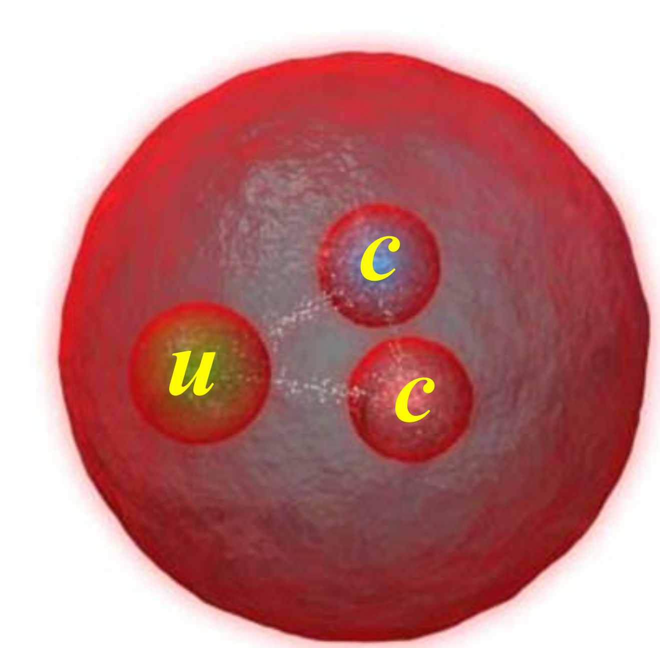
Weak Decays of Ξ_{cc}

— discovery potentials

Fu-Sheng Yu

Lanzhou University



Workshop on singly and doubly charmed baryons

LPNHE, 26 June 2018

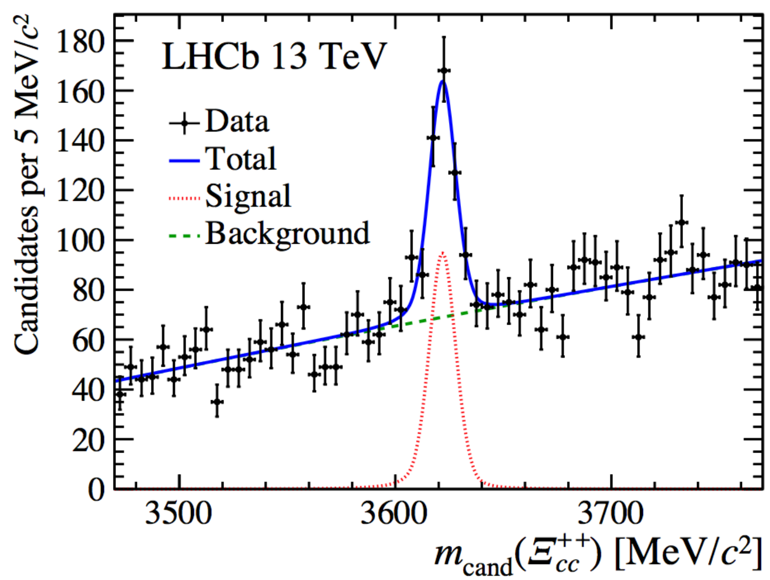
In collaboration with Hua-Yu Jiang, Run-Hui Li, Ying Li, Cai-Dian Lü, Wei Wang, Zhen-Xing Zhao, Zhi-Tian Zou

Outline

1. Introduction
2. Theoretical Framework
3. Discussions and Results
    - compare all the decay modes
4. Summary

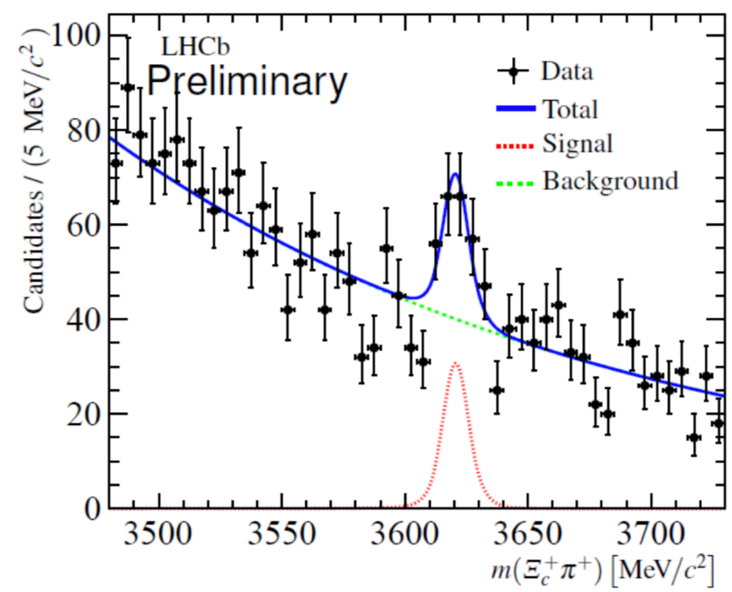
LHCb observed Ξ_{cc}^{++} See M.Traill's talk

July 2017



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

June 2018



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

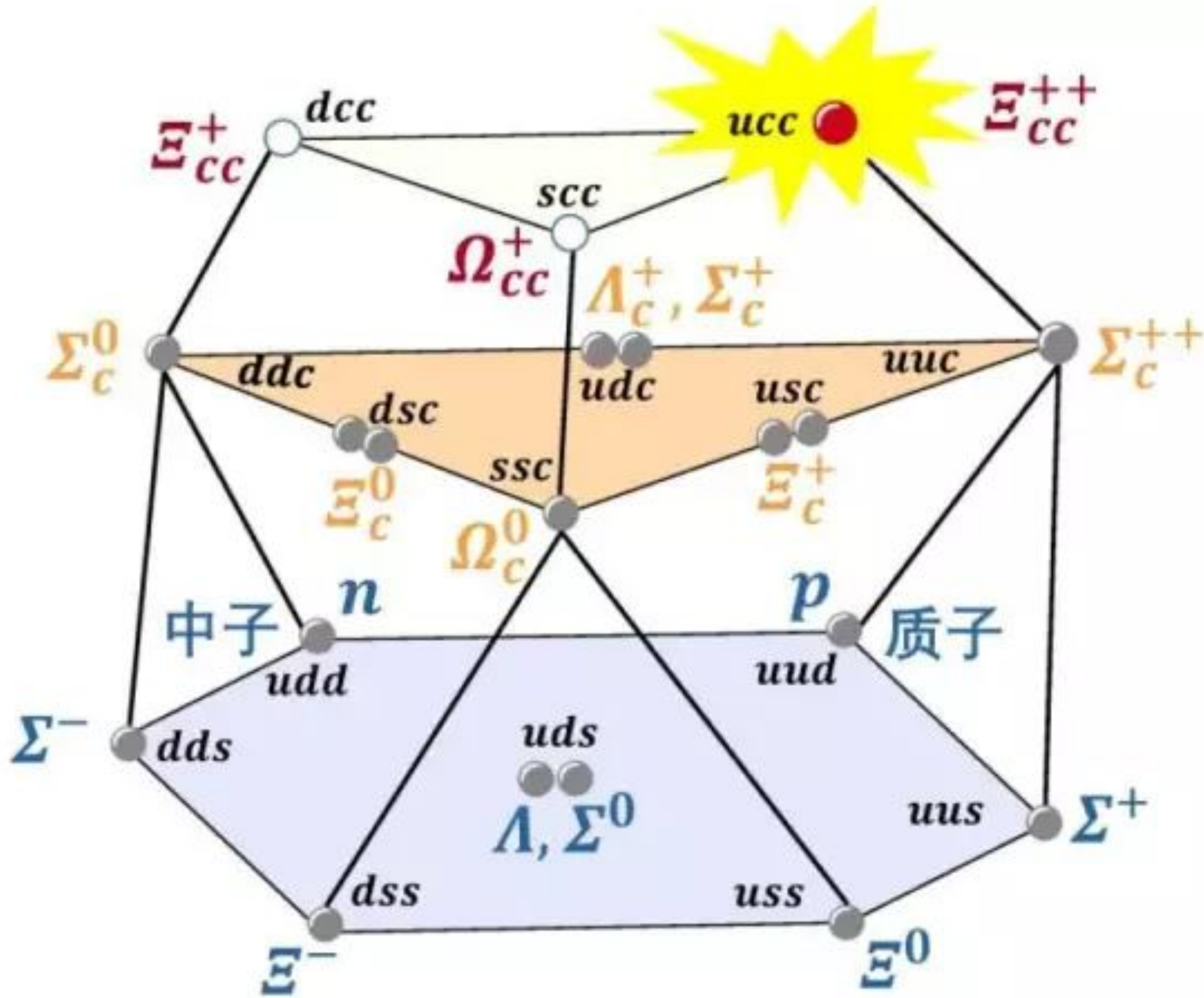
1703.09086v3

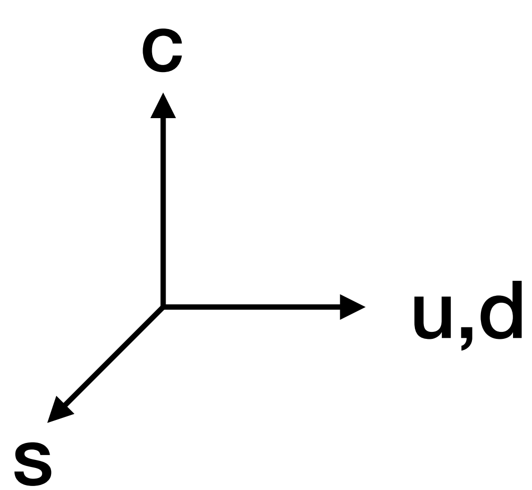
Abstract

The existence of doubly heavy flavor baryons h
this Letter we systematically investigate the weak
which should be helpful for experimental searches
first studied in the doubly heavy baryon decays, an
processes $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ are the
for doubly heavy baryons.

Two golden channels to search for doubly heavy baryons were pointed out in early 2017

FSY, Jiang, Li, Lü, Wang, Zhao, 1703.09086





SU(4) flavor symmetry

Searching History

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

$$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+ \qquad \Xi_{cc}^{+} \to p D^+ K^-$$ SELEX, ’02, ’04

- **But not confirmed by other experiments**

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

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

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

Answer can only be given by new measurement

Data = Production * Decay

cross sections of production @ LHC

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

Ξ_{cc}

-	$\sqrt{S}=7.0\text{TeV}$	$\sqrt{S}=14.0\text{TeV}$
$[^3S_1]$	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 $(\sqrt{S}=14.0\ \text{TeV})$ in unit of nb

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

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

Data = Production * Decay

The key issue

is to select the decaying processes

with largest possibility of observation

- Largest Branching Fractions

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

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

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

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}^{+}

Dynamics is challenging in both charmed baryon decays

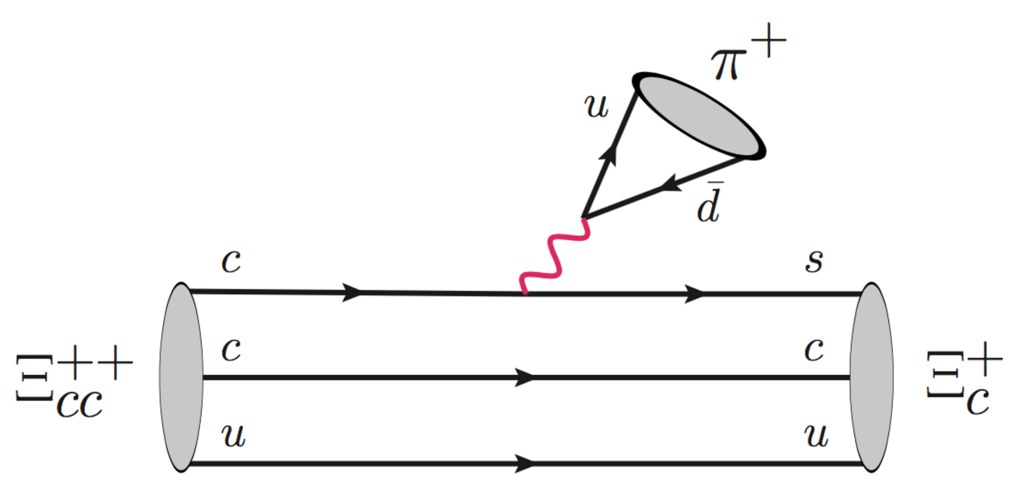
Theory Framework for weak decays of charmed baryons

Short + Long distance contributions

Short-distance contributions

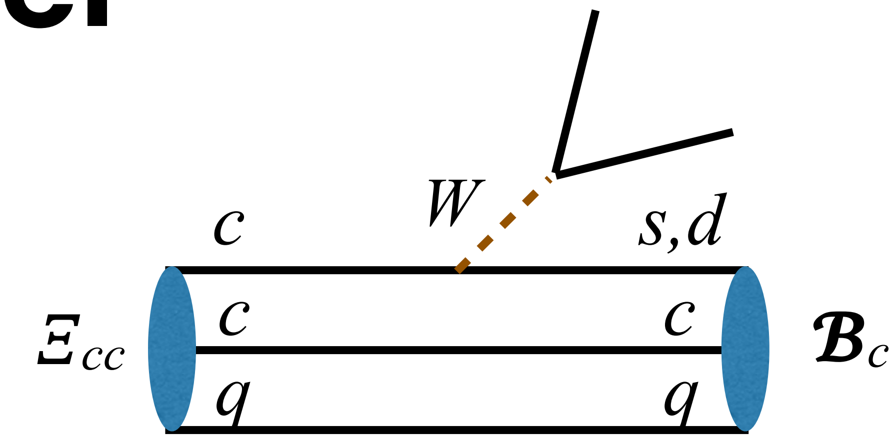
— external W-emission diagrams

- 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.



$c \to s$

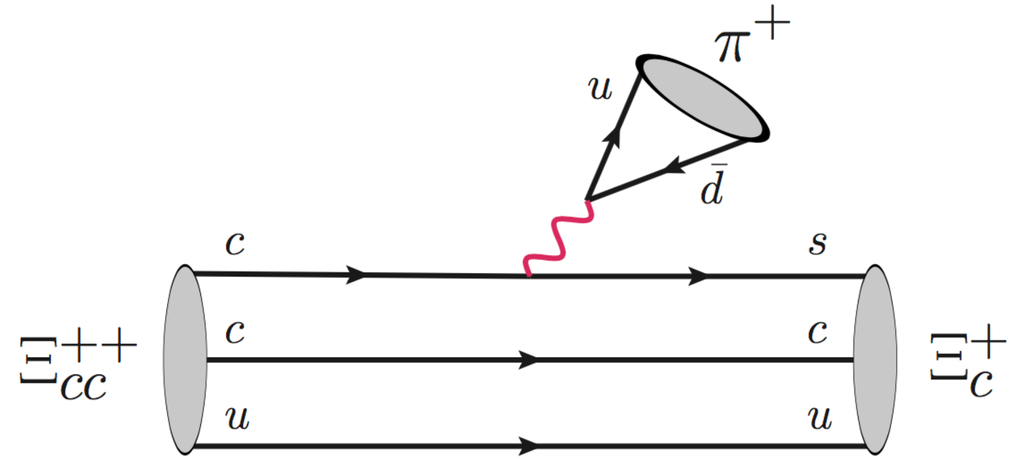
	$\Xi_{cc} \to \Xi_c/\Xi_c'(0^+)$				$\Xi_{cc} \to \Xi_c/\Xi_c'(1^+)$			
	f_1	g_1	f_2	g_2	f_1	g_1	f_2	g_2^*
$F(0)$	0.75	0.62	−0.78	−0.08	0.74	−0.20	0.80	−0.02
$m_{\rm fit}$	1.84	2.16	1.67	1.29	1.58	2.10	1.62	1.62
δ	0.25	0.35	0.30	0.52	0.36	0.21	0.31	1.37

$c \to d$

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

Wang, **FSY**, 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** small lifetime

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

Cabibbo-suppressed

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

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

missing energy

Other processes with large branching fractions, but

- either have neutral final-state particles

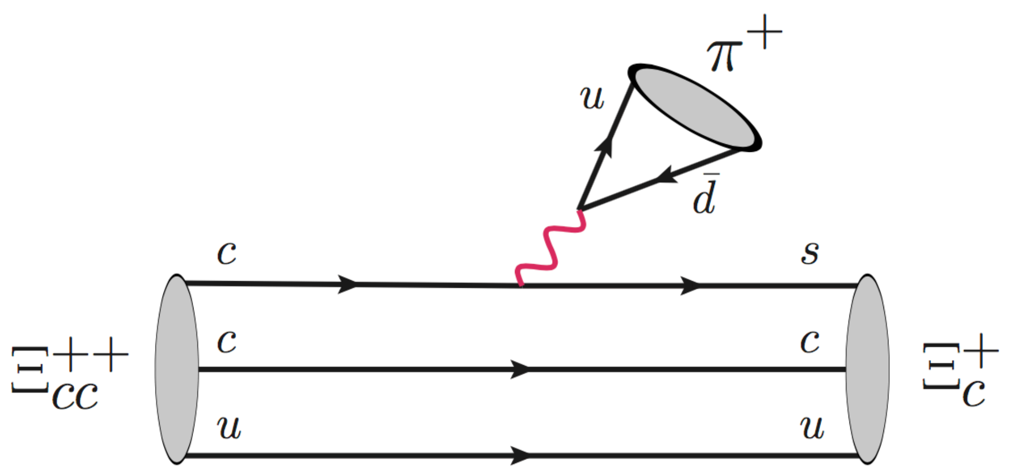
$$\Xi_c^+ \rho^+ (\to \pi^+ \pi^0) \qquad \Xi_c'^+ (\to \Xi_c^+ \gamma) \pi^+$$

- 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

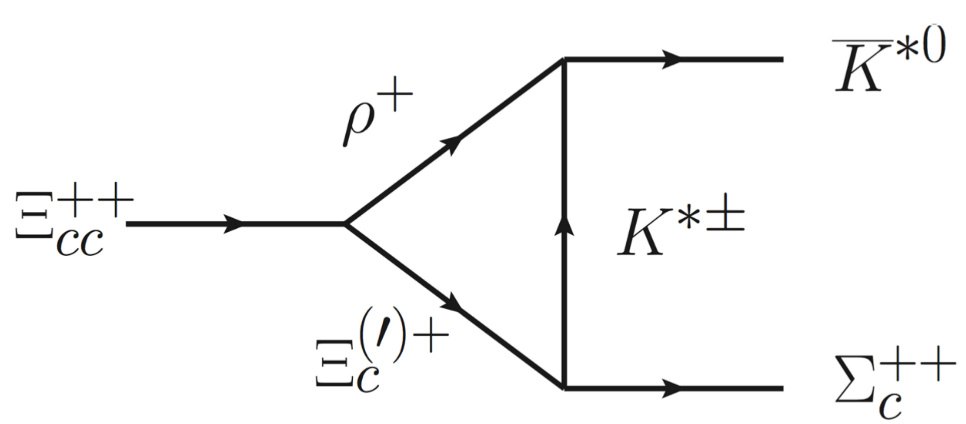
but predicted to be $(2.2 \pm 0.8)\%$

Long-distance contributions

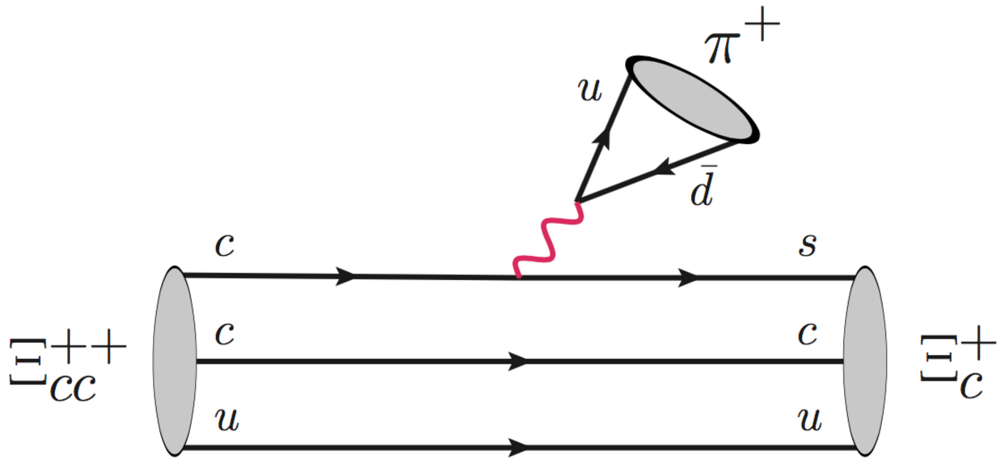
— final-state interacting (FSI) effects

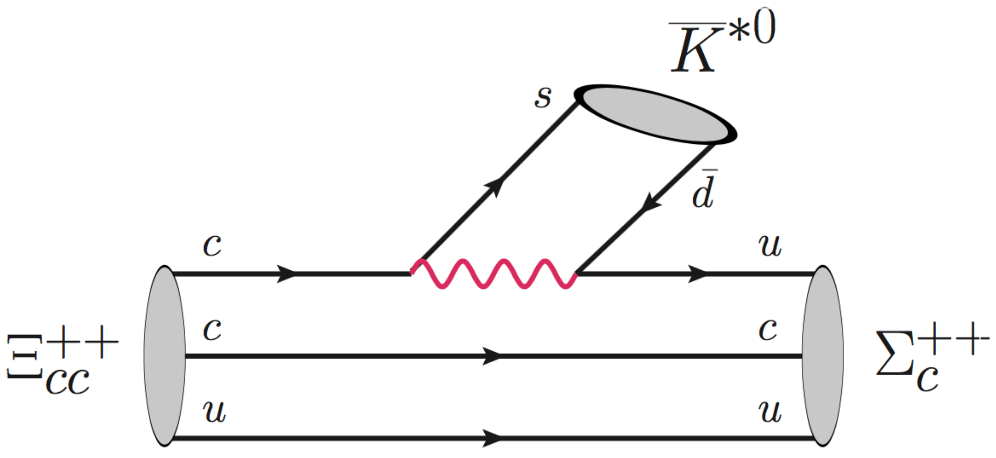
— significantly large in charm decays

- Calculate rescattering effects



Short-distance v.s. Long-distance Contributions





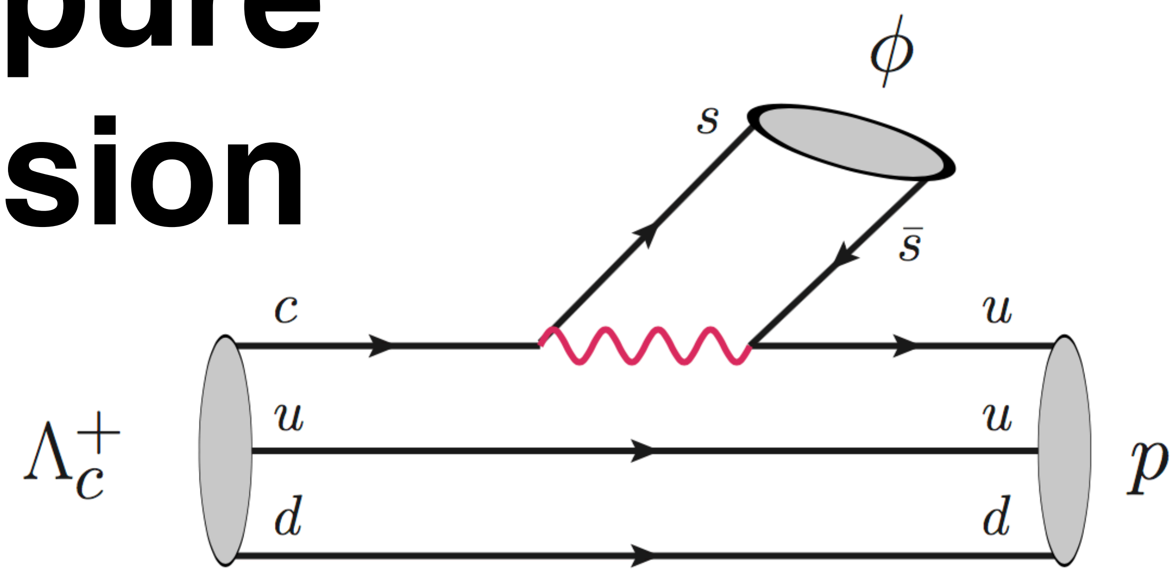
short-distance branching fractions

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

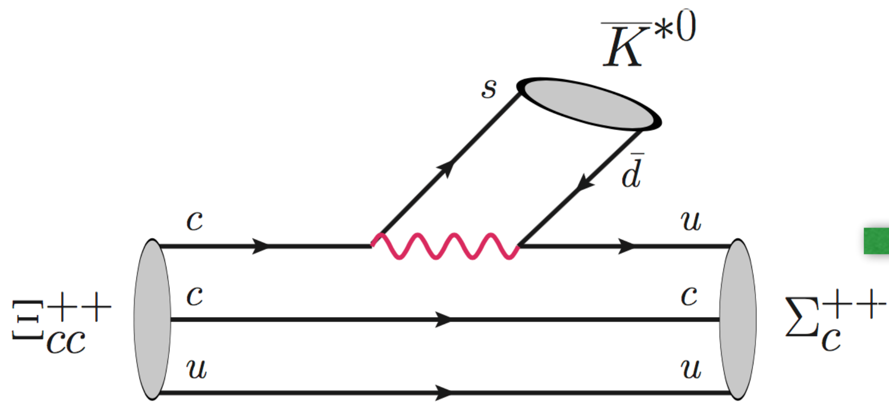
$|a_2^{eff}(\mu_c)|=0.7$

large-N_c limit

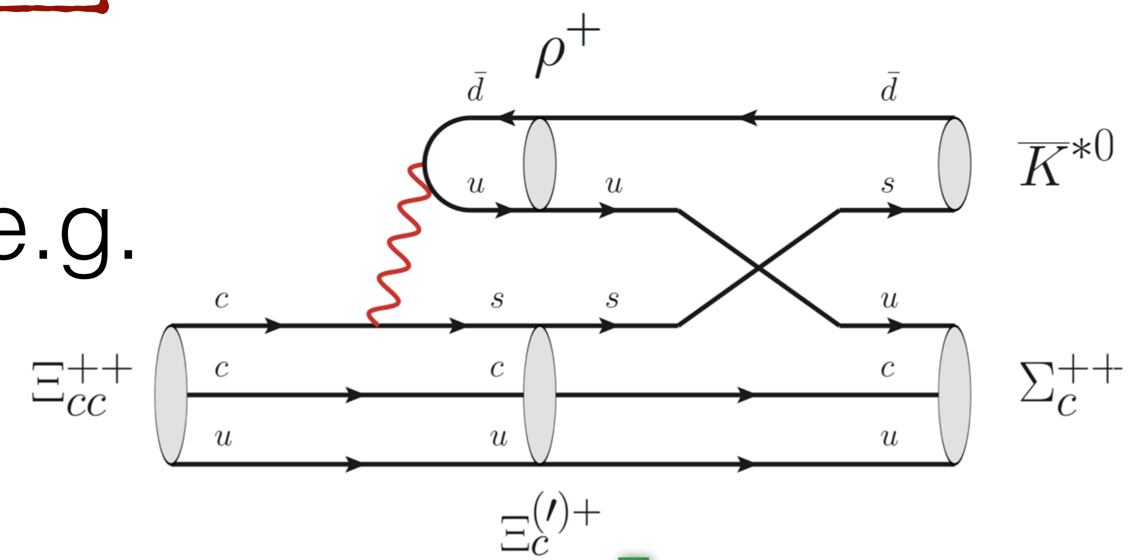
Understanding long-distance contributions is essential to find a best process

for the searches for doubly heavy baryons

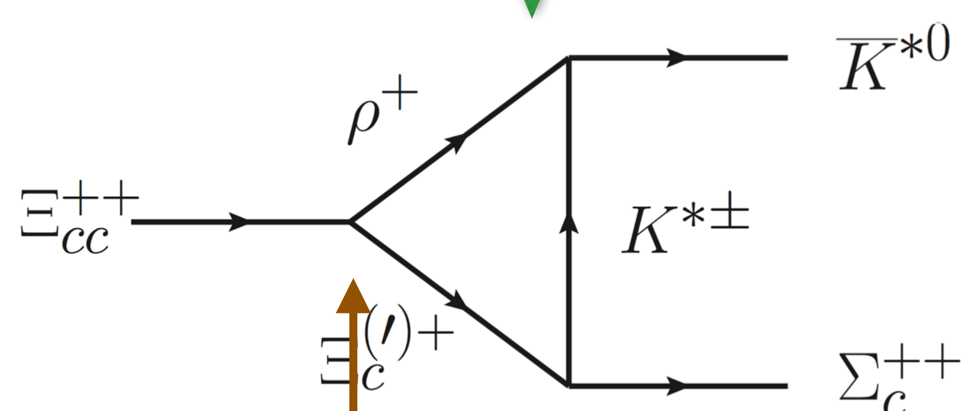
$$\Xi_{cc}^{++} \to \Sigma_c^{++} \overline{K}^{*0}$$



FSI e.g.



Rescattering mechanism of the final-state interacting effects



Absorptive part:

weak vertex

rescattering

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

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

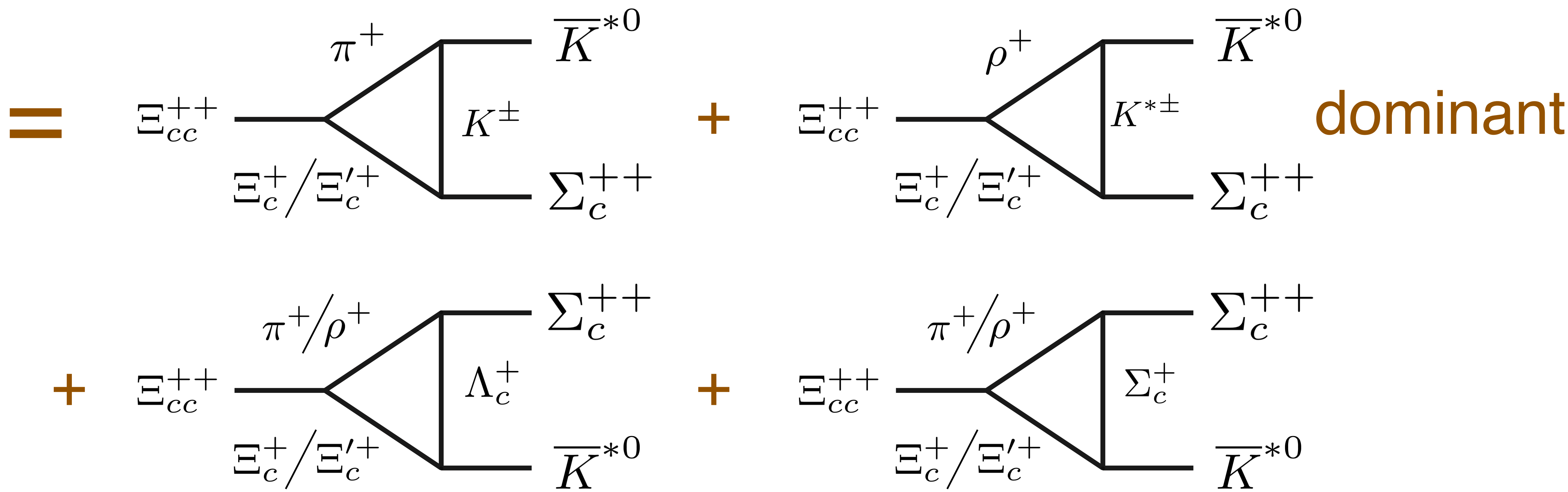
Relative Branching Fractions with long-distance contributions

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%

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



$$\eta = 1.0 \sim 2.0$$

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) = 3.4\%$$

$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \rho^+) = 6.3\%$$

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

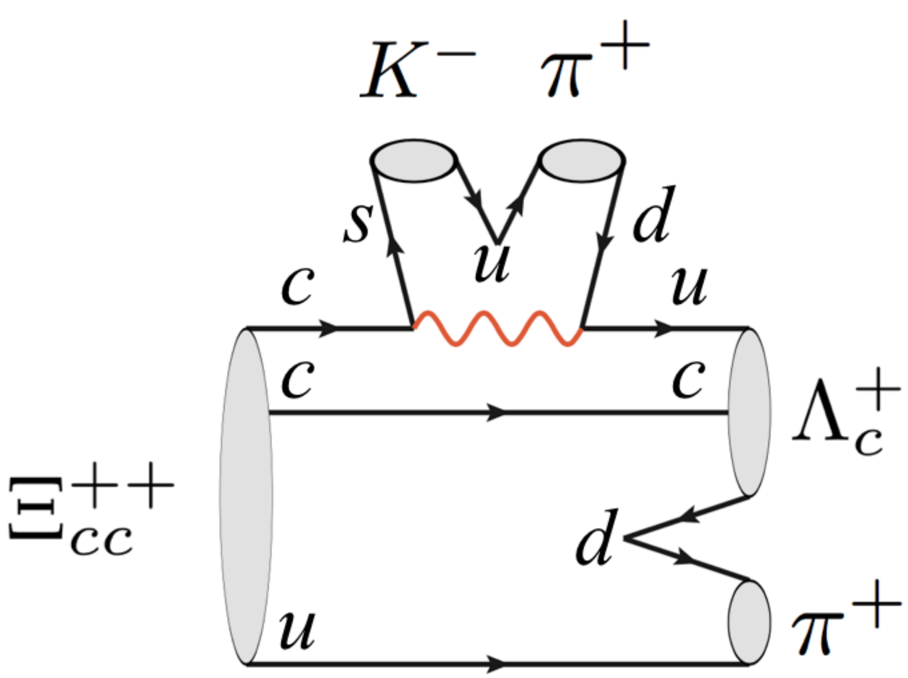
$$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c'^+ \rho^+) = 8.7\%$$

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

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

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

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

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ **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
	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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	$\Sigma_c^{++}(2455)K^-$	$(\mathcal{R}_\tau/0.3)\times 0.008$
	$\Xi_c^+\rho^0$	$(\mathcal{R}_\tau/0.3)\times 0.04$
	ΛD^+	$(\mathcal{R}_\tau/0.3)\times 0.004$
	pD^0	$(\mathcal{R}_\tau/0.3)\times 0.002$

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

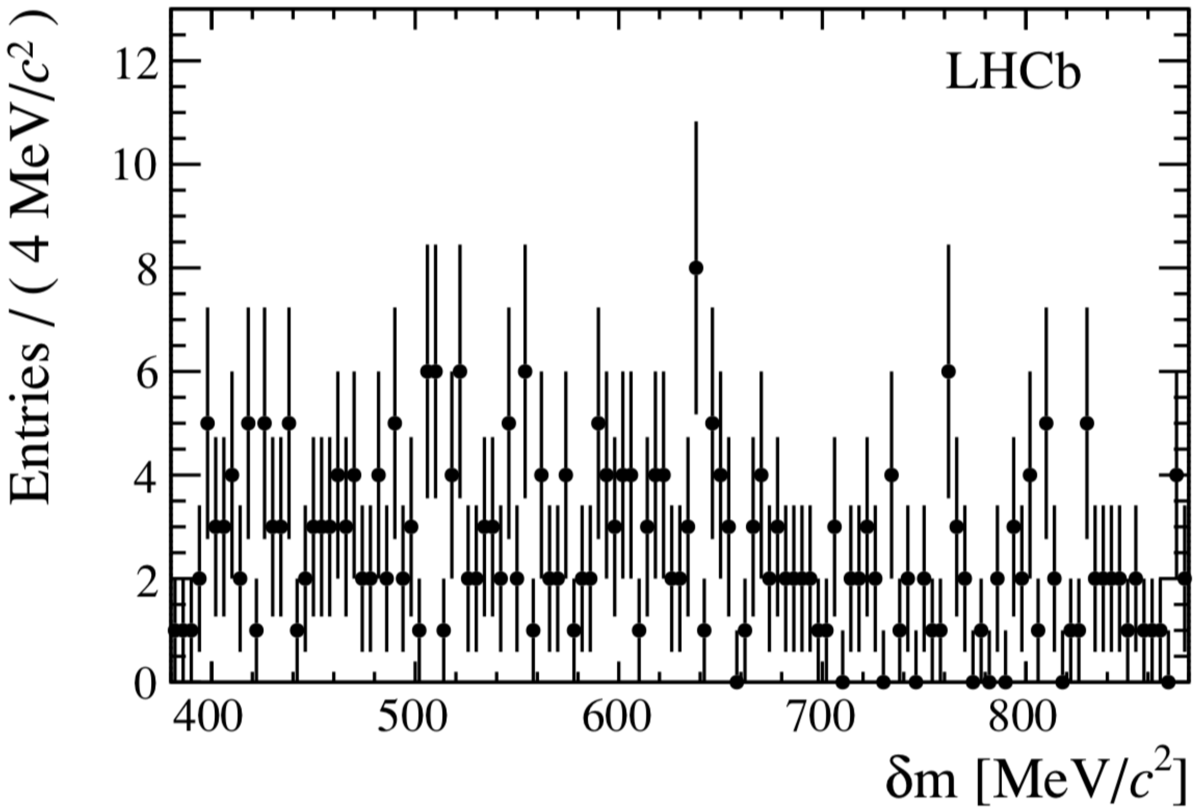
Λ is below *pK* threshold

$p D^+ K^-$

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

[FSY, *et al*, 1703.09086]

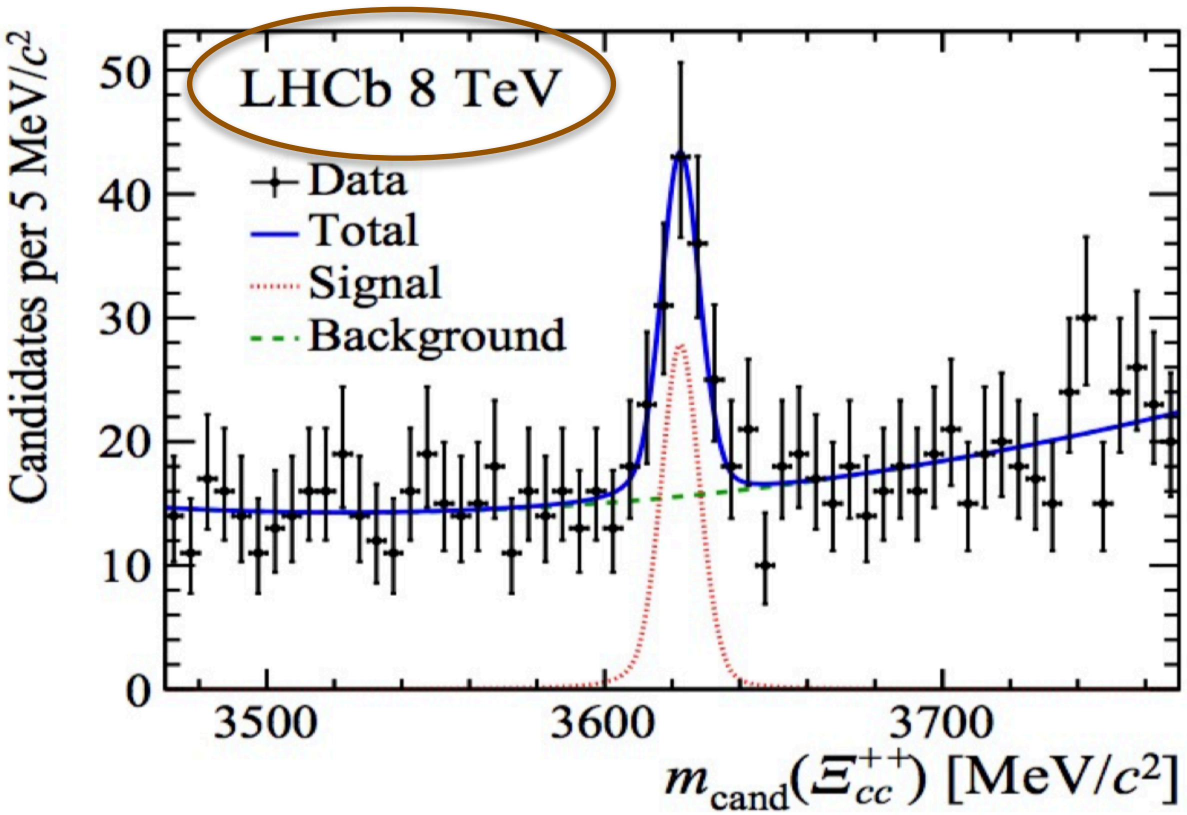
LHCb Run-I Data Analysis



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

No signal

[LHCb, JHEP 12 (2013)090]



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

Observation

LHCb talks

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

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 both processes!**
- Outlook: similar analysis to search for other particles.

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]
8. Weak decays of doubly heavy baryons: the 1/2 → 3/2 case
[arXiv:1805.10878]

Outlook

Prospect

- Study Ξ_{cc}^{++} in more channels?
- lifetime?
- Ξ_{cc}^{+}? $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+,\ pK^-\pi^+ D^0$
- $J^P = 1/2^+$?
- Semi-leptonic decay modes?
- CP Violation?
- …

A long long list…

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

Thank you !

Effective Lagrangian

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

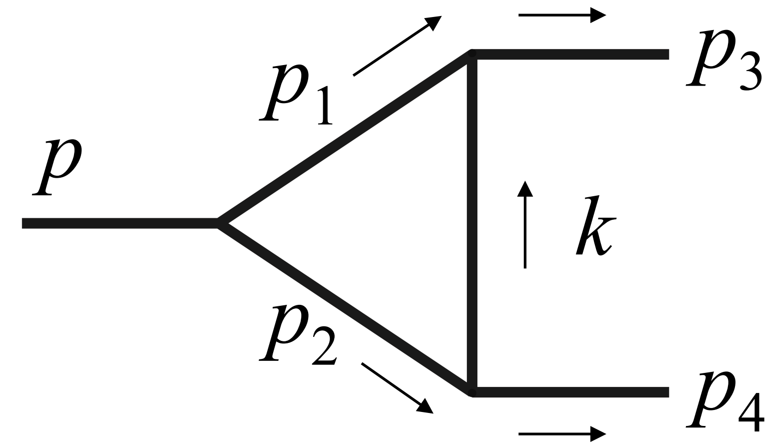
Hadronic coupling constants are related under the flavor SU(3) symmetry and the chiral and heavy quark symmetries

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



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

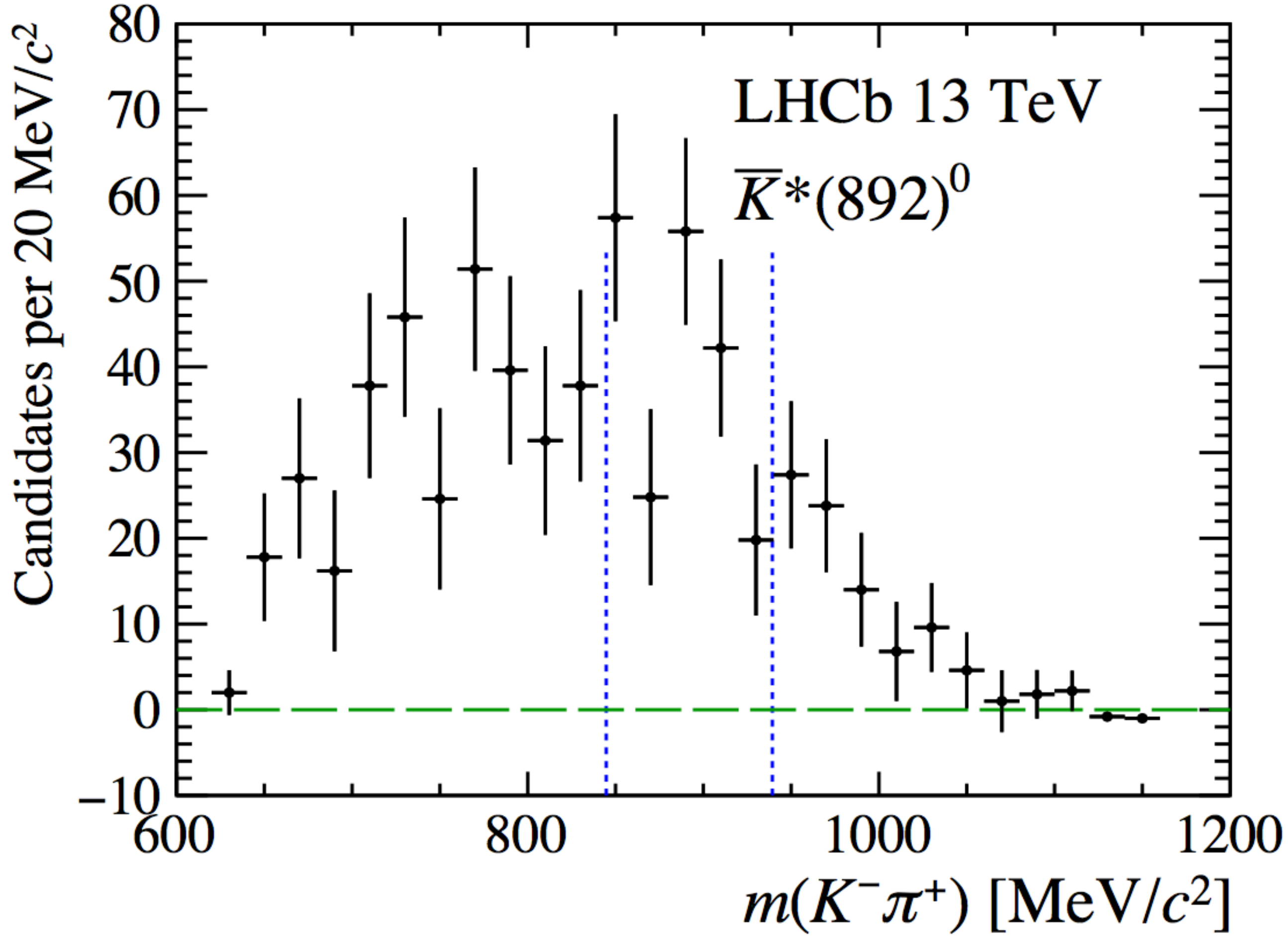
$$\Lambda = m_{\rm exc} + \eta\Lambda_{\rm QCD}$$

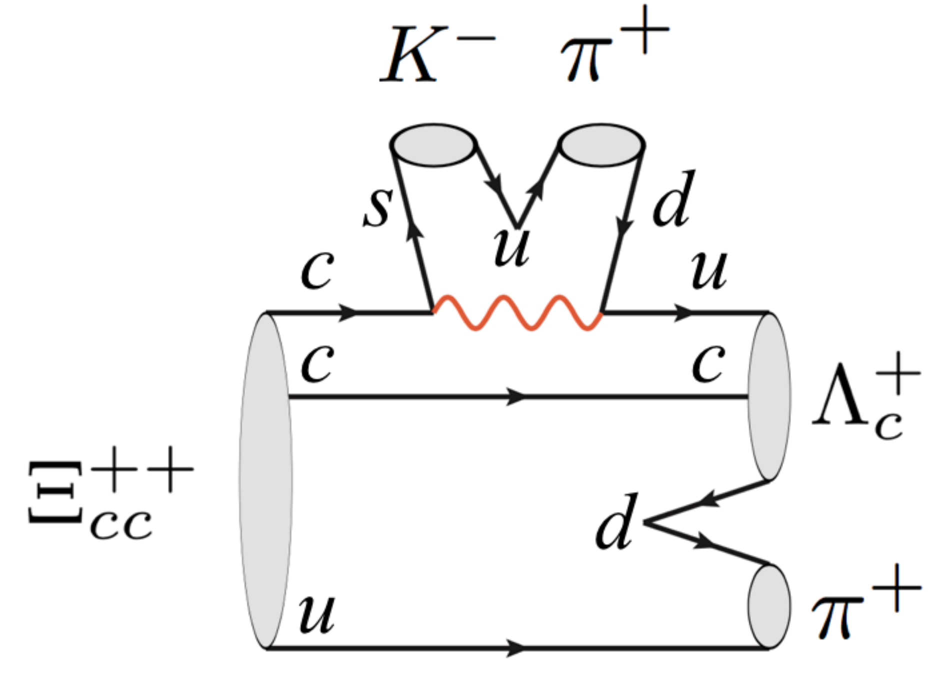
[Cheng, Chua, Soni, PRD 71, 014030 (2005)]

Results are very sensitive to the value of η

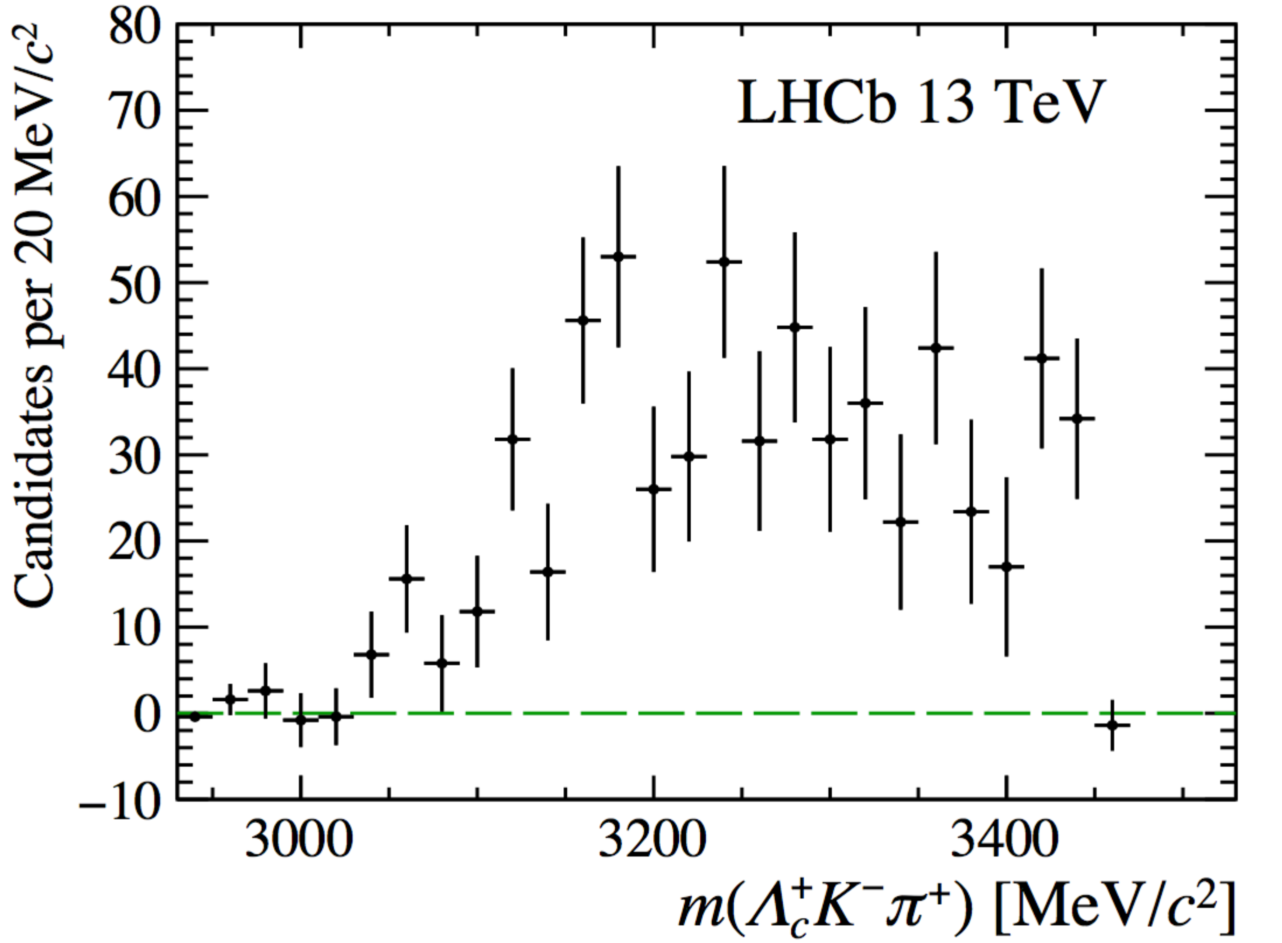
No first-principle calculations for η

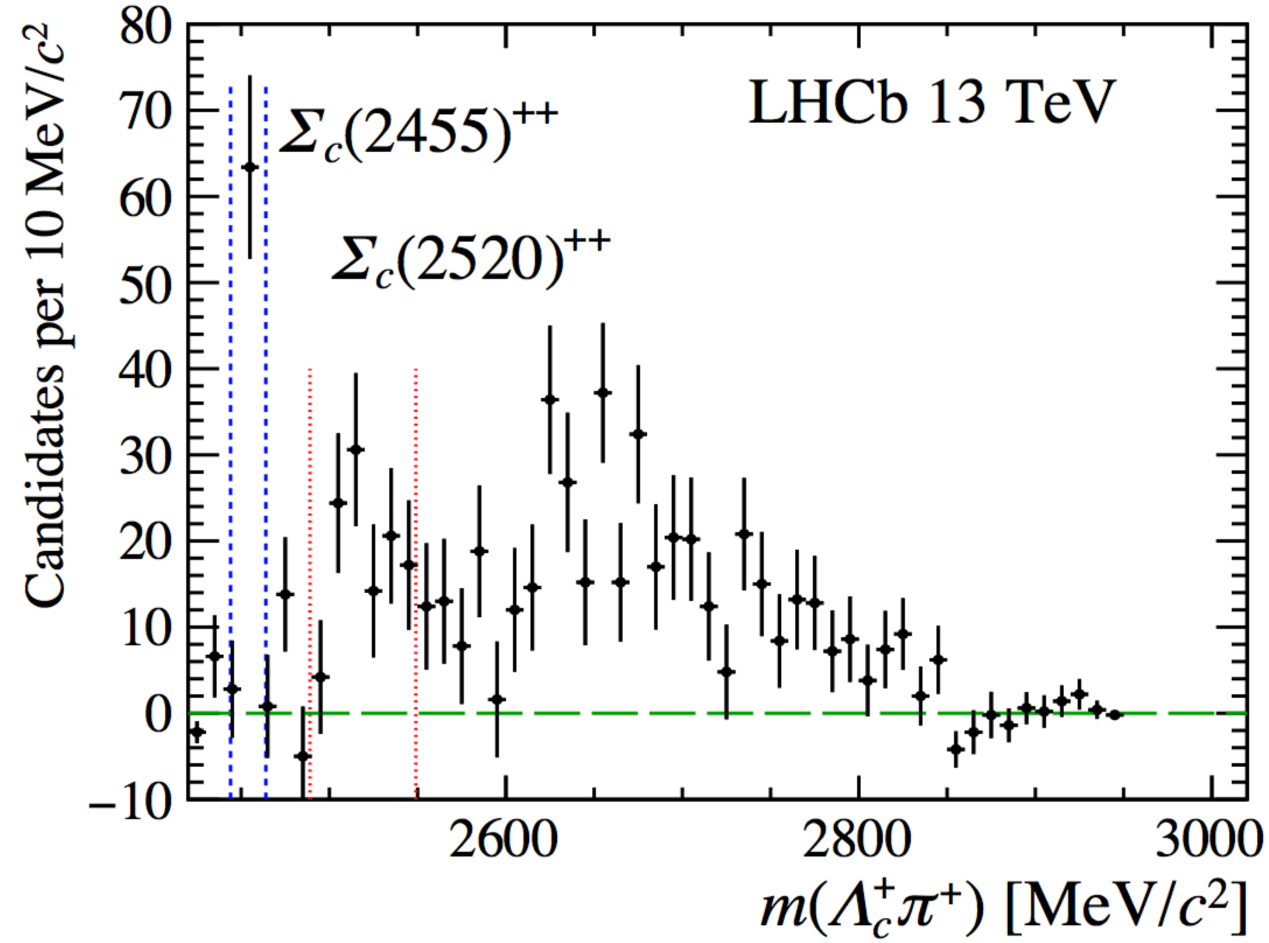
We take η from 1.0 to 2.0





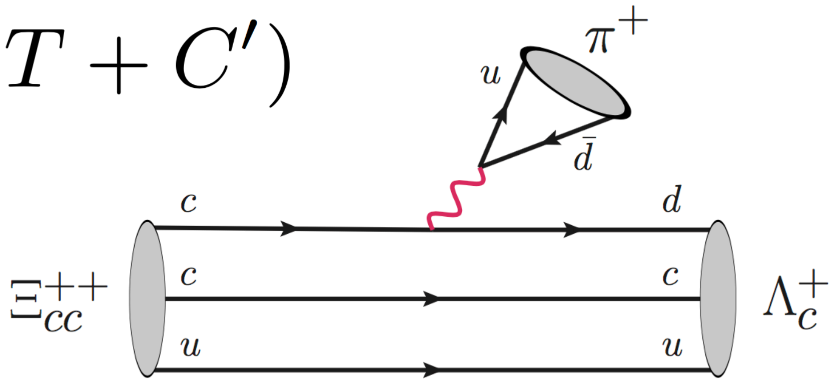
Resonances dominated

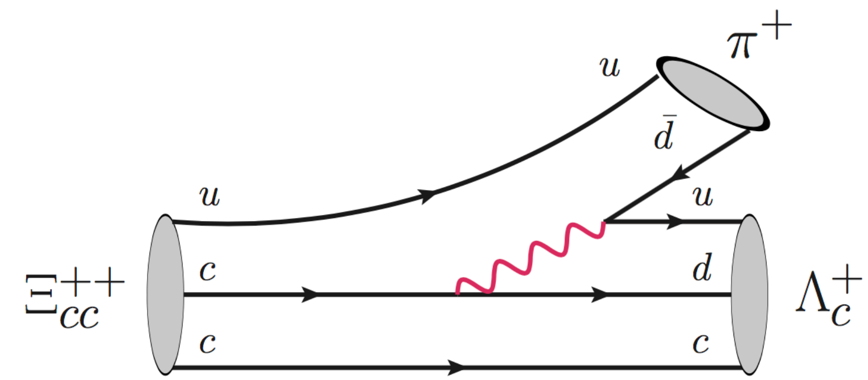


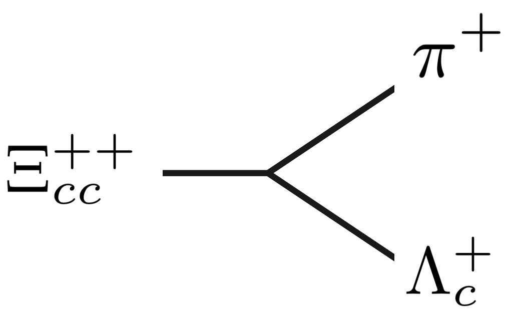


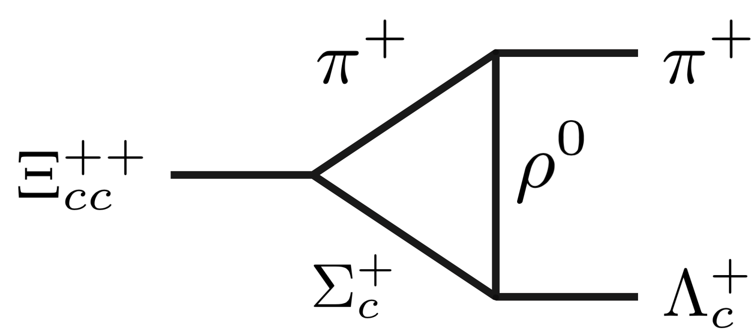
$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$

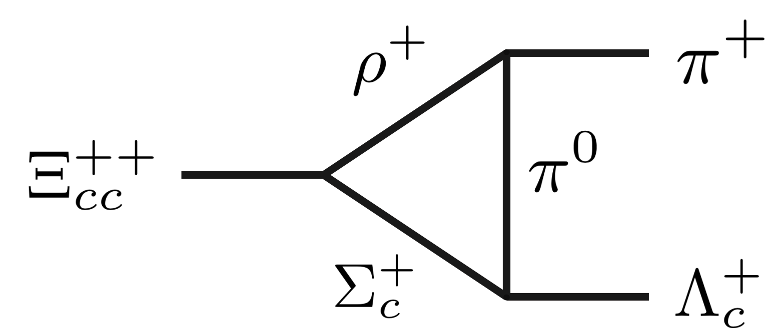
$V_{cd}^* V_{ud}(T + C')$

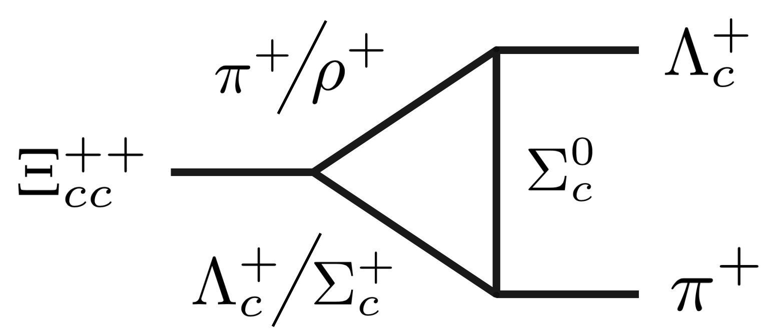
$=$ 

$+$ 

$=$ 

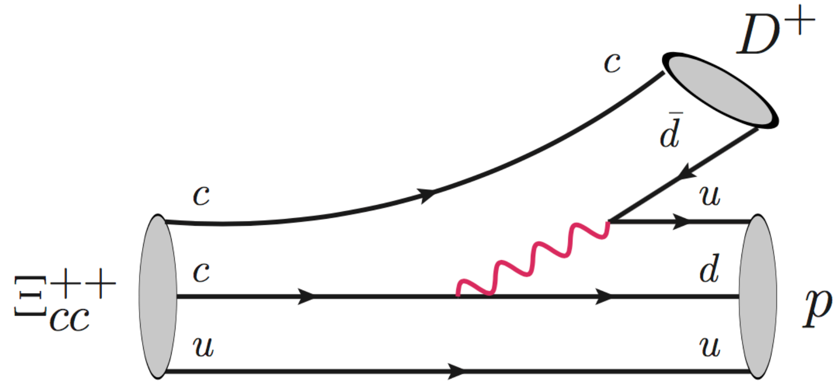
$+$ 

$+$ 

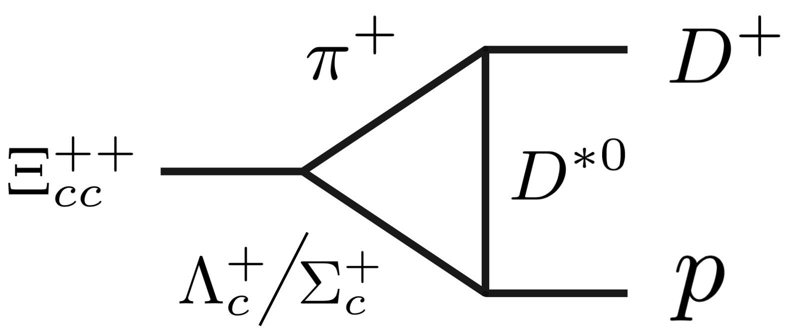
$+$ 

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

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



$=$



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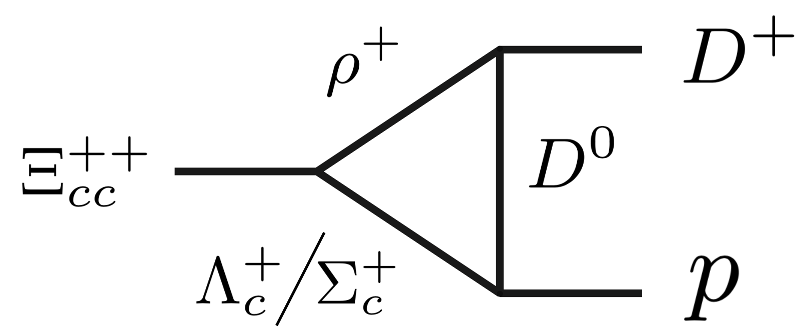

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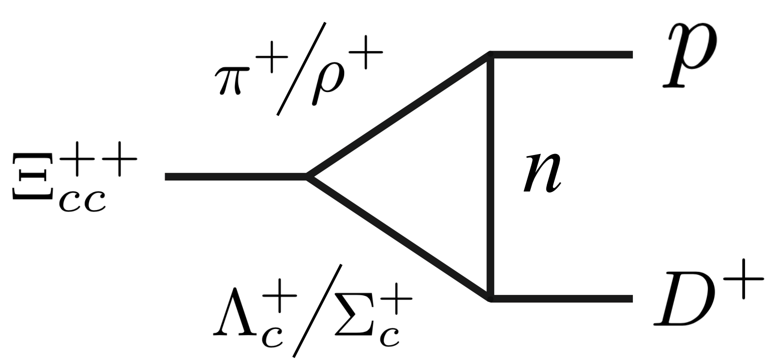
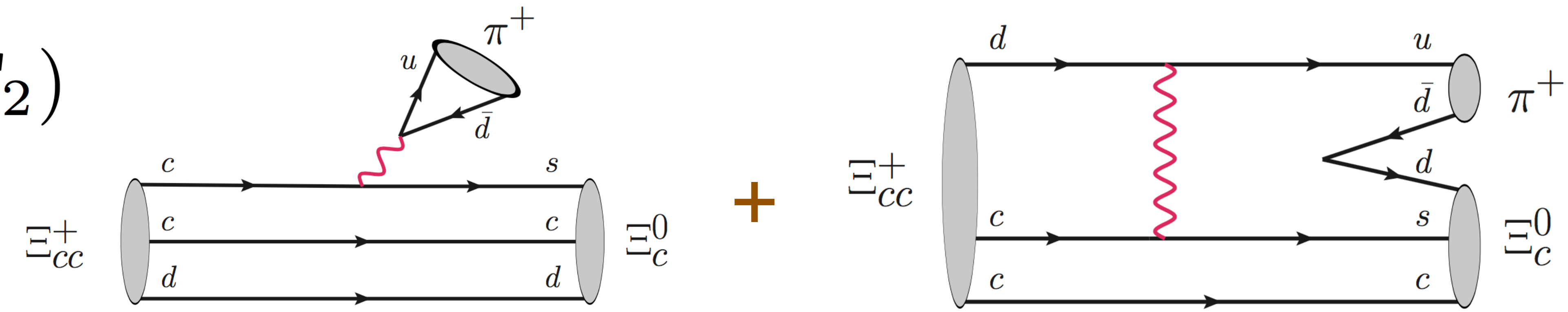


$\Xi_{cc}^{+} \to \Xi_c^0 \pi^+$

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

=



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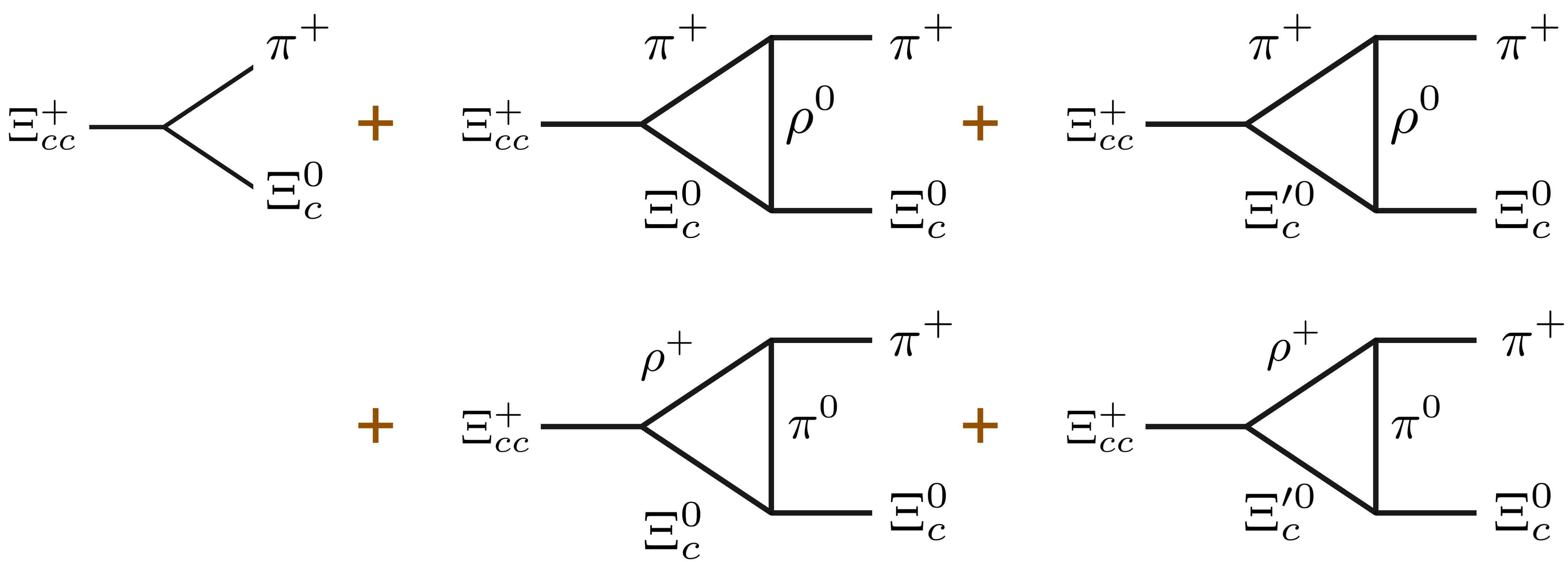
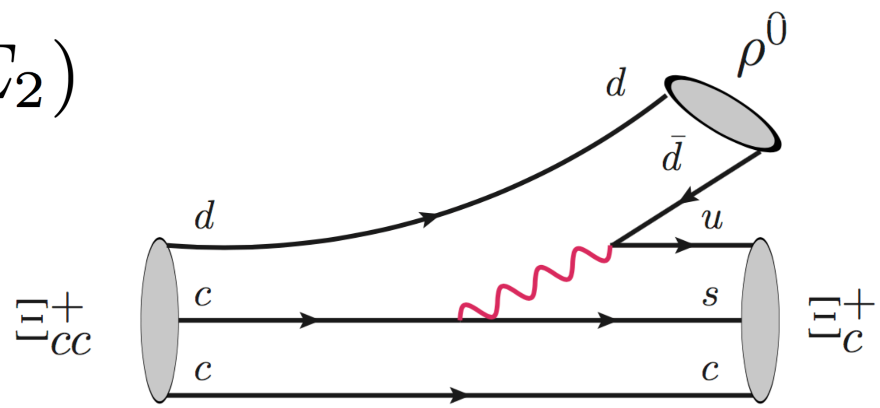


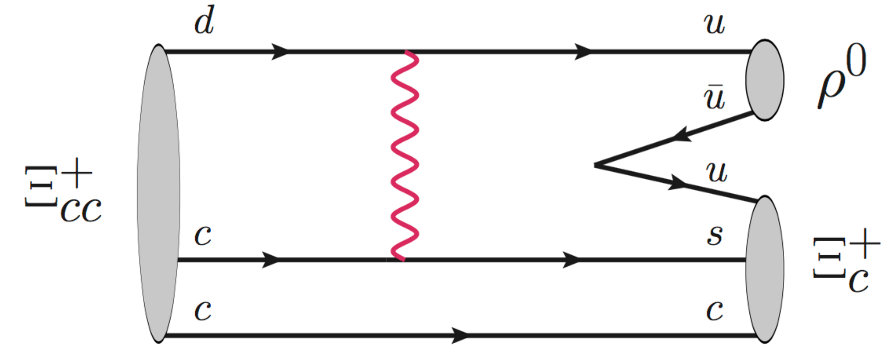
$$\Xi_{cc}^{+} \to \Xi_c^{+} \rho^0 \to \Xi_c^{+} \pi^{+} \pi^{-}$$

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

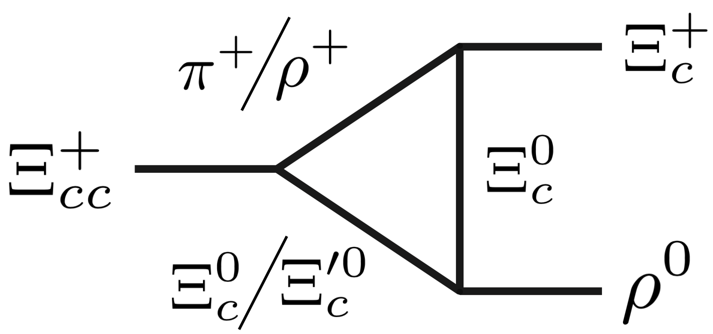
$=$



$-$



$=$



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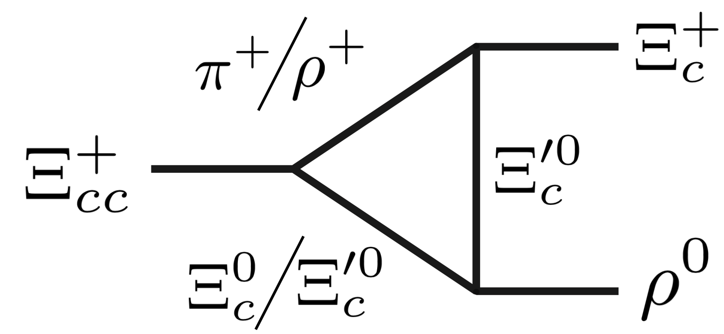
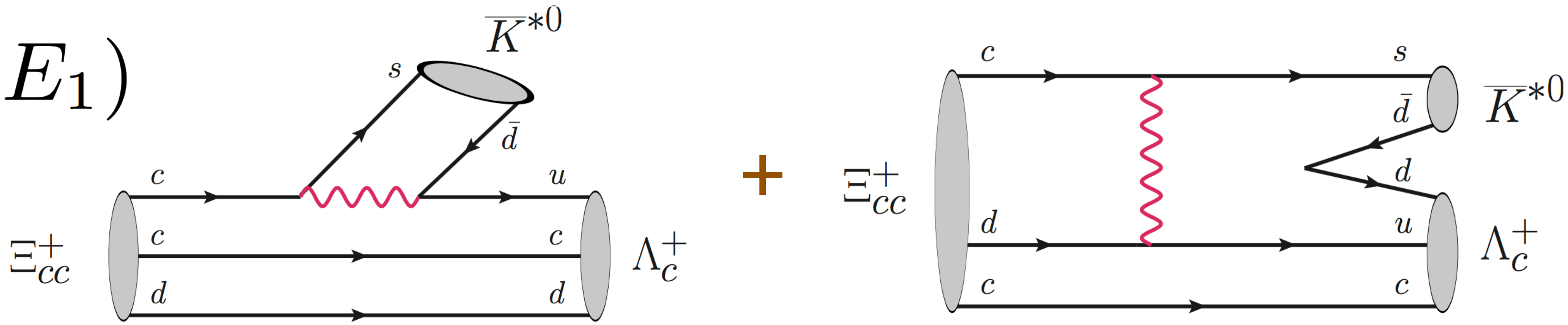


$$\Xi_{cc}^{+} \to \Lambda_c^{+} \overline{K}^{*0} \to \Lambda_c^{+} K^{-} \pi^{+}$$

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

=



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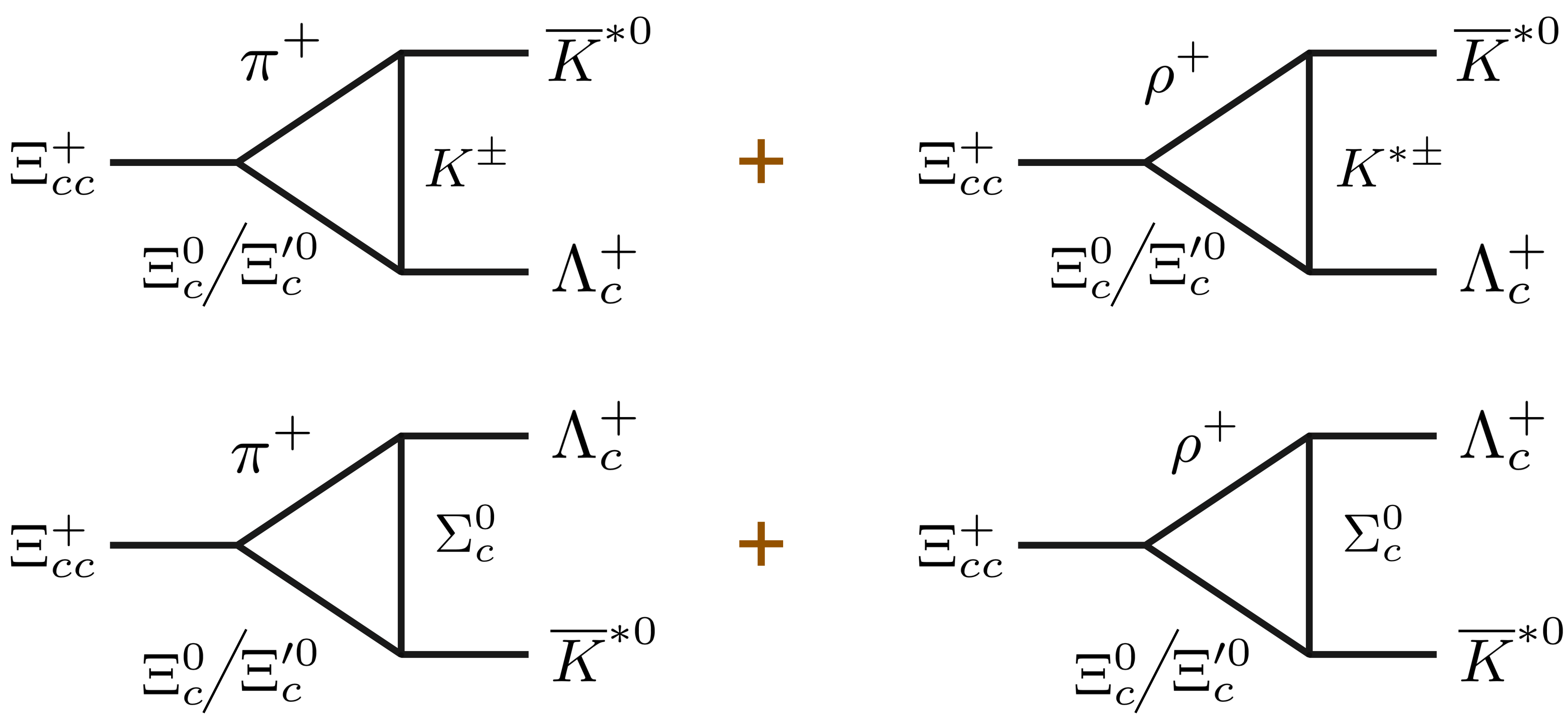
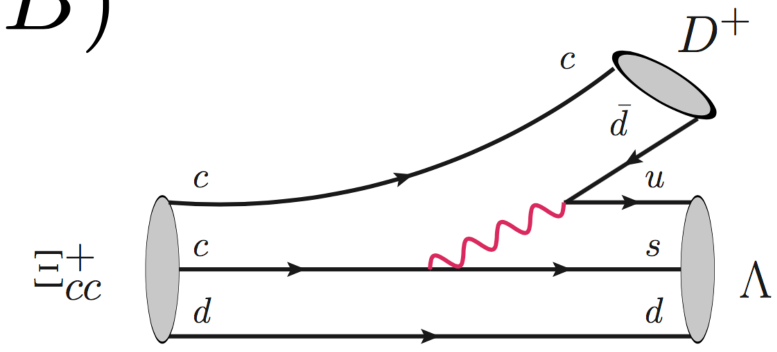
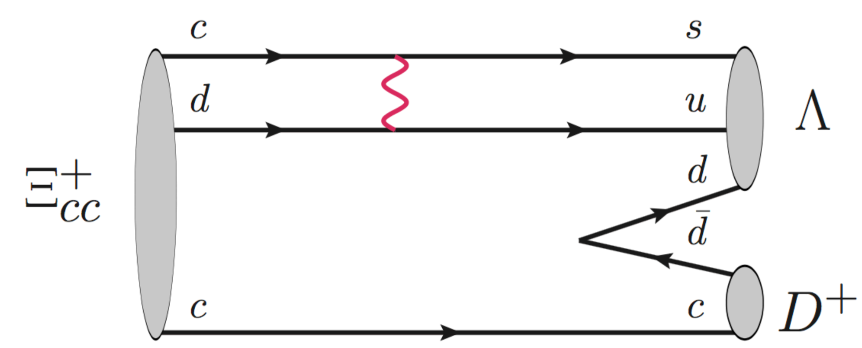
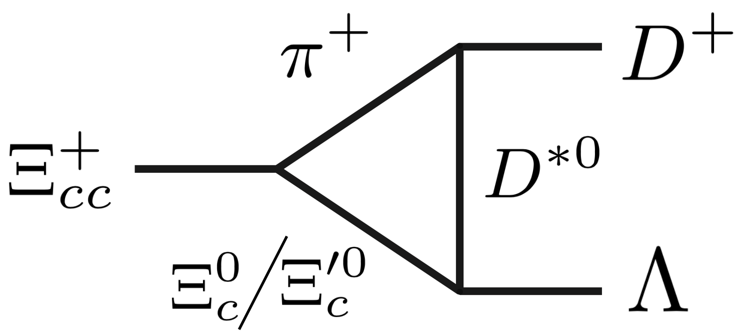


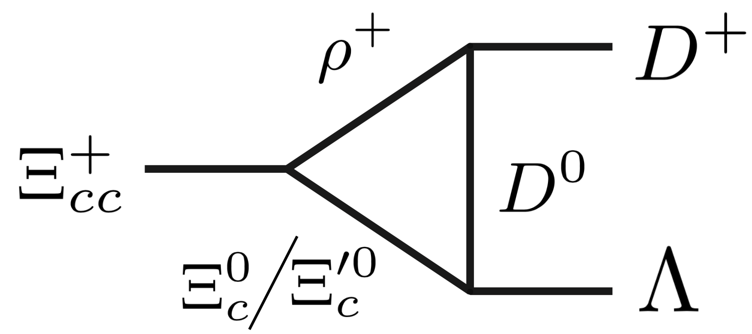
$$\Xi_{cc}^{+} \to \Lambda^0 D^+$$

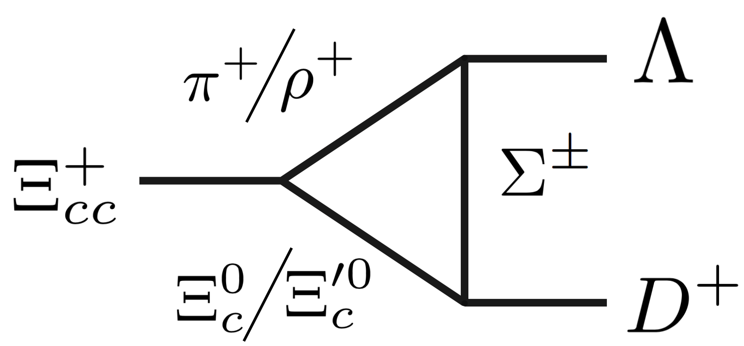
$V_{cs}^* V_{ud}(C' + B)$

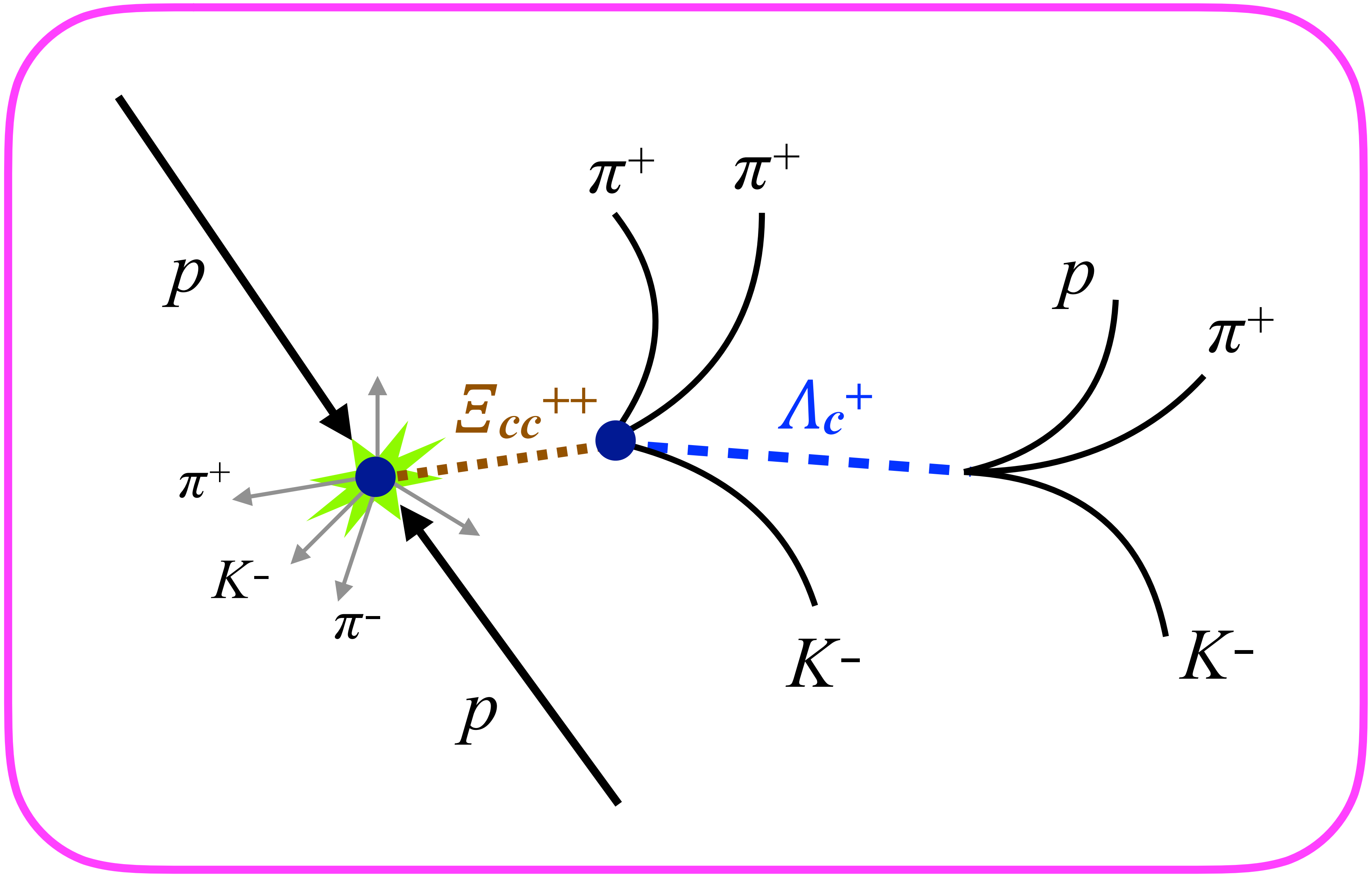
$=$ 

$+$ 

$=$ 

$+$ 

$+$ 



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)]