KEK Seminar (January 9, 2007)

Charm Baryons at B-factories

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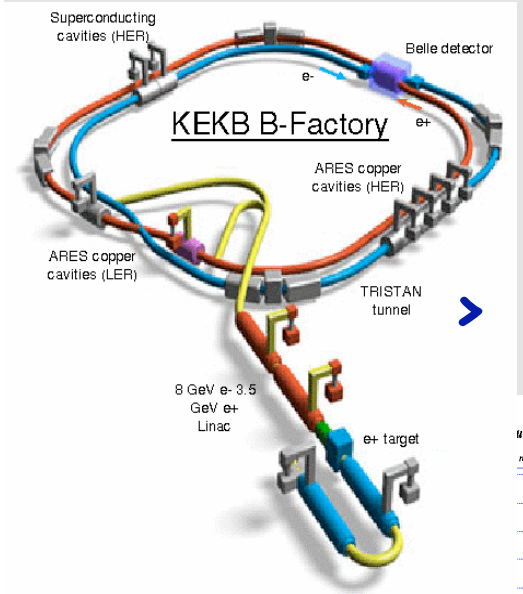
- Introduction: B-Factories and QCD

(A) Charm Baryon Spectroscopy
  (1) Prehistory: Charm Baryons before B-Factories Era
  (2) Observation of New Charm Baryons

(B) Charm Baryons from B-decays:
  New Charmful Baryonic B-decays and New Dynamics

(C) Summary and Perspectives

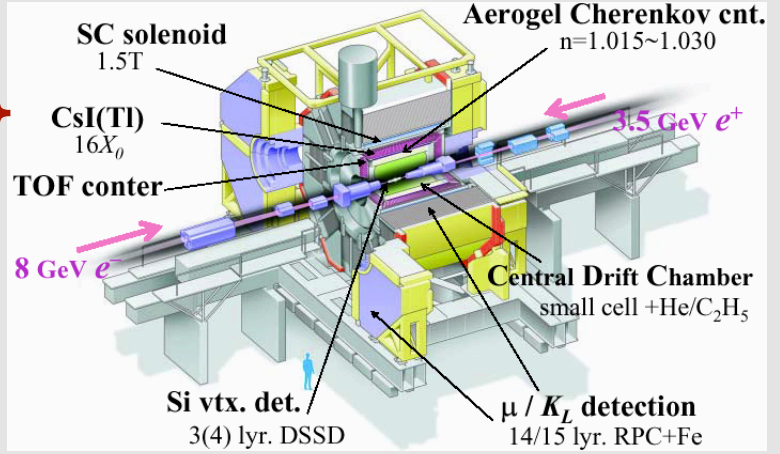
B-Factories and Data Sample

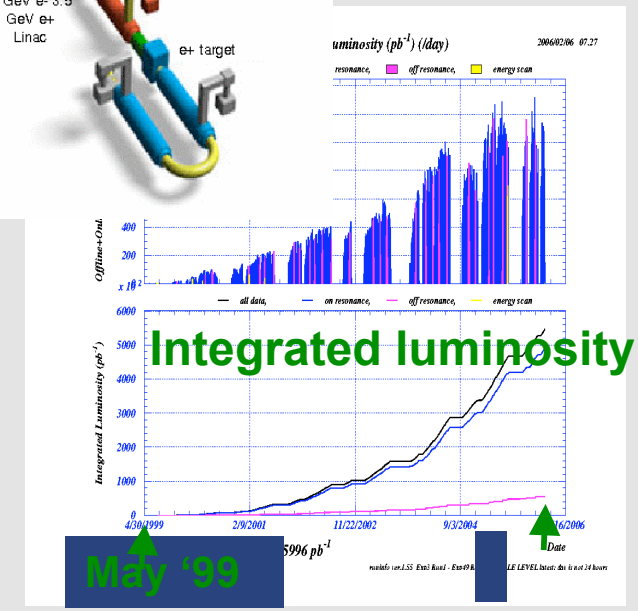


$e^+e^- \to \Upsilon(4S), \{l\bar{l}, c\bar{c}, q\bar{q}\}$

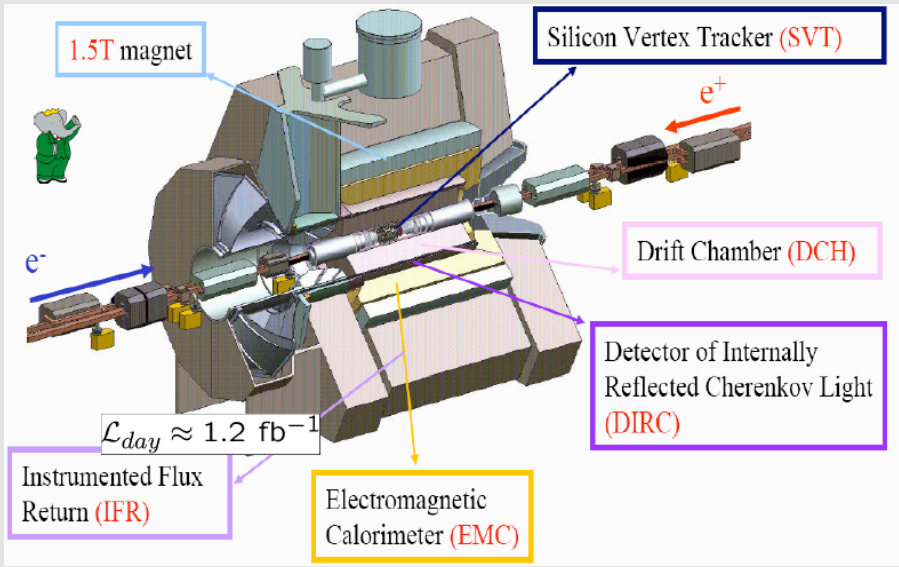
Not only EWP and CPV.

> 1 fb^{-1}/day





> 700 fb^{-1}
+ L (BaBar)
→ > 1ab^{-1}



Why it is important to study heavy hadron spectroscopy?

QCD is one of 3 theories describing the fundamental interactions (EW+QCD+G)

And we are far from understanding how QCD works at longer distances governing the hadron spectra since many hadrons have unexpected properties.

We need to understand it in order to separate the EWP from strong-interaction effects. Moreover we may need to use our experience with QCD in dealing with any non-perturbative effects encountered at higher energies (e.g. at LHC).

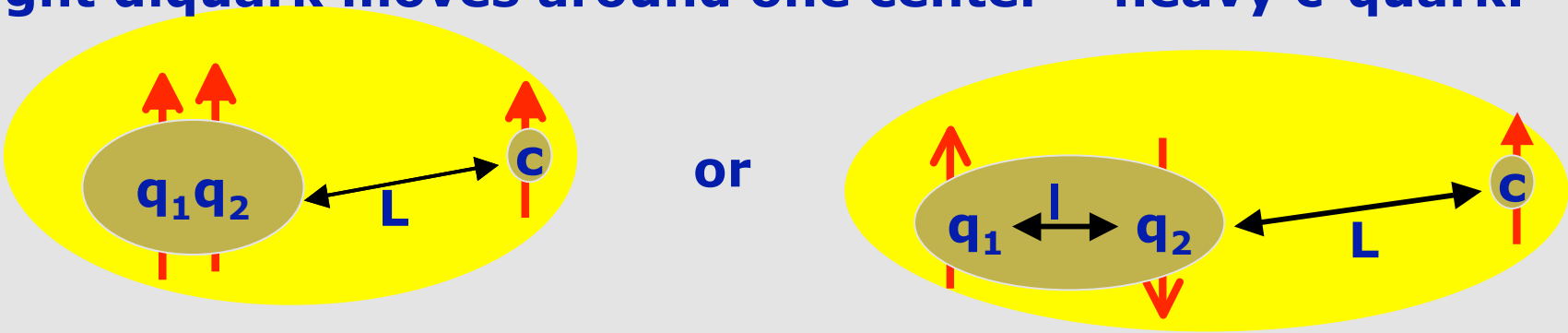
Heavy hadron spectroscopy is one of the best places to test different theoretical approaches in QCD.

Charm Baryons

Baryons are the main part of THE MATTER AROUND US and turn out to be very complicated objects built from 3 quarks. In baryons we face with the problem of relativistic non-perturbative 3-body system!! ⇒ Baryon is a very difficult object…

Thus we should study baryons to understand the nature of matter.

The charm baryons are more or less simple since they consists of one heavy c-quark. So, the generic picture is: Light diquark moves around one center – heavy c-quark.



B-Factories have started to study Charm Baryons

Now Belle and BaBar
are the reachest sources of charmed baryons.
They could provide new knowledge about the spectroscopy,
decay modes and production mechanism of charmed baryons.

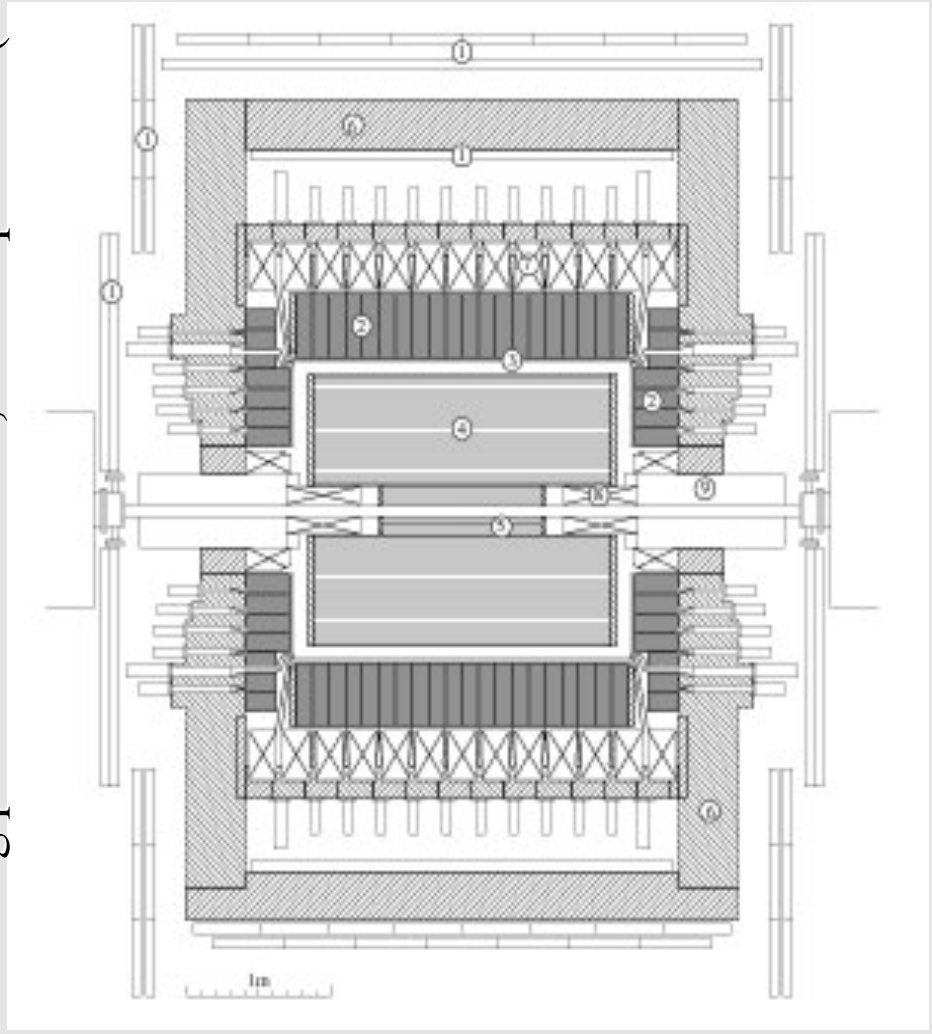
Baryonic B decays

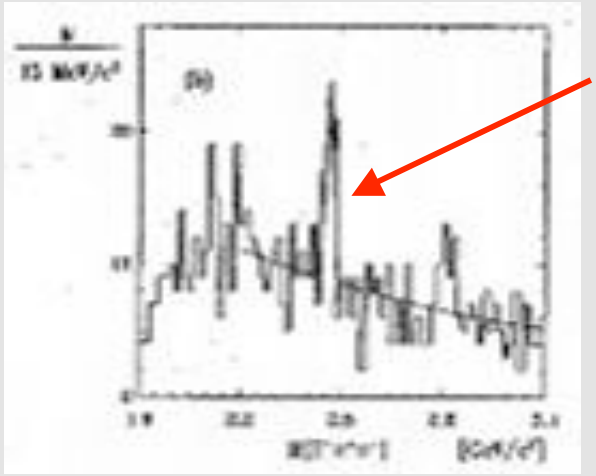
Charmed baryons
in $e^+e^- \to c\bar{c}$ continuum

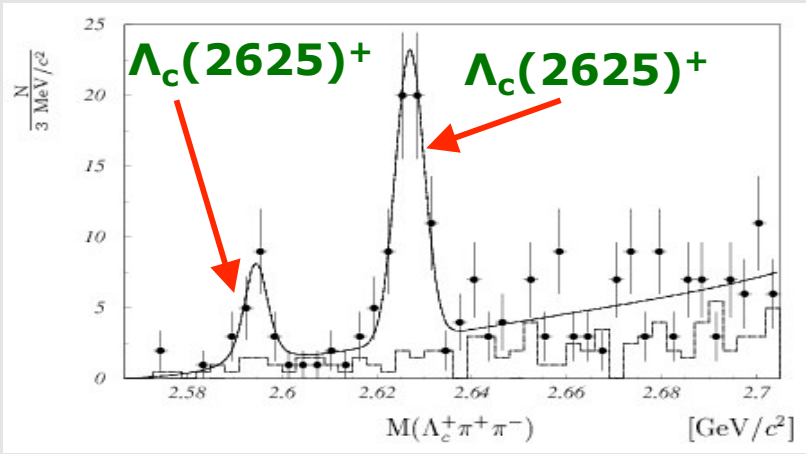
What was before?

Before B-factories: ARGUS detector

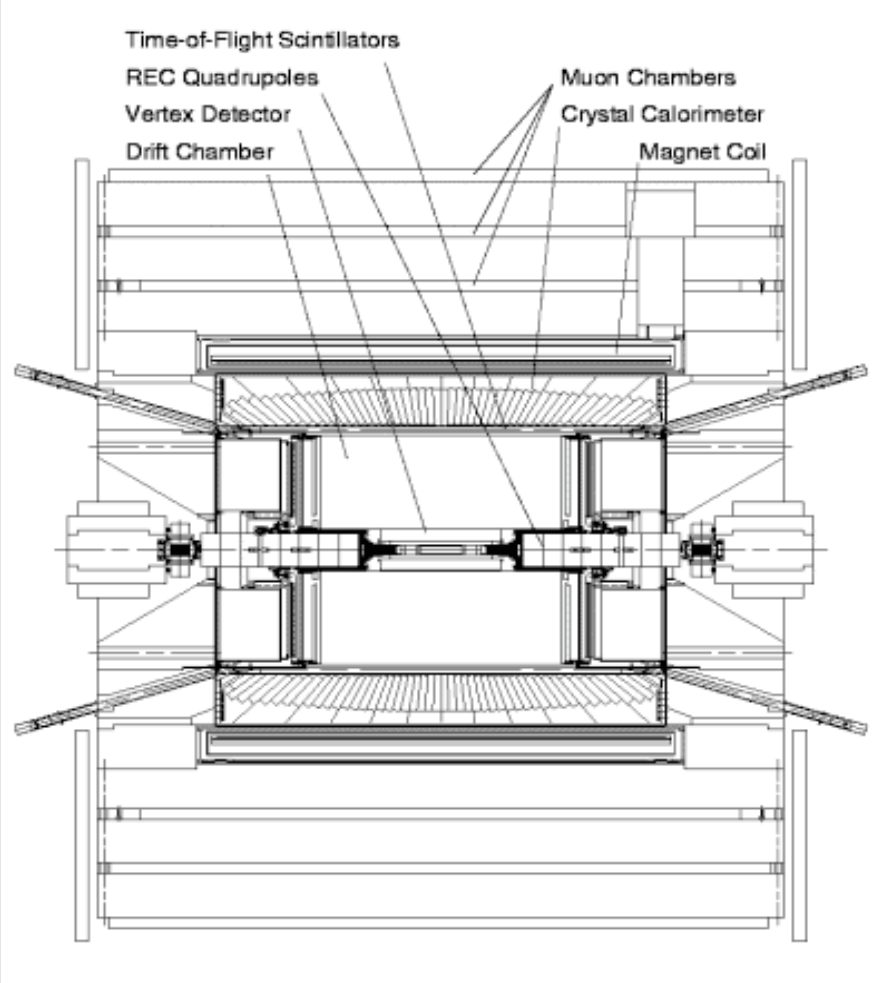
Runnig period: 1982-1992, L=200 pb^{-1} at Y(4S)

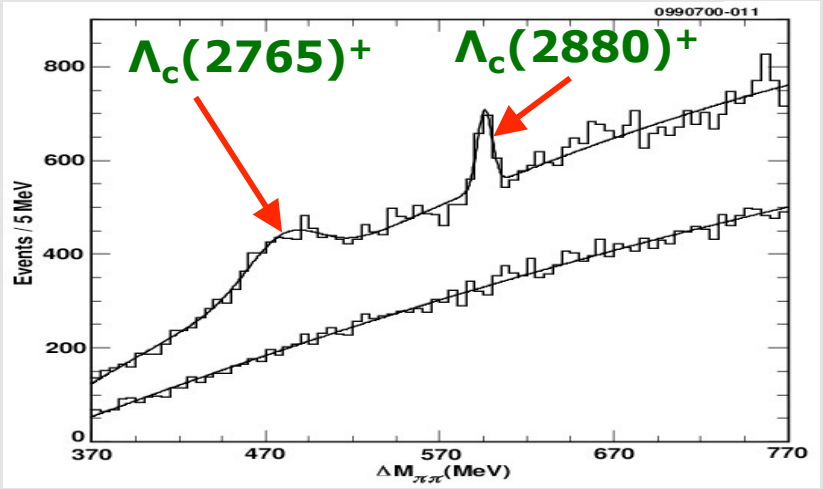


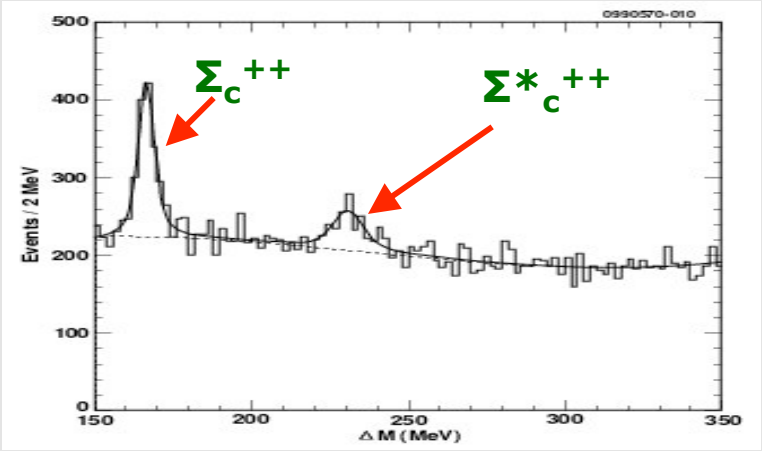




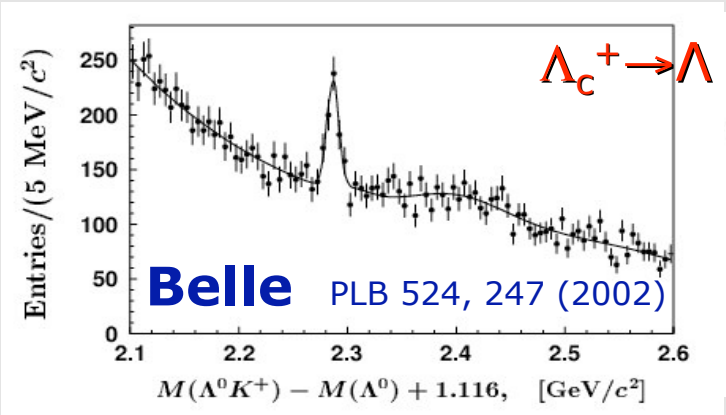
Before B-factories: CLEO detector

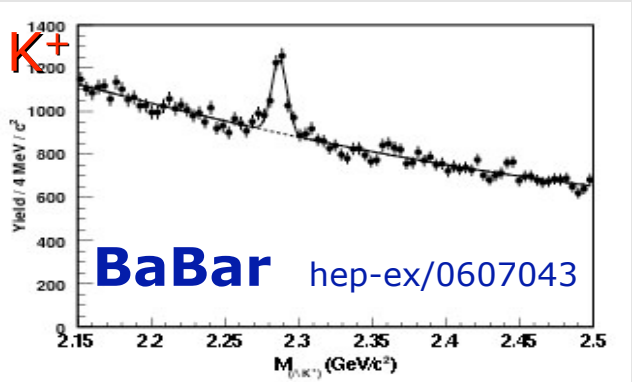




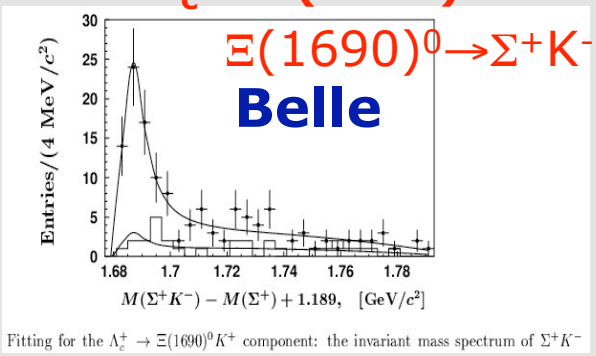


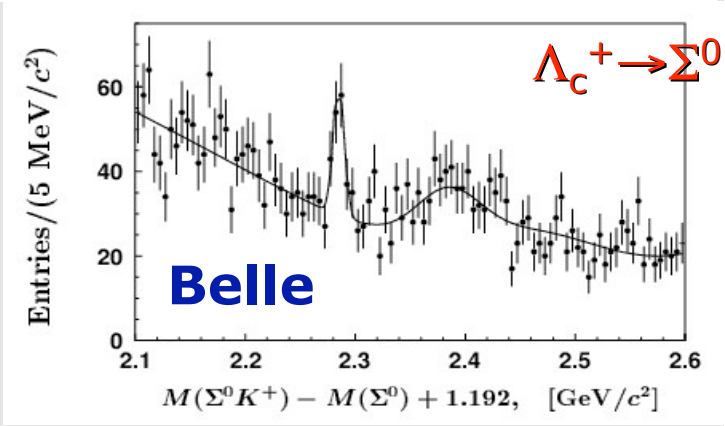
Observation of $\Lambda_c^+ \to \Lambda K^+$, $\Sigma^0 K^+$ at Belle and study of $\Xi(1690)^0$ at BaBar

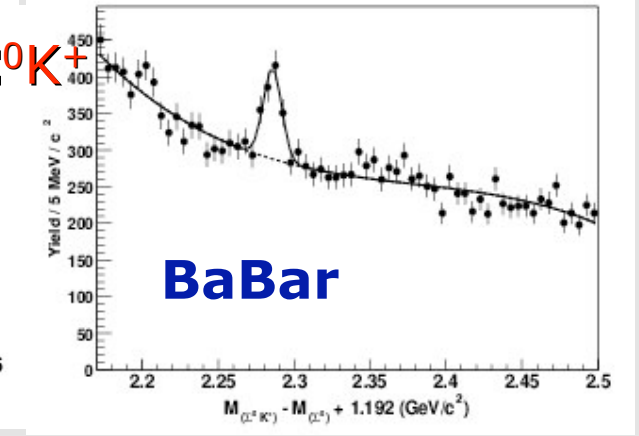


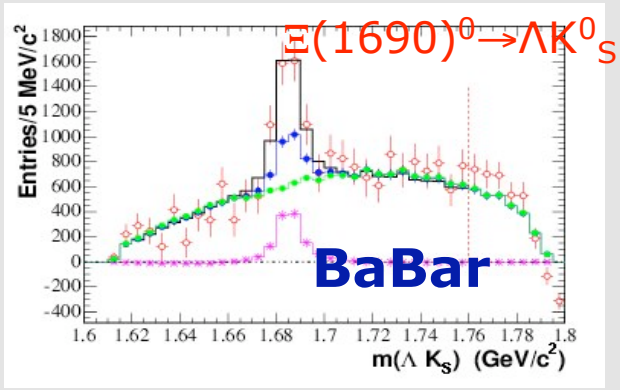


$\Lambda_c^+ \to \Xi(1690)^0 K^+$







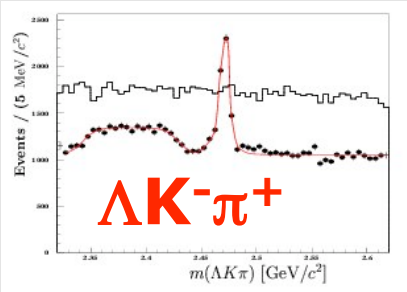


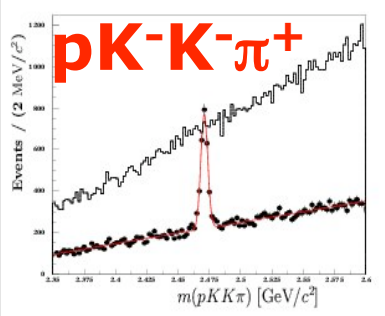
Improve knowledge on C.-s. decays → test different theoretical models

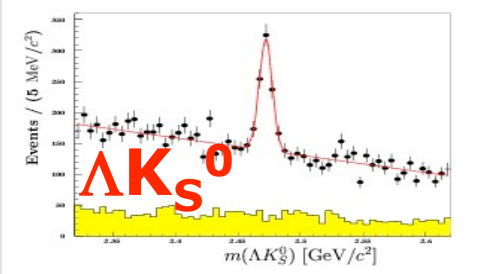
Improved measurement of Ξ_c^0 and Ξ_c^+ masses at Belle

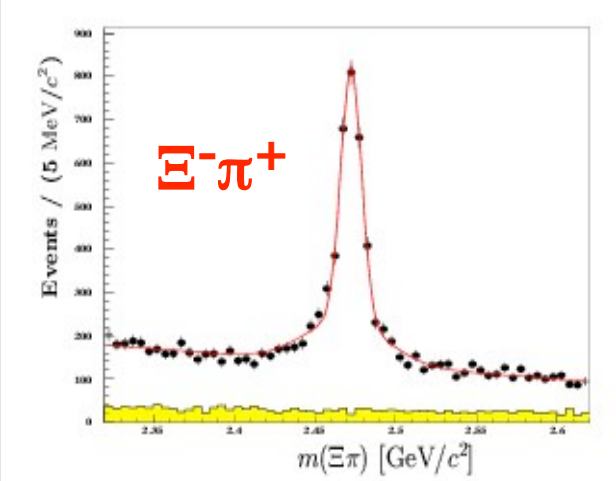
PLB 605, 237 (2005)

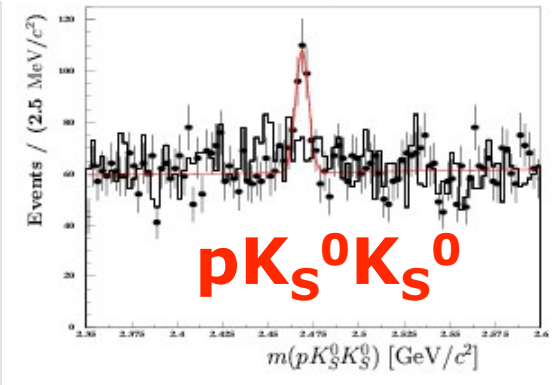
The Ξ_c's are reconstructed in 7 decay modes

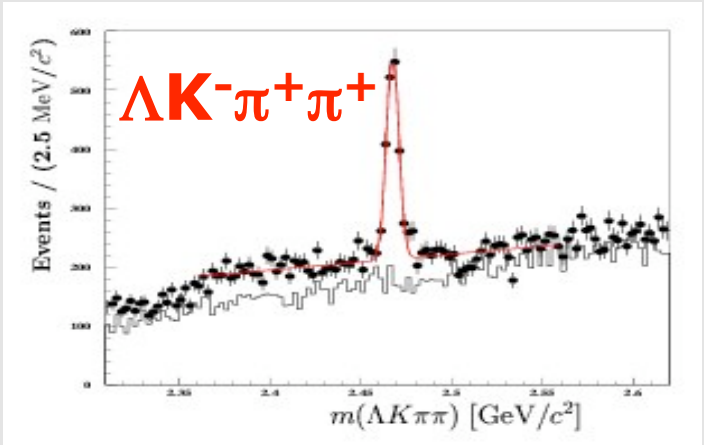


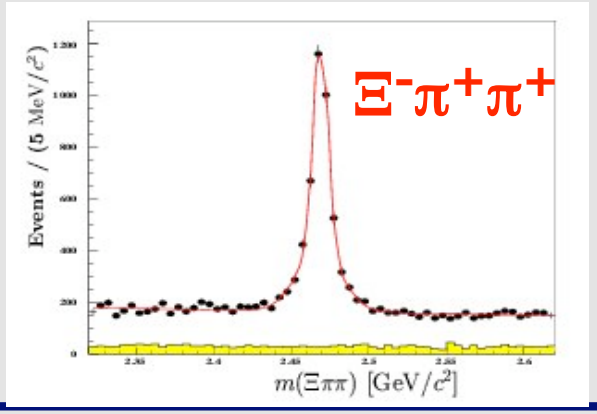












Improved measurement of Ξ_c^0 and Ξ_c^+ masses at Belle

PLB 605, 237 (2005),
Erratum PLB 617, 198 (2005)

Decay mode	# of events	mass [MeV/c^2]
$\Xi_c^+ \to \Xi^- \pi^+ \pi^+$	3605 ± 279	$2468.6 \pm 0.4 \pm 0.5$
$\Xi_c^+ \to \Lambda K^- \pi^+ \pi^+$	1177 ± 55	$2467.6 \pm 0.2 \pm 0.5$
$\Xi_c^+ \to p K_S^0 K_S^0$	168 ± 27	$2468.6 \pm 0.7 \pm 0.9$
$\Xi_c^0 \to \Xi^- \pi^+$	2979 ± 211	$2471.3 \pm 0.5 \pm 0.8$
$\Xi_c^0 \to \Lambda K^- \pi^+$	3268 ± 276	$2470.0 \pm 0.6 \pm 0.7$
$\Xi_c^0 \to \Lambda K_S^0$	465 ± 37	$2472.2 \pm 0.5 \pm 0.5$
$\Xi_c^0 \to p K^- K^- \pi^+$	1908 ± 62	$2470.9 \pm 0.1 \pm 0.2$

Due to the mass scale

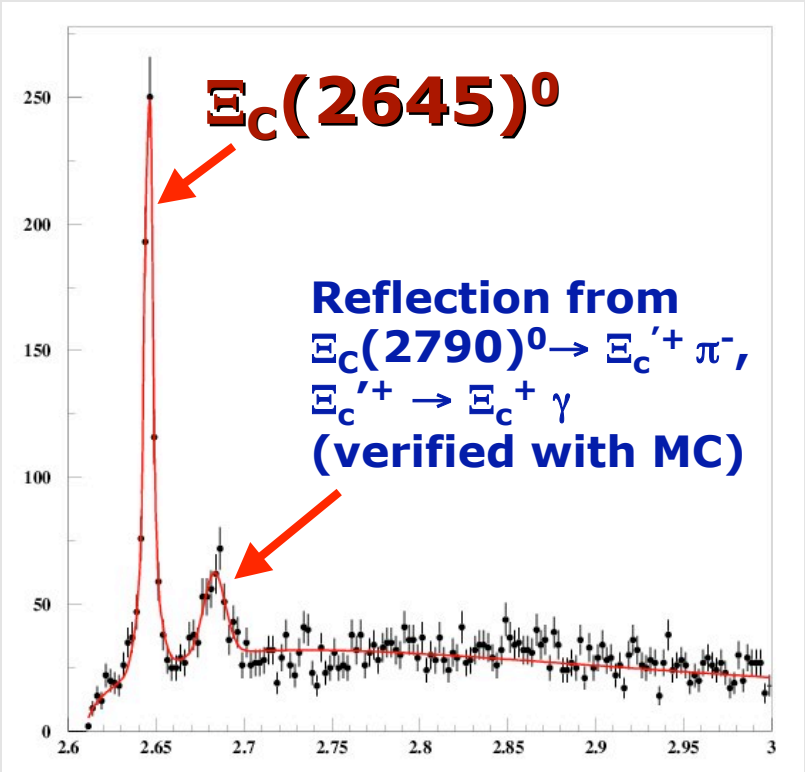
$$m_{\Xi_c^+} = (2468.1 \pm 0.4\,(\text{stat.} \oplus \text{syst.}\ ^{+0.2}_{-1.4}))\ \text{MeV}/c^2 \quad (\text{PDG}: (2466.3 \pm 1.4)\ \text{MeV}/c^2)$$

$$m_{\Xi_c^0} = (2471.0 \pm 0.3\,(\text{stat.} \oplus \text{syst.}\ ^{+0.2}_{-1.4}))\ \text{MeV}/c^2 \quad (\text{PDG}: (2471.8 \pm 1.4)\ \text{MeV}/c^2)$$

$$m_{\Xi_c^0} - m_{\Xi_c^+} = (2.9 \pm 0.5)\ \text{MeV}/c^2 \quad (\text{PDG}: (5.5 \pm 1.4)\ \text{MeV}/c^2)$$

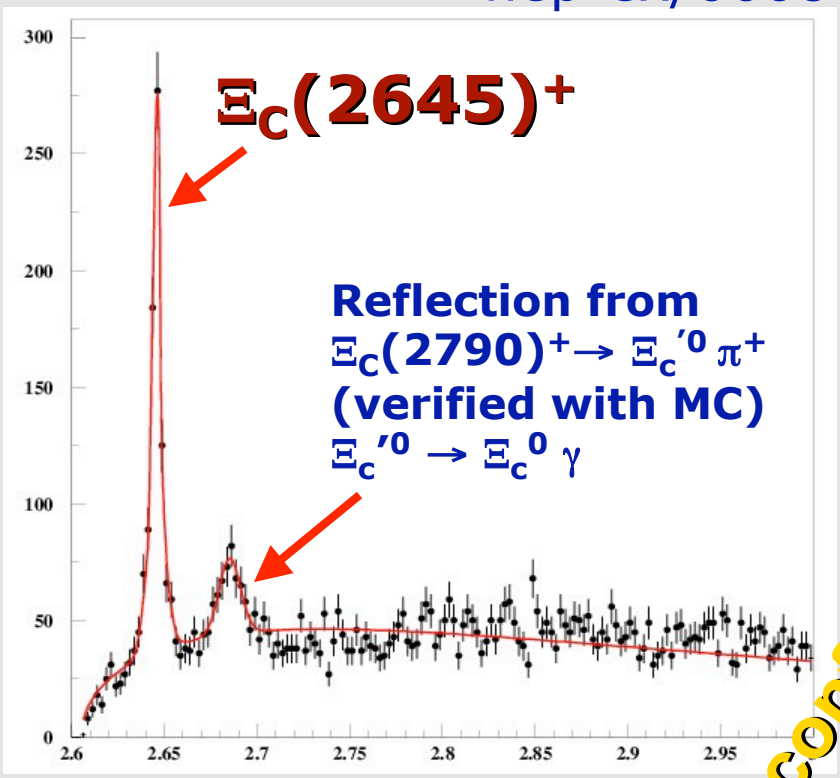
Belle: Study of excited states $\Xi_c(2645)$

hep-ex/0608012



$\text{Mass}(\Xi_c^+ \pi^-)$

$\Xi_c^+ \to \Xi^- \pi^+\pi^+$



$\text{Mass}(\Xi_c^0 \pi^+)$

$\Xi_c^0 \to \Xi^- \pi^+$

First confirmatio

L~450 fb^{-1}

Study of excited states $\Xi_c(2645)$: mass measurements at Belle

Belle (2006):

$$m_{\Xi_c(2645)^+} = (2645.4 \pm 0.1(\text{stat}) \pm 0.8(\text{syst}))\ \text{MeV}/c^2,$$

$$m_{\Xi_c(2645)^0} = (2645.6 \pm 0.2(\text{stat})^{+0.6}_{-0.7}(\text{syst}))\ \text{MeV}/c^2,$$

$$m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0} = (-0.2 \pm 0.3(\text{stat}) \pm 0.9(\text{syst}))\ \text{MeV}/c^2$$

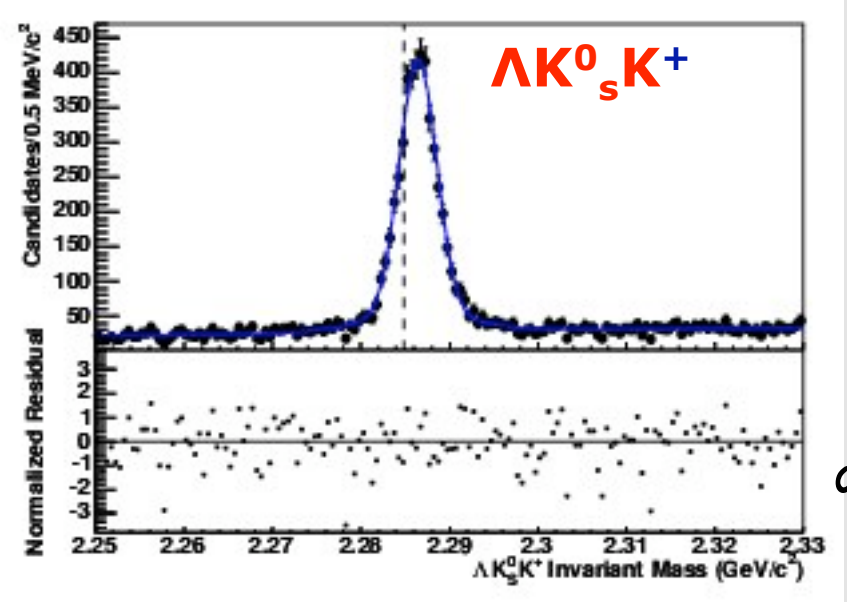
Preliminary

PDG(2006):

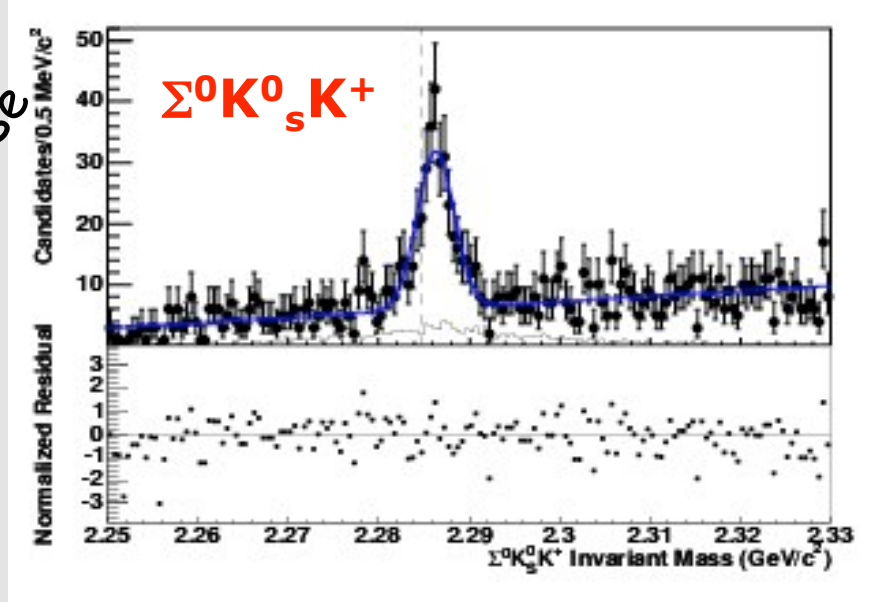
$\Xi_c(2645)^+$	2646.6 ± 1.5
$\Xi_c(2645)^0$	2646.2 ± 1.2

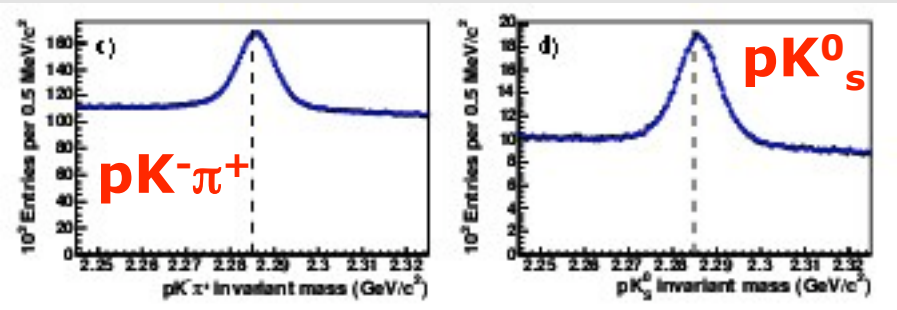
Improved measurement of Λ_c^+ mass at BaBar

Phys.Rev. D 72, 052006 (2005)



Small energy release

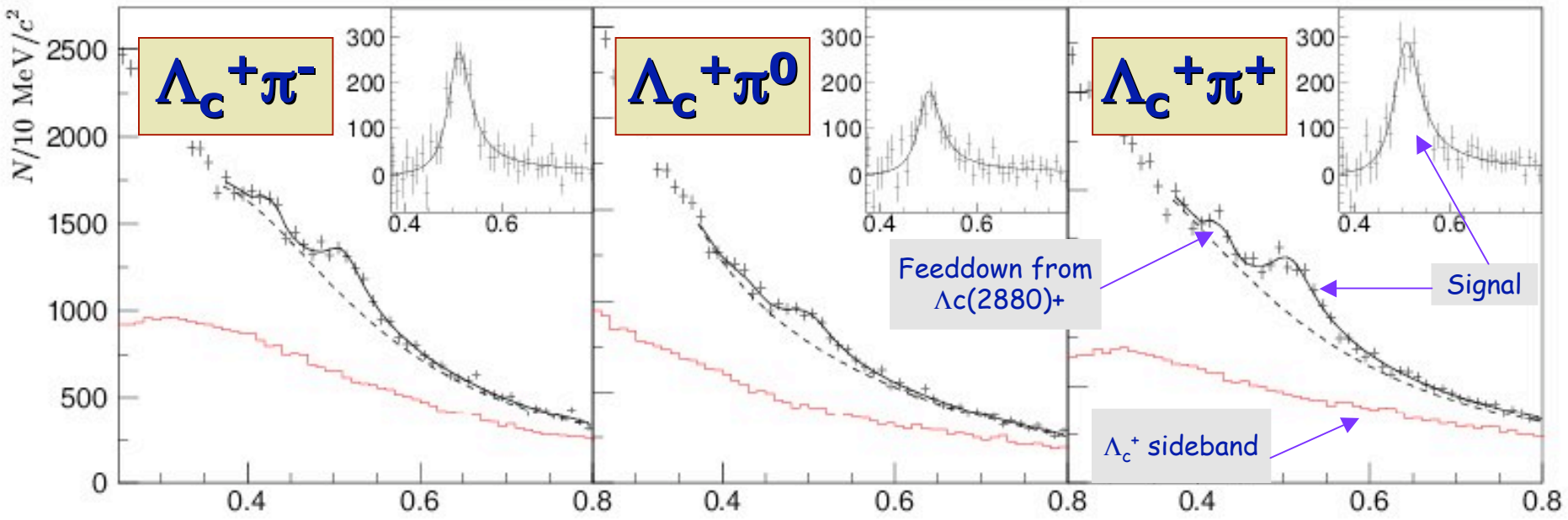




Mass(Λ_c^+)=2286.46±0.14 MeV
PDG: 2284.9±0.6 MeV

Stimulation of lattice QCD and potential models for improving predictions (uncertainties)

Observation of $\Sigma_c(2800)$ at Belle:
(PRL 94, 12202 (2005))



ISOTRIPLET!

State	Yield /10^3	ΔM, MeV/c^2	Γ, MeV
$\Sigma_c(2800)^0$	$2.24^{+0.79+1.03}_{-0.55-0.50}$	$515.4^{+3.2+2.1}_{-3.1-6.0}$	61^{+18+22}_{-13-13}
$\Sigma_c(2800)^+$	$1.54^{+1.05+1.40}_{-0.57-0.88}$	$505.4^{+5.8+12.4}_{-4.6-\ 2.0}$	62^{+37+52}_{-23-38}
$\Sigma_c(2800)^{++}$	$2.81^{+0.82+0.71}_{-0.60-0.49}$	$514.5^{+3.4+2.8}_{-3.1-4.9}$	75^{+18+12}_{-13-11}

Observation of $\Sigma_c(2800)$: Discussion

Theoretical models predict a rich spectrum of excited charmed baryons in the vicinity of the $\Sigma_c(2800)$
[L.A.Copley, N.Isgur and G.Karl, Phys. Rev D 20, 768 (1979)].

One of the candidates is a Σ_{c2} doublet with J^P=3/2- and 5/2-
(subscript 2 denotes the total angular momentum of light diquark.)
Σ_{c2} is expected to decay principally into $\Lambda_c^+\pi$ in D-wave.

The predicted mass is close to the measured but the predicted width is only 15 MeV.

But the Σ_{c2} (3/2-) can mix with the nearby Σ_{c1} (3/2-) which would produce a wider physical state.

2006: Most Notable Results on Charm Baryons

BaBar: Observation of $\Lambda_c(2880)^+$, $\Lambda_c(2940)^+ \rightarrow D^0 p$ (Moriond QCD'06)

Belle: Observation of $\Xi_{cx}(2980)^+$, $\Xi_{cx}(3077)^+ \rightarrow \Lambda_c^+ K^- \pi^+$ (Moriond QCD'06)

Belle: Observation of $\Xi_{cx}(3077)^0 \rightarrow \Lambda_c^+ K^0 \pi^-$
and Evidence for $\Xi_{cx}(2980)^0 \rightarrow \Lambda_c^+ K^0 \pi^-$ (Charm'06)

BaBar: Confirmation of $\Xi_{cx}(3077)^+$ and $\Xi_{cx}(2980)^+$ (ICHEP'06)

Belle: Observation of $\Xi_{cx}(2980)^{+/0} \rightarrow \Xi_c^{*0/+}\pi^{+/-}$ (ICHEP'06)

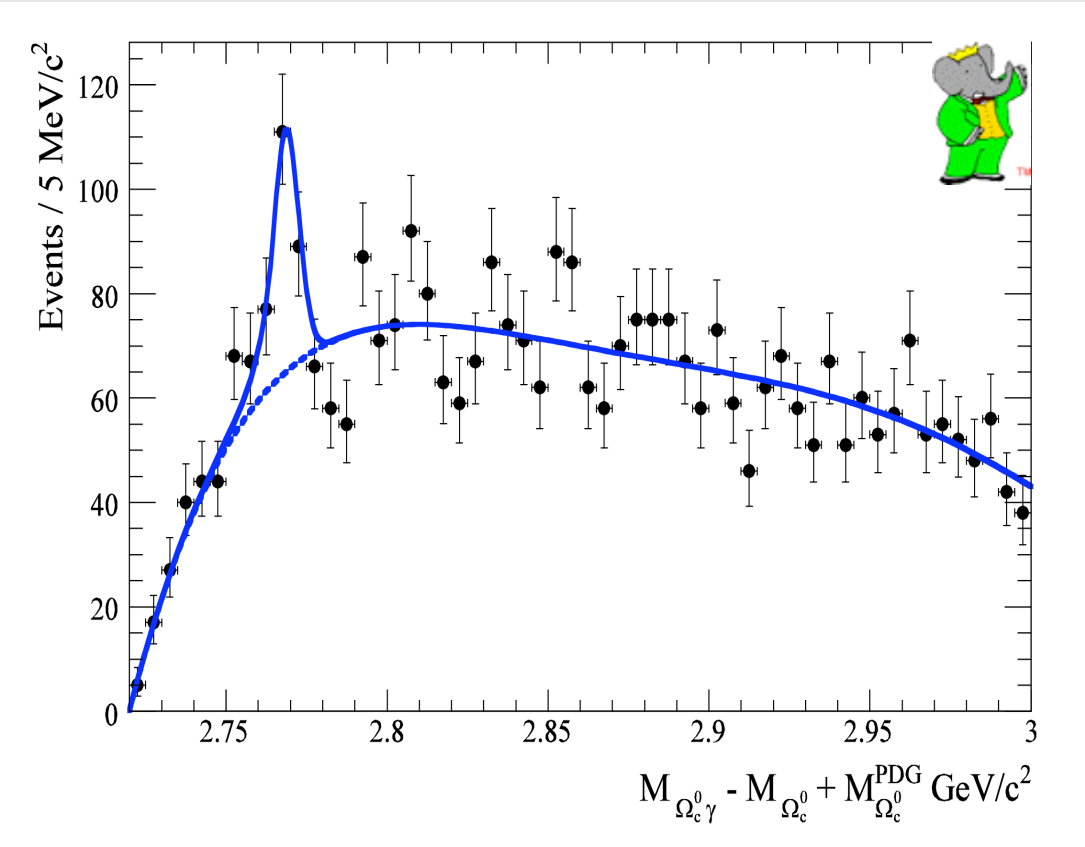
Belle: Observation of $\Lambda_c(2940)^+ \rightarrow \Sigma_c\pi$ (ICHEP'06)

BaBar: Observation of $\Omega_c^* \rightarrow \Omega_c \gamma$ (ICHEP'06)

Belle & BaBar: No signals for the production at $\sqrt{s} \sim 10.6$ GeV in e^+e^- collisions of the SELEX $\Xi_{cc}(3520)^+ \rightarrow \Lambda_c^+ K^- \pi^+$

BaBar: Observation of $\Omega_c^* \to \Omega_c\gamma$

hep-ex/0608055



$J^P = 3/2+$ from QM

$M(\Omega_c^*) - M(\Omega_c^0) =$
$(70.8 \pm 1.0 \pm 1.1)$ MeV/c²

ΔM Predictions (MeV/c²)

HQET	**80**
Lattice QCD	**90**
Non-relativistic Quark Model	**50 - 73**

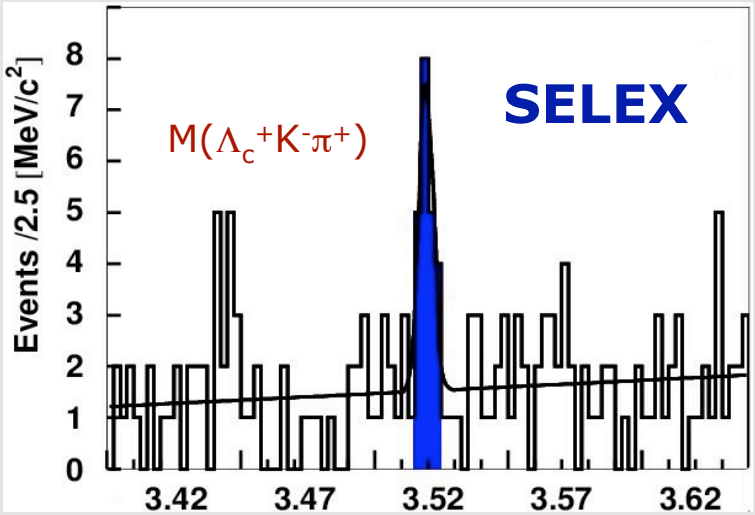
This is the excitation of (css), but what about (ccq)?

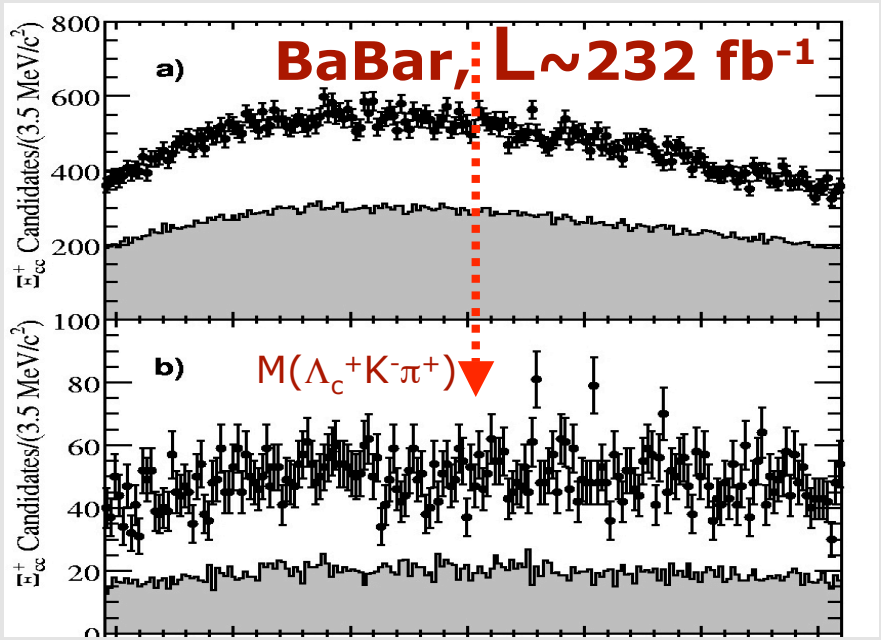
Search for the $\Xi_{cc}(3520)^+ \to \Lambda_c^+ K^- \pi^+$

Belle and BaBar observed $e^+e^- \to$ double-$c\bar{c}$; σ is ~10 larger than NRQCD predictions $\Rightarrow$ motivation to search

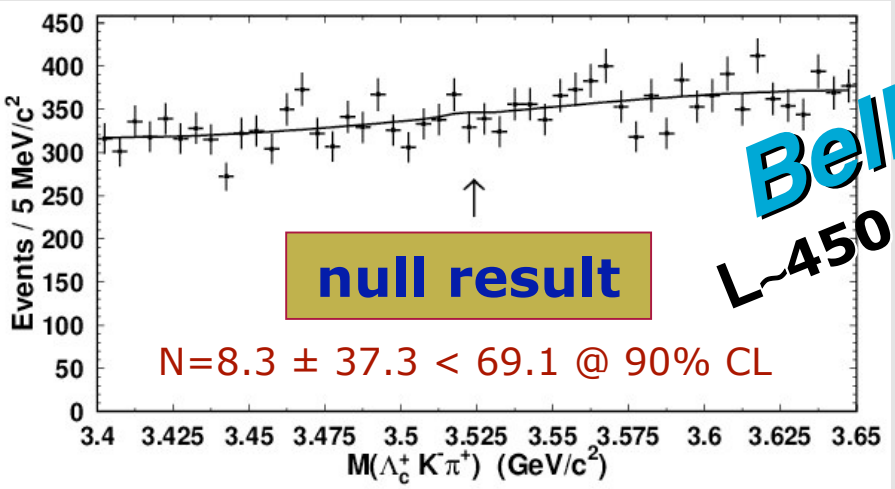
(recent work by A.K.Likhoded and A.V.Berezhnoy suggests – two prosesses are the same order – hep-ph/0602041)

PRL 89, 112001 (2002)





Phys. Rev. D74, 011103 (2006)



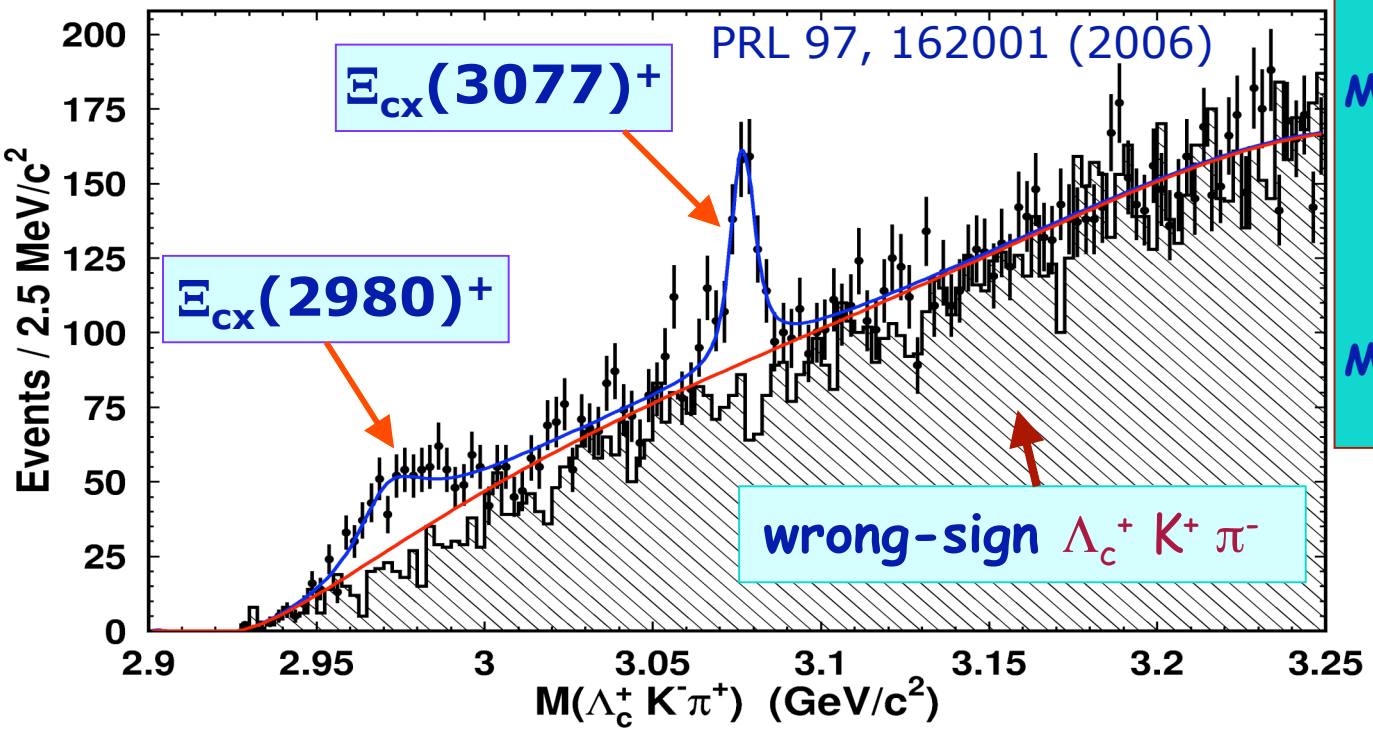
Similar search in $\Lambda_c K\pi\pi$, $\Xi_c\pi$, $\Xi_c\pi\pi$ also shows no signals. UL's are useful for models calculating $cc\bar{c}\bar{c}$.

New Charmed Baryons from Belle

Near threshold in Mass($\Lambda_c^+ K^- \pi^+$) two **new** charmed baryons

$\Xi_{cx}(2980)^+$ and $\Xi_{cx}(3077)^+$ were observed

L~450 fb^{-1}



$\Xi_{cx}(3077)^+$: 9.2σ
N=326.0 ± 39.6 events
M=3076.7 ± 0.9 ± 0.5 MeV
Γ=6.2 ± 1.2 ± 0.8 MeV

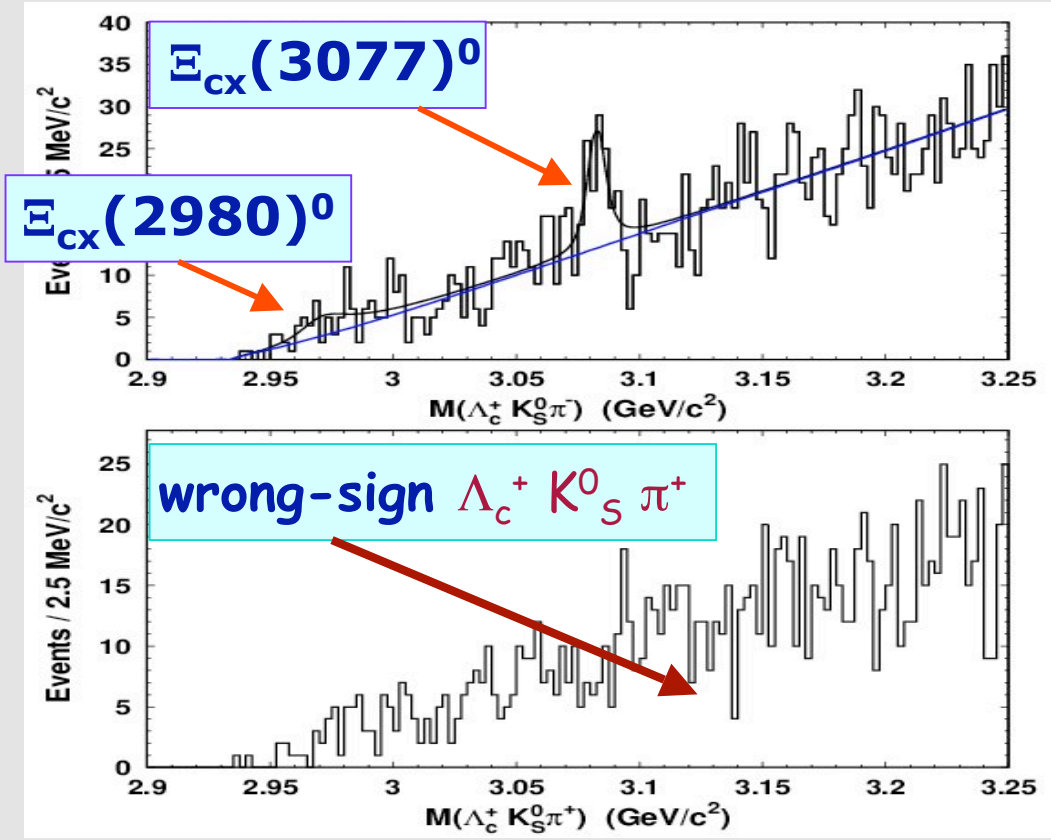
$\Xi_{cx}(2980)^+$: 5.7σ
N=405.3 ± 50.7 events
M=2978.5 ± 2.1 ± 2.0 MeV
Γ=43.5 ± 7.5 ± 7.0 MeV

What is a nature of these new states?

New Charmed Baryons from Belle

To get more information about the properties of found states Belle searched for their isopartners in Mass($\Lambda_c^+ K^0_S \pi^-$) and observe $\Xi_{cx}(3077)^0$

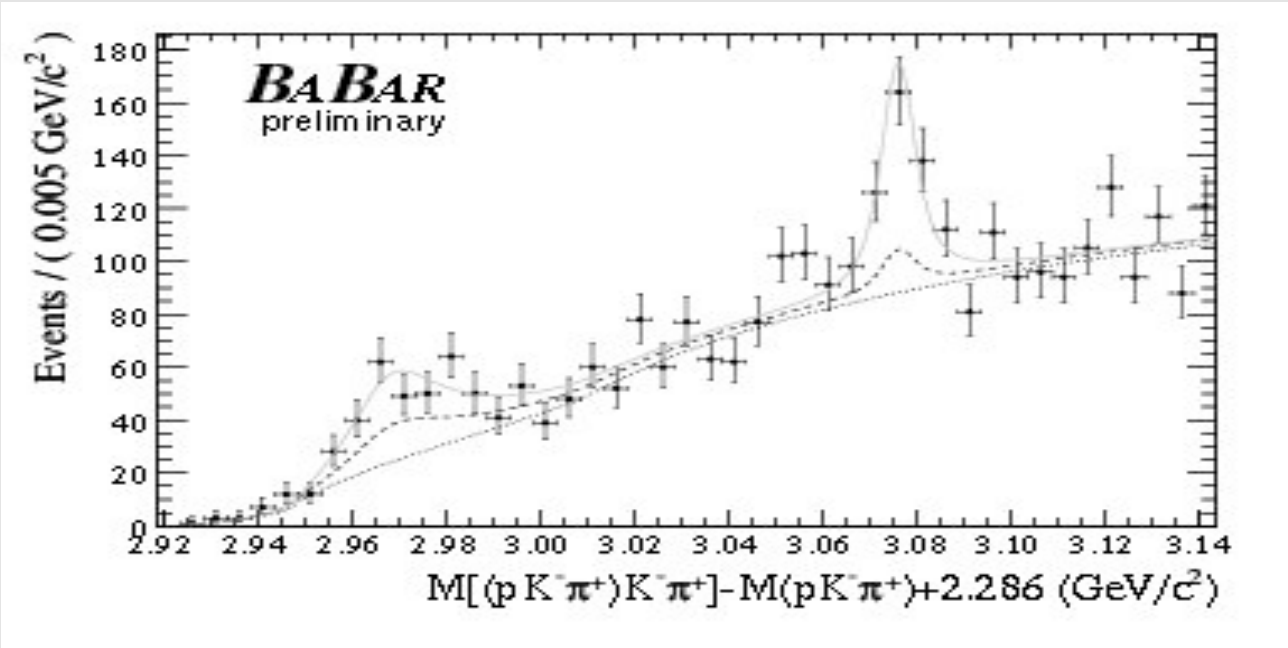
PRL 97, 162001 (2006) **L~450 fb^{-1}**



High mass state - $\Xi_{cx}(3077)^0$
N=67.1 ± 19.9
M=3082.8 ± 1.8 MeV
Γ=5.2 ± 3.1 MeV
Significance=4.4σ

Low mass state - $\Xi_{cx}(2980)^0$
N= 42.3 ± 23.8
M=2977.1 ± 8.8 MeV
Γ=43.6 MeV FIXED
Significance=1.5σ

BaBar : Confirmation of $\Xi_{cx}(2980)^+$ and $\Xi_{cx}(3077)^+$



	Mass (MeV/c^2)	Width (MeV)	Yield (Events)	Significance
BABAR $\Xi_c(2980)^+$	$2967.1 \pm 1.9 \pm 1.0$	$23.6 \pm 2.8 \pm 1.3$	$284 \pm 45 \pm 46$	$7.0\,\sigma$
Belle $\Xi_c(2980)^+$	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$	405 ± 51	$6.3\,\sigma$
BABAR $\Xi_c(3077)^+$	$3076.4 \pm 0.7 \pm 0.3$	$6.2 \pm 1.6 \pm 0.5$	$204 \pm 35 \pm 12$	$8.6\,\sigma$
Belle $\Xi_c(3077)^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$	326 ± 40	$9.7\,\sigma$

Reported on the resonant substructure: $\Sigma_c^{(*)}K$.

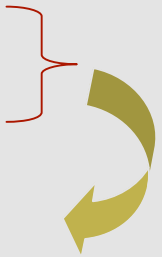
Belle also sees the res. substr. but didn't publish.

Results are consistent; BaBar performed 2D fit ($M(\Lambda_c K\pi)$ Vs. $M(\Lambda_c\pi)$)

Discussion of New Ξ_{cx} States

Observed Properties:

- Charm and strange quarks in the final state (Λ_c^+ and K^-);
- These new charm baryons have
  - *large masses (largest in grand family of charm baryons),
  - *finite widths;
- Neutral partners also observed



not double charm baryons

Most natural interpretation: excited charm strange baryons which *could be* D-wave excitations.

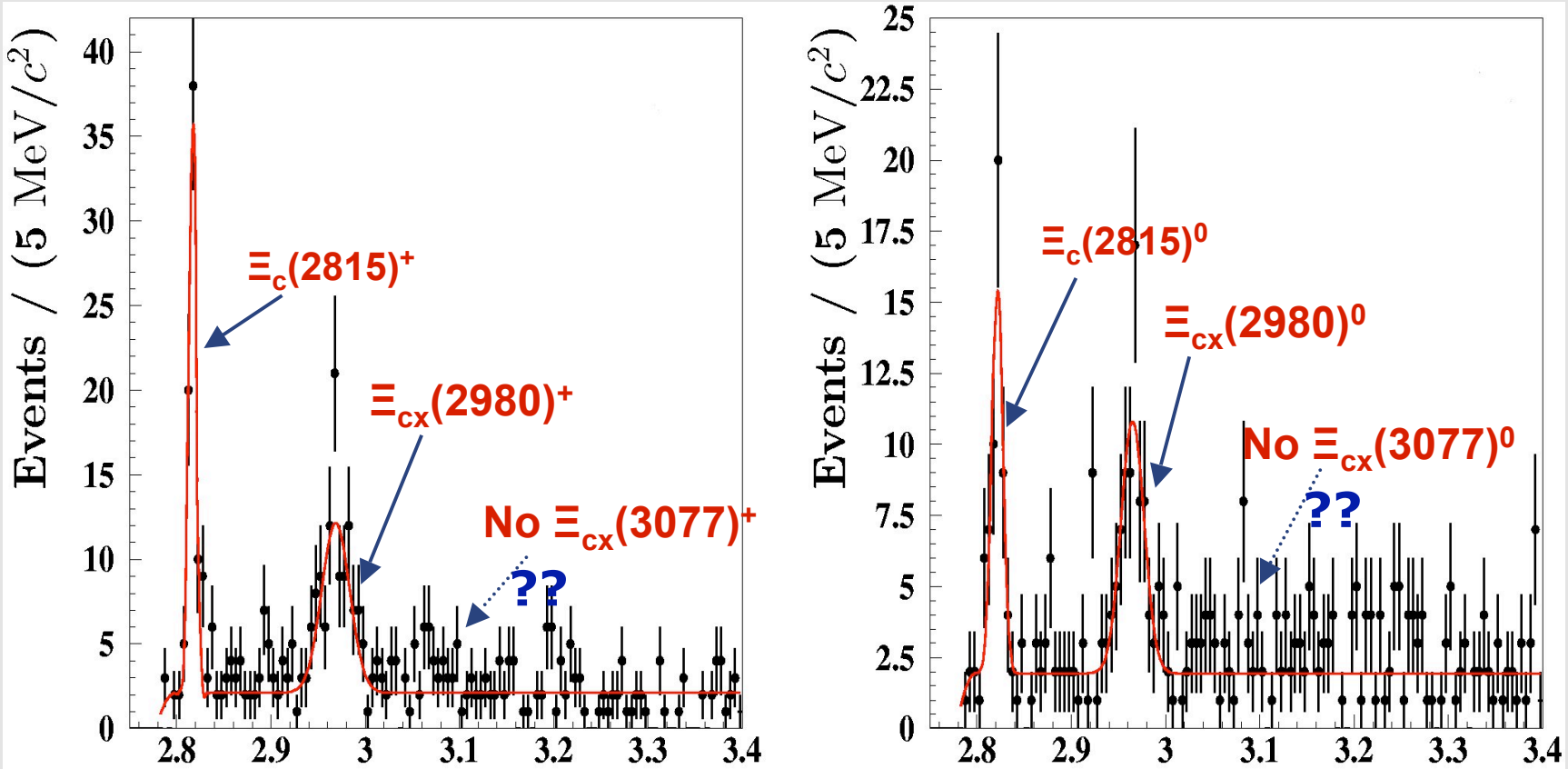
Possible J^P are 1/2+(or 3/2+) and 5/2+

(H.-Y.Cheng, C.-K.Chua, hep-ph/0610283;
J.L.Rosner, hep-ph/0612332)

Belle: Observation of $\Xi_{cx}(2980)^{+/0} \to \Xi_c^{*0/+}\pi^{+/-}$

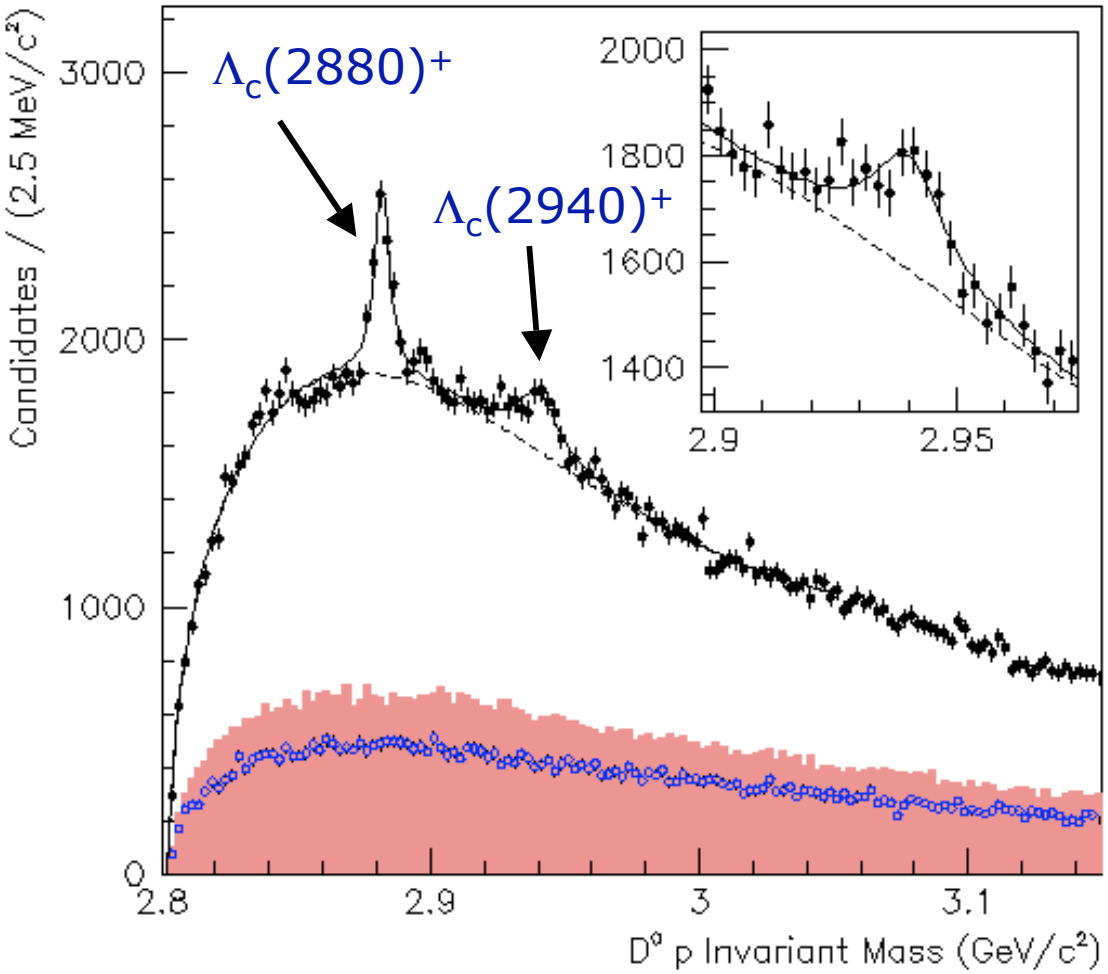
hep-ex/0608012

Search for another, "natural" channel for the new states Ξ_{cx}



Preliminary

BaBar: Observation of $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+ \to D^0 p$



hep-ex/0603052

$\Lambda_c(2880)^+$

A New Decay Mode; Improved Mass and Width

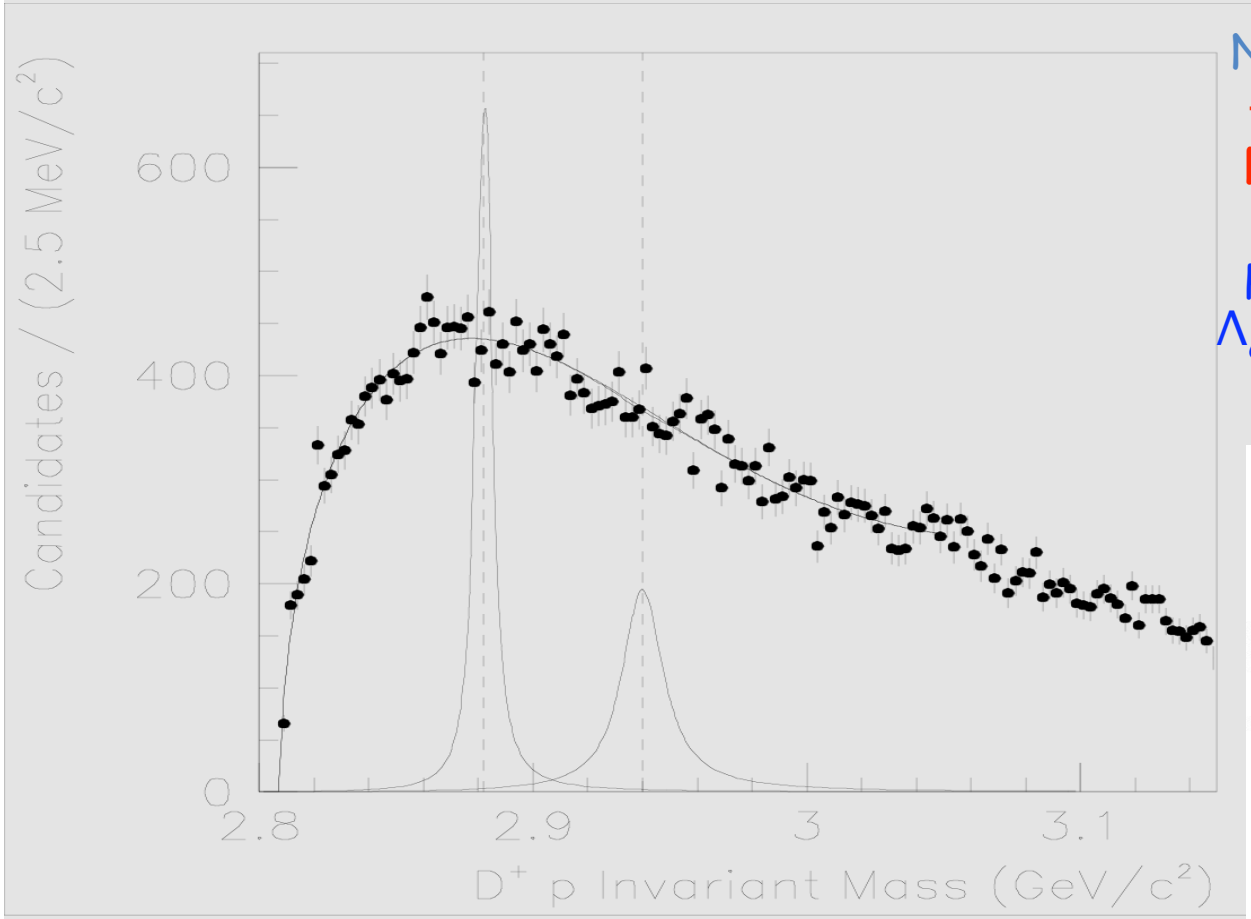
$M = (2882 \pm 0.1 \pm 0.5)$ MeV/c²
$\Gamma = (5.8 \pm 1.5 \pm 1.1)$ MeV

New Charm Baryon: $\Lambda_c(2940)^+$

$M = (2939.8 \pm 1.3 \pm 1.0)$ MeV/c²
$\Gamma = (17.5 \pm 5.2 \pm 5.9)$ MeV

Is it Λ_c^+ or Σ_c^+ ?
Search for Isospin Partners ⇒

BaBar: Observation of $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+ \rightarrow D^0 p$

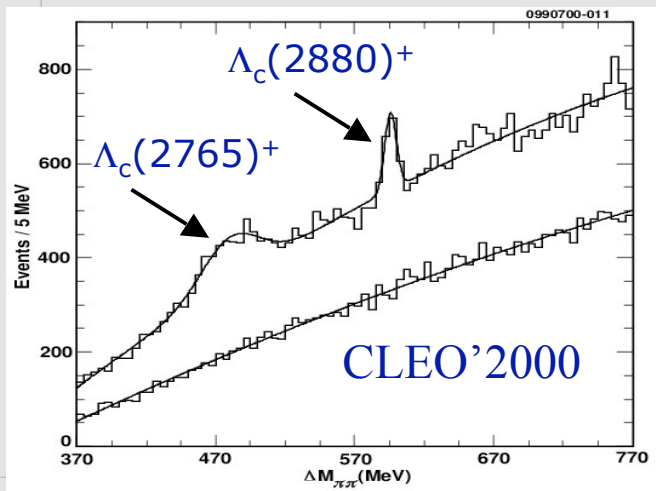


No signals at 2880 and 2940 MeV/c^2

→

both 2880 & 2940 states are Λc's

Previous CLEO data shows that $\Lambda_c(2940)^+$ not observed in $\Lambda_c^+\pi^+\pi^-$;
Suppression not understood

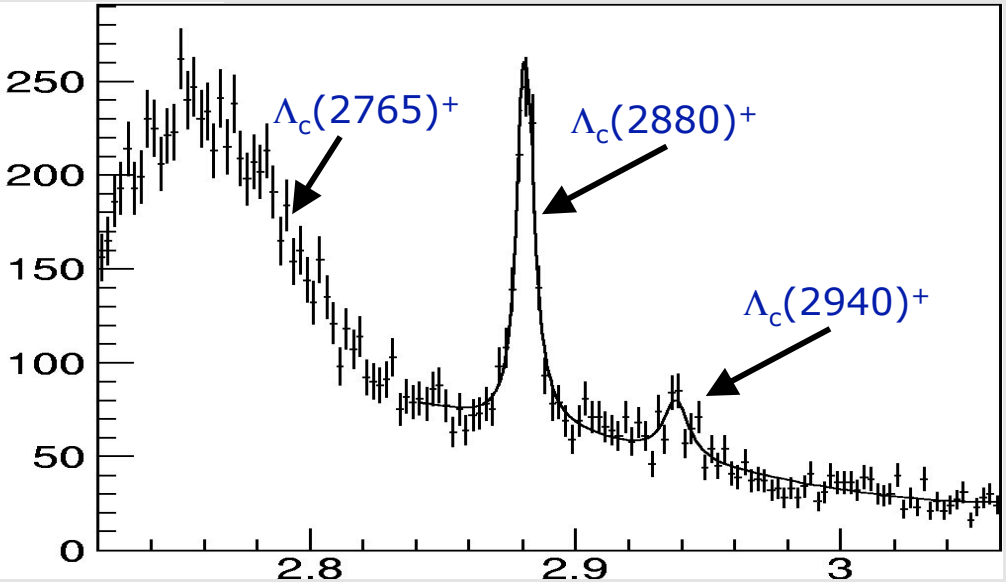


But..

⇒

Belle: Observation of $\Lambda_c(2940)^+ \to \Sigma_c\pi$

hep-ex/0608043



$M(\Sigma_c(2455)^{0,++}\pi^{\pm})$

	Yield	Mass, MeV/c^2	Width, MeV
$\Lambda_c(2880)^+$	$880 \pm 50 \pm 40$	$2881.2 \pm 0.2^{+0.4}_{-0.3}$	$5.5^{+0.7}_{-0.3} \pm 0.4$
$\Lambda_c(2940)^+$	$210^{+70+100}_{-40-60}$	$2937.9 \pm 1.0^{+1.8}_{-0.4}$	$10 \pm 4 \pm 5$

$\Lambda_c(2880)^+$	2800 ± 190	$2881.9 \pm 0.1 \pm 0.5$	$5.8 \pm 1.5 \pm 1.1$
$\Lambda_c(2940)^+$	2280 ± 310	$2939.8 \pm 1.3 \pm 1.0$	$17.5 \pm 5.2 \pm 5.9$

Confirmation of $\Lambda_c(2940)^+$

(Parameters are consistent)

Observation of a new decay mode

$\Rightarrow$ **One needs to measure BR($\to D^0p$)/ BR($\to \Sigma_c\pi$)**

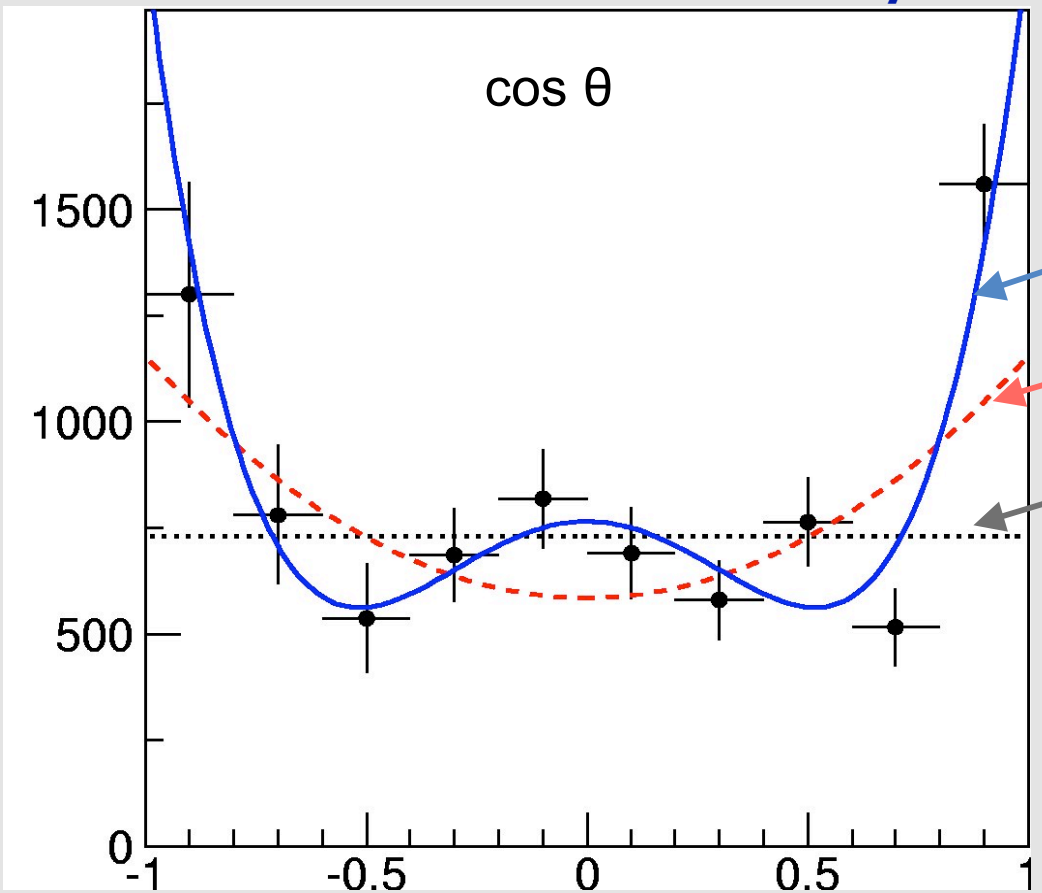
to check exotic interpretation of $\Lambda_c(2940)^+$ as $D^{*0}p$ molecular state

(hep-ph/0606015)

Belle: Angular analysis in $\Lambda_c(2880)^+ \to \Sigma_c \pi$

A lot of states are predicted at these masses.
One needs to determine J^P to identify.

hep-ex/0608043



J=5/2 hypothesis is strongly favored over 1/2 and 3/2 hypotheses.

J=5/2, χ^2/d.o.f.=10.8/7

J=3/2, χ^2/d.o.f.=36.0/8

J=1/2, χ^2/d.o.f.=49.9/9

Quark Model:

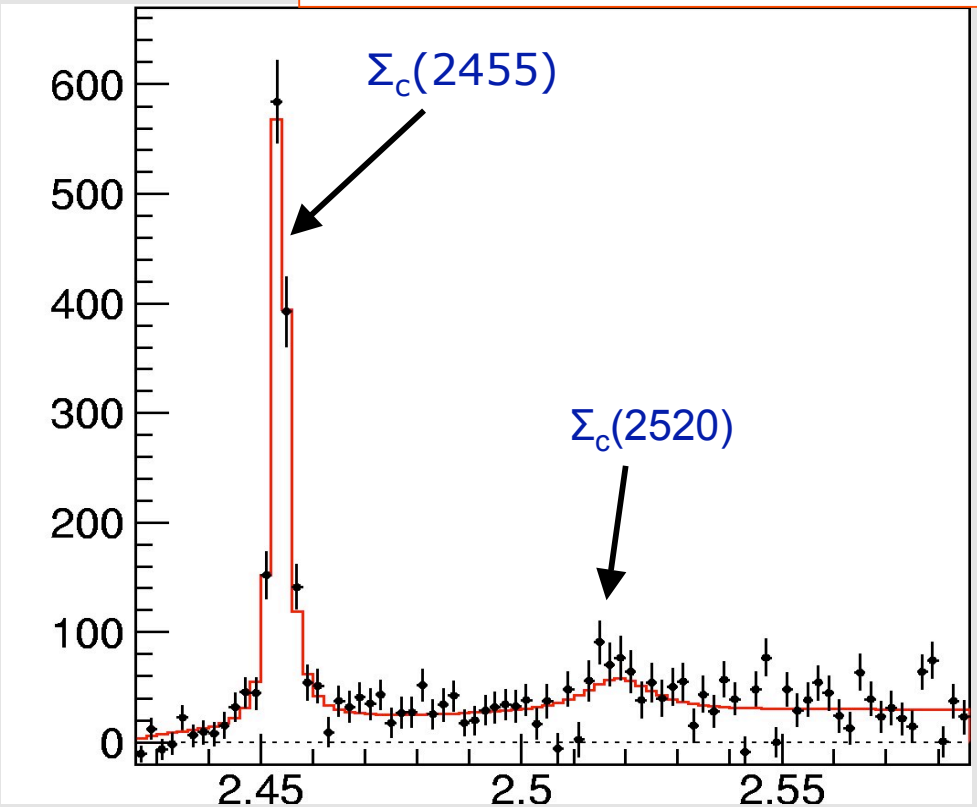
J^P	Mass	
*5/2-	2900	3130
7/2-	3125	
*5/2+	2910	3140
7/2+	3175	

Capstick, Isgur PRD34,2809(1986)

Belle: Observation of $\Lambda_c(2880)^+ \to \Sigma_c^* \pi$

hep-ex/0608043

$\Lambda_c(2880)^+$ yield vs. $M(\Lambda_c \pi^\pm)$



	CLEO	Belle
$\Gamma(\Sigma_c(2455)\pi^\pm)/\Gamma(\Lambda_c^+\pi^+\pi^-)$	$(31 \pm 6 \pm 3)\%$	$(39.8 \pm 2.1^{+1.6}_{-0.5})\%$
$\Gamma(\Sigma_c(2520)\pi^\pm)/\Gamma(\Lambda_c^+\pi^+\pi^-)$	$< 11\%$	$(9.6 \pm 2.5^{+0.5}_{-1.5})\%$
$\Gamma(\Sigma_c(2520)\pi^\pm)/\Gamma(\Sigma_c(2455)\pi^\pm)$	–	$(24.1 \pm 6.4^{+1.1}_{-4.5})\%$

Crutial for the constraint of the $\Lambda_c(2880)^+$ J^P $\Rightarrow$

Heavy Quark Symmetry: (Isgur, Wise PRL66,1130(1991))

5/2- $L=1\ s_{light}=1\ j_{light}=2 \Rightarrow \Gamma(\Sigma c^*\pi) / \Gamma(\Sigma c\pi) = 140\%$

5/2+ $L=2\ s_{light}=0\ j_{light}=2 \Rightarrow \Gamma(\Sigma c^*\pi) / \Gamma(\Sigma c\pi) = 23\%$

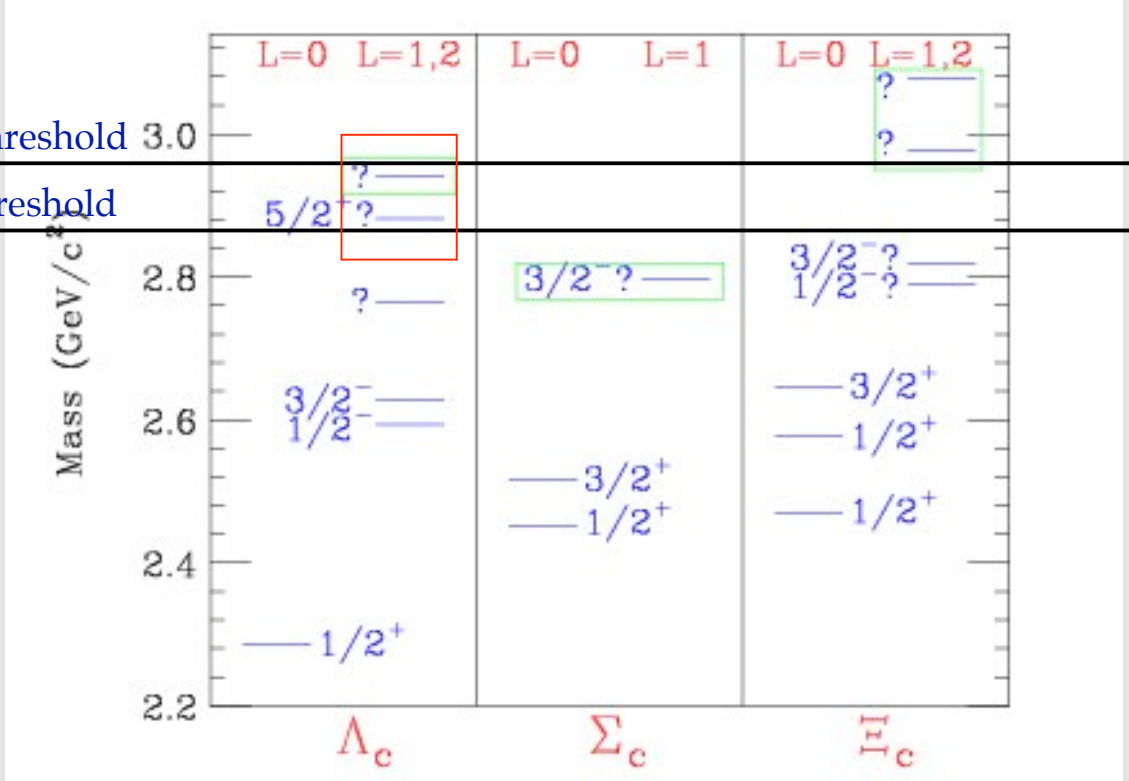
Summary for New Charm Baryons

New charm baryons with new decay mechanism were discovered by BaBar and Belle:

Studies of their properties are ongoing

$\Lambda_c(2880)^+ \to \Sigma_c\pi$ and D^0p (!), but
$\Lambda_c(2940)^+ \to$ mostly to D^0p,
$\Sigma_c\pi$ suppressed

$\Xi_{cx}(2980) \to \Xi_c^*\pi$ and $\Lambda_cK\pi$ ($\Sigma_c\pi$), but
$\Xi_{cx}(3077) \to$ only to $\Lambda_cK\pi$ ($\Sigma_c^{(*)}\pi$),
no signal for $\Xi_c^*\pi$



The list of new particles with not properly understood properties has been widen.

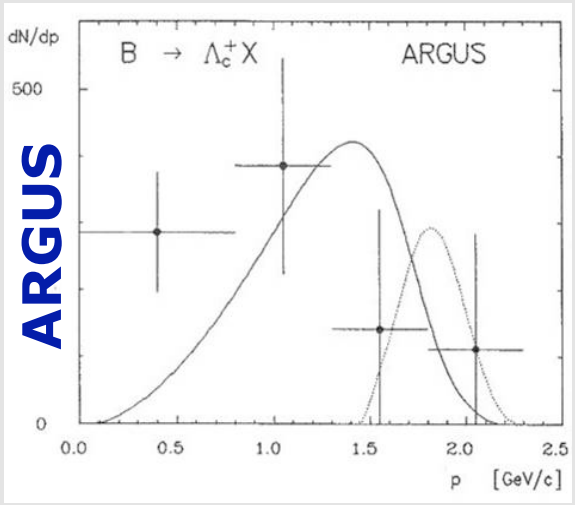
Charm Baryon Spectroscopy at B-Factories: Achievements and Perspectives:

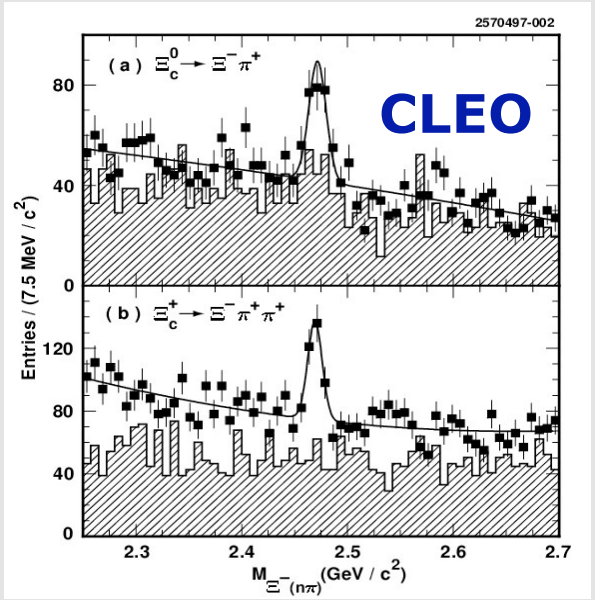
Several new decay modes of Λ_c^+ were observed;
Several new states were discovered.

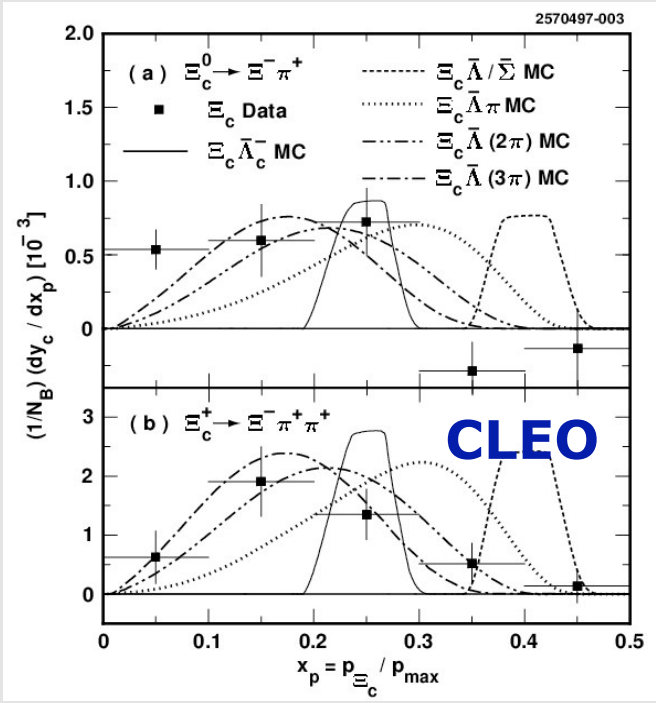
- **Ξ_{CX} and $\Lambda_c(2940)^+$ properties should be studied further;**
- **New searches unambiguously are necessary, e.g.:**
  - *** confirmation of Ω_c^{*0}**
  - *** search for orbitally excited Ω_c^0**
  - *** … continue to search for the processes resulting in production of double charm baryons.**
- **Measurement of Ξ_c absolute Br and precision measurement of Λ_c^+ Br.**

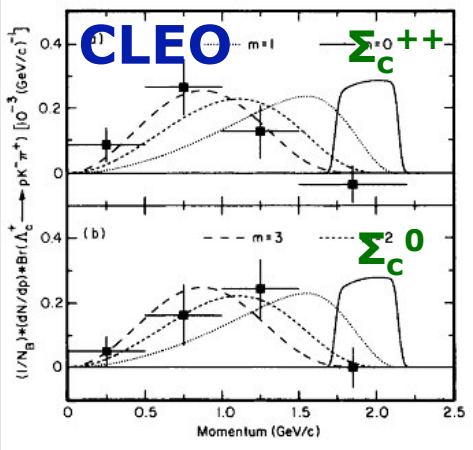
Charm Baryons from B-decays

Observation of Inclusive Production of Λ_c, Ξ_c, Σ_c at old years at ARGUS and CLEO







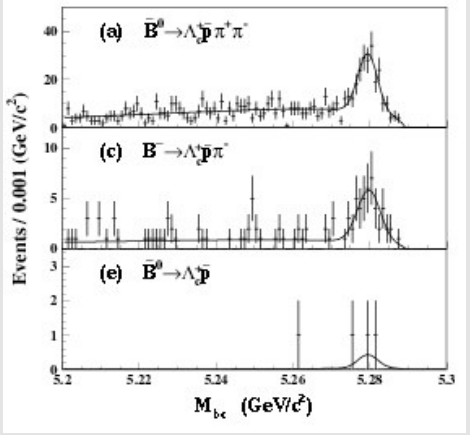


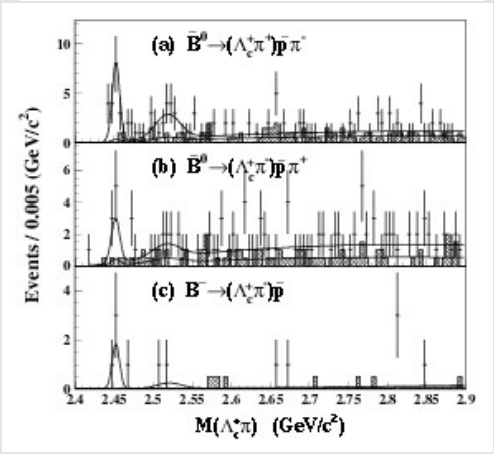
First evidences for softness of momentum spectra of charm baryons from B decays ➡ **Multibody charmful baryonic B decays are prefered?**

Study of $\bar{B}^0 \to \Lambda_c^+ \bar{p}\, n\pi$ at Belle

Belle

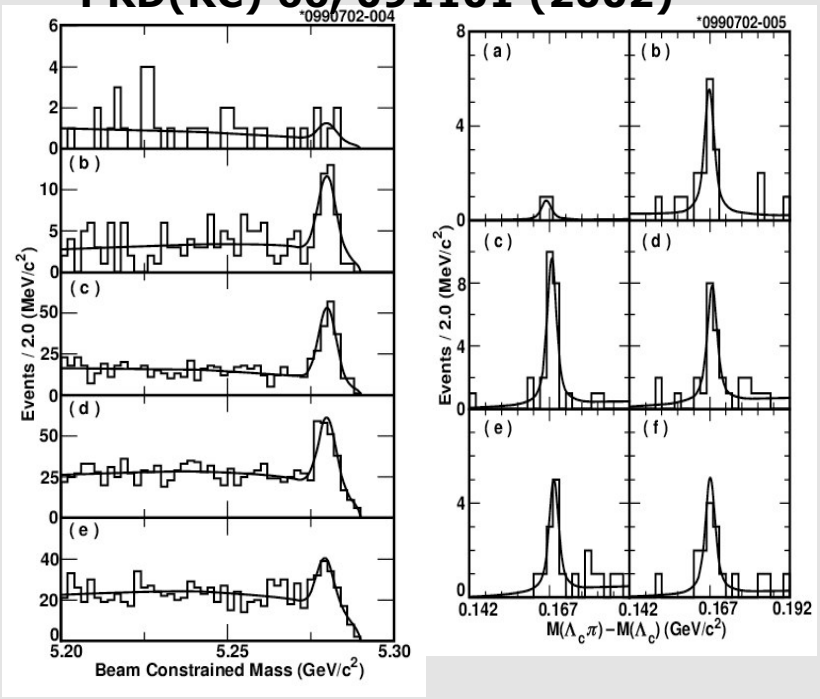
PRD(RC) 66, 091102 (2002)





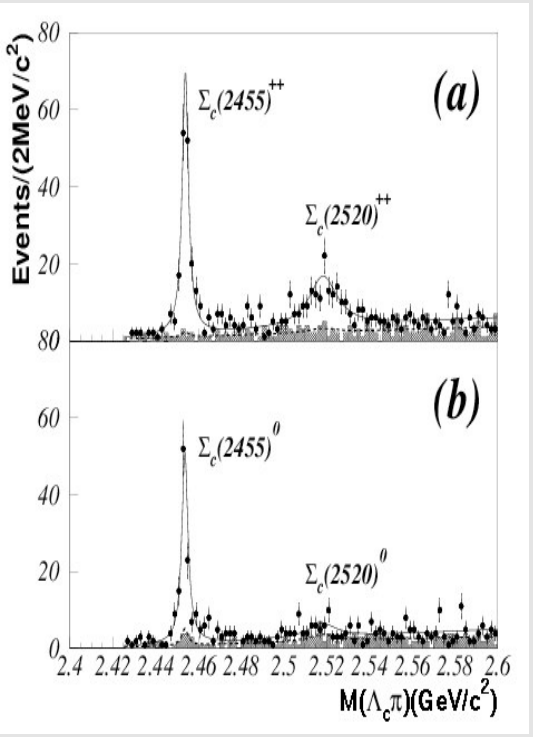
CLEO

PRD(RC) 66, 091101 (2002)



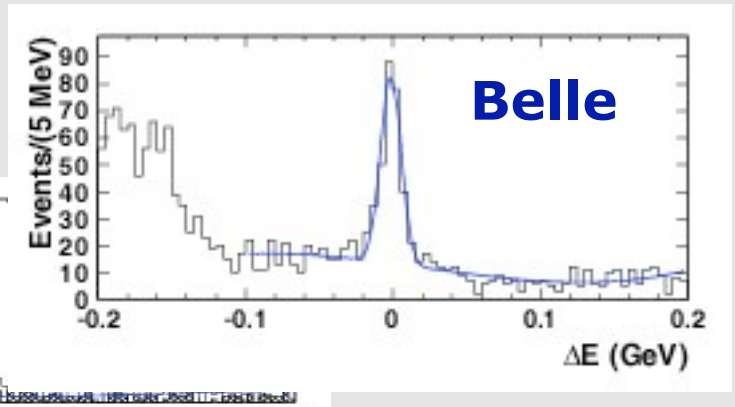
Belle hep-ex/0608025

To appear in PRD(RC)

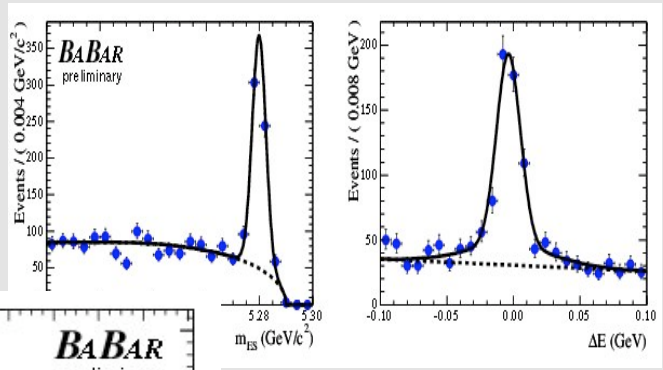


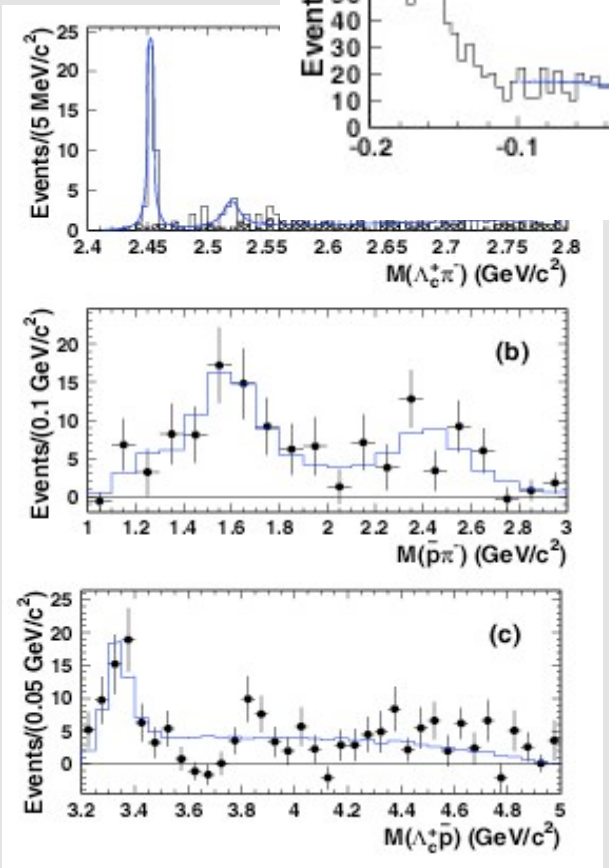
Variety of decays and final states
+ prominent resonant substructure

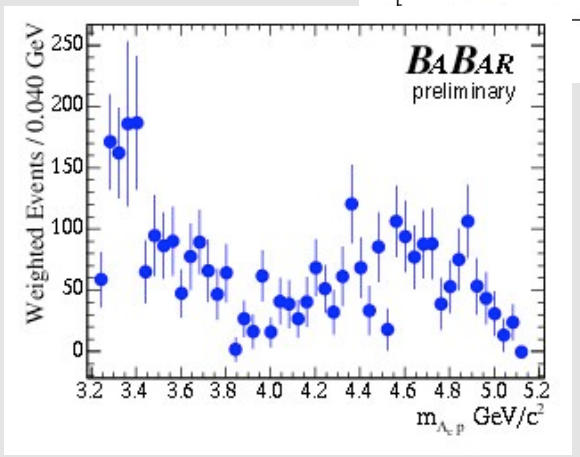
Study of $B^+ \to \Lambda_c^+ \bar{p} \pi^+$ at Belle



Br~10^{-4}







hep-ex/0607055

PRL 97, 242001 (2006)

An enhancement of the dibaryon invariant mass near threshold !

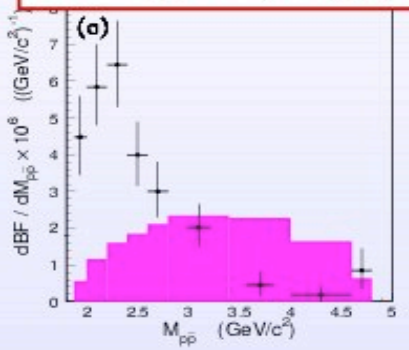
Extensive Theoretical study

Threshold peaking effect observed at Belle

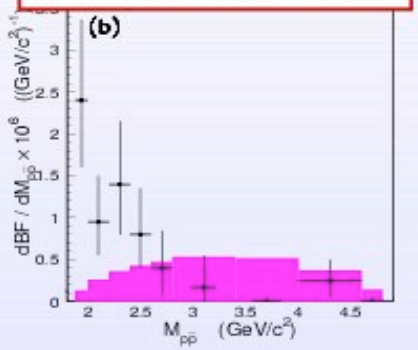
Threshold enhancement was first conjectured by Hou and Soni (PRL 86, 4247 (2001))

3-body baryonic B decays observed recently by Belle (latest review hep-ex/0505098):

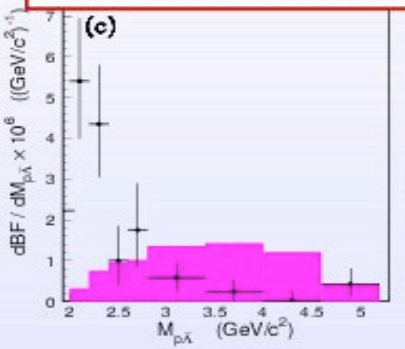
$B^+ \to p\bar{p}K^+,\ M(p\bar{p})$



$B^0 \to p\bar{p}K^0_S,\ M(p\bar{p})$

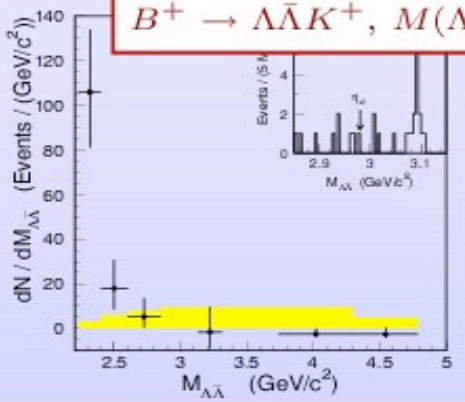


$B^0 \to p\bar{\Lambda}\pi^-,\ M(p\bar{\Lambda})$

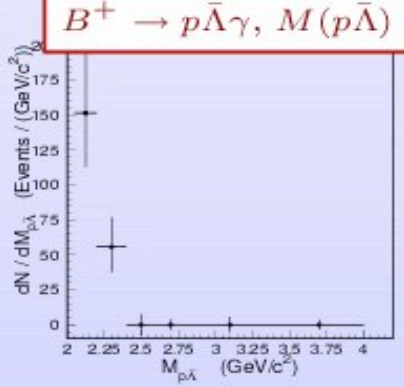


Histograms are phase space expectation

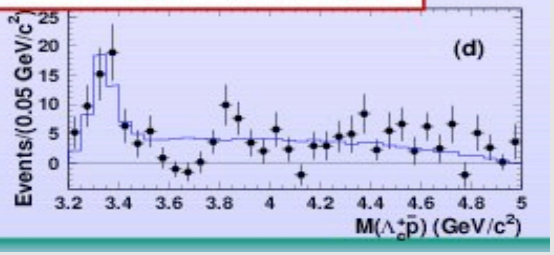
$B^+ \to \Lambda\bar{\Lambda}K^+,\ M(\Lambda\bar{\Lambda})$



$B^+ \to p\bar{\Lambda}\gamma,\ M(p\bar{\Lambda})$



$B^- \to \Lambda_c^+\bar{p}\pi^-,\ M(\Lambda_c^+\bar{p})$



Discussion of Baryonic B Decays

At the same time 2-body charmless baryonic B decays have not been observed yet and best @90% CL Upper Limits from Belle :

$\mathcal{B}(B^0 \to p\bar{p}) < 4.1 \times 10^{-7}$ $\mathcal{B}(B^0 \to \Lambda\bar{\Lambda}) < 6.9 \times 10^{-7}$

$\mathcal{B}(B^+ \to p\bar{\Lambda}) < 4.9 \times 10^{-7}$ (Phys.Rev. D71 (2005) 072007)

But multi-body charmfull baryonic B decays such as $B \to \Lambda_c^+ \bar{p}\pi^+\pi^-$ have $\mathcal{B}$'s ~ 10 times larger than charmfull 3-body modes (e.g. $B^- \to \Lambda_c^+ \bar{p}\pi^-$) and ~ 100 times larger than observed by Belle $B^0 \to \Lambda_c^+ \bar{p}$ (Phys.Rev.Lett. 90, 121802 (2003)).

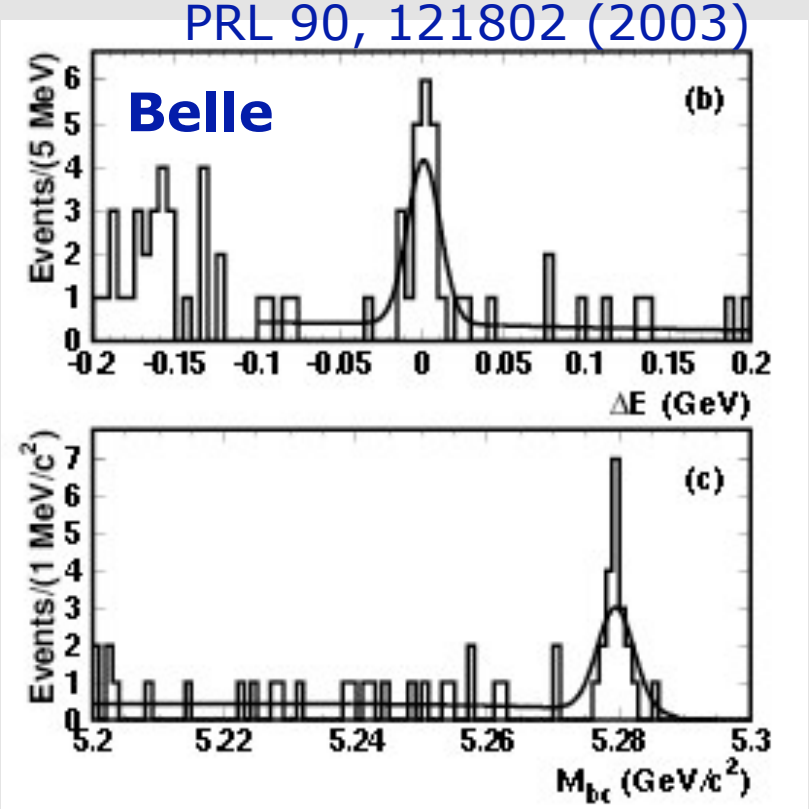
Two features of $B \to$ *baryons* decays observed by Belle:
threshold enhancement in baryon pair invariant mass spectra and
$\mathcal{B}(B \to 2\text{body}) < \mathcal{B}(3\text{body}) < \mathcal{B}(B \to 4\text{body})$ hierarchy.

Theoretical models to explain it: intermediate gluonic resonant states or non-perturb.QCD effects in the quark fragmentation.

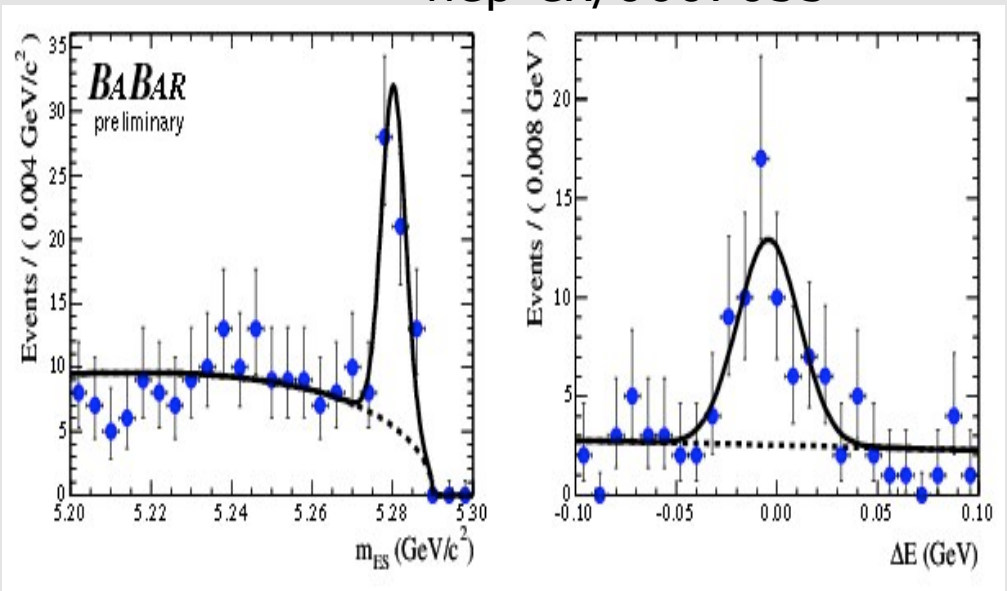
What about 2-body charmful baryonic B decays?

Belle: First Observation of $\bar{B}^0 \to \Lambda_c^+ \bar{p}$

PRL 90, 121802 (2003)



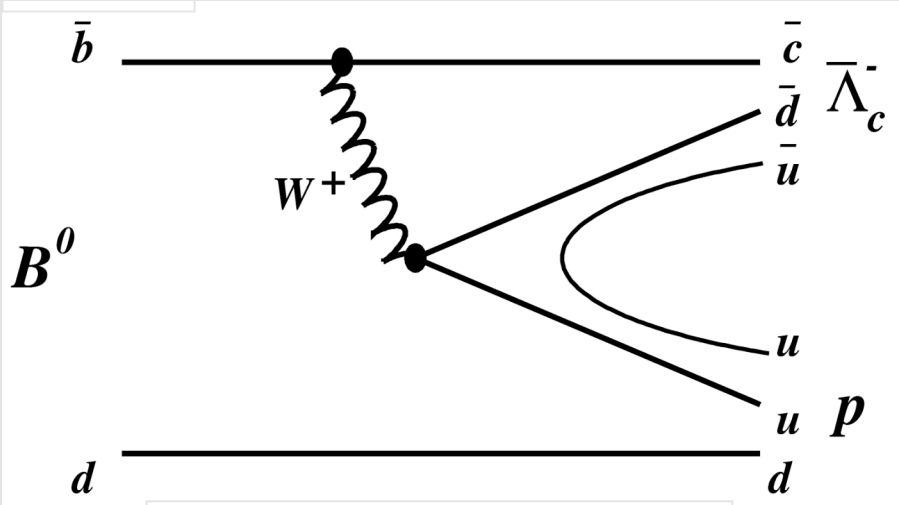
hep-ex/0607055



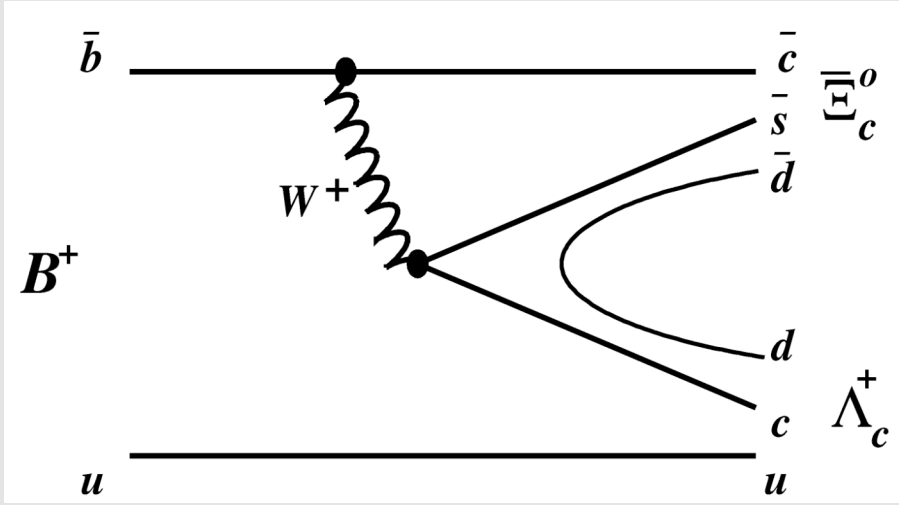
Br~10^{-5} → **B_cBM(~10^{-4}) >B_cB(~10^{-5})**

$B^0 \to \Lambda_c^- p$ and $B^+ \to \bar{\Xi}^0_c \Lambda_c^+$

Belle



PRL 90, 121802 (2003)



One can expect Br ~ 10^{-5}

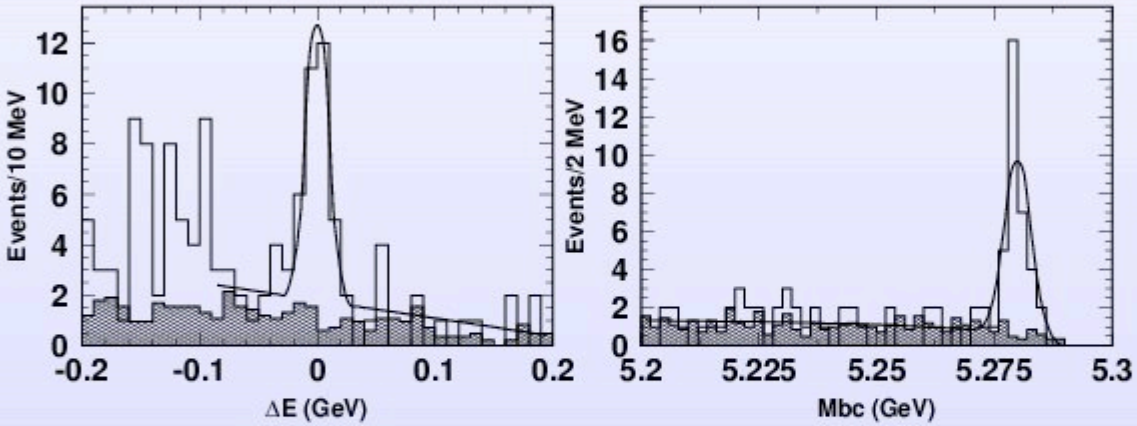
Br=(2.19+0.56-0.49+-0.32+-0.57)x 10^{-5}

Consistent with the pole model prediction
but 100 times smaller than
QCDsum rule predictions and diquark models

Belle: Observation of $B^+ \to \bar{\Xi}^0_c \Lambda_c^+$

PRD(RC) 74, 111105 (2006)

Model based on QCD sum rules predicts $\mathcal{B}(B \to \bar{\Xi}_c \Lambda_c^+) \sim 10^{-3}$
(V.L.Chernyak, I.R.Zhitnitsky, Nucl.Phys. B345, 137 (1990))



8.7σ stat. signif.

$$\mathcal{B}(B^+ \to \bar{\Xi}_c^0 \Lambda_c^+) \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (4.8^{+1.0}_{-0.9} \pm 1.1 \pm 1.1) \times 10^{-5}$$

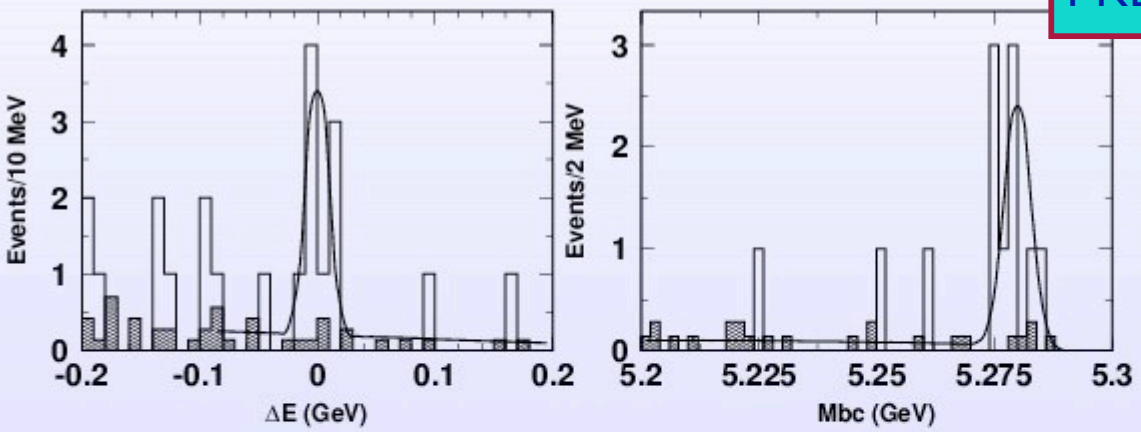
New type of B decays: 2body decay $B \to 2$ charmed baryons

If $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) \sim 1\% \Rightarrow \mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{p})$ is ~100 times smaller

Br ~ 10^{-3} !

Evidence for $B^0 \to \bar{\Xi}^-_c \Lambda_c^+$ at Belle

PRD(RC) 74, 111105 (2006)



$4\,\sigma$ stat. signif.

$$\mathcal{B}(B^0 \to \bar{\Xi}^-_c \Lambda_c^+) \times \mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) = (9.3^{+3.7}_{-2.8} \pm 1.9 \pm 2.2) \times 10^{-5}$$

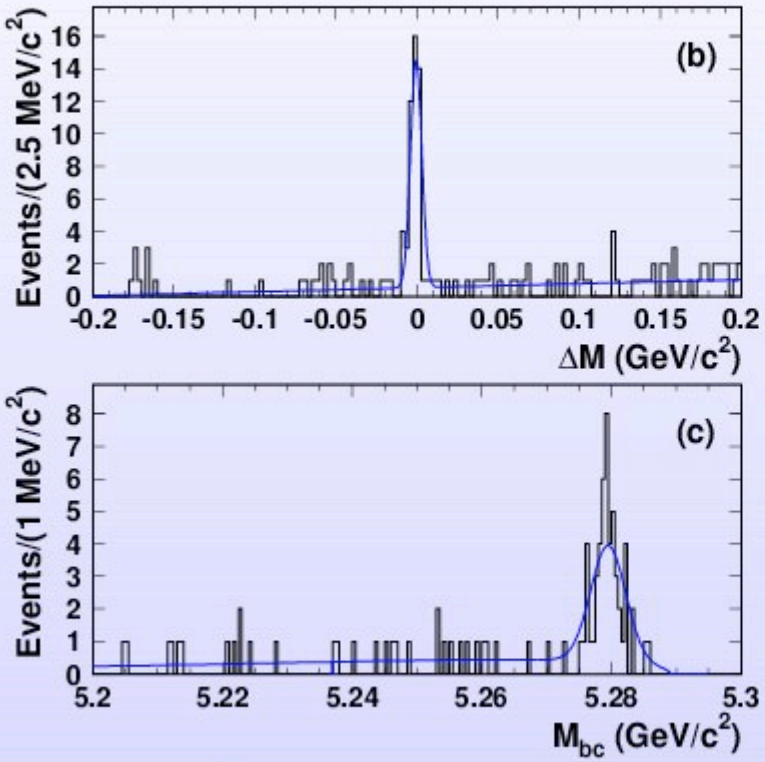
$\Rightarrow$ similar to $B^+ \to \bar{\Xi}^0_c \Lambda_c^+$

For further improvement one needs to know $\mathcal{B}(\Xi_c \to \ldots)$ and precise determination of $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$

This result has stimulated theory to study this effect.
The current explanation is that one soft gluon is needed for BcBc' but two hard gluons are needed for BcB (H.Y.Cheng, C.K.Chua, S.Y.Tsai, PRD 73, 074015 (2006))

Belle: Observation of $B^- \to \Lambda_c^+ \bar{\Lambda}_c^- K^+$

Belle observed significant signal for $B^- \to \Lambda_c^+ \overline{\Lambda}_c^- K^-$ mode:



PRL 97, 202003 (2006)

15.4 σ stat. signif.

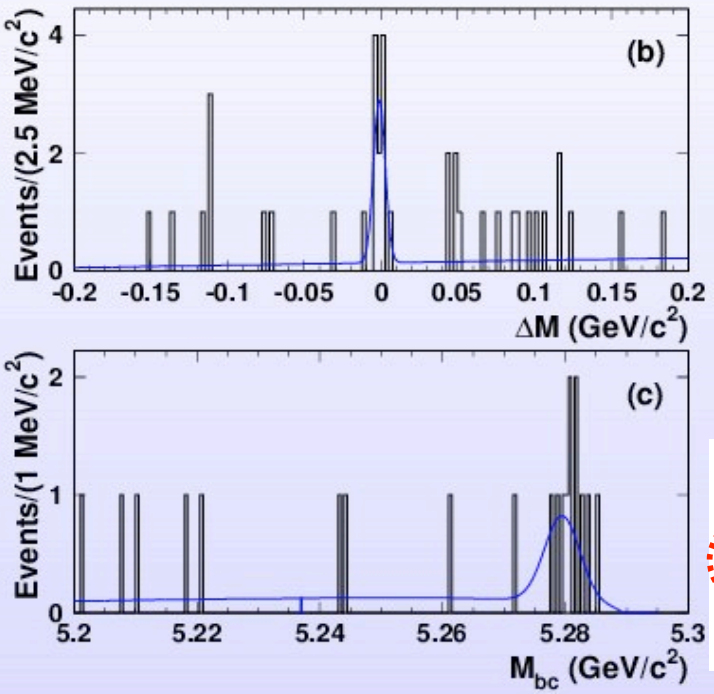
$\mathcal{B}(B^- \to \Lambda_c^+ \overline{\Lambda}_c^- K^-) = (6.5^{+1.0}_{-0.9} \pm 0.8 \pm 3.4) \times 10^{-4}$

The Br's of 2- and 3-body double charm baryonic decays are approximately the same in contrast of single charm baryonic decays.

Another new type of B decays: 3body decay $B \to 2$ charmed baryons

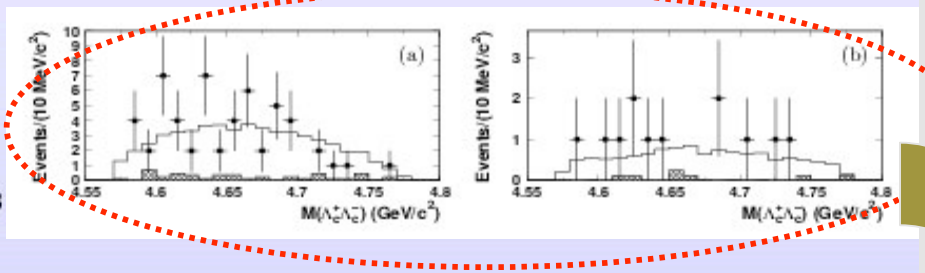
Belle: Observation of $B^0 \to \Lambda_c^+ \bar{\Lambda}_c^- K^0$

PRL 97, 202003 (2006)



6.6 σ stat. signif.

$\mathcal{B}(B^0 \to \Lambda_c^+ \bar{\Lambda}_c^- K_S^0) = (7.9^{+2.9}_{-2.3} \pm 1.2 \pm 4.2) \times 10^{-4}$

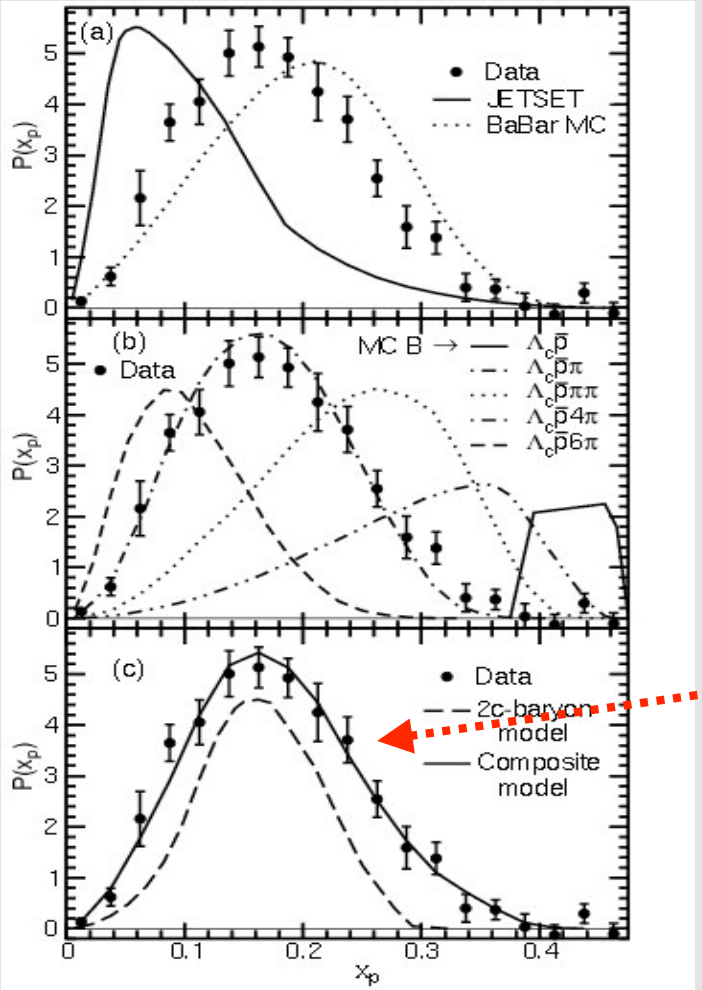


Br($B_c B_c'M$)~ Br($B_c B_c'$)

Further improvement of the observed by Belle $B \to 2$ charmed baryons decay modes is the question of as much as possible precise knowledge of $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$!

No evidence for threshold enhancement!
Decay proceeds through FSI ?..

Study of Λ_c^+ production from B decays at BaBar

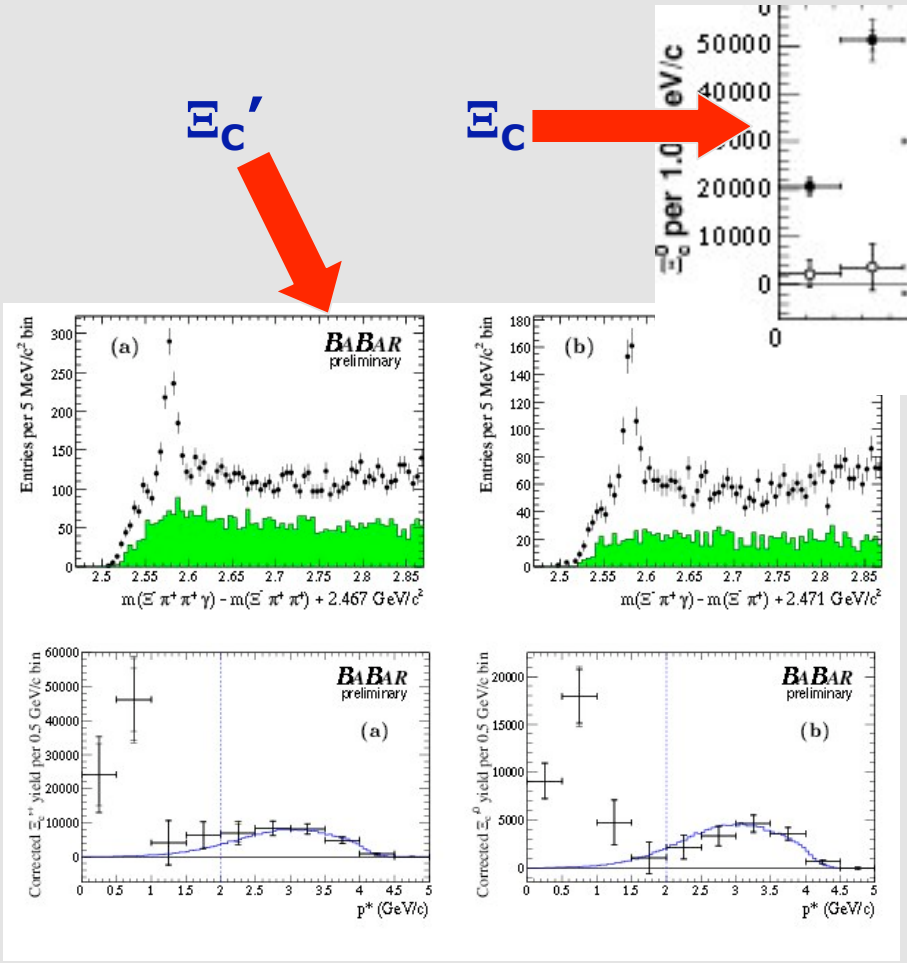


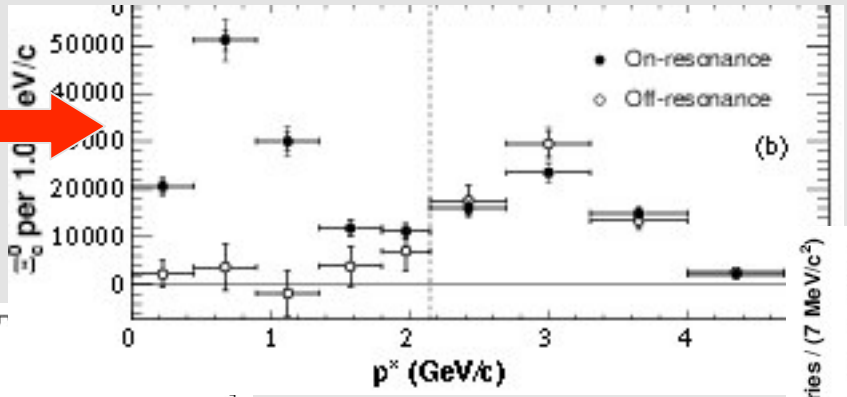
Inclusive momentum spectrum of Λ_c^+ from B decays turn out to be really soft!

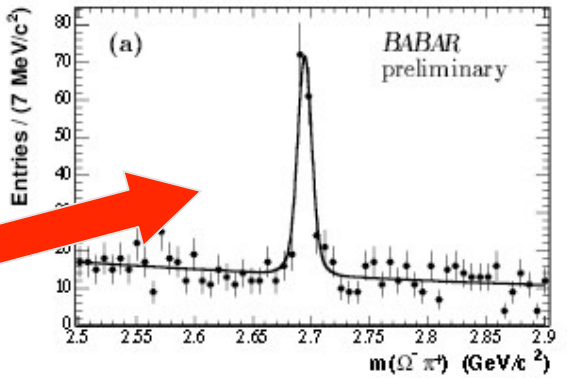
Nearly direct confirmation of Belle results on exclusive B decays to two charm baryons!

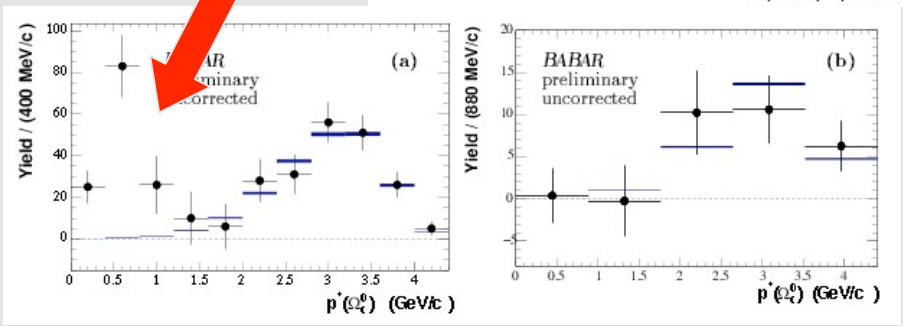
The same situation with inclusive spectra of Ξ_c, Ξ_c' and Ω_c from B decays!

Study of Inclusive Production of Ξ_c, Ξ_c' and Ω_c from B Decays at BaBar

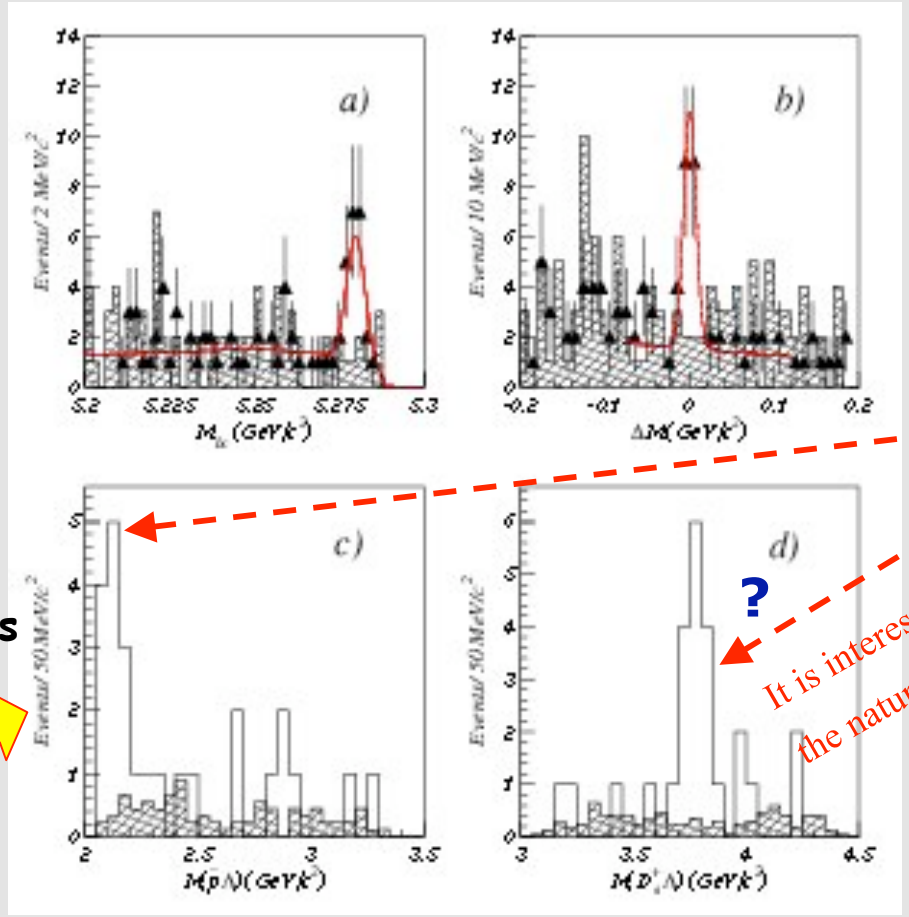






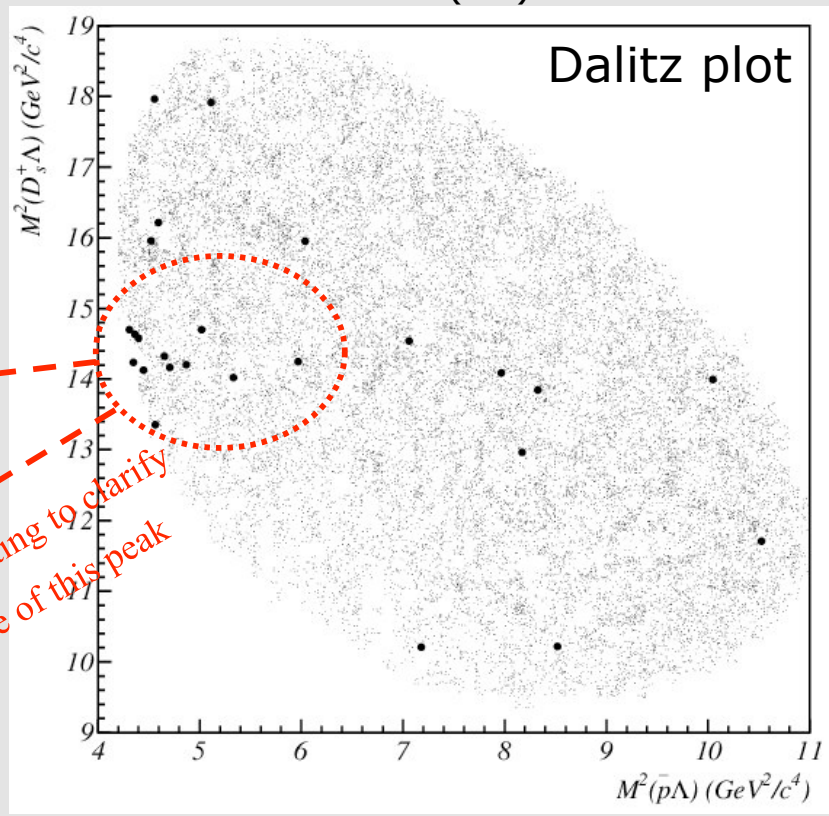


Observation of $\bar{B}^0 \to D_s^+ \Lambda \bar{p}$ at Belle



Threshold peaking of dibaryon mass

To be sumbitted to PRD(RC)



This decay proceeds with creation of ss pair, Br~10^{-5}

FSI $Dp \to D_s^+\Lambda$.. ?

Baryonic B-decays at B-Factories: Achievements and Perspectives

A lot of baryonic B-decay modes were observed;
New QCD effect of threshold peaking of dibaryon mass in baryonic B-decays is established

- **$B \to \Xi_c^{*,\prime} \Lambda_c$ and $\Xi_c^0 \Omega_c^0$ should be searched for to obtain coherent and unique description of 2-body baryonic B-decays;**
- **Searches for another charmful baryonic B-decays proceeding through the creation of ss-bar pair;**
- **Study of threshold enhancement in 3-body $B_c BM$;**

...

Hopefully, B-factories will contribute more soon!