Weak Decays of Ξ_{cc}

— discovery potentials

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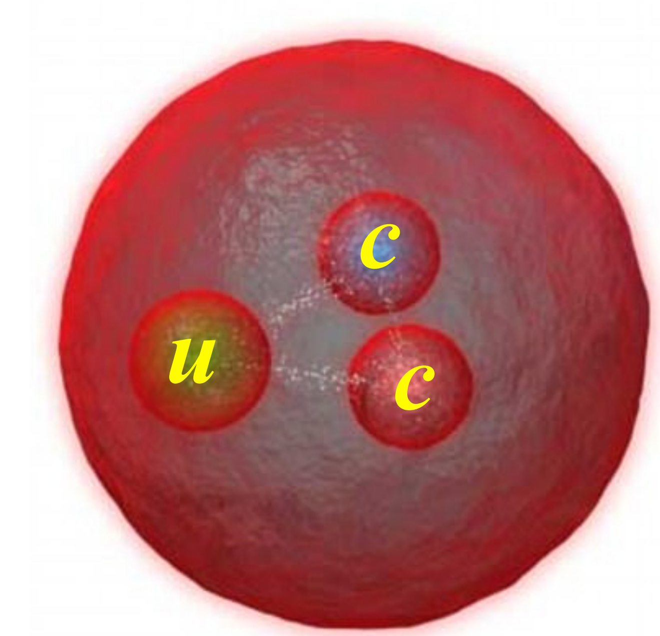

Thank Vincenzo, Vanya and Zhen-Wei for the invitation!

LHCb/Theory workshop on heavy hadron spectroscopy

17.07.2017 @ CERN

[FSY, Jiang, Li, Lu, Wang, Zhao, arXiv:1703.09086]

Stories on the theory side

- Mar 2016, Ji-Bo asked to estimate branching fractions of doubly heavy baryon decays, to search for them at LHCb.
- Dec 2016, invited talk at LHCb China working group
- Mar 2017, invited talk at LHCb Charm working group

July 2017, LHCb reports the discovery [arXiv:1707.01621]

Congratulations on the discovery of Ξ_{cc}^{++}

Outline

1. Introduction to doubly charmed baryons
   - What are the processes with the largest potentials to discovery doubly heavy baryons (DHB)
2. Theoretical Framework
3. Discussions and Results
   - compare all the decay modes
4. Summary

Motivations

- Properties and significances of doubly heavy flavor baryons, see Yan-Xi's, Anatoli's and Merek's talk
- This talk focus on the decaying processes for the searches for these particles
- In experiments
  - The only evidence was found for Ξ_{cc}^{+} by SELEX

    $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ $\quad$ $\Xi_{cc}^{+} \to p D^{+} K^{-}$ [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']

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 in predictions

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
Guberina, Melic, Stefancic, 1998	~~1550~~	220

Large ambiguity of lifetimes

Compared to

$$\tau(\Lambda_c^+) = (200 \pm 6) \times 10^{-15} s, \qquad \tau(\Xi_c^+) = (442 \pm 26) \times 10^{-15} s,$$
$$\tau(\Xi_c^0) = (112^{+13}_{-10}) \times 10^{-15} s, \qquad \tau(\Omega_c^0) = (69 \pm 12) \times 10^{-15} s.$$

Lifetimes

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Kiselev, Likhoded, Onishchenko, 1998	430±100	110±10
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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}^{++}

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

- 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}^{+}

for the first reason

Theoretical Framework

1. Short-distance contributions

   — external W-emission diagrams

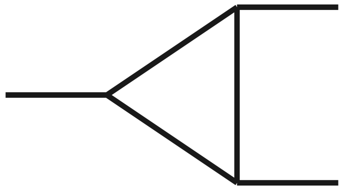
   - Calculate form factors in light-front quark model
   - Calculate amplitudes using factorization approach

2. Long-distance contributions

   — final-state interacting (FSI) effects

   — significantly large in charm decays

   - Calculate rescattering effects

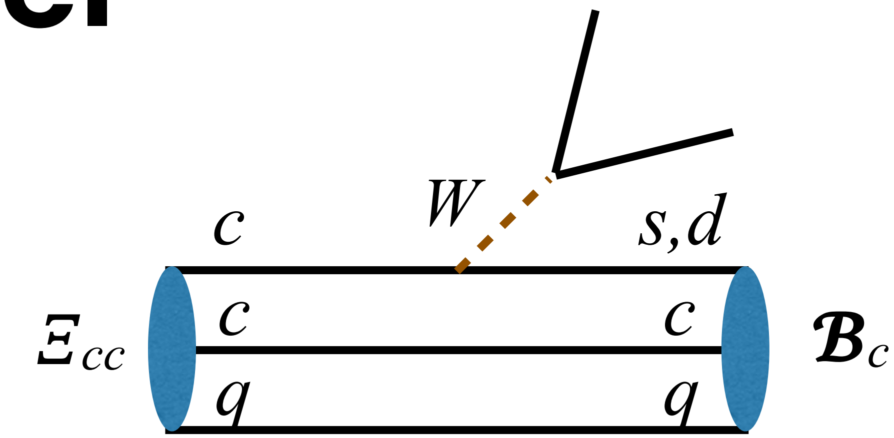


3. Relative branching fractions

   — most theoretical uncertainties cancelled

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

$$\langle \mathcal{B}_c(p_f)|J^{\rm w}_\mu|\Xi_{cc}(p_i)\rangle$$
$$= \bar{u}_f(p_f)\left[\gamma_\mu f_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{m_i} f_2(q^2) + \frac{q_\mu}{m_i} f_3(q^2)\right] u_i(p_i)$$
$$- \bar{u}_f(p_f)\left[\gamma_\mu g_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{m_i} g_2(q^2) + \frac{q_\mu}{m_i} g_3(q^2)\right] \gamma_5 u_i(p_i)$$

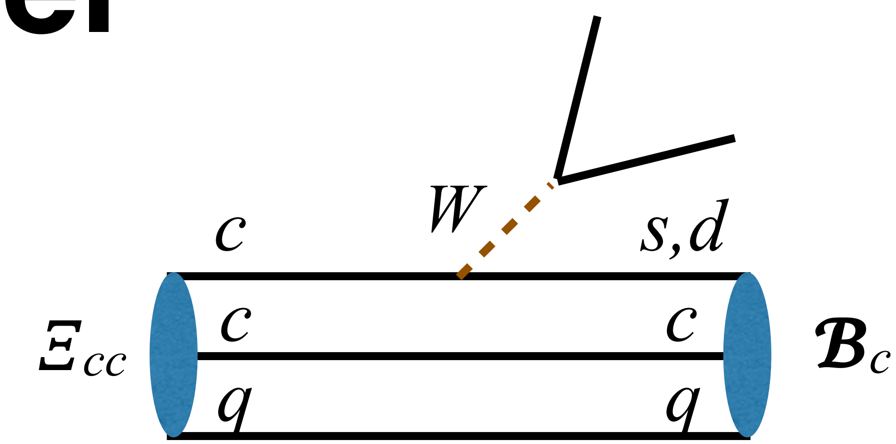


The di-quark picture:
[cq] = 0^+ or 1^+

$$\langle \mathcal{B}_c(\bar{\mathbf{3}})|J^{\rm w}_\mu|\Xi_{cc}\rangle = \frac{\sqrt{3}}{4}\langle J^{\rm w}_\mu\rangle_{0^+} + \frac{\sqrt{3}}{4}\langle J^{\rm w}_\mu\rangle_{1^+},$$
$$\langle \mathcal{B}_c(\mathbf{6})|J^{\rm w}_\mu|\Xi_{cc}\rangle = -\frac{3}{4}\langle J^{\rm w}_\mu\rangle_{0^+} + \frac{1}{4}\langle J^{\rm w}_\mu\rangle_{1^+}.$$

	$\Xi_{cc}\to\Xi_c/\Xi'_c(0^+)$				$\Xi_{cc}\to\Xi_c/\Xi'_c(1^+)$			
	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
	$\Xi_{cc}\to\Lambda_c/\Sigma_c(0^+)$				$\Xi_{cc}\to\Lambda_c/\Sigma_c(1^+)$			
	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

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.

$c \to s$

	$\Xi_{cc} \to \Xi_c/\Xi'_c(0^+)$ f_1	g_1	f_2	g_2	$\Xi_{cc} \to \Xi_c/\Xi'_c(1^+)$ 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

$c \to d$

	$\Xi_{cc} \to \Lambda_c/\Sigma_c(0^+)$ f_1	g_1	f_2	g_2	$\Xi_{cc} \to \Lambda_c/\Sigma_c(1^+)$ 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
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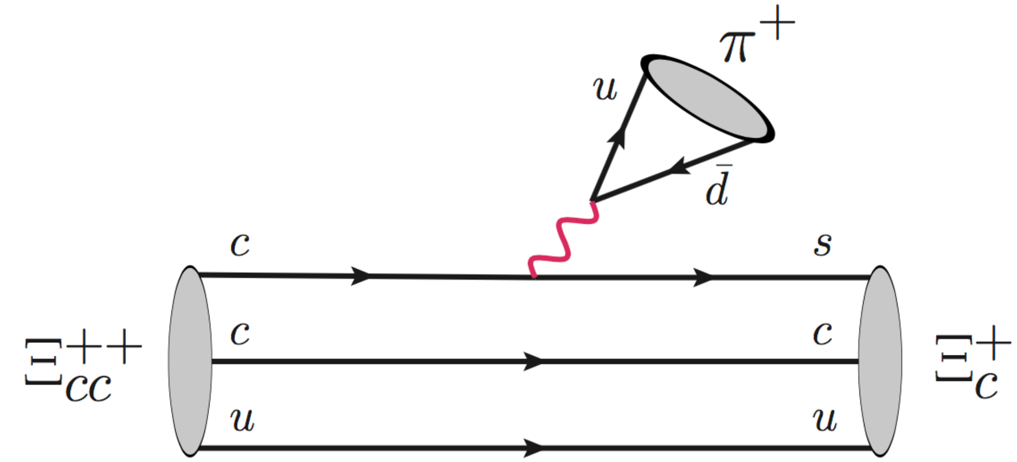
Short-Distance Contributions



- 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** small lifetime

Cabibbo-suppressed

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

$$\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.056,$$

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \ell^+ \nu)/\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 0.71,$$

missing energy

Other processes with large branching fractions, but

- either have neutral final-state particles

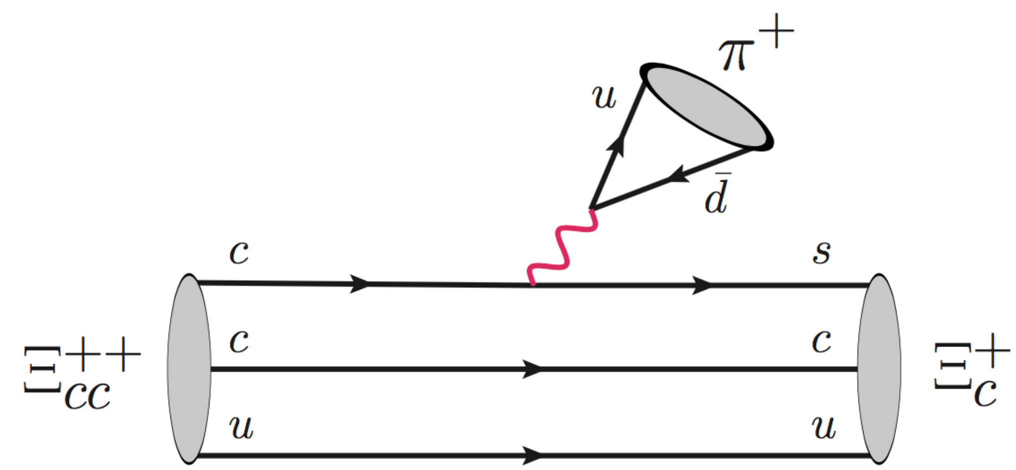
$$\Xi_c^+ \rho^+ (\to \pi^+ \pi^0) \qquad \Xi_c^{\prime +} (\to \Xi_c^+ \gamma) \pi^+$$

- 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:

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

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 $(2.2 \pm 0.8)\%$

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']

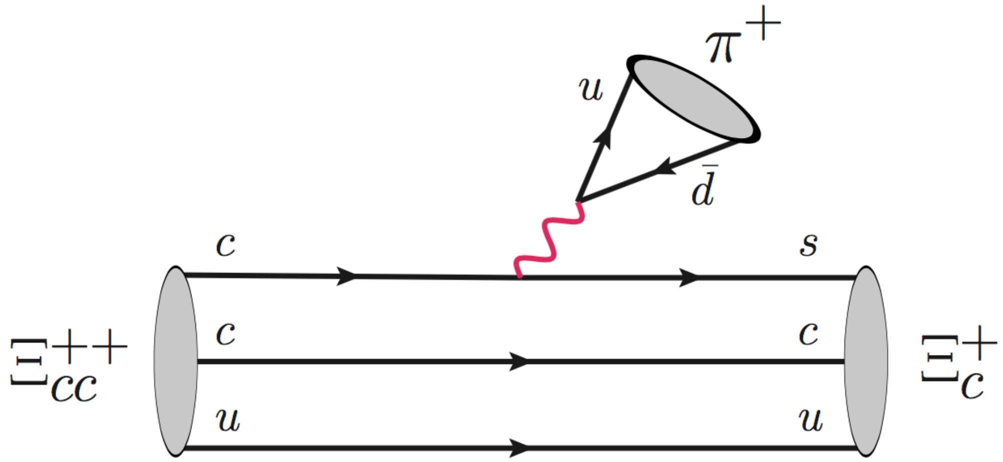
$$\mathcal{B}(\Xi_c^+ \to p\overline{K}^{*0})/\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = 0.54 \pm 0.10$$

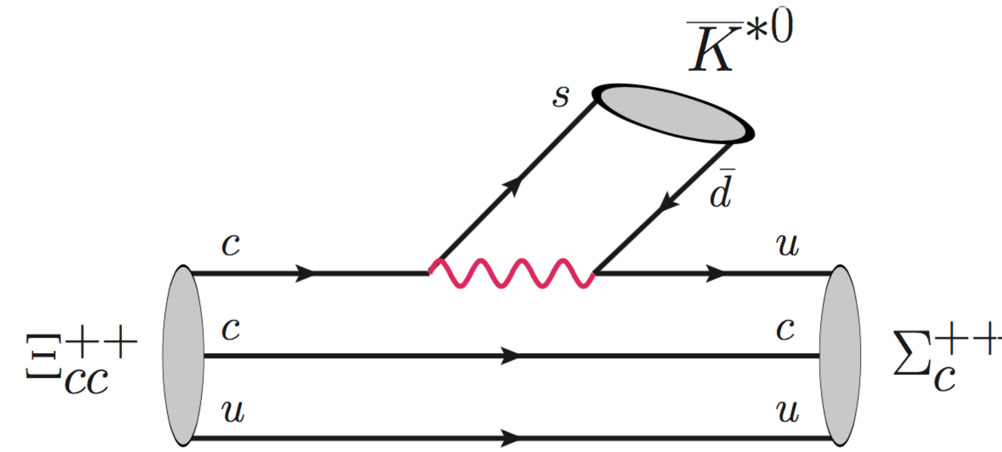
[FOCUS, 02']

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

[FSY, *et al*, 1703.09086]

Short-distance v.s. Long-distance Contributions





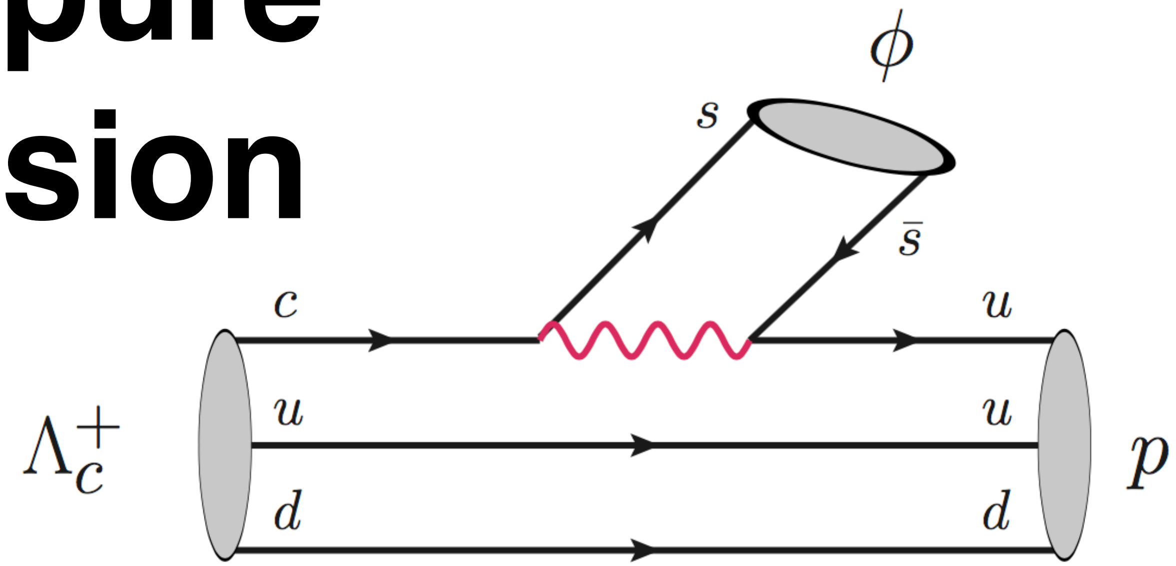
short-distance branching fractions

external W-emission	internal W-emission
Br=3.4%	Br=0.003%
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}

$|a_2(\mu_c)|=0.02$

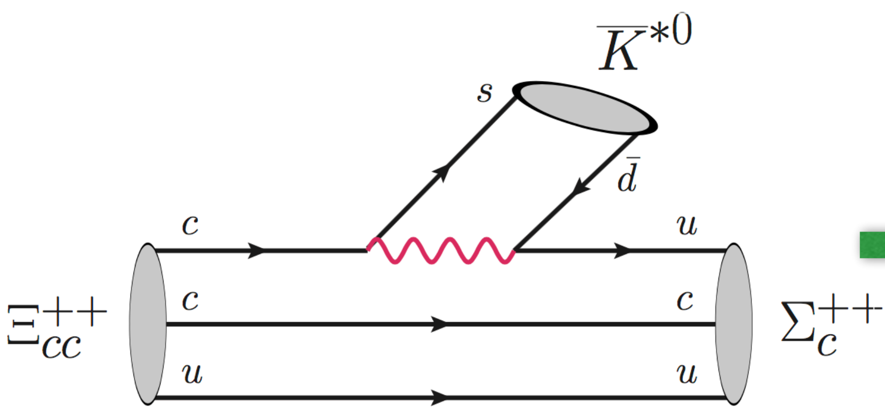
Br(exp)=$(1.04\pm0.21)\times10^{-3}$

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

large-N_c limit

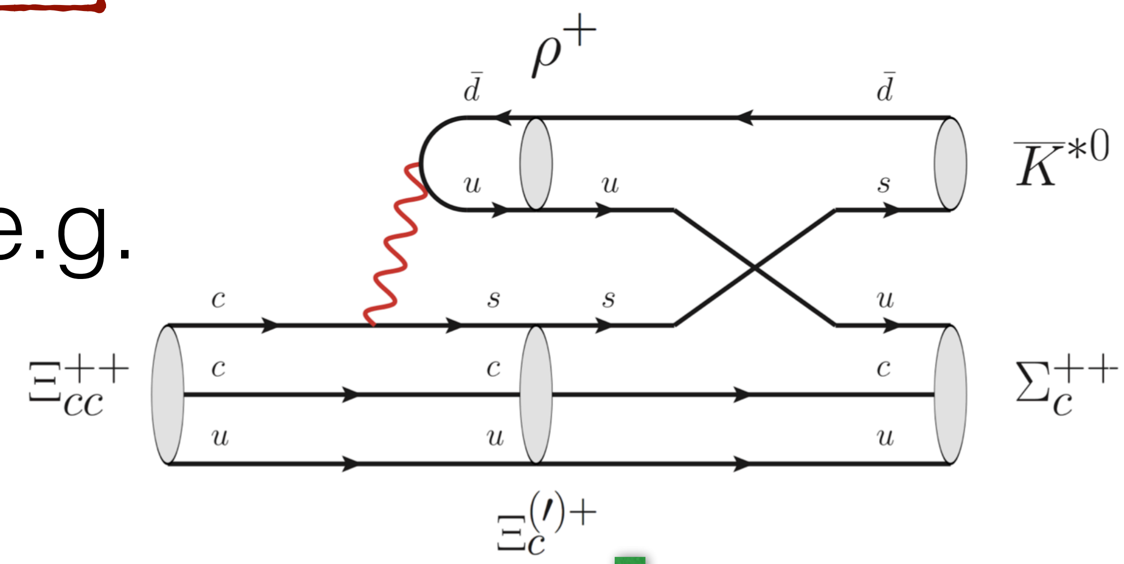
Understanding long-distance contributions is essential to find a best process
for the searches for doubly heavy baryons

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

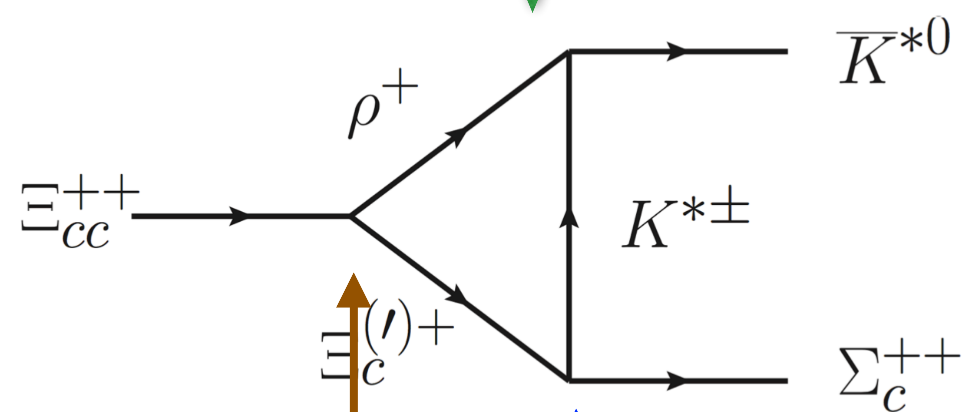


FSI

e.g.



Rescattering mechanism of the final-state interacting effects



Absorptive part:

weak vertex

rescattering

$$\mathrm{Abs}\mathcal{M}(p_i \to p_f q) =$$

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

Effective Lagrangian

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

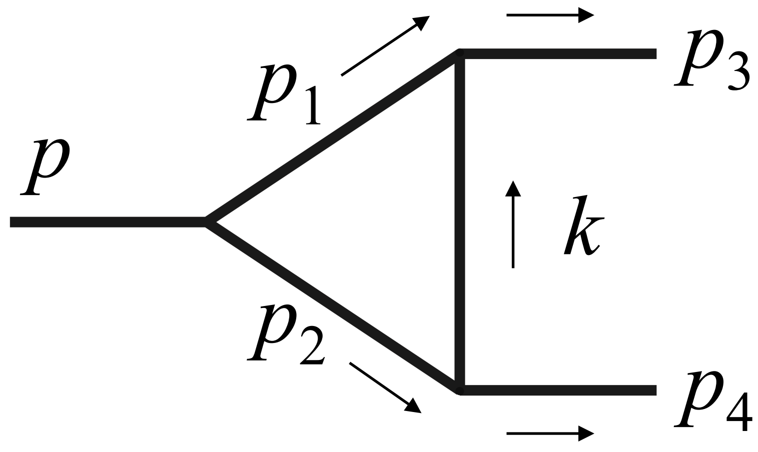
Hadronic coupling constants are related under the flavor SU(3) symmetry and the chiral and heavy quark symmetries

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

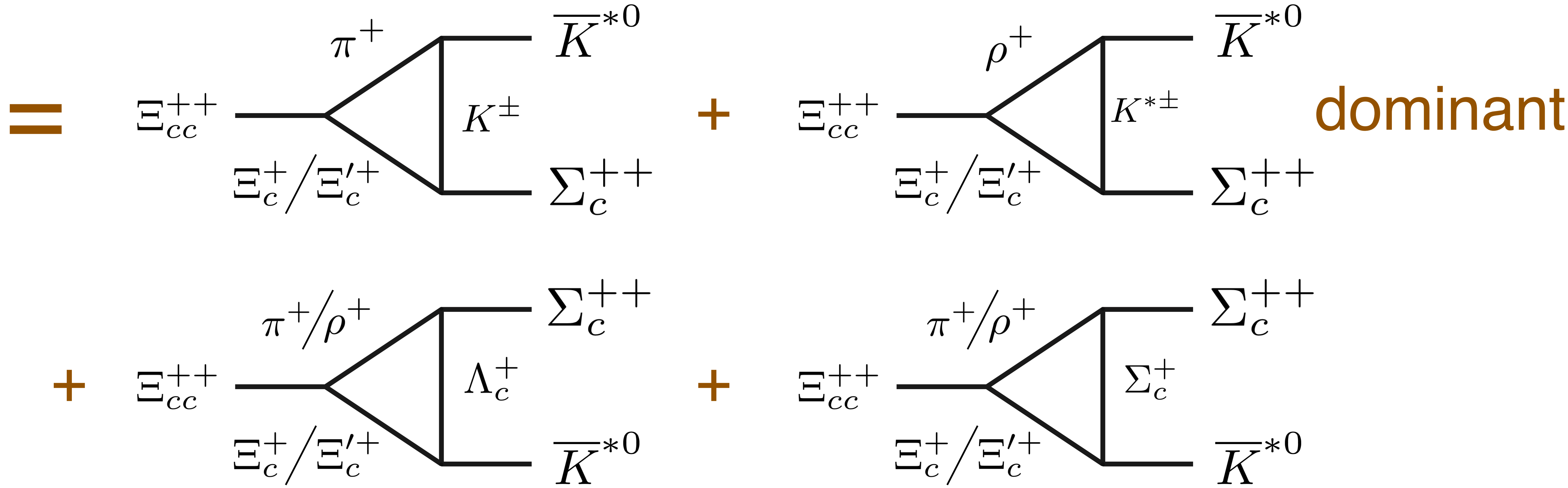
Relative Branching Fractions with long-distance contributions

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%

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



$\eta = 1.0 \sim 2.0$

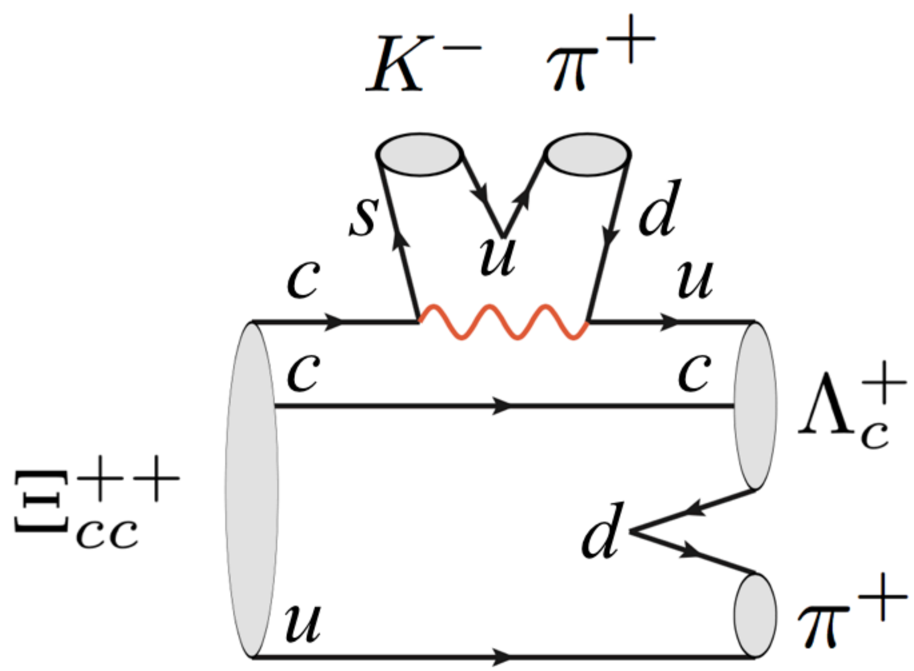
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 3.4\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \rho^+) = 6.3\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \pi^+) = 2.4\%$$
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \rho^+) = 8.7\%$$

$$\mathcal{B}(\Xi_{cc}^{++} \to \Sigma_c^{++}\overline{K}^{*0}) = (1.6 \sim 10.3)\% \times \frac{\tau_{\Xi_{cc}^{++}}}{300\ \text{fs}}$$

Large enough for measurements

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

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



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

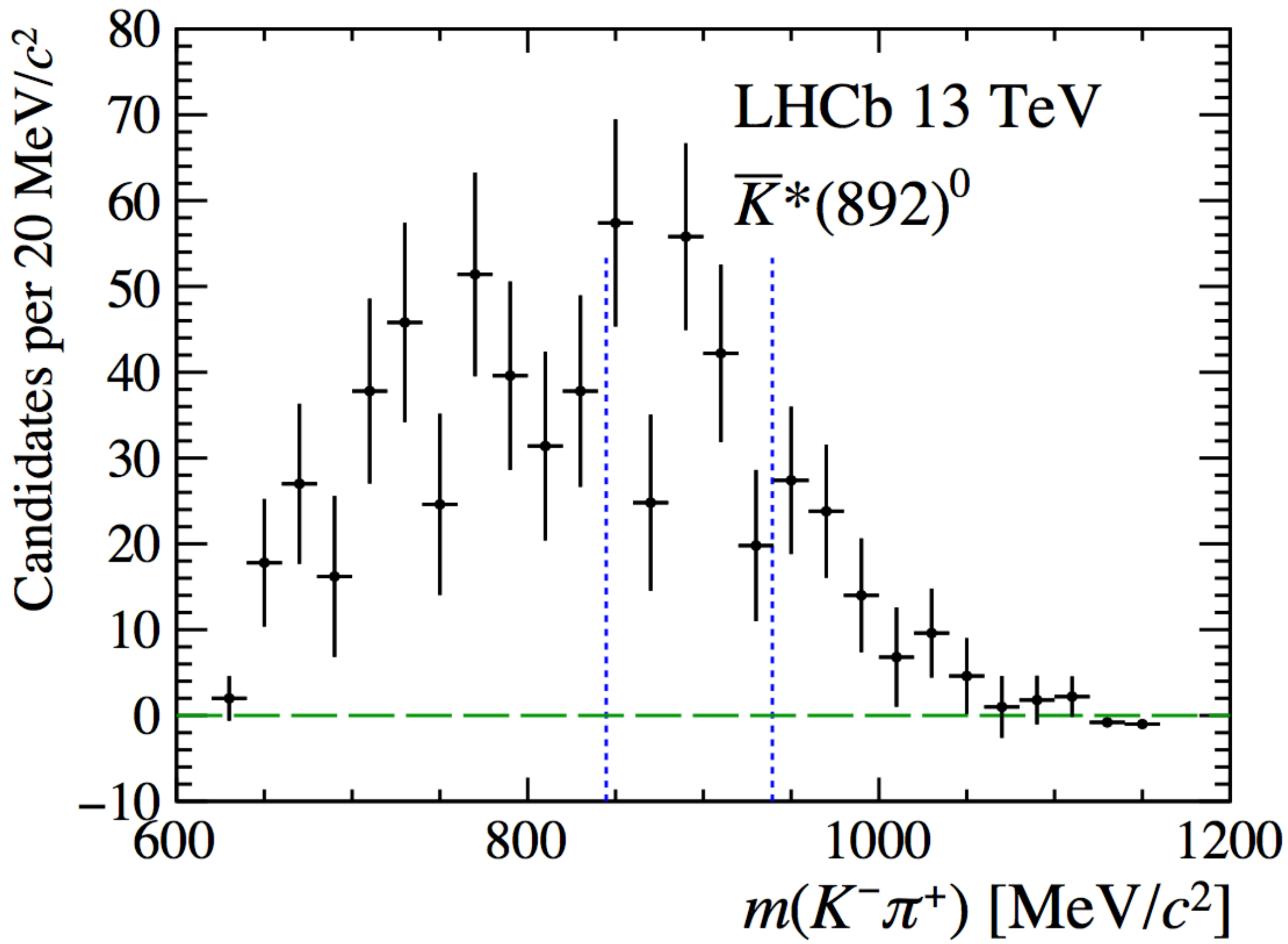
is actually a four-body decay

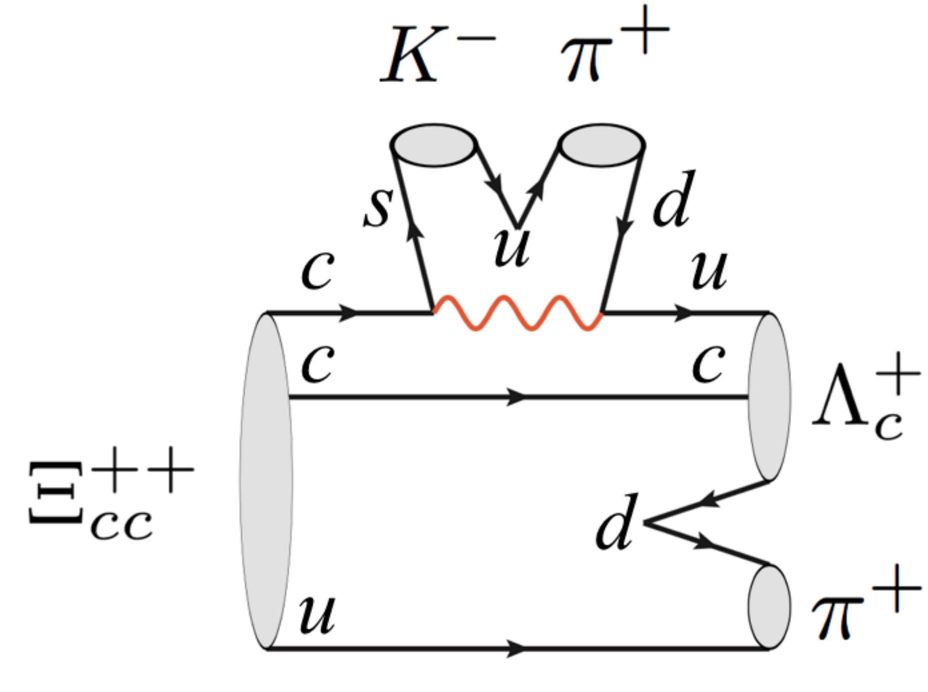
$\Sigma_c^{++}(2455)$ or $\Sigma_c^{++}(2520)$

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

$$\mathcal{B}(\Xi_{cc}^{++} \to \Sigma_c^{++}(2455)\overline{K}^{*0}) = \left(\frac{\tau_{\Xi_{cc}^{++}}}{300\,\text{fs}}\right) \times (1.6 \sim 10.3)\%$$

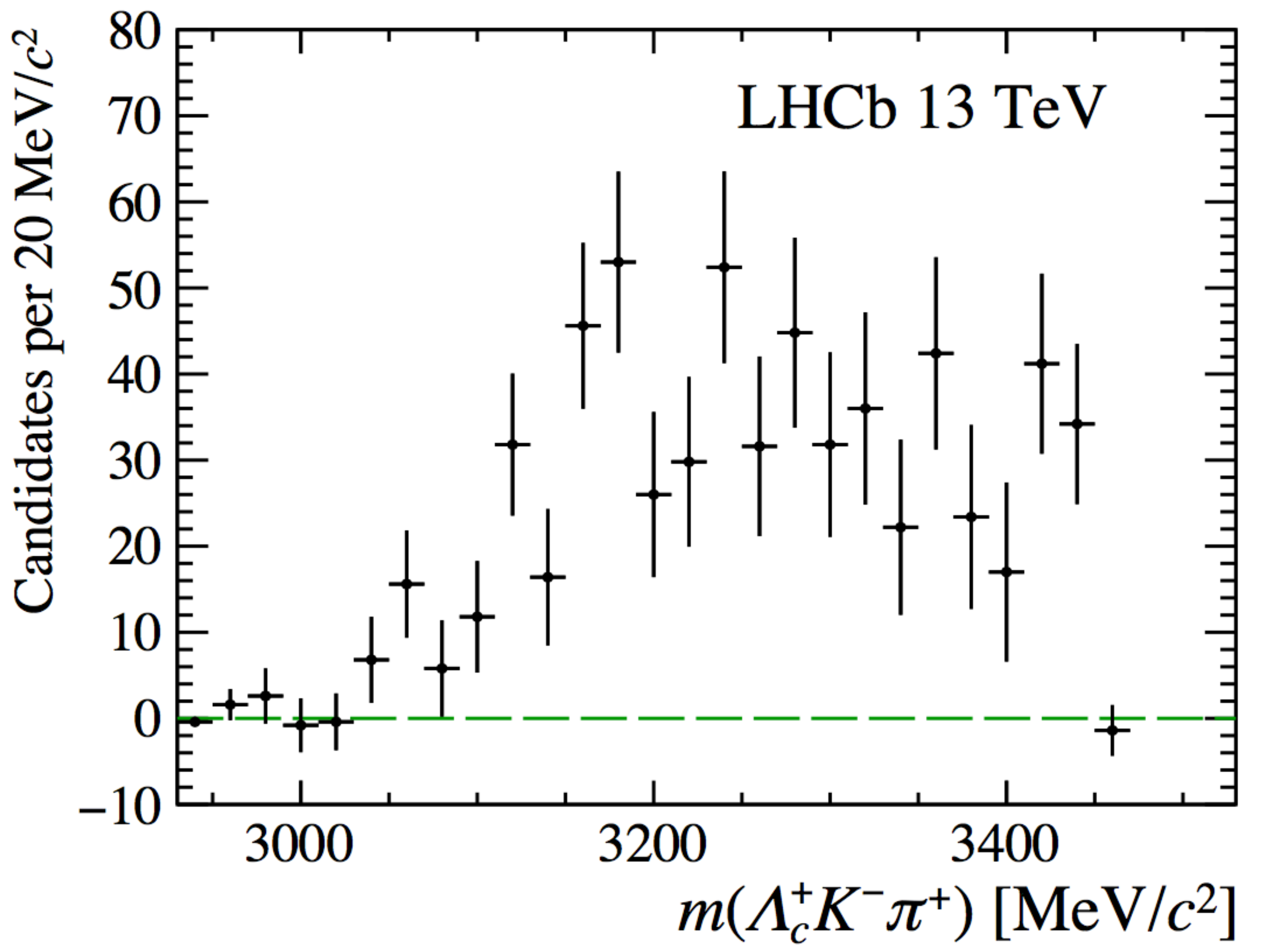
It would be expected to be as large as $O(10\%)$

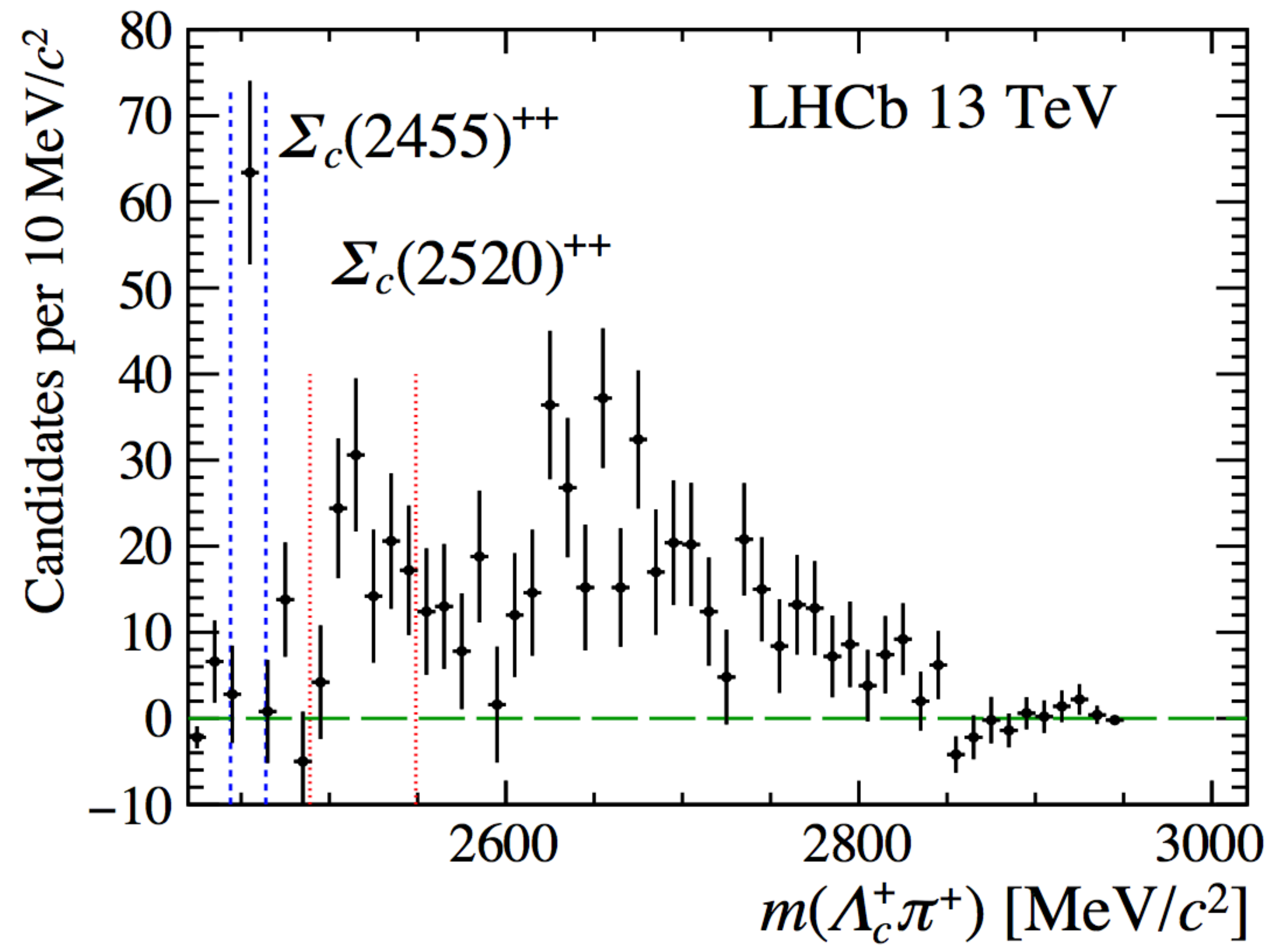




See Yan-Xi's talk

Resonances dominated





$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ **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
	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	$(\mathcal{R}_\tau/0.3)\times 0.002$

$\tau \times (\sim 3)$

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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	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]

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

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

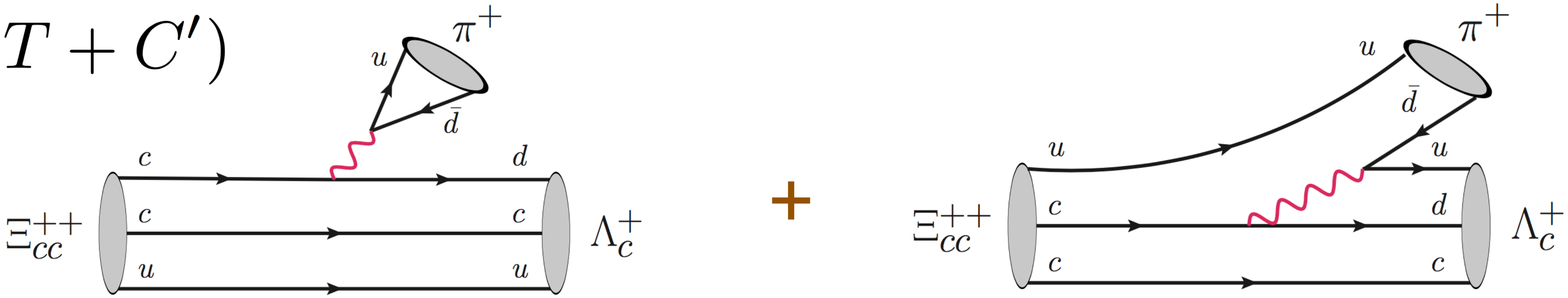
- And LHCb observed it via the first process.

Thank you !

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

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

$=$



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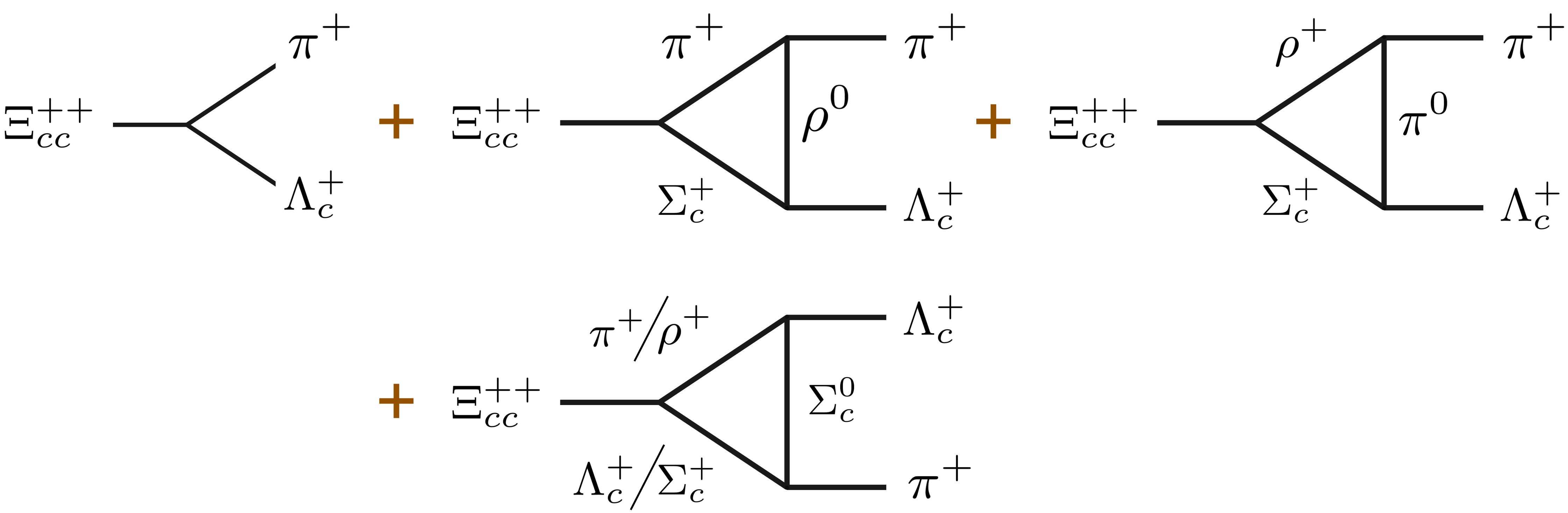
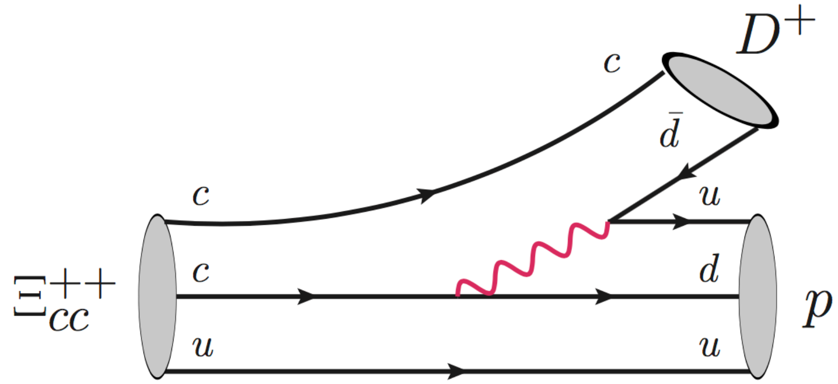


$$\Xi_{cc}^{++} \to pD^+$$

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



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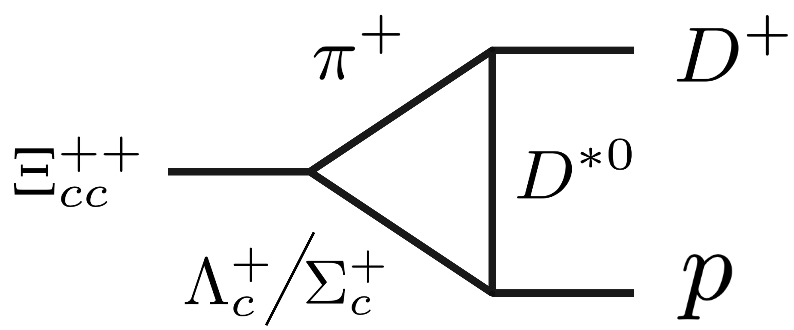

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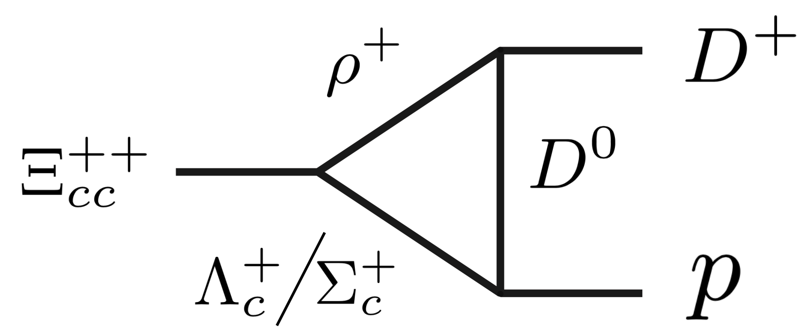

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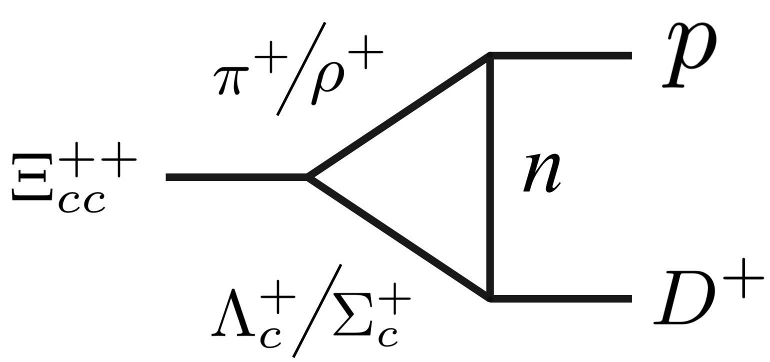
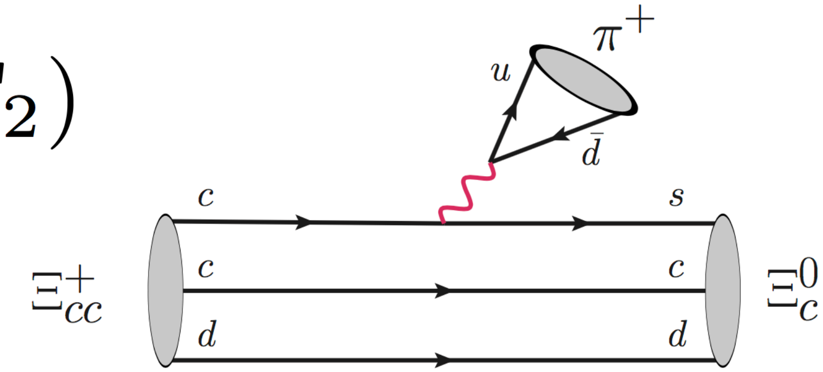


$$\Xi_{cc}^{+} \to \Xi_c^0 \pi^+$$

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

$=$



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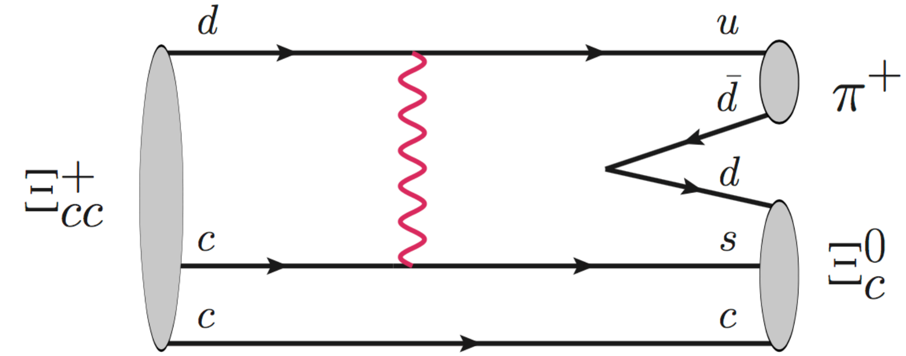

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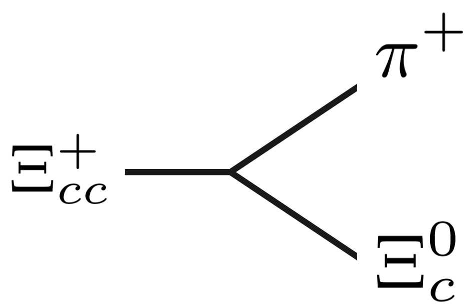

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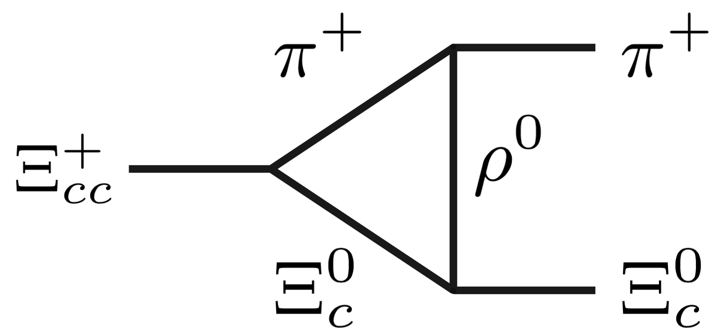

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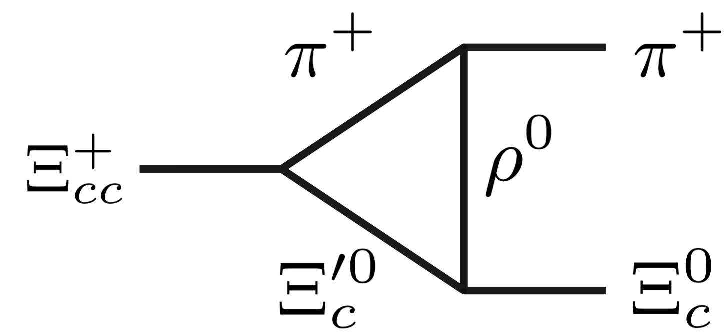

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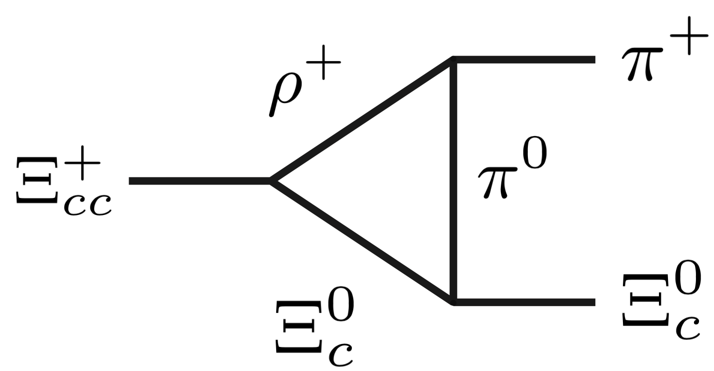

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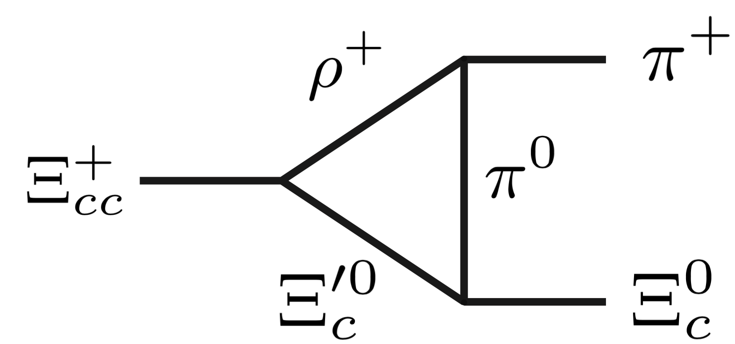
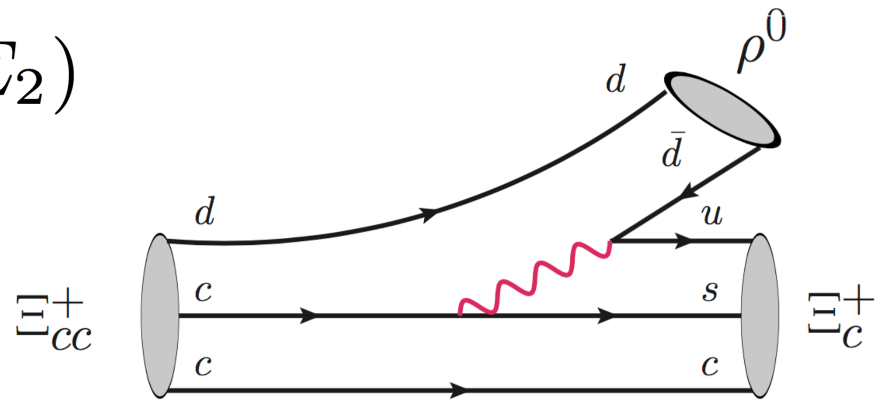


$$\boxed{\Xi_{cc}^{+} \to \Xi_{c}^{+}\rho^{0}} \to \Xi_{c}^{+}\pi^{+}\pi^{-}$$

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

$=$



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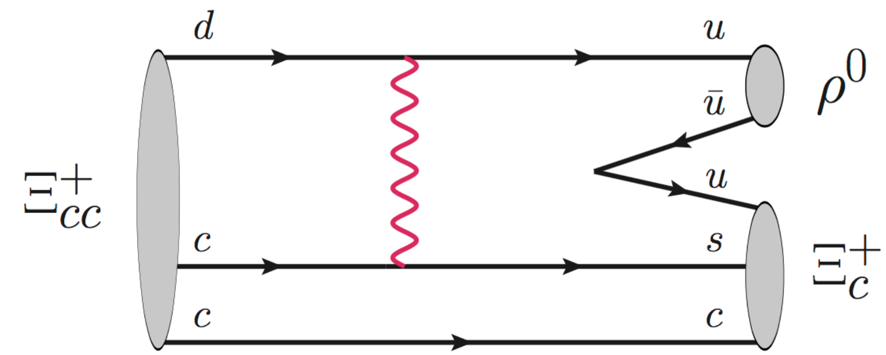

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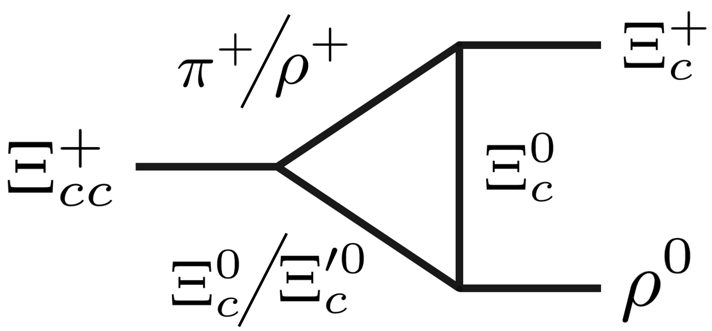

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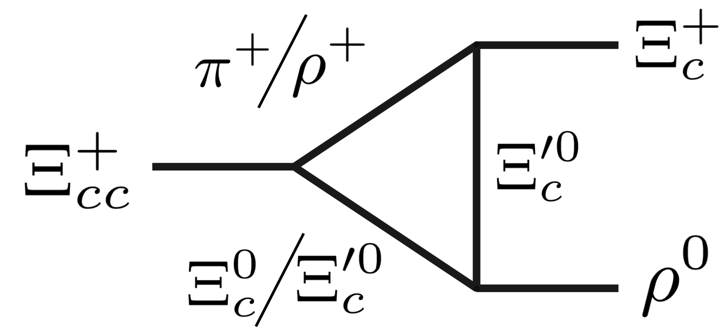
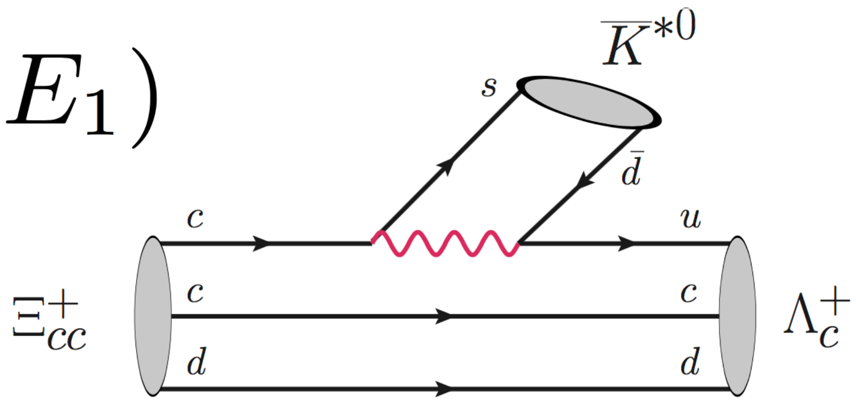


$$\boxed{\Xi_{cc}^{+} \to \Lambda_c^{+} \overline{K}^{*0}} \to \Lambda_c^{+} K^{-} \pi^{+}$$

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

$=$



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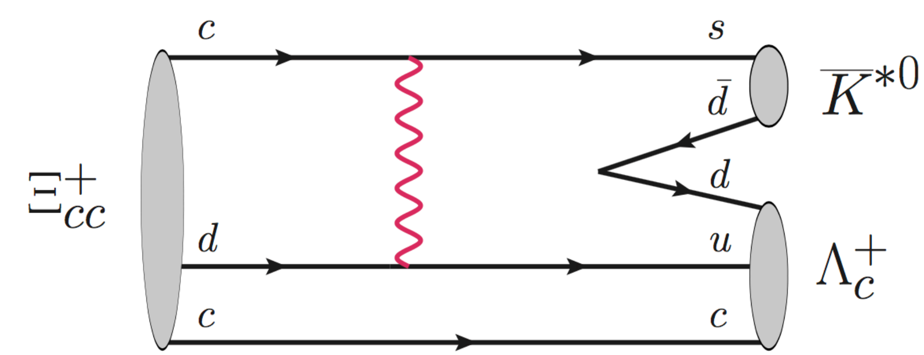

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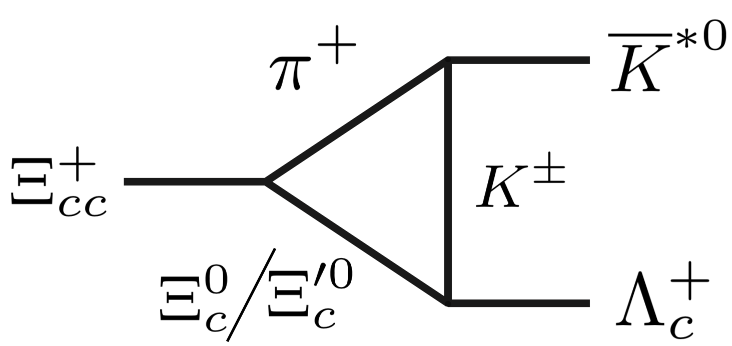

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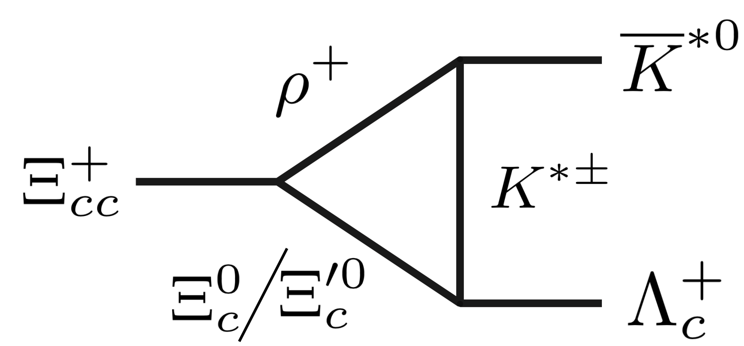

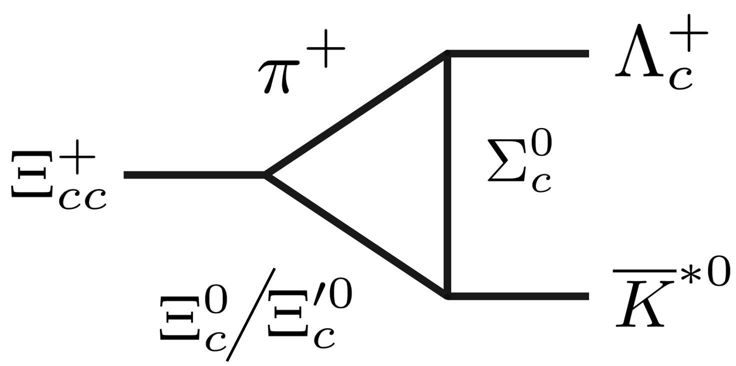

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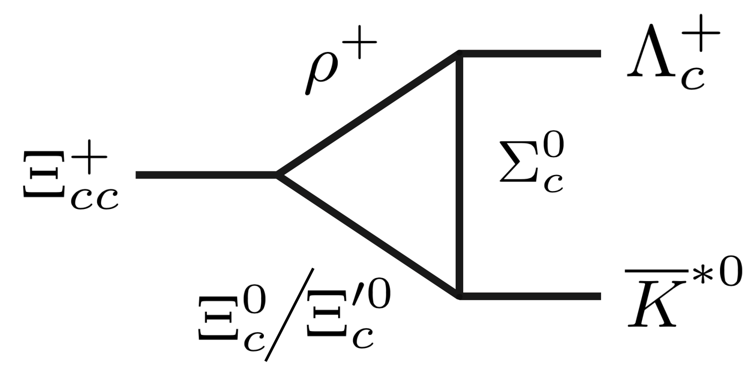
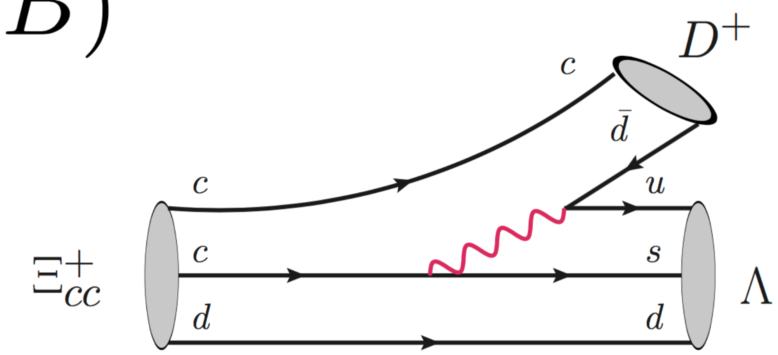


$\Xi_{cc}^{+} \to \Lambda^{0} D^{+}$

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

$=$



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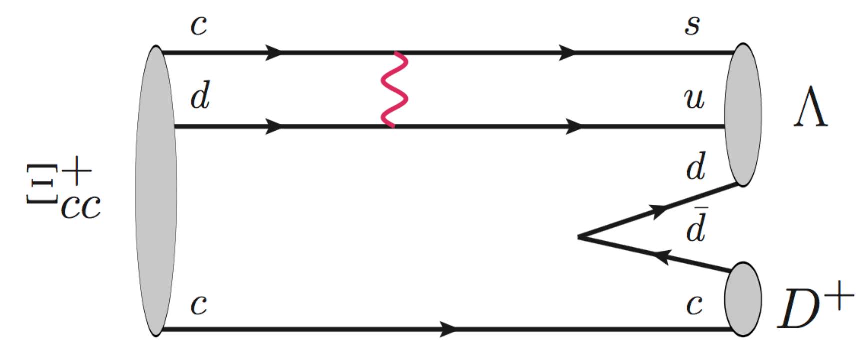

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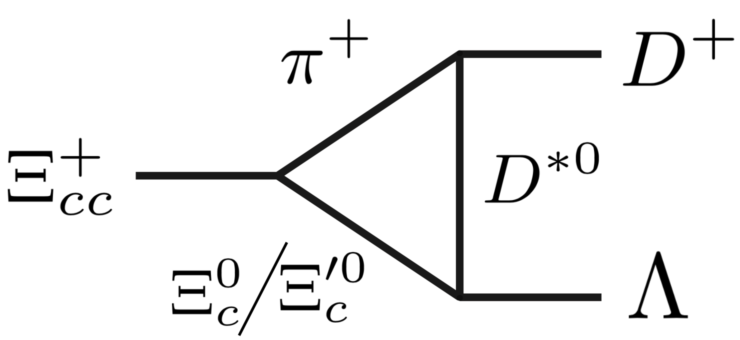

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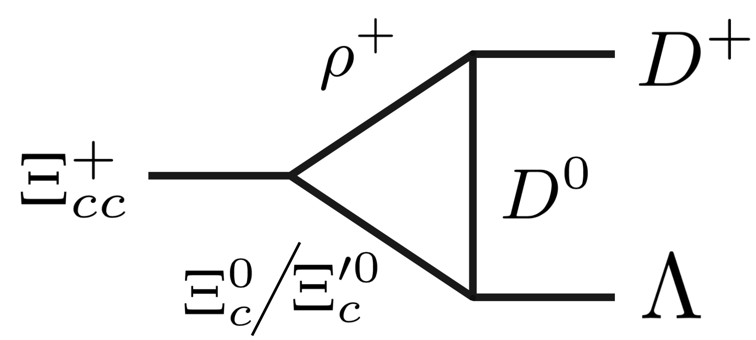

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