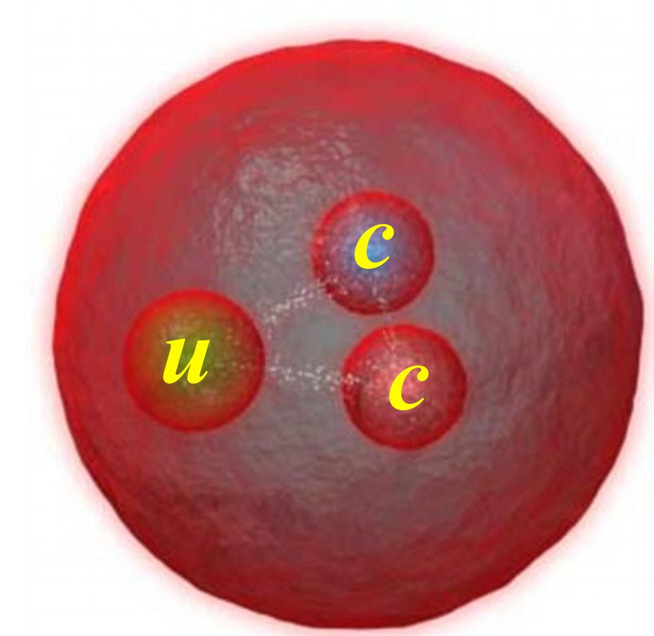
Weak Decays of Ξ_{cc}

— discovery potentials



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CHARM18 @ BINP, 2018.05.23

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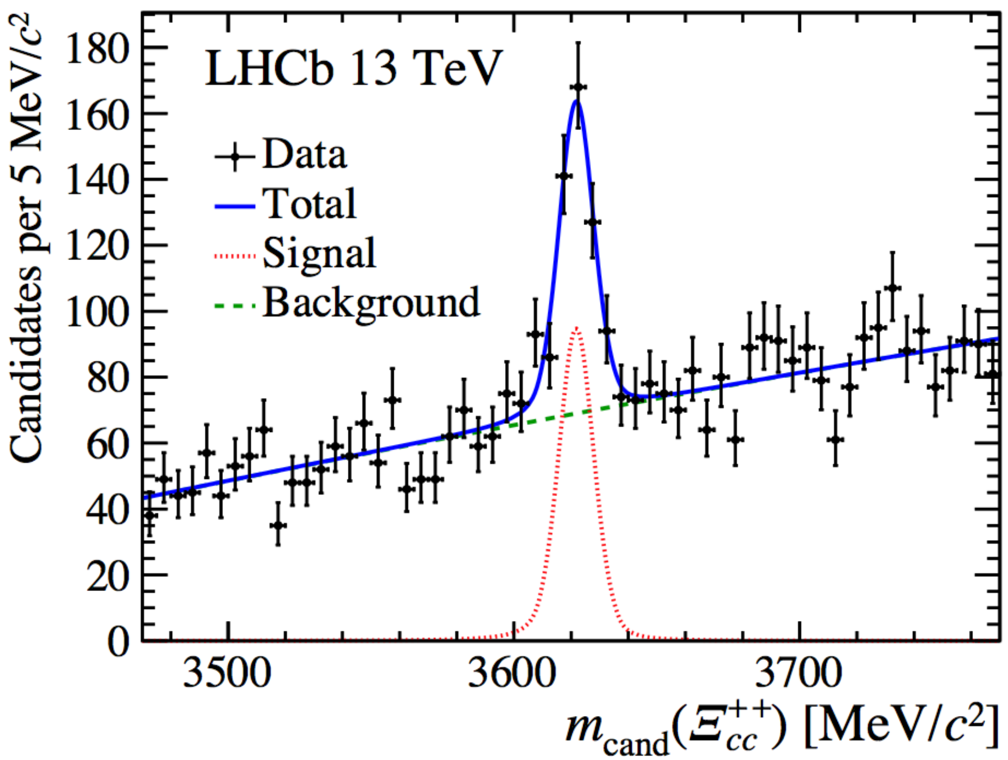
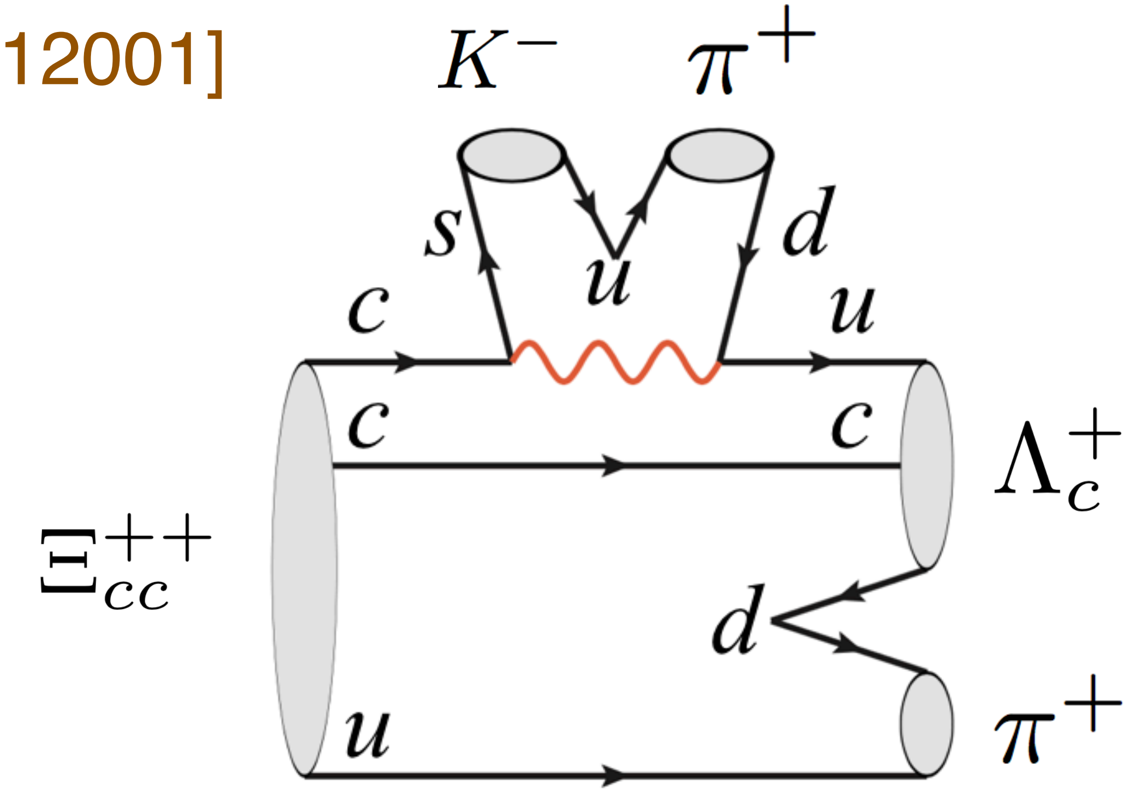
Outline

1. Introduction
2. Theoretical Framework and results
3. Outlook
4. Summary

LHCb observed Ξ_{cc}^{++}

[LHCb, PRL119,112001]





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

first reported on July 6, 2017

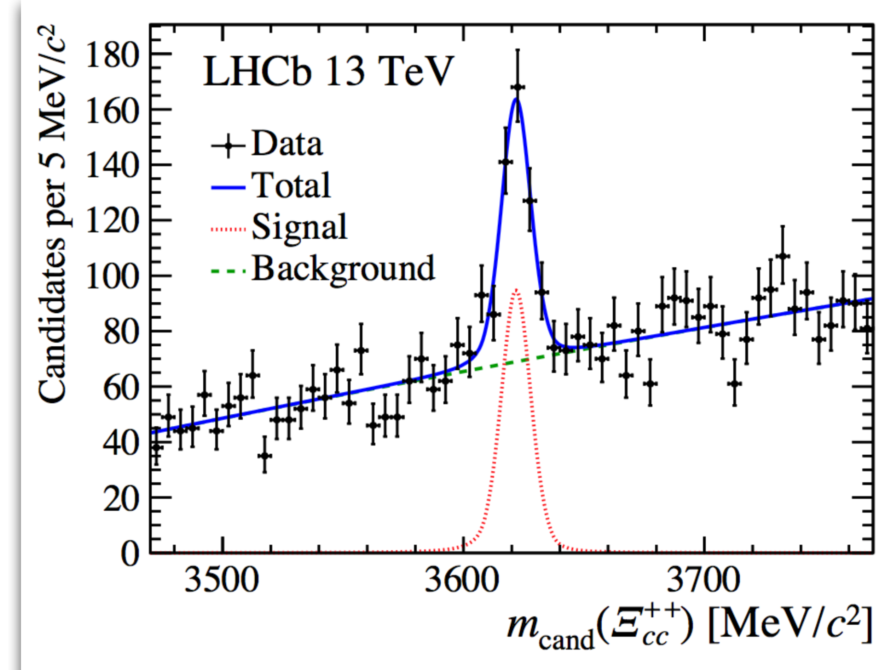
$$m_{\Xi_{cc}^{++}} = 3621.40 \pm 0.72 \pm 0.27 \pm 0.14 \text{ MeV}$$

$$\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022} \pm 0.014 \text{ ps}$$

See Daniel Vieira's talk yesterday

The discovery channel of $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ was suggested by

[**FSY**, Jiang, Li, Lü, Wang, Zhao, CPC42(2018)05001, [arXiv:1703.09086]]



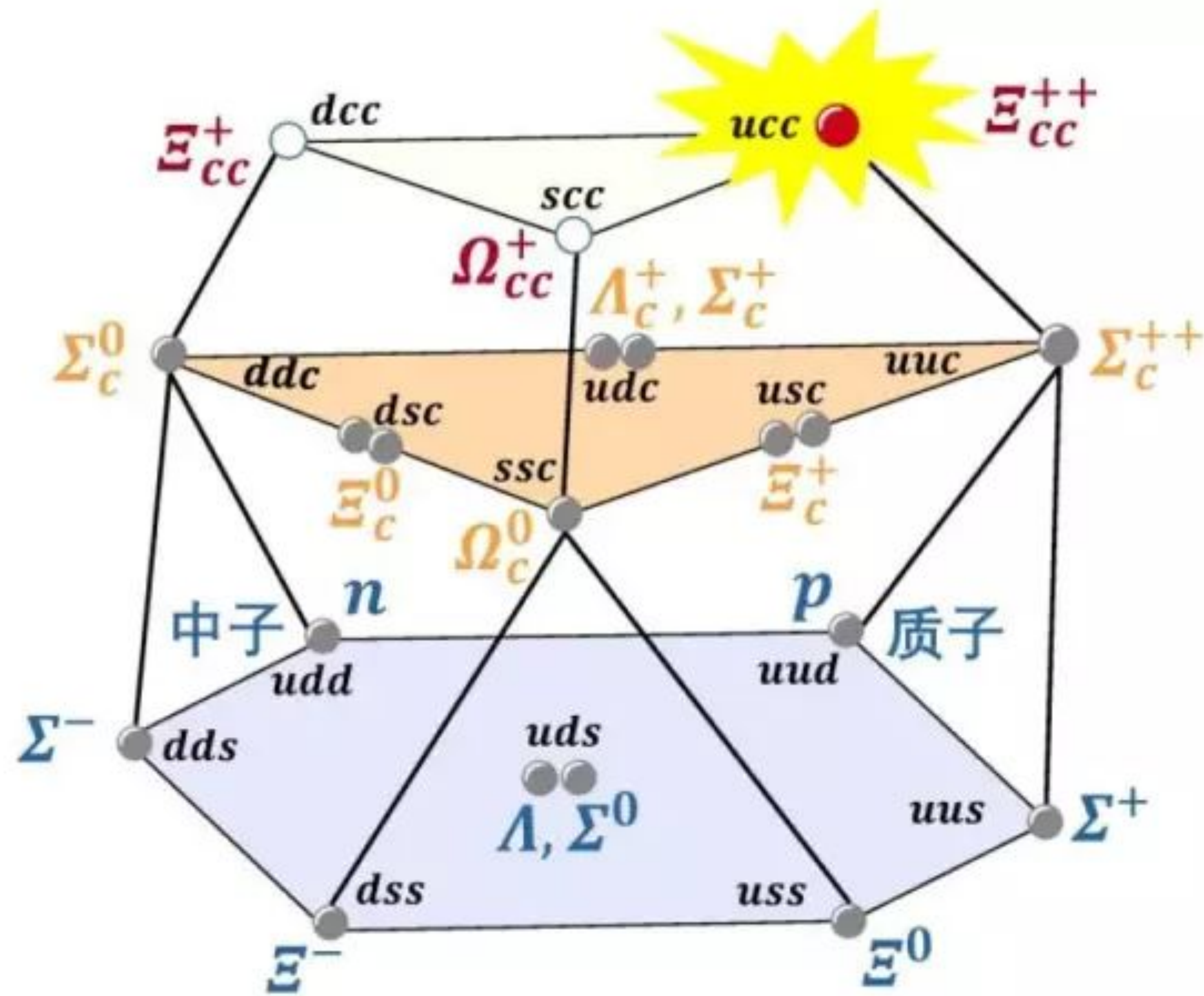
Theory talks on decays
@ LHCb-China, Dec 2016
@ LHCb-Charm, Mar 2017

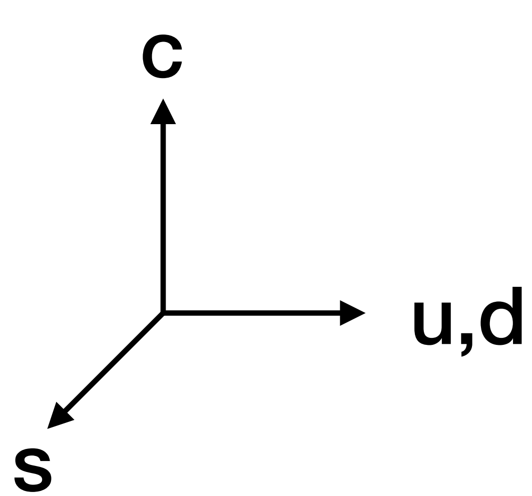
Observation reported by LHCb, Jul 2017

LHCb spokesperson Passaleva:

A group of Chinese theorists provided fundamental inputs to drive the analysis to the right direction and **gave key suggestions to achieve this result.**

Success by collaboration between theory and experiment





SU(4) flavor symmetry

Searching History

- In experiments
  - The only evidence was found for Ξ_{cc}^{+} by SELEX

    $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ $\Xi_{cc}^{+} \to p D^{+} K^{-}$ [SELEX, 02', 04']
  - But not confirmed by other experiments

    $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ [FOCUS, 02']

    $\Xi_{cc}^{+(+)} \to \Xi_c^{0} \pi^{+} (\pi^{+})$ and $\Lambda_c^{+} K^{-} \pi^{+} (\pi^{+})$ [Babar, 06'; Belle, 13']

    $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ [LHCb, 13']

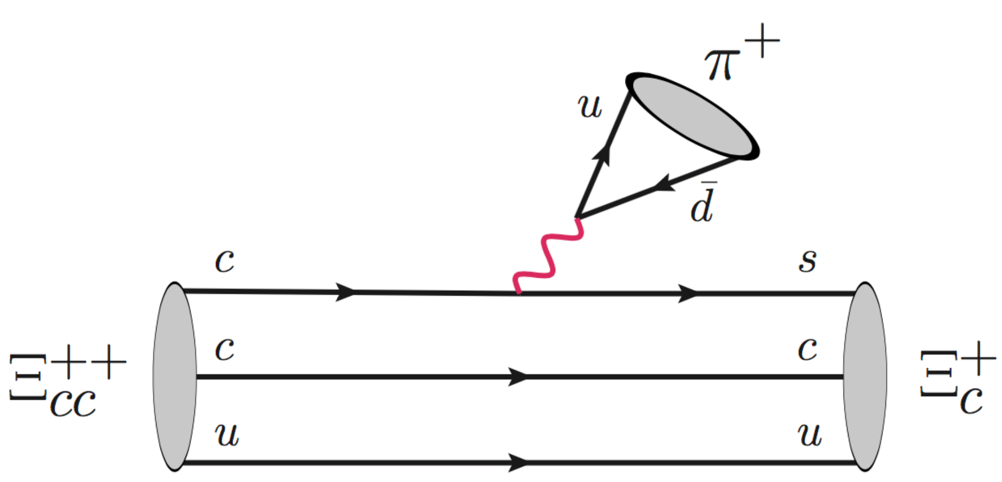
Theory Framework for weak decays of charmed baryons

Short + Long distance contributions

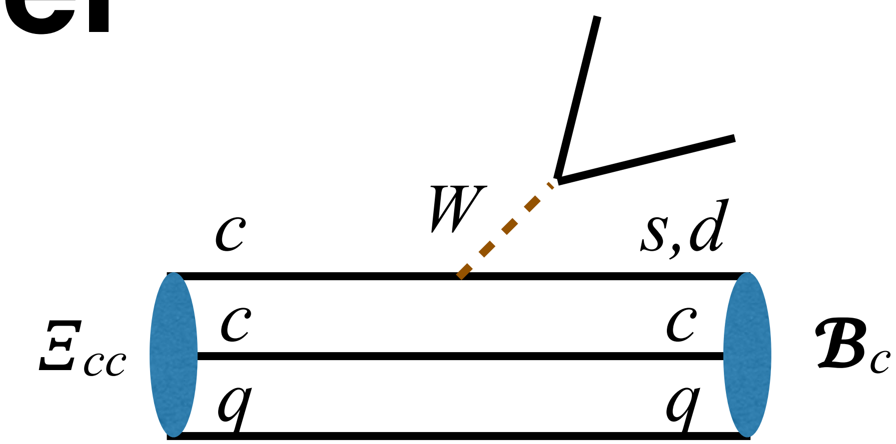
Short-distance contributions

— external W-emission diagrams

- Calculate form factors in light-front quark model
- Calculate amplitudes using factorization approach



Transition form factors (FF) in light-front quark model

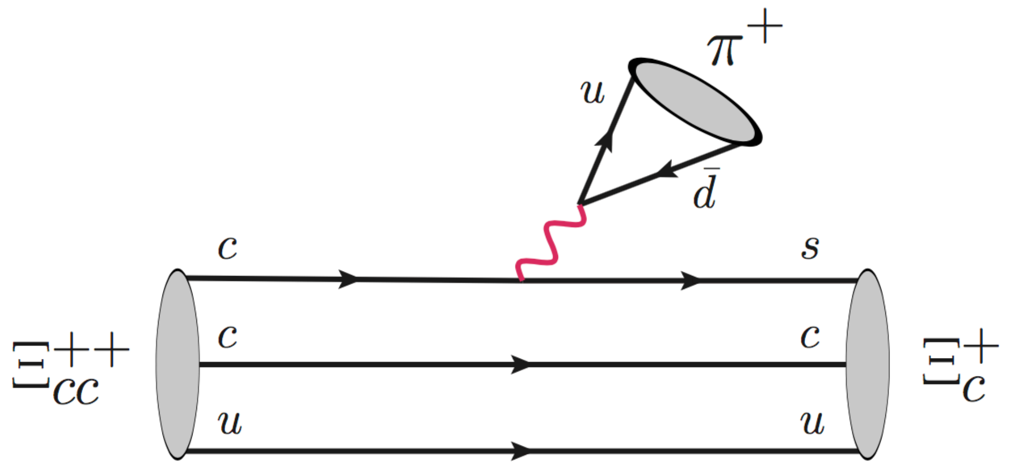


- Isospin symmetry relates FF's of Ξ_{cc}^{++} and Ξ_{cc}^{+}
- Flavor SU(3) symmetry relates FF's of $c \to s$ and $c \to d$ transitions
- Uncertainties in FFs are mostly cancelled in the relative branching fractions.

		$\Xi_{cc} \to \Xi_c/\Xi_c'(0^+)$				$\Xi_{cc} \to \Xi_c/\Xi_c'(1^+)$			
$c \to s$		f_1	g_1	f_2	g_2	f_1	g_1	f_2	g_2^*
	$F(0)$	0.75	0.62	-0.78	-0.08	0.74	-0.20	0.80	-0.02
	$m_{\rm fit}$	1.84	2.16	1.67	1.29	1.58	2.10	1.62	1.62
	δ	0.25	0.35	0.30	0.52	0.36	0.21	0.31	1.37
		$\Xi_{cc} \to \Lambda_c/\Sigma_c(0^+)$				$\Xi_{cc} \to \Lambda_c/\Sigma_c(1^+)$			
$c \to d$		f_1	g_1	f_2	g_2	f_1	g_1	f_2	g_2^*
	$F(0)$	0.65	0.53	-0.74	-0.05	0.64	-0.17	0.73	-0.03
	$m_{\rm fit}$	1.72	2.03	1.56	1.12	1.49	1.99	1.53	2.03
	δ	0.27	0.38	0.32	1.10	0.37	0.23	0.32	2.62

[W.Wang, FSY, Z.X.Zhao, '17]

Short-Distance Contributions



- External W-emission processes using factorization approach

$$A(\Xi_{cc} \to \mathcal{B}_c M)_{\rm SD}$$
$$= \frac{G_F}{\sqrt{2}} V_{cq'}^* V_{uq} a_1(a_2) \langle M | \bar{u}\gamma^\mu (1-\gamma_5) q | 0 \rangle \langle \mathcal{B}_c | \bar{q}' \gamma_\mu (1-\gamma_5) | \Xi_{cc} \rangle$$

- Relative branching fractions are reliable

$$\mathcal{B}(\Xi_{cc}^+ \to \Xi_c^0 \pi^+)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = \mathcal{R}_\tau = 0.25 \sim 0.37,$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.056,$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \ell^+ \nu)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.71,$$

Uncertainties of form factors are mostly cancelled

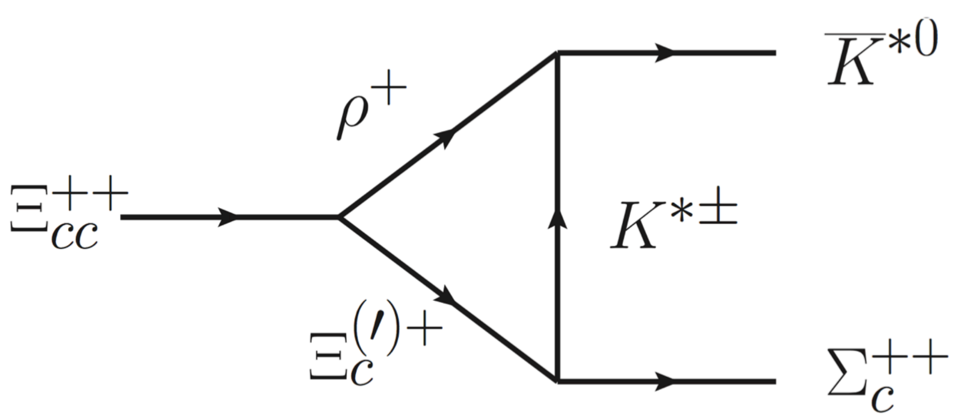
$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+)$ **is the largest one**

Long-distance contributions

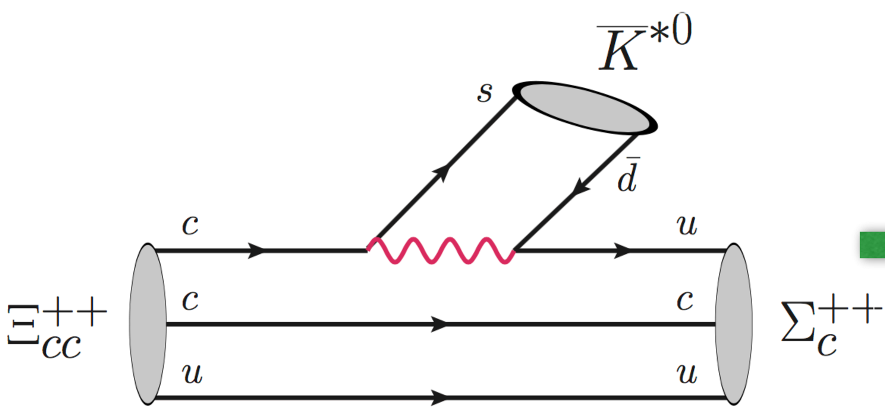
— final-state interacting (FSI) effects

  — significantly large in charm decays

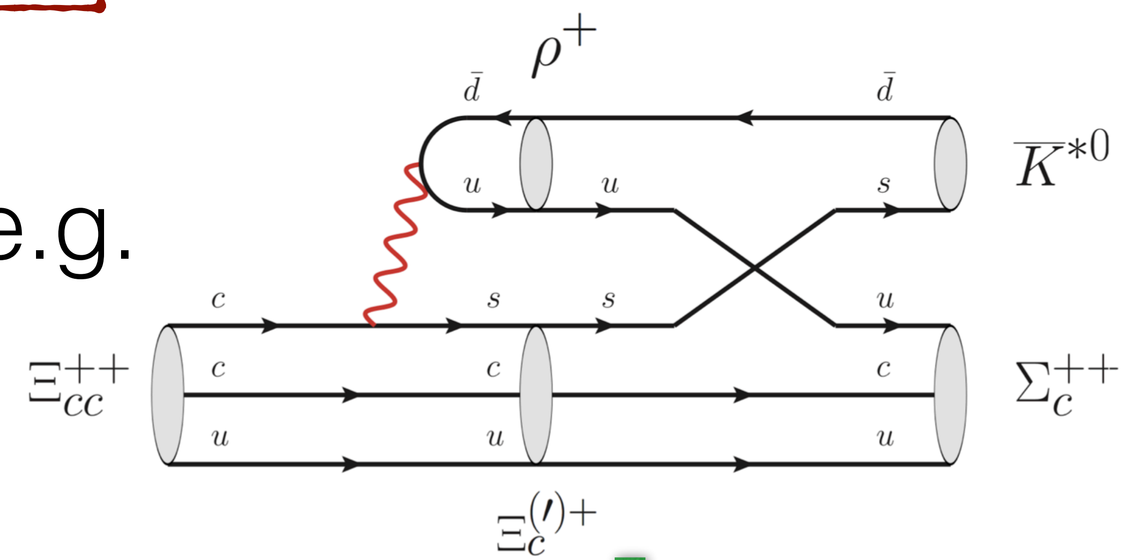
- Calculate rescattering effects



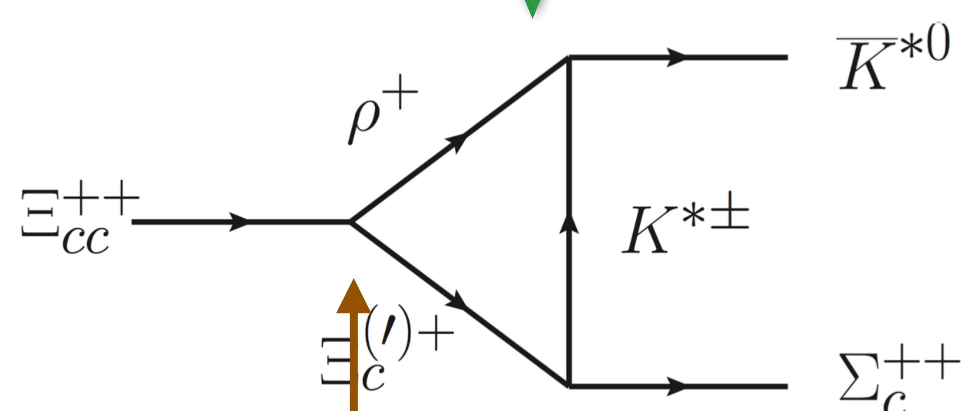
$$\Xi_{cc}^{++} \to \Sigma_c^{++} \overline{K}^{*0}$$



FSI e.g.



Rescattering mechanism of the final-state interacting effects



Absorptive part:

weak vertex

rescattering

$$\text{Abs}\mathcal{M}(p_i \to p_f q) = \frac{1}{2}\sum_j \left(\prod_{k=1}^{j} \int \frac{d^3 p_k}{(2\pi)^3 2E_k}\right)(2\pi)^4 \quad \times \delta^4\left(p_f + q - \sum_{k=1}^{j} p_k\right) M(p \to \{p_k\}) T^*(p_f q \to \{p_k\})$$

[See Jiang's talk in April 24]

Relative Branching Fractions with long-distance contributions

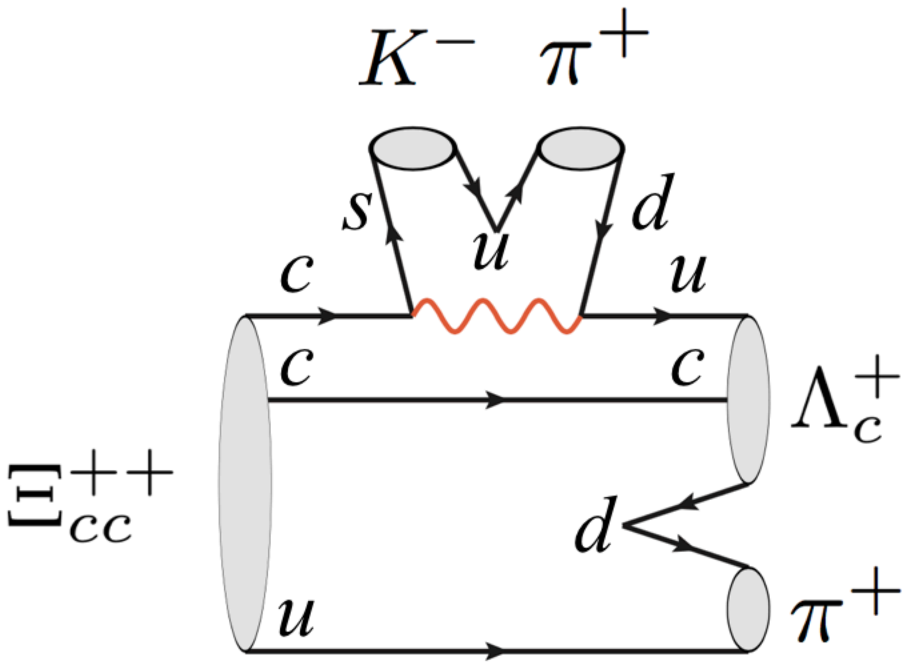
Baryons	Modes	$\mathcal{B}_{\rm LD}$
$\Xi_{cc}^{++}(ccu)$	$\Sigma_c^{++}(2455)\overline{K}^{*0}$	defined as 1
	pD^{*+}	0.04
	pD^{+}	0.0008
$\Xi_{cc}^{+}(ccd)$	$\Lambda_c^{+}\overline{K}^{*0}$	$(\mathcal{R}_\tau/0.3)\times 0.22$
	$\Sigma_c^{++}(2455)K^{-}$	$(\mathcal{R}_\tau/0.3)\times 0.008$
	$\Xi_c^{+}\rho^{0}$	$(\mathcal{R}_\tau/0.3)\times 0.04$
	ΛD^{+}	$(\mathcal{R}_\tau/0.3)\times 0.004$
	pD^{0}	$(\mathcal{R}_\tau/0.3)\times 0.002$

Largest

Uncertainties of the relative branching fractions induced by the parameter of η are less than 10%

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

$\overline{K}^{*0}$ or $(K\pi)_{\text{S-wave}}$



$$\Xi_{cc}^{++} \to \Sigma_c^{++}(2455)\overline{K}^{*0}$$

is actually a four-body decay

$\Sigma_c^{++}(2455)$ or $\Sigma_c^{++}(2520)$

In charmed hadron decays,
final-state particles are not energetic,
and easily located in the momentum range of resonances

$$\mathcal{B}(\Xi_{cc}^{++} \to \Sigma_c^{++}(2455)\overline{K}^{*0}) = \left(\frac{\tau_{\Xi_{cc}^{++}}}{300\,\text{fs}}\right) \times (3.8 \sim 24.6)\%$$

It would be expected to be as large as $O(10\%)$

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ **v.s.** $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$

SELEX's discovery channel,
LHCb measured

Baryons	Modes	$\mathcal{B}_{\rm LD}$
$\Xi_{cc}^{++}(ccu)$	$\Sigma_c^{++}(2455)\overline{K}^{*0}$	defined as 1
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$\Xi_{cc}^{+}(ccd)$	$\Lambda_c^+\overline{K}^{*0}$	$(\mathcal{R}_\tau/0.3)\times 0.22$
	$\Sigma_c^{++}(2455)K^-$	$(\mathcal{R}_\tau/0.3)\times 0.008$
	$\Xi_c^+\rho^0$	$(\mathcal{R}_\tau/0.3)\times 0.04$
	ΛD^+	$(\mathcal{R}_\tau/0.3)\times 0.004$
	pD^0	$(\mathcal{R}_\tau/0.3)\times 0.002$

$\tau \times (\sim 3)$

Br × 5

$\Lambda_c^+ K^- \pi^+ \pi^+$

$\Lambda_c^+ K^- \pi^+$

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ has more signal yields around one more order than $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ **v.s.** $\Xi_{cc}^{+} \to p D^+ K^-$

SELEX's discovery channel

Baryons	Modes	$\mathcal{B}_{\rm LD}$
$\Xi_{cc}^{++}(ccu)$	$\Sigma_c^{++}(2455)\overline{K}^{*0}$	defined as 1
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	$\Sigma_c^{++}(2455)K^-$	$(\mathcal{R}_\tau/0.3)\times 0.008$
	$\Xi_c^+\rho^0$	$(\mathcal{R}_\tau/0.3)\times 0.04$
	ΛD^+	$(\mathcal{R}_\tau/0.3)\times 0.004$
	pD^0	$(\mathcal{R}_\tau/0.3)\times 0.002$

$\Lambda_c^+ K^- \pi^+ \pi^+$

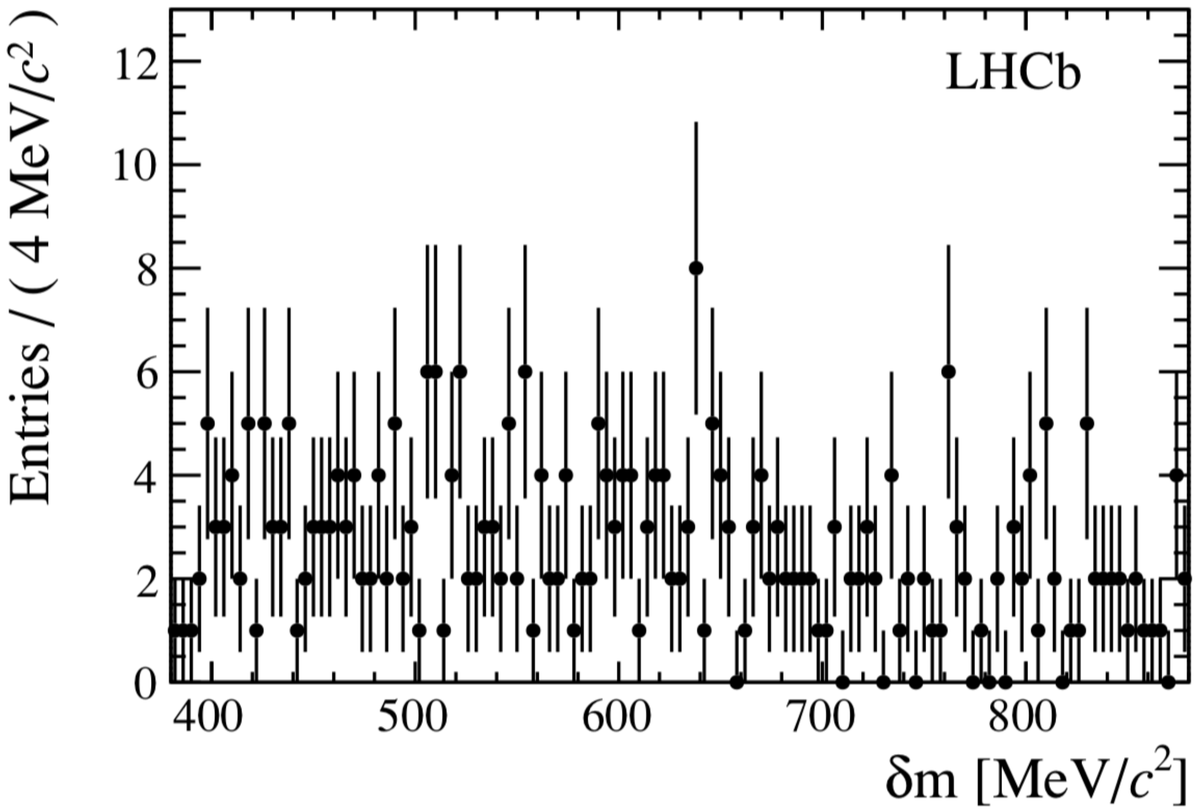
Λ is below *pK* threshold

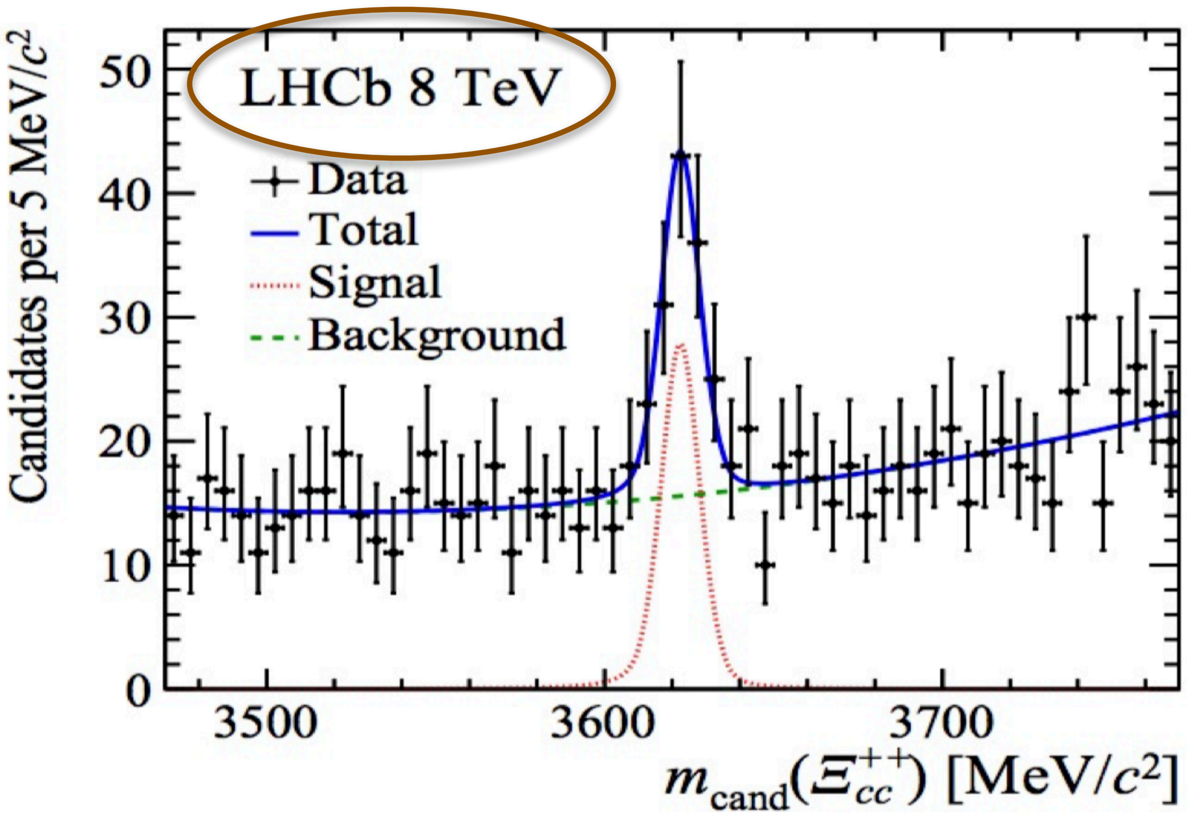
pD^+K^-

We recommend to measure $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ to search for doubly heavy baryons

[FSY, *et al*, 1703.09086]

LHCb Run-I Data Analysis





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

No signal

[LHCb, JHEP 12 (2013)090]

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

Observation

[See Vieira's talk yesterday]

It could be observed in 2013 if using the correct mode !!!

List of studies on weak decays

1. Doubly heavy baryon weak decays: $\Xi_{bc}{}^{0} \to pK^{-}$, $\Xi_{cc}{}^{+} \to \Sigma_c(2520)^{++}K^{-}$

[arXiv:1701.03284]

2. Discovery potentials of doubly charmed baryons: $\Xi_{cc}{}^{++} \to \Lambda_c{}^{+}K^{-}\pi^{+}\pi^{+}$

[arXiv:1703.09086]

3. Weak decays of doubly heavy baryons: the 1/2 → 1/2 case

[arXiv:1707.02834]

4. Weak decays of doubly heavy baryons : SU(3) analysis

[arXiv:1707.06570]

5. Weak decays of doubly heavy baryons : decay constant

[arXiv:1711.10289]

6. Weak decays of doubly heavy baryons : Multi-body decay channels

[arXiv:1712.03830]

7. Weak decays of triply heavy baryons

[arXiv:1803.01476]

List of studies on weak decays

Prospect

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

A long long list…

[W. Wang's talk @ Implication of LHCb, 2017]

Summary

- We systematically study the weak decays of doubly charmed baryons
- By comparing all the decay modes, we recommend to measure the following processes to search for doubly heavy baryons

$$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+ \qquad \Xi_{cc}^{++} \to \Xi_c^+ \pi^+$$

- And LHCb observed it via the first process.
- Outlook: similar analysis to search for other particles.

Thank you !

Backup

cross sections of production @ LHC

$\sigma(\Xi_{cc})$ is close to $\sigma(B_c)$ @ LHC

Ξ_{cc}

-	$\sqrt{S}=7.0$TeV	$\sqrt{S}=14.0$TeV
$[{}^3S_1]$	38.11	69.40
$[{}^1S_0]$	9.362	17.05
Total	47.47	86.45

in unit of nb

$p_t \geq 4GeV \qquad |y| \leq 1.5$

[J.-W. Zhang, X.-G. Wu, T. Zhong, Y. Yu, Z.-Y. Fang, Phys.Rev. D 83, 034026 (2011)]

B_c

-	$\|({}^1S_0)_{\mathbf{1}}\rangle$	$\|({}^3S_1)_{\mathbf{1}}\rangle$	$\|({}^1S_0)_{\mathbf{8}}g\rangle$	$\|({}^3S_1)_{\mathbf{8}}g\rangle$	$\|({}^1P_1)_{\mathbf{1}}\rangle$	$\|({}^3P_0)_{\mathbf{1}}\rangle$	$\|({}^3P_1)_{\mathbf{1}}\rangle$	$\|({}^3P_2)_{\mathbf{1}}\rangle$
LHC	71.1	177.	(0.357, 3.21)	(1.58, 14.2)	9.12	3.29	7.38	20.4

LHC ($\sqrt{S}=14.0$ TeV) in unit of nb

[C.-H. Chang, C.-F. Qiao, J.-X. Wang, X.-G. Wu, Phys.Rev. D71 (2005) 074012]

B_c well studied at LHCb,
discovery and establishment of Ξ_{cc} would not be far

The key issue

is to select the decaying processes

with the largest possibilities of

observing doubly charmed baryons

Lifetimes

Literatures	Ξ_{cc}^{++} (fs)	Ξ_{cc}^{+} (fs)
Karliner, Rosner, 2014	185	53
Kiselev, Likhoded, Onishchenko, 1998	430±100	110±10
Kiselev, Likhoded, 2002	460±50	160±50
Chang, Li, Li, Wang, 2007	670	250

But much less ambiguity of ratio of lifetimes

$$\mathcal{R}_\tau \equiv \frac{\tau_{\Xi_{cc}^{+}}}{\tau_{\Xi_{cc}^{++}}} = 0.25 \sim 0.37$$

$$\tau(\Xi_{cc}^{++}) \gg \tau(\Xi_{cc}^{+})$$

↑

Effect of destructive Pauli interference

Longer lifetime of Ξ_{cc}^{++}

$$\mathcal{R}_\tau \equiv \frac{\tau_{\Xi_{cc}^{+}}}{\tau_{\Xi_{cc}^{++}}} = 0.25 \sim 0.37$$

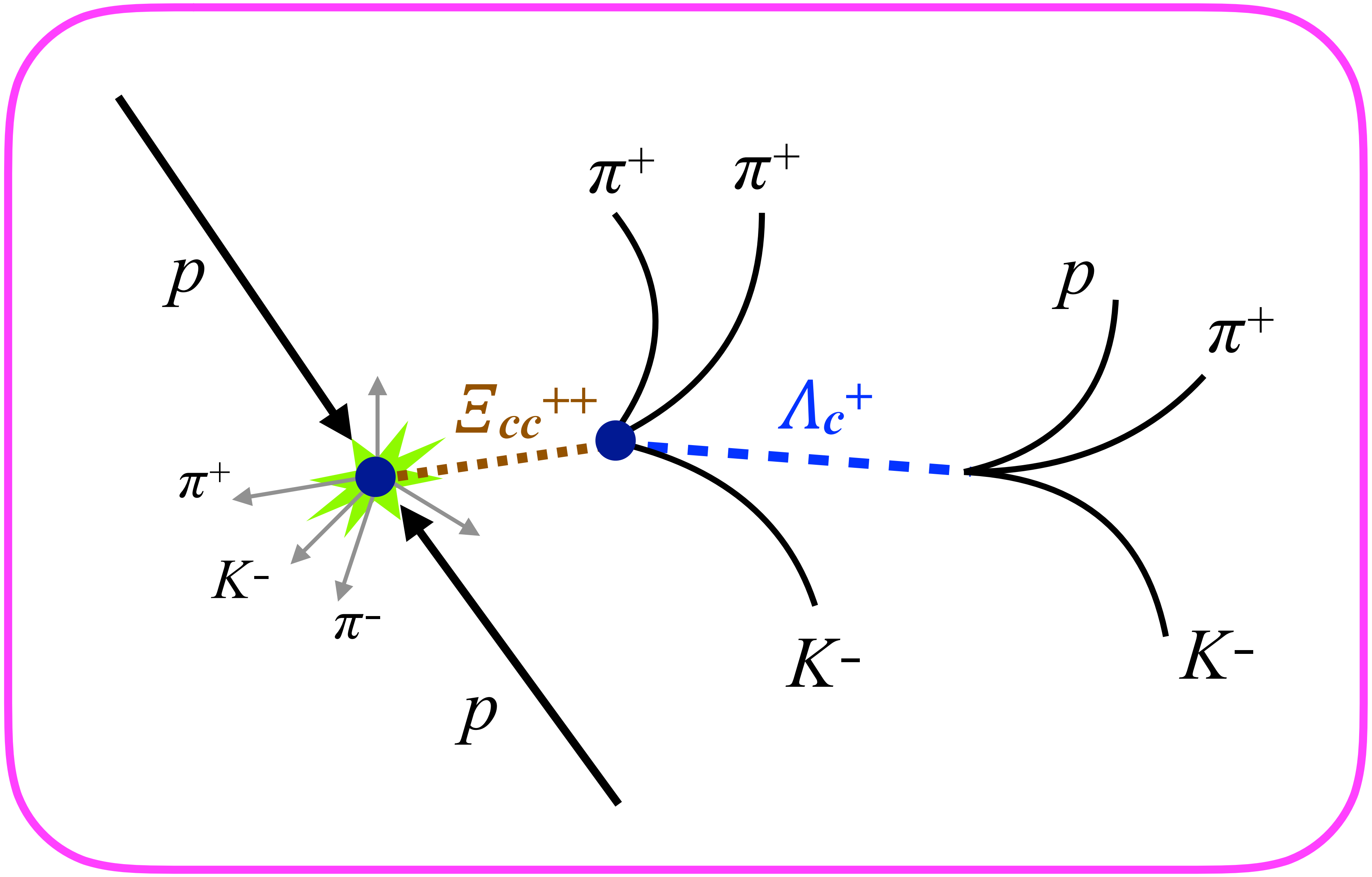
$$\tau(\Xi_{cc}^{++}) \gg \tau(\Xi_{cc}^{+})$$

- Longer lifetime ⇒ Larger branching fractions

$$\mathcal{B}_i = \Gamma_i \cdot \tau$$

- Longer lifetime ⇒ Higher efficiency of identification at hadron colliders

We recommend to search for Ξ_{cc}^{++} rather than Ξ_{cc}^{+}



Longer Lifetime

colliders [41–43], the longer lifetime of the Ξ_{cc}^{++} baryon should make it significantly easier to observe than the Ξ_{cc}^{+} baryon in such experiments, due to the use of real-time (online) event-selection requirements designed to reject backgrounds originating from the primary interaction point. [LHCb, PRL119,112001(2017)] small lifetime

Cabibbo-suppressed

missing energy

$$\mathcal{B}(\Xi_{cc}^{+} \to \Xi_c^0 \pi^+)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = \mathcal{R}_\tau = 0.25 \sim 0.37,$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.056,$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \ell^+ \nu)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.71,$$

Other processes with large branching fractions, but

- either have neutral final-state particles

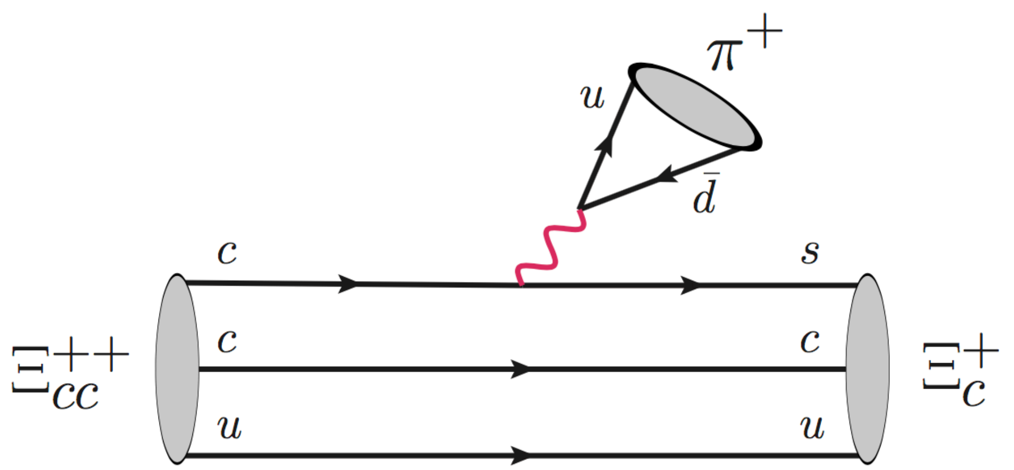
$$\Xi_c^+ \rho^+ (\to \pi^+ \pi^0) \qquad \Xi_c^{\prime +} (\to \Xi_c^+ \gamma) \pi^+$$

- or have more tracks

$$\Xi_c^+ a_1^+ (\to \pi^+ \pi^+ \pi^-)$$

$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ is the best one to search for doubly heavy baryons among external W-emission processes

$$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$$



Absolute branching fractions:

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = \left(\frac{\tau_{\Xi_{cc}^{++}}}{300\ \mathrm{fs}} \right) \times 3.4\%$$

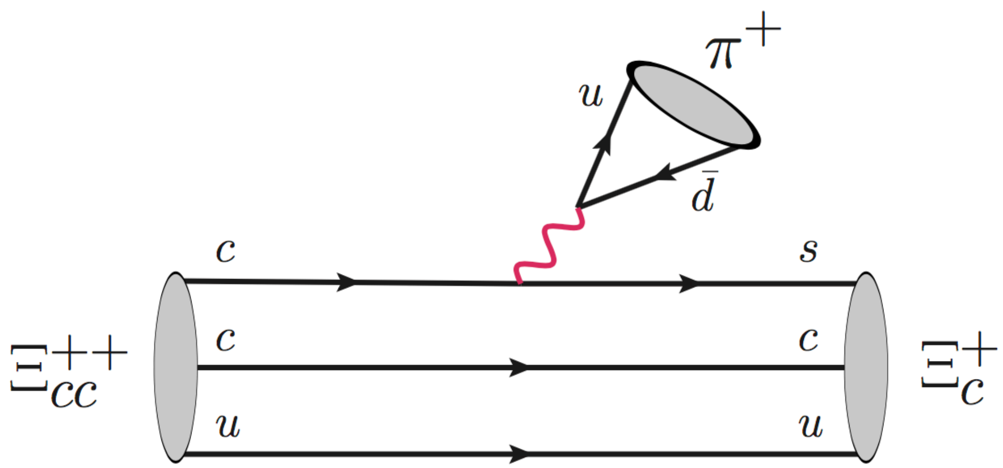
large enough for measurement

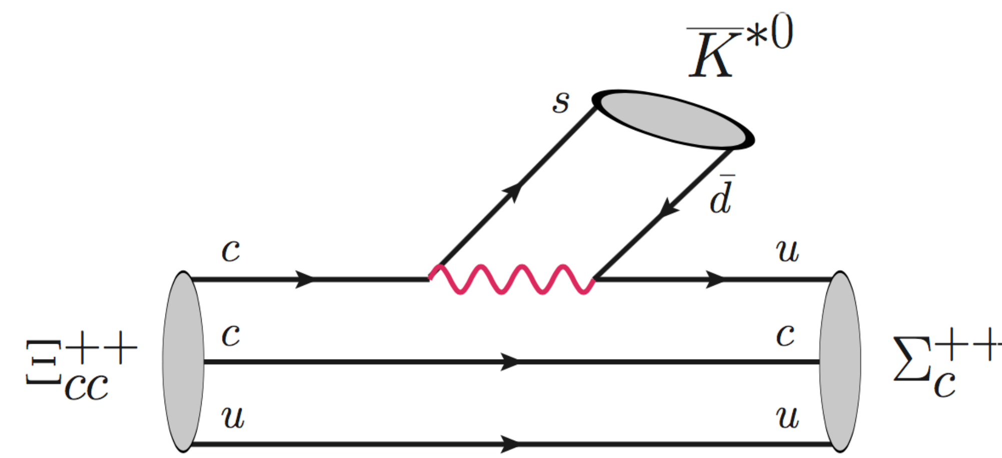
We suggest to measure $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ with the reconstruction of $\Xi_c^+ \to pK^-\pi^+$

[FSY, *et al*, 1703.09086]

$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ has never been directly measured but predicted to be $(2.2 \pm 0.8)\%$

Short-distance v.s. Long-distance Contributions





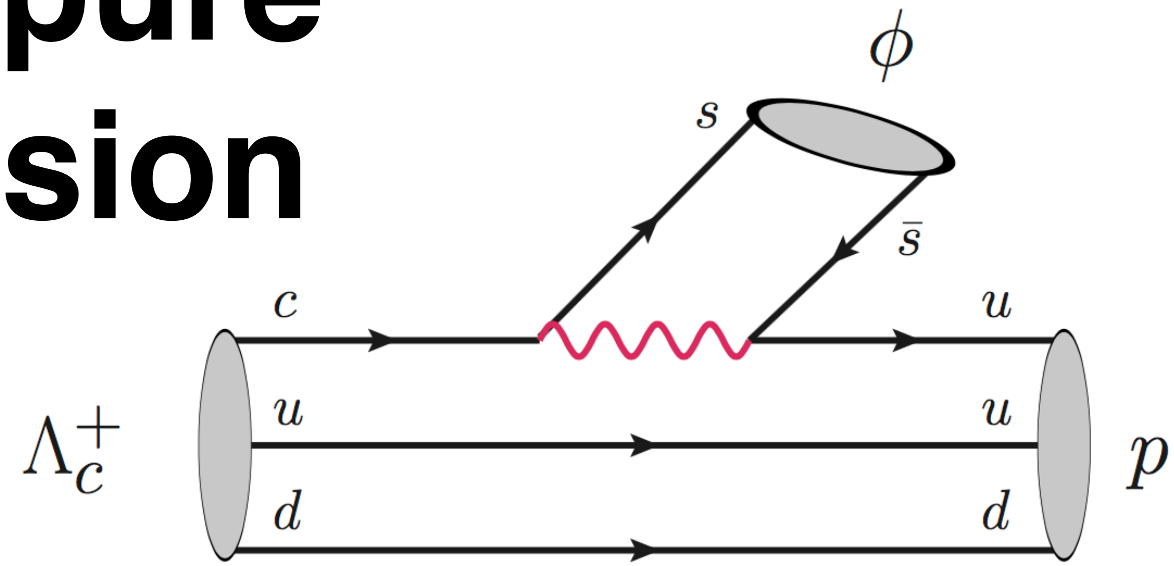
short-distance branching fractions

Br=3.4%	Br=0.003%
external W-emission	internal W-emission
color-favored	color-suppressed
$a_1(\mu_c)$=1.07	$a_2(\mu_c)$= - 0.02

But long-distance contributions are significantly enhanced in charmed hadron decays

Indication from pure internal W-emission

$$\Lambda_c^+ \to p\phi$$



Short-distance v.s. Long-distance

Br(SD)=10^{-6}

$|a_2(\mu_c)|=0.02$

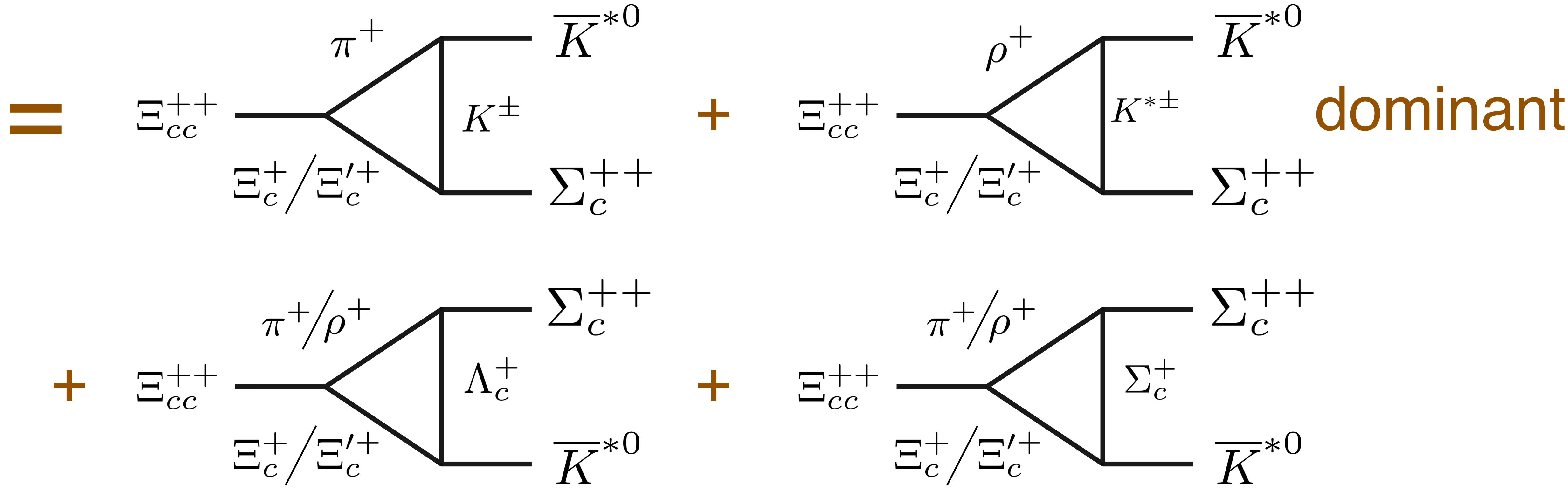
Br(exp)=$(1.04\pm0.21)\times10^{-3}$

$|a_2^{eff}(\mu_c)|=0.7$

large-N_c limit

Understanding long-distance contributions is essential to find a best process
for the searches for doubly heavy baryons

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



$\eta = 1.0 \sim 2.0$

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 3.4\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \rho^+) = 6.3\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \pi^+) = 2.4\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \rho^+) = 8.7\%$$

→

$$\mathcal{B}(\Xi_{cc}^{++} \to \Sigma_c^{++}\overline{K}^{*0}) = (3.8 \sim 24.6)\% \times \frac{\tau_{\Xi_{cc}^{++}}}{300\ \mathrm{fs}}$$

Large enough for measurements

Effective Lagrangian

$$\mathcal{L}_{\rm eff} = i\frac{g_{VPP}}{\sqrt{2}}Tr\{V^\mu[P,\partial_\mu P]\} + i\frac{g_{VVV}}{\sqrt{2}}Tr\{(\partial_\nu V_\mu - \partial_\mu V_\nu)V^\mu V^\nu\} - ig_{DDV}(D_i\partial_\mu D^{j\dagger} - \partial_\mu D_i D^{j\dagger})(V^\mu)^i_j$$
$$+ ig_{VD^*D^*}(D^{*\nu}_i\partial_\mu D^{*j\dagger}_\nu - \partial_\mu D^{*\nu}_i D^{*j\dagger}_\nu)(V^\mu)^i_j + 4if_{VD^*D^*}D^{*\dagger}_{i\mu}(\partial^\mu V^\nu - \partial^\nu V^\mu)^i_j D^{*j}_\nu$$
$$- ig_{PDD^*}(D^i\partial^\mu P_{ij}D^{*j\dagger}_\mu - h.c.) + g_{P\mathcal{B}\mathcal{B}}Tr[\overline{\mathcal{B}}i\gamma_5 P\mathcal{B}] + g_{1V\mathcal{B}\mathcal{B}}Tr[\overline{\mathcal{B}}\gamma_\mu V^\mu\mathcal{B}] + \frac{g_{2V\mathcal{B}\mathcal{B}}}{2m_\mathcal{B}}Tr[\overline{\mathcal{B}}\sigma_{\mu\nu}\partial^\mu V^\nu\mathcal{B}]$$
$$+ \{g_{P\mathcal{B}_{c\bar{3}}\mathcal{B}_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c\bar{3}}i\gamma_5 P\mathcal{B}_{c\bar{3}}] + (\mathcal{B}_{c\bar{3}} \to \mathcal{B}_{c6})\} + \{g_{P\mathcal{B}_{c6}\mathcal{B}_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c6}i\gamma_5 P\mathcal{B}_{c\bar{3}}] + h.c.\},$$
$$+ \{g_{1V\mathcal{B}_{c\bar{3}}\mathcal{B}_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c\bar{3}}\gamma_\mu V^\mu\mathcal{B}_{c\bar{3}}] + \frac{g_{2V\mathcal{B}_{c\bar{3}}\mathcal{B}_{c\bar{3}}}}{2m_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c\bar{3}}\sigma_{\mu\nu}\partial^\mu V^\mu\mathcal{B}_{c\bar{3}}] + (\mathcal{B}_{c\bar{3}} \to \mathcal{B}_{c6})\}$$
$$+ \{g_{1V\mathcal{B}_{c6}\mathcal{B}_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c6}\gamma_\mu V^\mu\mathcal{B}_{c\bar{3}}] + \frac{g_{2V\mathcal{B}_{c6}\mathcal{B}_{c\bar{3}}}}{m_{c6}+m_{c\bar{3}}}Tr[\overline{\mathcal{B}}_{c6}\sigma_{\mu\nu}\partial^\mu V^\mu\mathcal{B}_{c\bar{3}}] + h.c.\} + g_{\Lambda_c(\Sigma_c)ND_q}\{\overline{\Lambda}_c(\overline{\Sigma}_c)i\gamma_5 D_q N + h.c.\}$$
$$+ g_{1\Lambda_c(\Sigma_c)ND^*_q}\{\overline{\Lambda}_c(\overline{\Sigma}_c)\gamma_\mu D^{*\mu}_q N + h.c.\} + \frac{g_{2\Lambda_c(\Sigma_c)ND^*_q}}{m_{\Lambda_c(\Sigma_c)}+m_N}\{\overline{\Lambda}_c(\overline{\Sigma}_c)\sigma_{\mu\nu}\partial^\mu D^{*\nu}_q N + h.c.\}$$

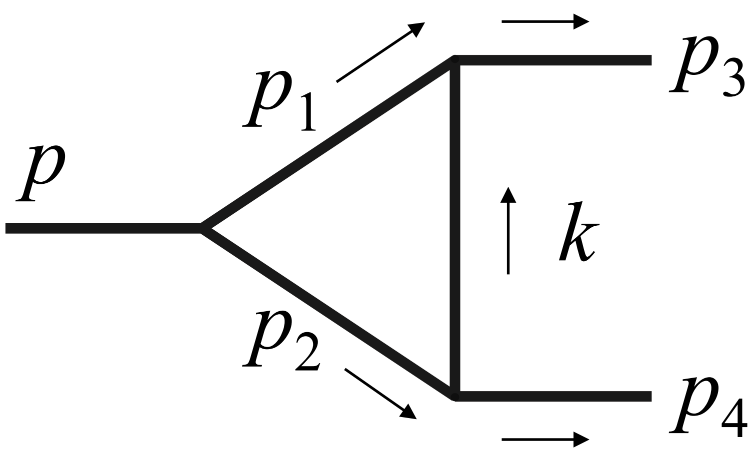
Hadronic coupling constants are related under the flavor SU(3) symmetry and the chiral and heavy quark symmetries

Uncertainties are mostly cancelled in relative Br's

[Yan, *et al*, PRD46,1148(1992)]
[Casalbuoni, *et al*, Phys.Rept.281,145(1997)]
[Meissner, Phys.Rept.161,213(1988)]

Theoretical Uncertainties

- Transition form factors —cancelled in relative Br's
- Hadronic coupling constants
  —cancelled in relative Br's
- Off-shell effects of intermediate states



$$F(t, m) = \left(\frac{\Lambda^2 - m^2}{\Lambda^2 - t}\right)^n \qquad t \equiv (p_1 - p_3)^2 \qquad n=1$$

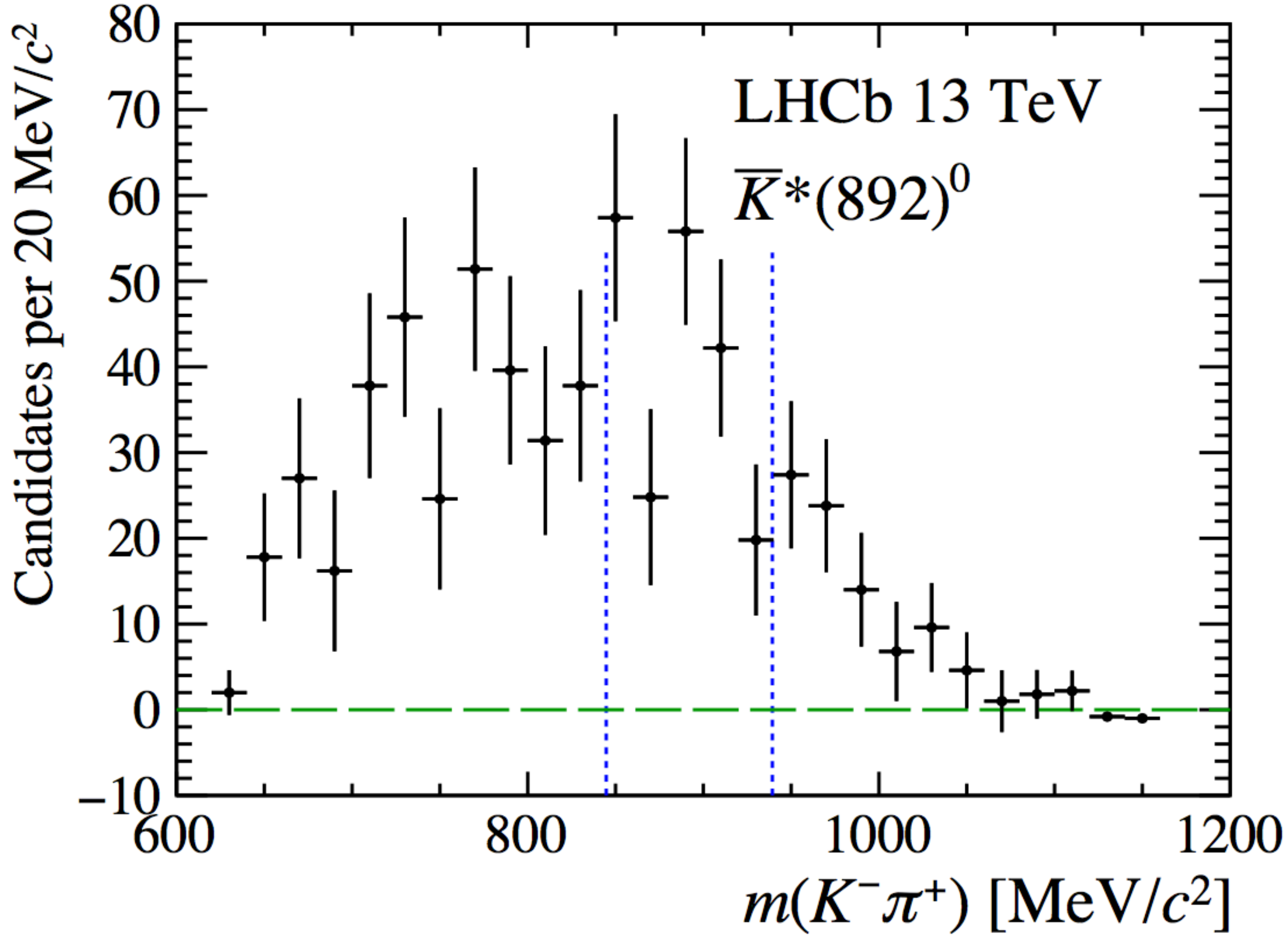
$$\Lambda = m_{\rm exc} + \eta \Lambda_{\rm QCD}$$

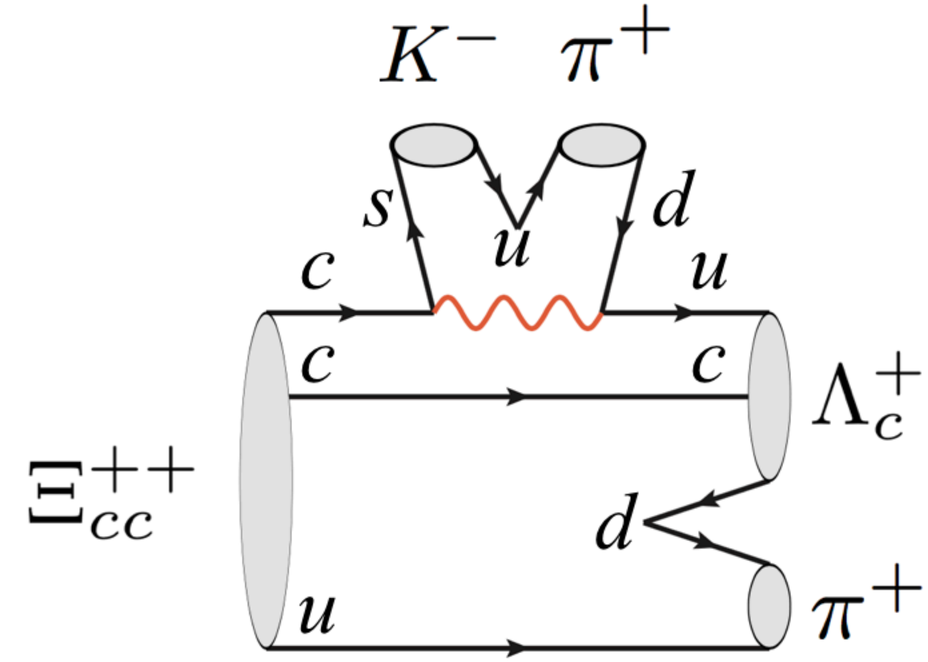
[Cheng, Chua, Soni, PRD 71, 014030 (2005)]

Results are very sensitive to the value of η

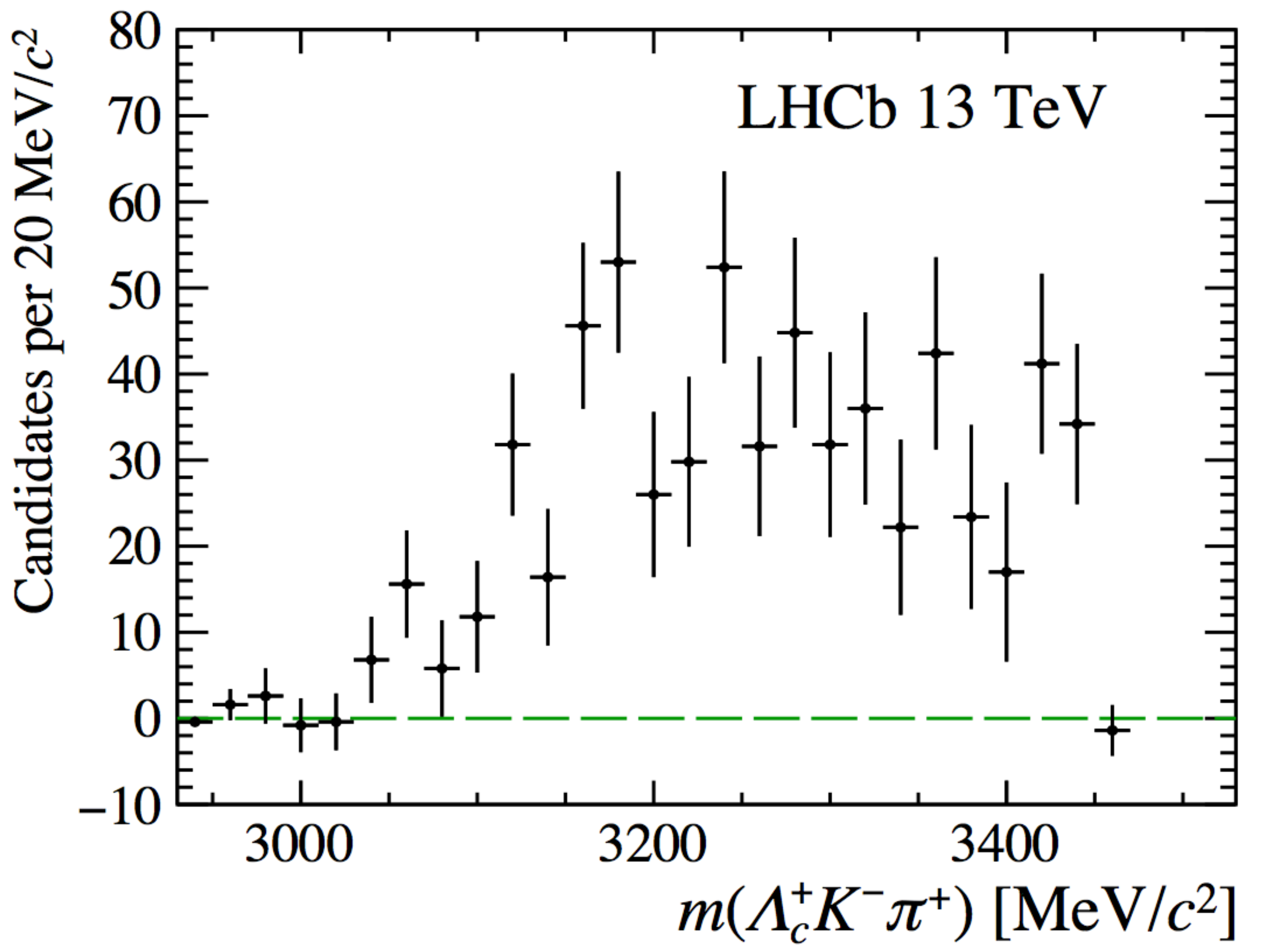
No first-principle calculations for η

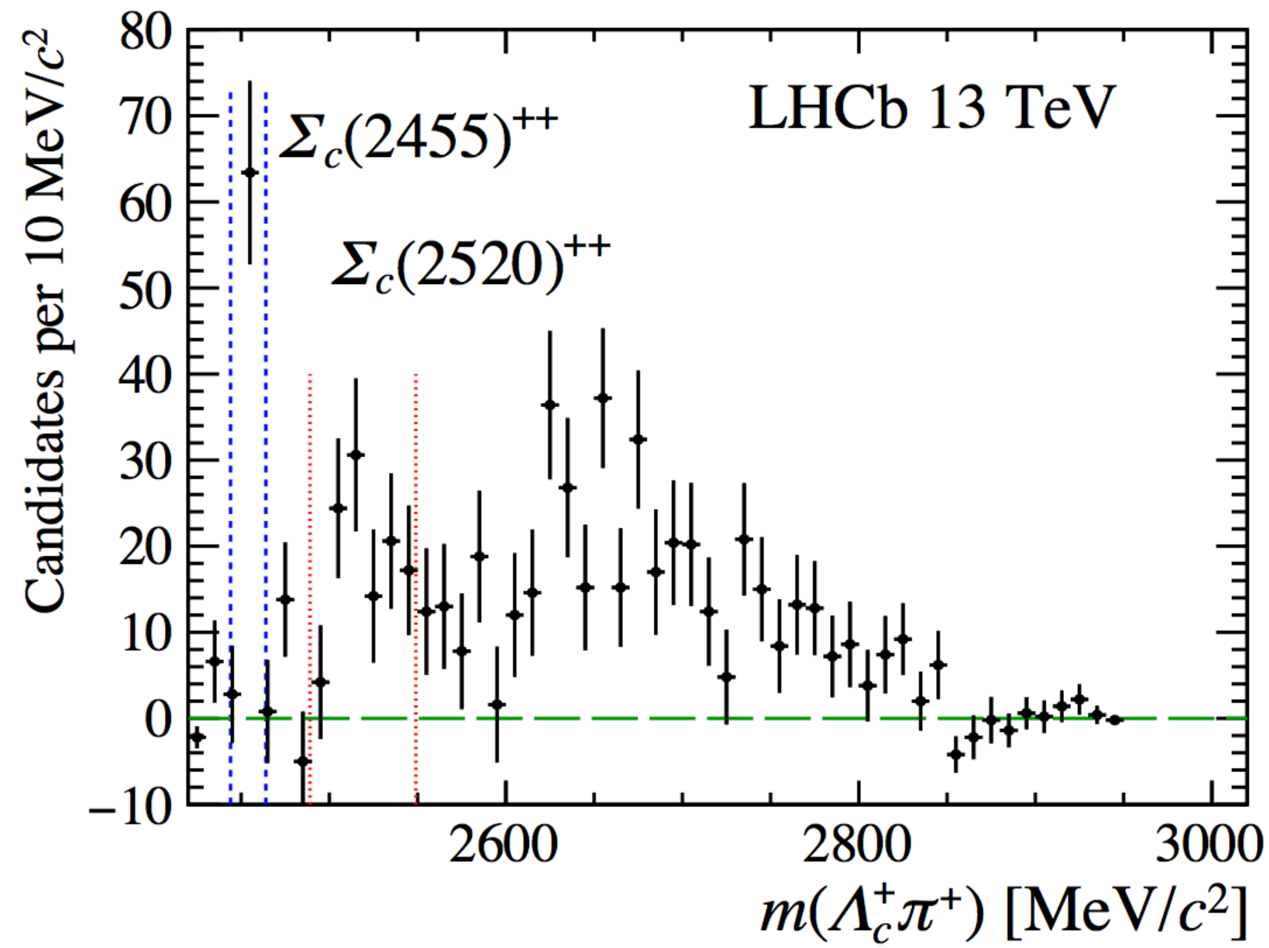
We take η from 1.0 to 2.0





Resonances dominated

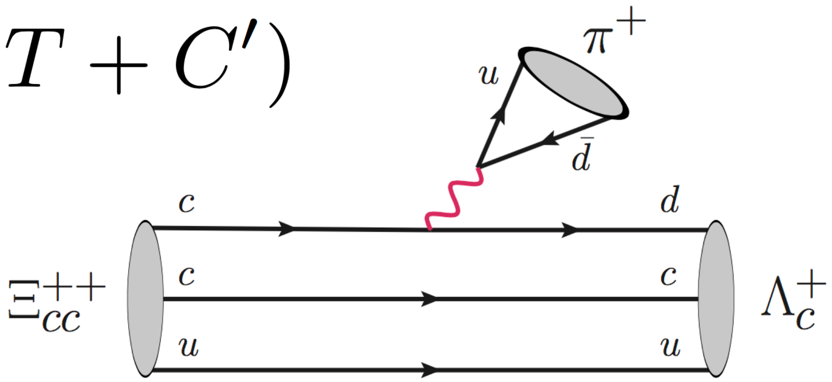




$$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$$

$$V_{cd}^* V_{ud} (T + C')$$

=



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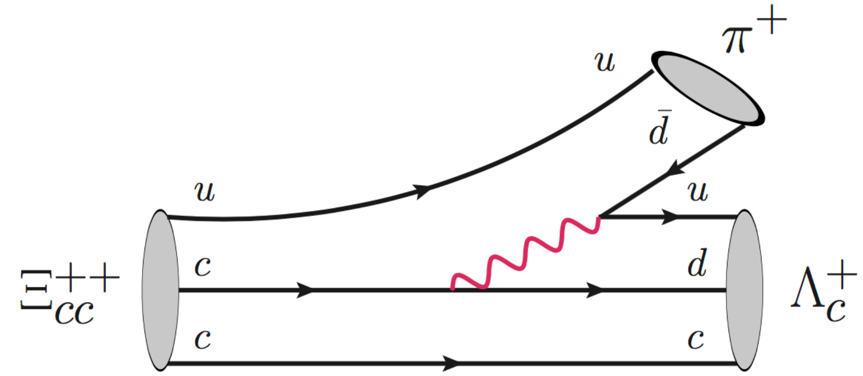

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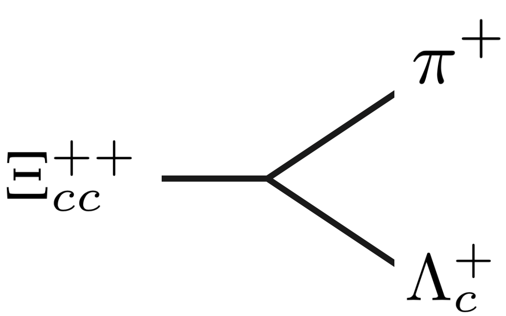

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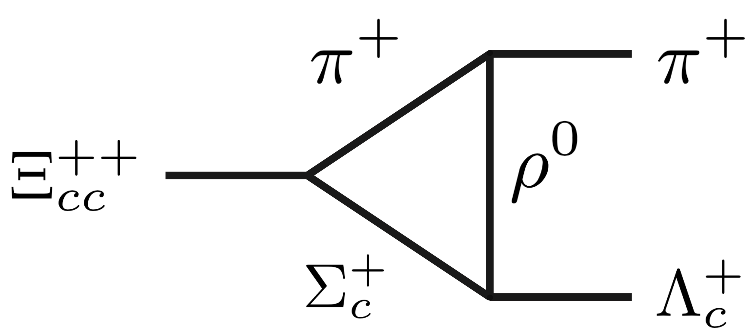

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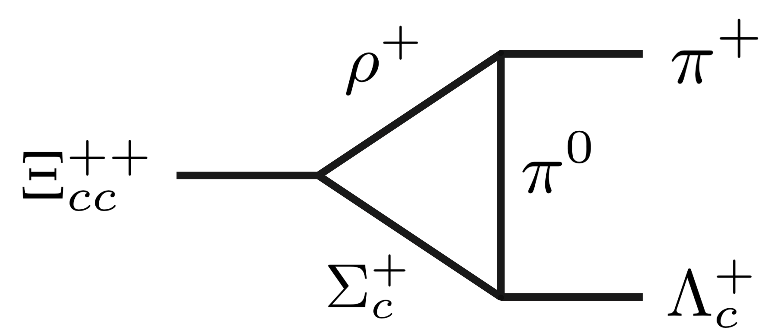

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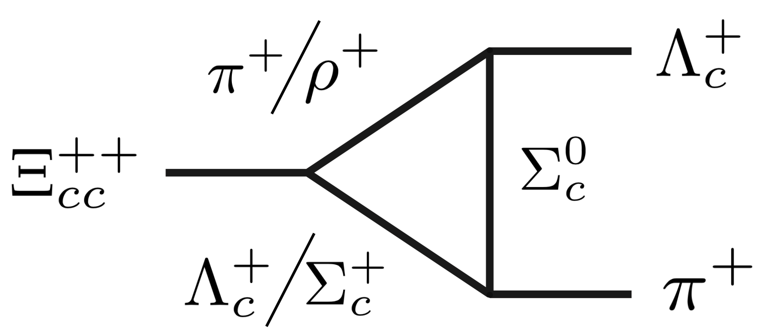
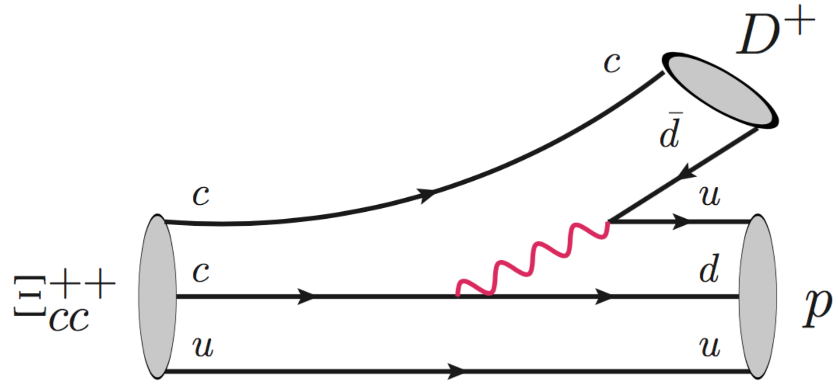


$$\Xi_{cc}^{++} \to pD^{+}$$

$V_{cd}^{*}V_{ud}C' =$



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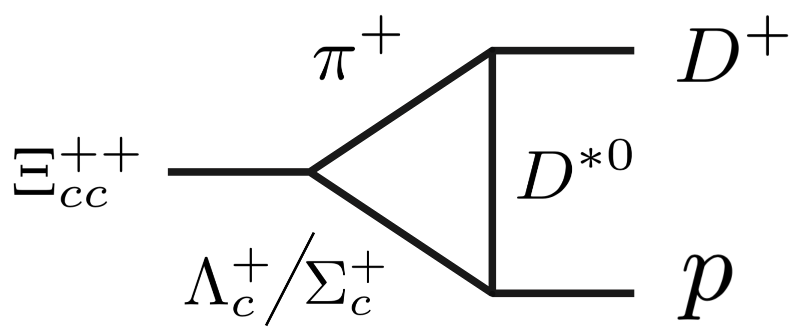

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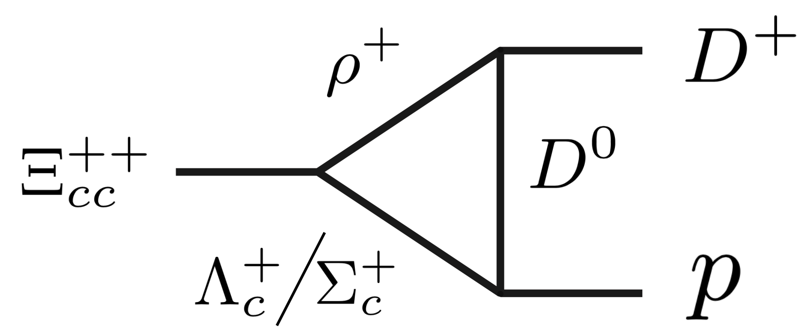

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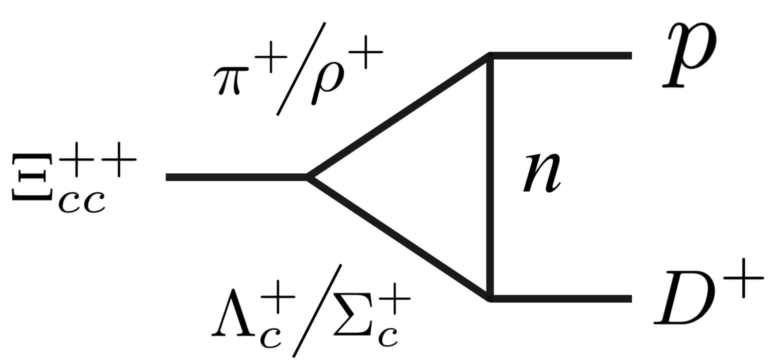
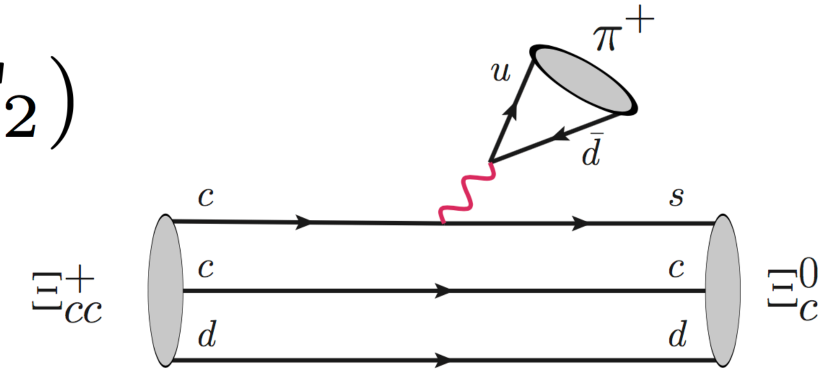


$$\Xi_{cc}^{+} \to \Xi_c^{0}\pi^{+}$$

$$V_{cs}^{*}V_{ud}(T+E_2)$$

$=$



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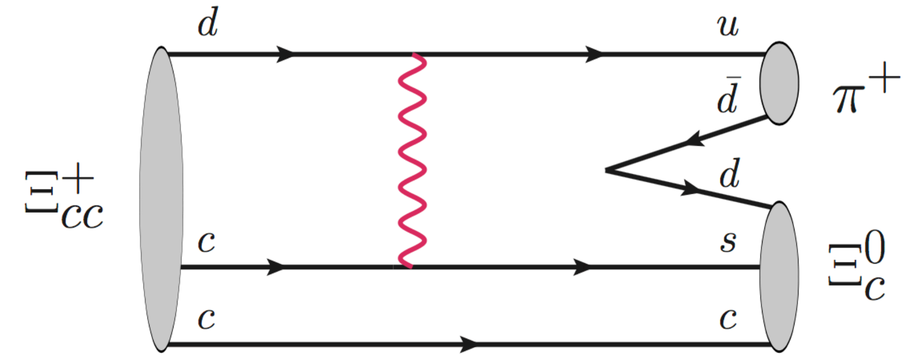

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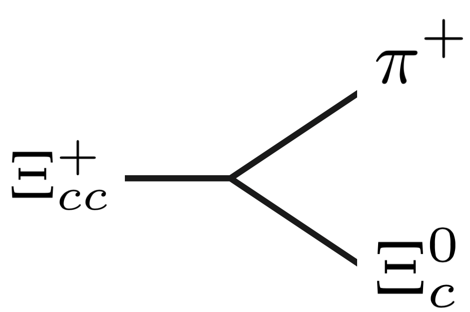

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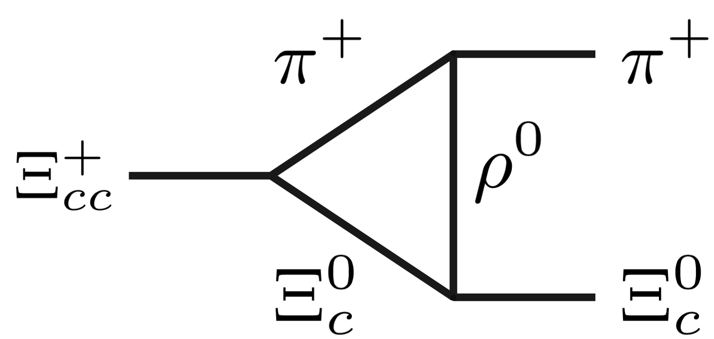

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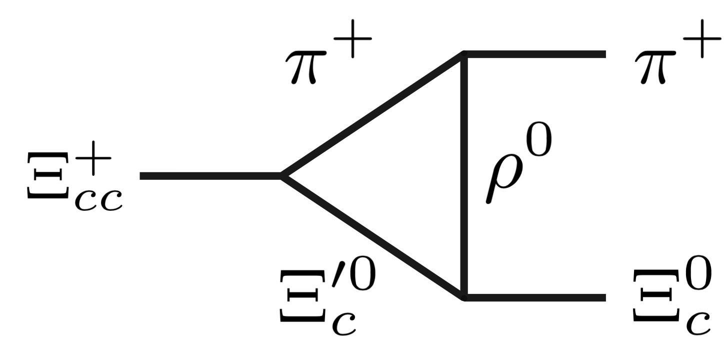

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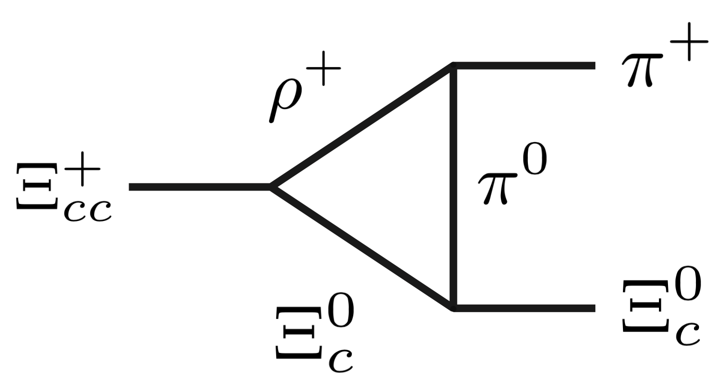

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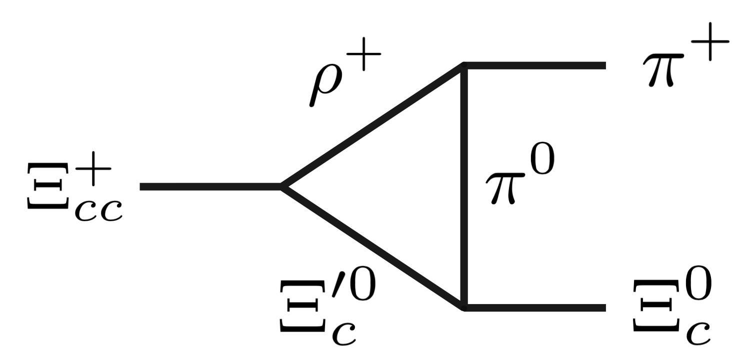
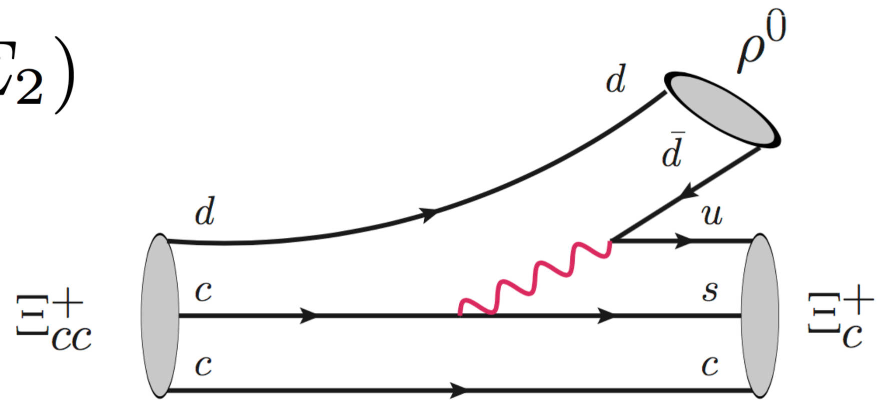


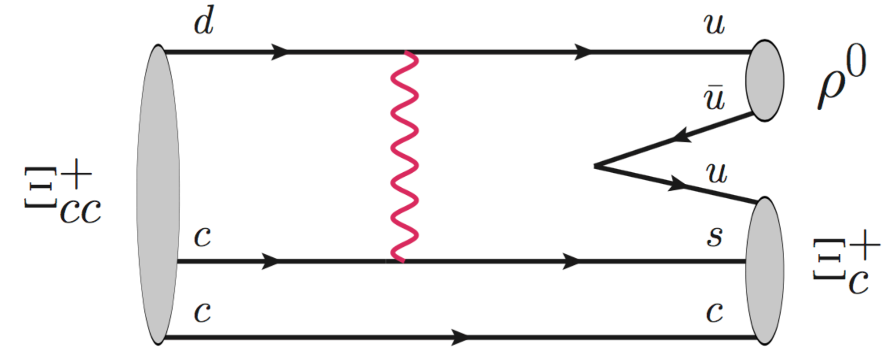
$$\Xi_{cc}^{+} \to \Xi_c^{+} \rho^0 \;\to \Xi_c^{+} \pi^{+} \pi^{-}$$

$$\frac{1}{\sqrt{2}} V_{cs}^{*} V_{ud} (C' - E_2)$$

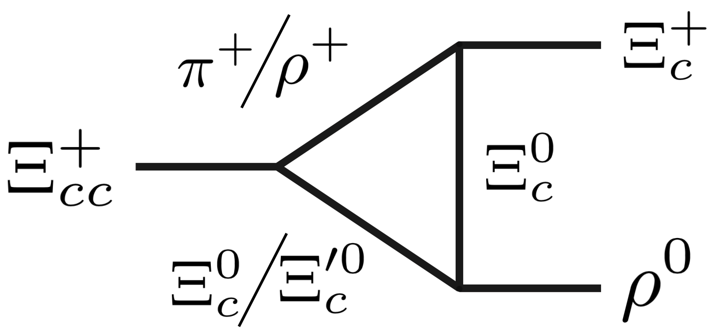
$$=$$



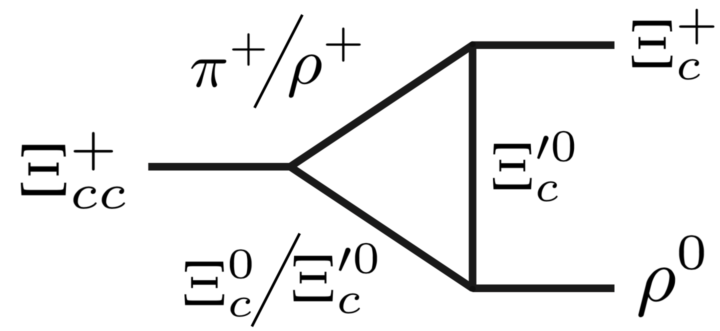
$$-$$



$$=$$



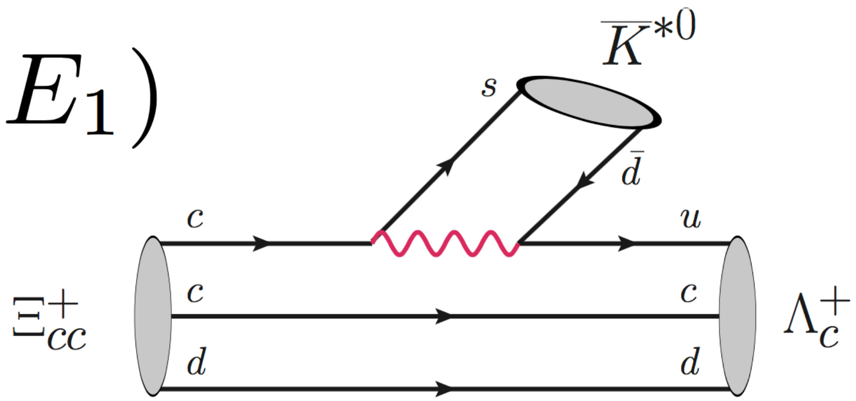
$$+$$



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

$$V_{cs}^{*} V_{ud} (C + E_1)$$

$=$



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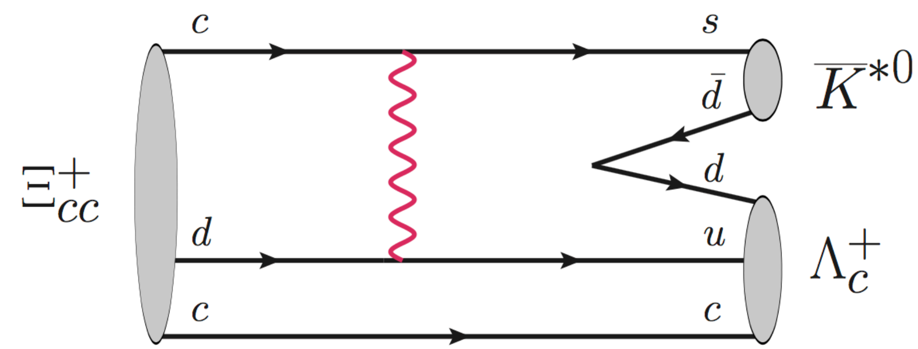

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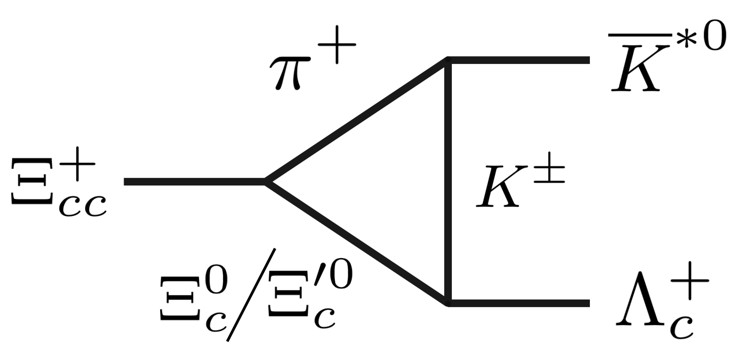

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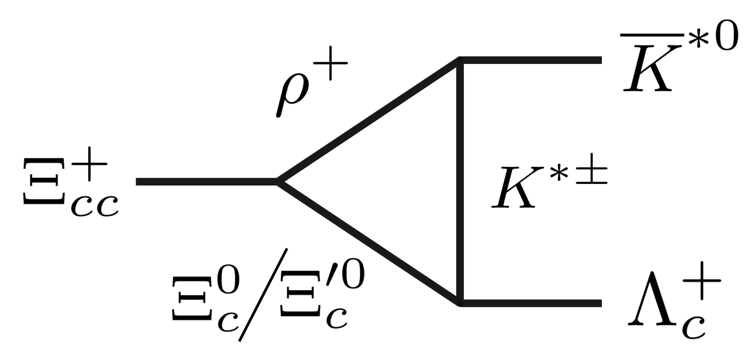

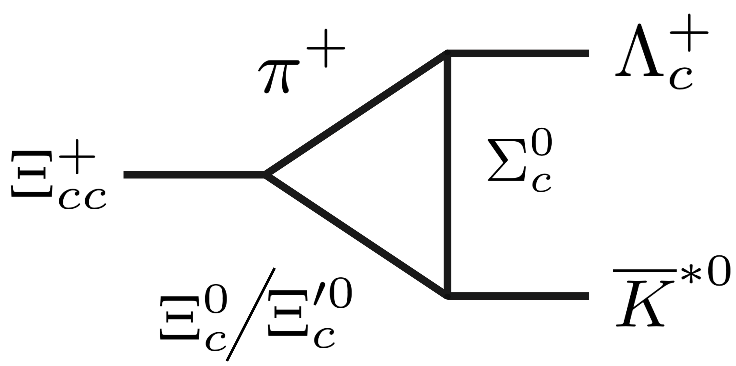

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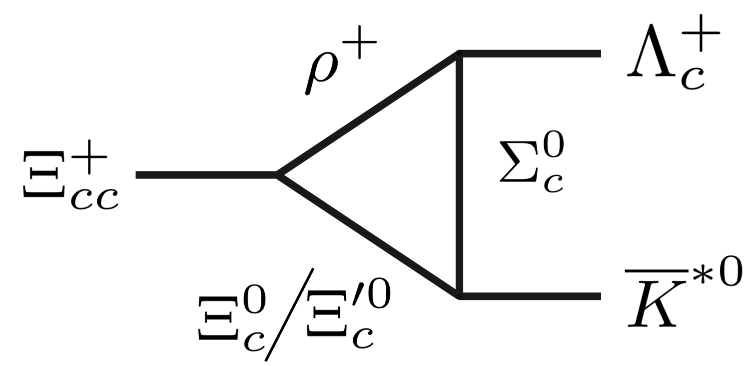
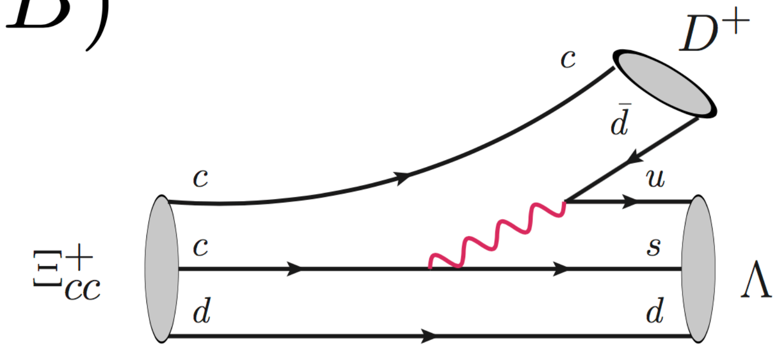


$$\Xi_{cc}^{+} \to \Lambda^{0} D^{+}$$

$$V_{cs}^{*} V_{ud} (C' + B)$$

$=$



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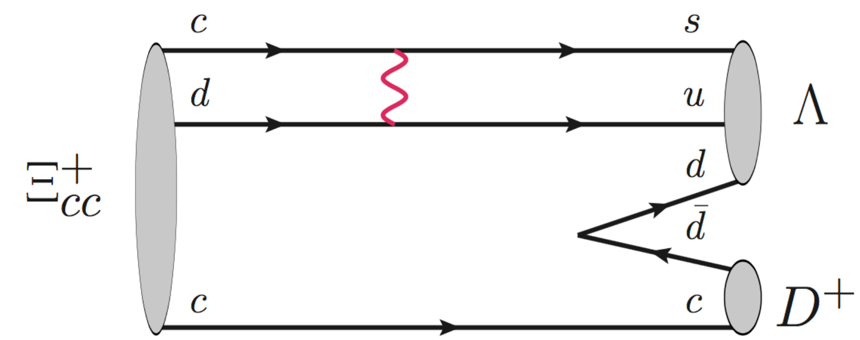

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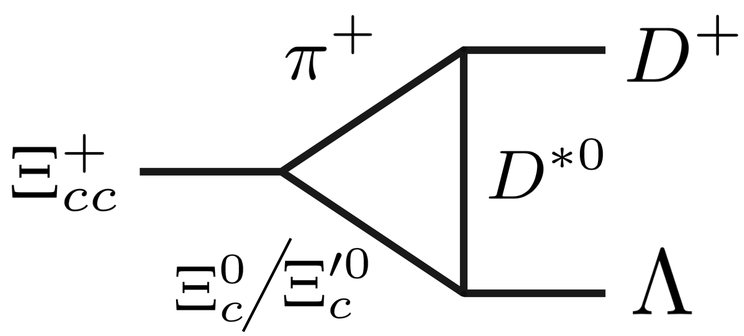

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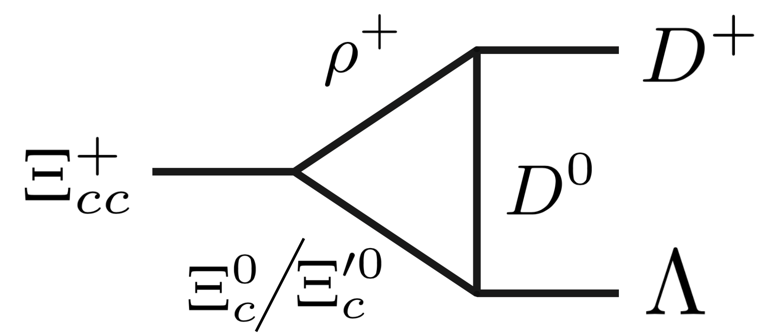

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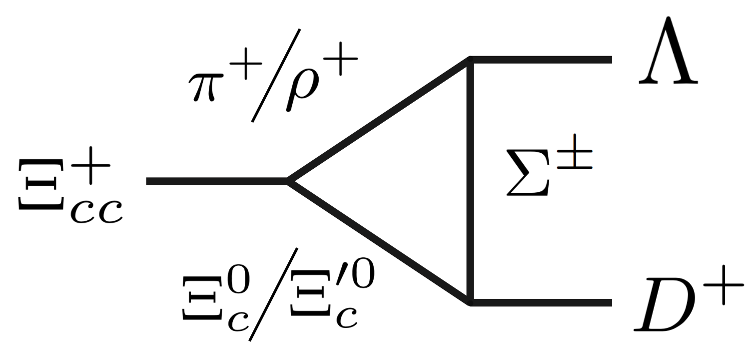

Branching Ratio of $\Xi_c^+ \to pK^-\pi^+$

Under U-spin symmetry, $d \leftrightarrow s$

$$\mathcal{A}(\Xi_c^+ \to p\overline{K}^{*0}) = \mathcal{A}(\Lambda_c^+ \to \Sigma^+ K^{*0})$$

$$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K^{*0}) = (0.36 \pm 0.10)\%$$

[FOCUS, 01']

$$\mathcal{B}(\Xi_c^+ \to p\overline{K}^{*0})/\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = 0.54 \pm 0.10$$

[FOCUS, 02']

$$Br(\Xi_c^+ \to pK^-\pi^+) = (2.2 \pm 0.8)\%$$

[FSY, *et al*, 1703.09086]