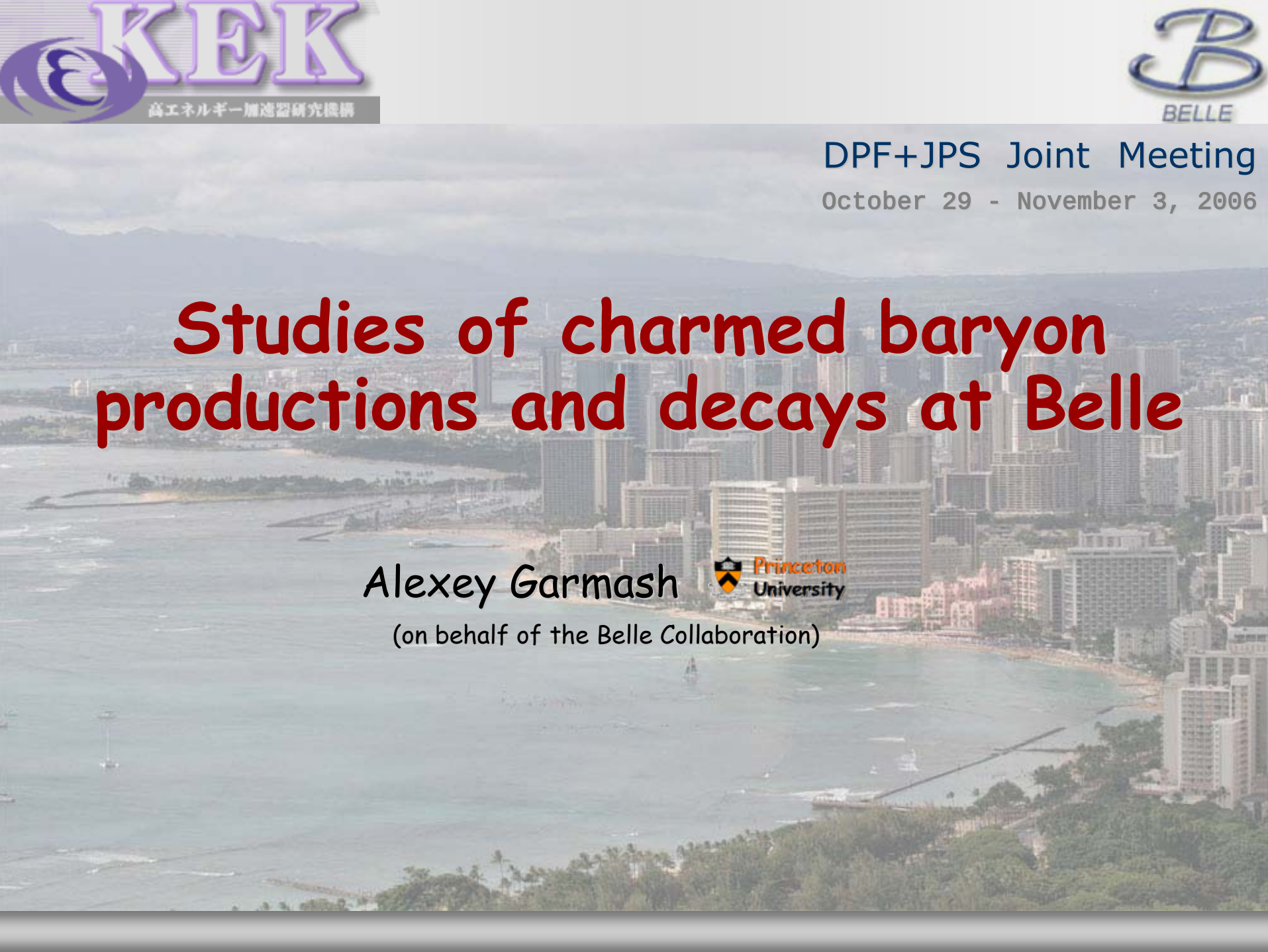


DPF+JPS Joint Meeting

October 29 - November 3, 2006

Studies of charmed baryon productions and decays at Belle

Alexey Garmash

Princeton University

(on behalf of the Belle Collaboration)

KEKB & Belle

Besides being a B-factory KEKB/Belle provides an excellent laboratory to study (charmed) baryons:

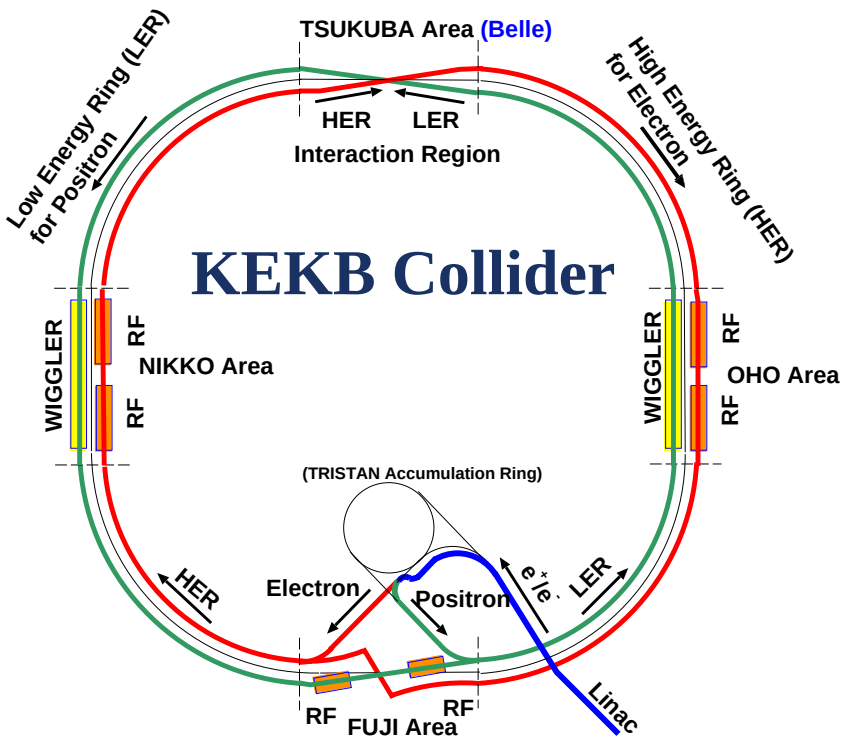
More than 20 (>10% of the total number of) published papers are on processes with baryons in the final state. This includes:

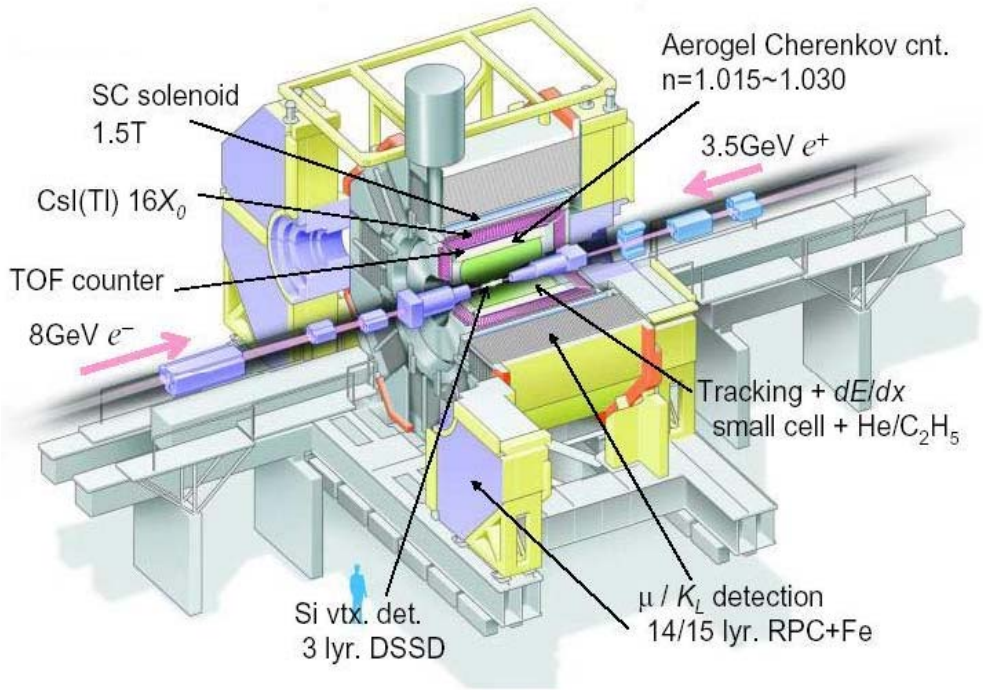
- 5 papers on B decays to final states with charmed baryons
- 3 papers on studies of charmed baryon properties

In this presentation:

- Observation of $\Sigma_c(2800)$
- Observation of new states decaying into $\Lambda_c^+ K^- \pi^+$ and $\Lambda_c^+ K_S \pi^-$
- Measurement of the $\Xi_c(2645)$ and $\Xi_c(2815)$ masses
- $\Lambda_c^+(2940)$ and study of the $\Lambda_c^+(2880)$

KEKB & Belle





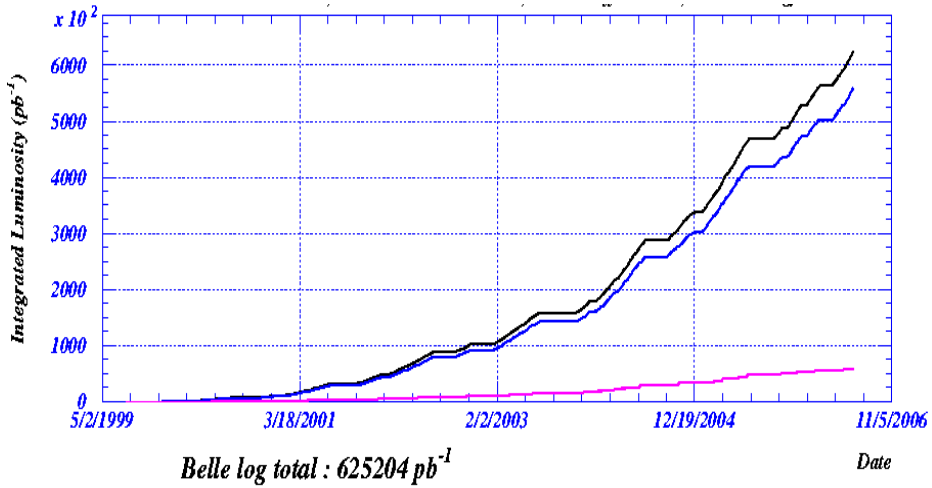
3.5 GeV e^+ & 8.0 GeV e^- beams

3 km circumference

± 11 mrad crossing angle

$L = 1.65 \times 10^{34}\ cm^{-2}s^{-1}$ (world record)

$\int L\,dt = 625\ fb^{-1}$ @ $\Upsilon(4S)$+off(~10%)



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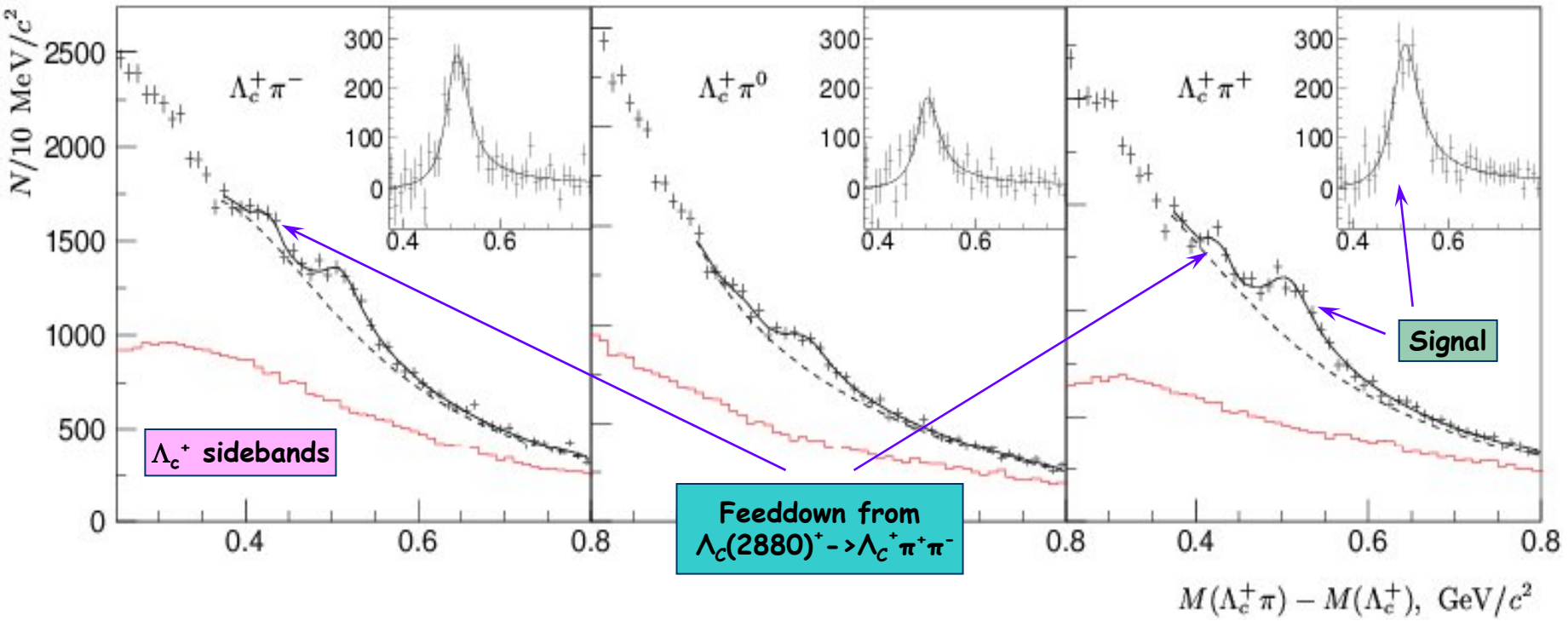
$\Sigma_c(2800)$: Observation

$\Lambda_c^+ \to pK^-\pi^+$, $x_p(\Lambda_c) > 0.5$



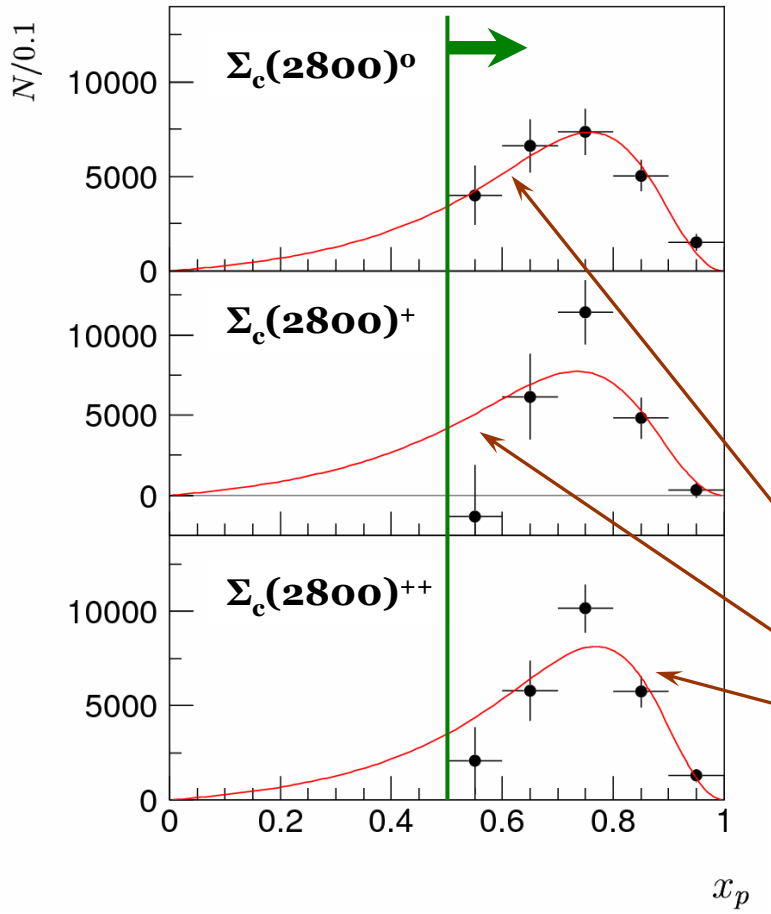
NEW CHARMED ISOTRIPLET!

PRL **94**, 122002, 2005

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}

$\Sigma_c(2800)$: Continuum Production

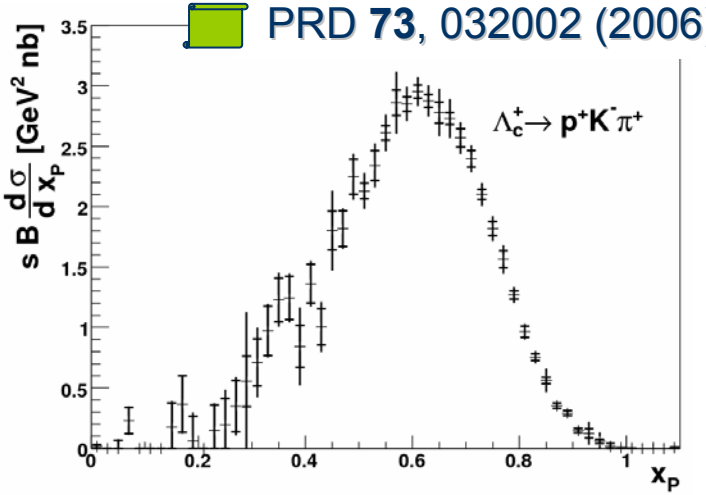
Scaled momentum distribution:



$$x_p \equiv p^* / \sqrt{E^{*2}_{\text{beam}} - M^2}$$

*calculated in the c.m. frame

PRD **73**, 032002 (2006)



Fit with Peterson parameterization

$$dN/dx_p \sim x_p^{-1}[1 - 1/x_p - \epsilon/(1-x_p)^2]^{-2}$$

$\Sigma_c(2800)$ x_p distribution is typical for charmed particle produced in e^+e^- ->cc continuum events

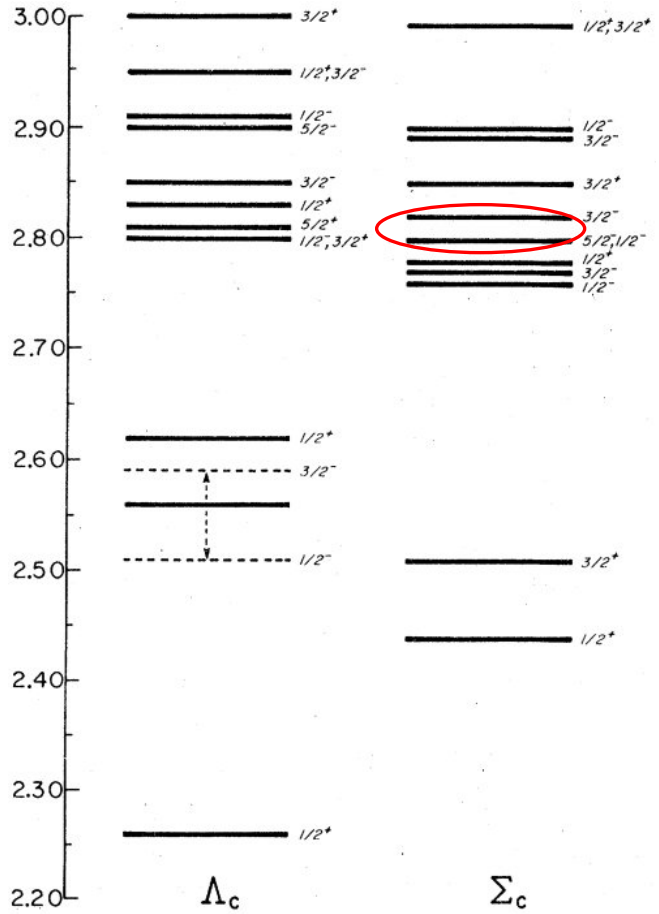
$\Sigma_c(2800)$: Identification

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)].

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

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

However, Σ_{c2} $(3/2^-)$ can mix with the nearby Σ_{c1} $(3/2^-)$ resulting in a wider physical state.



- Observation of $\Sigma_c(2800)$
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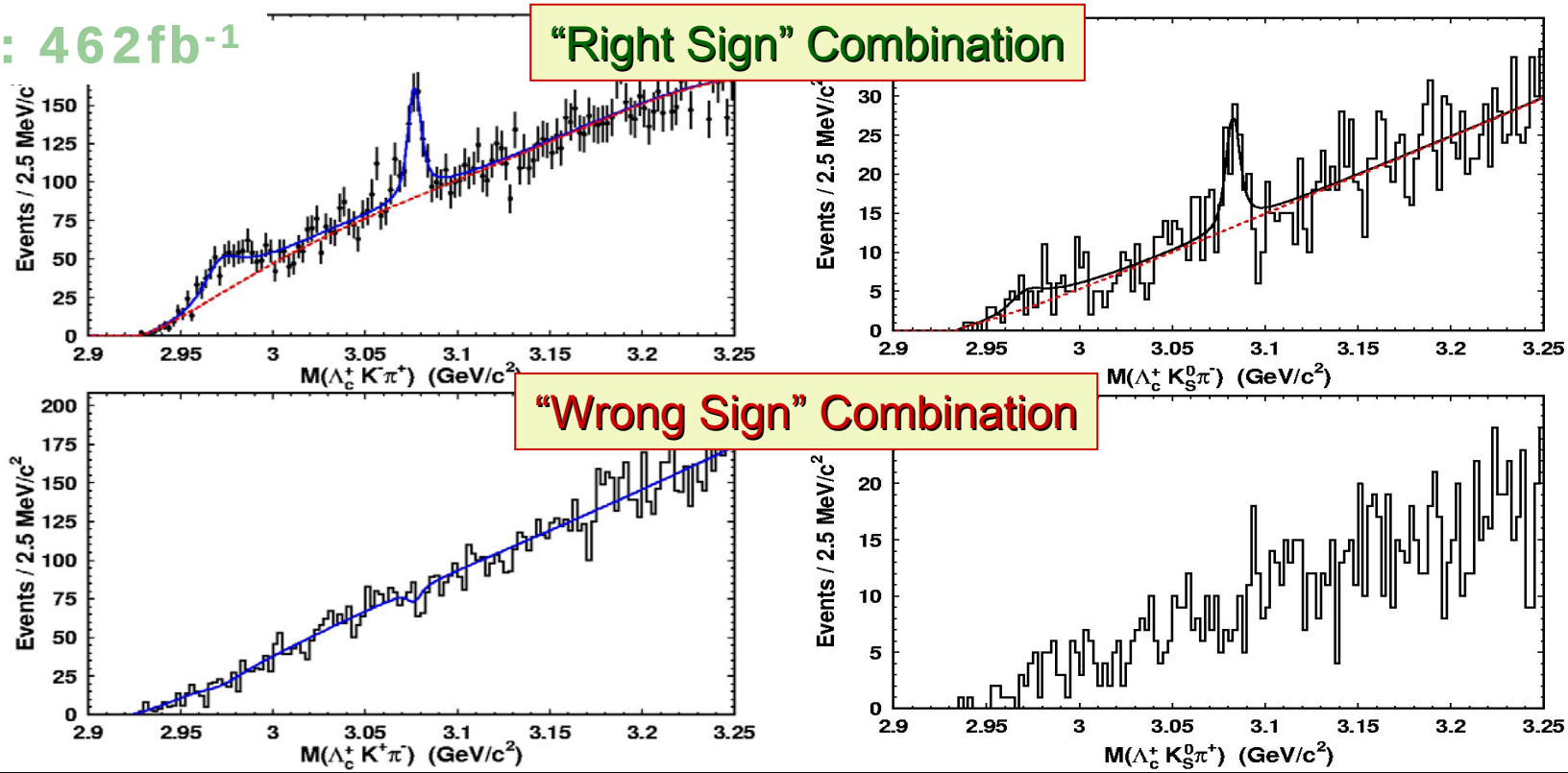
Observation of $\Xi_{cx}(2980)$ & $\Xi_{cx}(3077)$

Belle: 462fb^{-1}



	Yield	Mass, MeV/c^2	Width, MeV	Significance, σ
$\Xi_{cx}(2980)^+$	405 ± 51	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$	6.3 (6 w/ syst.)
$\Xi_{cx}(3077)^+$	326 ± 40	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$	9.7 (9 w/ syst.)
$\Xi_{cx}(2980)^0$	42 ± 24	$2977.1 \pm 8.8 \pm 3.5$	43.5 (fixed)	2.0
$\Xi_{cx}(3077)^0$	67 ± 20	$3082.8 \pm 1.8 \pm 1.5$	$5.2 \pm 3.1 \pm 1.8$	5.1 (5 w/ syst.)

hep-ex/0606051
PRL **97**, 162001 (2006)

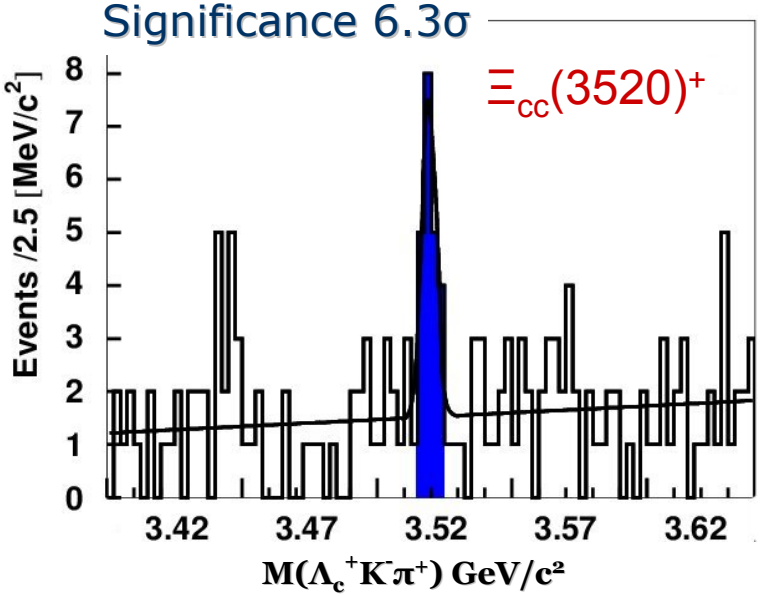
$\Xi_{cx}(2980)$ and $\Xi_{cx}(3077)$ { non-zero widths; c- and s-quarks } $\Rightarrow$ *excited charm strange baryons*

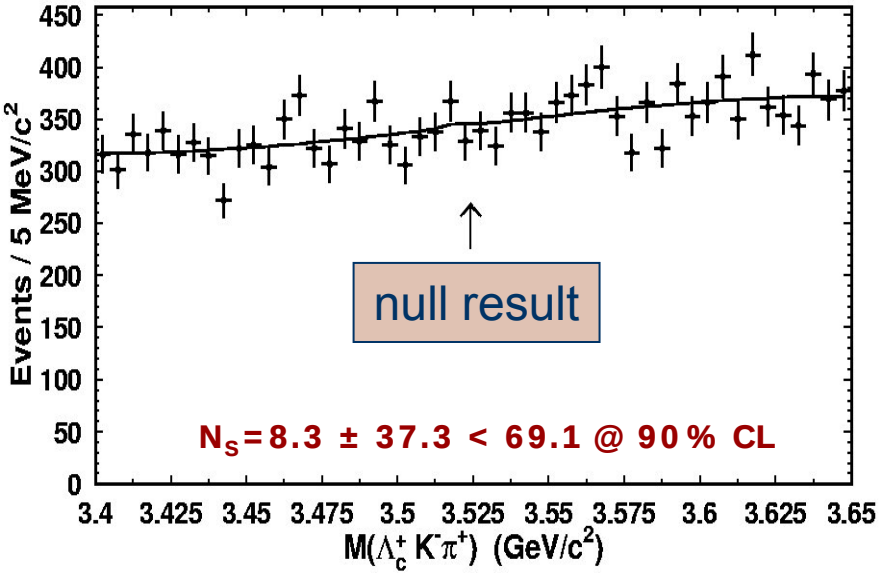
Search for SELEX State $\Xi_{cc}(3520)$

SELEX:
PRL **89**, 112001 (2002)

Belle:
PRL **97**, 162001 (2006)

Significance 6.3σ





With 835360±13748 reconstructed $\Lambda_c^+ \to pK^-\pi^+$ decays

$$\frac{\sigma(\Xi_{cc}(3520)^+)\times\mathcal{B}(\Xi_{cc}(3520)^+\to\Lambda_c^+K^-\pi^+)\mid p^*(\Lambda_c^+)>2.5\,\mathrm{GeV}/c}{\sigma(\Lambda_c^+)\mid p^*(\Lambda_c^+)>2.5\,\mathrm{GeV}/c} < 1.5\times10^{-4}\ @\ 90\%\ \mathrm{C.L.}$$

⇒ No signal of the $\Xi_{cc}(3520)^+ \to \Lambda_c^+ K^-\pi^+$ in e^+e^- annihilations is observed by Belle

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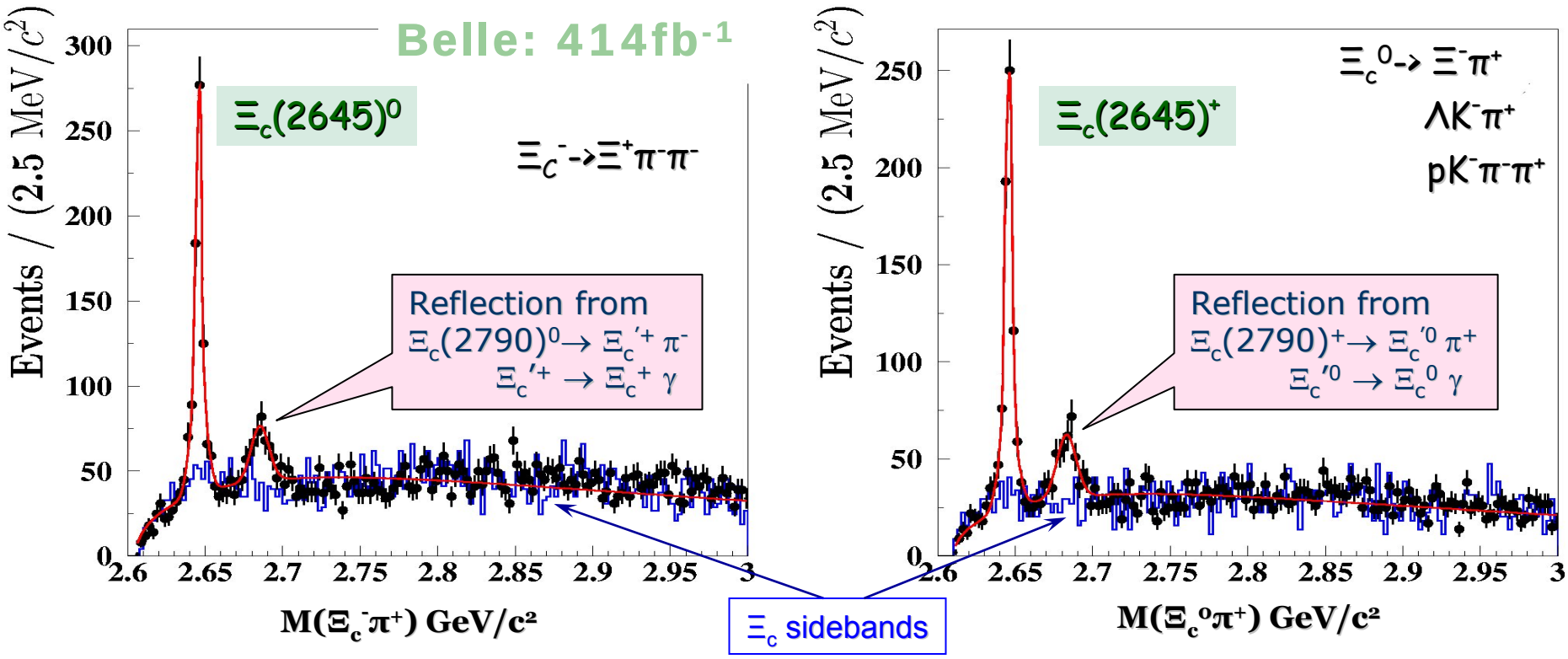
Measurement of the $\Xi_c(2645)$ Mass



Belle PRELIMINARY

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

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

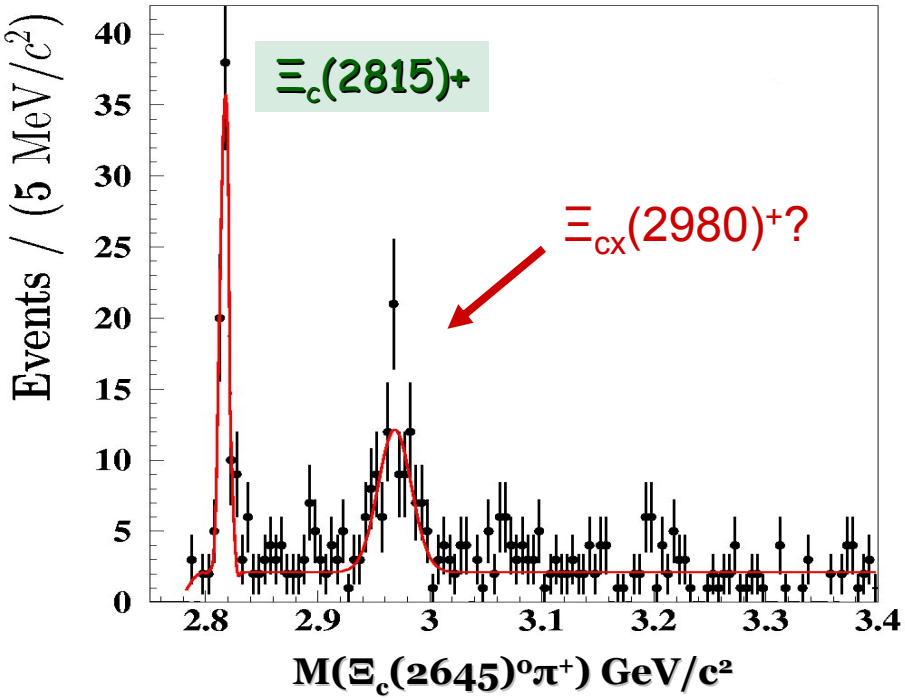
$$m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0} = (-0.2 \pm 0.3(\text{stat}) \pm 0.7(\text{syst}))\ \text{MeV}/c^2$$

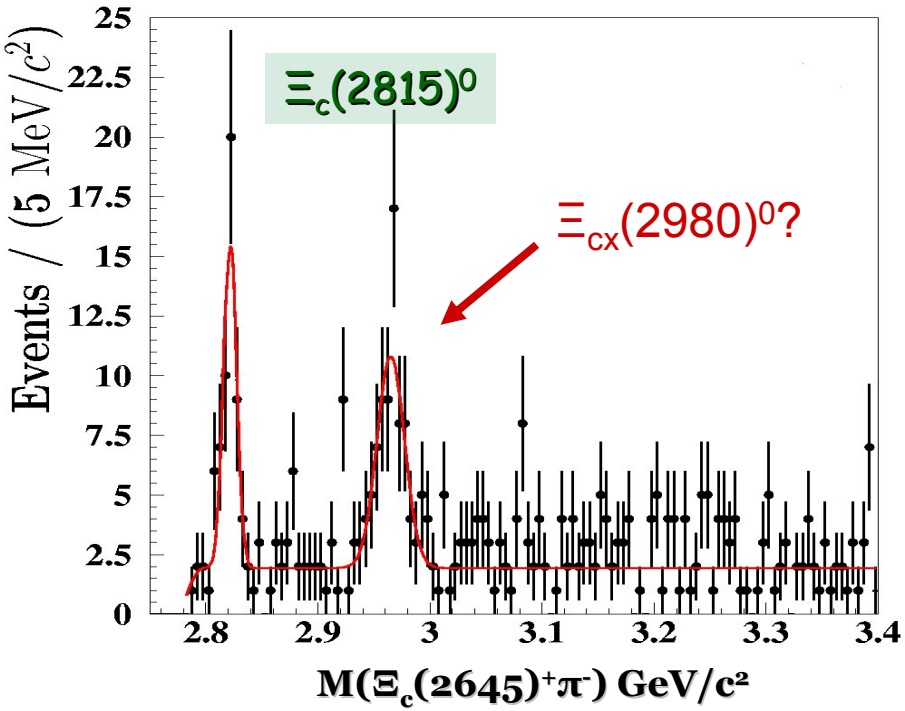
PDG 2006

2646.6 ± 1.4

2646.1 ± 1.2

Measurement of the $\Xi_c(2815)$ mass





Is the second peak a signal of $\Xi_{cx}(2980) \to \Xi_c(2645)\pi$? $\Rightarrow$ further study is needed

Belle PRELIMINARY

$$m_{\Xi_c(2815)^+} = (2816.7 \pm 0.6(\text{stat})^{+0.7}_{-0.8}(\text{syst}))\ \text{MeV}/c^2$$

$$m_{\Xi_c(2815)^0} = (2819.7 \pm 0.8(\text{stat}) \pm 0.9(\text{syst}))\ \text{MeV}/c^2$$

$$m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0} = (-3.0 \pm 1.0(\text{stat}) \pm 0.8(\text{syst}))\ \text{MeV}/c^2$$

PDG 2006

2816.5 ± 1.2

2818.2 ± 2.1

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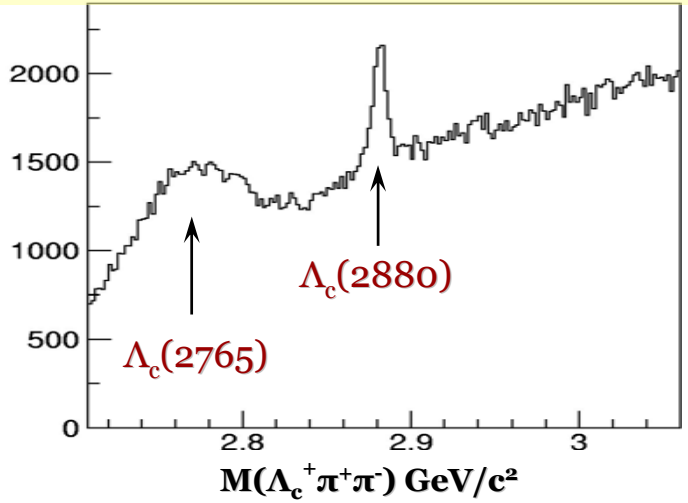
$\Lambda_c(2880)$: Mass Measurement I

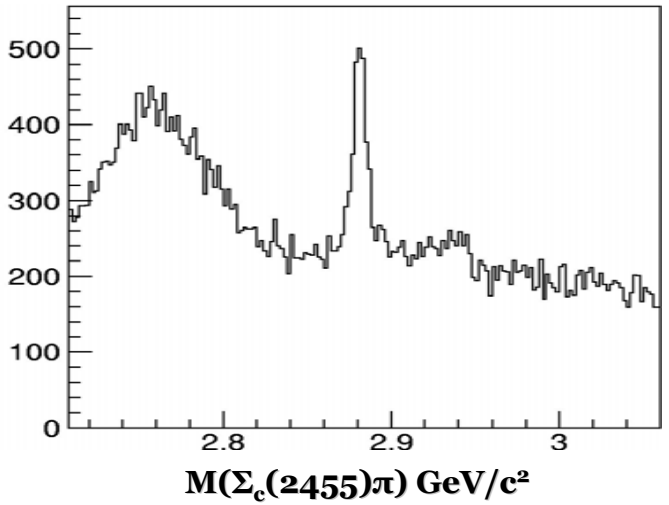
- All $\Lambda_c^+\pi^+\pi^-$ ($\Lambda_c^+ \to pK^-\pi^+$) combinations with $x_p > 0.7$

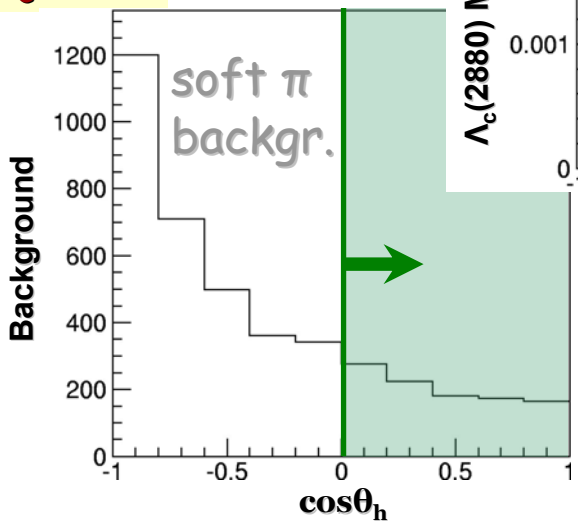
Belle: 553fb^{-1}

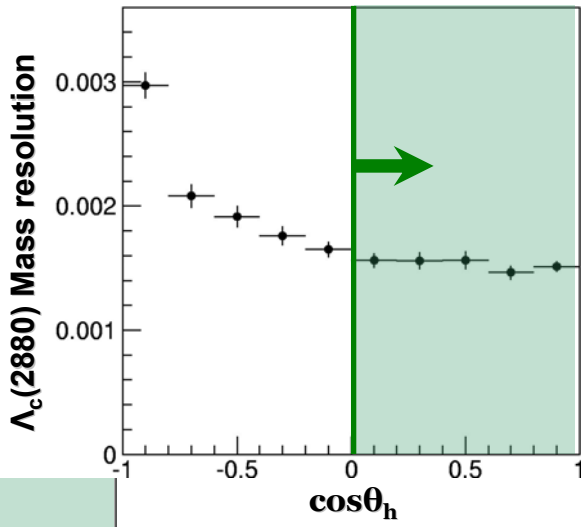


- Define helicity angle for the 2-body $\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi$ decay

- $\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi \to \Lambda_c^+\pi^+\pi^-$



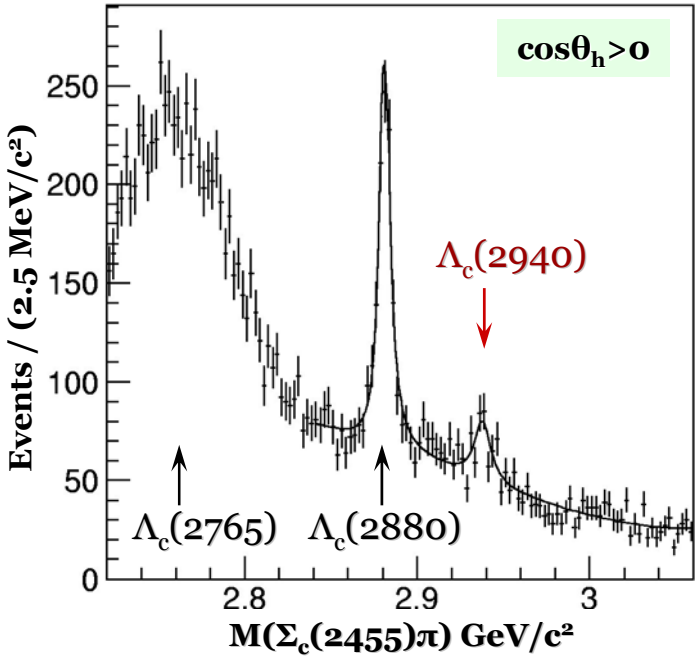




$\Lambda_c(2880)$: Mass Measurement II

- Apply requirement $\cos\theta_h > 0$
- Fit the $M(\Sigma_c(2455)\pi)$ spectrum

Significance of the $\Lambda_c(2940)^+$ signal is 5.6σ (5.1σ with systematic)



Belle PRELIMINARY

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

hep-ex/0608043

BaBar: $\Lambda_c^+ \Rightarrow D^0 p$ $\Rightarrow$

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

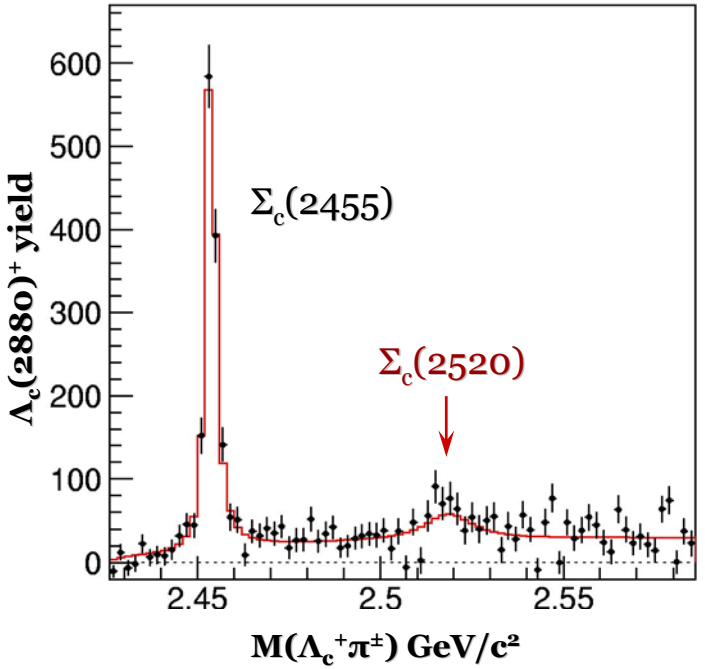
hep-ex/0603052

$\Rightarrow$ Results are consistent

$\Lambda_c^+(2880)^+ \to \Lambda_c^+\pi^+\pi^-$: Resonant substructure

- Release $\cos\theta_h > 0$ requirement
- Release $\Sigma_c(2455)$ requirement
- Fit $M(\Lambda_c\pi^+\pi^-)$ in bins of $M(\Lambda_c\pi^\pm)$

Significance of the $\Lambda_c(2880)^+ \to \Sigma_c(2520)\pi$ signal is 3.7σ (3σ with systematic)



PRL86,4479(2001)

Belle PRELIMINARY

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

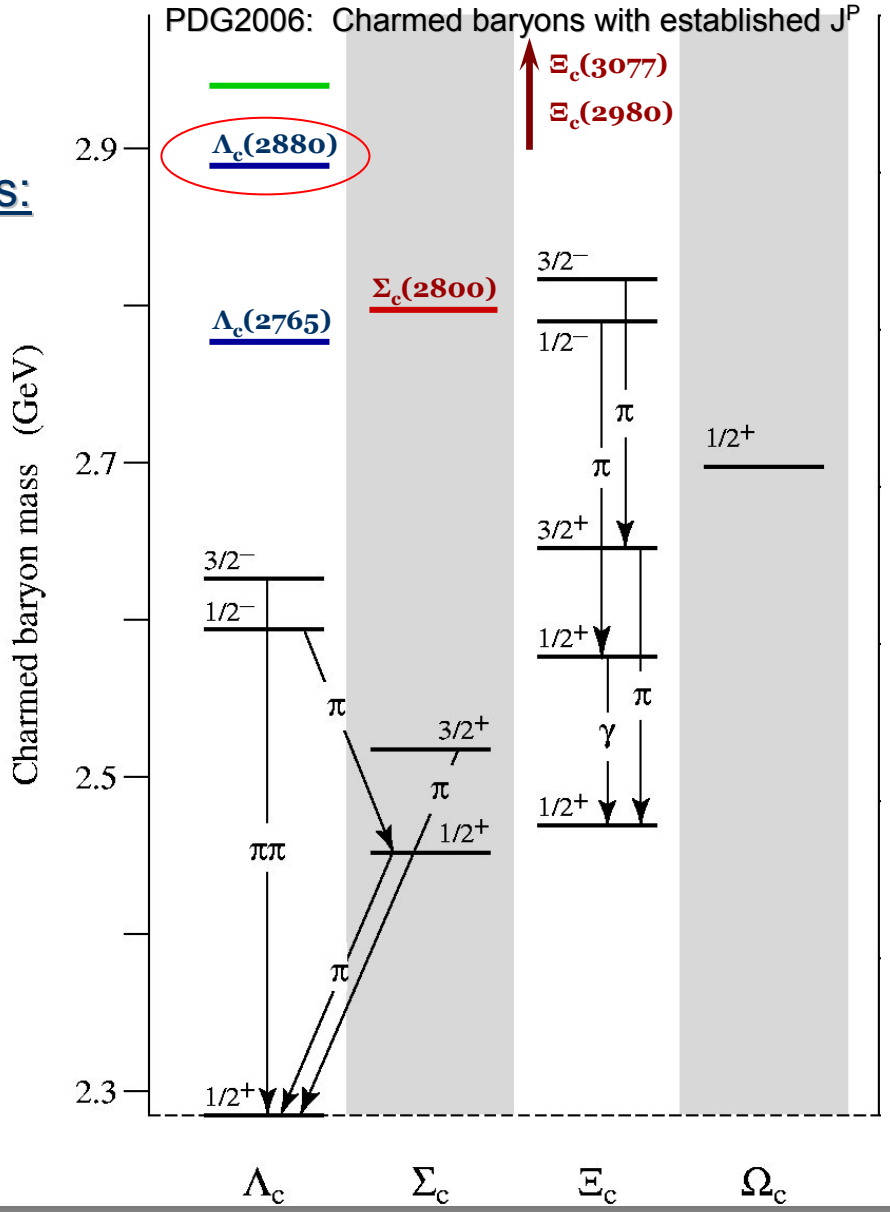
$\Lambda_c(2880)^+ \to \Sigma_c\pi$: Angular Analysis

New states:

CLEO

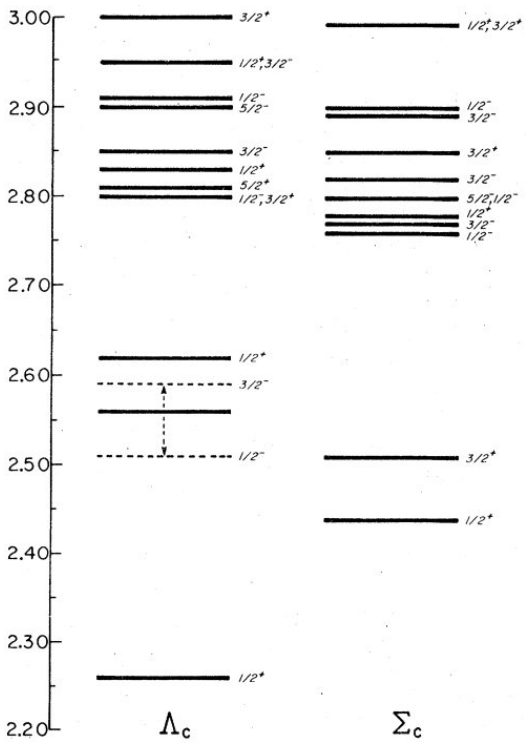
Belle

BaBar



Quark Model predictions

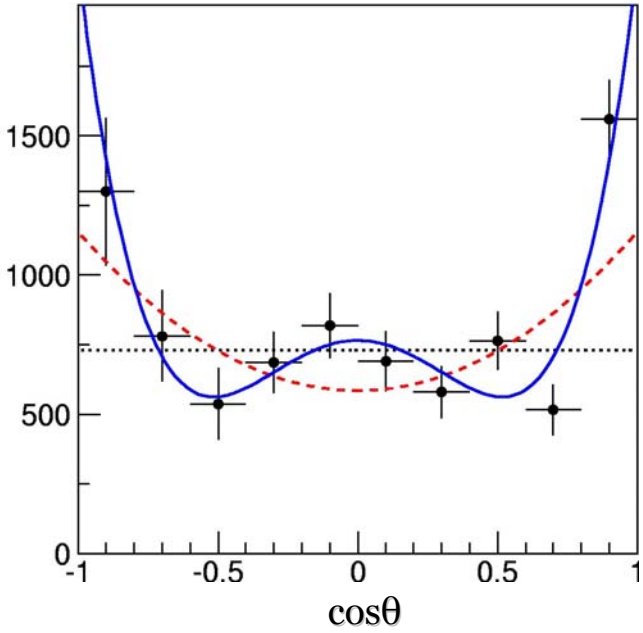
Copley,Isgur,Karl PRD20,768(1979)

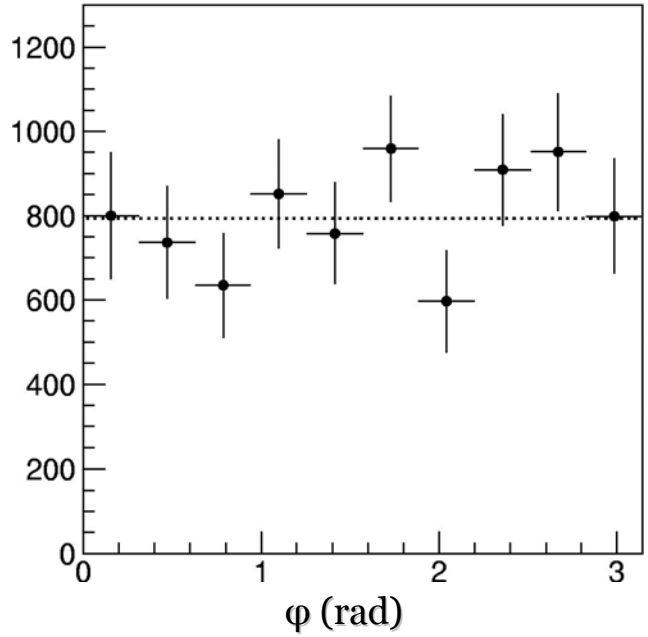


Many levels ⇒ difficult to identify J^P for new states based on M&Γ measurements only ⇒ angular analysis is required

$\Lambda_c(2880)^+ \to \Sigma_c\pi$: Angular Analysis

- Select $\Sigma_c(2455)$
- Fit to $M(\Sigma_c\pi)$ in cosθ and φ bins
- Subtract non-res. contribution using Σ_c sideband
- Correct for efficiency





Parameterization vs. spin of the $\Lambda_c(2880)^+$

J=1/2: W(θ,φ) = const χ^2/d.o.f.= 49.9/9

J=3/2: $$W(\theta,\phi) = \frac{3}{4\pi}[\rho_{33}\sin^2\theta + \rho_{11}(\frac{1}{3} + \cos^2\theta) - \frac{2}{\sqrt{3}}\mathrm{Re}\rho_{3-1}\sin^2\theta\cos 2\phi - \frac{2}{\sqrt{3}}\mathrm{Re}\rho_{31}\sin 2\theta\cos\phi]$$

χ^2/d.o.f.= 36.0/8

J=5/2: W(θ,φ) = P2(cos² θ) χ^2/d.o.f.= 10.8/7

$\rho_{11} = 0.85\pm0.07$ $\rho_{33} = 0.00\pm0.03$ $\rho_{55} = 0.08\pm0.03$

(mainly helicity ±1/2 states are populated)

⇒ J=5/2 hypothesis is strongly favored over 1/2 and 3/2 ones

$\Lambda_c(2880)^+ \to \Sigma_c\pi$: Parity

Quark Model mass prediction:

Capstick, Isgur PRD **34**, 2809(1986)

$J^P=5/2^-$: $M=2900$ MeV/c^2; $M'=3130$ MeV/c^2
$J^P=7/2^-$: $M=3125$ MeV/c^2
$J^P=5/2^+$: $M=2910$ MeV/c^2; $M'=3140$ MeV/c^2
$J^P=7/2^+$: $M=3175$ MeV/c^2

Heavy Quark Symmetry:

Isgur, Wise PRL **66**,1130(1991)

5/2- L=1 $s_{light}=1$ $j_{light}=2$ $\Rightarrow$ $\Gamma(\Sigma_c^*\pi) / \Gamma(\Sigma_c\pi) = 7/2\ (0.837)^{2*2+1} = 140\%$

5/2+ L=2 $s_{light}=0$ $j_{light}=2$ $\Rightarrow$ $\Gamma(\Sigma_c^*\pi) / \Gamma(\Sigma_c\pi) = 4/5\ (0.837)^{2*3+1} = 23\%$

Data: (24 ± 8)%

$\Rightarrow$ HQS favors $5/2^+$ over $5/2^-$ assignment for the $\Lambda_c(2880)$

Summary

- Observation of new charmed isotriplet $\Sigma_c(2880)$
- Observation of two new charmed baryons decaying into $\Lambda_c K\pi$

  $\Xi_{cx}(2980)$ and $\Xi_{cx}(3077)$

- Precision measurement of the $\Xi_c(2645)$ and $\Xi_c(2815)$ masses

- Experimental constraints on the J^P of the $\Lambda_c(2880)^+$:

  $\Lambda_c(2880)^+ \to \Sigma_c(2455)\pi$ angular analysis $\Rightarrow$ J = 5/2 is favored

  $\Lambda_c(2880)^+ \to \Lambda_c^+\pi^+\pi^-$ resonant structure $\Rightarrow$ $J^P = 5/2^+$ is favored

- Evidence for $\Lambda_c(2940)^+ \to \Sigma_c(2455)\pi$
- Measurement of the $\Lambda_c(2880)^+$ and $\Lambda_c(2940)^+$ masses and widths