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Weak Decays of Doubly Heavy (Charmed) Baryons

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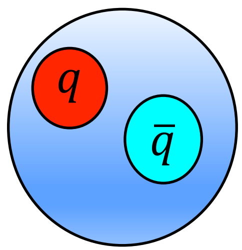
Implications of LHCb measurements and future prospects
08.11.2017-10.11.2017

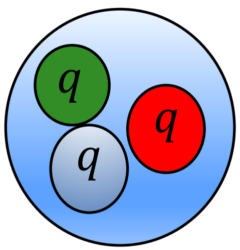
Content

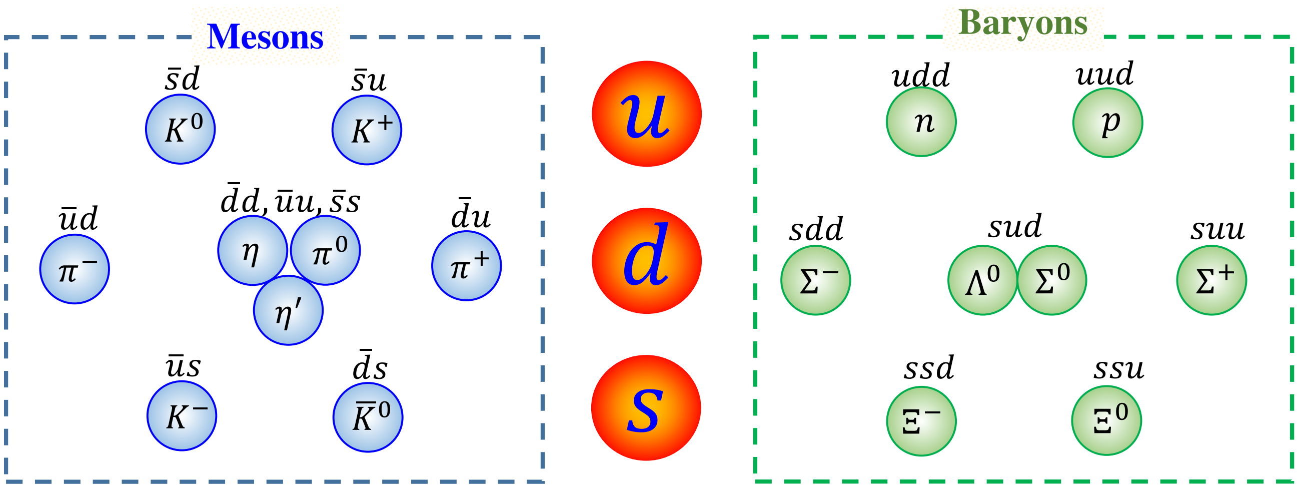
- Overview of doubly charmed baryons
- Golden(Discovery)decay modes: Ξ_{cc}, Ω_{cc}
- Semi-leptonic decays: form factors
- Non-leptonic decays: SU(3) Analysis
- Summary and Outlook

Quark Model

- In 1964, Gell-Mann and Zweig proposed a way to build the numerous hadrons out of three fundamental quarks.



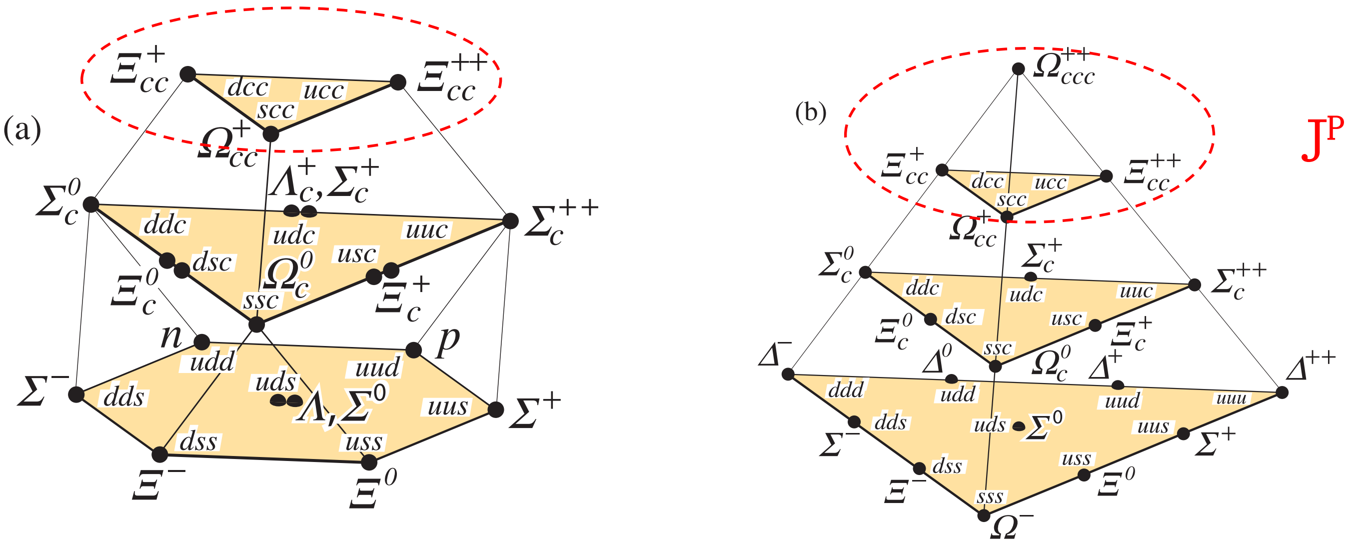




Quark Model

- Extending to SU(4) and SU(5) would include new quarks:
  - ✓ charm and bottom
- Mesons with charm and/or bottom have been well established
- For baryons with four flavors u, d, s, c, a 20-plet for $J^P=1/2^+$ and $J^P=3/2^+$, respectively

$J^P=1/2^+$



$J^P=3/2^+$

Searching for doubly/triply charmed baryons would be important for the spectroscopy and QCD studies.

Doubly charmed baryon spectrum

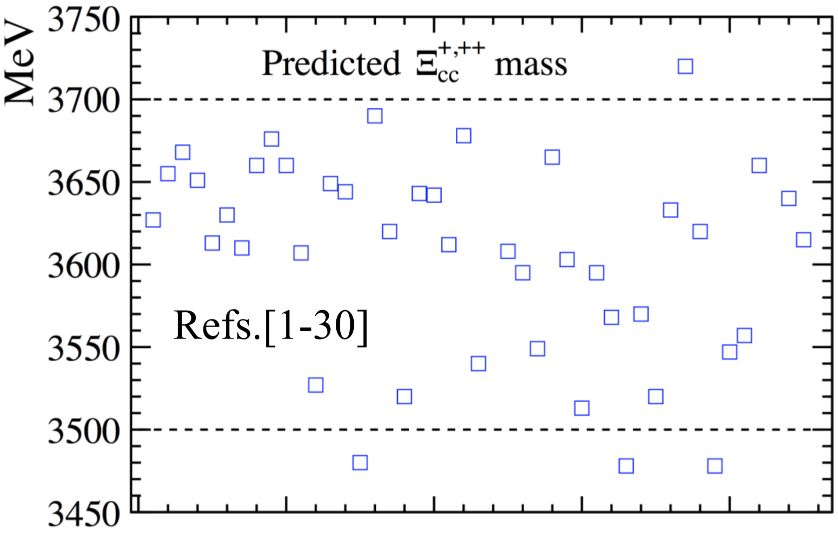
- Many models have been applied to calculate masses: quark models or QCD sum rules

  - ✓ Predicted Mass:

    $m(\Xi_{cc}^{++}) \sim m(\Xi_{cc}^{+}) \sim (3.5-3.7)\mathrm{GeV}$

    $m(\Omega_{cc}) \sim m(\Xi_{cc}^{+}) + 0.1\mathrm{GeV}$

  - ✓ Mass splitting between Ξ_{cc}^{++} and Ξ_{cc}^{+} is a few MeV



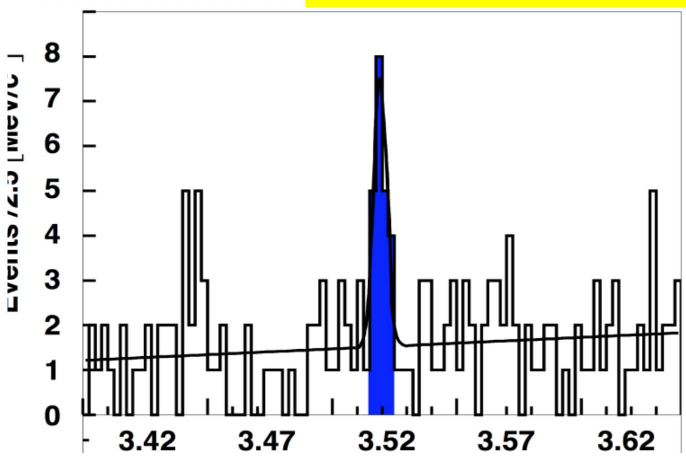
- Lattice QCD Calculation:
  $m(\Xi_{cc}) \sim 3.6\mathrm{GeV}, m(\Omega_{cc}) \sim 3.7\mathrm{GeV}$

References can be found in 1703.09086

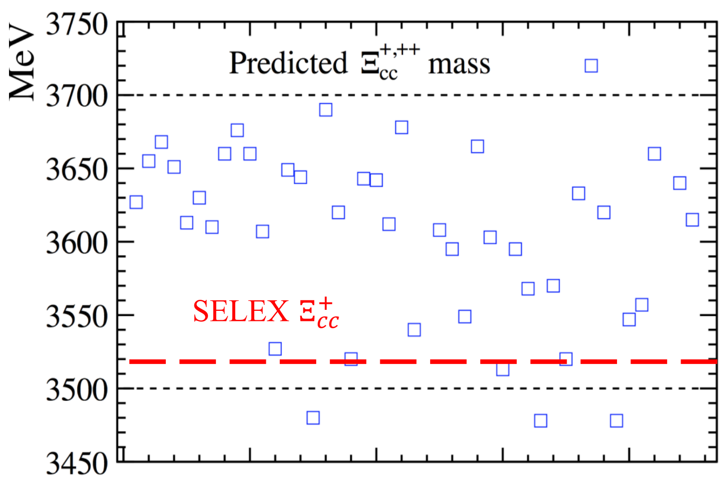
Experimental Search before 2017

- SELEX (Fermilab E781) collides high energy hyperon beams $(\boldsymbol{\Sigma^-, p})$ with nuclear targets, dedicated to study charm baryons
- Observed $\Xi_{cc}^{+}(ccd)$ in $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ and $\Xi_{cc}^{+} \to pD^+K^-$ decays
  - ✓ Signal yield: 15.9 $(\Lambda_c^+ K^- \pi^+)$ and 5.62 (pD^+K^-)
  - ✓ Short lifetime: $\tau(\Xi_{cc}^{+}) < 33fs@90\%\ CL$
  - ✓ Large production: $R = \frac{\sigma(\Xi_{cc}^{+}) \times B(\Xi_{cc}^{+} \to \Lambda_c^+ X)}{\sigma(\Lambda_c^+)} \sim 20\%$
  - ✓ Mass (combined): 3518.7$\pm$1.7MeV

$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ PRL 89 (2002) 112001



Refs.[1-30]

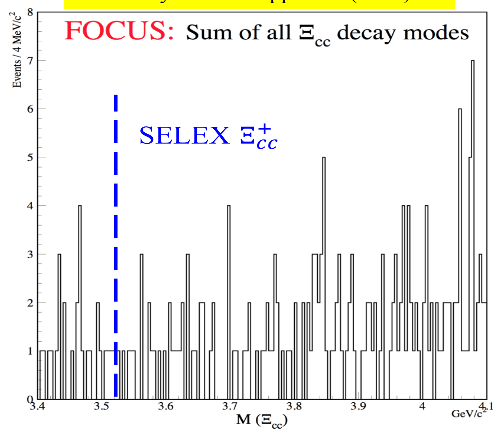


Experimental Search before 2017

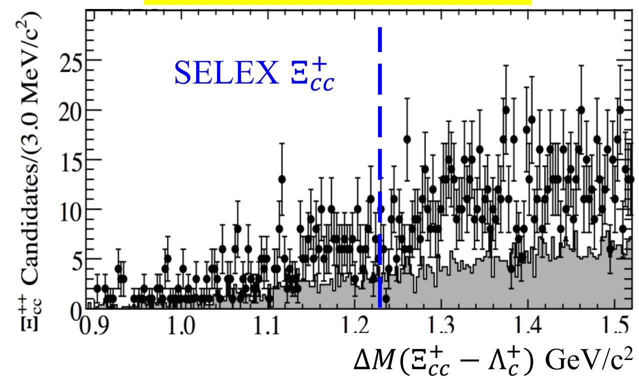
- SELEX results are not confirmed by FOCUS(2003), Babar(2006), Belle(2006) and LHCb (2013) searches.

Fermilab E831: photon-nuclear fixed target collisions

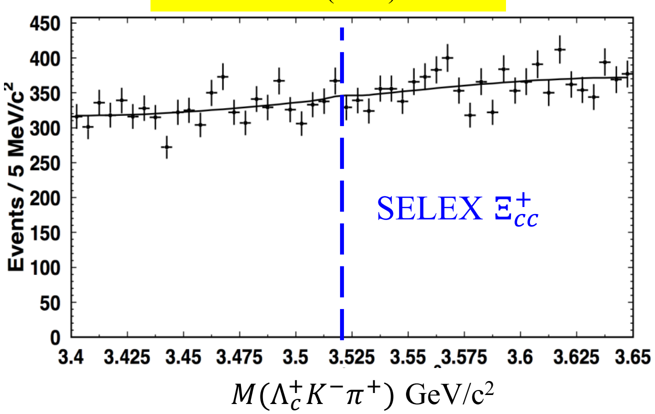
Nucl. Phys. Proc. Suppl. 115 (2003) 33



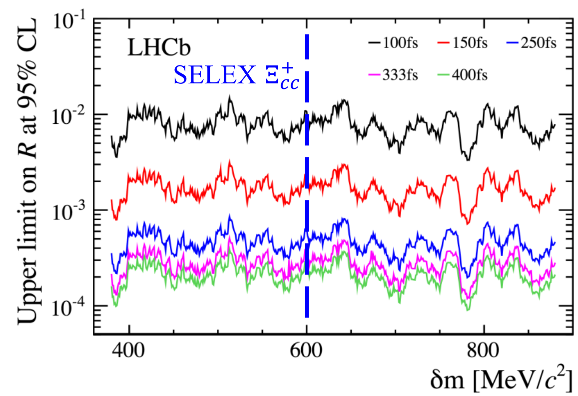
BaBar: PRD 74 (2006) 011103



Belle: PRL 97 (2006) 162001



LHCb: JHEP12(2013)090



7TeV
$0.65 fb^{-1}$

Production X-Section at LHC

- Theoretical studies based on NRQCD found the X-section is at 10nb-100nb level.
- B_c has been extensively studied by LHCb, $\sigma(\Xi_{cc}) \sim \sigma(B_c)$

-	Ξ_{cc} (Ξ_{cc}^{++}, Ξ_{cc}^{+})	
nb	$\sqrt{S}=7.0$TeV	$\sqrt{S}=14.0$TeV
$[^3S_1]$	38.11	69.40
$[^1S_0]$	9.362	17.05
Total	47.47	86.45

$p_t > 4GeV$, $|y| < 1.5$

J.W.Zhang, et.al. PRD83, 034026(2011)

B_c-(nb)	$\vert(^1S_0)_{\mathbf{1}}\rangle$	$\vert(^3S_1)_{\mathbf{1}}\rangle$	$\vert(^1S_0)_{\mathbf{8}}g\rangle$	$\vert(^3S_1)_{\mathbf{8}}g\rangle$	$\vert(^1P_1)_{\mathbf{1}}\rangle$	$\vert(^3P_0)_{\mathbf{1}}\rangle$	$\vert(^3P_1)_{\mathbf{1}}\rangle$	$\vert(^3P_2)_{\mathbf{1}}\rangle$
LHC 14	71.1	177.	(0.357, 3.21)	(1.58, 14.2)	9.12	3.29	7.38	20.4
TEVATRON	5.50	13.4	(0.0284, 0.256)	(0.129, 1.16)	0.655	0.256	0.560	1.35

C.H.Chang, et.al. PRD71, 074012(2005)

For details, see the talk by Prof. Xinggang Wu

Theoretical estimate of golden decay modes of Ξ_{cc} and Ω_{cc} would be helpful for experimental searches.

F.S. Yu, H.Y. Jiang, R.H. Li, C.D. Lü, WW, Z.X. Zhao, arXiv:1703.09086

Lifetime

- Large uncertainties: differ by a factor of 4~8
- $\tau(\Xi_{cc}^{++}) \gg \tau(\Xi_{cc}^{+}) \sim \tau(\Omega_{cc})$

literature	Ξ_{cc}^{++}	Ξ_{cc}^{+}	Ω_{cc}^{+}
Karliner, Rosner, 2014	185	53	
Chang, Li, Li, Wang, 2007	670	250	210
Kiselev, Likhoded,2002	460 ± 50	160 ± 50	270 ± 60
Kiselev, Likhoded, 1998	430 ± 100	110 ± 10	
Guberina, Melic, Stefancic, 1998	1550	220	250

Lifetime

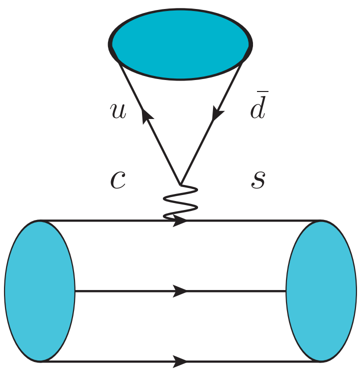
- Larger lifetime:
  - ✓ higher efficiency of identification at hadron colliders
  - ✓ smaller width, larger branching fractions
- It is better to search Ξ_{cc}^{++} first rather than Ξ_{cc}^{+} and Ω_{cc}

Golden modes

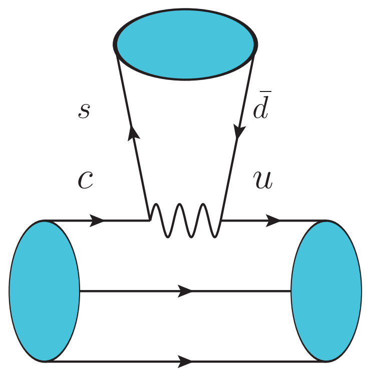
Criteria:

- Charged final states with high efficiency @LHC
- Large branching fractions
  - ✓ CKM favored
  - ✓ Leading power in $1/m_Q$?

Decay Amplitudes



T
Color-Allowed Tree



C
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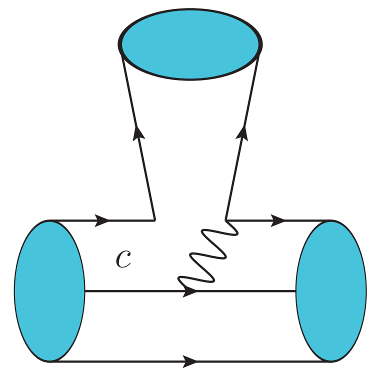
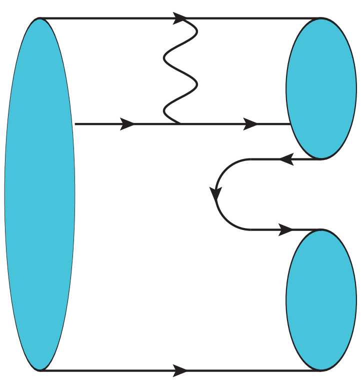
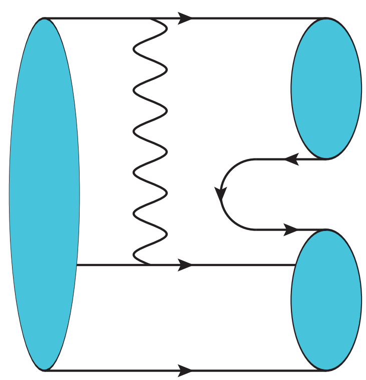


C'
Color-Commensurate



B
Bow-Tie



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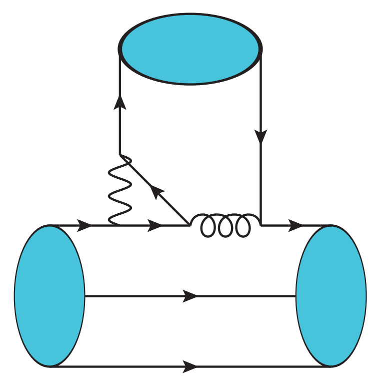
W-Exchange



P
Penguin

Decay Amplitudes

It is difficult to calculate charm quark decays.

- QCD expansion, not work well: *Inspired by D decays*
  - ✖ $\alpha_s\left(\frac{mc}{2}\right)\sim 1$
- Heavy quark expansion, not work well:
  - ✖ $\Lambda/(\frac{mc}{2}) \sim 1$
  - ✖ $T\sim C \sim C'\sim E\sim B$
- No Suppression:

$$\left|\frac{C}{T}\right| \sim \left|\frac{C'}{T}\right| \sim \left|\frac{\mathrm{E}}{\mathrm{T}}\right| \sim \left|\frac{\mathrm{B}}{\mathrm{E}}\right| \sim 1, \mathrm{P}\sim 0$$

Golden modes

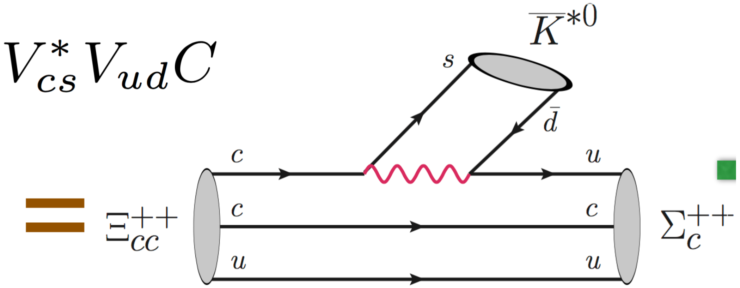
Criteria:

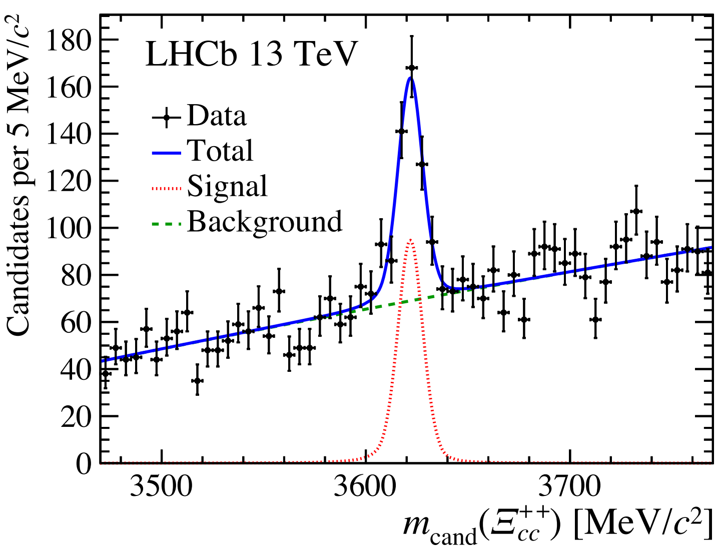
- ➢ Charged final states with high efficiency @LHC
- ➢ Large branching fractions
  - ✓ CKM allowed

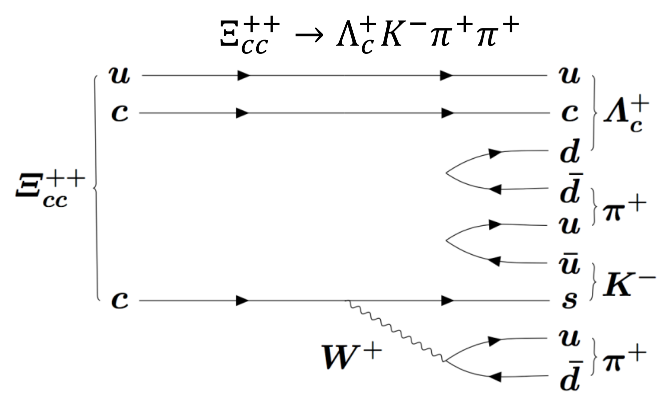
Golden modes

$$\Xi_{cc}^{++} \to \Sigma_c^{++}\overline{K}^{*0} \to \Lambda_c^+ K^- \pi^+ \pi^+$$

$V_{cs}^* V_{ud} C$







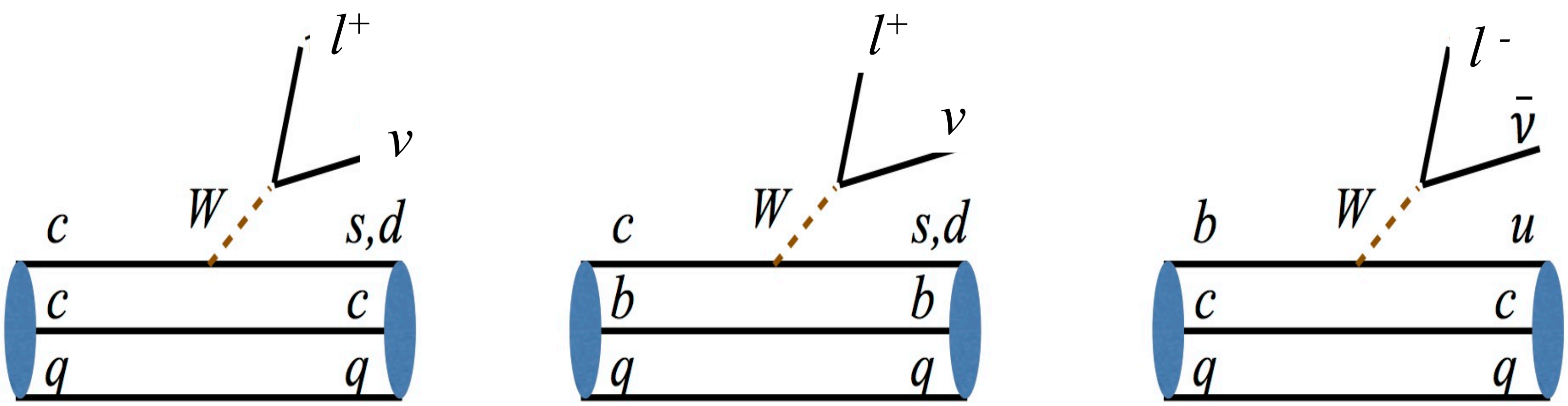
Talk by Mat Charles

LHCb, PRL119, 112001 (2017)

Golden modes

- $\Xi_{cc}^{++} > \Xi_{cc}^{+} > \Omega_{cc}$ since $\tau(\Xi_{cc}^{++}) \gg \tau(\Xi_{cc}^{+}) \sim \tau(\Omega_{cc})$
- Ξ_{cc}^{++}:
  - ✓ $\Xi_{cc}^{++} \to \Lambda_c K^- \pi^+ \pi^+$: discovery channel by LHCb
  - ✓ $\Xi_{cc}^{++} \to \Sigma'^+ D^+, \cdots$
- Ξ_{cc}^{+}:
  - ✓ $\Xi_{cc}^{+} \to \Lambda_c K^- \pi^+$, channel used by SELEX
  - ✓ $\Xi_{cc}^{+} \to \Xi_c^+ \pi^+ \pi^-, \cdots$
- Ω_{cc}:
  - ✓ $\Omega_c^+ \to \Xi_c^+ K^- \pi^+ \ldots$

Semi-leptonic decays



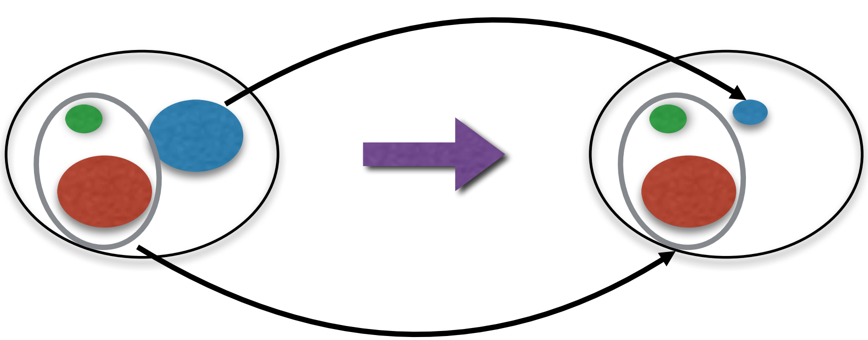
Form factors

$$\langle B'(P',S'_z)|(V-A)_\mu|B(P,S_z)\rangle = \bar{u}(P',S'_z)\left[\gamma_\mu f_1(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M}f_2(q^2) + \frac{q_\mu}{M}f_3(q^2)\right]u(P,S_z)$$
$$- \bar{u}(P',S'_z)\left[\gamma_\mu g_1(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M}g_2(q^2) + \frac{q_\mu}{M}g_3(q^2)\right]\gamma_5 u(P,S_z)$$

WW, F. S. Yu, Z. X. Zhao, arxiv:1707.02834

Semi-leptonic decays

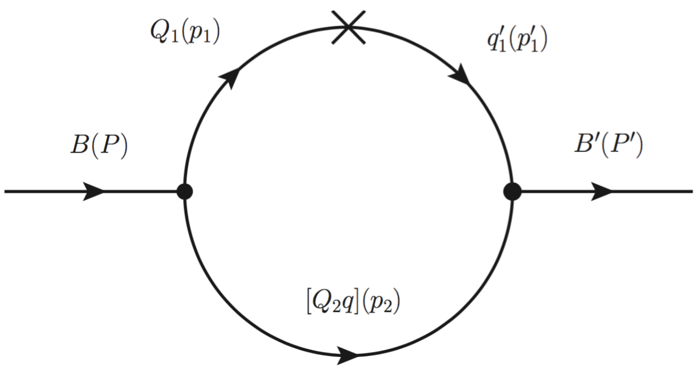
- Doubly heavy baryon decays: $Q_1Q_2q \to q_1'Q_2q$
  - ✓Weak transition $Q_1 \to q_1'$; spectator Q_2q
  - ✓For simplicity, treat Q_2q as a loosely bounded diquark, $J^P = 0^+, 1^+$
  - ✓Consider the ground state: L=1



Form Factor: A model estimate

$$\langle B'(P',S'_z)|(V-A)_\mu|B(P,S_z)\rangle = \bar{u}(P',S'_z)\left[\gamma_\mu f_1(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M}f_2(q^2) + \frac{q_\mu}{M}f_3(q^2)\right]u(P,S_z)$$
$$-\bar{u}(P',S'_z)\left[\gamma_\mu g_1(q^2) + i\sigma_{\mu\nu}\frac{q^\nu}{M}g_2(q^2) + \frac{q_\mu}{M}g_3(q^2)\right]\gamma_5 u(P,S_z)$$

$$\langle B'(P',S'_z)|(V-A)_\mu|B(P,S_z)\rangle = \int\{d^3p_2\}\frac{\phi'^*(x',k'_\perp)\phi(x,k_\perp)}{2\sqrt{p_1^+p_1'^+(p_1\cdot\bar{P}+m_1M_0)(p'_1\cdot\bar{P}'+m'_1M'_0)}}$$
$$\times\,\bar{u}(\bar{P}',S'_z)\bar{\Gamma}'(\not{p}'_1+m'_1)\gamma_\mu(1-\gamma_5)(\not{p}_1+m_1)\Gamma u(\bar{P},S_z)$$



Semi-leptonic decays

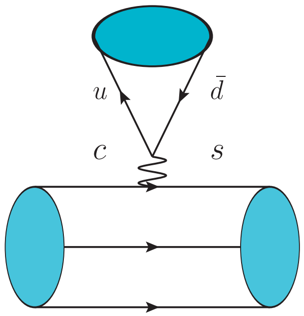
channels	$\Gamma/$ GeV	$\mathcal{B}$	Γ_L/Γ_T
$\Xi_{cc}^{++} \to \Xi_c^{+} l^+ \nu_l$	1.15×10^{-13}	5.25×10^{-2}	9.99
$\Xi_{cc}^{++} \to \Xi_c^{\prime +} l^+ \nu_l$	1.28×10^{-13}	5.84×10^{-2}	1.42
$\Xi_{cc}^{+} \to \Xi_c^{0} l^+ \nu_l$	1.14×10^{-13}	1.73×10^{-2}	9.99
$\Xi_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l$	1.27×10^{-13}	1.93×10^{-2}	1.42
$\Omega_{cc}^{+} \to \Omega_c^{0} l^+ \nu_l$	2.55×10^{-13}	10.5×10^{-2}	1.42
$\Xi_{cc}^{++} \to \Lambda_c^{+} l^+ \nu_l$	1.05×10^{-14}	4.81×10^{-3}	8.52
$\Xi_{cc}^{++} \to \Sigma_c^{+} l^+ \nu_l$	9.60×10^{-15}	4.38×10^{-3}	1.28
$\Xi_{cc}^{+} \to \Sigma_c^{0} l^+ \nu_l$	1.91×10^{-14}	2.91×10^{-3}	1.28
$\Omega_{cc}^{+} \to \Xi_c^{0} l^+ \nu_l$	8.06×10^{-15}	3.31×10^{-3}	8.84
$\Omega_{cc}^{+} \to \Xi_c^{\prime 0} l^+ \nu_l$	9.34×10^{-15}	3.83×10^{-3}	1.28

$|V_{cs}|^2 \sim 1$

- ✓ Ξ_{cc}, Ω_{cc} search
- ✓ test theory

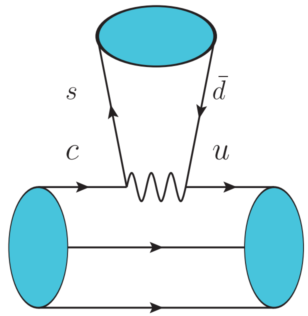
$|V_{cd}|^2 \sim 0.04$

Non-Leptonic decays



T

Color-Allowed Tree



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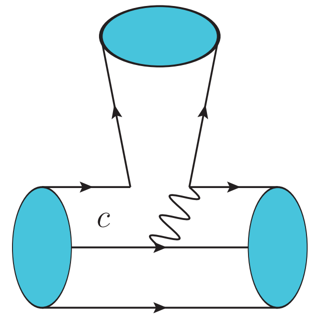
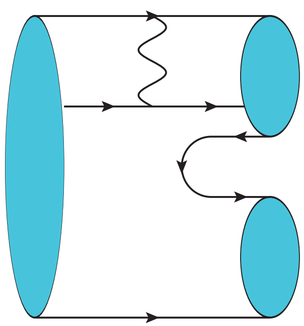


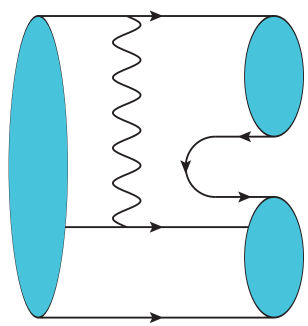
C'

Color-Commensurate



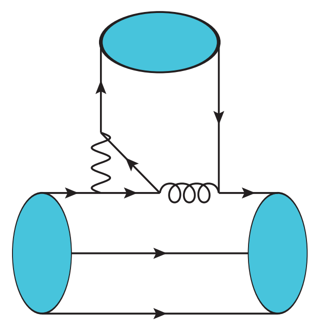
B

Bow-Tie



E

W-Exchange



P

Penguin

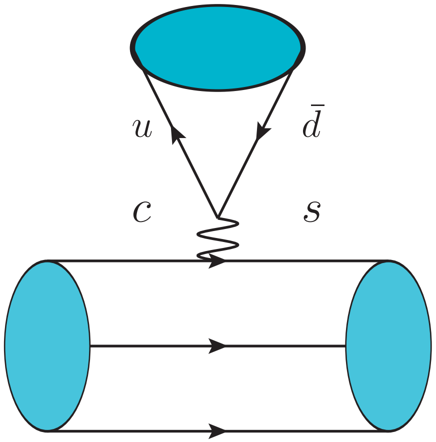
Weak Decays of Doubly Heavy Baryons: the SU(3) Analysis

WW, J. Xu, Z.P.Xing, 1707.06570

Non-Leptonic decays:SU(3) Analysis

- Charm decays are induced by the $c \to q_1\overline{q_2}q_3$
- SU(3) decomposition:
  - ✓ Initial state: triplet
  - ✓ Final state: light meson an octet

    charmed baryon antriplet
  - ✓ Operator $3 \otimes \bar{3} \otimes 3 = 3 \oplus 3 \oplus \bar{6} \oplus 15$



$$c \to s\bar{d}u\!: V_{cs}V_{ud}^{*} \sim 1$$

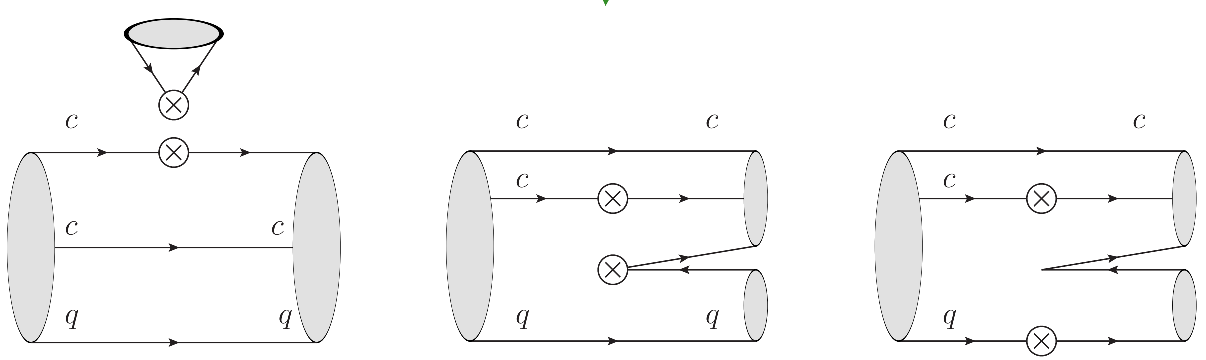
$$(H_{\overline{6}})^{31}_{2} = -(H_{\overline{6}})^{13}_{2} = 1, \quad (H_{15})^{31}_{2} = (H_{15})^{13}_{2} = 1$$

$$\begin{aligned}\mathcal{H}_{eff} \;=\; & b_3(T_{cc})^i(\overline{T}_{c\bar{3}})_{[ij]}M^k_l(H_{\overline{6}})^{jl}_k + b_4(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jl]}M^k_i(H_{\overline{6}})^{jl}_k + b_5(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jk]}M^k_l(H_{\overline{6}})^{jl}_i \\ & + b_6(T_{cc})^i(\overline{T}_{c\bar{3}})_{[ij]}M^k_l(H_{15})^{jl}_k + b_7(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jk]}M^k_l(H_{15})^{jl}_i\end{aligned}$$

See also Egolf, et.al. hep-ph/0211360

Non-Leptonic decays:SU(3) Analysis

$$\mathcal{H}_{eff} = b_3(T_{cc})^i(\overline{T}_{c\bar{3}})_{[ij]}M^k_l(H_{\overline{6}})^{jl}_k + b_4(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jl]}M^k_i(H_{\overline{6}})^{jl}_k + b_5(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jk]}M^k_l(H_{\overline{6}})^{jl}_i$$
$$+b_6(T_{cc})^i(\overline{T}_{c\bar{3}})_{[ij]}M^k_l(H_{15})^{jl}_k + b_7(T_{cc})^i(\overline{T}_{c\bar{3}})_{[jk]}M^k_l(H_{15})^{jl}_i$$



Non-Leptonic decays:SU(3) Analysis

TABLE V: Doubly charmed baryons decays into a cqq (antitriplet) and a light meson.

channel	amplitude	channel	amplitude
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$	$b_3 - 2b_4 + b_6$	$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$	$(b_3 - 2b_4 + b_6)(-\sin(\theta_C))$
$\Xi_{cc}^{+} \to \Lambda_c^+ \overline{K}^0$	$b_3 - b_5 - b_6 + b_7$	$\Xi_{cc}^{++} \to \Xi_c^+ K^+$	$(b_3 - 2b_4 + b_6)\sin(\theta_C)$
$\Xi_{cc}^{+} \to \Xi_c^+ \pi^0$	$\frac{2b_4 - b_5 - b_7}{\sqrt{2}}$	$\Xi_{cc}^{+} \to \Lambda_c^+ \pi^0$	$\frac{(b_3 - 2b_4 - b_6 + 2b_7)\sin(\theta_C)}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Xi_c^+ \eta$	$\frac{-2b_4 + b_5 - 3b_7}{\sqrt{6}}$	$\Xi_{cc}^{+} \to \Lambda_c^+ \eta$	$\frac{(-3b_3 + 2b_4 + 2b_5 + 3b_6)\sin(\theta_C)}{\sqrt{6}}$
$\Xi_{cc}^{+} \to \Xi_c^0 \pi^+$	$b_3 - b_5 + b_6 - b_7$	$\Xi_{cc}^{+} \to \Xi_c^+ K^0$	$(2b_4 - b_5 + b_7)(-\sin(\theta_C))$
$\Omega_{cc}^{+} \to \Xi_c^+ \overline{K}^0$	$b_3 - 2b_4 - b_6$	$\Xi_{cc}^{+} \to \Xi_c^0 K^+$	$(b_3 - b_5 + b_6 - b_7)\sin(\theta_C)$
$\Xi_{cc}^{++} \to \Lambda_c^+ K^+$	$(b_3 - 2b_4 + b_6)\sin^2(\theta_C)$	$\Omega_{cc}^{+} \to \Lambda_c^+ \overline{K}^0$	$(2b_4 - b_5 + b_7)\sin(\theta_C)$
$\Xi_{cc}^{+} \to \Lambda_c^+ K^0$	$(b_3 - 2b_4 - b_6)\sin^2(\theta_C)$	$\Omega_{cc}^{+} \to \Xi_c^+ \pi^0$	$\frac{(b_3 - b_5 - b_6 - b_7)\sin(\theta_C)}{\sqrt{2}}$
$\Omega_{cc}^{+} \to \Lambda_c^+ \pi^0$	$-\sqrt{2} b_7 \sin^2(\theta_C)$	$\Omega_{cc}^{+} \to \Xi_c^+ \eta$	$\frac{(-3b_3 + 4b_4 + b_5 + 3b_6 - 3b_7)\sin(\theta_C)}{\sqrt{6}}$
$\Omega_{cc}^{+} \to \Lambda_c^+ \eta$	$\sqrt{\frac{2}{3}}(2b_4 - b_5)\sin^2(\theta_C)$	$\Omega_{cc}^{+} \to \Xi_c^0 \pi^+$	$(b_3 - b_5 + b_6 - b_7)\sin(\theta_C)$
$\Omega_{cc}^{+} \to \Xi_c^+ K^0$	$(b_3 - b_5 - b_6 + b_7)\sin^2(\theta_C)$		
$\Omega_{cc}^{+} \to \Xi_c^0 K^+$	$(b_3 - b_5 + b_6 - b_7)(-\sin^2(\theta_C))$		

Non-Leptonic decays:SU(3) Analysis

- Golden channels with large BR: Ξ_{bc}

- Relations:

$$\Gamma(\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+) = \Gamma(\Xi_{cc}^{++} \to \Xi_c^+ K^+),$$
$$\Gamma(\Xi_{cc}^{+} \to \Xi_c^+ K^0) = \Gamma(\Omega_{cc}^{+} \to \Lambda_c^+ \overline{K}^0),$$
$$\Gamma(\Omega_{cc}^{+} \to \Xi_c^0 \pi^+) = \Gamma(\Xi_{cc}^{+} \to \Xi_c^0 K^+).$$

- Global fit in future

Summary

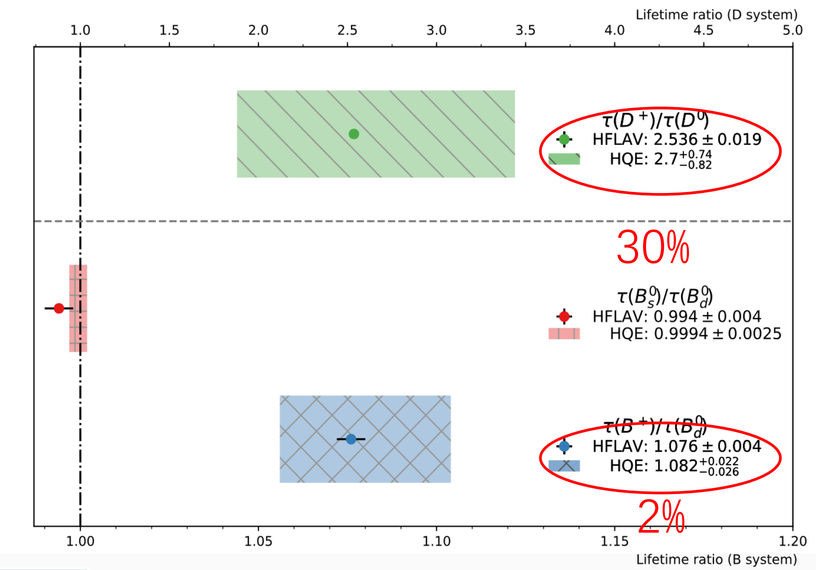
- Golden decay modes of $\Xi_{cc}^{++}, \Xi_{cc}^{+}, \Omega_{cc}$
- Semi-Leptonic decays
  - ✓ diquark approximation & model calculation
  - ✓ QCDSR analysis in future
- Non-leptonic decays: SU(3) Analysis

Prospect

- Study Ξ_{cc}^{++} in more channels?
- lifetime?
- Ξ_{cc}^{+}?
- $J^P = 1/2^+$?
- Semi-leptonic decay modes?
- CP Violation?
- …

A long long list…

Lifetime



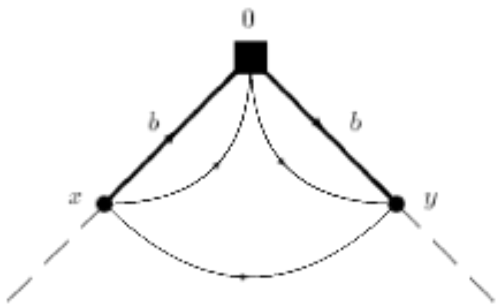
From Alexander Lenz’ s talk

Large uncertainties: 4~8

	Ξ_{cc}^{++}	Ξ_{cc}^{+}	Ω_{cc}^{+}
KR	185	53	
CLLW	670	250	210
KL	460 ± 50	160 ± 50	270 ± 60
KL	430 ± 100	110 ± 10	
GMS	1550	220	250

Lifetime

- Calculate the 4-quark operator matrix element
- Leading order contribution: 3-loop
- Next-to-leading order contribution: 4-loops



$$\langle \tilde{\mathcal{O}}^q_{V-A} \rangle_{\Lambda_b} = \frac{< \Lambda_b | \tilde{\mathcal{O}}^q_{V-A} | \Lambda_b >}{2 M_{\Lambda_b}} = \frac{f_B^2 M_B}{48} r$$

Colangelo, De Fazio, hep-ph/9604425

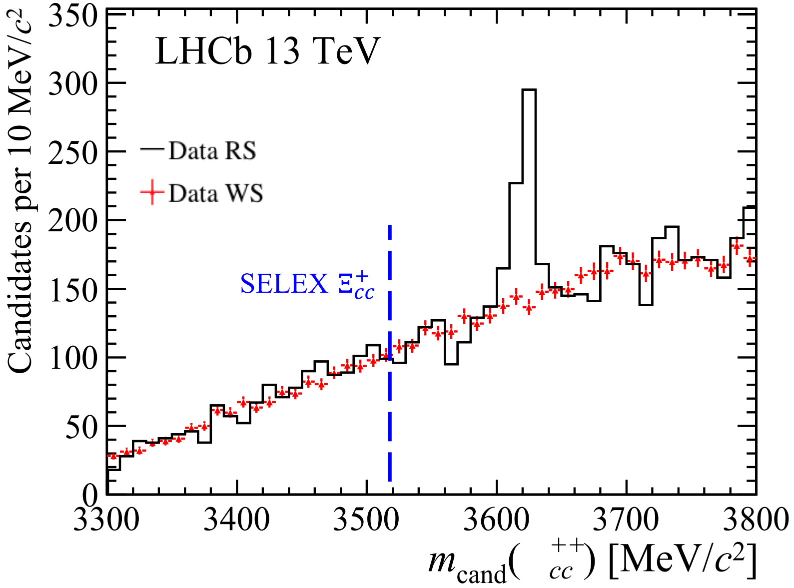
Challenging but worthwhile!

Thank you for your attention!

Backup Slides

Ξ_{cc}^{+}

- Search for Ξ_c^+ is important:
  - ✓ Large Isospin Symmetry Breaking?



SELEX, PRL 89, 112001 (2002)

LHCb, PRL119, 112001 (2017)

CKM allowed decays: ccq, BR a few %

channel	amplitude
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$	$b_3 - 2b_4 + b_6$
$\Xi_{cc}^{+} \to \Lambda_c^+ \overline{K}^0$	$b_3 - b_5 - b_6 + b_7$
$\Xi_{cc}^{+} \to \Xi_c^+ \pi^0$	$\frac{2b_4 - b_5 - b_7}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Xi_c^+ \eta$	$\frac{-2b_4 + b_5 - 3b_7}{\sqrt{6}}$
$\Xi_{cc}^{+} \to \Xi_c^0 \pi^+$	$b_3 - b_5 + b_6 - b_7$
$\Omega_{cc}^{+} \to \Xi_c^+ \overline{K}^0$	$b_3 - 2b_4 - b_6$

$\Xi_{cc}^{++} \to \Sigma_c^{++} \overline{K}^0$	$b_{10} - b_{13}$
$\Xi_{cc}^{++} \to \Xi_c'^+ \pi^+$	$\frac{b_{10} + 2b_{11} + b_{13}}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Sigma_c^{++} K^-$	$b_{12} - b_{14}$
$\Xi_{cc}^{+} \to \Sigma_c^+ \overline{K}^0$	$\frac{b_{10} + b_{12} - b_{13} - b_{14}}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Xi_c'^+ \pi^0$	$\frac{1}{2}(-2b_{11} + b_{12} + b_{14})$
$\Xi_{cc}^{+} \to \Xi_c'^+ \eta$	$\frac{2b_{11} - b_{12} + 3b_{14}}{2\sqrt{3}}$
$\Xi_{cc}^{+} \to \Xi_c'^0 \pi^+$	$\frac{b_{10} + b_{12} + b_{13} + b_{14}}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Omega_c^0 K^+$	$b_{12} + b_{14}$
$\Omega_{cc}^{+} \to \Xi_c'^+ \overline{K}^0$	$\frac{b_{10} + 2b_{11} - b_{13}}{\sqrt{2}}$
$\Omega_{cc}^{+} \to \Omega_c^0 \pi^+$	$b_{10} + b_{13}$

WW, J. Xu, Z.P.Xing, 1707.06570

CKM allowed decays: ccq, BR a few %

$\Xi_{cc}^{++} \to \Sigma^+ D^+$	$-c_7 - c_9$
$\Xi_{cc}^{+} \to \Lambda^0 D^+$	$\frac{-c_6-c_7+3c_8+3c_9}{\sqrt{6}}$
$\Xi_{cc}^{+} \to \Sigma^+ D^0$	$-c_6 - c_8$
$\Xi_{cc}^{+} \to \Sigma^0 D^+$	$\frac{c_6+c_7+c_8+c_9}{\sqrt{2}}$
$\Xi_{cc}^{+} \to \Xi^0 D_s^+$	$-c_6 + c_8$
$\Omega_{cc}^{+} \to \Xi^0 D^+$	$-c_7 + c_9$

$\Xi_{cc}^{++} \to \Sigma'^+ D^+$	$\frac{2d_4}{\sqrt{3}}$
$\Xi_{cc}^{+} \to \Sigma'^+ D^0$	$\frac{2d_5}{\sqrt{3}}$
$\Xi_{cc}^{+} \to \Sigma'^0 D^+$	$\sqrt{\frac{2}{3}}\,(d_4 + d_5)$
$\Xi_{cc}^{+} \to \Xi'^0 D_s^+$	$\frac{2d_5}{\sqrt{3}}$
$\Omega_{cc}^{+} \to \Xi'^0 D^+$	$\frac{2d_4}{\sqrt{3}}$

WW, J. Xu, Z.P.Xing, 1707.06570

CKM allowed decays: bcq, BR a few %

channel	amplitude
$\Xi_{bc}^{+} \to \Xi_b^0 \pi^+$	$b_3 - 2b_4 + b_6$
$\Xi_{bc}^{0} \to \Lambda_b^0 \overline{K}^0$	$b_3 - b_5 - b_6 + b_7$
$\Xi_{bc}^{0} \to \Xi_b^0 \pi^0$	$\frac{2b_4 - b_5 - b_7}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Xi_b^0 \eta$	$\frac{-2b_4 + b_5 - 3b_7}{\sqrt{6}}$
$\Xi_{bc}^{0} \to \Xi_b^- \pi^+$	$b_3 - b_5 + b_6 - b_7$
$\Omega_{bc}^{0} \to \Xi_b^0 \overline{K}^0$	$b_3 - 2b_4 - b_6$

$\Xi_{bc}^{+} \to \Sigma_b^+ \overline{K}^0$	$b_{10} - b_{13}$
$\Xi_{bc}^{+} \to \Xi_b^{\prime 0} \pi^+$	$\frac{b_{10} + 2b_{11} + b_{13}}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Sigma_b^+ K^-$	$b_{12} - b_{14}$
$\Xi_{bc}^{0} \to \Sigma_b^0 \overline{K}^0$	$\frac{b_{10} + b_{12} - b_{13} - b_{14}}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Xi_b^{\prime 0} \pi^0$	$\frac{1}{2}(-2b_{11} + b_{12} + b_{14})$
$\Xi_{bc}^{0} \to \Xi_b^{\prime 0} \eta$	$\frac{2b_{11} - b_{12} + 3b_{14}}{2\sqrt{3}}$
$\Xi_{bc}^{0} \to \Xi_b^{\prime -} \pi^+$	$\frac{b_{10} + b_{12} + b_{13} + b_{14}}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Omega_b^- K^+$	$b_{12} + b_{14}$
$\Omega_{bc}^{0} \to \Xi_b^{\prime 0} \overline{K}^0$	$\frac{b_{10} + 2b_{11} - b_{13}}{\sqrt{2}}$
$\Omega_{bc}^{0} \to \Omega_b^- \pi^+$	$b_{10} + b_{13}$

WW, J. Xu, Z.P.Xing, 1707.06570

CKM allowed decays: bcq, BR a few %

$\Xi_{bc}^{+} \to \Sigma^{+}\bar{B}^{0}$	$-c_7 - c_9$
$\Xi_{bc}^{+} \to \Lambda^{0}\bar{D}^{0}$	$\frac{-c_6-c_7+3c_8+3c_9}{\sqrt{6}}$
$\Xi_{bc}^{0} \to \Sigma^{+}B^{-}$	$-c_6 - c_8$
$\Xi_{bc}^{0} \to \Sigma^{0}\bar{D}^{0}$	$\frac{c_6+c_7+c_8+c_9}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Xi^{0}B_s^{0}$	$-c_6 + c_8$
$\Omega_{cc}^{0} \to \Xi^{0}\bar{B}^{0}$	$-c_7 + c_9$

$\Xi_{bc}^{+} \to \Sigma'^{+}\bar{B}^{0}$	$\frac{2d_4}{\sqrt{3}}$
$\Xi_{bc}^{0} \to \Sigma'^{+}B^{-}$	$\frac{2d_5}{\sqrt{3}}$
$\Xi_{bc}^{0} \to \Sigma'^{0}\bar{B}^{0}$	$\sqrt{\frac{2}{3}}(d_4 + d_5)$
$\Xi_{bc}^{0} \to \Xi'^{0}B_s^{-}$	$\frac{2d_5}{\sqrt{3}}$
$\Omega_{bc}^{0} \to \Xi'^{0}\bar{B}^{0}$	$\frac{2d_4}{\sqrt{3}}$

WW, J. Xu, Z.P.Xing, 1707.06570

CKM allowed decays: bcq, BR a few $*10^{-3}$

channel	amplitude
$\Xi_{bc}^{+} \to \Xi_c^{+} J/\psi$	$a_1 V_{cs}^*$
$\Xi_{bc}^{0} \to \Xi_c^{0} J/\psi$	$a_1 V_{cs}^*$
$\Xi_{bc}^{+} \to \Xi_c^{\prime +} J/\psi$	$\frac{a_2 V_{cs}^*}{\sqrt{2}}$
$\Xi_{bc}^{0} \to \Xi_c^{\prime 0} J/\psi$	$\frac{a_2 V_{cs}^*}{\sqrt{2}}$
$\Omega_{bc}^{0} \to \Omega_c^{0} J/\psi$	$a_2 V_{cs}^*$

$\Xi_{bc}^{+} \to \Xi_{cc}^{++} D_s^-$	$a_3 V_{cs}^*$
$\Xi_{bc}^{+} \to \Omega_{cc}^{+} \overline{D}^0$	$a_4 V_{cs}^*$
$\Xi_{bc}^{0} \to \Xi_{cc}^{+} D_s^-$	$a_3 V_{cs}^*$
$\Xi_{bc}^{0} \to \Omega_{cc}^{+} D^-$	$a_4 V_{cs}^*$
$\Omega_{bc}^{0} \to \Omega_{cc}^{+} D_s^-$	$(a_3 + a_4) V_{cs}^*$

WW, J. Xu, Z.P.Xing, 1707.06570

CKM allowed decays: bcq, BR a few *10^-3

$\Xi_{bc}^{+} \to \Xi_{cc}^{++}\pi^{-}$	$(a_5+a_7)\,V_{\rm ud}^{*}$
$\Xi_{bc}^{0} \to \Xi_{cc}^{+}\pi^{-}$	$(a_5+a_6)\,V_{\rm ud}^{*}$
$\Xi_{bc}^{+} \to \Xi_{cc}^{+}\pi^{0}$	$\frac{(a_6-a_7)V_{\rm ud}^{*}}{\sqrt{2}}$
$\Xi_{bc}^{+} \to \Xi_{cc}^{+}\eta$	$\frac{(a_6+a_7)V_{\rm ud}^{*}}{\sqrt{6}}$
$\Omega_{bc}^{0} \to \Xi_{cc}^{+}K^{-}$	$a_6 V_{\rm ud}^{*}$
$\Omega_{bc}^{0} \to \Omega_{cc}^{+}\pi^{-}$	$a_5 V_{\rm ud}^{*}$
$\Xi_{bc}^{+} \to \Omega_{cc}^{+}K^{0}$	$a_7 V_{\rm ud}^{*}$

$\Xi_{bc}^{+} \to \Lambda_{c}^{+}D^{0}$	$(a_8-a_9)\,V_{\rm ud}^{*}$
$\Xi_{bc}^{+} \to \Sigma_{c}^{+}D^{0}$	$\frac{(a_{10}+a_{11})V_{\rm ud}^{*}}{\sqrt{2}}$
$\Xi_{bc}^{+} \to \Sigma_{c}^{0}D^{+}$	$a_{11}V_{\rm ud}^{*}$
$\Xi_{bc}^{+} \to \Xi_{c}^{0}D_{s}^{+}$	$a_9 V_{\rm ud}^{*}$
$\Xi_{bc}^{+} \to \Xi_{c}^{\prime 0}D_{s}^{+}$	$\frac{a_{11}V_{\rm ud}^{*}}{\sqrt{2}}$
$\Omega_{bc}^{0} \to \Xi_{c}^{0}D^{0}$	$-a_8 V_{\rm ud}^{*}$
$\Xi_{bc}^{0} \to \Sigma_{c}^{0}D^{0}$	$a_{10}V_{\rm ud}^{*}$
$\Omega_{bc}^{0} \to \Xi_{c}^{\prime 0}D^{0}$	$\frac{a_{10}V_{\rm ud}^{*}}{\sqrt{2}}$

WW, J. Xu, Z.P.Xing, 1707.06570