Baryonic B Meson Decays

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- Introduction
- Charmless decays
- Charmed decays
- Summary

Introduction - Review

- 1997: first exclusive measurement of $B \to \Lambda_c \bar{p} X$ ($X = \pi, \pi\pi$) by CLEO
- 2001: first observation of charmless $B^+ \to p\bar{p}K^+$ by Belle
- 2002: observation of $\Sigma_c \bar{p} X$ ($X = \pi, \pi\pi$) by Belle, CLEO, $D^{(*)0} p\bar{p}$ by Belle
- 2003: first observation of 2-body decay: $B^0 \to \bar{\Lambda}_c p$ (Belle), first evidence of $J/\psi \bar{\Lambda} \bar{p}$ (BaBar)
- 2004: first observation of $b \to s\gamma$ penguin in baryonic B decays by Belle: $B^+ \to \bar{\Lambda} p \gamma$
- 2005: doubly charmed baryon modes $B \to \Xi_c \bar{\Lambda}_c$, $B \to \Lambda_c \bar{\Lambda}_c K$ by Belle

First Observation of Charmless Baryonic B Decays $B^+ \to p\bar{p}K^+$

With charmonium veto

PRL **88**, 181803 (2002)

♣ Large 3-body $p\bar{p}K^+$ signal observed

(31.7M $B\bar{B}$, PRL **88**, 181803 (2002))

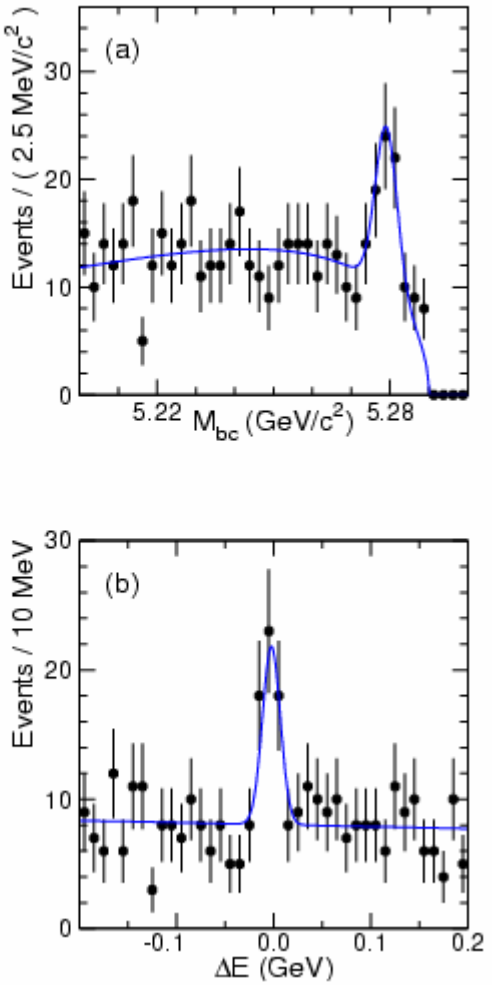
- $B^+ \to p\bar{p}K^+$
  - $42.8^{+10.8}_{-9.6}$ events, 5.6 σ
  - $\mathcal{B} = (4.3^{+1.1}_{-0.9} \pm 0.5) \times 10^{-6}$
- $B^+ \to p\bar{p}\pi^+$
  - $16.2^{+8.6}_{-8.0}$ events, 2.1 σ
  - $\mathcal{B} < 3.7 \times 10^{-6}$
- $B^0 \to p\bar{p}K^0_S$
  - $6.4^{+4.4}_{-3.7}$ events
  - $\mathcal{B}(B^0 \to p\bar{p}K^0) < 7.2 \times 10^{-6}$

♣ Prefer to decay to 3 body

BF(3-body) >> BF(2-body)

PRD 65 091103 (2002)

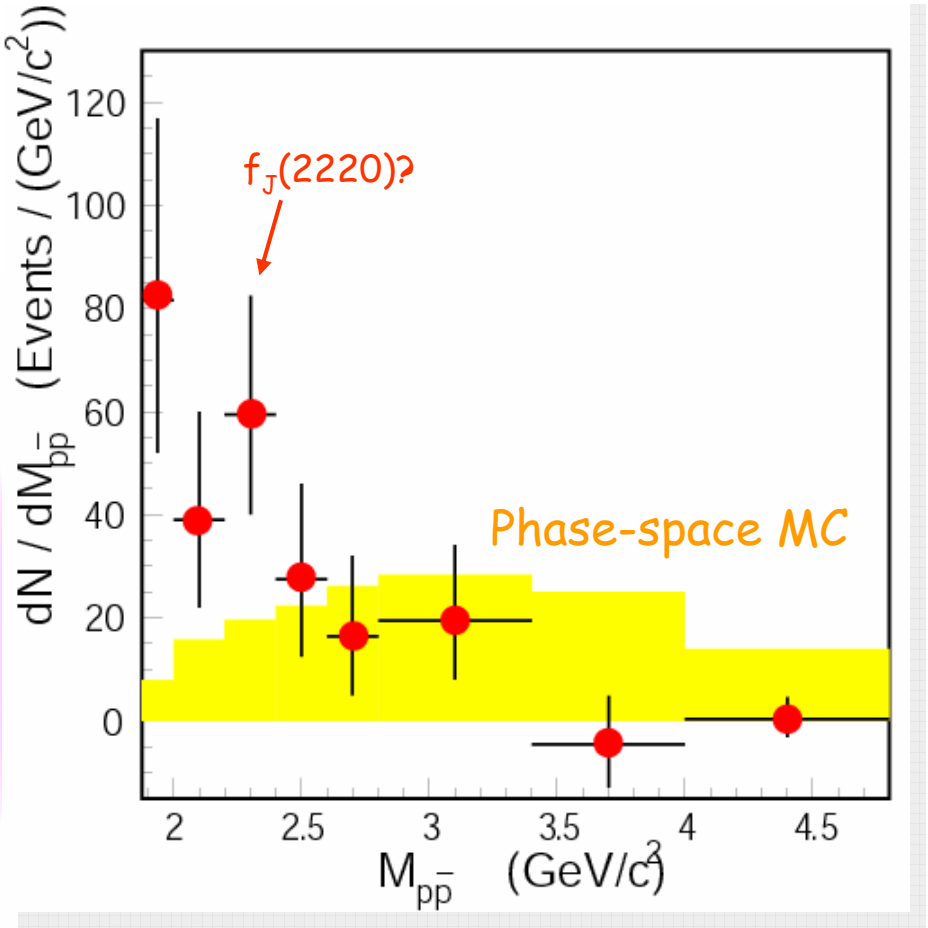
$p\bar{p}K^+$



New type of B Decays: $B^{\pm} \to p\bar{p}K^{\pm}$

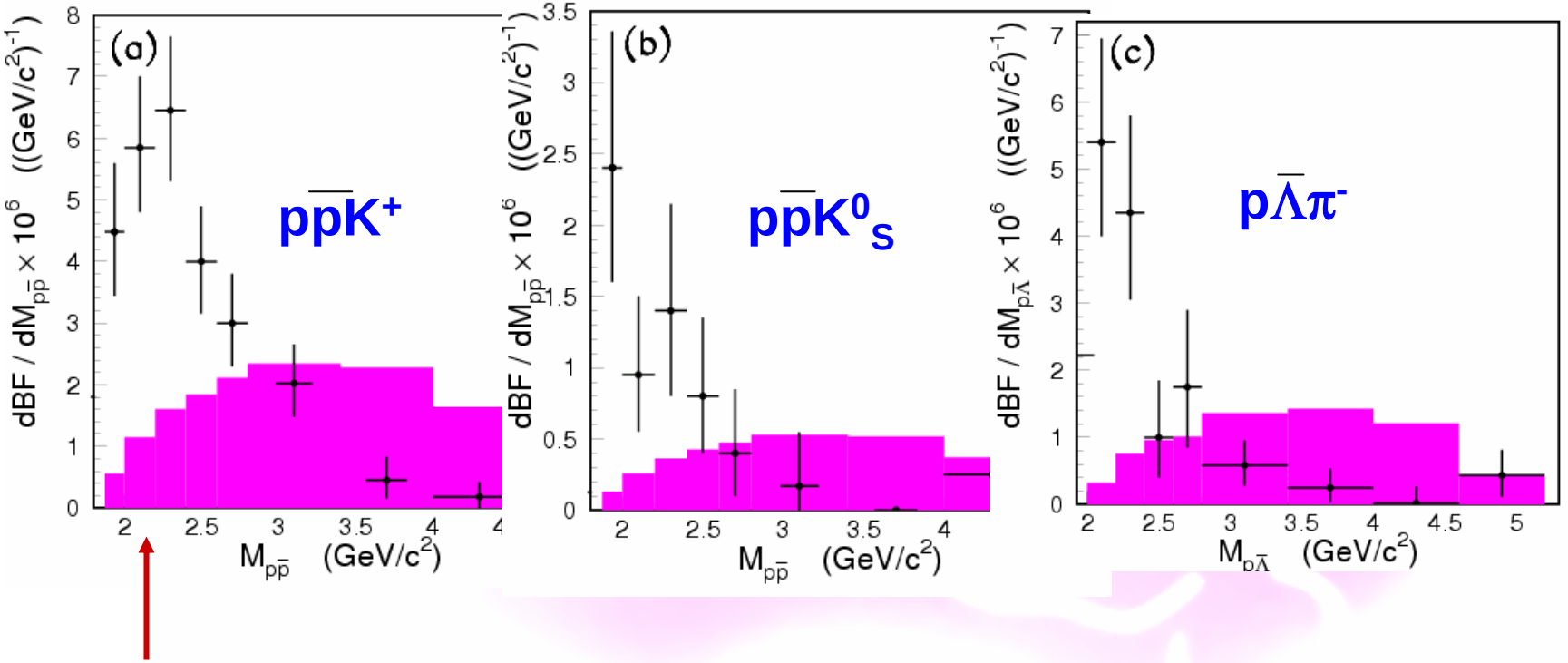
- **Peak at Low Mass**

- **Possible explanations**
  - ✓ Baryon form factor?
  - ✓ Quasi 2-body Decay?
    - glueball
    - baryonium
  - ✓ Fragmentation?



Threshold Enhancement

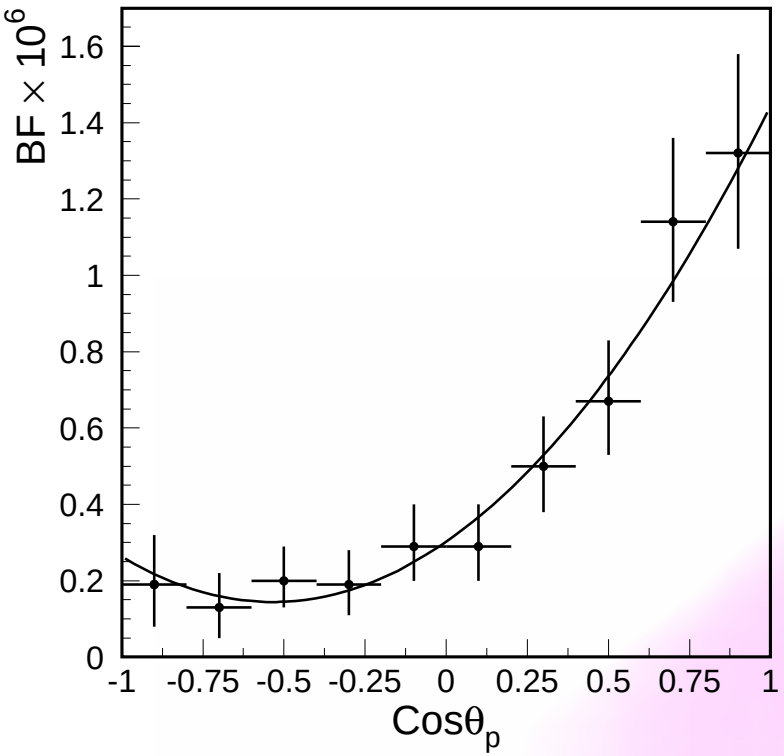
- PLB 617, 141-149, 2005

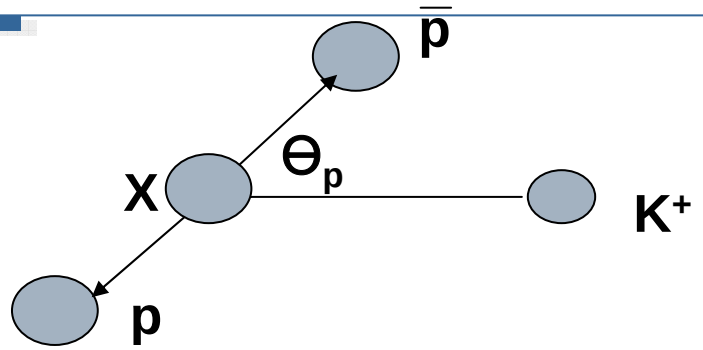


Glueball is ruled out

Angular distribution: $p\bar{p}K^+$

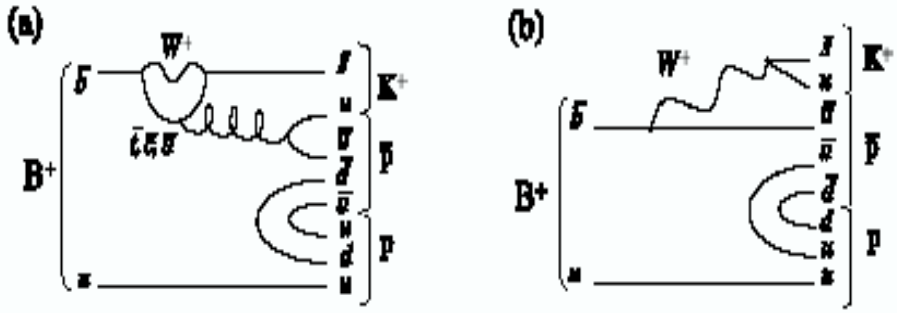
$p\bar{p}K$ signal





b→s dominant process

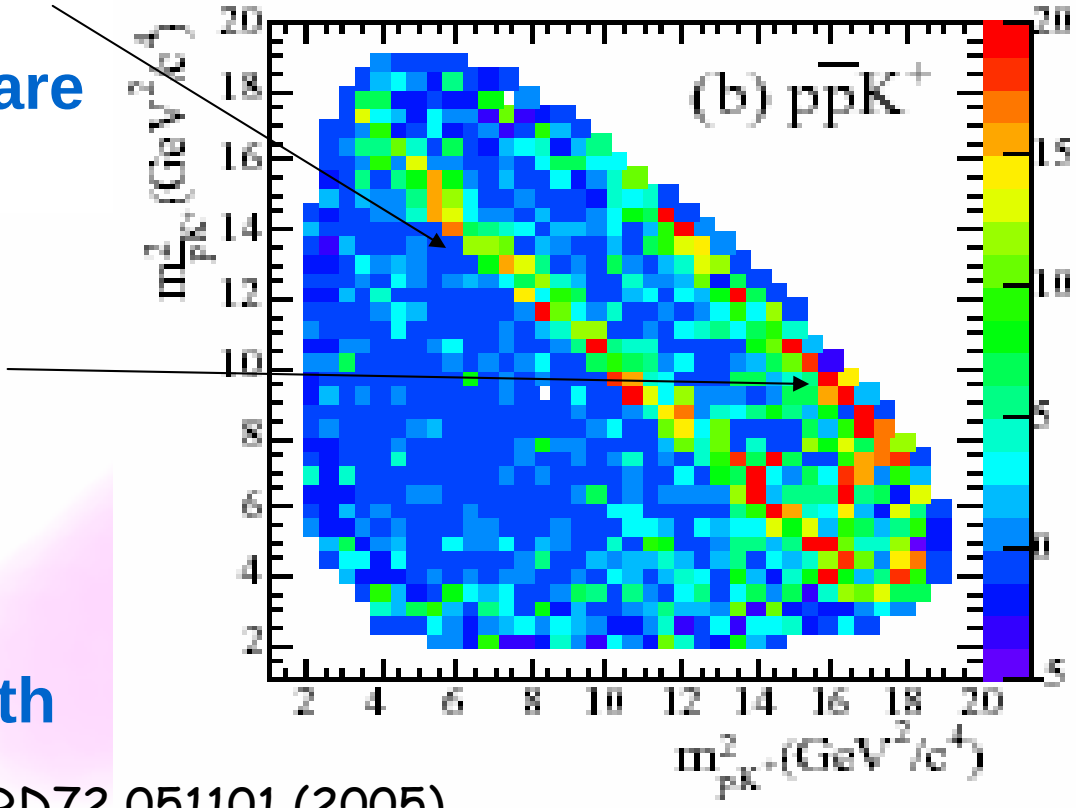
Fragmentation picture



Proton against K^- ($\bar{p}$ against K^+) : flavor dependence!

Information from the $p\bar{p}K^+$ Dalitz plot

- **The lower bands shown in the plots are J/psi and eta_c.**
- **Asymmetry near threshold of ppbar indicates flavor dependence**
- **Anti-proton moves slower in parallel with proton**



PRD72 051101 (2005)

Decay diagrams of J/Ψ to baryon pair

$< \lambda_1 \lambda_2|U|JM> = A^J_{\lambda 1 \lambda 2}$ links $D^J_{M \lambda 1- \lambda 2}(\theta,\varphi)$

$$\frac{dN}{d\cos\theta} \propto 1+\alpha\cos^2\theta$$

dominant decay diagram

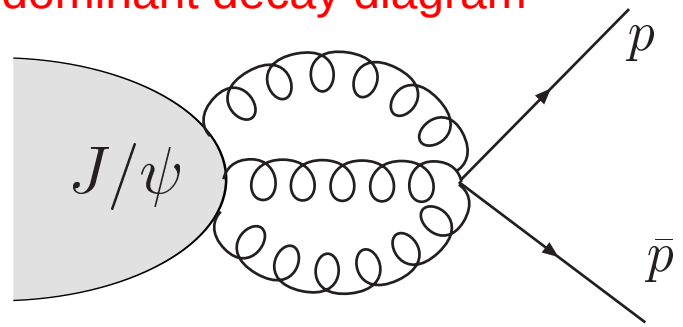


TABLE II: Different theoretical predictions on α value

Theoretical values of α	
α	authors
1.0[6]	Brodsky and Lepage
0.46[7]	Claudson, Glashow and Wise
0.69,0.70[8]	Carimalo

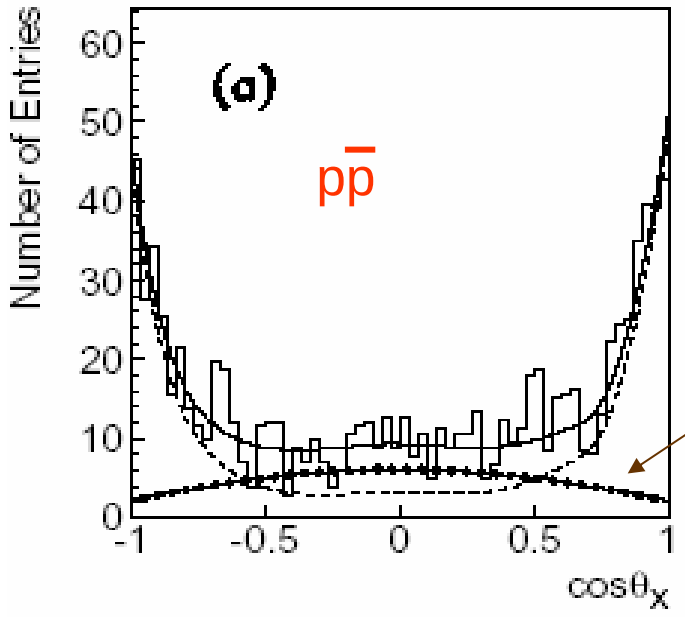
Latest BES result : $\alpha = 0.676 \pm 0.036 \pm 0.042$

Fit cosθ (J/ψ → p $\bar{p}$)

$L = e^{-(Ns+Nb)}/N! \cdot \Pi\,[N_s \cdot P_s(M_{bci}, \Delta E_i) \cdot \varepsilon(\cos\theta) \cdot P(\cos\theta) + N_b \cdot P_b(M_{bci}, \Delta E_i)]$

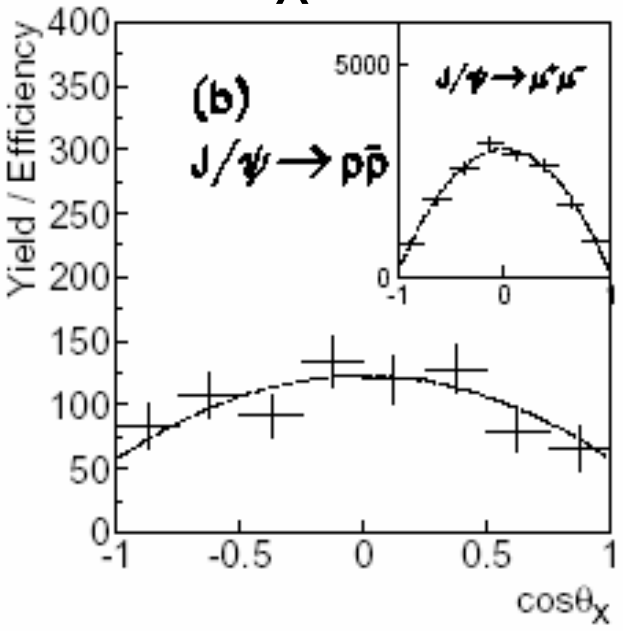
$\varepsilon(\cos\theta)$ - normalized efficiency, $P(\cos\theta) = (1+\alpha\cdot\cos^2\theta)/(2+2/3\cdot\alpha)$

Likelihood fit



signal

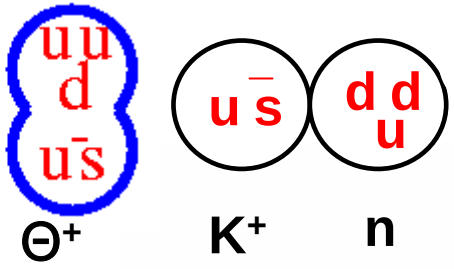
χ^2 fit



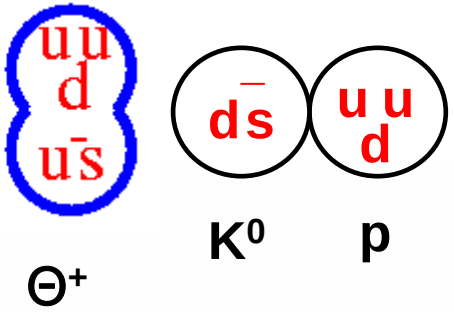
α_B= -0.60 ± 0.13 (stat) ± 0.14 (syst) **α= 0.43 ± 0.13 (stat) ± 0.14 (syst)**

Pentaquark search in $p\bar{p}Ks$

- $\Theta^+(1540)$: $uudd\bar{s}$
- $\Theta^+ \rightarrow K^+ n$



- $\Theta^+ \rightarrow K^0 p$

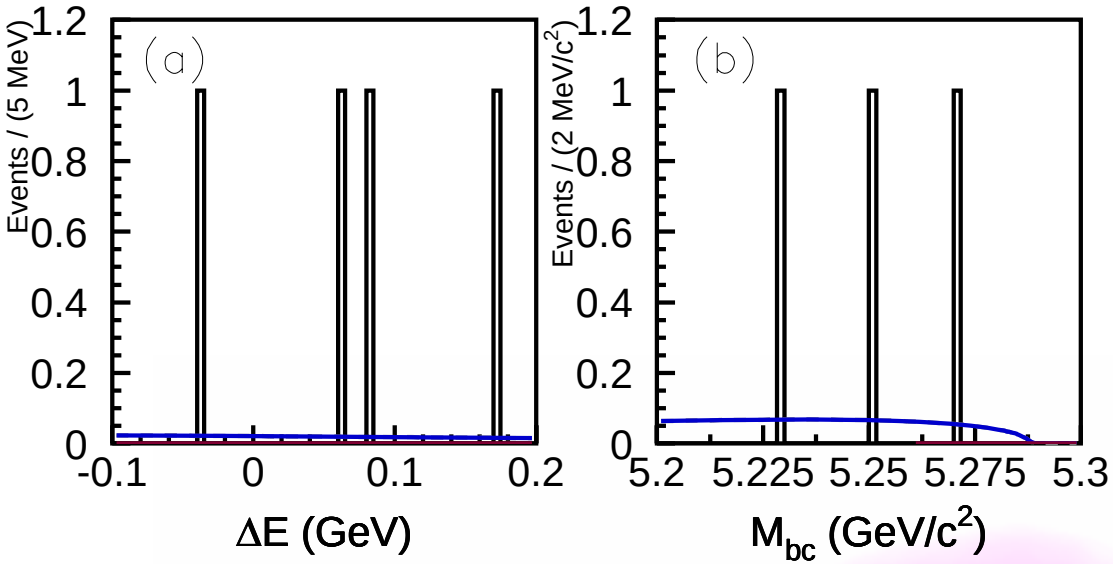


- $B^0 \rightarrow \Theta^+ \bar{p}$

  $B^0 \rightarrow p\bar{p}K^0$, $B \rightarrow p\bar{p}Ks$

  Search for B signal with a 20 MeV pKs mass window cut at 1540MeV

Pentaquark search in $p\bar{p}Ks$



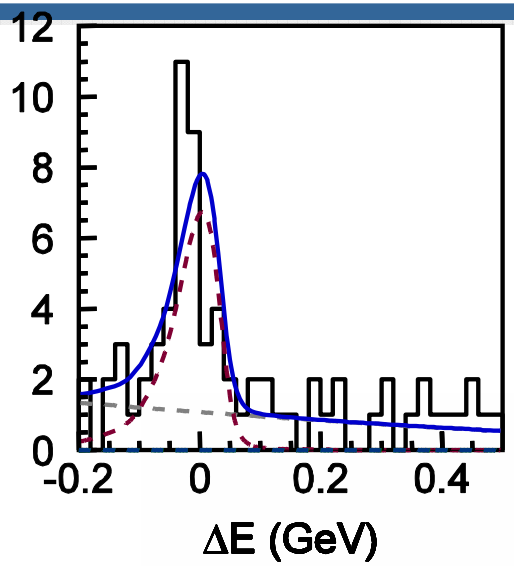
Fixed background shape from sideband data

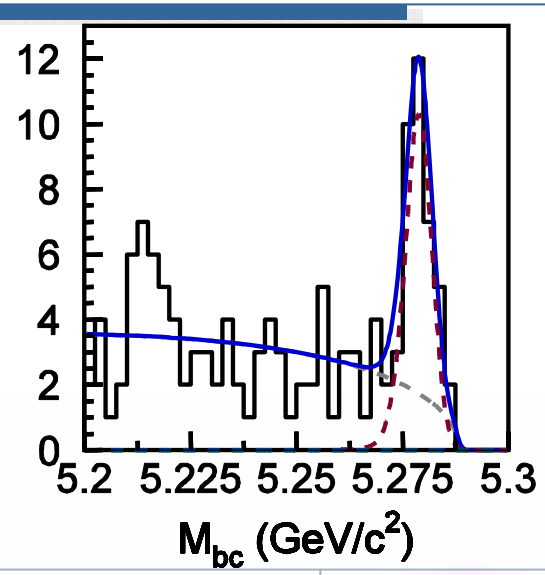
Count the events in signal region and compare with background estimation

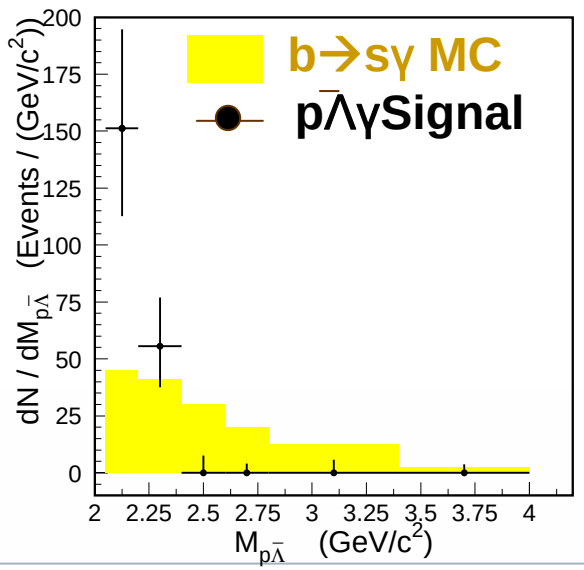
BF product upper limit $< 2.3 \times 10^{-7}$ at 90% C.L.

$B^+ \to p\bar{\Lambda}\gamma$ ($b \to s\gamma$)

140fb^{-1}

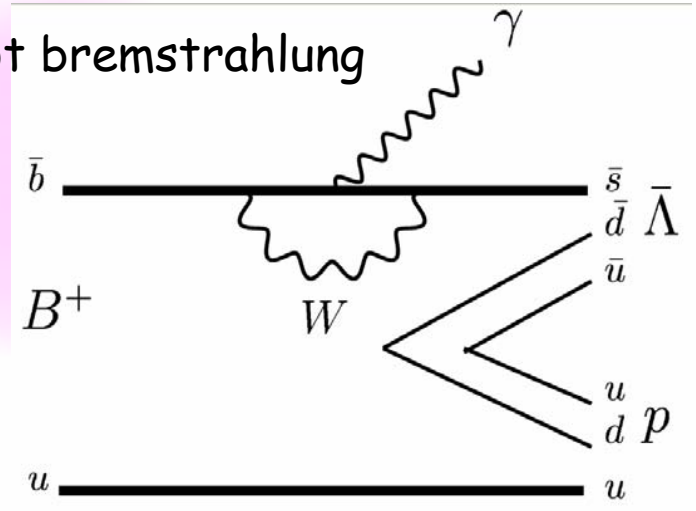




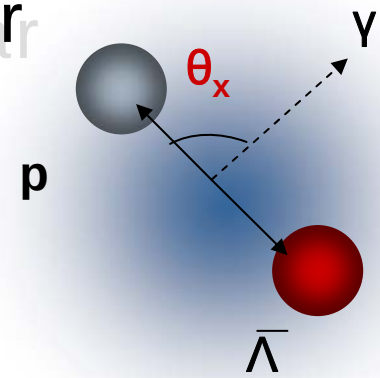


- PRL 95, 061802, 2005
- Simultaneous fit on $B \to p\bar{\Lambda}\gamma$ and $B \to p\bar{\Sigma}^0\gamma$
- Signal Yield for $B \to p\bar{\Lambda}\gamma$ with $M_{p\bar{\Lambda}} < 2.4 GeV/c^2$: $34.1^{+7.1}_{-6.6}$
- Statistical Significance: 8.6σ
- $BF(B \to p\bar{\Lambda}\gamma) (2.16^{+0.58}_{-0.53} \pm 0.20) \times 10^{-6}$
- $BF(B \to p\bar{\Sigma}^0\gamma) : < 4.6 \times 10^{-6}$

Not bremstrahlung

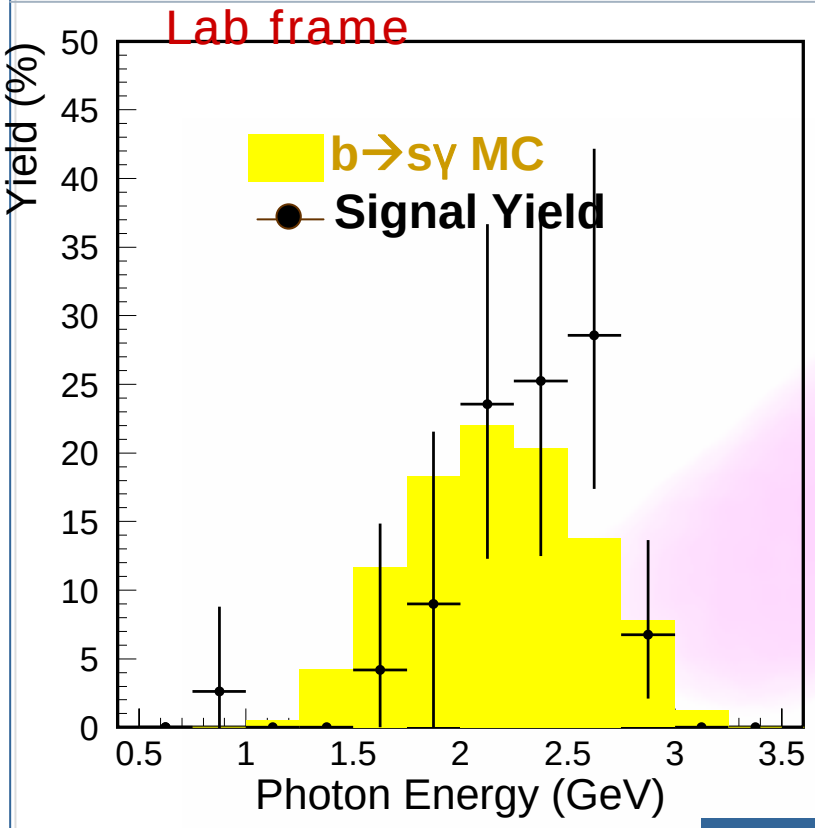


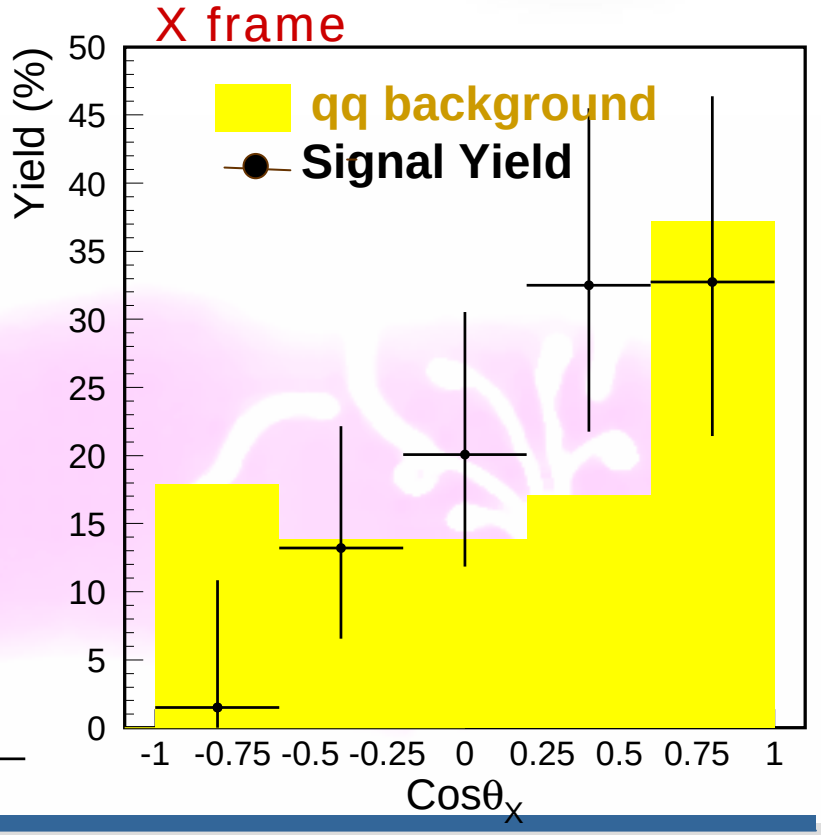
Photon energy and Angular distribution



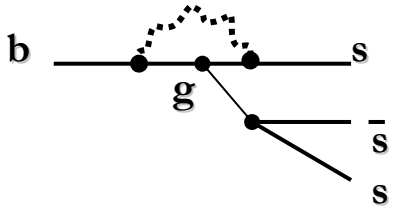
Fit results in bins of $\cos\theta_X$ with $M_{p\bar{\Lambda}}<4.0\text{GeV}/c^2$

(Assuming $X\rightarrow p\bar{\Lambda}$, calculated in X rest frame.)

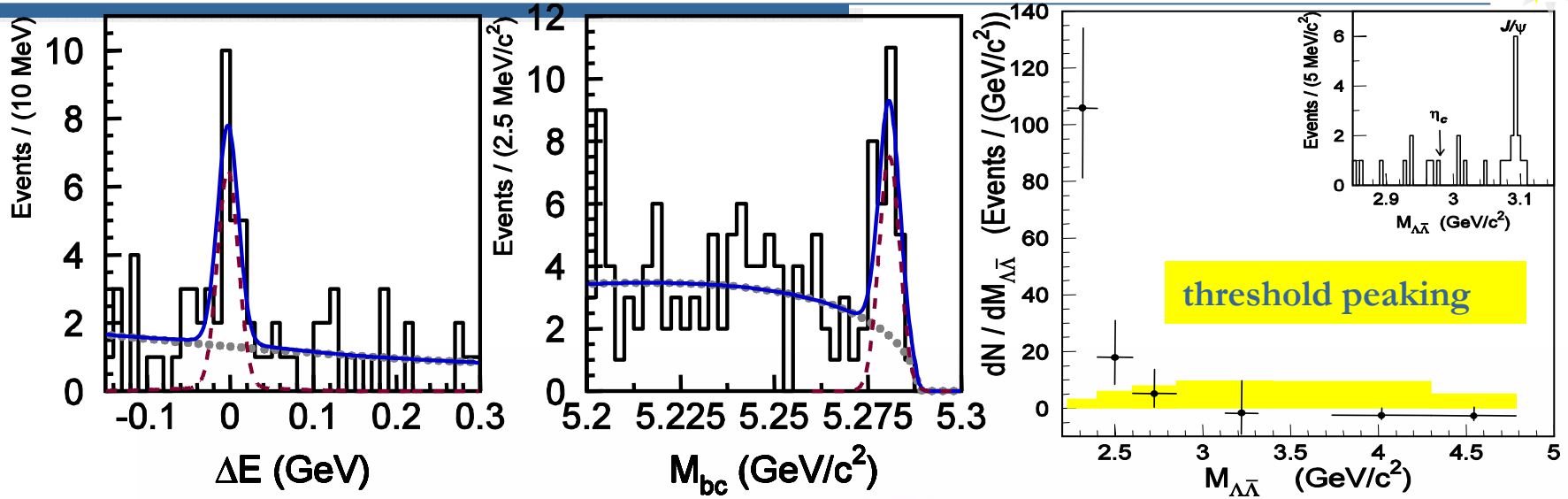




$B^+ \to \Lambda\bar{\Lambda}K^+$



140fb^{-1}



First observation of $b \to s\bar{s}s$ baryonic decay

Signal Yield in 2D fit: $19.9^{+6.5}_{-5.1}$

Efficiency: 4.0%-6.9%

Statistical Significance: 7.4σ

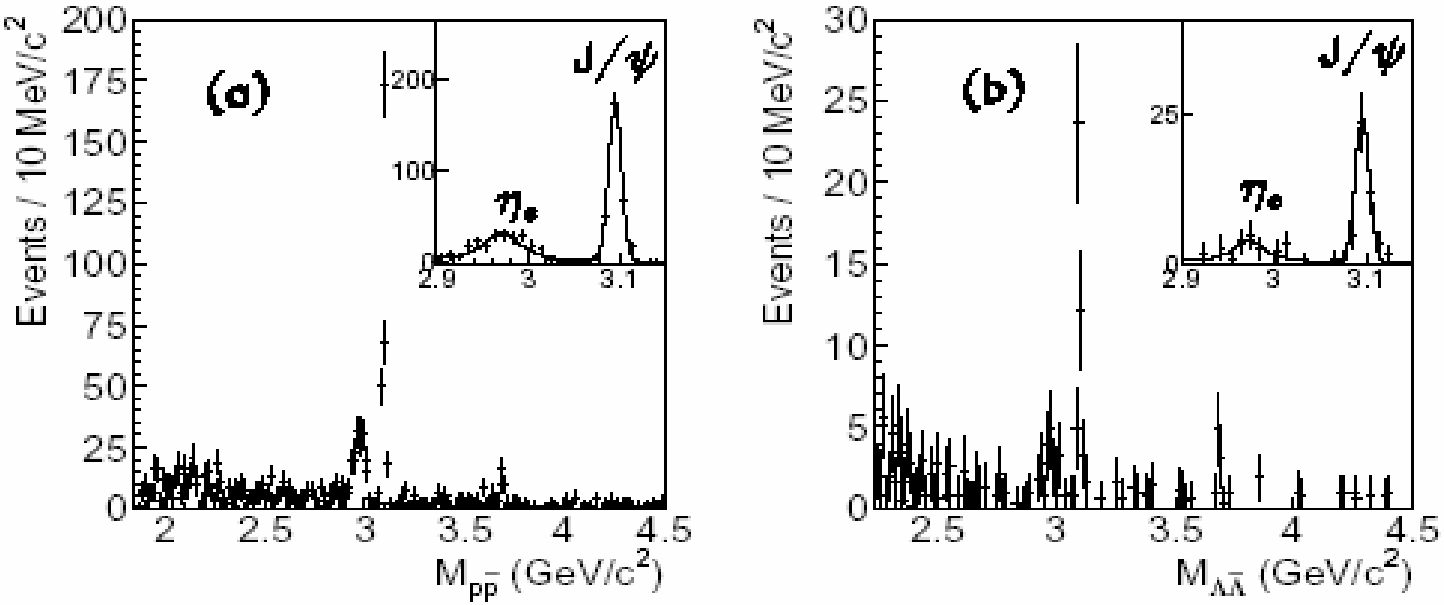
BF: $(2.91^{+0.90}_{-0.70} \pm 0.38) \times 10^{-6}$

1. **First Charmless B decay with two Λ!**
2. **Threshold enhancement again.**
3. **Compliment to $B \to \varphi K^{(*)}$ ($b \to s\bar{s}s$ penguin)**

PRL 93,211801, 2004

Observation of $\eta_c \to \Lambda\bar{\Lambda}$

hep-ex/0606022



new →

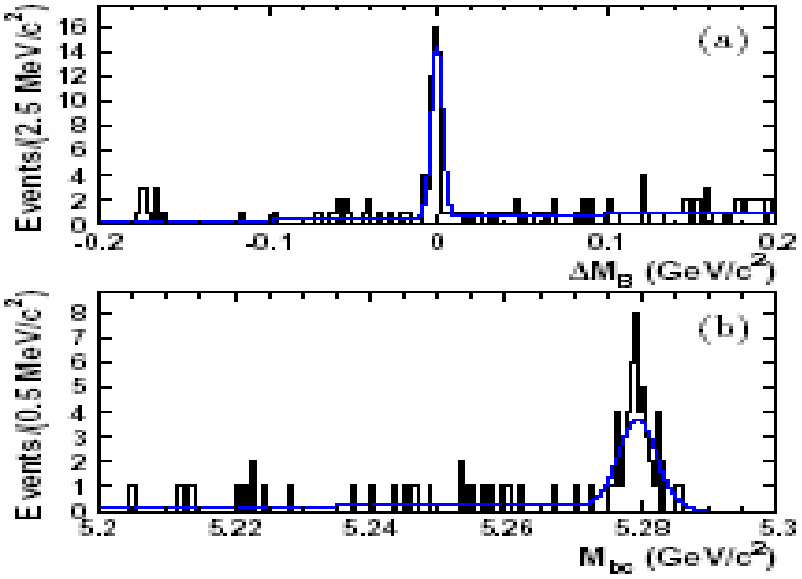
Modes	Yield	Efficiency(%)	Branching Fraction Product(10^{-6})	$\mathcal{B}(J/\psi, \eta_c \to p\bar{p}, \Lambda\bar{\Lambda})(10^{-3})$
$B^+ \to \eta_c K^+, \eta_c \to p\bar{p}$	195^{+16}_{-15}	$35.8^{+0.3}_{-0.3}$	$1.42^{+0.11\,+0.16}_{-0.11\,-0.20}$	$1.58 \pm 0.12^{+0.18}_{-0.22} \pm 0.47^{a}$
$B^+ \to \eta_c K^+, \eta_c \to \Lambda\bar{\Lambda}$	$19.5^{+5.2}_{-4.5}$	$5.3^{+0.1}_{-0.1}$	$0.95^{+0.25\,+0.08}_{-0.22\,-0.11}$	$0.87^{+0.24\,+0.09}_{-0.21\,-0.14} \pm 0.27^{b}$
$B^+ \to J/\psi K^+, J/\psi \to p\bar{p}$	317^{+19}_{-18}	$37.3^{+0.4}_{-0.4}$	$2.21^{+0.13}_{-0.13} \pm 0.10$	$2.21 \pm 0.13 \pm 0.31 \pm 0.10^{c}$
$B^+ \to J/\psi K^+, J/\psi \to \Lambda\bar{\Lambda}$	$45.9^{+7.7}_{-6.7}$	$5.9^{+0.3}_{-0.3}$	$2.00^{+0.34}_{-0.29} \pm 0.34$	$2.00^{+0.34}_{-0.29} \pm 0.34 \pm 0.08^{c}$

[a] $\mathcal{B}(B^+ \to \eta_c K^+) = 0.9 \pm 0.27 \times 10^{-3}$[25].
[b] We use $\mathcal{B}(B^+ \to \eta_c K^+, \eta_c \to \Lambda\bar{\Lambda})/\mathcal{B}(B^+ \to \eta_c K^+, \eta_c \to p\bar{p}) = 0.67^{+0.19}_{-0.16} \pm 0.12$ measured in this paper and $\mathcal{B}(\eta_c \to p\bar{p}) = 1.3 \pm 0.4 \times 10^{-3}$[25].
[c] $\mathcal{B}(B^+ \to J/\psi K^+) = 1.00 \pm 0.04 \times 10^{-3}$[25].

Ratio for baryon quark-diquark model check

Observation of $B^+ \to \Lambda_c^+ \Lambda_c^- K^+$

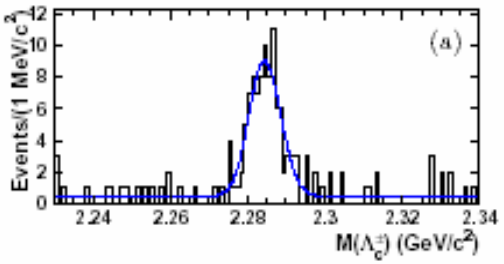
Hep-ex/0508015



Unexpected large rate considering the limited phase sapce →

Threshold effect?

$\Lambda_c^+ \to pK^-\pi^+$ **signal**



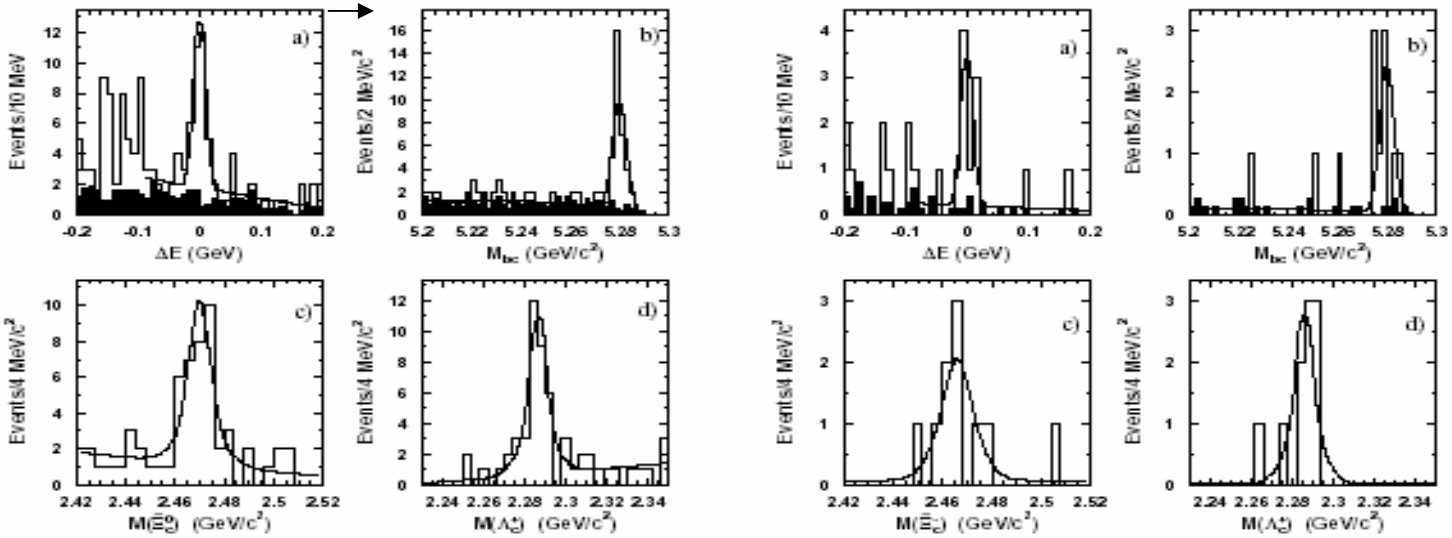
$$BF(B^+ \to \Lambda_c^+ \Lambda_c^- K^+) = (6.5\ ^{+1.0}_{-0.9} \pm 1.1 \pm 3.4) \times 10^{-4}$$

Observation of $B \to \bar{\Xi}_c \Lambda_c$

Hep-ex/0510074

Decay Mode	Yield	Efficiency(%)	Product of $\mathcal{B}$'s (10^{-5})	Significance
$B^+ \to \bar{\Xi}_c^0 \Lambda_c^+$, $\bar{\Xi}_c^0 \to \bar{\Xi}^+ \pi^-$	$12.4^{+4.2}_{-3.3}$	1.14	$5.6^{+1.9}_{-1.5} \pm 1.1 \pm 1.5$	6.8σ
$B^+ \to \bar{\Xi}_c^0 \Lambda_c^+$, $\bar{\Xi}_c^0 \to \bar{\Lambda} K^+ \pi^-$	$16.9^{+4.8}_{-4.0}$	2.04	$4.0^{+1.1}_{-0.9} \pm 0.9 \pm 1.0$	5.9σ
$B^+ \to \bar{\Xi}_c^0 \Lambda_c^+$, simultaneous fit			$4.8^{+1.0}_{-0.9} \pm 1.1 \pm 1.2$	8.7σ
$B^0 \to \bar{\Xi}_c^- \Lambda_c^+$, $\bar{\Xi}_c^- \to \bar{\Xi}^+ \pi^- \pi^-$	$8.3^{+3.3}_{-2.5}$	0.46	$9.3^{+3.7}_{-2.8} \pm 1.9 \pm 2.4$	3.8σ

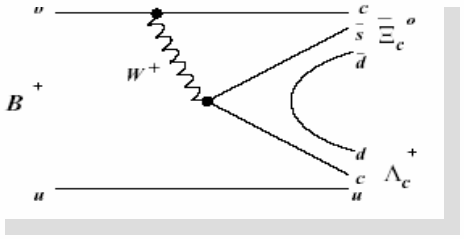
$B^+ \to \bar{\Xi}_c^0 \Lambda_c^+$ $\qquad$ $B^0 \to \bar{\Xi}_c^- \Lambda_c^+$



$CKM(\Xi_c\bar{\Lambda}_c)=VcbVcs^*$ <-> $CKM(\Lambda_c\bar{p})=VcbVud^*$

Enhancement for smaller Q ?

$\Xi_c \to \Xi\pi$ ~1% $\qquad$ $\Xi_c\bar{\Lambda}_c \sim 10^{-3}$ >> $\Lambda_c\bar{p} \sim 10^{-5}$

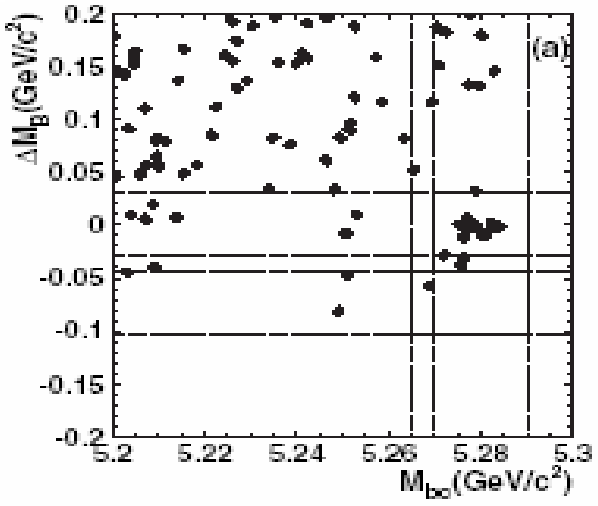


Observation of $J/\psi\Lambda\bar{p}$

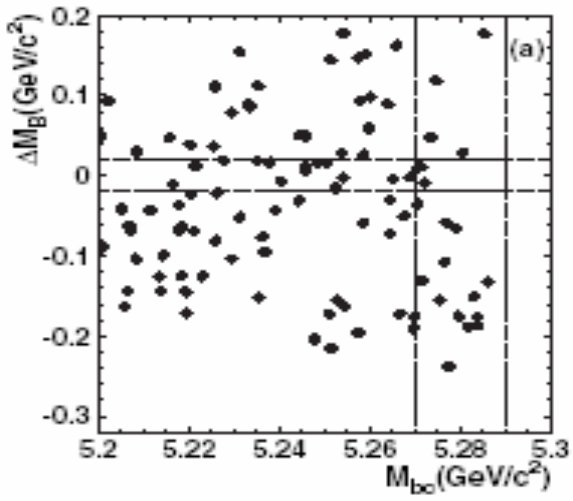
Mode	Y	b	n_0	$\epsilon(\%)$	Y_{90}	$\mathcal{B}$
$B^- \to J/\psi\Lambda\bar{p}$	17.2 ± 4.1	$0.41 \pm 0.09(\text{stat})$	16	$7.2^{+1.1}_{-1.4}$	$\cdots$	$11.6 \pm 2.8(\text{stat})^{+1.8}_{-2.3}(\text{sys}) \times 10^{-6}$
$B^- \to J/\psi\Sigma^0\bar{p}$	-1.1 ± 1.7	$0.31 \pm 0.04(\text{stat}) \pm 0.03(\text{sys})$	1	$2.3^{+0.9}_{-0.8}$	<5.3	$<1.1 \times 10^{-5}$
$B^0 \to J/\psi p\bar{p}$	-6.1 ± 2.2	$0.94 \pm 0.10(\text{stat})^{+0.04}_{-0.16}(\text{sys})$	3	$26.4^{+6.8}_{-5.4}$	<7.1	$<8.3 \times 10^{-7}$

PRD72 051105 (2005)

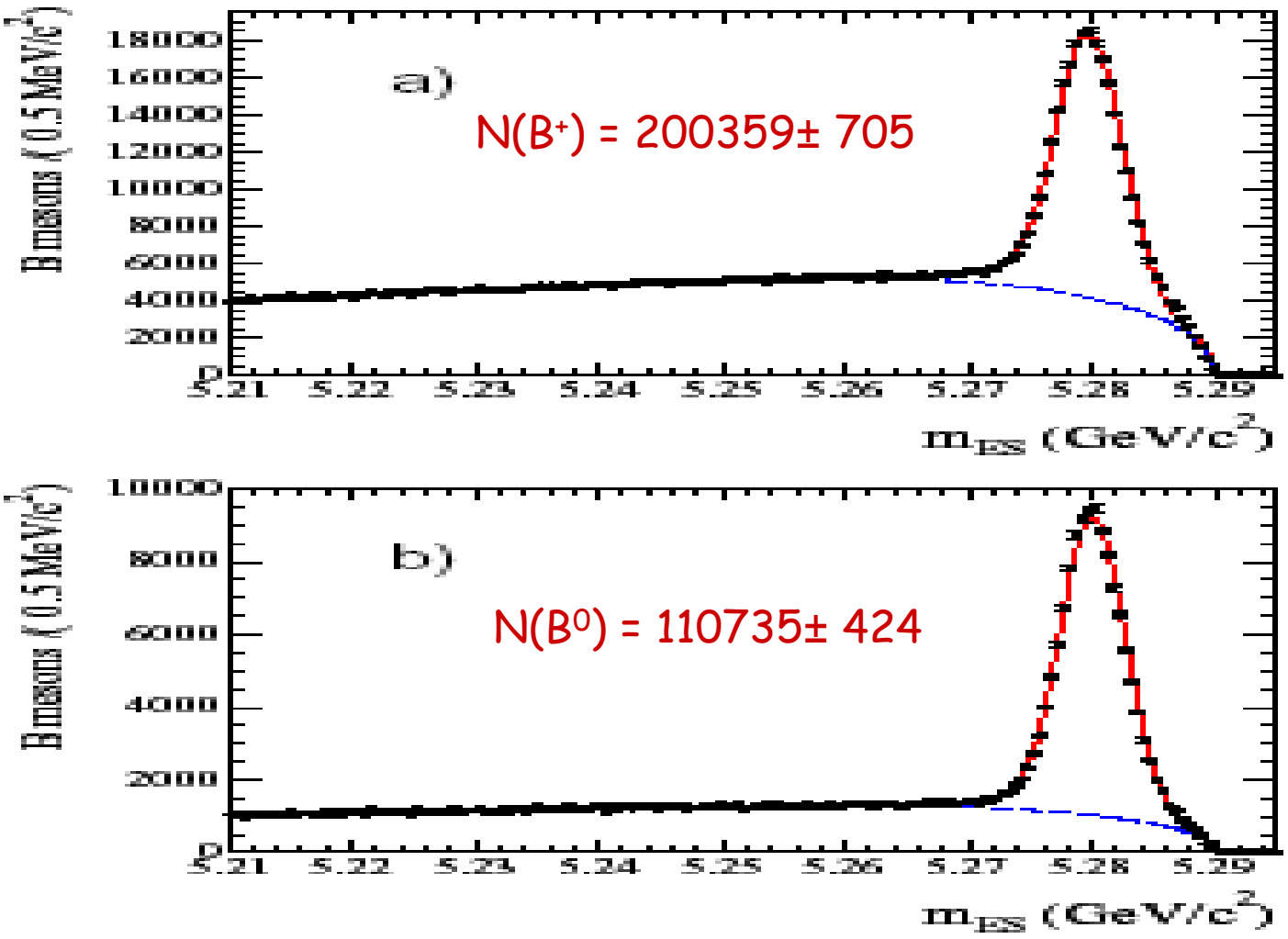
$J/\psi\Lambda\bar{p}$



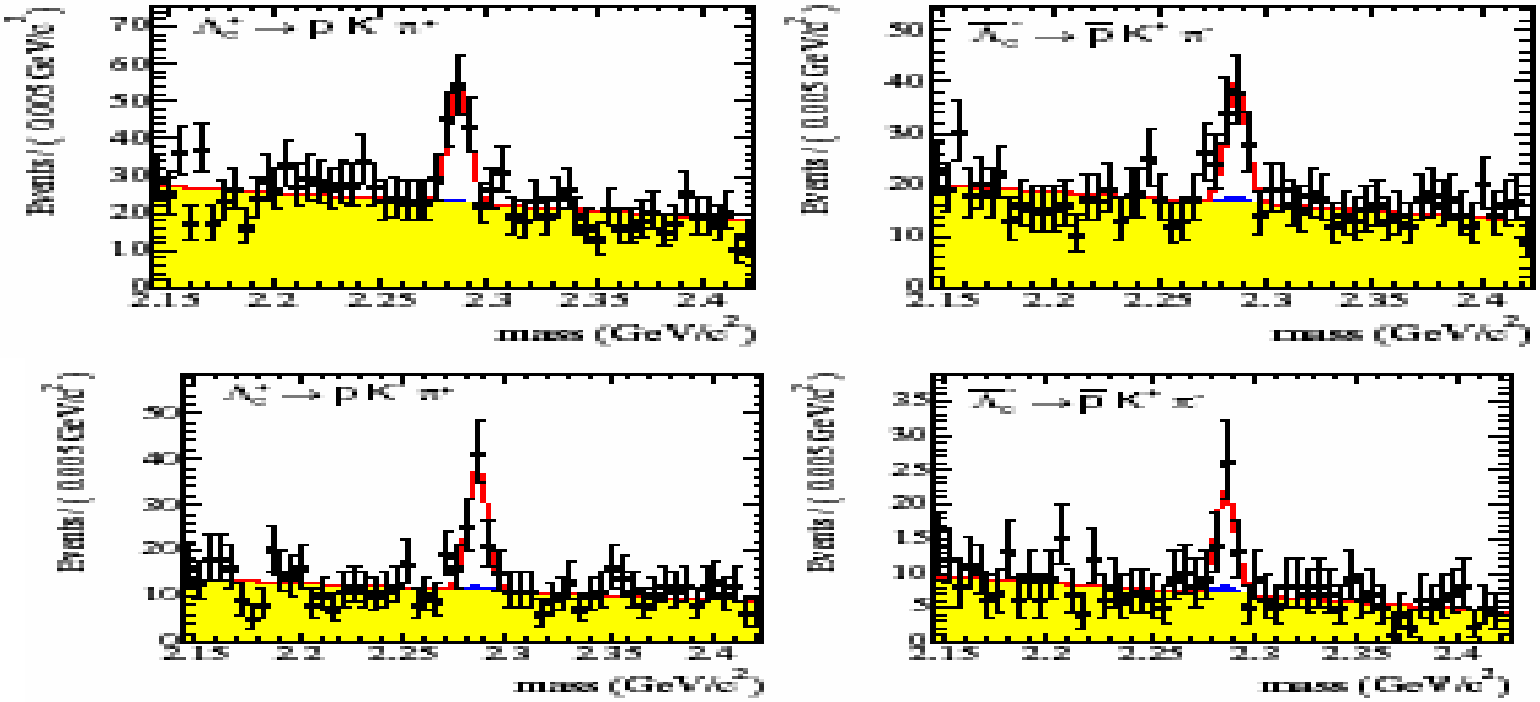
$J/\psi p\bar{p}$



Search for inclusive Λ_c^+ production in tagged B sample



Determination of BF($B \to \Lambda_c^+ X$)



hep-ex/0606026

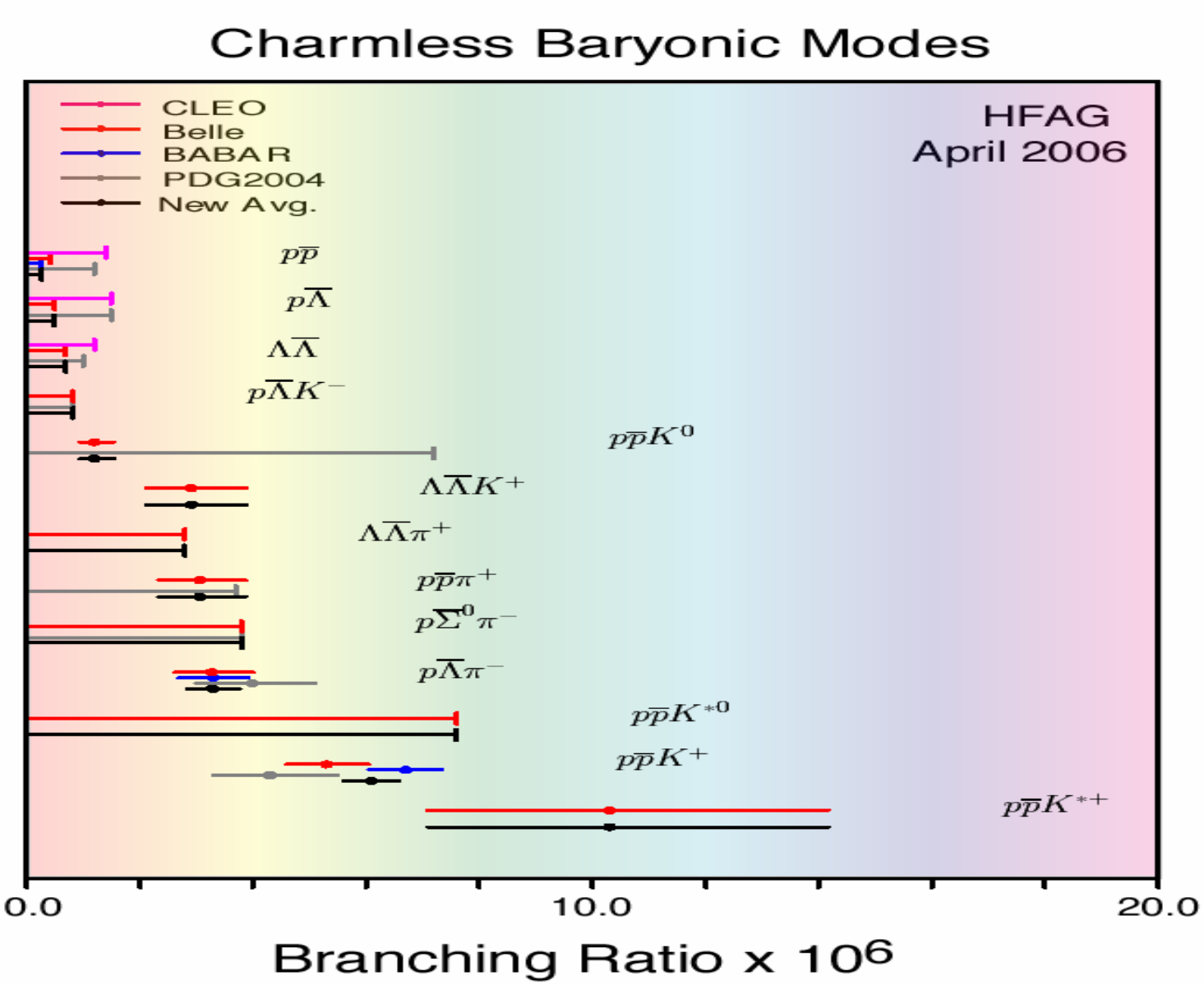
Useful for the understanding of the charm counting problem in b decays

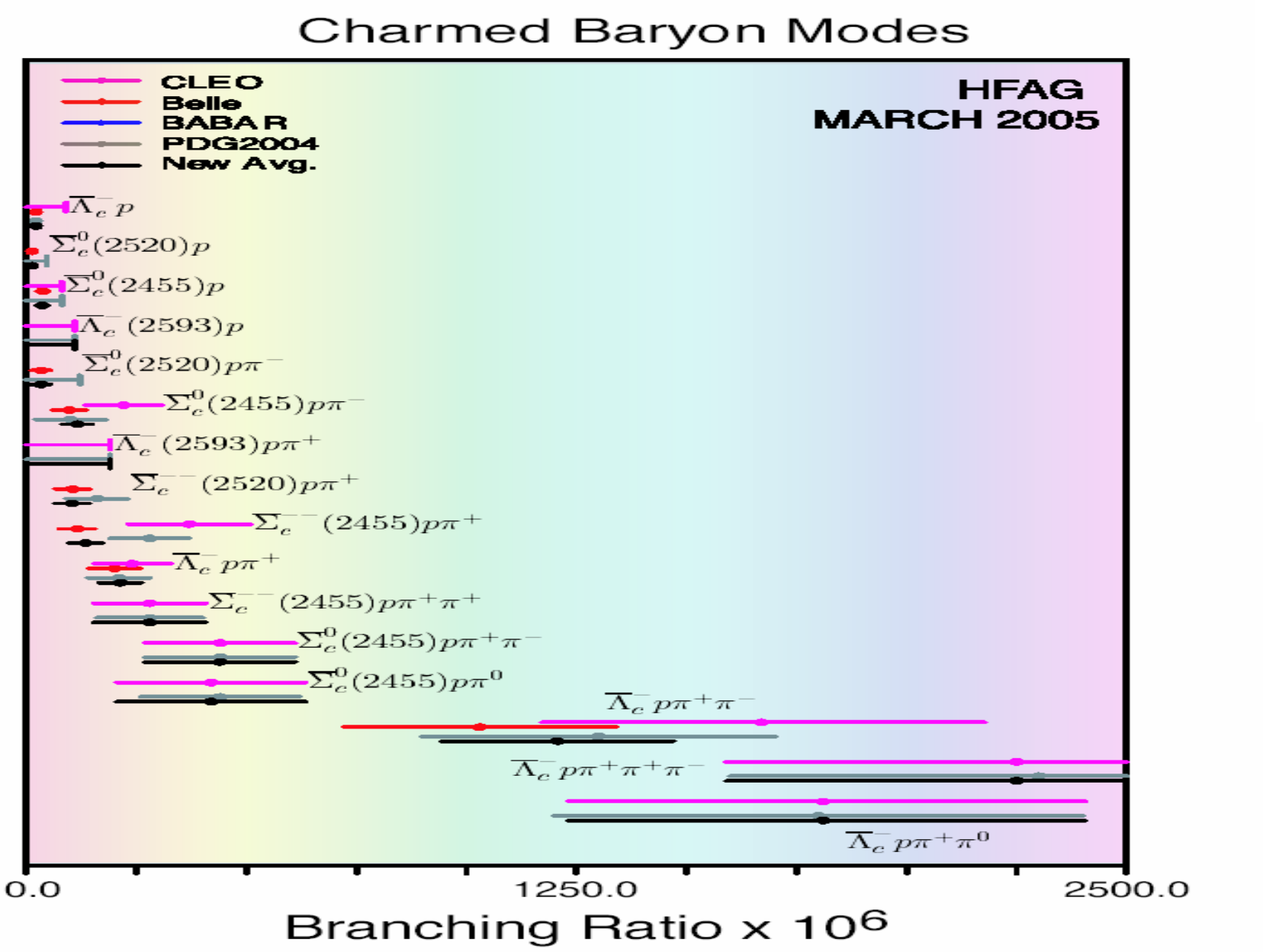
$BF(\bar{B}^- \to \Lambda_c^+ X) = (2.8 \pm 0.5 \pm 0.3\ ^{+1.0}_{-0.6})\%$

$BF(B^0 \to \Lambda_c^+ X) = (5.0 \pm 1.0 \pm 0.5\ ^{+1.8}_{-1.0})\%$

$BF(B^- \to \bar{\Lambda}_c^- X) = (2.1 \pm 0.5 \pm 0.2\ ^{+0.8}_{-0.4})\%$

$BF(\bar{B}^0 \to \bar{\Lambda}_c^- X) = (1.6 \pm 0.9 \pm 0.2\ ^{+0.6}_{-0.3})\%$


Charmless Baryonic Modes
CLEO
Belle
BABAR
PDG2004
New Avg.
HFAG
April 2006
$p\overline{p}$
$p\overline{\Lambda}$
$\Lambda\overline{\Lambda}$
$p\overline{\Lambda}K^-$
$p\overline{p}K^0$
$\Lambda\overline{\Lambda}K^+$
$\Lambda\overline{\Lambda}\pi^+$
$p\overline{p}\pi^+$
$p\Sigma^0\pi^-$
$p\overline{\Lambda}\pi^-$
$p\overline{p}K^{*0}$
$p\overline{p}K^+$
$p\overline{p}K^{*+}$
0.0
10.0
20.0
Branching Ratio x 10^6


Charmed Baryon Modes
CLEO
Belle
BABAR
PDG2004
New Avg.
HFAG
MARCH 2005
$\overline{\Lambda}_c^- p$
$\Sigma_c^0(2520)p$
$\Sigma_c^0(2455)p$
$\overline{\Lambda}_c^-(2593)p$
$\Sigma_c^0(2520)p\pi^-$
$\Sigma_c^0(2455)p\pi^-$
$\overline{\Lambda}_c^-(2593)p\pi^+$
$\Sigma_c^{--}(2520)p\pi^+$
$\Sigma_c^{--}(2455)p\pi^+$
$\overline{\Lambda}_c^- p\pi^+$
$\Sigma_c^{--}(2455)p\pi^+\pi^+$
$\Sigma_c^0(2455)p\pi^+\pi^-$
$\Sigma_c^0(2455)p\pi^0$
$\overline{\Lambda}_c^- p\pi^+\pi^-$
$\overline{\Lambda}_c^- p\pi^+\pi^+\pi^-$
$\overline{\Lambda}_c^- p\pi^+\pi^0$
0.0
1250.0
2500.0
Branching Ratio x 10^6

Summary

- Exclusive baryonic B decays: Well established after few years of B-factory running
- BF(2-body) < BF(3-body) < BF(4-body)
- Threshold enhancement in the baryon-antibaryon system
- Searching ground for exotic states
- Good crosscheck for baryonic charmonium decays
- More results will be shown this summer