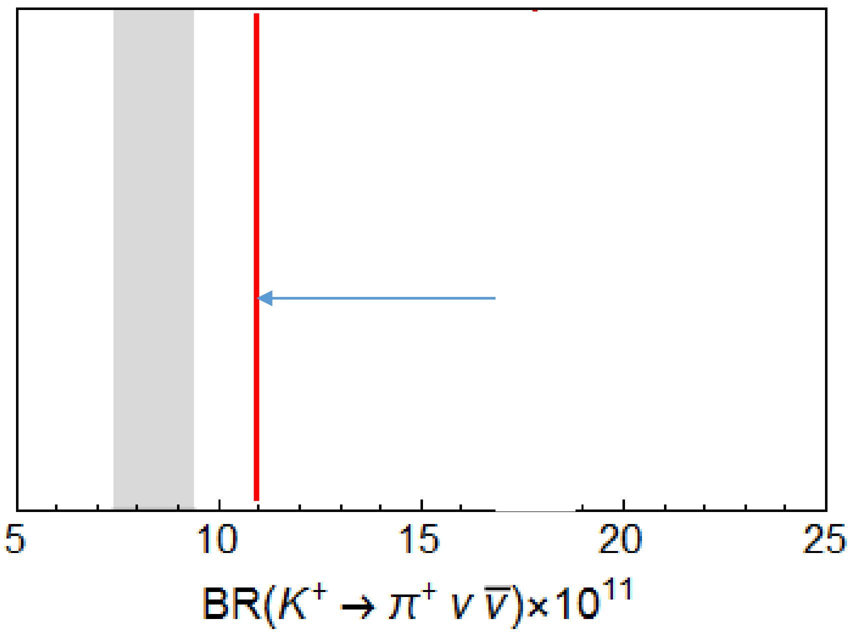




- **The K → π ν ν̄ results imply that there is still room for new physics (NP), but maybe not so much. However, they are only sensitive to the vectorial (parity even) couplings of the s → d currents.**

$K \to \pi\nu\bar{\nu}$

☐ Branching ratio in $K^+ \to \pi^+\nu\bar{\nu}$ further reduced



Measurement of $Br(K^+ \to \pi^+\nu\bar{\nu})$
with the NA62 experiment at CERN SPS

Francesco Brizioli

University of Perugia and INFN (Italy)

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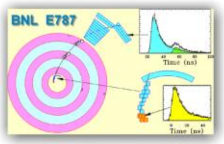
on behalf of the NA62 Collaboration

CERN EP seminar 27.10.2020

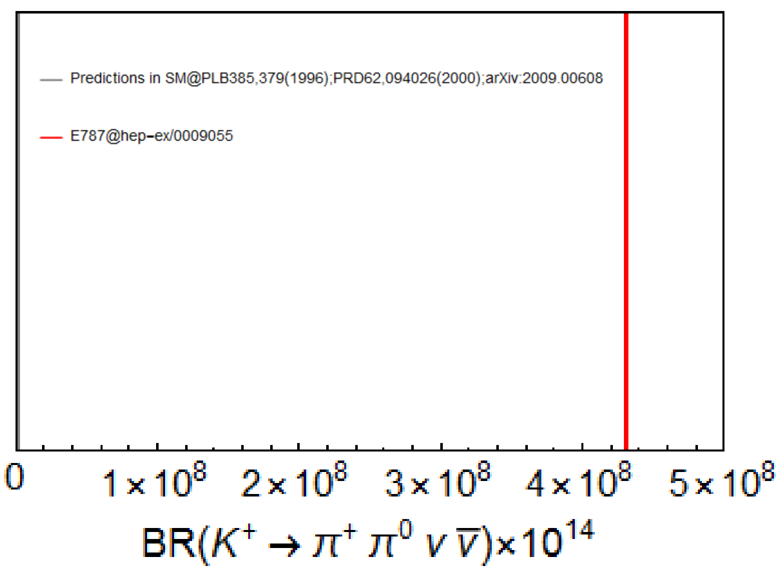
- New preliminary result from NA62:
  $Br^{NA62}_{16+17+18}(K^+ \to \pi^+\nu\bar{\nu}) = (1.10^{+0.40}_{-0.35\,stat} \pm 0.03_{syst}) \cdot 10^{-10}$
  3.5σ significance

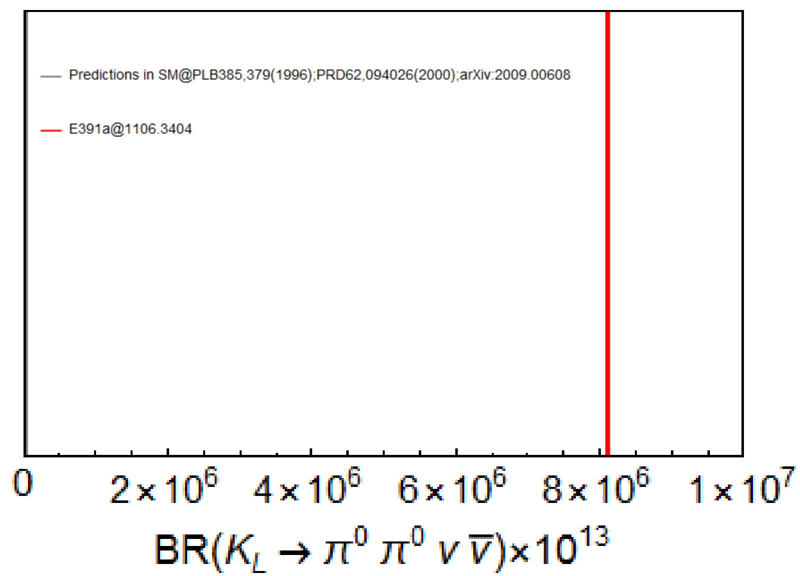
$K \to \pi\pi\nu\bar{\nu}$

- **Latest experimental results**



KEK-PS E391a





- **Although the $K \to \pi\,\pi\,\nu\,\bar{\nu}$ modes receive contributions from the axial-vectorial type of NP, the current results provide little constraints on them**

$K_L \to \mu^+\mu^-$ and $K^+ \to \pi^+\mu^+\mu^-$

- **The branching ratio of the $K_L \to \mu^+\mu^-$ decay and the leptonic forward-backward asymmetry (AFB) of the $K^+ \to \pi^+\mu^+\mu^-$ decay have been measured**

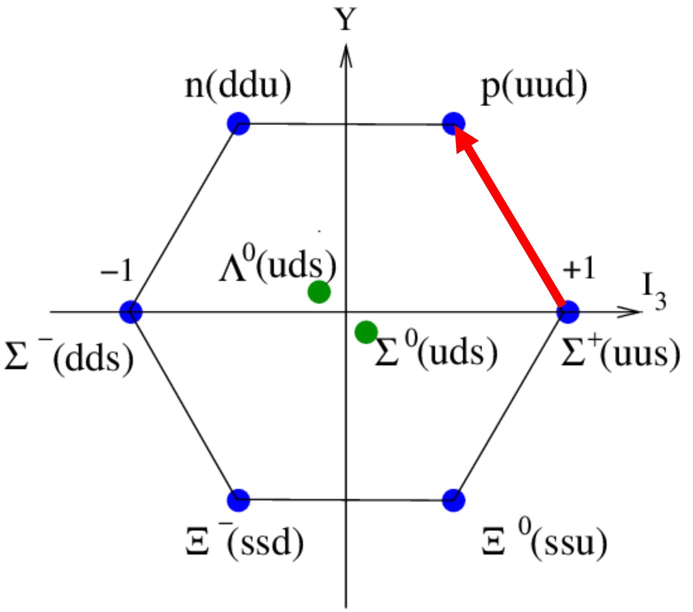
$$\mathrm{BR}(K_L \to \mu^+\mu^-) = (6.84 \pm 0.11) \times 10^{-9}$$ PTEP 2020, 083C01 (2020)

$$|A_{FB}| < 2.3 \times 10^{-2}, \qquad \text{at } 90\% \text{ CL}$$ PLB 697, 107 (2011)

- **They not only are dominated by long-range contributions , but also cannot probe all the interesting axial-vectorial, scalar operators, and their spin flip structures**

Hyperons might be a game changer

- **Having spin ½ (instead of spin 0), they lead to different decay modes, observables, as well as sensitivities to the underlying structure of the $s \to d$ currents**



- **Experimentally and theoretically more challenging, compared to their kaon siblings**
  - **No direct data for $B_1 \to B_2 \nu\bar{\nu}$; first theoretical studies only appeared recently**
  - **Latest measurement of $\Sigma^+ \to p\mu^+\mu^-$ only with a signal significance of 4.1 sigma**

$B_1 \to B_2 \nu\bar{\nu}$

Different from their kaonic counterparts, they are sensitive to both vectorial and axial-vectorial couplings of the $s \to d$ currents

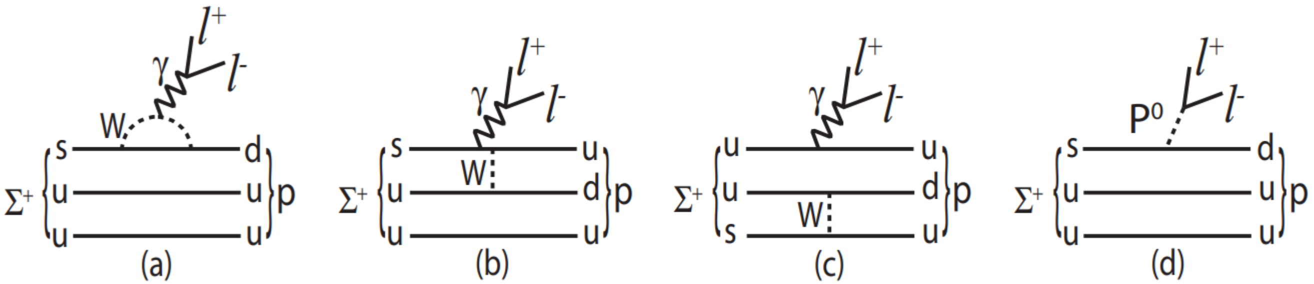
- **No direct data yet, but promising data from BESIII & LHCb**
  - BESIII/LHCb experiments in the near future *Front. Phys. 12, 121301 (2017)* *JHEP05(2019)048*
  - Upper limits derived from Hyperon lifetime *PRD 102,015023 (2020)*
- **On the theory side, the first studies just appeared**

  Xiao-Hui Hu et al., CPC43(2019)093104; Jusak Tandean, JHEP04(2019)104
- **More theoretical studies are needed**
  - Constraints from/compare with more kaon modes: 2, 3, 4 final states
  - The state of the art results from **covariant baryon chiral perturbation theory for the relevant form factors**

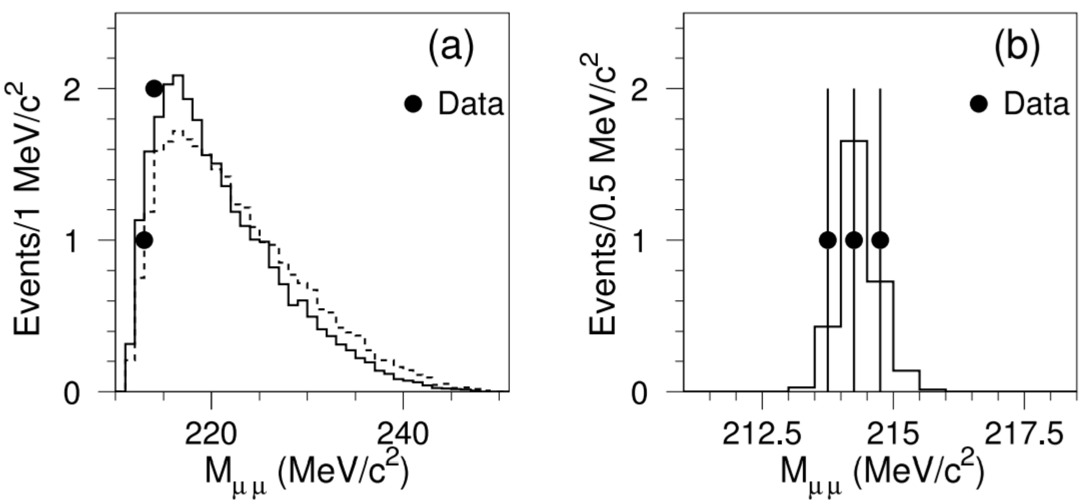
L. S. Geng et al., Phys. Rev. D 79, 094022 (2009)
T. Ledwig et al., Phys. Rev. D 90, 054502 (2014)

$\Sigma^+ \to p\mu^+\mu^-$

- **Experimental results from HyperCP@**PRL 94, 021801 (2004)



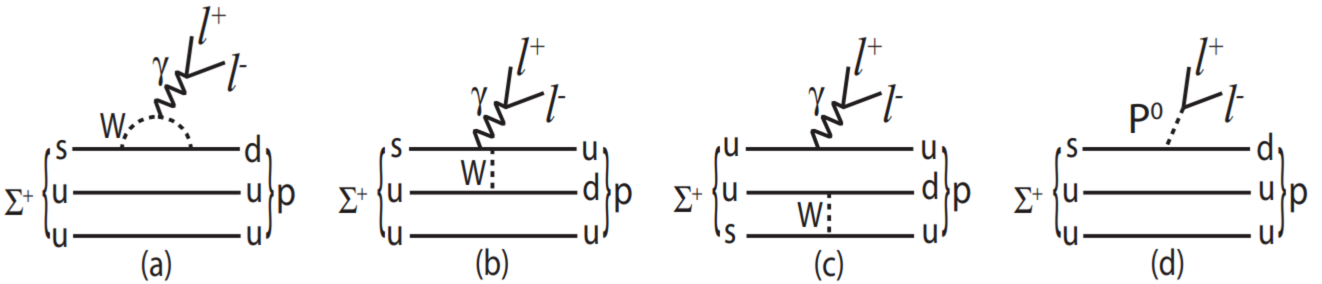
$$[8.6^{+6.6}_{-5.4}(\text{stat}) \pm 5.5(\text{syst})] \times 10^{-8}$$



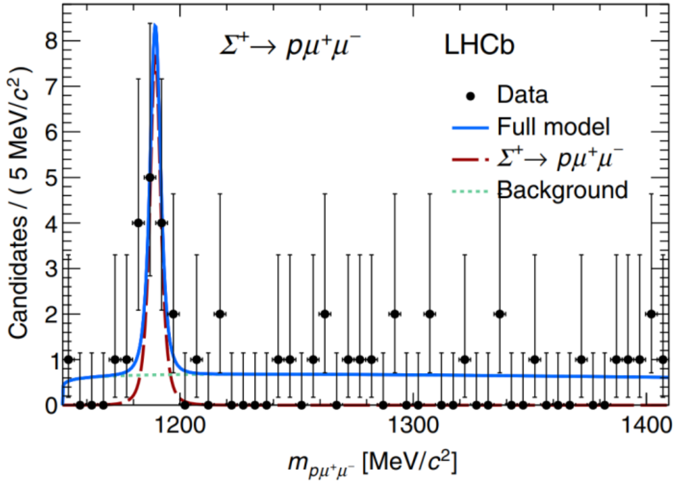
Di-muon meson
214.3 ± 0.5 MeV

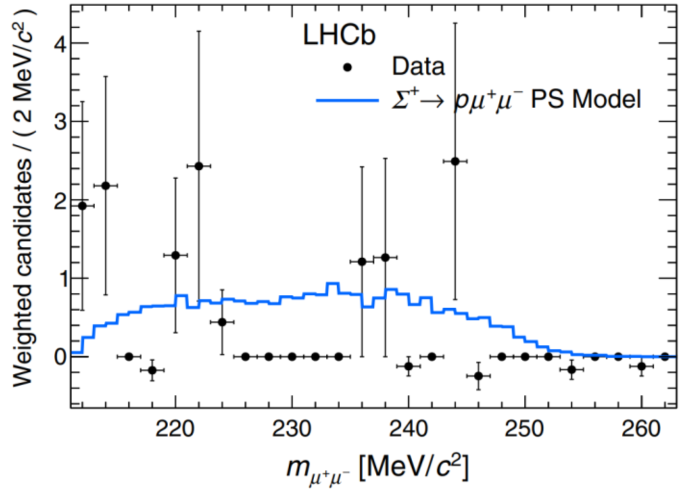
$\Sigma^+ \to p\mu^+\mu^-$

□ Experimental results from LHCb @PRL120, 221803(2018)



$$(2.2^{+1.8}_{-1.3}) \times 10^{-8}$$





Our purpose

Study the hyperon rare decays and compare with their kaon counterparts and investigate their sensitivities to different structures of new physics.

□ $s \to d\,\nu\,\bar{\nu}$ **transitions dominated by short−distance contributions**

$\Lambda \to n\nu\bar{\nu}$

$\Sigma^+ \to p\nu\bar{\nu}$

$\Xi^0 \to \Sigma^0\nu\bar{\nu}$

$\Xi^0 \to \Lambda\nu\bar{\nu}$

V.S

$K^+ \to \pi^+\nu\bar{\nu}$

$K_L \to \pi^0\nu\bar{\nu}$

$K^+ \to \pi^+\pi^0\nu\bar{\nu}$

$K_L \to \pi^0\pi^0\nu\bar{\nu}$

Channels	$\delta C^L_{\nu_\ell} + C^R_{\nu_\ell}$	$\delta C^L_{\nu_\ell} - C^R_{\nu_\ell}$
$\Lambda \to n\nu\bar{\nu}$	✓	✓
$\Sigma^+ \to p\nu\bar{\nu}$	✓	✓
$\Xi^0 \to \Sigma^0\nu\bar{\nu}$	✓	✓
$\Xi^0 \to \Lambda\nu\bar{\nu}$	✓	✓

Channels	$\delta C^L_{\nu_\ell} + C^R_{\nu_\ell}$	$\delta C^L_{\nu_\ell} - C^R_{\nu_\ell}$
$K^+ \to \pi^+\nu\bar{\nu}$	✓	✗
$K_L \to \pi^0\nu\bar{\nu}$	✓	✗
$K^+ \to \pi^+\pi^0\nu\bar{\nu}$	✓	✓
$K_L \to \pi^0\pi^0\nu\bar{\nu}$	✗	✓

Our purpose

Study the hyperon rare decays and compare with their kaon counterparts and investigate their sensitivities to different structures of new physics.

- **$s \to d\mu^+\mu^-$ transitions dominated by long-distance contributions**

$\Sigma^+ \to p\mu^+\mu^-$

V.S

$K_L \to \mu^+\mu^-$

$K^+ \to \pi^+\mu^+\mu^-$

Channels	$\delta C_{10} + C'_{10}$	$\delta C_{10} - C'_{10}$	$C_S + C'_S$	$C_S - C'_S$
$A_{FB}(\Sigma^+ \to p\mu^+\mu^-)$	✓	✓	✓	✓
$\mathrm{BR}(K_L \to \mu^+\mu^-)$	✗	✓	✗	✓
$A_{FB}(K^+ \to \pi^+\mu^+\mu^-)$	✗	✗	✓	✗

The leptonic forward backward asymmetry can be useful to constrain new physics

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The LE effective Hamiltonian $s \to d$ *transitions*

◻ In SM

$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}}\lambda_t\left(\sum_{i=1}^{10} C_i O_i + \sum_{\ell=e,\mu,\tau} C^L_{\nu_\ell} O^L_{\nu_\ell}\right) \qquad \lambda_q = V_{qs}V^*_{qd}$$

Nucl. Phys. B548, 309 (1999)

- $s \to d\,\nu\bar{\nu}$ ***transitions***

$$C^L_{\nu_\ell} = \frac{1}{2\pi\sin^2\theta_W}\left(\frac{\lambda_c}{\lambda_t}X^\ell_c + X_t\right) \qquad O^L_{\nu_\ell} = \alpha\left(\bar{d}\gamma_\mu(1-\gamma_5)s\right)\left(\bar{\nu}_\ell\gamma^\mu(1-\gamma_5)\nu_\ell\right)$$

- $s \to d\ell^+\ell^-$ ***transitions***

Short-distance

$$O_7 = \frac{e}{4\pi}m_s\bar{d}\sigma_{\mu\nu}(1+\gamma_5)sF^{\mu\nu}$$

$$O_9 = \alpha\left(\bar{d}\gamma_\mu(1-\gamma_5)s\right)\left(\bar{\ell}^-\gamma^\mu\ell^+\right)$$

$$O_{10} = \alpha\left(\bar{d}\gamma_\mu(1-\gamma_5)s\right)\left(\bar{\ell}^-\gamma^\mu\gamma_5\ell^+\right)$$

Long-distance

$$\mathcal{M}_{\rm LD} = -\frac{e^2G_F}{q^2}\bar{B}_2\sigma_{\mu\nu}q^\nu(a+b\gamma_5)B_1\bar{\ell}^-\gamma^\mu\ell^+ - e^2G_F\bar{B}_2\gamma_\mu(c+d\gamma_5)B_1\bar{\ell}^-\gamma^\mu\ell^+$$

◻ In BSM (NP)

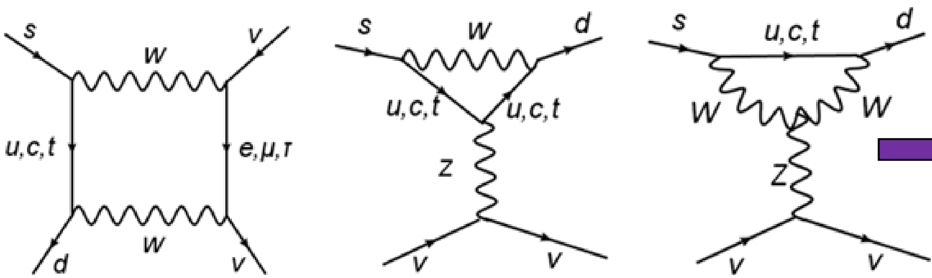
$\Sigma^+ \to p\gamma^*$

- The NP operators can be obtained by a **chiral flip** in the quark current, and one also has scalar, pseudoscalar and their primed operators.

$$O_S = \alpha\left(\bar{d}(1+\gamma_5)s\right)\left(\bar{\ell}^-\ell^+\right), \qquad O'_S = \alpha\left(\bar{d}(1-\gamma_5)s\right)\left(\bar{\ell}^-\ell^+\right),$$

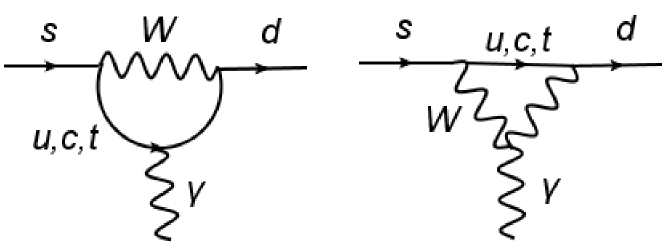
$$O_P = \alpha\left(\bar{d}(1+\gamma_5)s\right)\left(\bar{\ell}^-\gamma_5\ell^+\right), \qquad O'_P = \alpha\left(\bar{d}(1-\gamma_5)s\right)\left(\bar{\ell}^-\gamma_5\ell^+\right).$$

SM operators and Feynman diagrams for $s \to d\nu\bar{\nu}$ and $s \to d\mu^+\mu^-$ decays



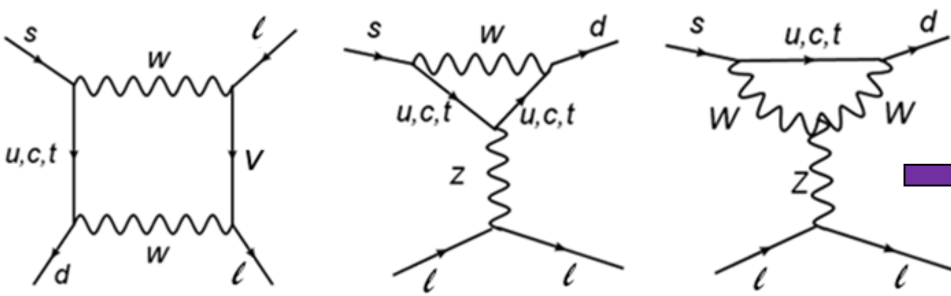
$s \to d\nu\bar{\nu}$ transitions:

$$\frac{G_F\lambda_t\alpha}{\sqrt{2}}C^L_{\nu_\ell}\left(\bar{d}\gamma_\mu(1-\gamma_5)s\right)\left(\bar{\nu}_\ell\gamma^\mu(1-\gamma_5)\nu_\ell\right)$$



$s \to d\mu^+\mu^-$ transitions:

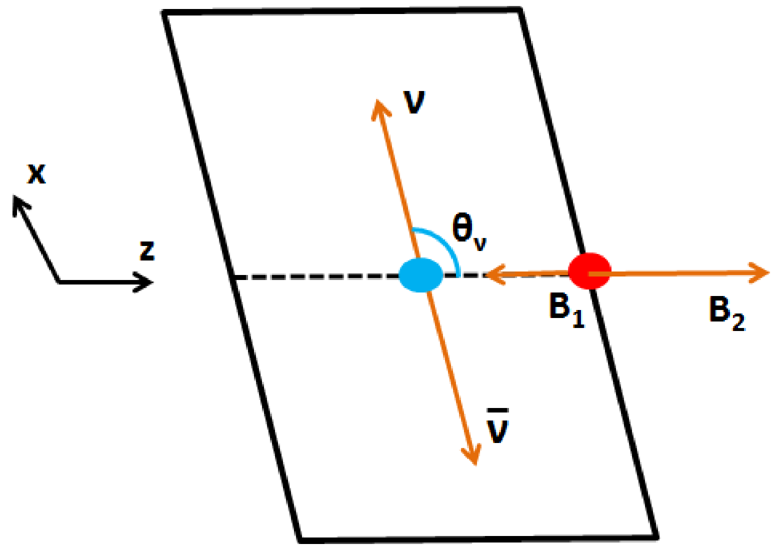
$$\frac{G_F\lambda_t}{\sqrt{2}}C_7\frac{e}{4\pi}m_s\bar{d}\sigma_{\mu\nu}(1+\gamma_5)sF^{\mu\nu}$$



$$\frac{G_F\lambda_t\alpha}{\sqrt{2}}C_{9(10)}\left(\bar{d}\gamma_\mu(1-\gamma_5)s\right)\left(\bar{\ell}^-\gamma^\mu(\gamma_5)\ell^+\right)$$

- **Wilson coefficient $C_i(\mu)$ are calculated in PT at $\mu=m_W$ and rescaled to $\mu=1$ GeV.**
- **O_T does not contribute to $s \to d\mu^+\mu^-$ transitions PRL.113.241802.**

Decay mode 1: $B_1 \to B_2 \nu \bar{\nu}$



$$\Delta = M_1 - M_2$$

$$\delta = \Delta / M_1$$

The total decay width in the presence of NP, expanded up to NLO in δ, can be written as

$$\Gamma = \sum_{\ell=e,\mu,\tau} \frac{\alpha^2 G_F^2 |\lambda_t|^2 f_1(0)^2 \Delta^5}{60\pi^3} \cdot \left[\left(1 - \frac{3}{2}\delta\right) \left|C_{\nu_\ell}^L + C_{\nu_\ell}^R\right|^2 + 3\left(1 - \frac{3}{2}\delta\right) \frac{g_1(0)^2}{f_1(0)^2} \left|C_{\nu_\ell}^L - C_{\nu_\ell}^R\right|^2 + \mathcal{O}\left(\delta^2\right) \right]$$

- These decay channels are sensitive to vectorial (parity even) and axial-vectorial (parity odd) couplings of the $s \to d$ currents
- A reliable determination of the form factors is necessary to better control uncertainties

Form factors relevant to $B_1 \to B_2 \nu\bar{\nu}$

- **Following** *PRL114 (2015) 161802*, **the form factors are obtained from covariant baryon chiral perturbation theory up to one loop order, and thus providing model independent inputs**

$$f_1(0)^{\Lambda n} = -\sqrt{\frac{3}{2}} \cdot \left(1 + \delta f_1(0)^{\Lambda n}\right),$$

$$f_1(0)^{\Sigma^+ p} = -1 \cdot \left(1 + \delta f_1(0)^{\Sigma^+ p}\right),$$

$$f_1(0)^{\Xi^0 \Sigma^0} = -\sqrt{\frac{1}{2}} \cdot \left(1 + \delta f_1(0)^{\Xi^0 \Sigma^0}\right),$$

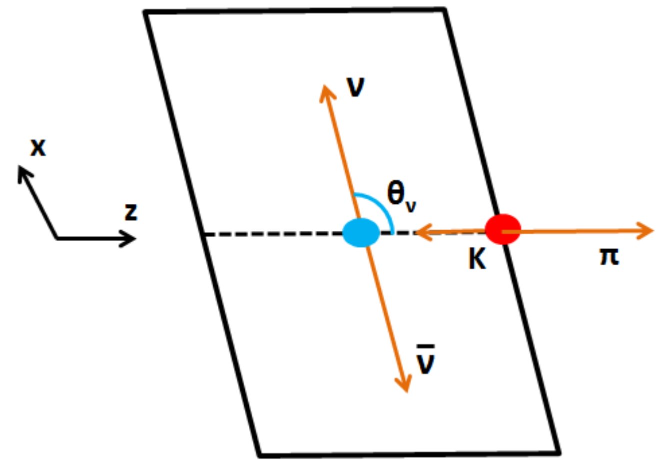
$$f_1(0)^{\Xi^0 \Lambda} = \sqrt{\frac{3}{2}} \cdot \left(1 + \delta f_1(0)^{\Xi^0 \Lambda^0}\right),$$

	Λn	$\Sigma^+ p$	$\Xi^0 \Sigma^0$	$\Xi^0 \Lambda$
$\delta f_1(0)$	$0.001^{+0.013}_{-0.010}$	$0.087^{+0.042}_{-0.031}$	$0.017^{+0.022}_{-0.016}$	$0.040^{+0.028}_{-0.021}$
$g_1(0)$	$-0.89(2)$	$0.33(2)$	$-0.86(3)$	$0.24(4)$

L. S. Geng et al., Phys. Rev. D 79, 094022 (2009)
T. Ledwig et al., Phys. Rev. D 90, 054502 (2014)

Decay mode 2: $K \to \pi\nu\bar{\nu}$

- **Isospin symmetry relate the form factors in the FCNC processes to those of the well-known charge-current decays**



$$\langle\pi^+|(\bar{s}d)_{V-A}|K^+\rangle = \sqrt{2}\langle\pi^0|(\bar{s}u)_{V-A}|K^+\rangle,$$

$$\langle\pi^0|(\bar{s}d)_{V-A}|K^0\rangle = \langle\pi^0|(\bar{s}u)_{V-A}|K^+\rangle,$$

- **Branching ratios of two K → π ν $\bar{\nu}$ processes in the presence of NP are**

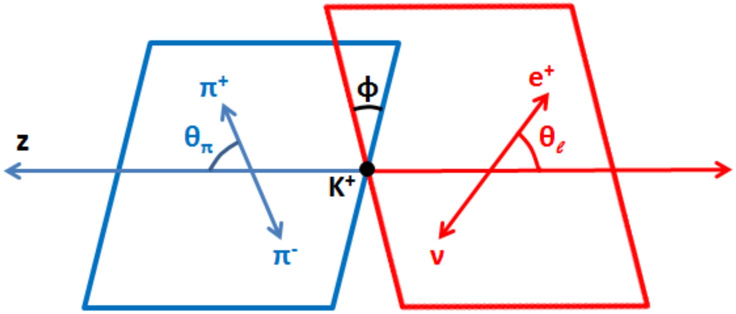
$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = \frac{2\alpha^2|\lambda_t|^2\mathrm{BR}(K^+ \to \pi^0 e^+\nu_e)}{|V_{us}|^2}\sum_{\ell=e,\mu,\tau}|C^L_{\nu_\ell} + C^R_{\nu_\ell}|^2,$$

$$\mathrm{BR}(K_L \to \pi^0\nu\bar{\nu}) = \frac{2\alpha^2\tau_{K_L}\mathrm{BR}(K^+ \to \pi^0 e^+\nu_e)}{\tau_{K^+}|V_{us}|^2}\sum_{\ell=e,\mu,\tau}\left(\mathrm{Im}[(C^L_{\nu_\ell} + C^R_{\nu_\ell})\lambda_t^*]\right)^2,$$

- The 3-body decay channels are only sensitive to **vectorial couplings** of the $s \to d$ currents
- Uncertainties are mainly from the measurements of the charged current $K^+ \to \pi^0 \mathrm{e}^+ \upsilon$ decay.

Decay mode 3: $K \to \pi\pi\nu\bar{\nu}$ (I)

- **Isospin symmetry relate the form factors in the FCNC processes to those of the well-known charged-current decay**



$$\langle \pi^+\pi^0 | (\bar{s}d)_{V-A} | K^+ \rangle = -\sqrt{2} \langle (\pi^+\pi^-)_{I=1} | (\bar{s}u)_{V-A} | K^+ \rangle,$$

$$\langle \pi^0\pi^0 | (\bar{s}d)_{V-A} | K^0 \rangle = \langle (\pi^+\pi^-)_{I=0} | (\bar{s}u)_{V-A} | K^+ \rangle.$$

- **Four-body differential decay rate in terms of 9 angular coefficients**

$$\frac{d^5\Gamma}{ds_\pi ds_\ell d(\cos\theta_\pi) d(\cos\theta_\ell) d\phi} = \alpha^2 G_F^2 |\lambda_t|^2 N(s_\pi, s_\ell) J_5(s_\pi, s_\ell, \theta_\pi, \theta_\ell, \phi)$$

$$J_5 = I_1 + I_2 \cos 2\theta_\ell + I_3 \sin^2\theta_\ell \cos 2\phi + I_4 \sin 2\theta_\ell \cos\phi + I_5 \sin\theta_\ell \cos\phi$$

$$+ I_6 \cos\theta_\ell + I_7 \sin\theta_\ell \sin\phi + I_8 \sin 2\theta_\ell \sin\phi + I_9 \sin^2\theta_\ell \sin 2\phi,$$

- After integrating out the angle θ_ℓ and ϕ, only I_1 and I_2 contribute to the **total decay width**, i.e.,

$$\Gamma = \int_{4m_\pi^2}^{m_K^2} \int_0^{(m_K - \sqrt{s_\pi})^2} \int_{-1}^{1} \alpha^2 G_F^2 |\lambda_t|^2 N(s_\pi, s_\ell) \cdot 4\pi (I_1 - \frac{1}{3} I_2) \cdot ds_\pi ds_\ell d(\cos\theta_\pi).$$

Decay mode 3: $K \to \pi\pi\nu\bar{\nu}$ (II)

- I_1 and I_2 in terms of helicity amplitudes

$$I_1 = \frac{s_\ell}{2}\left(3|H_+^V|^2 + 3|H_-^V|^2 + 2|H_0^V|^2 + 3|H_+^A|^2 + 3|H_-^A|^2 + 2|H_0^A|^2\right),$$
$$I_2 = \frac{s_\ell}{2}\left(|H_+^V|^2 + |H_-^V|^2 - 2|H_0^V|^2 + |H_+^A|^2 + |H_-^A|^2 - 2|H_0^A|^2\right).$$

- Helicity amplitudes for $K^+ \to \pi^+\pi^0 \nu\bar{\nu}$

$$H_0^{V(A)} = \frac{i(C_{\nu_\ell}^L - C_{\nu_\ell}^R)\left(4F \cdot m_K^2 X + G \cdot \sigma_\pi \cos\theta_\pi \left(-(s_l - s_\pi)^2 + m_K^4 + 4X^2\right)\right)}{4m_K^3\sqrt{s_l}},$$

$$H_+^{V(A)} = -\frac{i\sqrt{s_\pi}\sigma_\pi \sin\theta_\pi \left(G \cdot m_K^2 (C_{\nu_\ell}^L - C_{\nu_\ell}^R) + H \cdot X (C_{\nu_\ell}^L + C_{\nu_\ell}^R)\right)}{\sqrt{2}m_K^3},$$

$$H_-^{V(A)} = \frac{i\sqrt{s_\pi}\sigma_\pi \sin\theta_\pi \left(G \cdot m_K^2 (C_{\nu_\ell}^L - C_{\nu_\ell}^R) - H \cdot X (C_{\nu_\ell}^L + C_{\nu_\ell}^R)\right)}{\sqrt{2}m_K^3},$$

- Helicity amplitudes for $K_L \to \pi^0\pi^0 \nu\bar{\nu}$

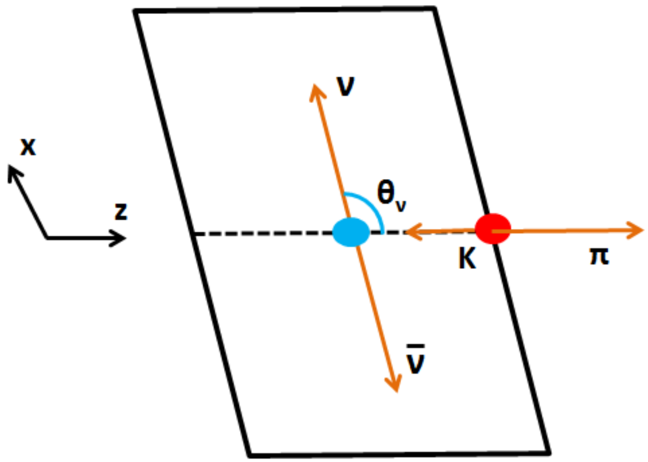
$$H_0^{V(A)} = \frac{i\sqrt{2}X \cdot F \cdot \mathrm{Re}\left[(C_{\nu_\ell}^L - C_{\nu_\ell}^R)\lambda_t^*\right]}{m_K\sqrt{s_l}},$$

$$H_+^{V(A)} = 0,$$

$$H_-^{V(A)} = 0,$$

Decay modes 4&5: $K_L \to \mu^+\mu^-$ and $K^+ \to \pi^+\mu^+\mu^-$ (I)

- **Branching ratio of $K_L \to \mu^+\mu^-$** JHEP 08, 088 (2006)



$$\mathrm{BR}(K_L \to \mu^+\mu^-) = \left[6.7 + \left(\frac{0.08\alpha\pi^2}{\sqrt{2}G_F m_s m_\mu} \mathrm{Im}\left[\lambda_t^*(C_S - C_S')\right] \right)^2 + \left(1.1(C_{10}' - C_{10}) + \frac{0.10\alpha\pi^2}{\sqrt{2}G_F m_s m_\mu} \mathrm{Re}\left[\lambda_t^*(C_P - C_P')\right] - 0.2 \pm 0.4^{+0.5}_{-0.5} \right)^2 \right] 10^{-9},$$

- **For the $K^+ \to \pi^+\mu^+\mu^-$ decay**

$$\frac{d\Gamma}{dq^2 d\cos\theta_\mu} = \Gamma_0 \beta_\mu \sqrt{\lambda(q^2)} \left[a(q^2) + b(q^2)\cos\theta_\mu + c(q^2)\cos^2\theta_\mu \right]$$

$$\begin{aligned} a(q^2) =& q^2 \left(\beta_\mu^2 \left|F_S(q^2)\right|^2 + \left|F_P(q^2)\right|^2 \right) + \frac{\lambda(q^2)}{4} \left(\left|F_A(q^2)\right|^2 + \left|F_V(q^2)\right|^2 \right) \\ &+ 4m_\mu^2 m_{K^+}^2 \left|F_A(q^2)\right|^2 + 2m_\mu \left(m_{K^+}^2 - m_{\pi^+}^2 + q^2 \right) \mathrm{Re}\left[F_P(q^2) F_A(q^2)^* \right], \\ b(q^2) =& 2m_\mu \beta_\mu \sqrt{\lambda(q^2)} \mathrm{Re}\left[F_S(q^2) F_V(q^2)^* \right], \\ c(q^2) =& -\frac{\beta_\mu^2 \lambda(q^2)}{4} \left(\left|F_A(q^2)\right|^2 + \left|F_V(q^2)\right|^2 \right), \end{aligned}$$

Decay modes 4&5: $K_L \to \mu^+\mu^-$ and $K^+ \to \pi^+\mu^+\mu^-$ (II)

$$F_V(q^2) = \left(C_9 + C_9'\right) f_+(q^2) + \frac{2m_s}{m_{K^+} + m_{\pi^+}} f_T(q^2) C_7 + F_{V\gamma}(q^2),$$

$$F_A(q^2) = \left(C_{10} + C_{10}'\right) f_+(q^2),$$

$$F_S(q^2) = \frac{m_{K^+}^2 - m_{\pi^+}^2}{2(m_s - m_d)} f_0(q^2)\left(C_S + C_S'\right),$$

$$F_P(q^2) = \frac{m_{K^+}^2 - m_{\pi^+}^2}{2(m_s - m_d)} f_0(q^2)\left(C_P + C_P'\right) - m_\mu \left(C_{10} + C_{10}'\right)\left[f_+(q^2) - \frac{m_{K^+}^2 - m_{\pi^+}^2}{q^2}\left(f_0(q^2) - f_+(q^2)\right)\right]$$

where $\Gamma_0 = \frac{G_F^2 \alpha^2 |\lambda_t|^2}{512\pi^3 m_{K^+}^3}$, $\beta_\mu = \sqrt{1 - \frac{4m_\mu^2}{q^2}}$ and $\lambda(q^2) = q^4 + m_{K^+}^4 + m_{\pi^+}^4 - 2(m_{K^+}^2 m_{\pi^+}^2 + m_{K^+}^2 q^2 + m_{\pi^+}^2 q^2)$

Long-distance contribution $F_{V\gamma}(q^2) = -\left[\left(\alpha_+ + \beta_+ \frac{q^2}{m_{K^+}^2}\right) + \frac{1}{m_{K^+}^2 G_F} W_+^{\pi\pi}(q^2)\right] \frac{\sqrt{2}}{2\pi\lambda_t^*}$, JHEP 08, 004 (1998)

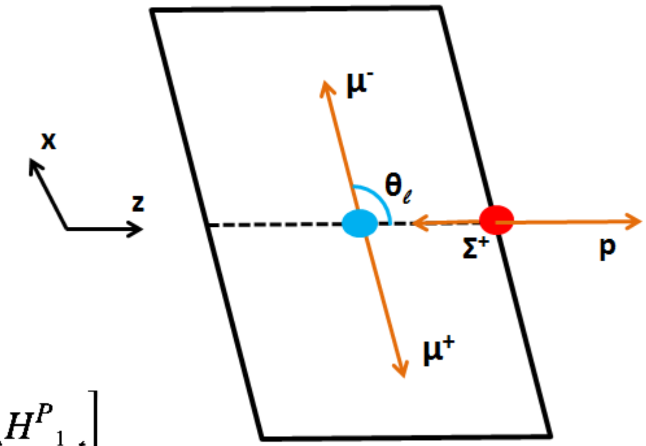
The branching ratio and forward-backward asymmetry are defined as

$$\mathrm{BR} = 2\Gamma_0 \int_{q^2_{\min}}^{q^2_{\max}} \beta_\mu \sqrt{\lambda(q^2)} \left(a(q^2) + \frac{1}{3} c(q^3)\right),$$

$$A_{FB} = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \beta_\mu \sqrt{\lambda(q^2)}\, b(q^2)}{2 \int_{q^2_{\min}}^{q^2_{\max}} \beta_\mu \sqrt{\lambda(q^2)} \left(a(q^2) + \frac{1}{3} c(q^3)\right)},$$

Decay mode 6: of $\Sigma^+ \to p\mu^+\mu^-$(I)

Helicity basis allows for an explicit separation of long and short range contributions



$$\frac{d\Gamma}{dq^2 d\cos\theta_\ell} = \mathcal{N}(q^2)\left[I_1(q^2) + I_2(q^2)\cos\theta_\ell + I_3(q^2)\cos^2\theta_\ell\right]$$

$$\begin{aligned}
I_1(q^2) =& \left(|H^A_{\frac{1}{2},t}|^2 + |H^A_{-\frac{1}{2},t}|^2\right)\cdot 8m_\ell^2 + \left(|H^S_{\frac{1}{2},t}|^2 + |H^S_{-\frac{1}{2},t}|^2\right)\cdot\left(2q^2 - 5m_\ell^2\right) \\
&+ \left(|H^P_{\frac{1}{2},t}|^2 + |H^P_{-\frac{1}{2},t}|^2\right)\cdot\left(2q^2 - 3m_\ell^2\right) - 8m_\ell\sqrt{q^2}\cdot\mathrm{Re}\left[H^{A*}_{\frac{1}{2},t}H^P_{\frac{1}{2},t} + H^{A*}_{-\frac{1}{2},t}H^P_{-\frac{1}{2},t}\right] \\
&+ \left(|H^V_{\frac{1}{2},0}|^2 + |H^V_{-\frac{1}{2},0}|^2\right)\cdot\left(8m_\ell^2 + 2q^2\beta^2\right) + \left(|H^A_{\frac{1}{2},0}|^2 + |H^A_{-\frac{1}{2},0}|^2\right)\cdot 2q^2\beta^2 \\
&+ \left(|H^V_{\frac{1}{2},+}|^2 + |H^V_{-\frac{1}{2},-}|^2\right)\cdot\left(8m_\ell^2 + q^2\beta^2\right) + \left(|H^A_{\frac{1}{2},+}|^2 + |H^A_{-\frac{1}{2},-}|^2\right)\cdot q^2\beta^2,
\end{aligned}$$

Short-distance

$$I_2(q^2) = -8m_\ell\sqrt{q^2}\beta\cdot\mathrm{Re}\left[H^S_{\frac{1}{2},t}H^{V*}_{\frac{1}{2},0} + H^S_{-\frac{1}{2},t}H^{V*}_{-\frac{1}{2},0}\right] - 4q^2\beta\cdot\mathrm{Re}\left[H^A_{\frac{1}{2},+}H^{V*}_{\frac{1}{2},+} - H^A_{-\frac{1}{2},-}H^{V*}_{-\frac{1}{2},-}\right]$$

$$\begin{aligned}
I_3(q^2) =& \left(|H^V_{\frac{1}{2},0}|^2 + |H^V_{-\frac{1}{2},0}|^2 + |H^A_{\frac{1}{2},0}|^2 + |H^A_{-\frac{1}{2},0}|^2\right)\cdot\left(-2q^2\beta^2\right) \\
&+ \left(|H^V_{\frac{1}{2},+}|^2 + |H^V_{-\frac{1}{2},-}|^2 + |H^A_{\frac{1}{2},+}|^2 + |H^A_{-\frac{1}{2},-}|^2\right)\cdot q^2\beta^2,
\end{aligned}$$

H^V includes long-distance contributions, and $H^{A,S,P}$ only contain short-distance contributions

$$\begin{aligned}
H^V_{\frac{1}{2},0} =& -\frac{iC_7 m_s\left[\sqrt{Q_-}\left(g_T(q^2) - g_T^{(1)}(q^2)\frac{M_1+M_2}{M_1} - g_T^{(2)}(q^2)\frac{Q_+}{M_1^2}\right) + \sqrt{Q_+}\left(g_{T5}(q^2) + g_{T5}^{(1)}(q^2)\frac{M_1-M_2}{M_1} - g_T^{(2)}(q^2)\frac{Q_-}{M_1^2}\right)\right]}{2\pi\sqrt{q^2}} \\
&+ \frac{\sqrt{Q_-}\left(C_9 + C_9'\right)\left[f_1(q^2)(M_1+M_2) + f_2(q^2)\frac{q^2}{M_1}\right]}{\sqrt{q^2}} + \frac{\sqrt{Q_+}\left(C_9 - C_9'\right)\left[g_1(q^2)(M_1-M_2) - g_2(q^2)\frac{q^2}{M_1}\right]}{\sqrt{q^2}} \\
&+ \frac{4\sqrt{2}\pi[-a\sqrt{Q_-} - b\sqrt{Q_+} - c\sqrt{Q_-}(M_1+M_2) + d\sqrt{Q_+}(M_1-M_2)]}{\sqrt{q^2}\lambda_t},
\end{aligned}$$

Long-distance

Decay mode 6: $\Sigma^+ \to p\mu^+\mu^-$ (II)

Decay width expanded in δ reads

$$\frac{d\Gamma}{d\cos\theta_\ell} = \mathcal{N}\left[I_1 + I_2\cos\theta_\ell + I_3\cos^2\theta_\ell\right]$$

$$\begin{aligned}
I_2 =& \left(C_S + C_S'\right)\mathrm{Re}\left[(-0.08i)\,\frac{f_S(0)g_T(0)}{f_1(0)f_1(0)}\delta\cdot C_7^* - 0.26\left(1-\frac{3}{2}\delta\right)\frac{f_S(0)}{f_1(0)}\left(C_9 + C_9'\right)^*\right.\\
&\left.+\left(\frac{2.32}{\Delta f_1(0)}\delta\right)\frac{f_S(0)}{f_1(0)}\left(\frac{a}{\lambda_t}\right)^* + \left(\frac{4.64}{f_1(0)}\right)\left(1-\frac{3}{2}\delta\right)\frac{f_S(0)}{f_1(0)}\left(\frac{c}{\lambda_t}\right)^*\right]\\
&+\left(C_S - C_S'\right)\mathrm{Re}\left[(-0.08i)\,\frac{g_P(0)g_{T5}(0)}{f_1(0)f_1(0)}\delta\cdot C_7^* - 0.13\delta\frac{g_P(0)}{f_1(0)}\left(C_9 - C_9'\right)^*\right.\\
&\left.+\left(\frac{2.32}{\Delta f_1(0)}\delta\right)\frac{g_P(0)}{f_1(0)}\left(\frac{b}{\lambda_t}\right)^* - \left(\frac{2.32}{f_1(0)}\delta\right)\frac{g_P(0)}{f_1(0)}\left(\frac{d}{\lambda_t}\right)^*\right]\\
&+\left(C_{10} + C_{10}'\right)\mathrm{Re}\left[(-0.01i)\,\frac{g_{T5}(0)}{f_1(0)}\delta\cdot C_7^* - 0.26\delta\frac{g_1(0)}{f_1(0)}\left(C_9 - C_9'\right)^*\right.\\
&+\left(\frac{5.51}{\Delta f_1(0)}\delta\right)\left(\frac{b}{\lambda_t}\right)^* - \left(\frac{4.68}{f_1(0)}\delta\right)\left(\frac{d}{\lambda_t}\right)^* + (-0.23i)\,\frac{f_2(0)g_{T5}(0)}{f_1(0)f_1(0)}\delta\cdot C_7^*\\
&\left.-0.53\delta\frac{f_2(0)g_1(0)}{f_1(0)f_1(0)}\left(C_9 - C_9'\right)^* + \left(\frac{11.02}{\Delta f_1(0)}\delta\right)\frac{f_2(0)}{f_1(0)}\left(\frac{b}{\lambda_t}\right)^* - \left(\frac{9.36}{f_1(0)}\delta\right)\frac{f_2(0)}{f_1(0)}\left(\frac{d}{\lambda_t}\right)^*\right]\\
&+\left(C_{10} - C_{10}'\right)\mathrm{Re}\left[(-0.23i)\,\frac{g_1(0)g_T(0)}{f_1(0)f_1(0)}\delta\cdot C_7^* - 0.26\delta\frac{g_1(0)}{f_1(0)}\left(C_9 + C_9'\right)^*\right.\\
&\left.-0.53\delta\frac{g_1(0)f_2(0)}{f_1(0)f_1(0)}\left(C_9 + C_9'\right)^* + \left(\frac{11.02}{\Delta f_1(0)}\right)\frac{g_1(0)}{f_1(0)}\left(1-\frac{3}{2}\delta\right)\left(\frac{a}{\lambda_t}\right)^* + \left(\frac{4.68}{f_1(0)}\delta\right)\frac{g_1(0)}{f_1(0)}\left(\frac{c}{\lambda_t}\right)^*\right],
\end{aligned}$$

$$\begin{aligned}
I_1 =& \left[\left(1-\frac{3}{2}\delta\right) + 1.71\frac{f_2(0)}{f_1(0)}\delta\right]\left|C_{10} + C_{10}'\right|^2 + \left[0.35\frac{g_1(0)^2}{f_1(0)^2}\left(1-\frac{3}{2}\delta\right)\right]\left|C_{10} - C_{10}'\right|^2\\
&+\left[0.49\frac{f_S(0)^2}{f_1(0)^2}\left(1-\frac{3}{2}\delta\right)\right]\left|C_S + C_S'\right|^2 + \left(0.01\frac{g_P(0)^2}{f_1(0)^2}\delta\right)\left|C_S - C_S'\right|^2\\
&+\left(\frac{137.06}{\Delta^2 f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{a}{\lambda_t}\right|^2 + \left(\frac{58.50}{f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{c}{\lambda_t}\right|^2 + \left(\frac{168.52}{\Delta f_1(0)^2}\delta\right)\mathrm{Re}\left[\frac{ac^*}{\lambda_t\lambda_t^*}\right]\\
&+\left(\frac{1221.67}{\Delta^2 f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{b}{\lambda_t}\right|^2 + \left(\frac{974.60}{f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{d}{\lambda_t}\right|^2 - \left(\frac{2199.79}{\Delta f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\mathrm{Re}\left[\frac{bd^*}{\lambda_t\lambda_t^*}\right]
\end{aligned}$$

$$\begin{aligned}
I_3 =& 0.2\left(1-\frac{3}{2}\delta\right)\left|C_{10} + C_{10}'\right|^2 - 0.02\frac{g_1(0)^2}{f_1(0)^2}\left(1-\frac{3}{2}\delta\right)\left|C_{10} - C_{10}'\right|^2\\
&+\left(\frac{8.30}{\Delta^2 f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{a}{\lambda_t}\right|^2 - \left(\frac{6.99}{f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{c}{\lambda_t}\right|^2\\
&+\left(\frac{9.00}{\Delta^2 f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{b}{\lambda_t}\right|^2 - \left(\frac{7.00}{f_1(0)^2}\right)\left(1-\frac{3}{2}\delta\right)\left|\frac{d}{\lambda_t}\right|^2,
\end{aligned}$$

where $\Delta = M_1 - M_2$ and $\mathcal{N} = \dfrac{G_F^2\alpha^2|\lambda_t|^2\Delta^5 f_1(0)^2}{2048\pi^3}$.

$$\boxed{\begin{aligned}\mathrm{BR} &= 2\tau_{B_1}\mathcal{N}\left(I_1 + \frac{1}{3}I_3\right),\\ A_{FB} &= \frac{I_2}{I_1 + \frac{1}{3}I_3}.\end{aligned}}$$

$f_2(0)$ is relevant for A_{FB}.

Contents

Five $s \to d\nu\bar{\nu}$ processes

Kaon	$K^+\pi^+$	$K_L\pi^0$	$K^+\pi^+\pi^0$	$K_L\pi^0\pi^0$
SM	$8.17(6)\ 10^{-11}$	$2.60(2) \times 10^{-11}$	$7.90(34) \times 10^{-15}$	$3.11(6) \times 10^{-13}$
Expt.	$< 1.78 \times 10^{-10}$	$< 3.0 \times 10^{-9}$	$< 4.3 \times 10^{-5}$	$< 8.1 \times 10^{-7}$
$\delta C^L_{\nu_\ell} + C^R_{\nu_\ell}$	$(-3.4, 0.7)$	$(-12.0, 10.0)$	$(-2.3, 2.3) \times 10^4$	✗
$\delta C^L_{\nu_\ell} - C^R_{\nu_\ell}$	✗	✗	$(-1.1, 1.1) \times 10^5$	$(-3.0, 3.0) \times 10^3$

Hyperon		Λn	$\Sigma^+ p$	$\Xi^0\Sigma^0$	$\Xi^0\Lambda$
	SM-NLO	$6.0(2) \times 10^{-13}$	$3.8(2) \times 10^{-13}$	$8.4(5) \times 10^{-14}$	$5.7(3) \times 10^{-13}$
BESIII [11]	data	$< 0.3\ 10^{-6}$	$< 0.4\ 10^{-6}$	$< 0.9\ 10^{-6}$	$< 0.8\ 10^{-6}$
	$\delta C^L_{\nu_\ell} + C^R_{\nu_\ell}$	$(-1.6, 1.6) \times 10^3$	$(-1.7, 1.7) \times 10^3$	$(-1.1, 1.1) \times 10^4$	$(-1.8, 1.8) \times 10^3$
	$\delta C^L_{\nu_\ell} - C^R_{\nu_\ell}$	$(-1.3, 1.3) \times 10^3$	$(-3.3, 3.3) \times 10^3$	$(-5.4, 5.4) \times 10^3$	$(-7.4, 7.4) \times 10^3$
Hyperon lifetime [51]	data	$< 8.5\ 10^{-3}$	$< 4.9\ 10^{-3}$	$< 2.3\ 10^{-4}$	$< 2.3\ 10^{-4}$
	$\delta C^L_{\nu_\ell} + C^R_{\nu_\ell}$	$(-2.7, 2.7) \times 10^5$	$(-1.9, 1.9) \times 10^5$	$(-1.7, 1.7) \times 10^5$	$(-3.0, 3.0) \times 10^4$
	$\delta C^L_{\nu_\ell} - C^R_{\nu_\ell}$	$(-2.2, 2.2) \times 10^5$	$(-3.7, 3.7)\ 10^5$	$(-8.5, 8.5) \times 10^4$	$(-1.3, 1.3) \times 10^5$

- $\delta C^L_{\nu l} + C^R_{\nu l}$ **is constrained more stringently by the kaon modes**
- $B_1 \to B_2 \mathcal{V}\bar{\mathcal{V}}$ **are better than their kaon siblings to constrain** $\delta C^L_{\nu l} - C^R_{\nu l}$

Comparison of the SM predictions for $B_1 \to B_2 \nu\bar{\nu}$

	Λn	$\Sigma^+ p$	$\Xi^0\Sigma^0$	$\Xi^0\Lambda$
SM-NLO	$6.0(2) \times 10^{-13}$	$3.8(2) \times 10^{-13}$	$8.4(5) \times 10^{-14}$	$5.7(3) \times 10^{-13}$
In Ref. [19]	7.1×10^{-13}	4.3×10^{-13}	1.0×10^{-13}	6.3×10^{-13}
In Ref. [53]	1.98×10^{-12}	5.01×10^{-13}	1.24×10^{-13}	7.35×10^{-13}

[19] Jusak Tandean, JHEP 04, 104 (2019)
[53] Xiao-Hui Hu et al., Chin. Phys. C 43, 093104 (2019)

$s \to d\mu^+\mu^-$

$\Sigma^+ \to p\mu^+\mu^-$

	$a\,(\mathrm{GeV}^2) \times 10^{-3}$	$b\,(\mathrm{GeV}^2) \times 10^{-3}$	$\mathrm{BR} \times 10^8$	$A_{FB} \times 10^5$	$\mathrm{BR} \times 10^8$ [19, 20]	$A_{FB} \times 10^5$ [19, 20]
Case 1	$13.3 + 2.84i$	$-6.0 - 1.83i$	1.7	−1.7(2)	1.6	3.7
Case 2	$-13.3 + 2.84i$	$6.0 - 1.83i$	3.5	0.3(1)	3.5	−1.4
Case 3	$6.0 + 2.84i$	$-13.3 - 1.83i$	5.5	0.4(0)	5.1	0.9
Case 4	$-6.0 + 2.84i$	$13.3 - 1.83i$	9.3	−0.4(0)	9.1	−0.3

	$\mathrm{BR}(K_L \to \mu^+\mu^-)$	$\lvert A_{FB}\rvert(K^+ \to \pi^+\mu^+\mu^-)$	$\lvert A_{FB}\rvert(\Sigma^+ \to p\mu^+\mu^-)$
SM	$(7.64 \pm 1.22)\, 10^{-9}$	0	$(-1.7 \sim 0.4)\, 10^{-5}$
Expt.	$(6.84 \pm 0.11)\, 10^{-9}$	$< 2.3\, 10^{-2}$ (90% C.L.)	$< 2.3\, 10^{-2}$ (90% C.L.)
$C_S + C'_S$	✗	$(-3.05, 3.05)$	$(-5.3, 5.3) \times 10^3$
$C_S - C'_S$	$(-0.12, 0.12)$	✗	$(-1.7, 1.7) \times 10^3$
$\delta C_{10} + C'_{10}$	✗	✗	$(-2.2, 2.2) \times 10^3$
$\delta C_{10} - C'_{10}$	$(-2.35, 0.59)$	✗	$(-1.4, 1.4) \times 10^3$

- **The contribution of the form factor $f_2(0)$ can be relevant for AFB.**
- **Current kaon bounds except for the $\delta C_{10} + C'_{10}$ scenario are a few orders of magnitude better than those of $\Sigma^+ \to p\mu^+\mu^-$ if measured up to the same precision.**

[19] X.G. He et al., PRD72, 074003 (2005)
[20] X.G. He et al., JHEP 10, 040 (2018)

Summary

- For the $s \to d\nu\bar{\nu}$ transitions, $\delta C^L_{\nu l} + C^R_{\nu l}$ can be determined well by the kaon modes but the $B_1 \to B_2\nu\bar{\nu}$ modes are better than their kaon counterparts for the constraint on $\delta C^L_{\nu l} - C^R_{\nu l}$.

- For the $s \to d\mu^+\mu^-$ transitions, current kaon bounds are a few orders of magnitude better than those of $\Sigma^+ \to p\mu^+\mu^-$ if they are measured up to the same precision, except for the $\delta C_{10} + C'_{10}$ scenario. In addition, the contribution of the form factor $f_2(0)$ is relevant for A_{FB}.

Outlook

- For the $s \to d\nu\bar{\nu}$ transitions, measurements of $B_1 \to B_2\nu\bar{\nu}$ decays can help better constrain the axial-vectorial coupling $\delta C^{L}_{\nu l} - C^{R}_{\nu l}$.

- For the $\Sigma^+ \to p\mu^+\mu^-$ decay, a measurement of leptonic forward-backward asymmetry A_{FB} can help constrain $\delta C_{10} + C'_{10}$.

BESIII + LHCb → CEPC

北京航空航天大學
BEIHANG UNIVERSITY

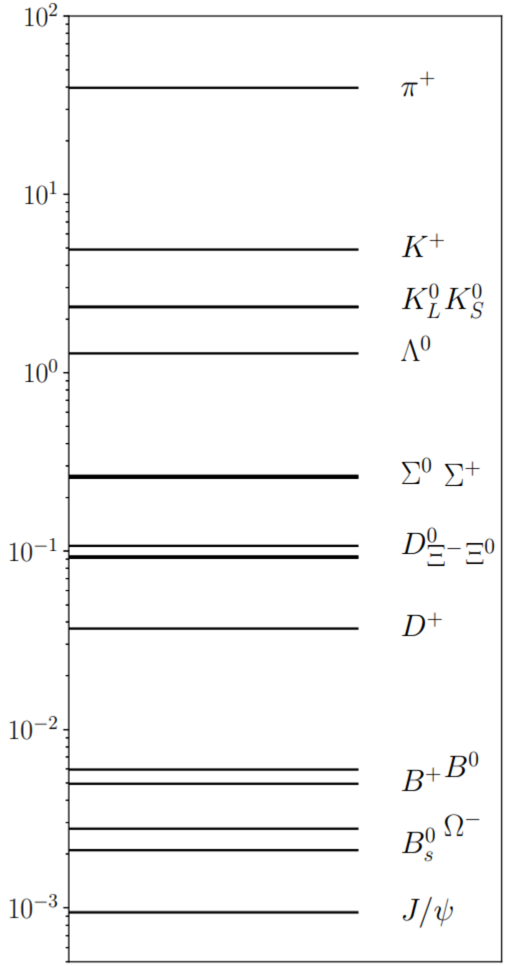
Thanks for your attention！

Xiao-Gang He, Jusak Tandean, G. Valencia, PRD72, 074003 (2005)

TABLE I. Branching ratios of $\Sigma^+ \to p\mu^+\mu^-$, pe^+e^- in the standard model. The unbracketed branching ratios receive contributions from all the form factors, with the expressions in Eq. (B2) [Eq. (B8)] for the imaginary parts contributing to the numbers in the first (last) four rows. Within each pair of square brackets, the first number has been obtained with $c = d = 0$, and the second with only the real parts of all the form factors.

Rea (MeV)	Reb (MeV)	$10^8\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-)$	$10^6\mathcal{B}(\Sigma^+ \to pe^+e^-)$
13.3	−6.0	1.6 [2.2, 1.3]	9.1 [9.2, 8.6]
−13.3	6.0	3.4 [2.2, 3.1]	9.4 [9.2, 8.8]
6.0	−13.3	5.1 [6.7, 4.7]	9.6 [9.8, 9.0]
−6.0	13.3	9.0 [6.7, 8.6]	10.1 [9.8, 9.5]
11.1	−7.3	2.3 [2.9, 1.5]	9.3 [9.3, 7.2]
−11.1	7.3	4.5 [2.9, 3.7]	9.6 [9.3, 7.5]
7.3	−11.1	4.0 [5.1, 3.2]	9.5 [9.6, 7.4]
−7.3	11.1	7.3 [5.1, 6.4]	10.0 [9.6, 7.8]

Bright future ahead



Multiplicity of particles produced in a single pp interaction at √ s = 13 TeV within LHCb acceptance.

Channel	$\mathcal{R}$	ϵ_L	ϵ_D	$\sigma_L(\mathrm{MeV}/c^2)$	$\sigma_D(\mathrm{MeV}/c^2)$
$K_S^0 \to \mu^+\mu^-$	1	1.0 (1.0)	1.8 (1.8)	~ 3.0	~ 8.0
$K_S^0 \to \pi^+\pi^-$	1	1.1 (0.30)	1.9 (0.91)	~ 2.5	~ 7.0
$K_S^0 \to \pi^0\mu^+\mu^-$	1	0.93 (0.93)	1.5 (1.5)	~ 35	~ 45
$K_S^0 \to \gamma\mu^+\mu^-$	1	0.85 (0.85)	1.4 (1.4)	~ 60	~ 60
$K_S^0 \to \mu^+\mu^-\mu^+\mu^-$	1	0.37 (0.37)	1.1 (1.1)	~ 1.0	~ 6.0
$K_L^0 \to \mu^+\mu^-$	~ 1	2.7 (2.7) $\times 10^{-3}$	0.014 (0.014)	~ 3.0	~ 7.0
$K^+ \to \pi^+\pi^+\pi^-$	~ 2	9.0 (0.75) $\times 10^{-3}$	41 (8.6) $\times 10^{-3}$	~ 1.0	~ 4.0
$K^+ \to \pi^+\mu^+\mu^-$	~ 2	6.3 (2.3) $\times 10^{-3}$	0.030 (0.014)	~ 1.5	~ 4.5
$\Sigma^+ \to p\mu^+\mu^-$	~ 0.13	0.28 (0.28)	0.64 (0.64)	~ 1.0	~ 3.0
$\Lambda \to p\pi^-$	~ 0.45	0.41 (0.075)	1.3 (0.39)	~ 1.5	~ 5.0
$\Lambda \to p\mu^-\bar{\nu}_\mu$	~ 0.45	0.32 (0.31)	0.88 (0.86)	–	–
$\Xi^- \to \Lambda\mu^-\bar{\nu}_\mu$	~ 0.04	39 (5.7) $\times 10^{-3}$	0.27 (0.09)	–	–
$\Xi^- \to \Sigma^0\mu^-\bar{\nu}_\mu$	~ 0.03	24 (4.9) $\times 10^{-3}$	0.21 (0.068)	–	–
$\Xi^- \to p\pi^-\pi^-$	~ 0.03	0.41(0.05)	0.94 (0.20)	~ 3.0	~ 9.0
$\Xi^0 \to p\pi^-$	~ 0.03	1.0 (0.48)	2.0 (1.3)	~ 5.0	~ 10
$\Omega^- \to \Lambda\pi^-$	~ 0.001	95 (6.7) $\times 10^{-3}$	0.32 (0.10)	~ 7.0	~ 20

Table 1. Acceptance scale factors ϵ, and mass resolutions σ, for only long (L) and only downstream (D) tracks obtained from our simplified description of the LHCb Upgrade tracking system geometry. The production ratio of the strange hadron with respect to K_S^0 is shown as $\mathcal{R}$. All efficiencies are normalised to that of fully reconstructed $K_S^0 \to \mu^+\mu^-$ and averaged over particles and anti-particles. Channels containing a photon, neutrino and π^0 are partially reconstructed.

Bright future ahead

Super Tau-Charm/CEPC

Decay mode	Current data $\mathcal{B}$ ($\times 10^{-6}$)	Sensitivity $\mathcal{B}$ (90% C.L.) ($\times 10^{-6}$)	Type
$\Lambda \to n e^+ e^-$	–	< 0.8	Type A
$\Sigma^+ \to p e^+ e^-$	< 7	< 0.4	
$\Xi^0 \to \Lambda e^+ e^-$	7.6 ± 0.6	< 1.2	
$\Xi^0 \to \Sigma^0 e^+ e^-$	–	< 1.3	
$\Xi^- \to \Sigma^- e^+ e^-$	–	< 1.0	
$\Omega^- \to \Xi^- e^+ e^-$	–	< 26.0	
$\Sigma^+ \to p \mu^+ \mu^-$	$(0.09^{+0.09}_{-0.08})$	< 0.4	
$\Omega^- \to \Xi^- \mu^+ \mu^-$	–	< 30.0	
$\Lambda \to n \nu \bar{\nu}$	–	< 0.3	Type B
$\Sigma^+ \to p \nu \bar{\nu}$	–	< 0.4	
$\Xi^0 \to \Lambda \nu \bar{\nu}$	–	< 0.8	
$\Xi^0 \to \Sigma^0 \nu \bar{\nu}$	–	< 0.9	
$\Xi^- \to \Sigma^- \nu \bar{\nu}$	–	–*	
$\Omega^- \to \Xi^- \nu \bar{\nu}$	–	< 26.0	

Rare and forbidden hyperon decays and expected sensitivities with 10^{10} events on the J/ψ peak and 3×10^9 events on the ψ(2S) peak.