

Observation of an anomalous ($\Lambda_c^+ \bar{p}$) structure in $B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-$

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- Introduction
- Dalitz plot analysis
- Invariant mass analysis
- Interpretation and Summary

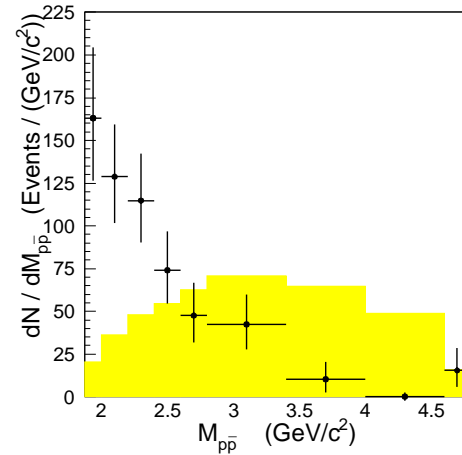
$B \rightarrow$ Baryon studies at Belle

- Several new 3-body modes were observed:
 - $B^- \rightarrow p\bar{p}K^-$ [PRL 88, 181803 (2002)]
 - * $\mathcal{B}(B^+ \rightarrow p\bar{p}K^+) = (5.66_{-0.57}^{+0.67} \pm 0.62) \times 10^{-6}$
 - $\bar{B}^0 \rightarrow D^{(*)0}p\bar{p}$ [PRL 89, 151802 (2002)]
 - * $\mathcal{B}(\bar{B}^0 \rightarrow D^0p\bar{p}) = (1.18 \pm 0.15 \pm 0.16)10^{-4}$
 - $B^0 \rightarrow p\bar{\Lambda}\pi^-$ [PRL 90, 201802 (2003)]
 - * $\mathcal{B}(B^0 \rightarrow p\bar{\Lambda}\pi^-) = (3.97_{-0.80}^{+1.00} \pm 0.56) \times 10^{-6}$
 - $B^{(+,0,+)} \rightarrow p\bar{p}(\pi^+, K^0, K^{*+})$ [hep-ex/0310018]
 - * $\mathcal{B}(B^+ \rightarrow p\bar{p}\pi^+) = (3.06_{-0.62}^{+0.73} \pm 0.37) \times 10^{-6}$,
 - * $\mathcal{B}(B^+ \rightarrow p\bar{p}K^0) = (1.88_{-0.60}^{+0.77} \pm 0.23) \times 10^{-6}$

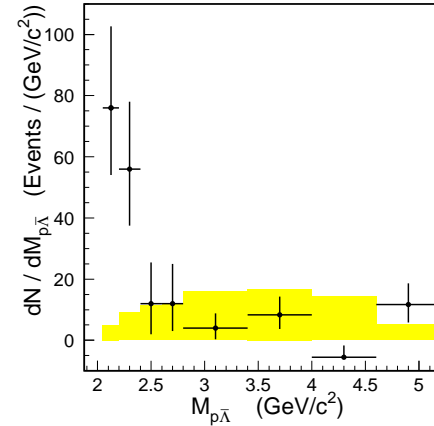
Invariant mass for **baryon-antibaryon** state is **peaked** near threshold

$M(\text{baryon} - \text{antibaryon})$ in 3-body B Decay

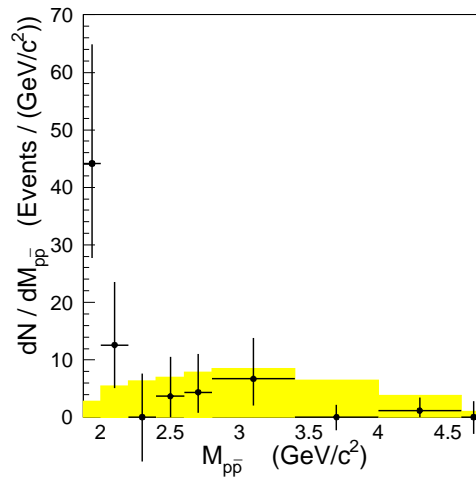
$$B \rightarrow p\bar{p}K$$



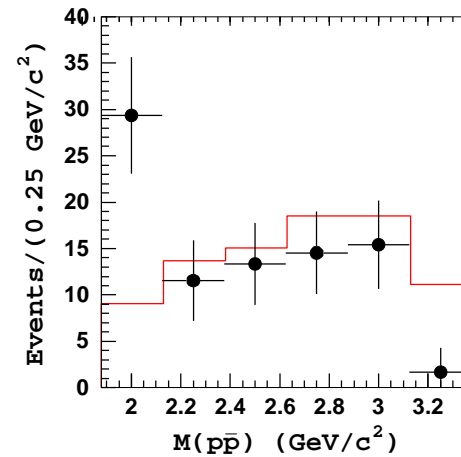
$$B \rightarrow p\bar{\Lambda}\pi$$



$$B \rightarrow p\bar{p}K_S$$



$$B \rightarrow p\bar{p}D^0$$



Event Reconstruction

- Reconstruct $B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-$

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

$$\rightarrow p K_S$$

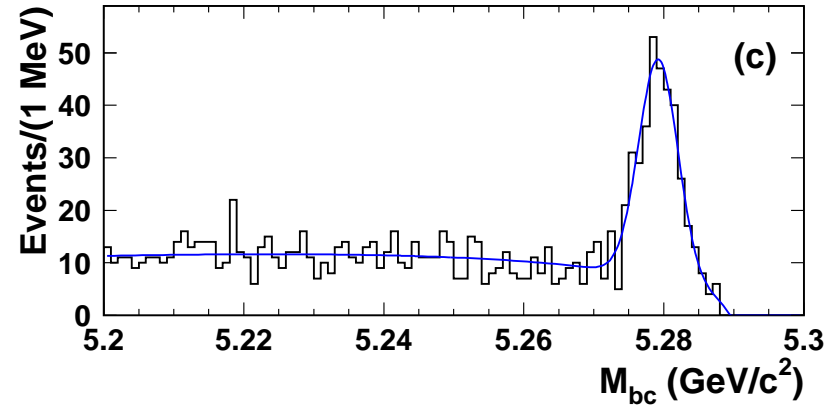
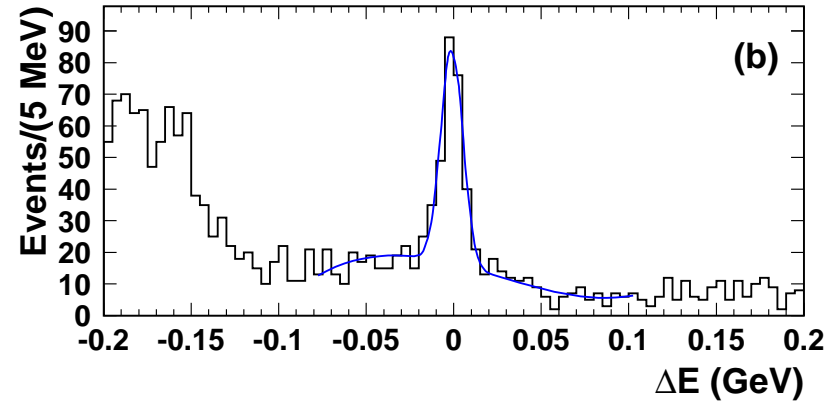
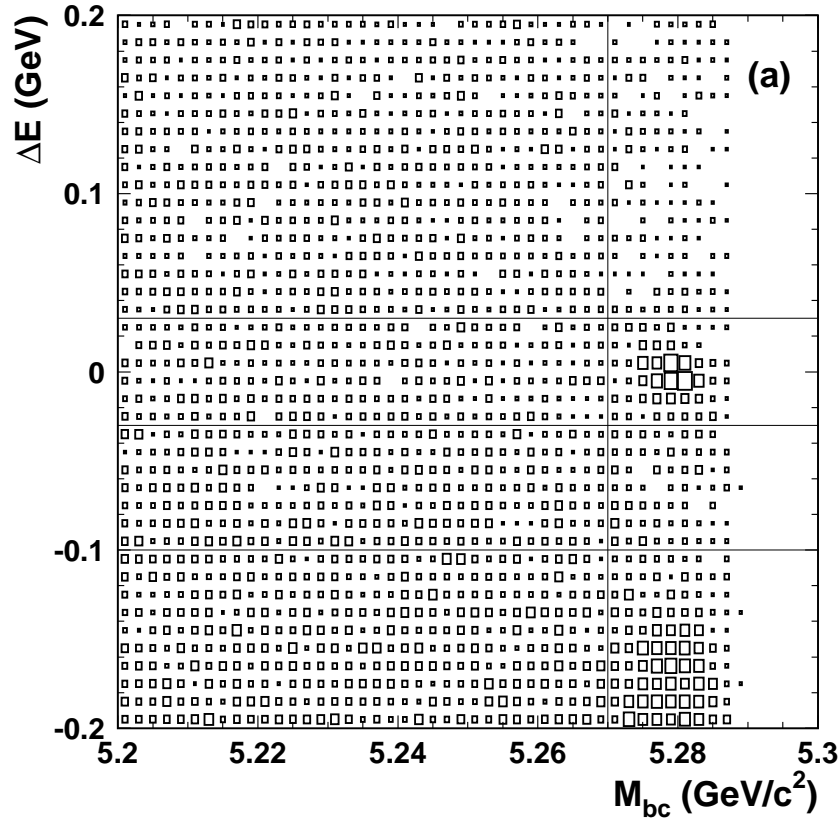
$$\rightarrow \Lambda \pi^+$$

$$\rightarrow p K_S \pi^+ \pi^-$$

$$\rightarrow \Lambda \pi^+ \pi^+ \pi^-$$

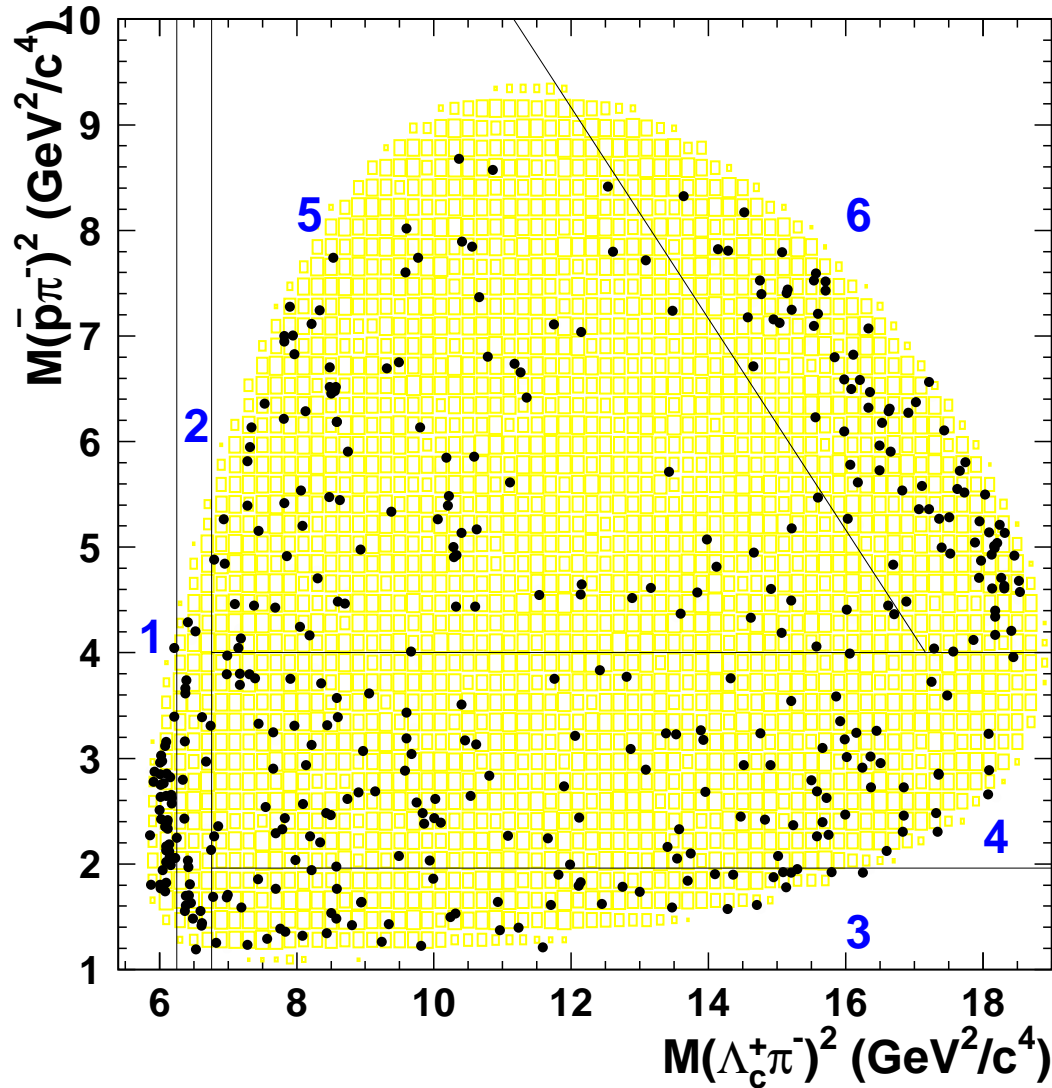
- p, K, π are identified using the aerogel Čerenkov counters, TOF and dE/dx measurements.
- Continuum suppression using event topology.
($|\cos \theta_{\text{thr}}| < 0.80; R_2 < 0.35$)

$B \rightarrow \Lambda_c \bar{p} \pi^-$ Signal Yield (140 fb^{-1})



Projection	Yield, events	Sign., σ
ΔE ($M_{bc} > 5.27 \text{ GeV}/c^2,$ $-0.075 < \Delta E < 0.1 \text{ GeV}$)	233 ± 19	15.3
M_{bc} ($ \Delta E < 0.03 \text{ GeV}$)	293 ± 21	17.9

Dalitz Plot for $B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-$ and Model for Intermediate States



Intermediate states model

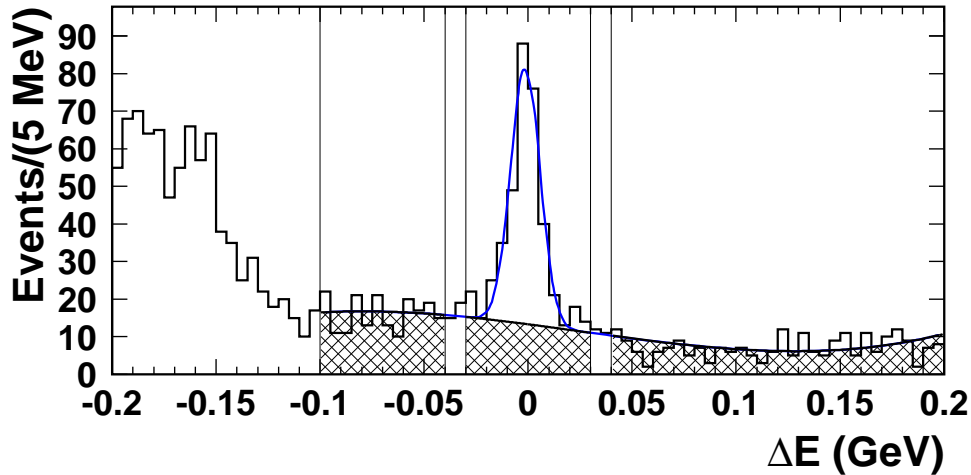
- 1 $B^- \rightarrow \Sigma_c(2455)^0 \bar{p}$
- 2 $B^- \rightarrow \Sigma_c(2520)^0 \bar{p}$
- 3 $B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1232)^--$
- 4 $B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1600)^--$
- 5 $B^- \rightarrow \Lambda_c^+ \bar{\Delta}(2420)^--$
- 6 $\Lambda_c^+ \bar{p}$ structure

Regions subdivision:

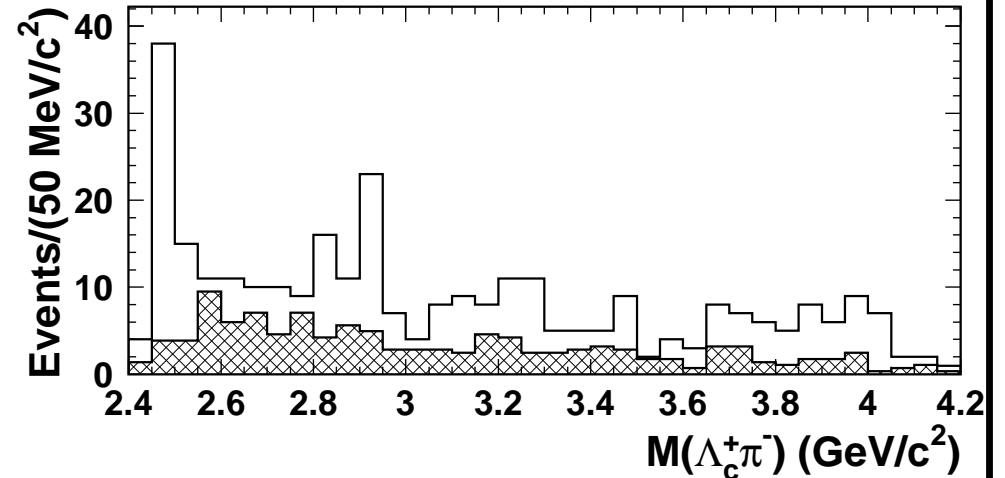
	Mass range, GeV/c^2
1	$M(\Lambda_c^+ \pi^-) < 2.48$
2	$2.48 < M(\Lambda_c^+ \pi^-) < 2.6$
3	$M(\Lambda_c^+ \pi^-) > 2.6, M(\bar{p} \pi^-) < 1.4$
4	$M(\Lambda_c^+ \pi^-) > 2.6,$ $1.4 < M(\bar{p} \pi^-) < 2$
5	$M(\Lambda_c^+ \pi^-) > 2.6, M(\bar{p} \pi^-) > 2,$ $M(\Lambda_c^+ \bar{p}) > 3.6$
6	$M(\bar{p} \pi^-) > 2, M(\Lambda_c^+ \bar{p}) < 3.6$

$B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-$: sub-masses

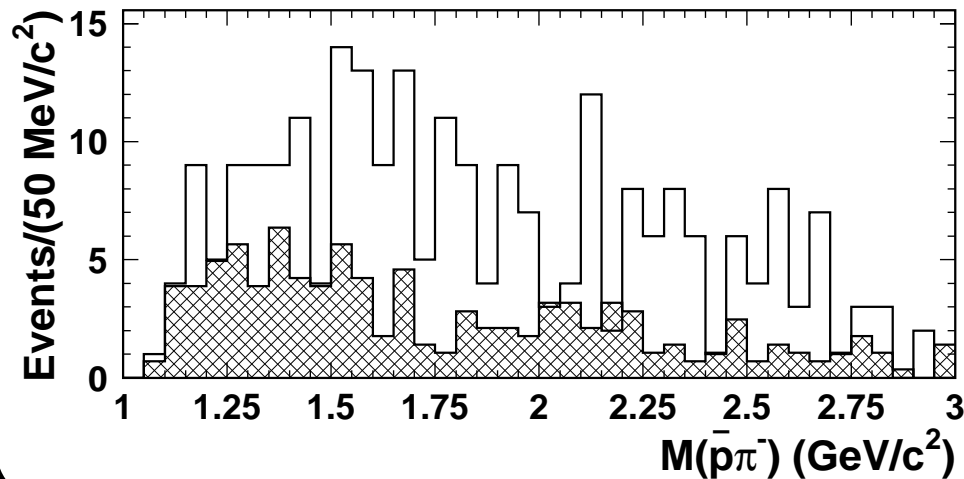
B signal and Sideband regions:



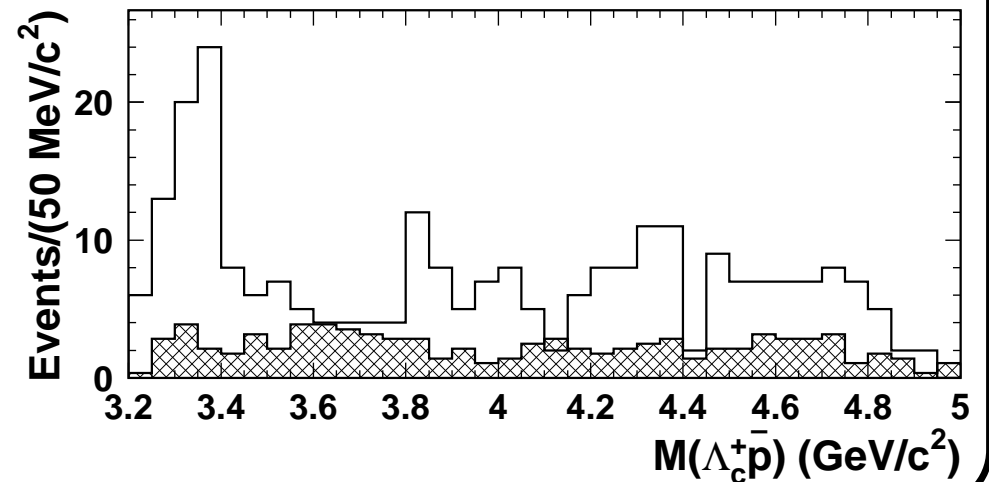
$M(\Lambda_c^+ \pi^-)$:



$M(\bar{p} \pi^-)$:



$M(\Lambda_c^+ \bar{p})$:

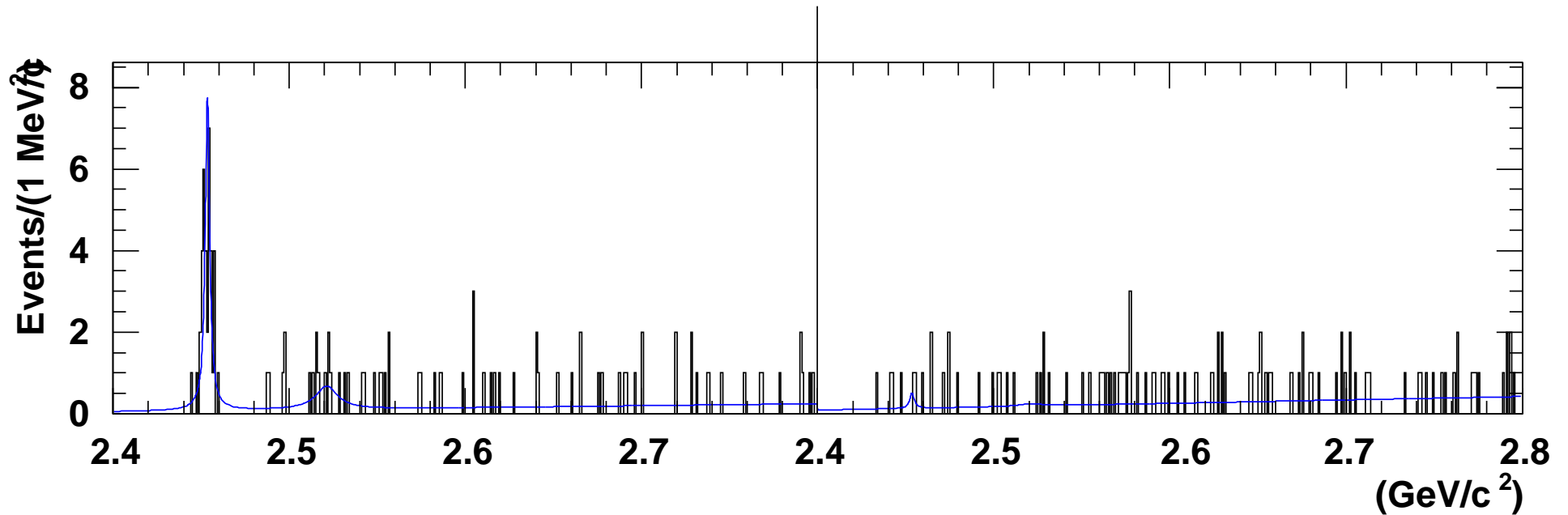


Simultaneous Fit to $M(\Lambda_c^+ \pi^-)$ Invariant Mass

$$M(\Lambda_c^+ \bar{p}) > 3.5 \text{ GeV}$$

B signal region:

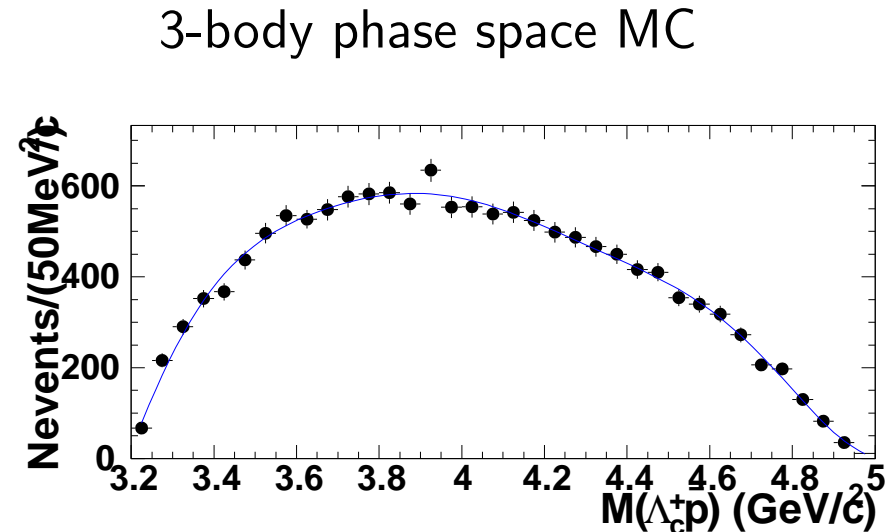
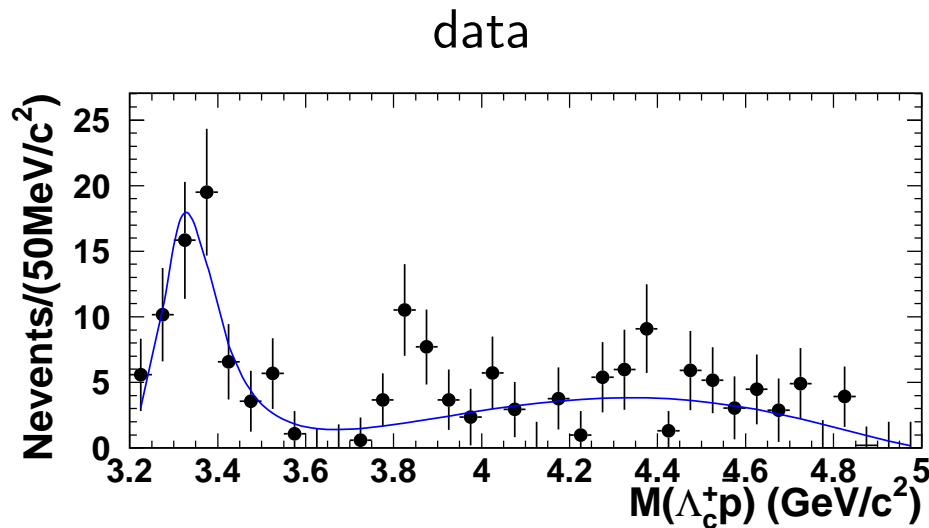
B sideband region:



Mode	Signal yield	Sign.	M (MeV)
$\Sigma_c(2455)^0 \bar{p}$	$35.3^{+6.4}_{-6.0}$	8.2	$2453.4 \pm 0.7(\text{stat.})$
$\Sigma_c(2520)^0 \bar{p}$	$12.6^{+5.4}_{-4.7}$	3.0	$2521.3 \pm 4.5(\text{stat.})$

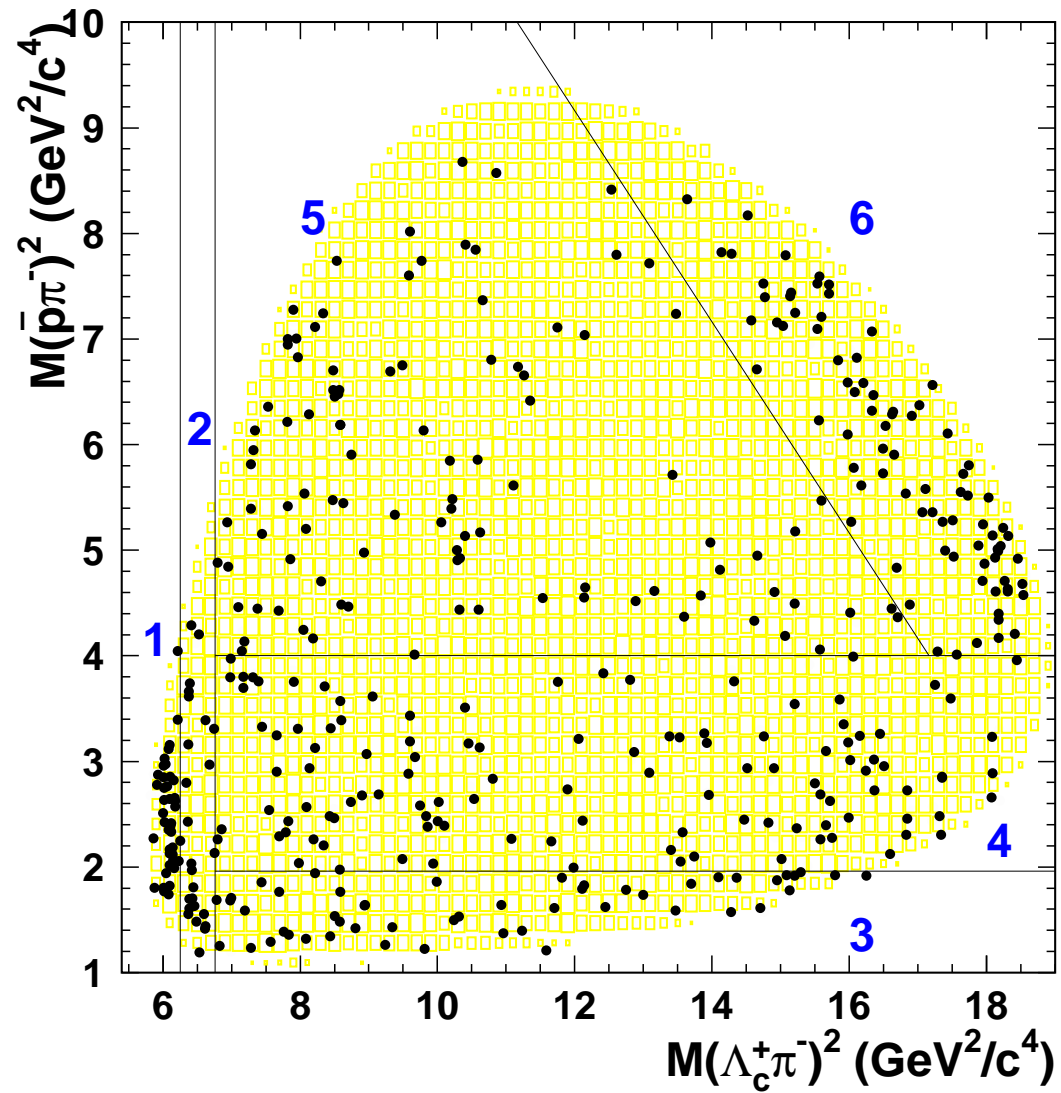
Fit to $M(\Lambda_c^+ \bar{p})$ invariant mass

- $M(\Lambda_c^+ \pi^-) > 2.6 \text{ GeV}$, $M(\bar{p} \pi^-) > 1.6 \text{ GeV}$
(to remove contributions from $\Sigma_c \bar{p}$ and $\Delta \Lambda_c$)
- Parameterize the enhancement as a Breit-Wigner and fit:

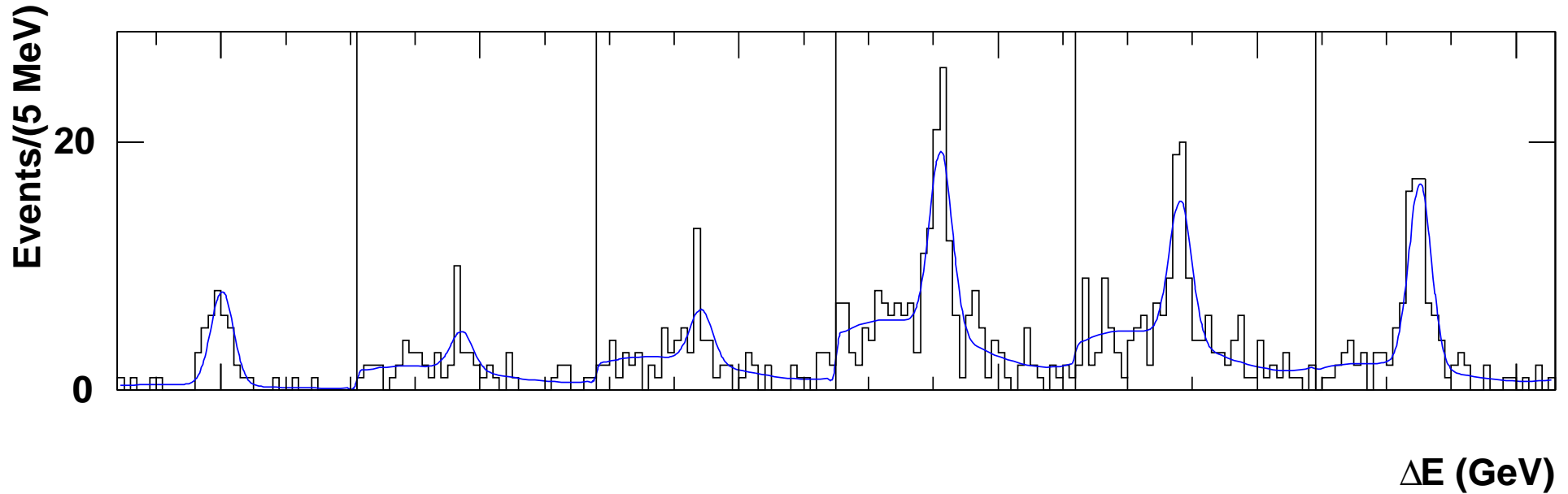


$$M: 3.322 \pm 0.023 \text{ GeV}/c^2; \quad \Gamma: 0.153 \pm 0.052 \text{ GeV}/c^2$$

$$(\Lambda_c \bar{p}) \text{ structure: } N = 75.0 \pm 16.9, S = 5.8\sigma$$



Dalitz Plot: Simultaneous Fit and B Branching Fractions



Mode	Signal yield, ev.	Sign., σ	Branching fraction $\mathcal{B}, 10^{-5}$
$B^- \rightarrow \Sigma_c(2455)^0 \bar{p}$	$32.8^{+6.6}_{-5.9}$	8.5	$3.64^{+0.73}_{-0.66}$
$B^- \rightarrow \Sigma_c(2520)^0 \bar{p}$	$12.2^{+5.6}_{-4.9}$	2.8	$1.19^{+0.55}_{-0.48}$
$B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1232)^{--}$	$7.1^{+7.3}_{-6.6}$	1.1	$0.52^{+0.53}_{-0.48}$
$B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1600)^{--}$	$84.6^{+14.7}_{-13.7}$	7.6	$5.87^{+1.02}_{-0.95}$
$B^- \rightarrow \Lambda_c^+ \bar{\Delta}(2420)^{--}$	$67.7^{+14.6}_{-13.5}$	5.9	$4.83^{+1.04}_{-0.96}$
$(\Lambda_c^+ \bar{p})$ structure	$57.2^{+11.4}_{-10.7}$	6.1	$3.79^{+0.75}_{-0.71}$
$B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-$	244 ± 25	12.9	19.84 ± 1.88

- Belle previously observed the first two body baryonic mode,
 $B \rightarrow \Lambda_c \bar{p}$.
- We now establish the two body decay mode $B \rightarrow \Sigma_c(2455)^0 \bar{p}$,

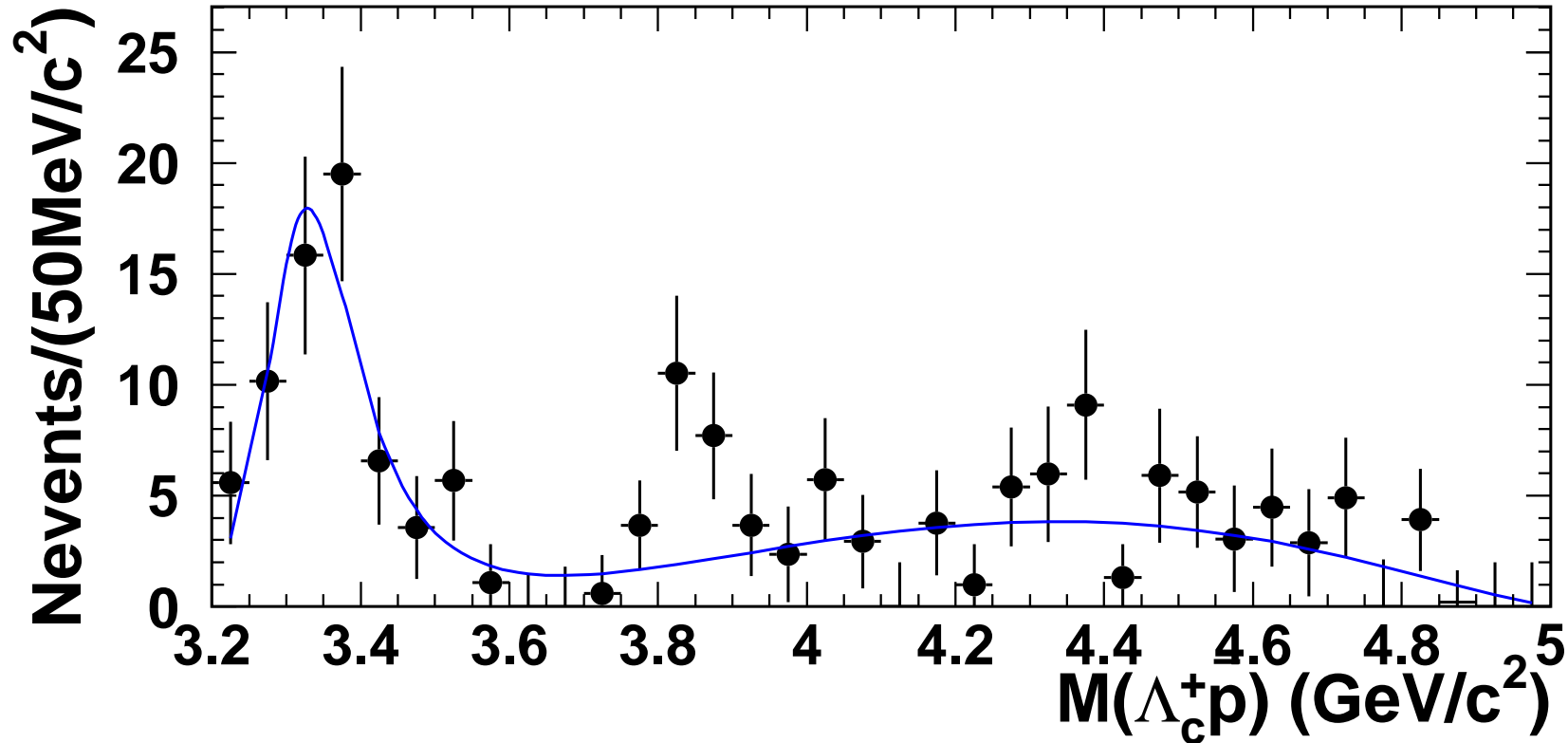
$$\mathcal{B}(B^- \rightarrow \Sigma_c(2455)^0 \bar{p}) = 3.64_{-0.66}^{+0.73} \times 10^{-5},$$

this can be compared to the theoretical prediction of H. Y. Cheng *et al.*, $\mathcal{B}(B \rightarrow \Sigma_c(2455)^0 \bar{p}) = 6 \times 10^{-5}$,

- $\mathcal{B}(B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1232)^{-}) < 0.70 \times 10^{-5}$,

which can be compared to the theoretical prediction of H. Y. Cheng *et al.*, $\mathcal{B}(B^- \rightarrow \Lambda_c^+ \bar{\Delta}(1232)^{-}) = 1.9 \times 10^{-5}$.

$M(\Lambda_c^+ \bar{p})$ invariant mass



- The $\Lambda_c \bar{p}$ mass distribution is inconsistent with phase space
- Fragmentation effect ? (cf. $M(p \bar{p})$ in $B \rightarrow p \bar{p} K$ etc.)
- A new intermediate state ?

Summary

- Total branching fraction:

$$\mathcal{B}(B^- \rightarrow \Lambda_c^+ \bar{p} \pi^-) = (19.8 \pm 1.9) \times 10^{-5}.$$

- Observation of a new two-body baryonic B decay:

$$\mathcal{B}(B^- \rightarrow \Sigma_c(2455)^0 \bar{p}) = (3.64_{-0.66}^{+0.73}) \times 10^{-5}, S = 8.5\sigma.$$

- Observation of an anomalous structure in the $M(\Lambda_c^+ \bar{p})$ system from $\bar{B} \rightarrow \Lambda_c^+ \bar{p} \pi$ decay ($S = 6.1\sigma$).

– fragmentation effect?

– If interpreted as a resonance

$M:$	$3.32 \pm 0.02 \text{ GeV}/c^2$
$\Gamma:$	$0.15 \pm 0.05 \text{ GeV}/c^2$