

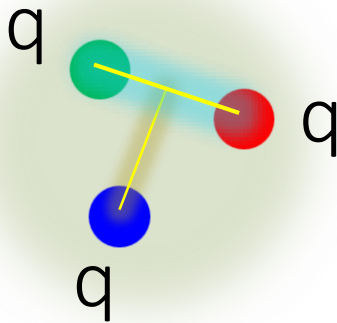
# Study of Charmed Baryons at Belle

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# Physics of charmed baryons - di-quark picture

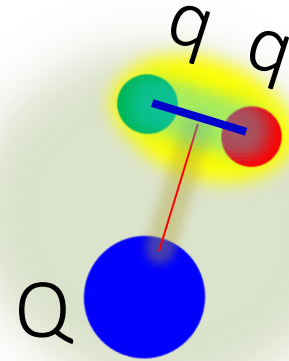
Interaction between quarks : **di-quark** correlations



→ Nucleon / Strange baryons

$m_u, m_d \approx m_s \rightarrow (qqq)$  uniform

Every pair can not be distinguished.



→ Charmed baryon

$m_u, m_d \ll m_c \rightarrow$  **di-quark + c-quark**  
**(qq) (Q)**

di-quark correlation is enhanced by  
weak Color Magnetic Interaction with  
a heavy quark

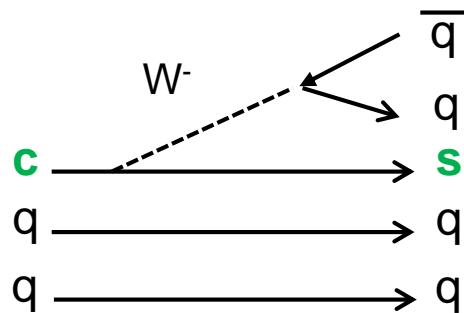
di-quark as new degree of freedom.  
- Easier to understand baryons.

# Physics of charmed baryons

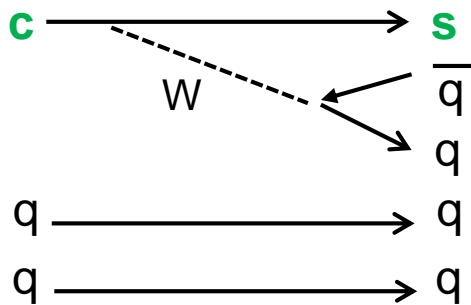
## -weak decay process

- **Weak decay of charmed baryon** is not well understood.

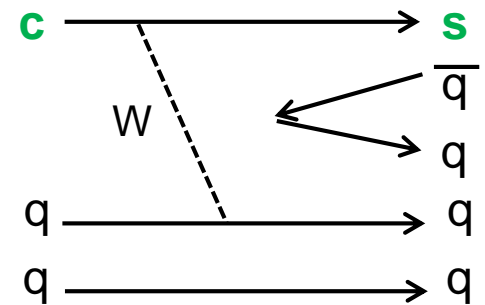
- Three diagrams contribute, strength of each is not known.



Spectator



Internal W



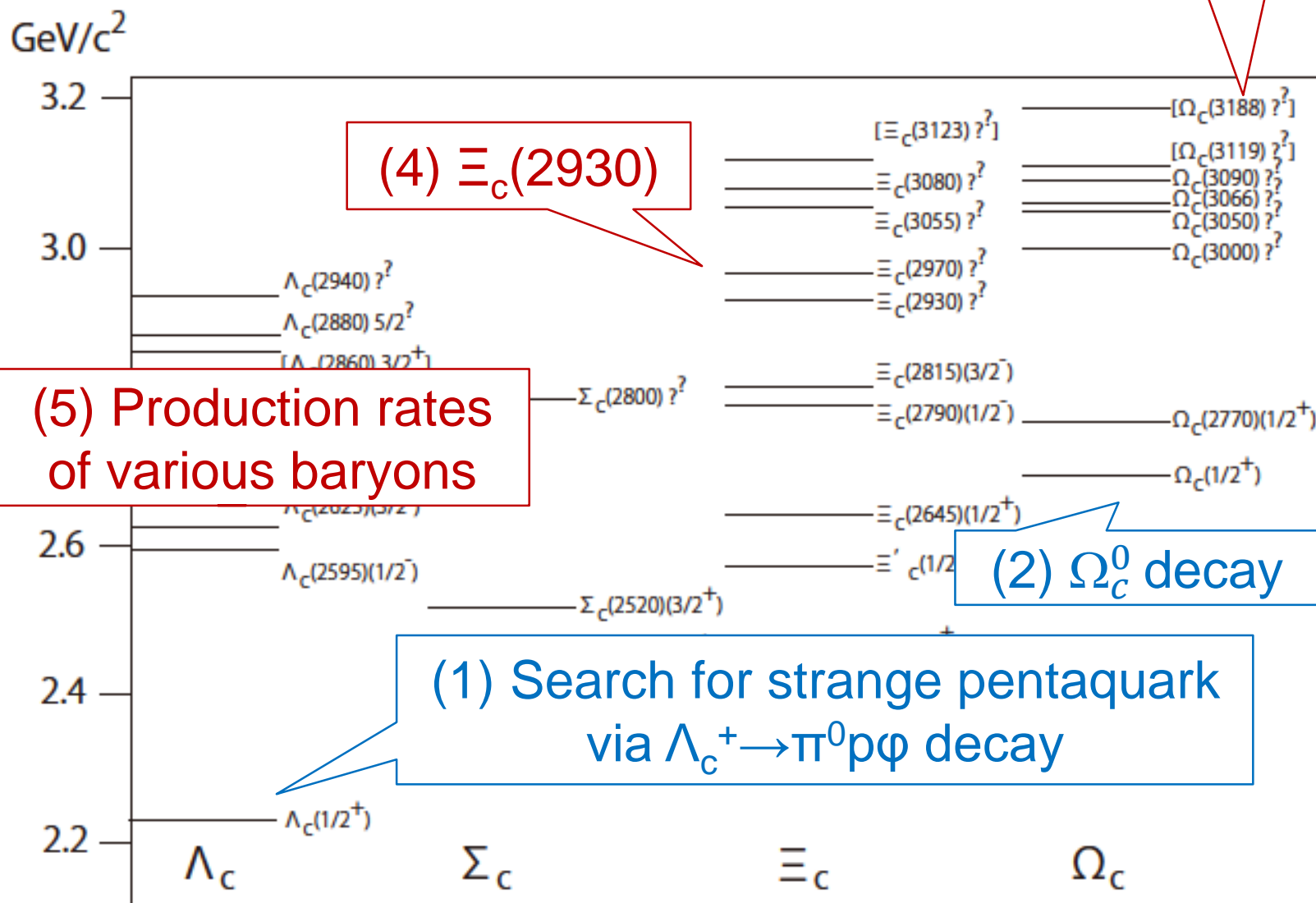
W-exchange

- **Laboratory of strange baryons** as decay proceed via  $c \rightarrow s$  transition.
  - intermediate states in decays of charmed baryons
- **Belle has  $e^+e^-$  data collected with  $\sim 1 \text{ ab}^{-1}$  luminosity** (mainly at  $Y(4S)$ ).
  - $10^9 \text{ } e^+e^- \rightarrow c\bar{c}$  samples
  - $7.7 \times 10^8 \text{ BB}$  samples

**Huge data enable to study many charmed baryons  
in various production/decay processes.**

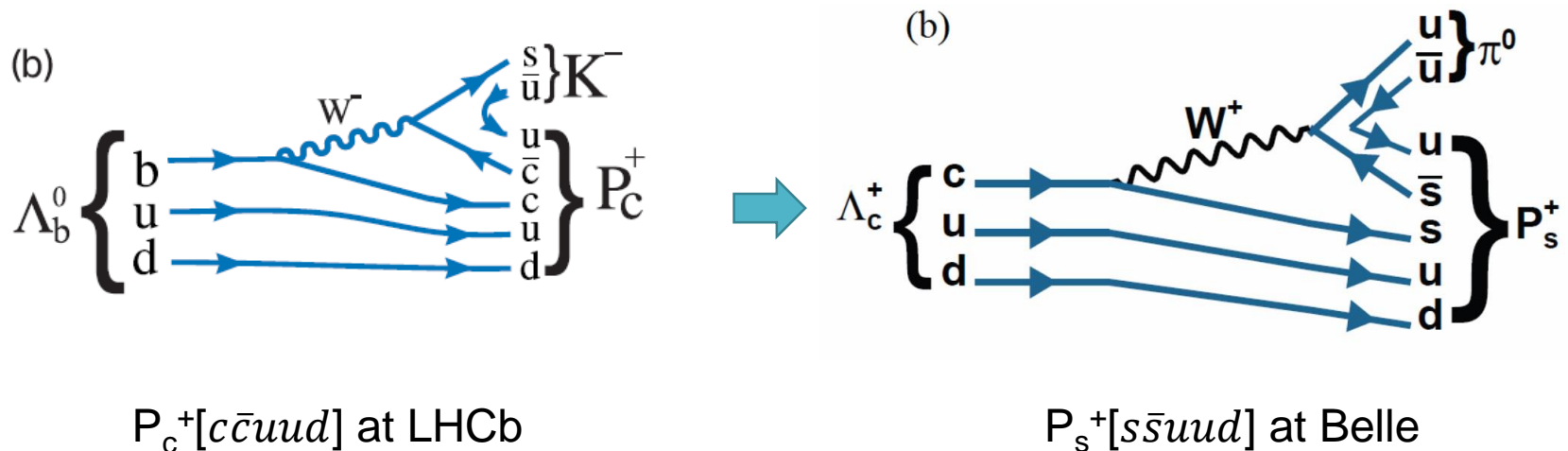
# Contents

(3) Excited  $\Omega_c^{*0}$

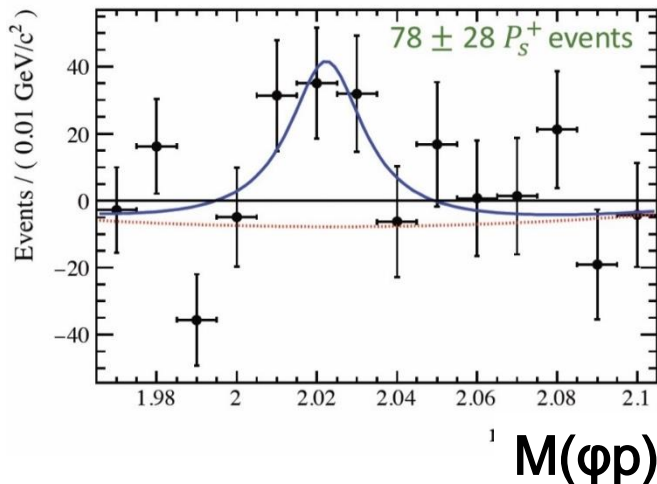
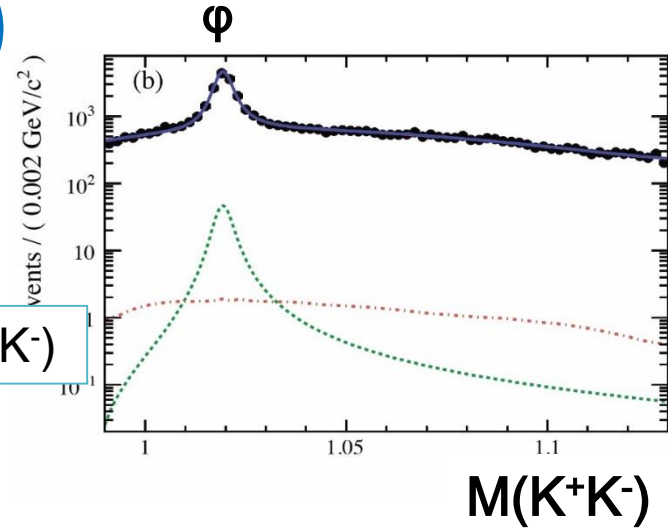
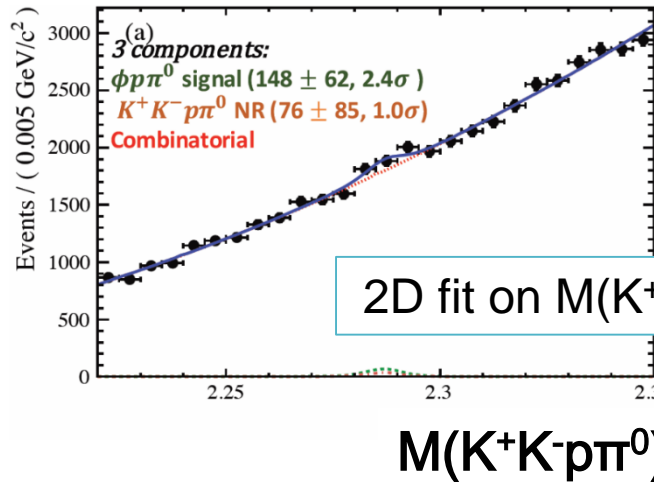


# Pentaquark search via $\Lambda_c^+ \rightarrow \pi^0 \phi p$

- Hidden charm pentaquark state [ $c\bar{c}uud$ ] at LHCb  
in  $\Lambda_b^0 \rightarrow K^- P_c^+ \rightarrow K^- (J/\psi p)$ .
- Search for hidden-strangeness pentaquark [ $s\bar{s}uud$ ] at Belle  
in  $\Lambda_c^+ \rightarrow \pi^0 P_s^+ \rightarrow \pi^0 (\phi p)$   
switching  $b \rightarrow c$  ( $\Lambda_b^0 \rightarrow \Lambda_c^+$ ),  $c \rightarrow s$  ( $J/\psi \rightarrow \phi$ )



# Pentaquark search via $\Lambda_c^+ \rightarrow \pi^0 \phi p$ (result)



● No significant  $\Lambda_c^+$  signals is observed so far.

New upper limits:

- $\text{Br}(\Lambda_c^+ \rightarrow \phi p \pi^0) < 15.3 \times 10^{-5}$
- $\text{Br}(\Lambda_c^+ \rightarrow K^+K^-\pi^0)_{\text{NR}} < 6.3 \times 10^{-5}$

● No significant  $P_s^+$  signal observed in  $M(\phi p)$

- $\text{Br}(\Lambda_c^+ \rightarrow \pi^0 P_s^+) \times \text{Br}(P_s^+ \rightarrow \phi p) < 8.3 \times 10^{-5}$
- $\text{Br}(\Lambda_b^+ \rightarrow \pi^0 P_c^+) \times \text{Br}(P_c^+ \rightarrow J/\psi p) = 1.3 \times 10^{-5}$

From LHCb Phys. Rev. Lett. 115, 072001

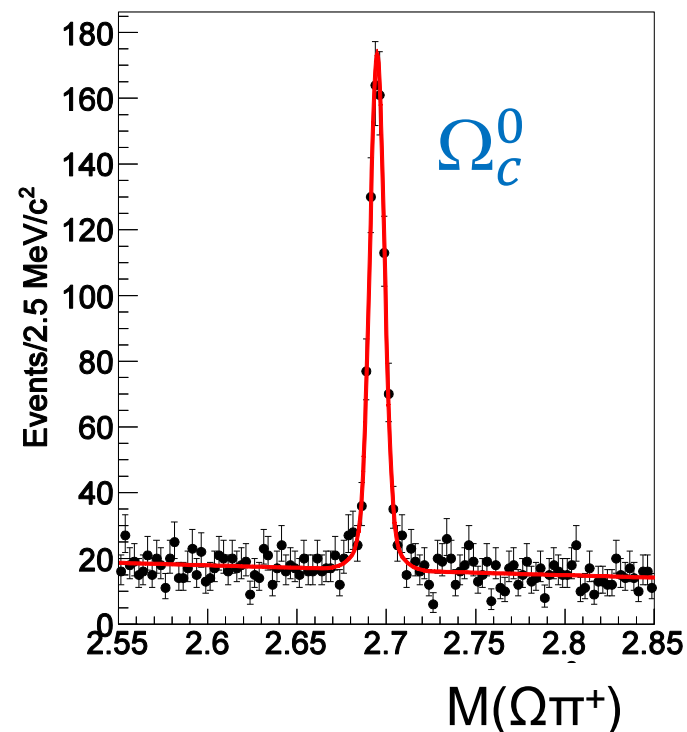
# Hadronic decays of $\Omega_c^0$ *g.s.*

- Among 4 ground state charmed baryons ( $\Lambda_c^+$ ,  $\Xi_c^0$ ,  $\Xi_c^+$ ,  $\Omega_c^0$ ),  
 -  $\Omega_c^0$  (css) is not studied well. [cud] [csd] [csu] [css]  
 - Only  $\Omega_c^0$  has the same flavor light quarks (ss). Spectator[ss] in weak decay  
 - Constructive interference is thought to be the origin of its short life time.

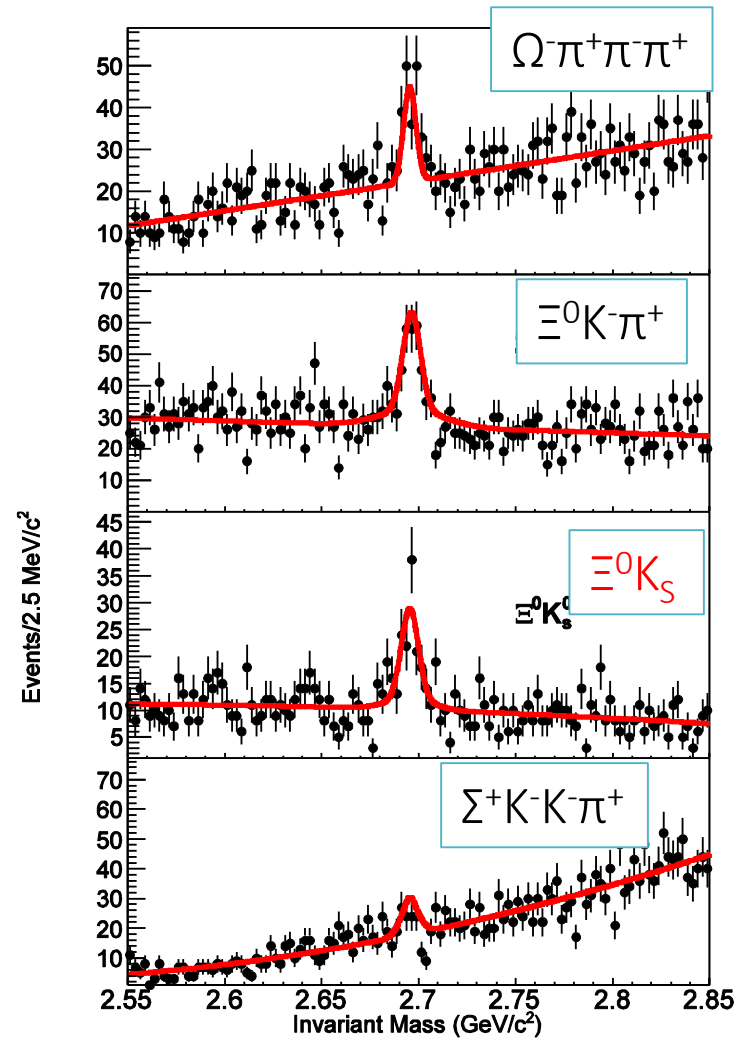
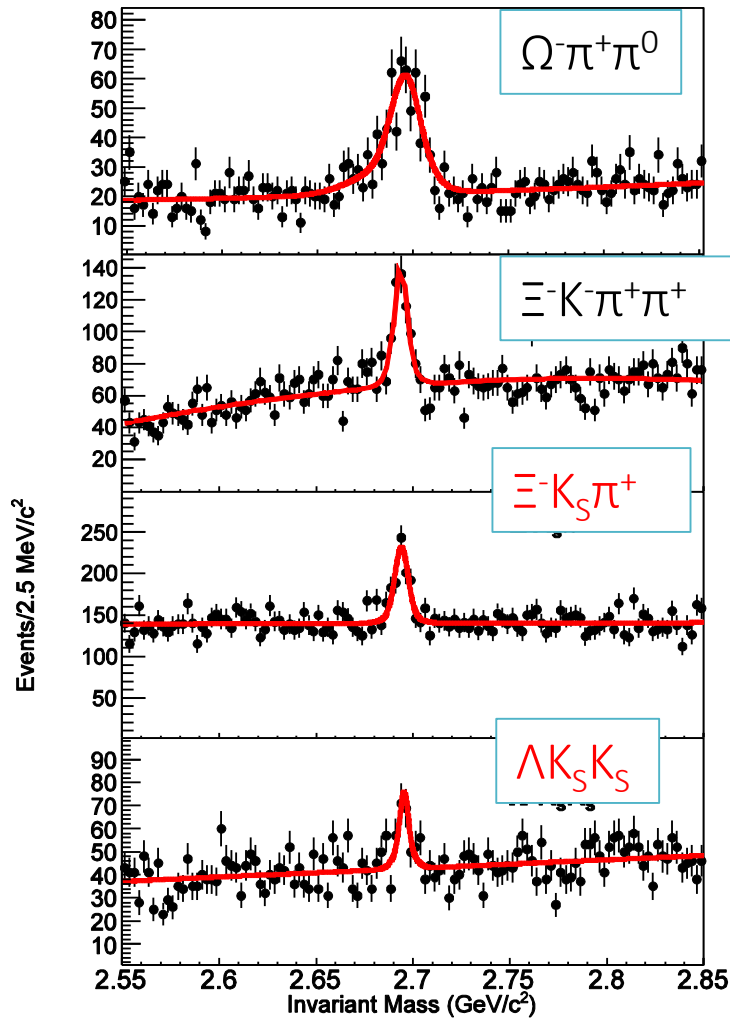
**Life time (ps)**

$\Lambda_c^+(\text{udc})$	$\Xi_c^0(\text{dsc})$	$\Xi_c^+(\text{usc})$	$\Omega_c(\text{ssc})$
$200 \pm 6$	$112^{+13}_{-10}$	$442 \pm 26$	$69 \pm 12$

- Precise measurements will shed light on the dynamics of baryon weak decays.
- Belle performed measurements of 8 decay modes relative to the bench mark mode:  $\Omega_c^- \pi^+$



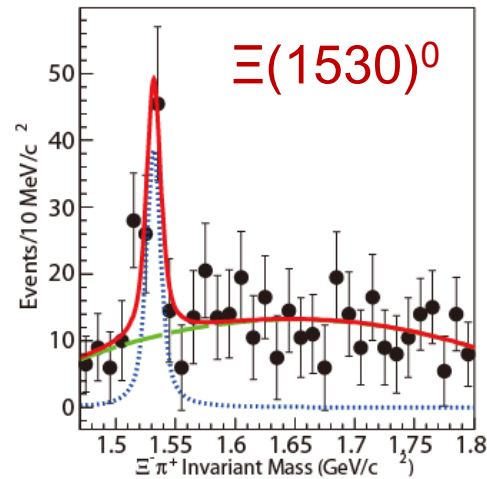
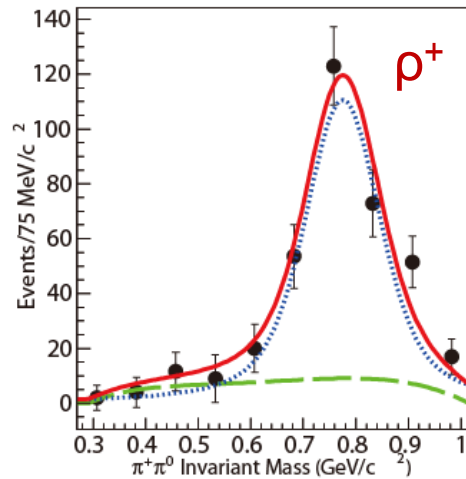
# Mass distributions for 8 decay modes





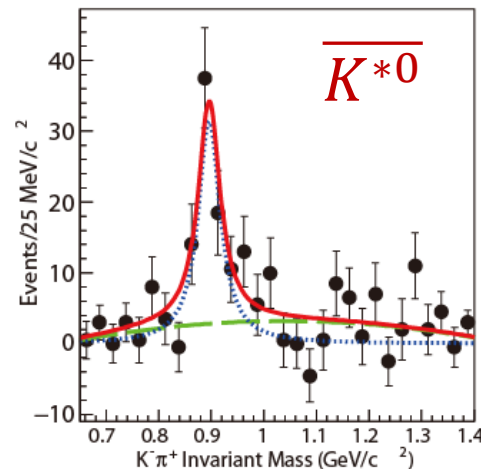
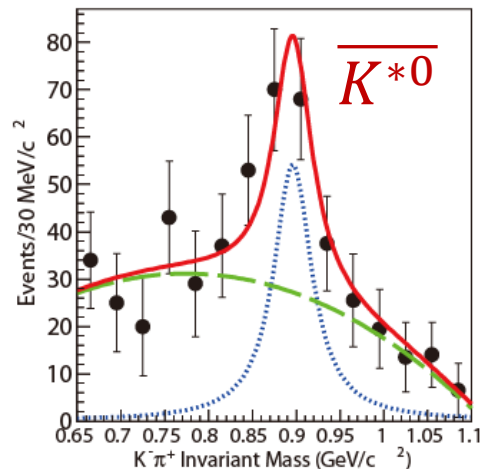
# Intermediate states

$$\Omega^- \rho^+ \rightarrow \Omega^- \pi^+ \pi^0$$



$$\Xi(1530)^0 K^- \pi^+ \rightarrow \Xi^- \pi^+ K^- \pi^+$$

$$\Xi^- \pi^+ \overline{K^{*0}} \rightarrow \Xi^- \pi^+ K^- \pi^+$$



$$\Xi^0 \overline{K^{*0}} \rightarrow \Xi^0 \pi^+ K^-$$

Intermediate resonances are studied for the first time in 3 decays.

# Results of the branching fraction

Mode	Branching ratio with respect to $\Omega^- \pi^+$	Substructure	Previous measurement
$\Omega^- \pi^+$	1		
$\Omega^- \pi^+ \pi^0$	$2.00 \pm 0.17 \pm 0.11$	$> 71\%$	$1.27 \pm 0.3 \pm 0.11$ [4]
$\Omega^- \rho^+$			
$\Omega^- \pi^+ \pi^- \pi^+$	$0.32 \pm 0.05 \pm 0.02$		$0.28 \pm 0.09 \pm 0.01$ [4]
$\Xi^- K^- \pi^+ \pi^+$	$0.68 \pm 0.07 \pm 0.03$		$0.46 \pm 0.13 \pm 0.03$ [4]
$\Xi^0(1530) K^- \pi^+$		$(33 \pm 9)\%$	
$\Xi^- \bar{K}^{*0} \pi^+$		$(55 \pm 16)\%$	
$\Xi^0 K^- \pi^+$	$1.20 \pm 0.16 \pm 0.08$		$4.0 \pm 2.5 \pm 0.4$ [2]
$\Xi^0 \bar{K}^{*0}$		$(57 \pm 10)\%$	
$\Xi^- \bar{K}^0 \pi^+$	$2.12 \pm 0.24 \pm 0.14$		
$\Xi^0 \bar{K}^0$	$1.64 \pm 0.26 \pm 0.12$		
$\Lambda \bar{K}^0 \bar{K}^0$	$1.72 \pm 0.32 \pm 0.14$		
$\Sigma^+ K^- K^- \pi^+$	$< 0.32$ (90% CL)		

New!

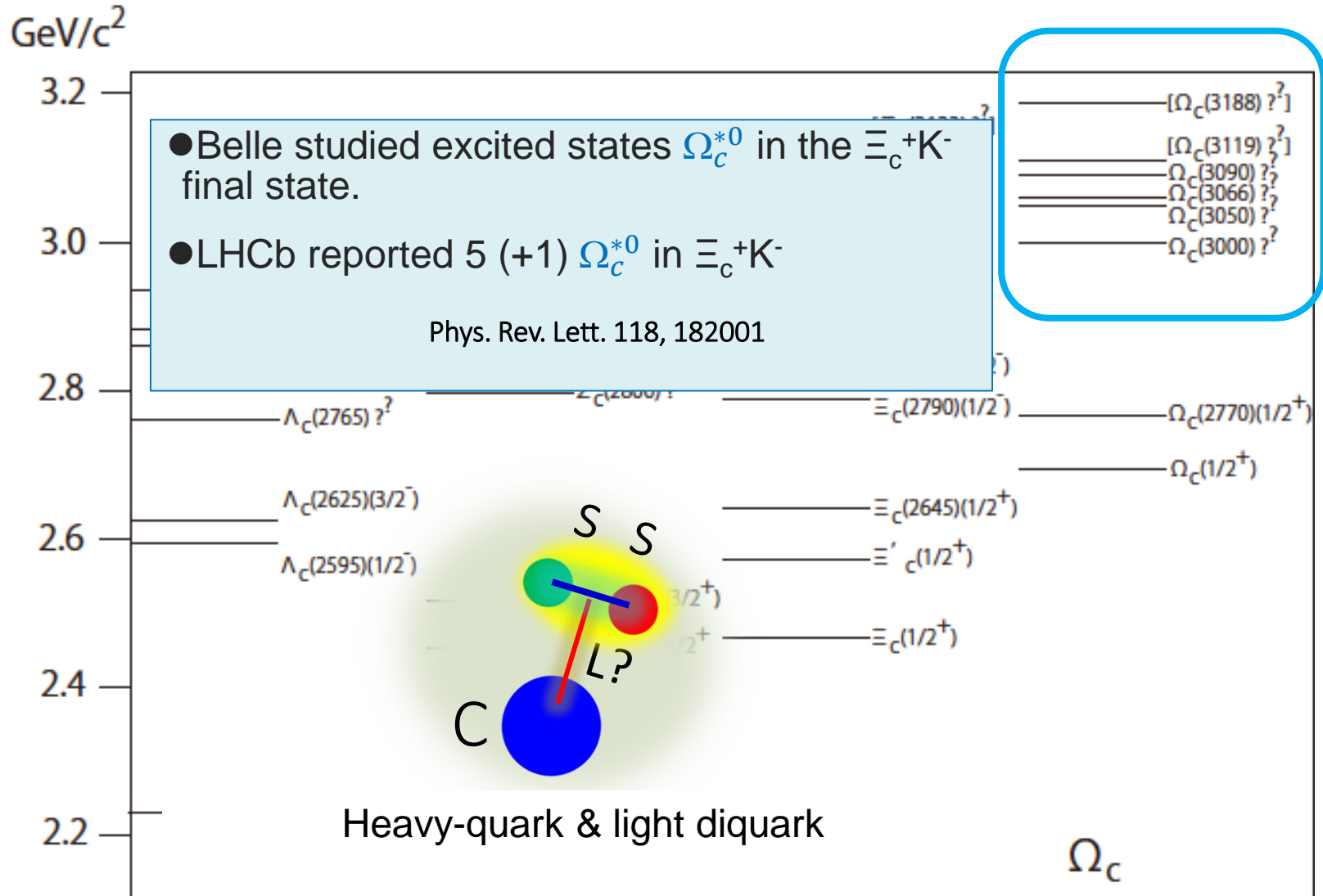
Precision improved by ~factor 2 for already measured modes.

First measurements of intermediate resonances.

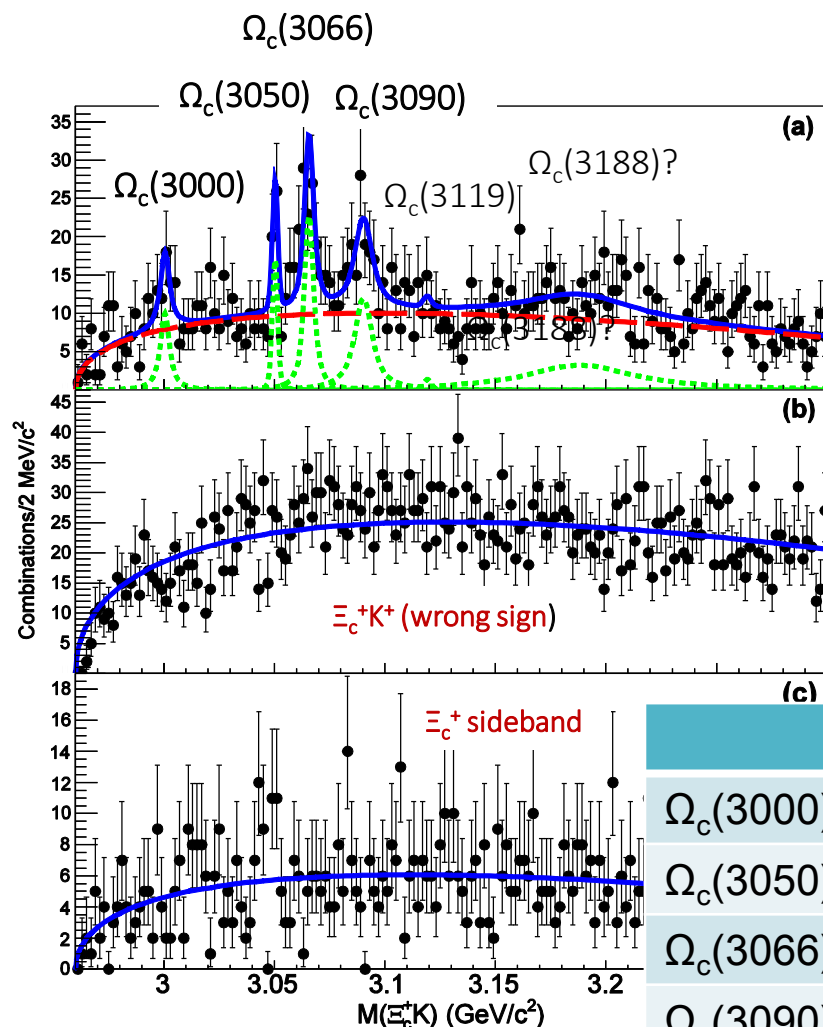
- Dominant contributions.

Three first observations.

# Excited $\Omega_c^{*0}$ baryons



# Observation at Belle



- The  $\Xi_c^+$  is reconstructed in 7 decay modes:

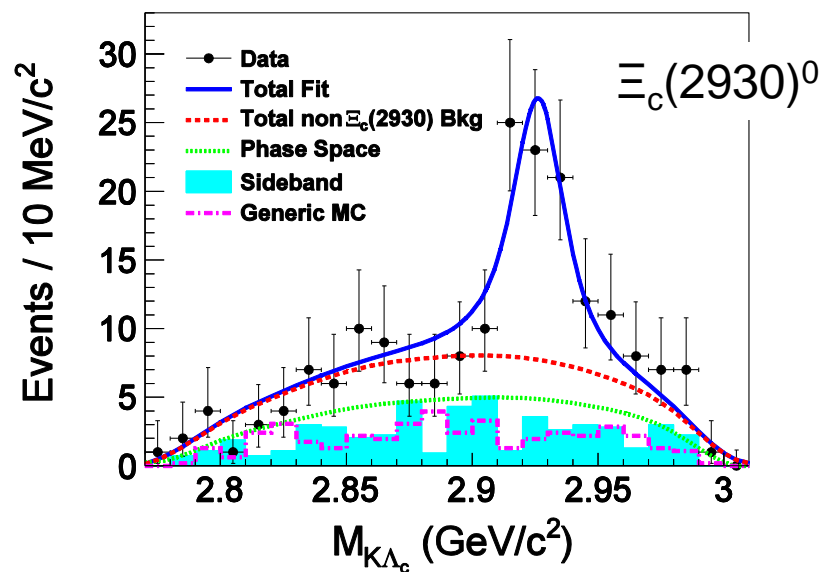
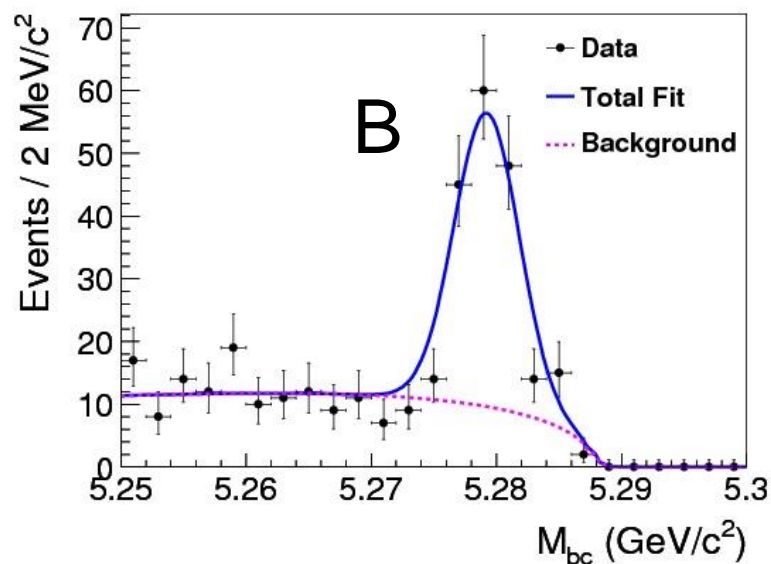
$\Xi^- \pi^+ \pi^+$ ,  $\Lambda K^- \pi^+ \pi^+$ ,  $\Xi^0 \pi^+$ ,  $\Xi^0 \pi^+ \pi^- \pi^+$ ,  $\Sigma^+ K^- \pi^+$ ,  $\Lambda K_S^0 \pi^+$ ,  $\Sigma^0 K_S^0 \pi^+$

- Apply a fit to mass and obtained masses.
  - 4 of 5 states are confirmed ( $>3\sigma$ )
- Only  $\Omega_c(3119)$  was not confirmed.
- The mass is consistent with LHCb.

	Belle	LHCb
$\Omega_c(3000)$	$3000.7 \pm 1.0 \pm 0.2$ ( $3.9\sigma$ )	$3000.4 \pm 0.2 \pm 0.4^{+0.3}_{-0.5}$
$\Omega_c(3050)$	$3050.2 \pm 0.4 \pm 0.2$ ( $4.6\sigma$ )	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$
$\Omega_c(3066)$	$3064.9 \pm 0.6 \pm 0.2$ ( $7.2\sigma$ )	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$
$\Omega_c(3090)$	$3089.3 \pm 1.2 \pm 0.2$ ( $5.7\sigma$ )	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$
$\Omega_c(3119)$	$3119.0 \pm 0.3 \pm 0.9$ ( $0.4\sigma$ )	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$

# Observation of $\Xi_c(2930)^0$ in $B \rightarrow \Xi_c(2930)^0 \bar{\Lambda}_c^-$ , $\Xi_c(2930)^0 \rightarrow \Lambda_c^+ K^-$

- One star in PDG (need confirmation)
- Weak evidence by BaBar  $\rightarrow$  Belle has  $\sim 3$  times statistics.  
Phys. Rev. D 77, 031101(R)



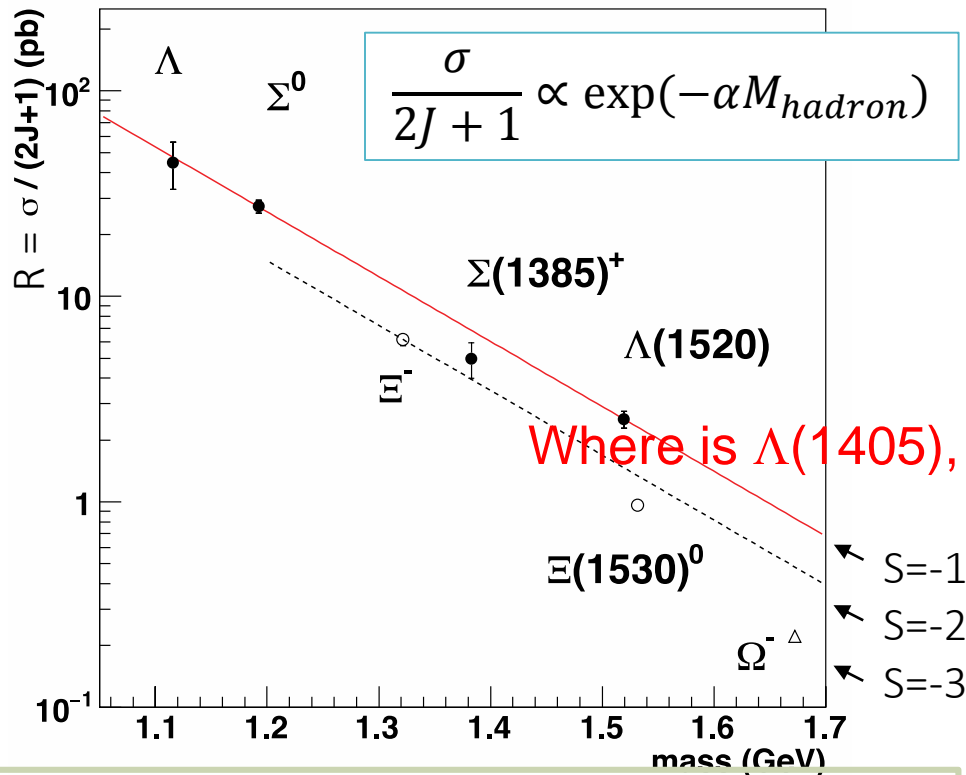
	Mass (MeV/c <sup>2</sup> )	Width (MeV)
BaBar	$2931 \pm 3 \pm 5$	$36 \pm 7 \pm 11$
Belle	$2928.9 \pm 3.0^{+0.8}_{-12.0}$	$19.5 \pm 8.4^{+5.4}_{-7.9}$

consistent

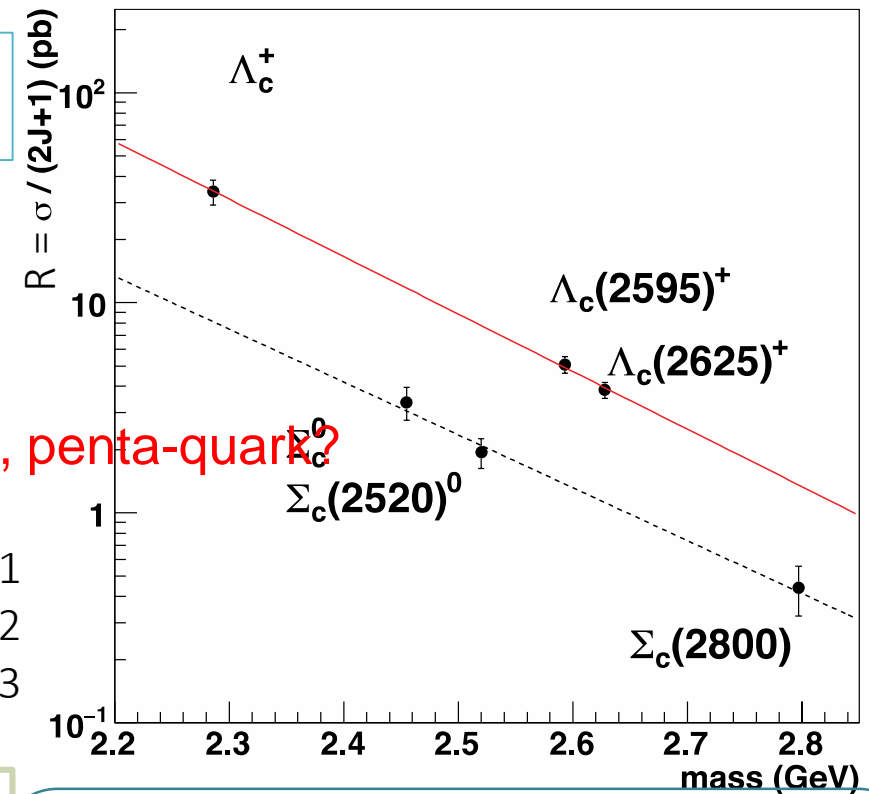
- The statistical significance is  $5.1\sigma$ .
- Assignment in models?
- Can see in prompt process in  $e^+e^- \rightarrow cc$ ?

# Production rate for baryons in $e^+e^-$

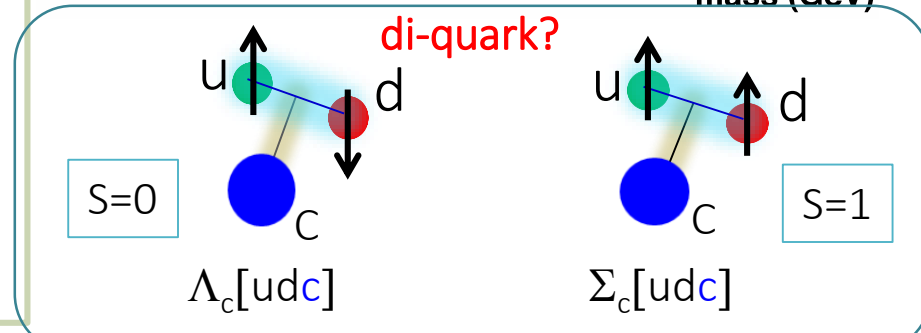
## Strange baryon



## Charmed baryon



- $R(S=-1) > R(S=-2) > R(S=-3) \rightarrow$  strangeness suppression
  - Suppression of  $\Sigma(1385) \cdot \Xi(1530) \rightarrow$  decuplet suppression
  - Suppression of  $\Sigma_c$  (spin=1 diquark)  $\ll \Lambda_c$  (spin=0 diquark)
- Suggesting a di-quark structure in the charmed baryon



# Summary

- Belle is still actively working on charmed baryons.
  - Hidden-strange pentaquark in  $\Lambda_c^+ \rightarrow p\phi\pi^0$ 
    - No evidence
  - Branching fractions of hadronic decay of  $\Omega_c^0$  g.s.
    - First measurements of intermediate resonances
  - Confirmation of excited  $\Omega_c$ 
    - consistent with LHCb
  - Observation of  $\Xi_c(2930)^0$  “one star”
    - confirm the existence, theoretical model
  - Production rate of various baryons
    - di-quark model
- Belle I & II will discover more baryons