Weak decays of doubly heavy baryons: recent progresses

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Phys.Rev. D98 (2018) no.5, 056002
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arXiv:1811.xxxxx

In collaboration with Xiao-Hui Hu, Yue-Long Shen, Yu-Ji Shi, Wei Wang, Zhi-Peng Xing, Fu-Sheng Yu

Outline

- Introduction
- Weak decays of doubly heavy baryons: the 1/2 -> 1/2 case
- Weak decays of doubly heavy baryons: the 1/2 -> 3/2 case
- Weak decays of doubly heavy baryons: the FCNC processes
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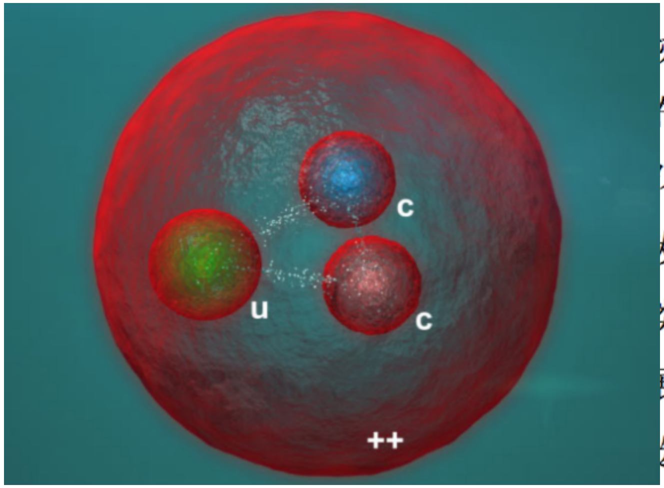
Introduction

Observation of the doubly charmed baryon Ξ_{cc}^{++}

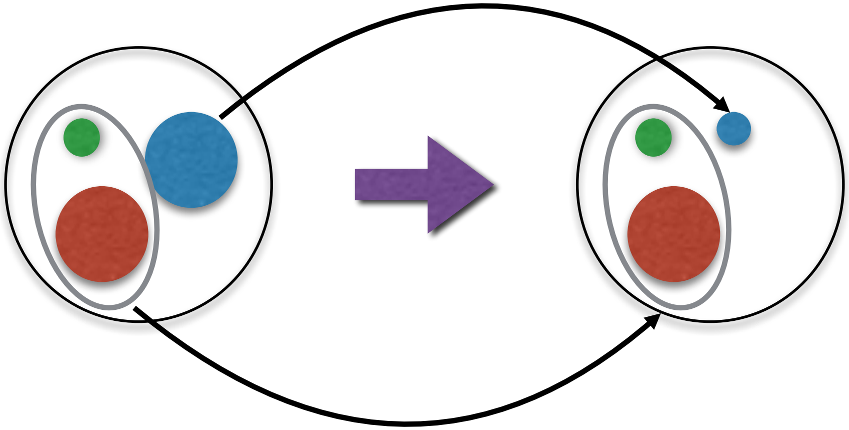
2017年度中国科学十大进展正式对外发布

日期：2018年03月01日　来源：科技部

2018年2月27日，科技部基础研究司与科技部基础研究管理中心在北京联合召开“2017年度中国科学十大进展专家解读会”，正式对外公布“2017年度中国科学十大进展”遴选结果，并邀请相关领域专家对十大进展逐项进行解读。科技部基础研究司崔拓副司长，科技部基础研究管理中心刘敏主任、卞曙光副主任，十大进展解读专家，十大进展主要完成人代表，中国科学院和教育部等部门代表，在京高校、科研院所等单位代表，新华社和中央
办单位相关人员等140余人出席了会议，会议由卞曙光副主任主持。
布了2017年度中国科学十大进展遴选结果：实现星地千公里级量子纠缠
化为活疫苗及治疗性药物、首次探测到双粲重子、实验发现三重简并费
发出基于共格纳米析出强化的新一代超高强钢、利用量子相变确定性制
类化石、酵母长染色体的精准定制合成、研制出可实现自由状态脑成像
展入选“2017年度中国科学十大进展”。崔拓副司长、刘敏主任为十大进展
选十大进展一一进行了解读。

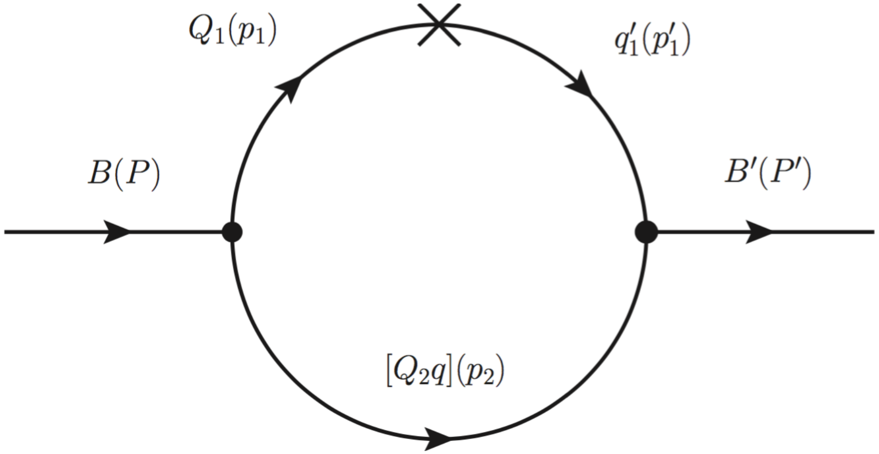


Basic ideas



diquark

0^+ or 1^+



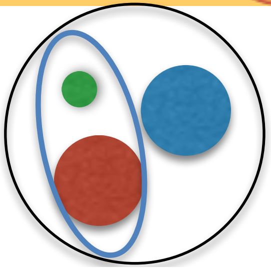
H. W. Ke, X. Q. Li and Z. T. Wei, Phys. Rev. D 77, 014020 (2008)

H. W. Ke, X. H. Yuan, X. Q. Li, Z. T. Wei and Y. X. Zhang, Phys. Rev. D 86, 114005 (2012)

$$|B\rangle^{\text{phys}} = c_S|B,[di]\rangle + c_A|B,\{di\}\rangle$$

c_S and c_A are determined by the flavor-spin wave functions

Overview of LFQM



$$
\begin{aligned}
|B(P,S,S_z)\rangle = &\int \{d^3p_1\}\{d^3p_2\}2(2\pi)^3\delta^3(\tilde{P}-\tilde{p}_1-\tilde{p}_2) \\
&\times \sum_{\lambda_1,\lambda_2} \boxed{\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2)} |q_1(p_1,\lambda_1)[di](p_2,\lambda_2)\rangle
\end{aligned}
$$

$$
\tilde{p} = (p^+, p_\perp), \quad \{d^3p\} \equiv \frac{dp^+d^2p_\perp}{2(2\pi)^3}, \qquad \delta^3(\tilde{p}) = \delta(p^+)\delta^2(p_\perp).
$$

$$
p^- = \frac{p_\perp^2 + m^2}{p^+}
$$

Overview of LFQM

$$\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2)=\sum_{s_1,s_2}\langle\lambda_1|\mathcal{R}_M^{\dagger}(x_1,-k_\perp,m_1)|s_1\rangle\langle\lambda_2|\mathcal{R}_M^{\dagger}(x_2,k_\perp,m_2)|s_2\rangle$$

$$\times\langle\frac{1}{2}s_1;s_{[di]}s_2|\frac{1}{2}S_z\rangle\varphi(x,k_\perp),$$

$$\frac{1}{\sqrt{2(p_1\cdot\bar{P}+m_1M_0)}}\bar{u}(p_1,\lambda_1)\Gamma u(\bar{P},S_z)$$

0^+ $\quad\Gamma=1$

1^+ $\quad\Gamma=-\frac{1}{\sqrt{3}}\gamma_5\not{\epsilon}^*(p_2,\lambda_2)$

H. W. Ke, X. H. Yuan, X. Q. Li, Z. T. Wei and Y. X. Zhang, Phys. Rev. D 86, 114005 (2012)

Overview of LFQM

$$\Psi^{SS_z}(\tilde{p}_1,\tilde{p}_2,\lambda_1,\lambda_2)=\sum_{s_1,s_2}\langle\lambda_1|\mathcal{R}_M^{\dagger}(x_1,-k_\perp,m_1)|s_1\rangle\langle\lambda_2|\mathcal{R}_M^{\dagger}(x_2,k_\perp,m_2)|s_2\rangle$$

$$\times\langle\frac{1}{2}s_1;s_{[di]}s_2|\frac{1}{2}S_z\rangle\boxed{\varphi(x,k_\perp)},$$

$$A\phi(x,k_\perp)$$

0^+ $$A=1$$

1^+ $$A=\sqrt{\frac{3(M_0m_1+p_1\cdot\bar{P})}{3M_0m_1+p_1\cdot\bar{P}+(2p_1\cdot p_2p_2\cdot\bar{P})/m_2^2}}$$

$$\phi(x,\vec{k}_\perp)=4\left(\frac{\pi}{\beta^2}\right)^{3/4}\sqrt{\frac{e_1e_2}{x_1x_2M_0}}\exp\left(-\frac{\vec{k}_\perp^2+k_z^2}{2\beta^2}\right)$$

Singly heavy baryon decays

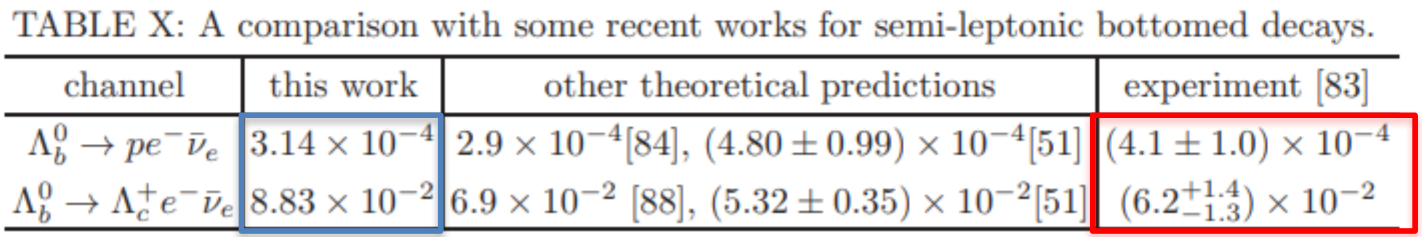


TABLE X: A comparison with some recent works for semi-leptonic bottomed decays.

channel	this work	other theoretical predictions	experiment [83]
$\Lambda_b^0 \to p e^- \bar{\nu}_e$	3.14×10^{-4}	2.9×10^{-4}[84], $(4.80 \pm 0.99) \times 10^{-4}$[51]	$(4.1 \pm 1.0) \times 10^{-4}$
$\Lambda_b^0 \to \Lambda_c^+ e^- \bar{\nu}_e$	8.83×10^{-2}	6.9×10^{-2} [88], $(5.32 \pm 0.35) \times 10^{-2}$[51]	$(6.2^{+1.4}_{-1.3}) \times 10^{-2}$

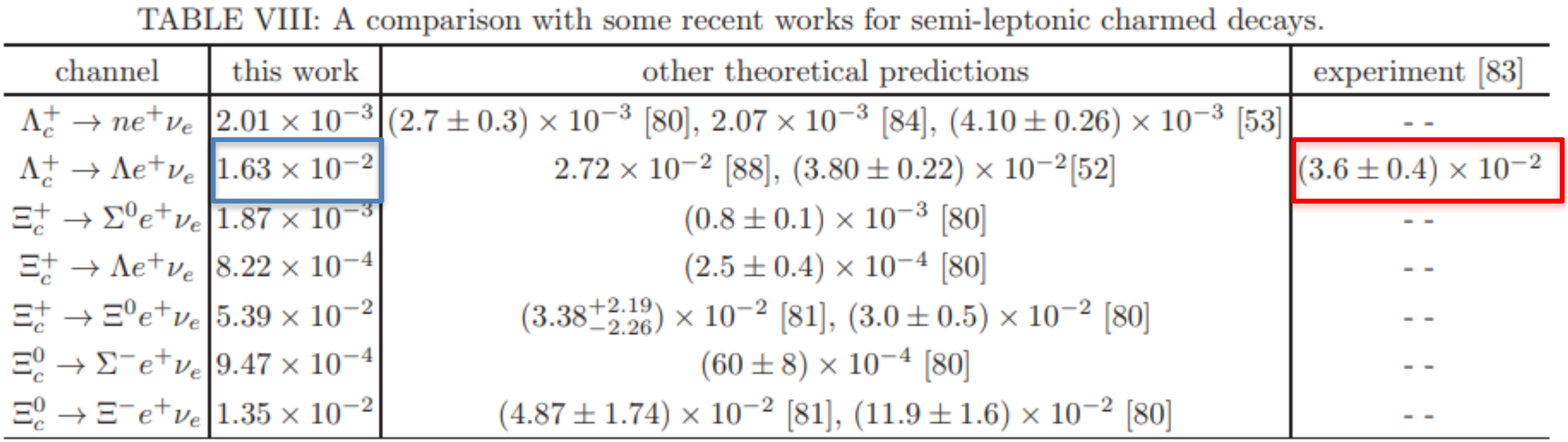


TABLE VIII: A comparison with some recent works for semi-leptonic charmed decays.

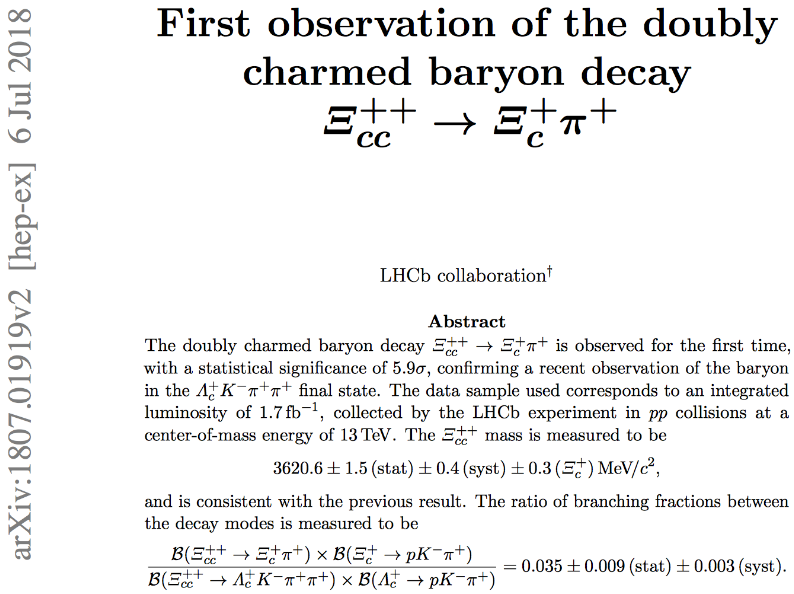
channel	this work	other theoretical predictions	experiment [83]
$\Lambda_c^+ \to n e^+ \nu_e$	2.01×10^{-3}	$(2.7 \pm 0.3) \times 10^{-3}$ [80], 2.07×10^{-3} [84], $(4.10 \pm 0.26) \times 10^{-3}$ [53]	- -
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	1.63×10^{-2}	2.72×10^{-2} [88], $(3.80 \pm 0.22) \times 10^{-2}$[52]	$(3.6 \pm 0.4) \times 10^{-2}$
$\Xi_c^+ \to \Sigma^0 e^+ \nu_e$	1.87×10^{-3}	$(0.8 \pm 0.1) \times 10^{-3}$ [80]	- -
$\Xi_c^+ \to \Lambda e^+ \nu_e$	8.22×10^{-4}	$(2.5 \pm 0.4) \times 10^{-4}$ [80]	- -
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	5.39×10^{-2}	$(3.38^{+2.19}_{-2.26}) \times 10^{-2}$ [81], $(3.0 \pm 0.5) \times 10^{-2}$ [80]	- -
$\Xi_c^0 \to \Sigma^- e^+ \nu_e$	9.47×10^{-4}	$(60 \pm 8) \times 10^{-4}$ [80]	- -
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	1.35×10^{-2}	$(4.87 \pm 1.74) \times 10^{-2}$ [81], $(11.9 \pm 1.6) \times 10^{-2}$ [80]	- -

Z. X. Zhao, Chin.Phys. C42 (2018) no.9, 093101

Weak decays of doubly heavy baryons: the 1/2 -> 1/2 case

W. Wang, F. S. Yu and Z. X. Zhao, Eur.Phys.J. C77 (2017) no.11, 781

The 1/2 -> 1/2 case



arXiv:1807.01919v2 [hep-ex] 6 Jul 2018

First observation of the doubly charmed baryon decay $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

LHCb collaboration[†]

Abstract

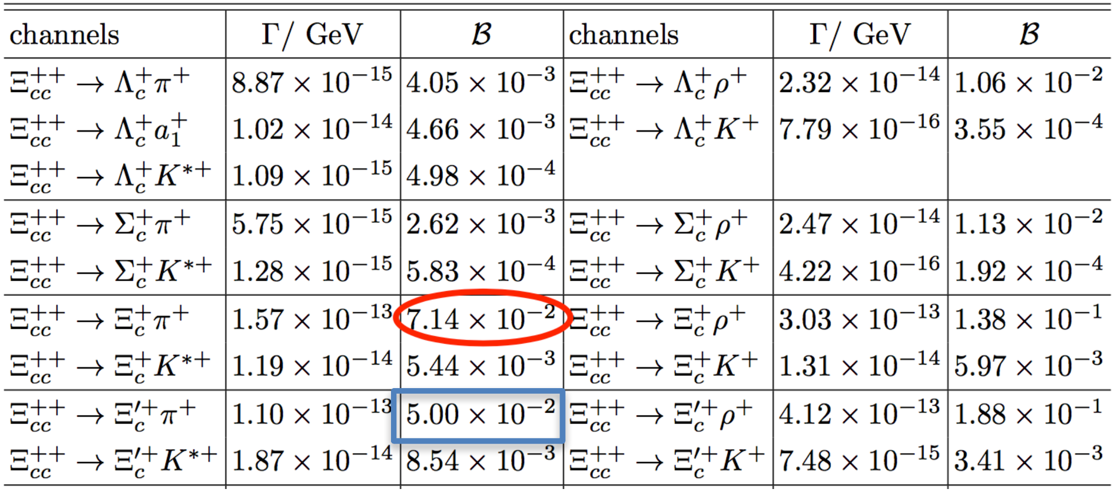
The doubly charmed baryon decay $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ is observed for the first time, with a statistical significance of 5.9σ, confirming a recent observation of the baryon in the $\Lambda_c^+ K^- \pi^+ \pi^+$ final state. The data sample used corresponds to an integrated luminosity of $1.7\,\mathrm{fb}^{-1}$, collected by the LHCb experiment in pp collisions at a center-of-mass energy of 13 TeV. The Ξ_{cc}^{++} mass is measured to be

$$3620.6 \pm 1.5\,(\mathrm{stat}) \pm 0.4\,(\mathrm{syst}) \pm 0.3\,(\Xi_c^+)\ \mathrm{MeV}/c^2,$$

and is consistent with the previous result. The ratio of branching fractions between the decay modes is measured to be

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \times \mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+) \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.035 \pm 0.009\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst}).$$

TABLE XXII: Partial decay widths (in units of GeV) and branching ratios for non-leptonic decays of the doubly charmed baryons.



channels	Γ/ GeV	$\mathcal{B}$	channels	Γ/ GeV	$\mathcal{B}$
$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$	8.87×10^{-15}	4.05×10^{-3}	$\Xi_{cc}^{++} \to \Lambda_c^+ \rho^+$	2.32×10^{-14}	1.06×10^{-2}
$\Xi_{cc}^{++} \to \Lambda_c^+ a_1^+$	1.02×10^{-14}	4.66×10^{-3}	$\Xi_{cc}^{++} \to \Lambda_c^+ K^+$	7.79×10^{-16}	3.55×10^{-4}
$\Xi_{cc}^{++} \to \Lambda_c^+ K^{*+}$	1.09×10^{-15}	4.98×10^{-4}			
$\Xi_{cc}^{++} \to \Sigma_c^+ \pi^+$	5.75×10^{-15}	2.62×10^{-3}	$\Xi_{cc}^{++} \to \Sigma_c^+ \rho^+$	2.47×10^{-14}	1.13×10^{-2}
$\Xi_{cc}^{++} \to \Sigma_c^+ K^{*+}$	1.28×10^{-15}	5.83×10^{-4}	$\Xi_{cc}^{++} \to \Sigma_c^+ K^+$	4.22×10^{-16}	1.92×10^{-4}
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$	1.57×10^{-13}	7.14×10^{-2}	$\Xi_{cc}^{++} \to \Xi_c^+ \rho^+$	3.03×10^{-13}	1.38×10^{-1}
$\Xi_{cc}^{++} \to \Xi_c^+ K^{*+}$	1.19×10^{-14}	5.44×10^{-3}	$\Xi_{cc}^{++} \to \Xi_c^+ K^+$	1.31×10^{-14}	5.97×10^{-3}
$\Xi_{cc}^{++} \to \Xi_c'^+ \pi^+$	1.10×10^{-13}	5.00×10^{-2}	$\Xi_{cc}^{++} \to \Xi_c'^+ \rho^+$	4.12×10^{-13}	1.88×10^{-1}
$\Xi_{cc}^{++} \to \Xi_c'^+ K^{*+}$	1.87×10^{-14}	8.54×10^{-3}	$\Xi_{cc}^{++} \to \Xi_c'^+ K^+$	7.48×10^{-15}	3.41×10^{-3}

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 7.14 \times 10^{-2}$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \pi^+) = 5.00 \times 10^{-2}$$

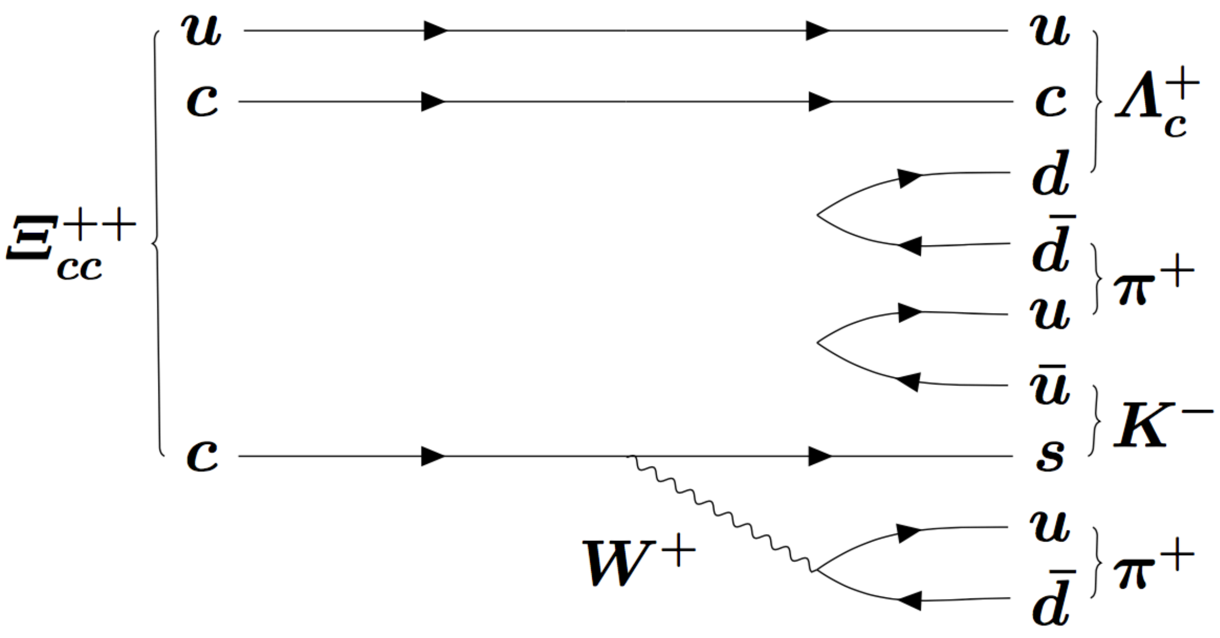
$$\Xi_c'^+ \to \Xi_c^+ \gamma$$

$$m_{\Xi_c'^+} - m_{\Xi_c^+} \approx 107.8\ \mathrm{MeV}$$

Weak decays of doubly heavy baryons: the 1/2 -> 3/2 case

Z. X. Zhao, Eur.Phys.J.C78 (2018) no.9, 756

Motivation



$$\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$$

Difficulty and conculsion

- Difficulty: The vectorial spinor for spin-3/2 baryon

$$u^{\alpha} = (\epsilon^{\alpha} - \frac{1}{3}(\gamma^{\alpha} + v^{\alpha})\not{\epsilon})u$$

$$u^{\alpha}(p,\lambda) = \sum_{\lambda_1,\lambda_2} \langle \frac{1}{2}, \lambda_1, 1, \lambda_2 | \frac{3}{2}, \lambda \rangle \times u(p,\lambda_1)\epsilon^{\alpha}(p,\lambda_2)$$

- Conculsion: Approximately one order of magnitude smaller than its 1/2 to 1/2 counterpart

The 1/2 -> 3/2 case

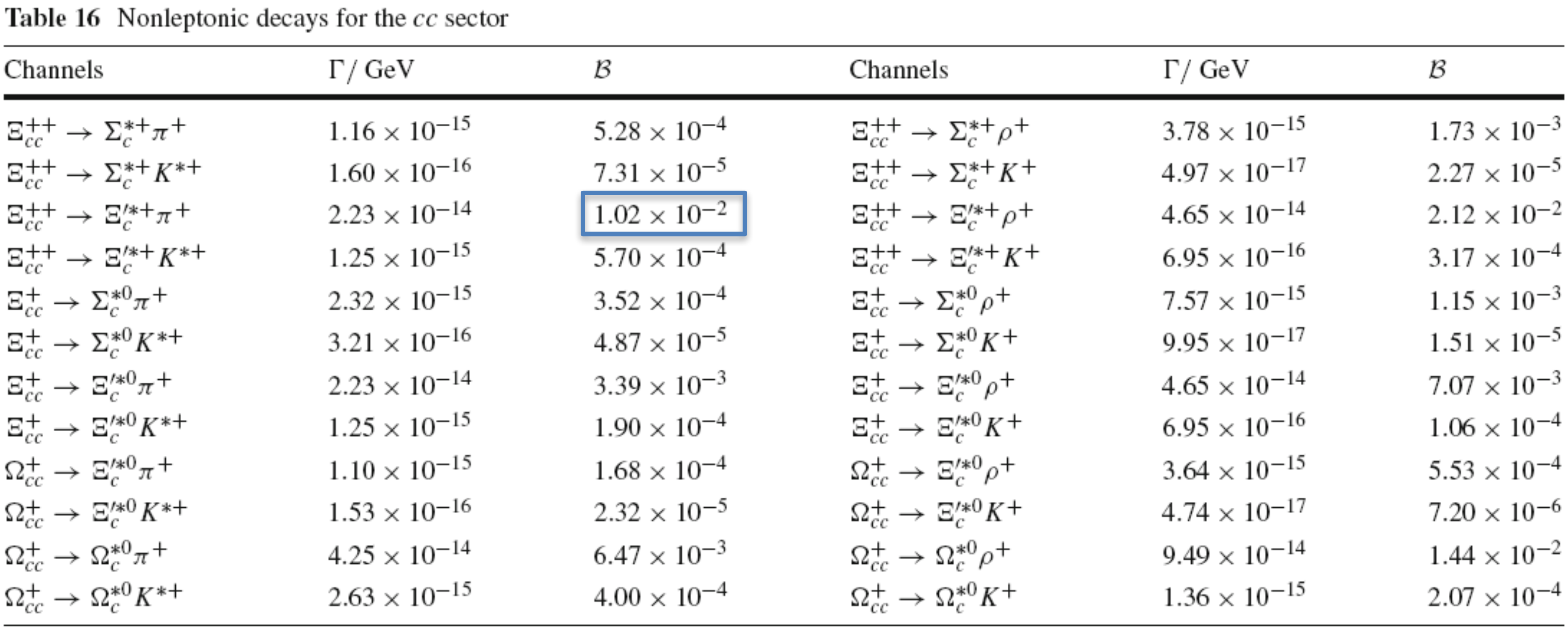


Table 16 Nonleptonic decays for the cc sector

Channels	Γ/ GeV	$\mathcal{B}$	Channels	Γ/ GeV	$\mathcal{B}$
$\Xi_{cc}^{++} \to \Sigma_c^{*+}\pi^+$	1.16×10^{-15}	5.28×10^{-4}	$\Xi_{cc}^{++} \to \Sigma_c^{*+}\rho^+$	3.78×10^{-15}	1.73×10^{-3}
$\Xi_{cc}^{++} \to \Sigma_c^{*+}K^{*+}$	1.60×10^{-16}	7.31×10^{-5}	$\Xi_{cc}^{++} \to \Sigma_c^{*+}K^+$	4.97×10^{-17}	2.27×10^{-5}
$\Xi_{cc}^{++} \to \Xi_c^{\prime*+}\pi^+$	2.23×10^{-14}	$\boxed{1.02 \times 10^{-2}}$	$\Xi_{cc}^{++} \to \Xi_c^{\prime*+}\rho^+$	4.65×10^{-14}	2.12×10^{-2}
$\Xi_{cc}^{++} \to \Xi_c^{\prime*+}K^{*+}$	1.25×10^{-15}	5.70×10^{-4}	$\Xi_{cc}^{++} \to \Xi_c^{\prime*+}K^+$	6.95×10^{-16}	3.17×10^{-4}
$\Xi_{cc}^{+} \to \Sigma_c^{*0}\pi^+$	2.32×10^{-15}	3.52×10^{-4}	$\Xi_{cc}^{+} \to \Sigma_c^{*0}\rho^+$	7.57×10^{-15}	1.15×10^{-3}
$\Xi_{cc}^{+} \to \Sigma_c^{*0}K^{*+}$	3.21×10^{-16}	4.87×10^{-5}	$\Xi_{cc}^{+} \to \Sigma_c^{*0}K^+$	9.95×10^{-17}	1.51×10^{-5}
$\Xi_{cc}^{+} \to \Xi_c^{\prime*0}\pi^+$	2.23×10^{-14}	3.39×10^{-3}	$\Xi_{cc}^{+} \to \Xi_c^{\prime*0}\rho^+$	4.65×10^{-14}	7.07×10^{-3}
$\Xi_{cc}^{+} \to \Xi_c^{\prime*0}K^{*+}$	1.25×10^{-15}	1.90×10^{-4}	$\Xi_{cc}^{+} \to \Xi_c^{\prime*0}K^+$	6.95×10^{-16}	1.06×10^{-4}
$\Omega_{cc}^{+} \to \Xi_c^{\prime*0}\pi^+$	1.10×10^{-15}	1.68×10^{-4}	$\Omega_{cc}^{+} \to \Xi_c^{\prime*0}\rho^+$	3.64×10^{-15}	5.53×10^{-4}
$\Omega_{cc}^{+} \to \Xi_c^{\prime*0}K^{*+}$	1.53×10^{-16}	2.32×10^{-5}	$\Omega_{cc}^{+} \to \Xi_c^{\prime*0}K^+$	4.74×10^{-17}	7.20×10^{-6}
$\Omega_{cc}^{+} \to \Omega_c^{*0}\pi^+$	4.25×10^{-14}	6.47×10^{-3}	$\Omega_{cc}^{+} \to \Omega_c^{*0}\rho^+$	9.49×10^{-14}	1.44×10^{-2}
$\Omega_{cc}^{+} \to \Omega_c^{*0}K^{*+}$	2.63×10^{-15}	4.00×10^{-4}	$\Omega_{cc}^{+} \to \Omega_c^{*0}K^+$	1.36×10^{-15}	2.07×10^{-4}

$$\boxed{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{\prime*+}\pi^+) = 1.02 \times 10^{-2}}$$

$$\Xi_c^{\prime*+} \to \Xi_c^0 \pi^+$$

$$\boxed{\Xi_c^0 \to \Xi^- \pi^+}$$

Weak decays of doubly heavy baryons: the FCNC processes

Z. P. Xing and Z. X. Zhao, Phys.Rev. D98 (2018) no.5, 056002

Motivation

- FCNC processes are considered to be an ideal place to the precise test of Standard Model and the search for new physics, while the discovery of the doubly heavy baryon provides us a new platform.

- With the accumulation of data, we are in an increasingly better position to study these semi-leptonic process.

The FCNC processes

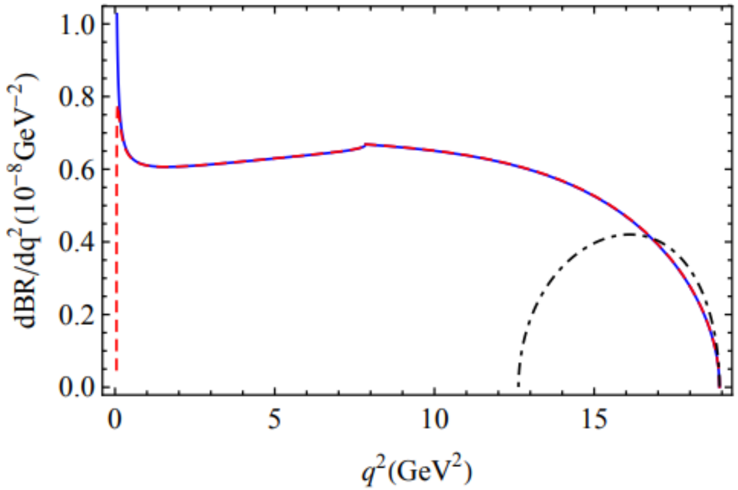


FIG. 3: $d\mathcal{B}/dq^2$ for $\Xi_{bb}^0 \to \Xi_b^0 l^+ l^-$ with $l = e, \mu, \tau$. The blue solid line, the red dashed line and the black dotdashed line correspond to the cases of $l = e, \mu, \tau$, respectively. Here the resonant contributions are not taken into account.

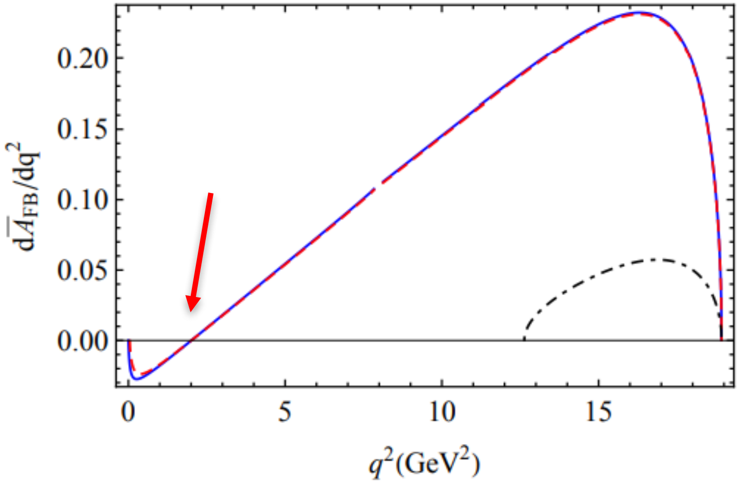
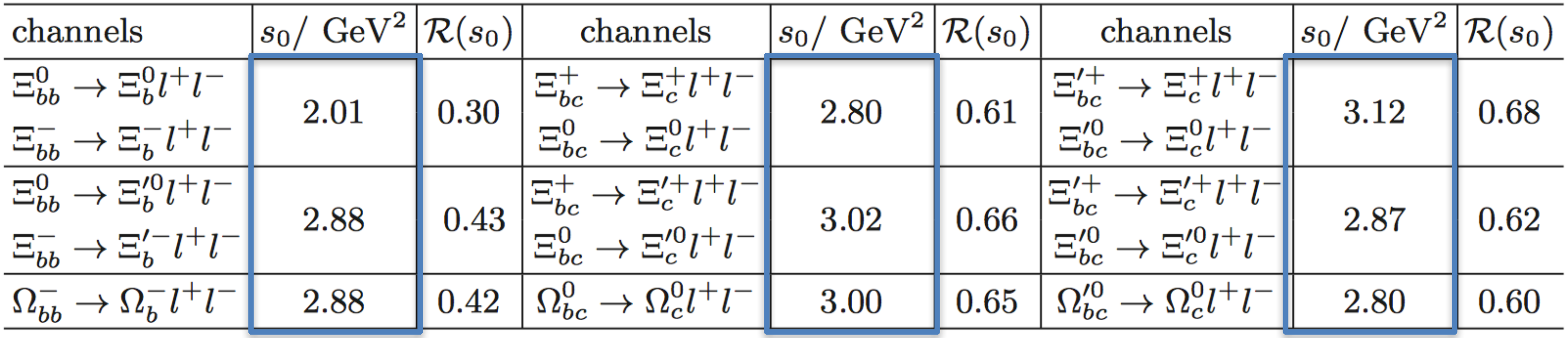


FIG. 4: Same as FIG. 3 but for $d\bar{A}_{FB}/dq^2$.

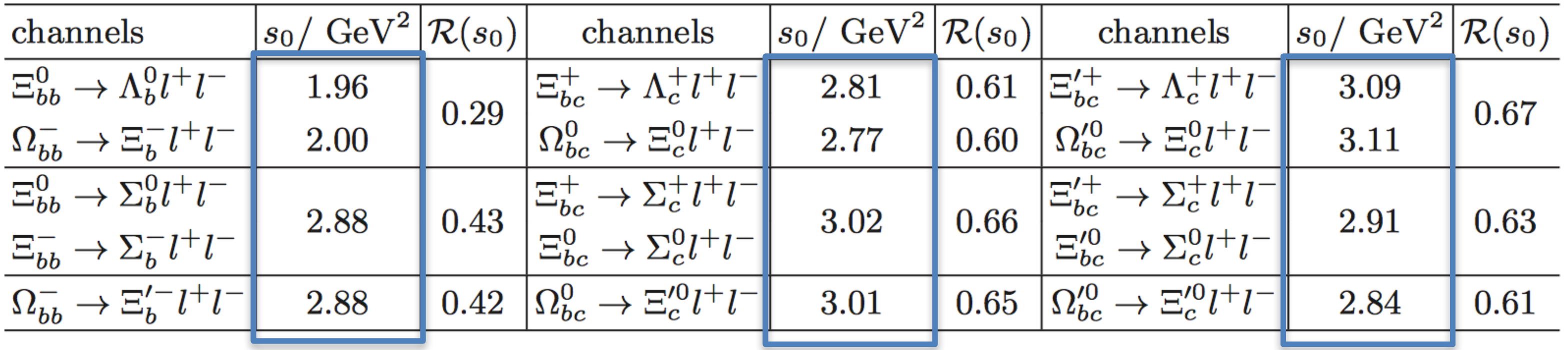
Zero-crossing points

TABLE XIX: Zero-crossing points of $d\bar{A}_{FB}/dq^2$ and $\mathcal{R}$ defined in Eqs. (51) and (52) for $b \to s$ process with $l = e/\mu$.



channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$	channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$	channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$
$\Xi_{bb}^0 \to \Xi_b^0 l^+ l^-$ $\Xi_{bb}^- \to \Xi_b^- l^+ l^-$	2.01	0.30	$\Xi_{bc}^+ \to \Xi_c^+ l^+ l^-$ $\Xi_{bc}^0 \to \Xi_c^0 l^+ l^-$	2.80	0.61	$\Xi_{bc}^{\prime +} \to \Xi_c^+ l^+ l^-$ $\Xi_{bc}^{\prime 0} \to \Xi_c^0 l^+ l^-$	3.12	0.68
$\Xi_{bb}^0 \to \Xi_b^{\prime 0} l^+ l^-$ $\Xi_{bb}^- \to \Xi_b^{\prime -} l^+ l^-$	2.88	0.43	$\Xi_{bc}^+ \to \Xi_c^{\prime +} l^+ l^-$ $\Xi_{bc}^0 \to \Xi_c^{\prime 0} l^+ l^-$	3.02	0.66	$\Xi_{bc}^{\prime +} \to \Xi_c^{\prime +} l^+ l^-$ $\Xi_{bc}^{\prime 0} \to \Xi_c^{\prime 0} l^+ l^-$	2.87	0.62
$\Omega_{bb}^- \to \Omega_b^- l^+ l^-$	2.88	0.42	$\Omega_{bc}^0 \to \Omega_c^0 l^+ l^-$	3.00	0.65	$\Omega_{bc}^{\prime 0} \to \Omega_c^0 l^+ l^-$	2.80	0.60

TABLE XX: Same as XIX but for $b \to d$ process.



channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$	channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$	channels	$s_0/\ \mathrm{GeV}^2$	$\mathcal{R}(s_0)$
$\Xi_{bb}^0 \to \Lambda_b^0 l^+ l^-$ $\Omega_{bb}^- \to \Xi_b^- l^+ l^-$	1.96 2.00	0.29	$\Xi_{bc}^+ \to \Lambda_c^+ l^+ l^-$ $\Omega_{bc}^0 \to \Xi_c^0 l^+ l^-$	2.81 2.77	0.61 0.60	$\Xi_{bc}^{\prime +} \to \Lambda_c^+ l^+ l^-$ $\Omega_{bc}^{\prime 0} \to \Xi_c^0 l^+ l^-$	3.09 3.11	0.67
$\Xi_{bb}^0 \to \Sigma_b^0 l^+ l^-$ $\Xi_{bb}^- \to \Sigma_b^- l^+ l^-$	2.88	0.43	$\Xi_{bc}^+ \to \Sigma_c^+ l^+ l^-$ $\Xi_{bc}^0 \to \Sigma_c^0 l^+ l^-$	3.02	0.66	$\Xi_{bc}^{\prime +} \to \Sigma_c^+ l^+ l^-$ $\Xi_{bc}^{\prime 0} \to \Sigma_c^0 l^+ l^-$	2.91	0.63
$\Omega_{bb}^- \to \Xi_b^{\prime -} l^+ l^-$	2.88	0.42	$\Omega_{bc}^0 \to \Xi_c^{\prime 0} l^+ l^-$	3.01	0.65	$\Omega_{bc}^{\prime 0} \to \Xi_c^{\prime 0} l^+ l^-$	2.84	0.61

$$B \to K_J^*(\to K\pi)\mu^+\mu^- \qquad s_0 = (3.1 \pm 0.1)\mathrm{GeV}^2$$

C. D. Lu and W. Wang, Phys. Rev. D 85, 034014 (2012)

Weak decays of doubly heavy baryons: decay constants (with QCDSR method)

X. H. Hu, Y. L. Shen, W. Wang and Z. X. Zhao, Chin.Phys. C42 (2018) no.12, 123102

Motivation

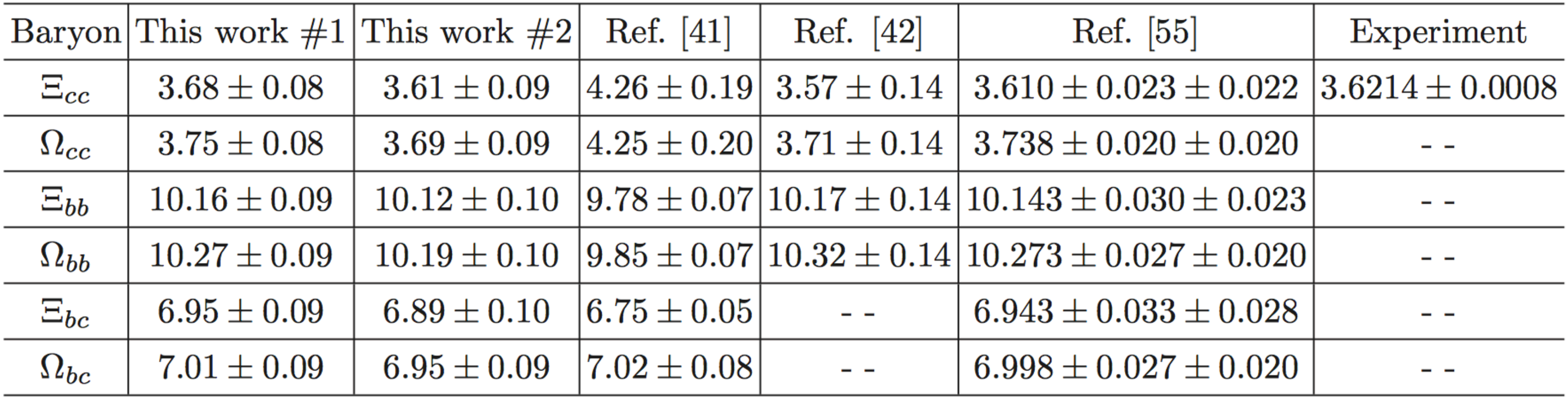
An indispensable input for the calculation of

- the form factors
- lifetime

$$\langle 0|J_H|H(q,s)\rangle = \boxed{\lambda_H} u(q,s)$$

decay constant

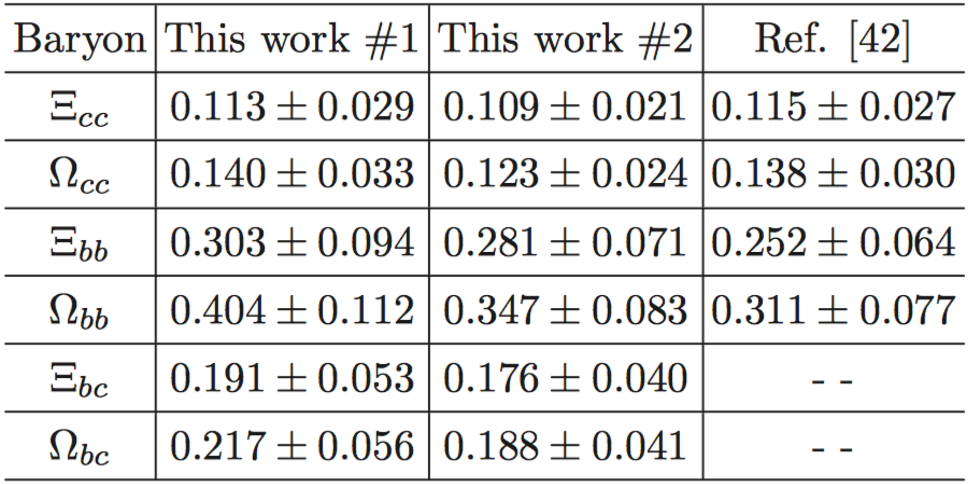
“Decay constants”



Baryon	This work #1	This work #2	Ref. [41]	Ref. [42]	Ref. [55]	Experiment
Ξ_{cc}	3.68 ± 0.08	3.61 ± 0.09	4.26 ± 0.19	3.57 ± 0.14	$3.610 \pm 0.023 \pm 0.022$	3.6214 ± 0.0008
Ω_{cc}	3.75 ± 0.08	3.69 ± 0.09	4.25 ± 0.20	3.71 ± 0.14	$3.738 \pm 0.020 \pm 0.020$	- -
Ξ_{bb}	10.16 ± 0.09	10.12 ± 0.10	9.78 ± 0.07	10.17 ± 0.14	$10.143 \pm 0.030 \pm 0.023$	- -
Ω_{bb}	10.27 ± 0.09	10.19 ± 0.10	9.85 ± 0.07	10.32 ± 0.14	$10.273 \pm 0.027 \pm 0.020$	- -
Ξ_{bc}	6.95 ± 0.09	6.89 ± 0.10	6.75 ± 0.05	- -	$6.943 \pm 0.033 \pm 0.028$	- -
Ω_{bc}	7.01 ± 0.09	6.95 ± 0.09	7.02 ± 0.08	- -	$6.998 \pm 0.027 \pm 0.020$	- -

Z.G.Wang,Eur.Phys.J.A45,267(2010)

Z. S. Brown, W. Detmold, S. Meinel and K. Orginos, Phys. Rev. D 90, no. 9, 094507 (2014)



Baryon	This work #1	This work #2	Ref. [42]
Ξ_{cc}	0.113 ± 0.029	0.109 ± 0.021	0.115 ± 0.027
Ω_{cc}	0.140 ± 0.033	0.123 ± 0.024	0.138 ± 0.030
Ξ_{bb}	0.303 ± 0.094	0.281 ± 0.071	0.252 ± 0.064
Ω_{bb}	0.404 ± 0.112	0.347 ± 0.083	0.311 ± 0.077
Ξ_{bc}	0.191 ± 0.053	0.176 ± 0.040	- -
Ω_{bc}	0.217 ± 0.056	0.188 ± 0.041	- -

Weak decays of doubly heavy baryons: the form factors (with QCDSR method)

Y. J. Shi, W. Wang, and Z. X. Zhao, arXiv:1811.xxxxx

12 Dirac structures

$$\Pi_\mu = \lambda_1\lambda_2 \frac{(\not{p}_2 + M_2)(F_1\frac{p_{1\mu}}{M_1} + F_2\frac{p_{2\mu}}{M_2} + F_3\gamma_\mu)(\not{p}_1 + M_1)}{(p_1^2 - M_1^2)(p_2^2 - M_2^2)}$$

1 $\not{p}_2 p_{1\mu} \not{p}_1$

2 $\not{p}_2 p_{1\mu}$

3 $\not{p}_2 p_{2\mu} \not{p}_1$

4 $\not{p}_2 p_{1\mu}$

5 $\not{p}_2 \gamma_\mu \not{p}_1$

6 $\not{p}_2 \gamma_\mu$

7 $p_{1\mu} \not{p}_1$

8 $p_{1\mu}$

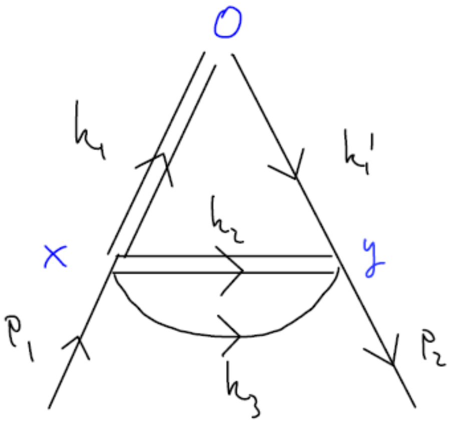
9 $p_{2\mu} \not{p}_1$

10 $p_{2\mu}$

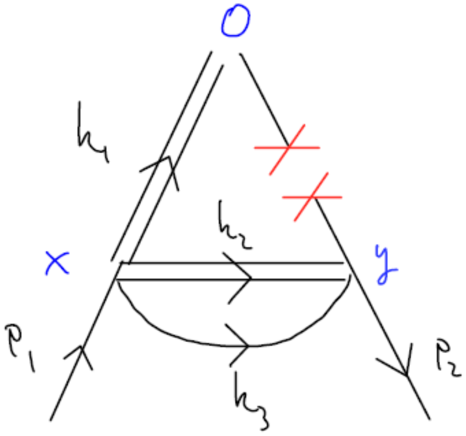
11 $\gamma_\mu \not{p}_1$

12 γ_μ

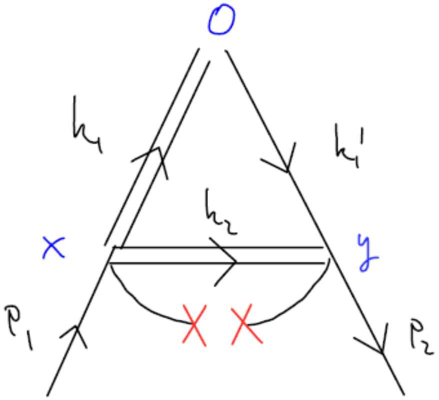
Dim-0 and dim-3



pert

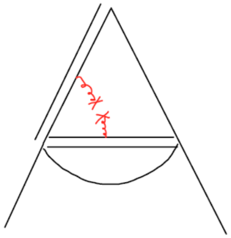


qq1

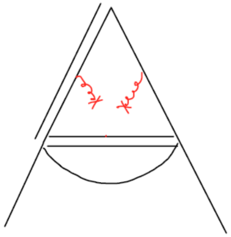


qq2

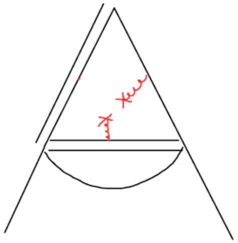
Dim-4



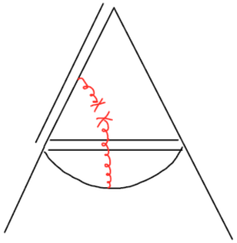
gg1



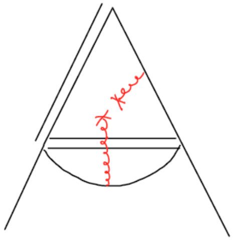
gg2



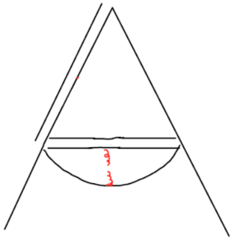
gg3



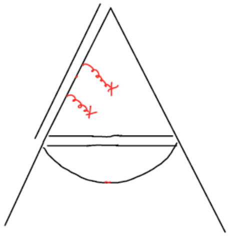
gg4



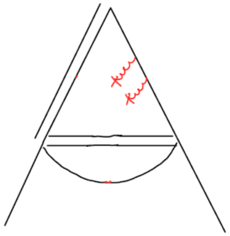
gg5



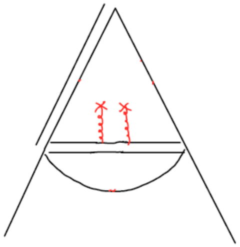
gg6



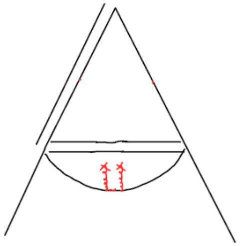
gg7



gg8

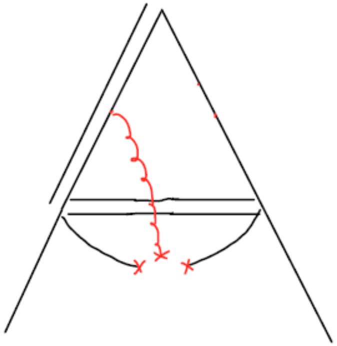


gg9

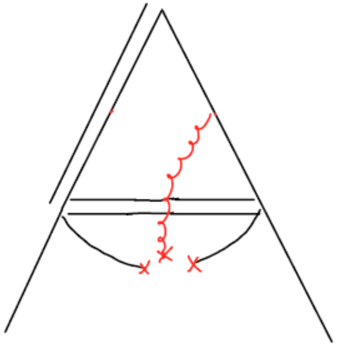


gg10

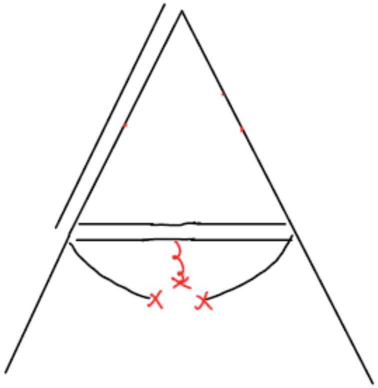
Dim-5



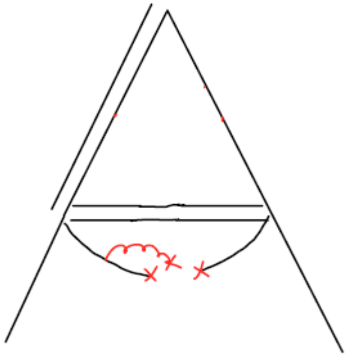
qgq1



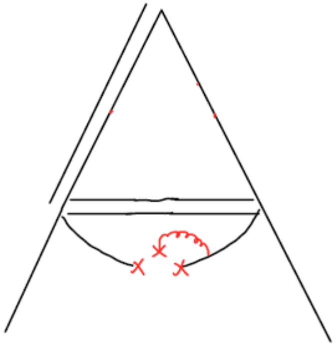
qgq2



qgq3

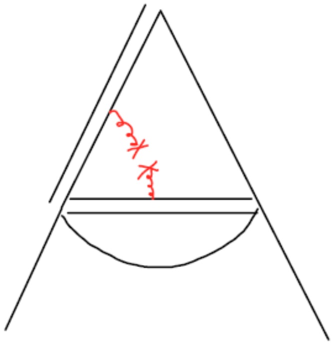


qgq4



qgq5

Feynman rules



gg1

$$
\begin{aligned}
&= 2\sqrt{2}i^2\epsilon_{a'b'c'}\epsilon_{abc}\int\frac{d^4k_2}{(2\pi)^4}\int\frac{d^4k_3}{(2\pi)^4}\int\frac{d^4u}{(2\pi)^4}\int\frac{d^4v}{(2\pi)^4}\\
&* \Bigg[\gamma_{\nu'}\gamma_5\\
&\left(\frac{i}{\not k_2+\not v-m_2}\delta_{c'j'}(igT^b_{j'j}\gamma^\beta)\left(\frac{-i}{2}(2\pi)^4\frac{\partial}{\partial v_\sigma}\delta^4(v)G^b_{\sigma\beta}(0)\right)\frac{i}{\not k_2-m_2}\delta_{jb}\right)\\
&\gamma^\nu\\
&\left(\frac{i}{\not p_1-\not k_2-\not k_3+m_1}\delta_{ia}(igT^a_{i'i}\gamma^\alpha)\left(\frac{-i}{2}(2\pi)^4\frac{\partial}{\partial u_\rho}\delta^4(u)G^a_{\rho\alpha}(0)\right)\frac{i}{\not p_1-\not k_2-\not k_3+\not u+m_1}\delta_{a''i'}\right)\\
&\gamma_\mu\\
&\frac{i}{\not p_2-\not k_2-\not k_3-\not v+m_1'}\delta_{b'a''}\\
&\gamma^{\nu'}\\
&\frac{i}{\not k_3-m_3}\delta_{a'c}\\
&\gamma_\nu\gamma_5\Bigg]
\end{aligned}
$$

1 term, 15 gamma’s -> 2 terms, each with 19 gamma’s

Contribution < 1%

Summary and outlook

Summary

- Weak decays of doubly heavy baryons: the 1/2 -> 1/2 case
- Weak decays of doubly heavy baryons: the 1/2 -> 3/2 case
- Weak decays of doubly heavy baryons: the FCNC processes
- Weak decays of doubly heavy baryons: decay constants
- Weak decays of doubly heavy baryons: the form factors

Outlook

- lifetime ---- HQE + QCD sum rule

Phys. Rev. Lett. 121, 052002 (2018) $\mathbf{\Xi_{cc}^{++}(ccu)}$

$$0.256\,^{+0.024}_{-0.022}\,(\mathrm{stat})\ \pm 0.014\,(\mathrm{syst})\ \mathrm{ps}$$

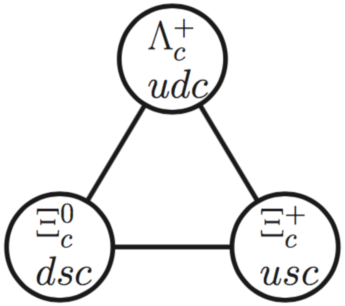
Phys. Rev. Lett. 121, 092003 (2018) $\mathbf{\Omega_c^0(css)}$

268 fs vs 69 fs

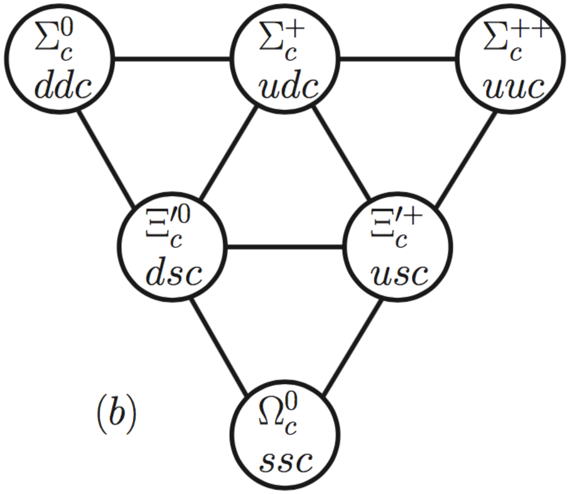
Thank you for your attention!

Backup

backup


Λ_c^+
udc
Ξ_c^0
dsc
Ξ_c^+
usc

(a)


Σ_c^0
ddc
Σ_c^+
udc
Σ_c^{++}
uuc
$\Xi_c^{\prime 0}$
dsc
$\Xi_c^{\prime +}$
usc
Ω_c^0
ssc

(b)

The FCNC processes

$$\frac{d^2\Gamma}{dq^2 d\cos\theta} = \frac{|\vec{P}'||\vec{p}_1|}{16(2\pi)^3 M^2\sqrt{q^2}}\overline{|\mathcal{M}|^2}$$

$$\overline{|\mathcal{M}|^2} = \frac{1}{2}|\lambda|^2(I_0 + I_1\cos\theta + I_2\cos 2\theta)$$

$$\begin{aligned}
I_0 &= (q^2+4m_l^2)(|H^{V,\frac{1}{2}}_{-\frac{1}{2},0}|^2+|H^{V,-\frac{1}{2}}_{\frac{1}{2},0}|^2)+(\frac{3}{2}q^2+2m_l^2)(|H^{V,\frac{1}{2}}_{\frac{1}{2},1}|^2+|H^{V,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2)\\
&\quad +(q^2-4m_l^2)(\frac{3}{2}|H^{A,\frac{1}{2}}_{\frac{1}{2},1}|^2+\frac{3}{2}|H^{A,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2+|H^{A,\frac{1}{2}}_{-\frac{1}{2},0}|^2+|H^{A,-\frac{1}{2}}_{\frac{1}{2},0}|^2)\\
&\quad +8m_l^2(|H^{A,\frac{1}{2}}_{-\frac{1}{2},t}|^2+|H^{A,-\frac{1}{2}}_{\frac{1}{2},t}|^2),\\
I_1 &= 4\sqrt{q^2(q^2-4m_l^2)}\mathrm{Re}(H^{A,\frac{1}{2}*}_{\frac{1}{2},1}H^{V,\frac{1}{2}}_{\frac{1}{2},1}-H^{A,-\frac{1}{2}*}_{-\frac{1}{2},-1}H^{V,-\frac{1}{2}}_{-\frac{1}{2},-1}),\\
I_2 &= \frac{1}{2}(q^2-4m_l^2)(|H^{V,\frac{1}{2}}_{\frac{1}{2},1}|^2+|H^{V,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2-2|H^{V,\frac{1}{2}}_{-\frac{1}{2},0}|^2-2|H^{V,-\frac{1}{2}}_{\frac{1}{2},0}|^2\\
&\qquad +|H^{A,\frac{1}{2}}_{\frac{1}{2},1}|^2+|H^{A,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2-2|H^{A,\frac{1}{2}}_{-\frac{1}{2},0}|^2-2|H^{A,-\frac{1}{2}}_{\frac{1}{2},0}|^2).
\end{aligned}$$

The FCNC processes

$$
\begin{aligned}
\frac{d\Gamma_L}{dq^2} &= |\lambda|^2 \frac{|\vec{P}'||\vec{p}_1|}{12(2\pi)^3 M^2 \sqrt{q^2}} \Big\{ (q^2 + 2m_l^2)(|H^{V,\frac{1}{2}}_{-\frac{1}{2},0}|^2 + |H^{V,-\frac{1}{2}}_{\frac{1}{2},0}|^2) \\
&\qquad + (q^2 - 4m_l^2)(|H^{A,\frac{1}{2}}_{-\frac{1}{2},0}|^2 + |H^{A,-\frac{1}{2}}_{\frac{1}{2},0}|^2) \\
&\qquad + 6m_l^2(|H^{A,\frac{1}{2}}_{-\frac{1}{2},t}|^2 + |H^{A,-\frac{1}{2}}_{\frac{1}{2},t}|^2) \Big\}, \\
\frac{d\Gamma_T}{dq^2} &= |\lambda|^2 \frac{|\vec{P}'||\vec{p}_1|}{12(2\pi)^3 M^2 \sqrt{q^2}} \Big\{ (q^2 + 2m_l^2)(|H^{V,\frac{1}{2}}_{\frac{1}{2},1}|^2 + |H^{V,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2) \\
&\qquad + (q^2 - 4m_l^2)(|H^{A,\frac{1}{2}}_{\frac{1}{2},1}|^2 + |H^{A,-\frac{1}{2}}_{-\frac{1}{2},-1}|^2) \Big\}.
\end{aligned}
$$

$$
\frac{d\bar{A}_{FB}}{dq^2} \equiv \frac{(\int_0^1 - \int_{-1}^0) d\cos\theta \frac{d^2\Gamma}{dq^2 d\cos\theta}}{(\int_0^1 + \int_{-1}^0) d\cos\theta \frac{d^2\Gamma}{dq^2 d\cos\theta}}
$$

$$
\frac{d\bar{A}_{FB}}{dq^2} = \frac{I_1}{2(I_0 - I_2/3)}
$$

“Decay constants”

$$J_{\Xi_{QQ}} = \epsilon_{abc} \left(Q_a^T C \gamma^\mu Q_b \right) \gamma_\mu \gamma_5 q_c,$$

$$J_{\Xi_{bc}} = \sqrt{2} \epsilon_{abc} (b_a^T C \gamma^\mu c_b) \gamma_\mu \gamma_5 q_c$$

V. Braun, R. J. Fries, N. Mahnke and E. Stein, Nucl. Phys. B 589, 381 (2000)

Sources of uncertainty

- Input parameters:
  - quark masses

$$m_u = m_d = 0.25\mathrm{GeV}, \quad m_s = 0.37\mathrm{GeV}, \quad m_c = 1.4\mathrm{GeV}, \quad m_b = 4.8\mathrm{GeV}.$$

  - diquark masses

$$m_{[ud]} = 0.50\mathrm{GeV}, \quad m_{[us]} = m_{[ds]} = 0.60\mathrm{GeV},$$
$$m_{\{uu\}} = m_{\{ud\}} = m_{\{dd\}} = 0.77\mathrm{GeV}, \quad m_{\{us\}} = m_{\{ds\}} = 0.87\mathrm{GeV}, \quad m_{\{ss\}} = 0.97\mathrm{GeV}.$$

  - shape parameters

$$\begin{aligned}
&\beta_{b[ud]} = 0.66\mathrm{GeV}, \quad \beta_{b[us]} = \beta_{b[ds]} = 0.68\mathrm{GeV}, \quad \beta_{b\{ss\}} = 0.78\mathrm{GeV},\\
&\beta_{c[ud]} = 0.56\mathrm{GeV}, \quad \beta_{c[us]} = \beta_{c[ds]} = 0.58\mathrm{GeV}, \quad \beta_{c\{ss\}} = 0.66\mathrm{GeV},\\
&\beta_{s[ud]} = 0.45\mathrm{GeV}, \quad \beta_{s[us]} = \beta_{s[ds]} = 0.46\mathrm{GeV},\\
&\beta_{d[ud]} = 0.40\mathrm{GeV}, \quad \beta_{d[us]} = \beta_{d[ds]} = 0.41\mathrm{GeV}, \quad \beta_{d\{ss\}} = 0.44\mathrm{GeV},\\
&\beta_{u[ud]} = 0.40\mathrm{GeV}, \quad \beta_{u[us]} = \beta_{u[ds]} = 0.41\mathrm{GeV}, \quad \beta_{u\{ss\}} = 0.44\mathrm{GeV}.
\end{aligned}$$

Sources of uncertainty

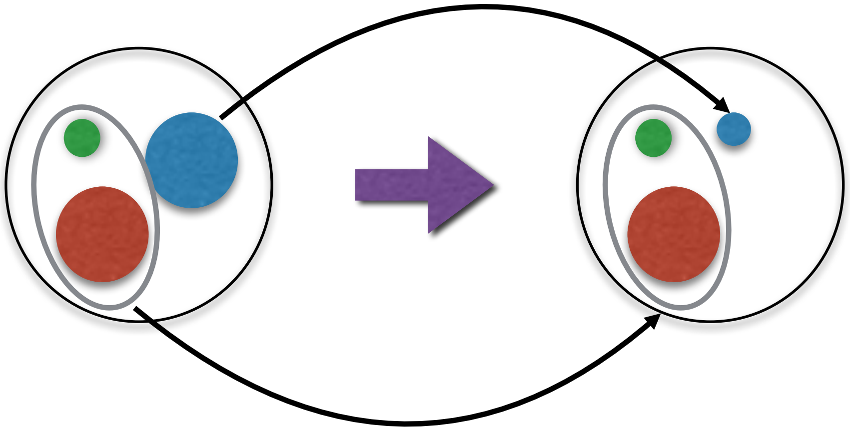
$$\Lambda_c^+ \to \Lambda$$

Varying the model parameters m_{di}, β_i and β_f by 10% respectively

$$\begin{aligned}
\Gamma(\Lambda_c^+ \to \Lambda e^+ \nu_e) &= (5.36 \pm 0.03 \pm 0.10 \pm 0.07) \times 10^{-14}, \\
\Gamma(\Lambda_c^+ \to \Lambda \pi^+) &= (4.77 \pm 0.08 \pm 0.14 \pm 0.34) \times 10^{-14}, \\
\Gamma(\Lambda_c^+ \to \Lambda \rho^+) &= (1.39 \pm 0.01 \pm 0.02 \pm 0.02) \times 10^{-13}, \\
\Gamma(\Lambda_c^+ \to \Lambda K^+) &= (3.47 \pm 0.04 \pm 0.11 \pm 0.22) \times 10^{-15}, \\
\Gamma(\Lambda_c^+ \to \Lambda K^{*+}) &= (6.47 \pm 0.02 \pm 0.10 \pm 0.19) \times 10^{-15}.
\end{aligned}$$

Sources of uncertainty

- For non-leptonic process, we have only considered the external W-emission diagram
- Model hypothesis



diquark

0^+ or 1^+