國科大杭州高等研究院
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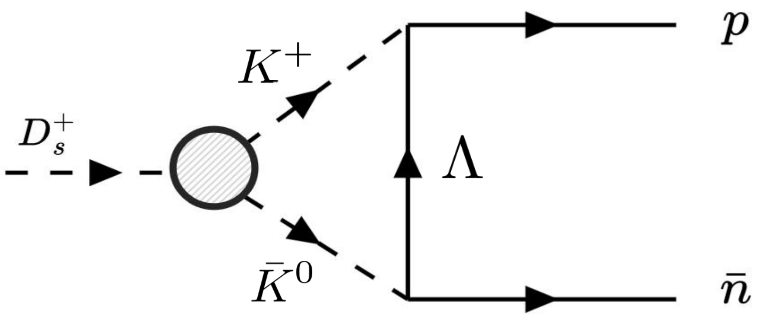
HFCPV2024

Hidden strangeness in meson weak decays to baryon pair

arXiv: 2409.11374



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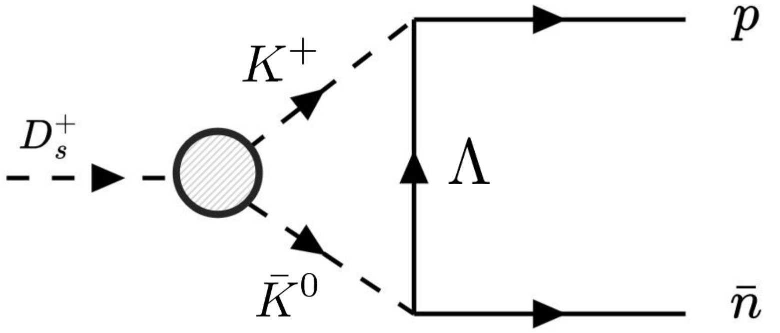
Oct. 26, 2024

Research Motivation

1. Long distance contributions at charm scale



A. Calculations of CPV

$a_{CP}^{\pi\pi} = (23.2 \pm 6.1) \times 10^{-4}$ $\quad$ $a_{CP}^{KK} = (7.7 \pm 5.7) \times 10^{-4}$

PRL 131, 091802 (2023) $\quad$ PRL 122, 211803 (2019)

$H.\ Y.\ Cheng\ and\ C.\ W.\ Chiang, Phys.Rev.D\mathbf{109}, no.7, 073008(2024)$

$H.\ n.\ Li, C.\ D.\ Lu\ and\ F.\ S.\ Yu, Phys.Rev.D\mathbf{86}, 036012(2012)$

B. Charm meson mixing

$D^0 - \overline{D}^0$ mixing →

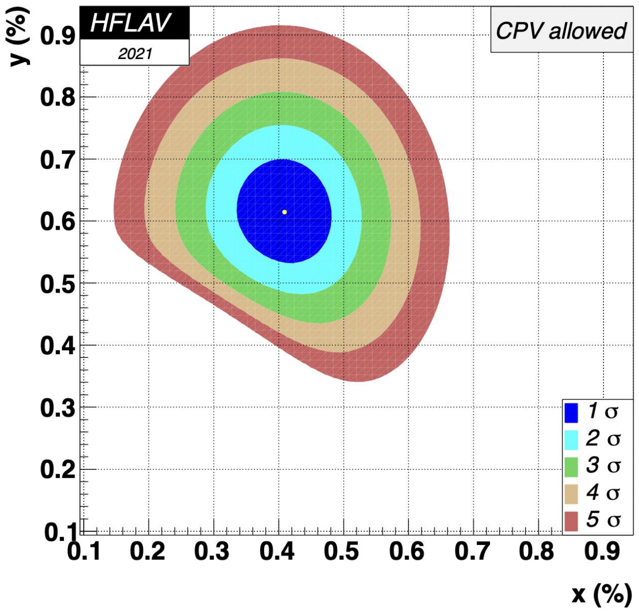
Research Motivation

Global fit : $\frac{\Delta m}{\Gamma} = (0.409^{+0.048}_{-0.049})\%$

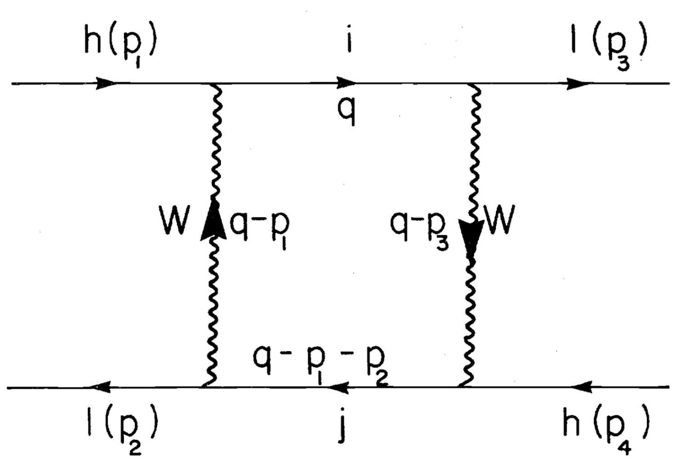
$\frac{\Delta\Gamma}{2\Gamma} = (0.615^{+0.056}_{-0.055})\%$

Large cancellation from GIM

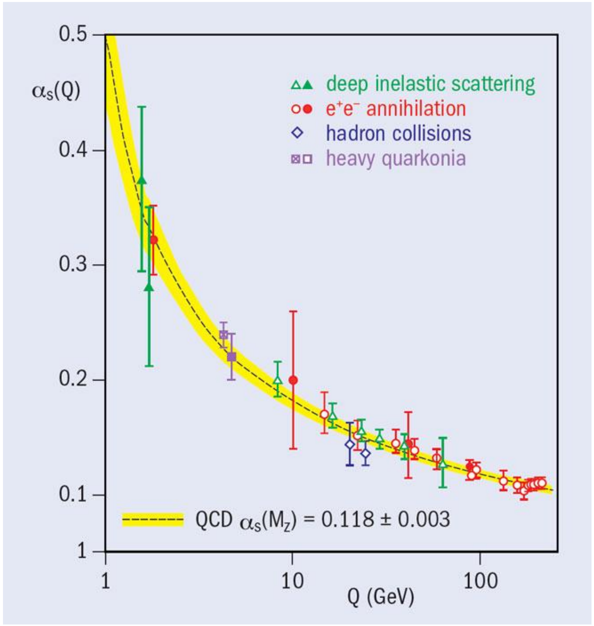
Theory from short distance ~ 10^{-6}



[HFLAV], Phys. Rev. D 107, 052008 (2023)



H. Y. Cheng, Phys. Rev. D 26, 143 (1982)



Peter Zerwas 2004 *Physik Journal* **3** 12 31

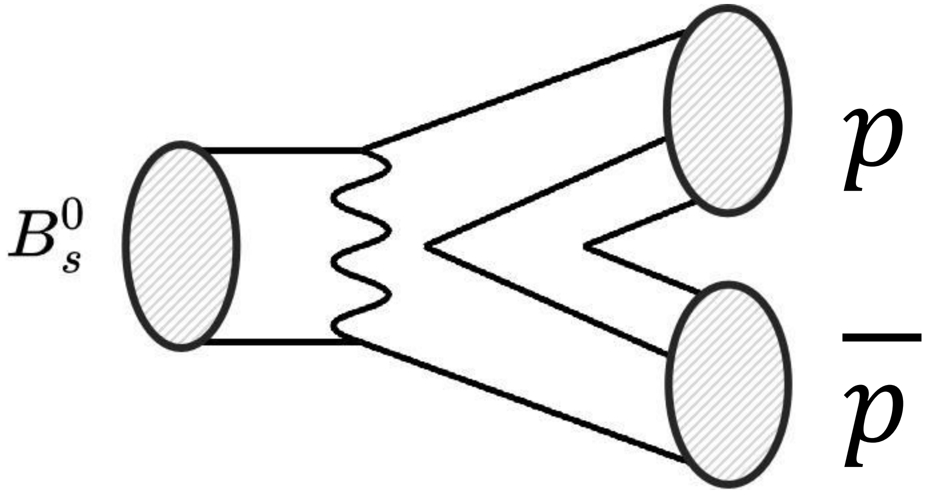
Research Motivation

2. Experimental progress

LHCb:

$\mathcal{B}(B_s^0 \to p\bar{p}) < 10^{-10}$ X.N.Jin, C.W.Liu and C.Q.Geng, Phys.Rev.D 105 (2022) 5, 053005

$\mathcal{B}(B_s^0 \to p\bar{p}) < 5.1 \times 10^{-9}$ R. Aaij et al. [LHCb], Phys. Rev. D 108, no.1, 012007(2023)



Annihilation-diagram → suppression from $m_{u,d,s}$

$$\mathcal{A} = \frac{G_F}{\sqrt{2}} V_{ub} V_{us}^* f_{B_s^0} (c_2 + c_1/3) 2m_u \langle p\overline{p} | \overline{u}\gamma_5 u | 0 \rangle$$

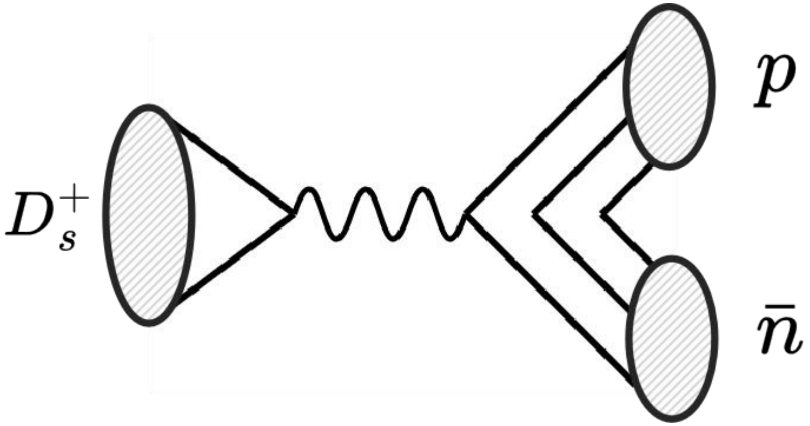
$$\approx 0$$

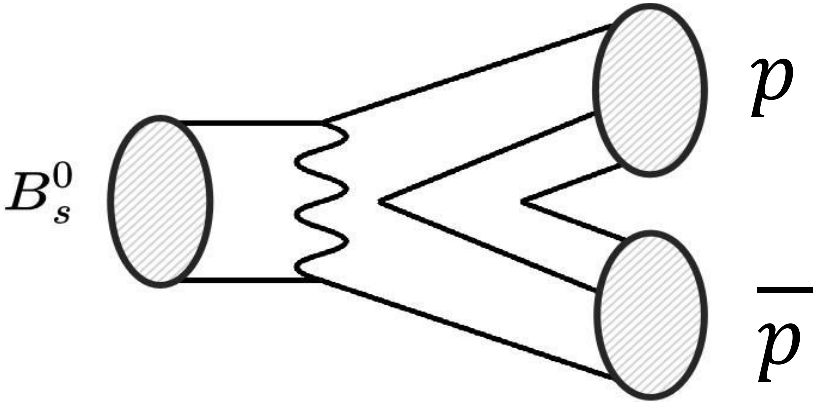
Hidden strangeness in meson weak decays to baryon pair

Both channels are expected to be proportional to $m_{u,d}$…

Chiral suppression does not hold in D_s^+ ?

	Data	Theory
✔ $\mathcal{B}(B_s^0 \to p\bar{p})$	$< 5.1 \times 10^{-9}$	$\sim 10^{-10}$
$\mathcal{B}(D_s^+ \to p\bar{n})$	$(1.22 \pm 0.11) \times 10^{-3}$ pdg	$(0.4^{+1.1}_{-0.3}) \times 10^{-6}$ Phys. Lett. B **663**, 326 (2008)





Hidden strangeness in meson weak decays to baryon pair

$D_s^+ \to p\bar{n}$ C.H.Chen, H.Y.Cheng and Y.K.Hsiao, Phys. Lett. B **663**, 326-329 (2008)

The **only** two-body baryonic decays in D mesons !

Tiny released energy; $m_{D_s} - m_p - m_n \approx m_\pi/2$

Short-distance QCD contributions are **suppressed** by light quark mass

At this energy scale, **the degree of freedom is hadrons** instead of gluons and quarks.

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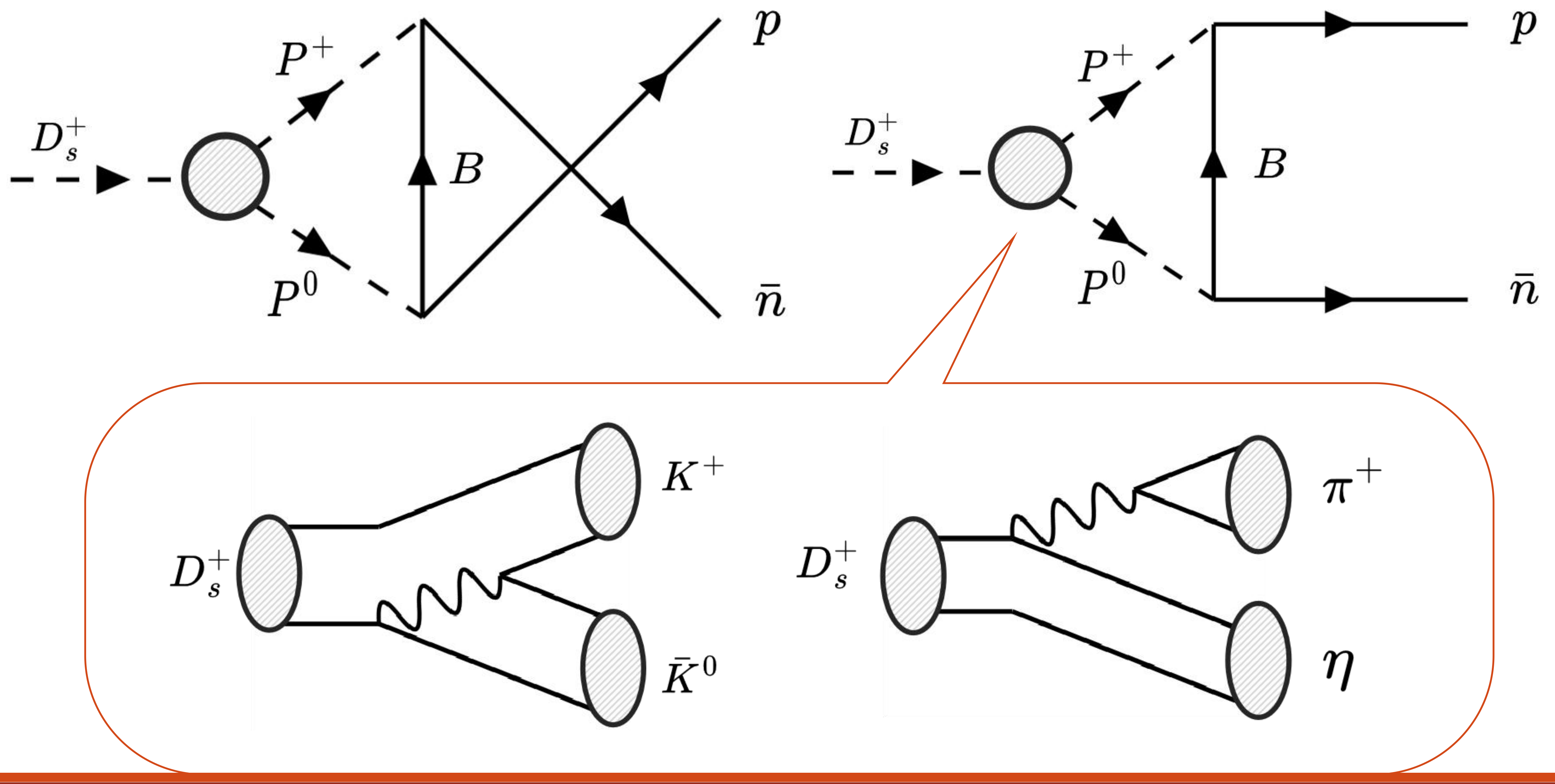

Hidden strangeness in meson weak decays to baryon pair

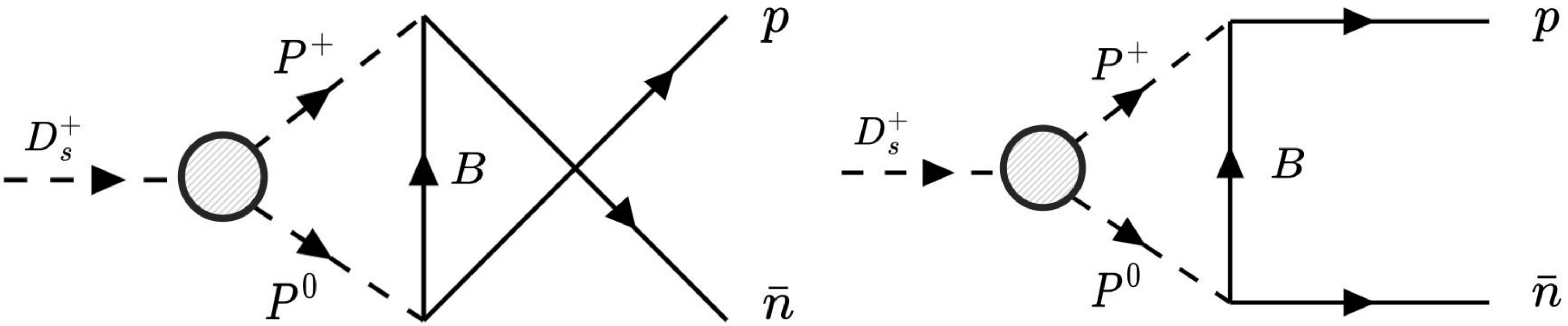

FIG. 2. The LD triangular diagrams for $D_s^+ \to p\bar{n}$. The blob stands for the insertion of $\mathcal{H}_{eff}$ with the underlying SD transition at quark level. The considered intermediate hadrons are $(P^0, P^+) = (\overline{K}^0, K^+)$ or (η, π^+), and $B \in (\Lambda, \Sigma^{0,+}, p, n)$.

$$\sum_{P^0, P^+, B} T^{\text{weak}}_{D_s^+ P^0 P^+} g_{P^0 B n} g_{P^+ p B} \int \frac{d^4 q}{(2\pi)^4} \frac{-(q-p_1)^\mu \gamma_\mu + m_2}{(q^2 - m_1^2)[(q-p_1)^2 - m_2^2][(q-p_1-p_2)^2 - m_3^2]}$$

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$$\sum_{P^0,P^+,B} T^{weak}_{D_s^+ P^0 P^+} g_{P^0 Bn} g_{P^+ pB} \int \frac{d^4q}{(2\pi)^4} \frac{-(q-p_1)^\mu \gamma_\mu + m_2}{(q^2-m_1^2)[(q-p_1)^2-m_2^2][(q-p_1-p_2)^2-m_3^2]}$$

Weak SD transitions;
PDG branching fractions

Strong couplings;
Goldberger-Treiman relations

$$(T^{\rm weak}_{D_s^+\overline{K}^0K^+}, T^{\rm weak}_{D_s^+\eta\pi^+}) = (0.180 \pm 0.02, -0.132 \pm 0.003) G_F\, GeV^3$$

$$g_{\overline{K}^0\Sigma^0 n} = g_{K^+ p\Sigma^0} = \frac{1}{\sqrt{2}} g_{K^+\Sigma^+ n} = -\frac{1}{\sqrt{2}} g_{\overline{K}^0\Sigma^+ p} = 3.215 \pm 0.163\,,$$

$$g_{\overline{K}^0\Lambda n} = -g_{K^+ p\Lambda} = 9.228 \pm 0.209\,, \qquad \frac{1}{\sqrt{2}} g_{\pi^+ pn} = 12.897 \pm 0.047\,.$$

$$\mathcal{B}(D_s^+ \to p\overline{n}) = (1.43 \pm 0.10) \times 10^{-3}\,,$$

This work

$$\mathcal{B}(D_s^+ \to p\overline{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$$ CLEO

Phys. Rev. Lett. **100**, 181802 (2008).

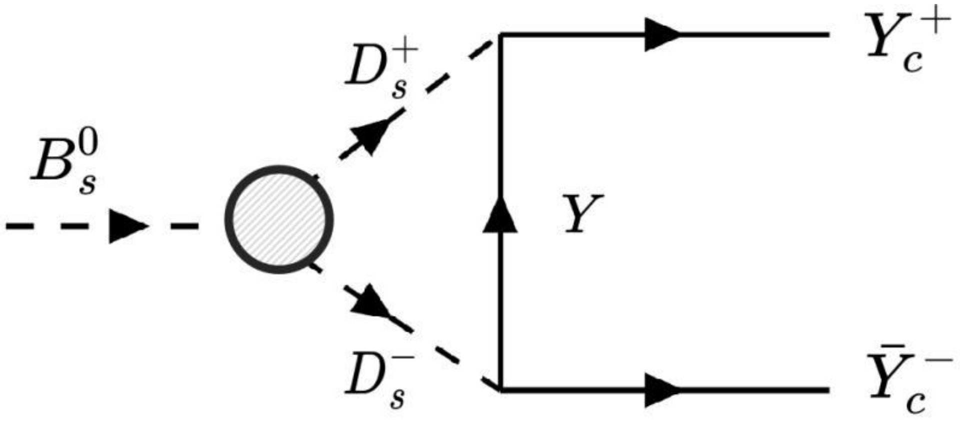
$$\mathcal{B}(D_s^+ \to p\overline{n}) = (1.21 \pm 0.10 \pm 0.05) \times 10^{-3}$$ BesIII

Phys. Rev. D **99**, 031101 (2019).

Hidden strangeness in meson weak decays to baryon pair

CP symmetry leads to a selection rule in partial waves:

$$\mathcal{B}(B^0_{s\,H} \to \Lambda_c^+\overline{\Lambda}_c^-) = 2\mathcal{B}_P(B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^-), \mathcal{B}(B^0_{s\,L} \to \Lambda_c^+\overline{\Lambda}_c^-) = 2\mathcal{B}_S(B_s^0 \to \Lambda_c^+\overline{\Lambda}_c^-).$$



The LD triangular diagram for $B_s^0 \to Y_c^+\overline{Y}_c^-$ with $Y = \Lambda, \Sigma$.

pQCD: Rui, Zhou and Zou, Zhi-Tian and Li, Ying, arXiv:2409.16113 [hep-ph]

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$$A_{LD} = T^{\text{weak}}_{B_s^0 D_s^+ D_s^-} (g_{D_s^+ Y_c^+ Y})^2 \int \frac{d^4 q}{(2\pi)^4} \frac{-(q-p_1)^\mu \gamma_\mu + m_2}{(q^2 - m_1^2)[(q-p_1)^2 - m_2^2][(q-p_1-p_2)^2 - m_3^2]}$$

$\Gamma \propto (g_{D^+ \Lambda_c^+ n})^4$ The coupling is poorly known

$g_{D^+ \Lambda_c^+ n} = 10.7^{+5.3}_{-4.3}$ A. Khodjamirian, C. Klein, T. Mannel and Y. M. Wang, JHEP **09**, 106 (2011).

$\mathcal{B}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) > 4.7 \times 10^{-5}$ this work

$\mathcal{B}(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-) < 8 \times 10^{-5}$ R. Aaij *et al.* [LHCb], Phys. Rev. Lett. **112**, 202001 (2014)

$\frac{\Gamma(B^0 \to \Xi_c^+ \overline{\Xi}_c^-)}{\Gamma(B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-)} = 1.4\%$ 5.3% in the exact SU(3)!

$m_{B^0} - 2m_{\Xi_c} = 0.34\text{GeV}$

$m_{B_s^0} - 2m_{\Lambda_c} = 0.76\text{GeV}$

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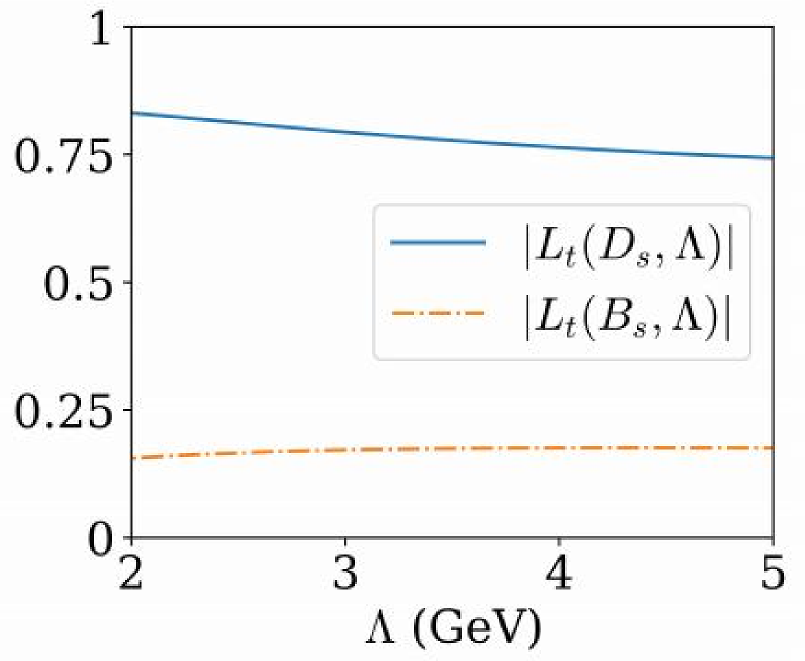
- At high energy, the picture of hadron scattering may not be valid.

$$L_t(\Lambda)=\int\frac{d^4q}{(2\pi)^4}\frac{-(q-p_1)^\mu\gamma_\mu+m_2}{(q^2-m_1^2)[(q-p_1)^2-m_2^2][(q-p_1-p_2)^2-m_3^2]}\frac{\Lambda^2}{\Lambda^2-(q-p_2)^2}$$

- A **cut-off** has been included to study the high energy dependence.

- The **cut-off** dependence of the integrals are tiny! It shows that our numerical results are **stable** and provide an **univocal** prediction.



Hidden strangeness in meson weak decays to baryon pair

TABLE I. Collections of the branching fractions compared to the data [22]. The prediction of $\mathcal{B}_P(D_s^+ \to p\bar{n})$ is taken from Ref. [7]. Here, $\mathcal{B}_{S,P}$ stand for the branching S and P wave parts of the branching fractions, respectively.

Channel	$\mathcal{B}_S$	$\mathcal{B}_P$	$\mathcal{B}_{\rm tot}$	$\mathcal{B}_{\rm tot}^{\rm exp}$
$D_s^+ \to p\bar{n}$	$(1.43 \pm 0.10) \times 10^{-3}$	$(0.4^{+1.1}_{-0.3}) \times 10^{-6}$	$(1.43 \pm 0.10) \times 10^{-3}$	$(1.22 \pm 0.11) \times 10^{-3}$
$B_s^0 \to \Lambda_c^+ \overline{\Lambda}_c^-$	$> 4.2 \times 10^{-5}$	$(3.9 \pm 1.5) \times 10^{-6}$	$> 4.7 \times 10^{-5}$	$< 8 \times 10^{-5}$
$B_s^0 \to \Sigma_c^+ \overline{\Sigma}_c^-$	$< 10^{-6}$	$(3.4 \pm 1.6) \times 10^{-6}$	$(3.9 \pm 2.1) \times 10^{-6}$	–
$B^0 \to \Xi_c^+ \overline{\Xi}_c^-$	$> 7 \times 10^{-5}$	$(1.3 \pm 0.5) \times 10^{-7}$	$> 7 \times 10^{-5}$	–
$B^0 \to \Xi_c'^+ \overline{\Xi}_c'^-$	$< 3 \times 10^{-8}$	$(8 \pm 3) \times 10^{-8}$	$(1.0 \pm 0.4) \times 10^{-7}$	–

We are working on CPV in these decays. To be appeared on arXiv soon.

Thank you!

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