Recent Studies of Baryon Production at Belle and BABAR

$B^- \rightarrow p\bar{p}l^-\nu$

$B^0 \rightarrow p\bar{\Lambda}\pi^-\gamma$

$\Upsilon(nS) \rightarrow \bar{d} + X$

$\Lambda_c^+ \rightarrow pK^-\pi^+$

Mass and width of $\Sigma_c(2455)^{0/++}$,

$\Sigma_c(2525)^{0/++}$

Search for $\Xi_{cc}^{+(+)}$, Ξ_c

$\Upsilon(1S,2S) \rightarrow \Lambda\bar{\Lambda}X$

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The Physics of the B Factories

422

17.12 *B* decays to baryons

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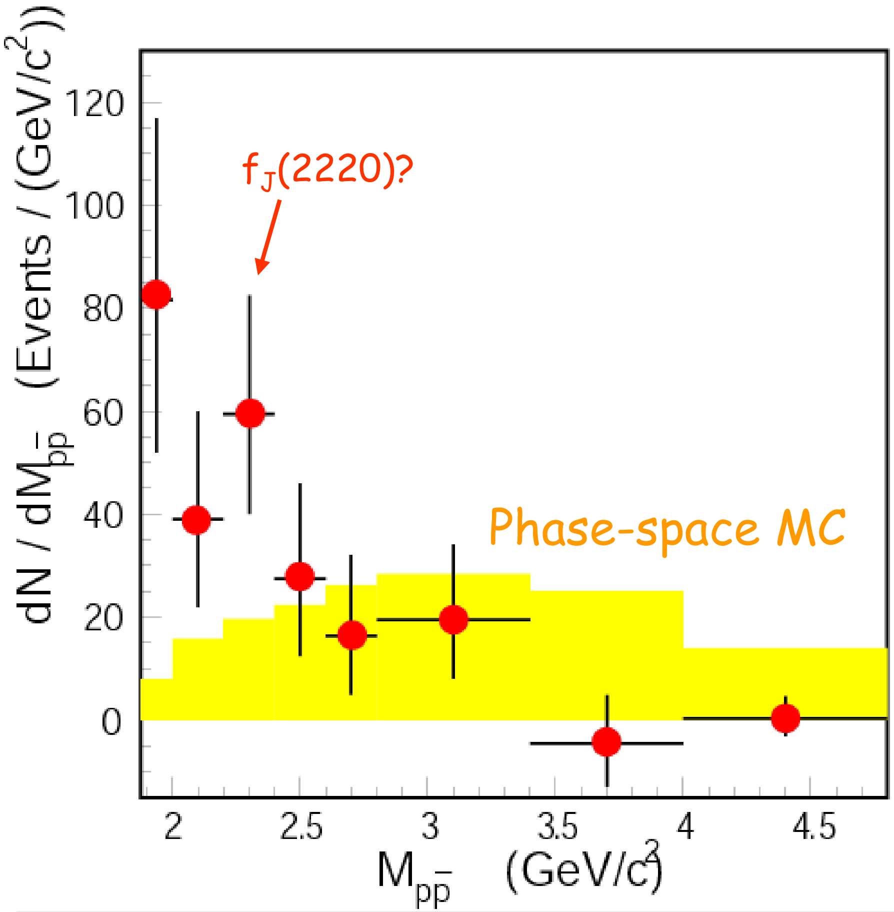
Introduction

- Charmless decays: a good searching ground for large Direct CP Violation
  due to tree-penguin interference
- $b \to s$ (d) FCNC loop process: sensitive to new physics
- Baryonic decays: Well established after a few years of B-factory running
- Threshold enhancement in the baryon-antibaryon system:
  Puzzle of angular distribution!
- BF(2-body) < BF(3-body) < BF(4-body)

Observed Rare Baryonic B Decays in 2002: $B^{\pm} \to p\bar{p}K^{\pm}$

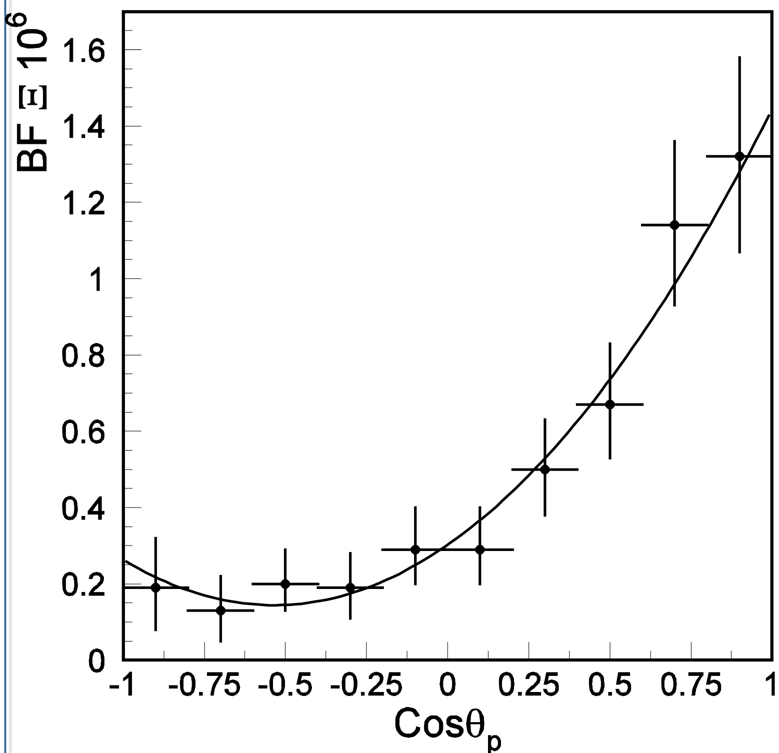
- Peak at Low Mass
- Baryon form factor?
  - Cheng & Yang PRD **66** 014020 ('02)
  - Chua, Hou, Tsai PRD **66** 054004 ('02)
- Quasi 2-body Decay?
  - Chua, Hou, Tsai PLB **544** 139 ('02)
  - Glueball?
- Baryonium
- Fragmentation
- Final state interaction

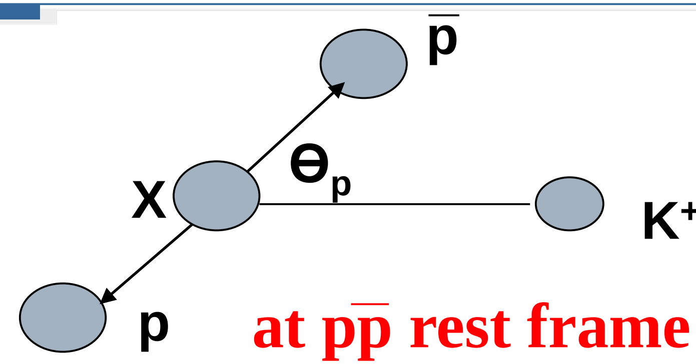


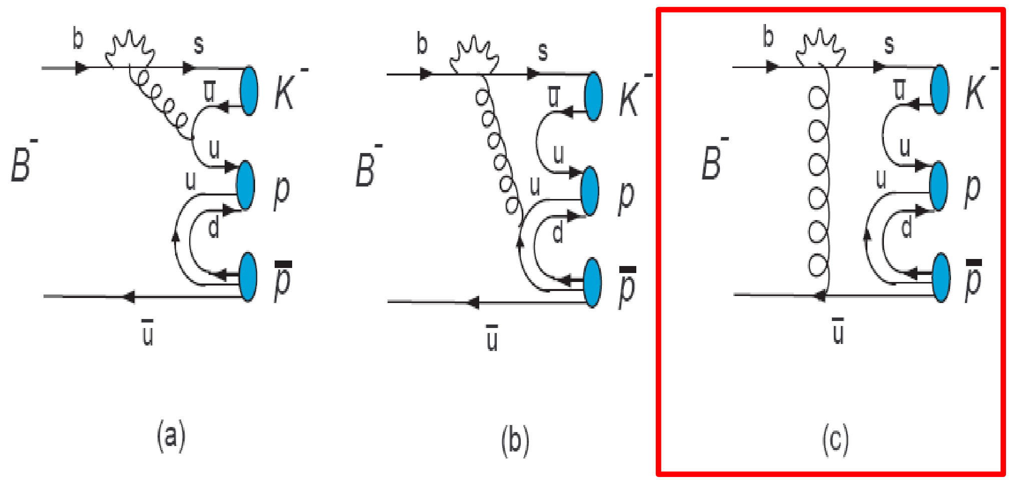
Threshold enhancement: a universal feature of charmless baryonic B decays

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

$p\bar{p}K$ signal



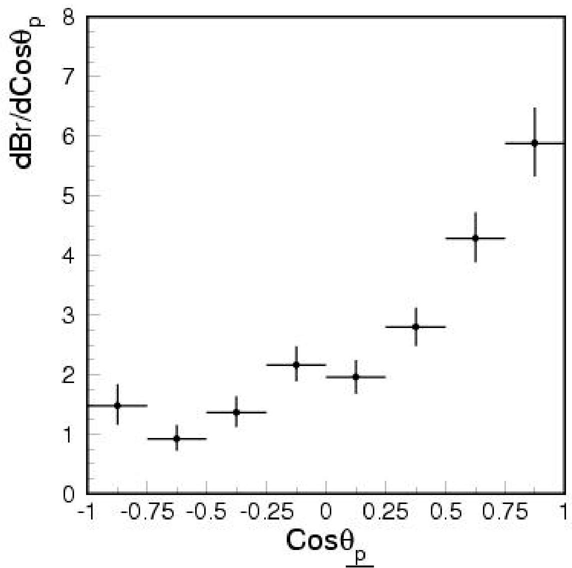




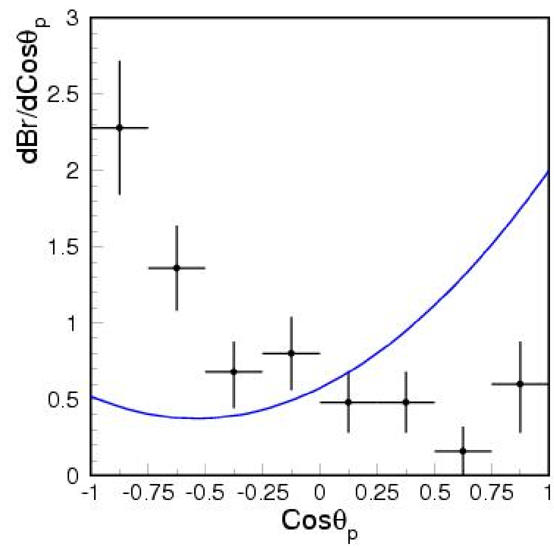
Proton against K^- ($\bar{p}$ against K^+) : flavor dependence!

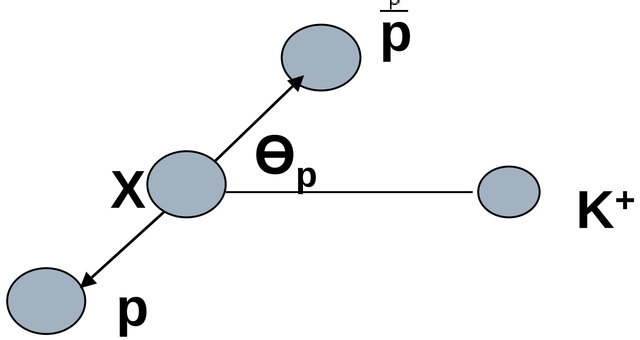
Angular asymmetry (puzzle)

$$B^- \to p\bar{p}K^-$$



$$B^- \to p\bar{p}\pi^-$$

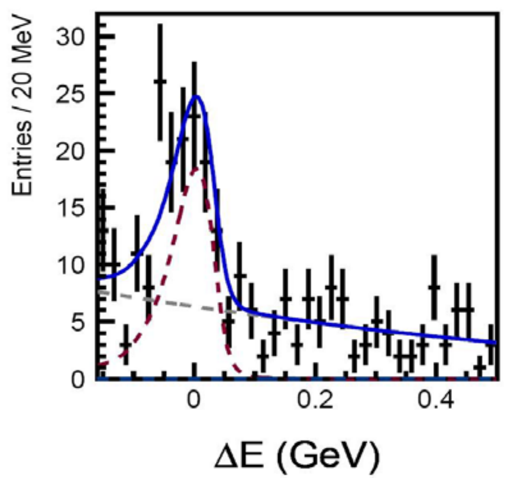


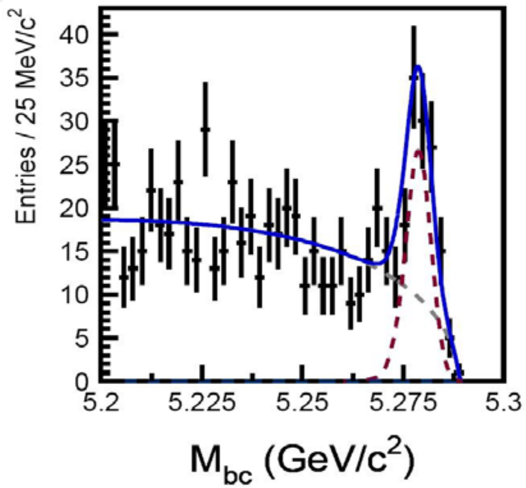


Proton against K^- or π^-

Study of $B^+ \to p\overline{\Lambda}\gamma$

414fb^{-1}





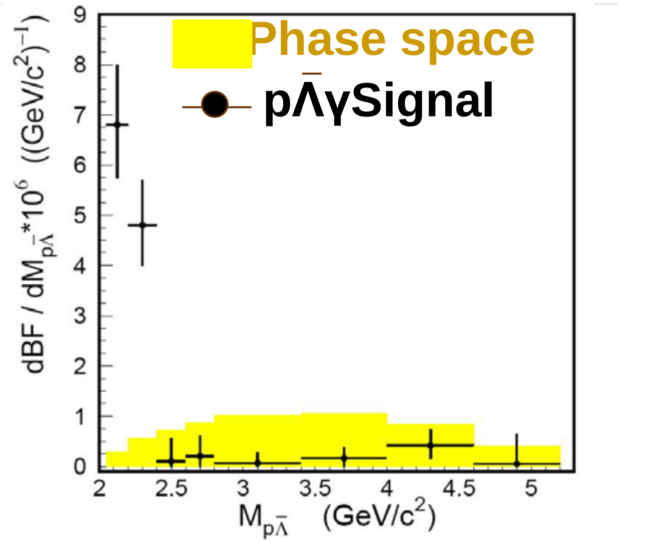


Table 17.12.10. Predicted branching fractions for radiative baryonic B decays where A_θ is the angular asymmetry defined in Eq. (17.12.7) and "$\mathcal{B}$(tot)" denotes the sum of the baryon and meson pole contributions (Cheng and Yang, 2006).

Mode	Baryon	Meson	$\mathcal{B}$(tot)	A_θ
$B^- \to \Lambda\overline{p}\gamma$	7.9×10^{-7}	9.5×10^{-7}	2.6×10^{-6}	0.25
$B^- \to \Sigma^0\overline{p}\gamma$	4.6×10^{-9}	2.5×10^{-7}	2.9×10^{-7}	0.07
$B^- \to \Xi^0\overline{\Sigma}^-\gamma$	7.5×10^{-7}	1.6×10^{-7}	5.6×10^{-7}	0.43
$B^- \to \Xi^-\overline{\Lambda}\gamma$	1.6×10^{-7}	2.4×10^{-7}	2.2×10^{-7}	0.13

2.6×10^{-6} is in good agreement with the latest measurement (Wang, 2007b)

$$\mathcal{B}(B^- \to \Lambda\overline{p}\gamma) = (2.45^{+0.44}_{-0.38} \pm 0.22)\times10^{-6}\ . \quad (17.12.16)$$

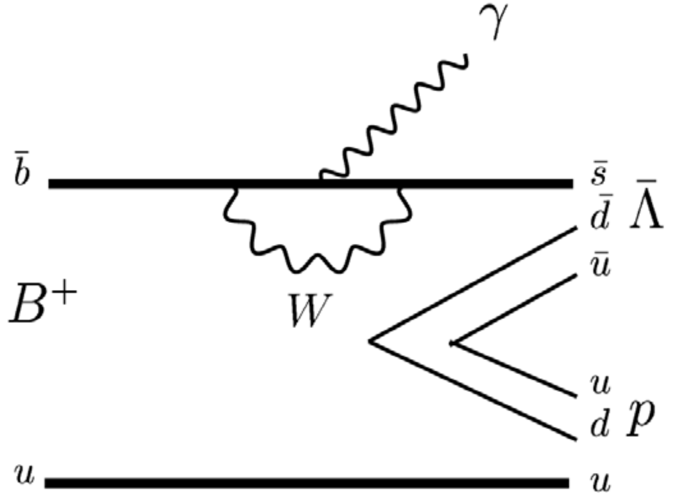
Theoretical prediction:

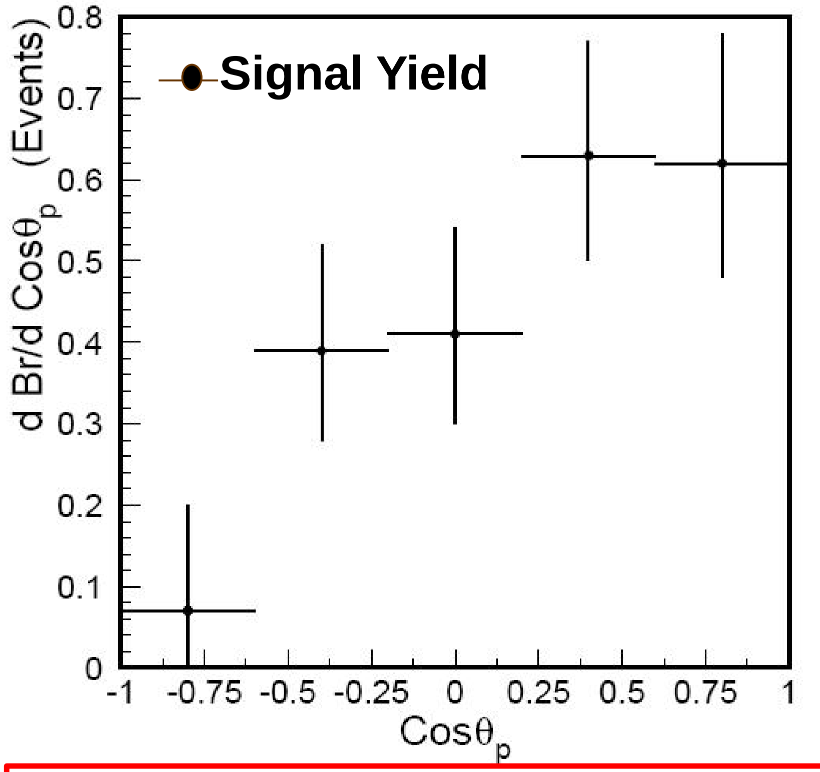
***Pole Model**: Cheng and Yang
Phys.Lett. B533 (2002)

BF($B \to p\overline{\Lambda}\gamma$): $(2.45\ ^{+0.44}_{-0.38} \pm 0.22)\times10^{-6}$

Angular distribution

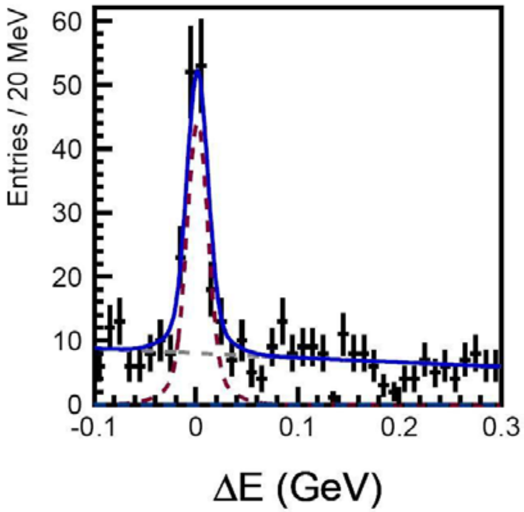
Fit results in bins of $\cos\theta_p$ with $M_{p\bar{\Lambda}}<4.0 GeV/c^2$
(Assuming $X \rightarrow p\bar{\Lambda}$, calculated in X rest frame. θ_p is defined as the angle between the proton direction and the meson/photon direction.)

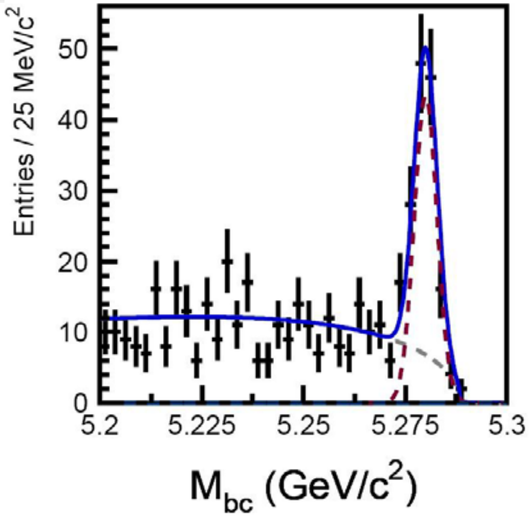


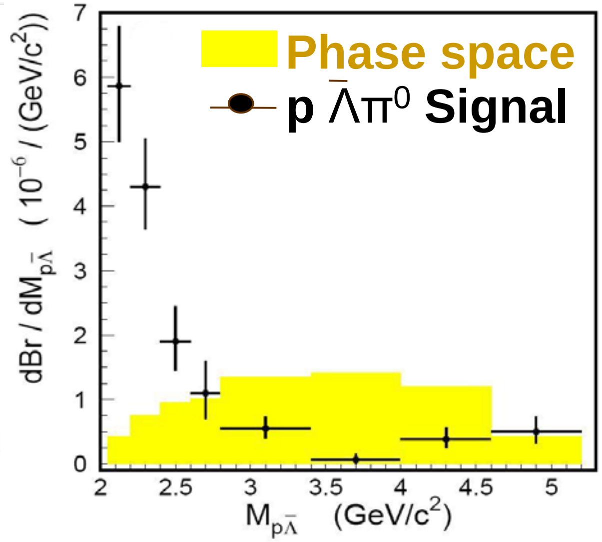


Agree with theoretical prediction!

Study of $B^+ \to p\bar{\Lambda}\pi^-$







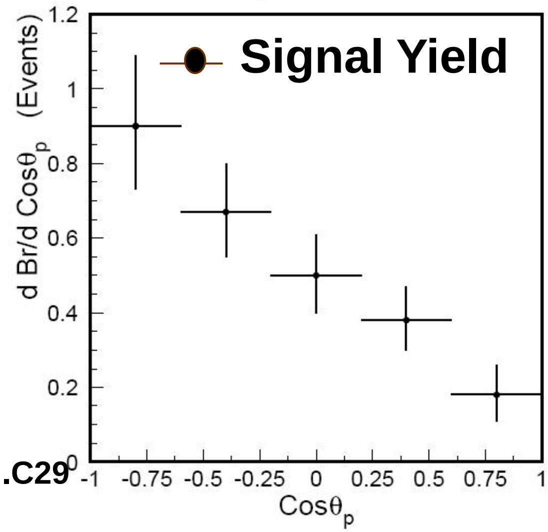
Signal yield:

Signal Yield for $B \to p\bar{\Lambda}\pi^-$ with $M_{p\bar{\Lambda}}<2.8\mathrm{GeV/c^2}$: 129.4

Statistical Significance: 20.0σ

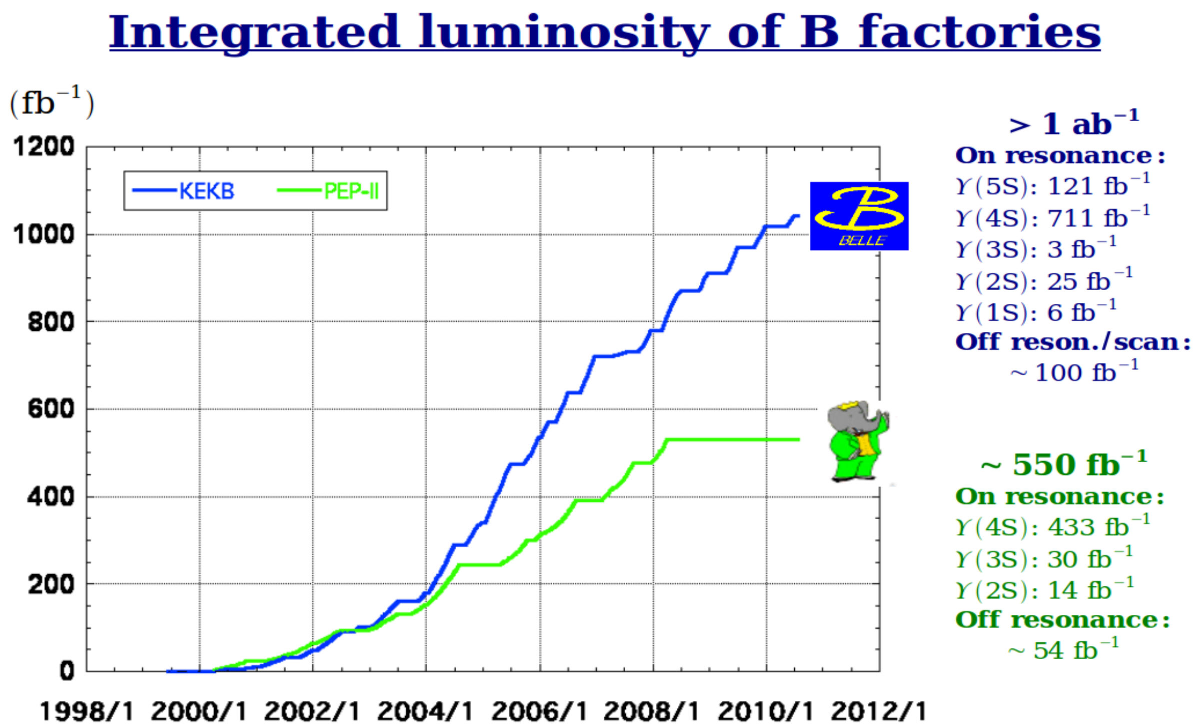
$BF(B \to p\bar{\Lambda}\pi^-)$: $(3.23\ ^{+0.33}_{-0.29} \pm 0.29)\times 10^{-6}$

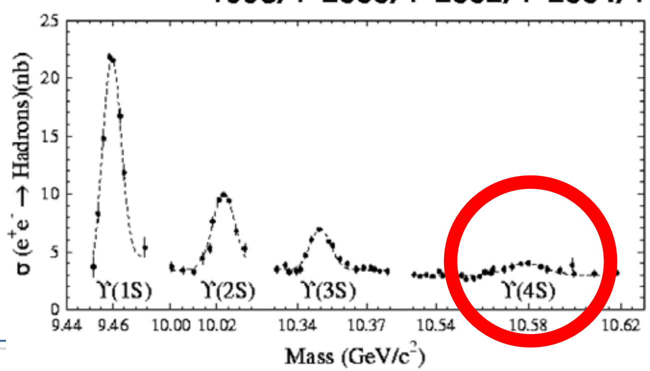
$$\frac{BF(B^+ \to p\bar{\Lambda}\pi^0)}{BF(B^+ \to p\bar{\Lambda}\pi^-)} = 0.93 \pm 0.21$$ ≠1/2?

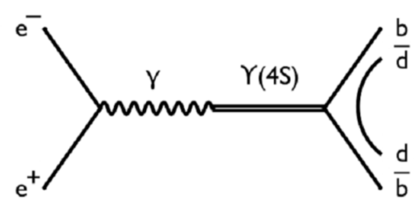


Chua&Hou Eur. Phys. J.C29 (2003)

Full data Sets of two B-factories



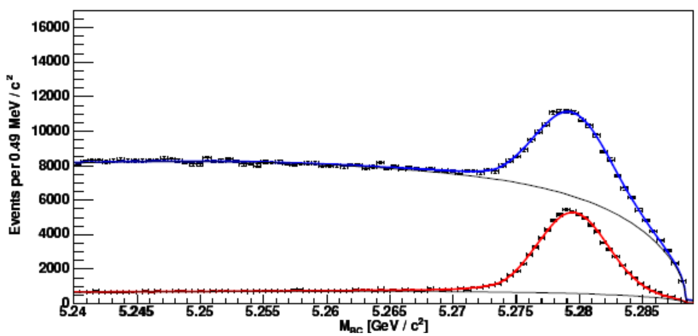




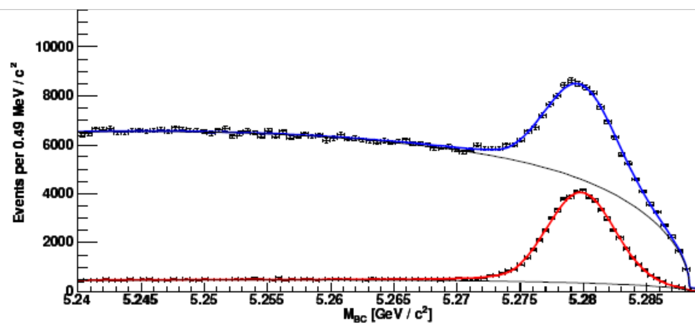
~770M BBbar pairs

Neutrino in the final state - performance of Hadronic Tagging

Neural network (NeuroBayes) with output quality selection
Typical eff 0.2%-0.4%



Improvement of purity with roughly equal efficiency level for $B^+(\uparrow)$ and $B^0(\downarrow)$.

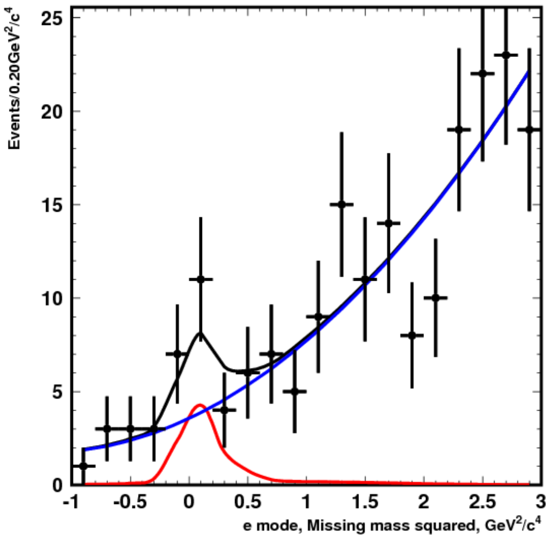


Particle	Decay modes
$\bar{B}^0$	$D^{*+}\pi^-$, $D^{*+}\pi^-\pi^0$, $D^{*+}\pi^-\pi^+\pi^-$, $D^{*+}\pi^-\pi^+\pi^-\pi^0$ $D^+\pi^-$, $D^+\pi^-\pi^0$, $D^+\pi^-\pi^+\pi^-$, $D^{*+}D_s^{*-}$, $D^{*+}D_s^-$, $D^+D_s^{*-}$, $D^+D_s^-$, $J/\psi K_s^0$, $J/\psi K^-\pi^+$, $J/\psi K_s^0\pi^+\pi^-$, $D^0\pi^0$ Totally 489 modes!
B^-	$D^{*0}\pi^-$, $D^{*0}\pi^-\pi^0$, $D^{*0}\pi^-\pi^+\pi^-$, $D^{*0}\pi^-\pi^+\pi^-\pi^0$, $D^0\pi^-$, $D^0\pi^-\pi^0$, $D^0\pi^-\pi^+\pi^-$, $D^{*0}D_s^{*-}$, $D^{*0}D_s^-$, $D^0D_s^{*-}$, $D^0D_s^-$, $J/\psi K^-$, $J/\psi K^-\pi^+\pi^-$, $J/\psi K^-\pi^0$, $J/\psi K_s^0\pi^-$ D^0K^-, $D^+\pi^-\pi^-$ Totally 615 modes!
D^{*+}	$D^0\pi^+$, $D^+\pi^0$
D^{*0}	$D^0\pi^0$, $D^0\gamma$
D_s^{*+}	$D_s^+\gamma$
D^0	$K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^-$, $K_s^0\pi^0$, $K_s^0\pi^+\pi^-$, $K_s^0\pi^+\pi^-\pi^0$, $K_s^0K^+K^-$, K^+K^-, $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$
D^+	$K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K_s^0\pi^+$, $K_s^0\pi^+\pi^0$, $K_s^0\pi^+\pi^+\pi^-$, $K^-K^+\pi^+$, $K^-K^+\pi^+\pi^0$
D_s^+	$K^+K^-\pi^+$, $K^+K^-\pi^+\pi^0$, $K^+K^-\pi^+\pi^+\pi^-$, $K_s^0K^+$, $K_s^0K^-\pi^+\pi^+$, $K_s^0K^+\pi^+\pi^-$, $K^+\pi^+\pi^-$, $\pi^+\pi^+\pi^-$
J/ψ	e^-e^+, $\mu^-\mu^+$

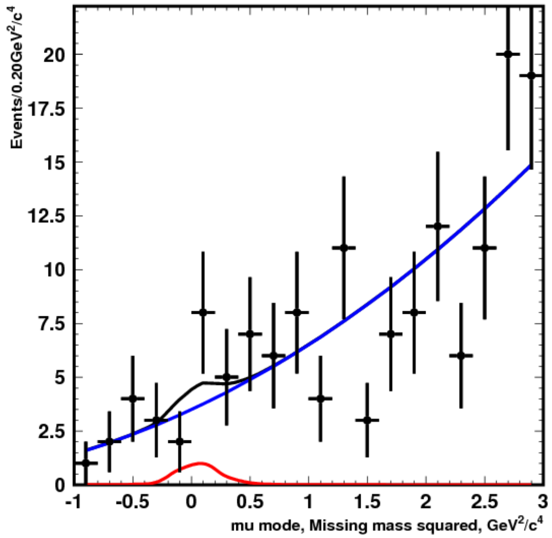
Phys.Rev.D89:011101

Results for $B^- \to p\bar{p}l^-\nu$

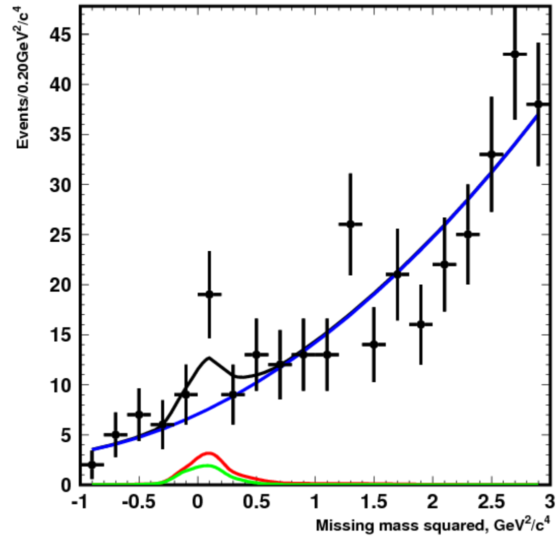
Electron mode	muon mode	Combined fit



Significance 3.0σ



Significance 1.3σ



Significance 3.2σ

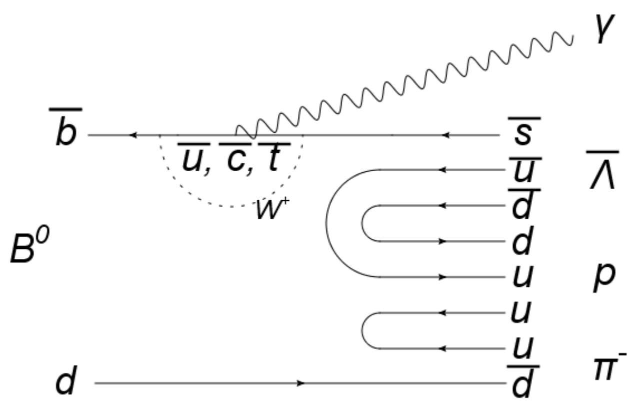
Mode	$\mathcal{B}$ measurement (10^{-6})	$\mathcal{B}$ upper limit (10^{-6})
$B^- \to p\bar{p}e^-\bar{\nu}_e$	$8.22^{+3.74}_{-3.20}(stat.) \pm 0.55(syst.)$	13.8
$B^- \to p\bar{p}\mu^-\bar{\nu}_\mu$	$3.13^{+3.10}_{-2.40}(stat.) \pm 0.71(syst.)$	8.5
Combined Fit	$5.78^{+2.42}_{-2.13}(stat.) \pm 0.86(syst.)$	9.6

Motivation - searching for $B^0 \to p\overline{\Lambda}\pi^-\gamma$

- In these two cases mentioned above, the more bodies involved in decay, the larger branching fraction is in these modes, at least the same order.

  Exp. b → s γ almost saturate theo. prediction at 10^{-5} level

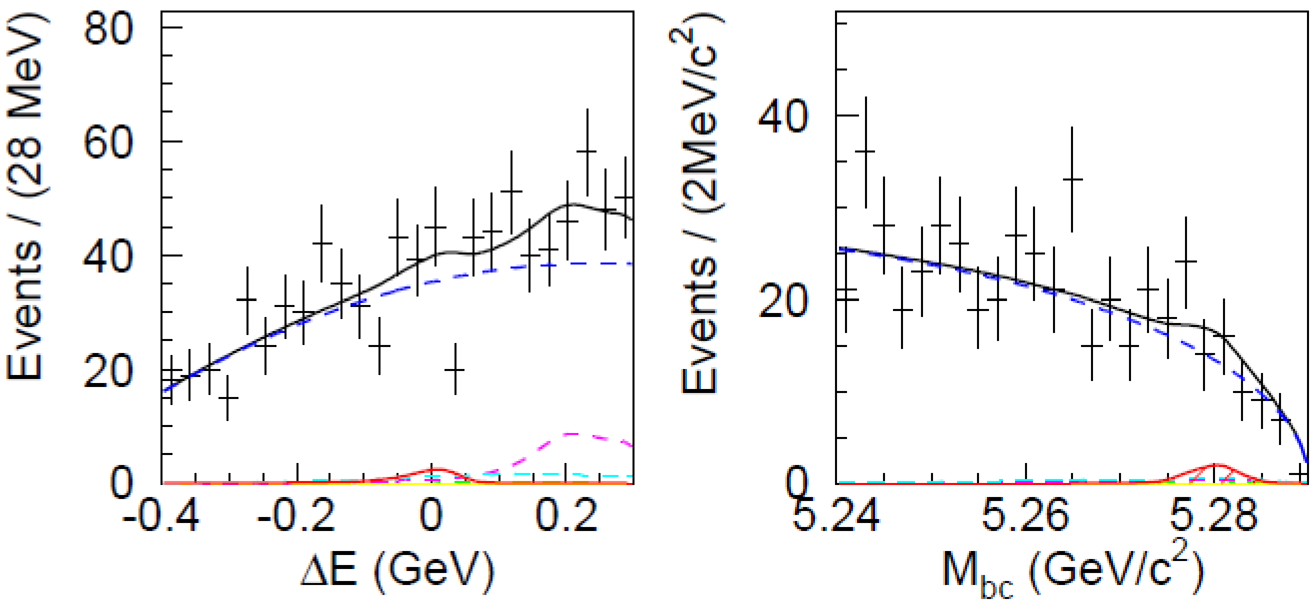
- Bf $(B^+ \to p\overline{\Lambda}\gamma) = (2.16 \pm 0.20) * 10^{-6}$
- Consider the $b \to s\gamma$ transition, according to the two cases mentioned above, Bf $(B^0 \to p\overline{\Lambda}\pi^-\gamma)$ should be larger than Bf $(B^+ \to p\overline{\Lambda}\gamma)$, at least the same order, so this mode may contribute 6% in $b \to s\gamma$ (experiment result: $(3.55 \pm 0.32) * 10^{-4}$) at most.



BF(2-body) < BF(3-body) < BF(4-body)

Phys.Rev.D89:091102

Results for $B^0 \to p\bar{\Lambda}\pi^-\gamma$



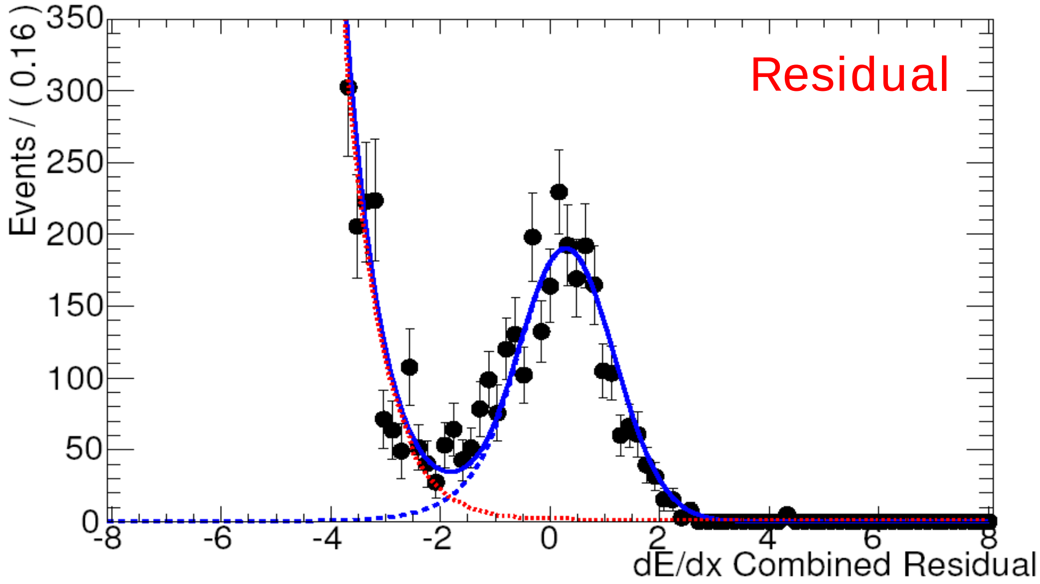
Black error bar: data
Black: total PDF
Red: true
Green: Self-cross feed
Blue: qq background
Magenta: $B^+ \to p\bar{\Lambda}\gamma$
Cyan: $B^+ \to p\bar{\Lambda}\pi^0$

- The shift of signal yield from the 5 rare B modes is from the correlation of PDF, and the results are all in one σ of statistical error. So finally we won't consider them into systematic uncertainties.
- Because the $B^0 \to p\bar{\Lambda}\pi^-\gamma$ decay is not significant, we evaluate the 90% confidence level upper limit for the branching fraction. The upper limit is about $O(10^{-7})$

$\Upsilon(nS) \rightarrow \bar{d} + X$

Phys.Rev.D89:111102

- ARGUS, CLEO observed $\Upsilon(1S,2S) \rightarrow \bar{d} + X$
- Kinetic energy much bigger than binding energy
- Cosmic anti-nuclei probes dark matter annihilation
- dE/dx to identify $\bar{d}$

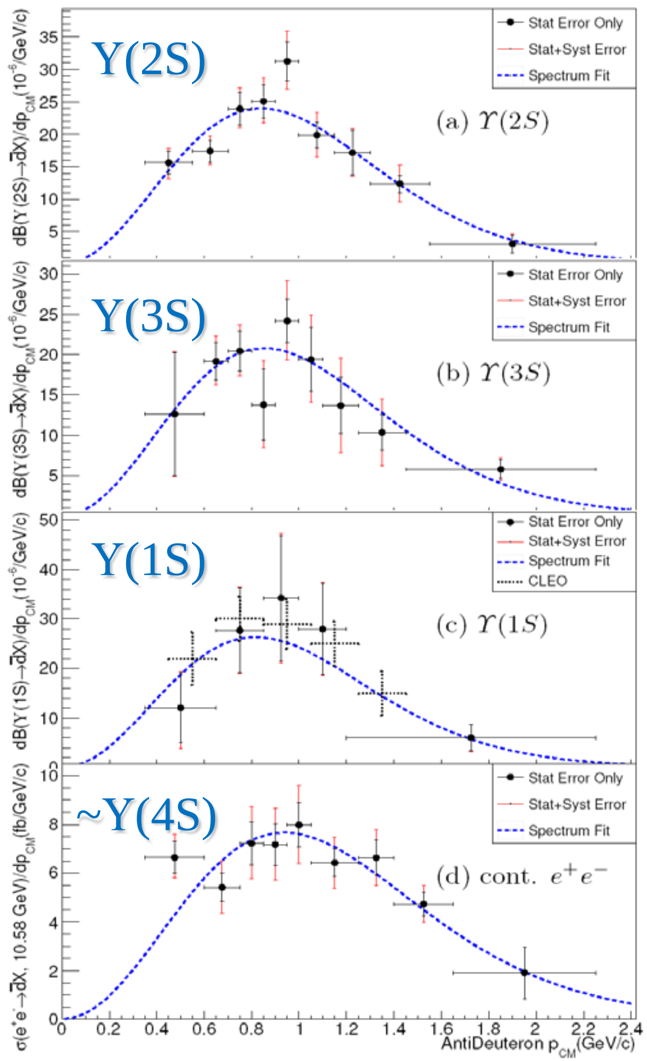


Anti-deuteron CM mom. spectrum

- Evt. weighted by eff.
- Simultaneous fit to on-off resonance Υ(2S,3S) data
- Use Υ(2S) data π π recoil mass to determine Υ(1S) signal yield
- Υ(4S) same as $e^+e^- \rightarrow q\bar{q}$
- Spectrum fit with fire ball model

$$P(E) = \alpha v^2 e^{-\beta E}$$

$$\beta = (4.71 \pm 0.19)\,\mathrm{GeV}^{-1}$$



Anti-deuteron production rate at Υ(nS)

Process	Rate
$\mathcal{B}(\Upsilon(3S) \to \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(2S) \to \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-5}$
$\mathcal{B}(\Upsilon(1S) \to \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-5}$
$\sigma(e^+e^- \to \bar{d}X)$ $[\sqrt{s} \approx 10.58\,\mathrm{GeV}]$	$(9.63 \pm 0.41^{+1.17}_{-1.01})$ fb
$\dfrac{\sigma(e^+e^- \to \bar{d}X)}{\sigma(e^+e^- \to \mathrm{Hadrons})}$	$(3.01 \pm 0.13^{+0.37}_{-0.31}) \times 10^{-6}$

Quark dominant decay ~Υ(4S) suppressed by an order of magnitude to gluon dominant decay at **Υ(1S,2S,3S)**

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

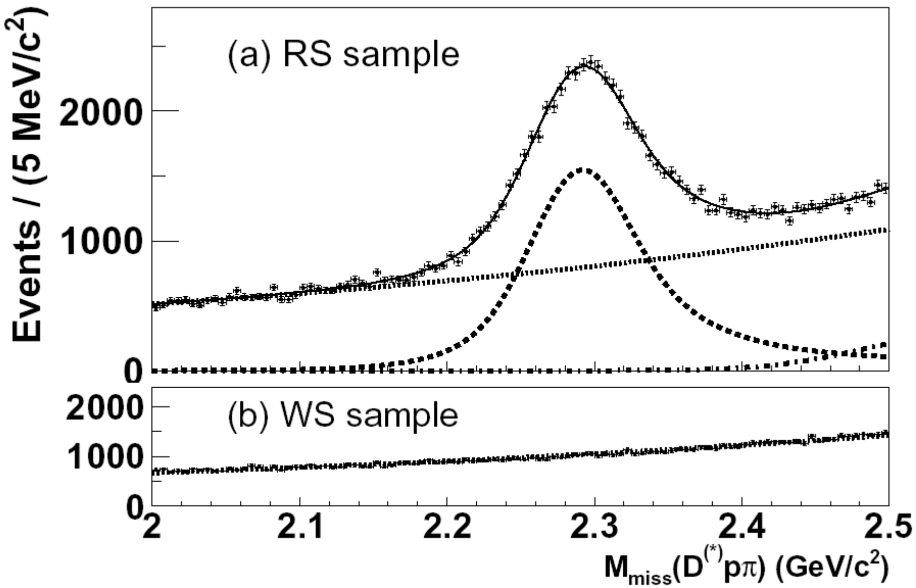
Phys.Rev.Lett.113:042002

- Normalization mode for charmed baryons
- Large uncertainty due to modeling

$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$$

- Missing mass spect. to determine yield

$$e^+e^- \to D^{(*)-}\overline{p}\pi^+\Lambda_c^+$$



978 fb^{-1}

12 D decay modes

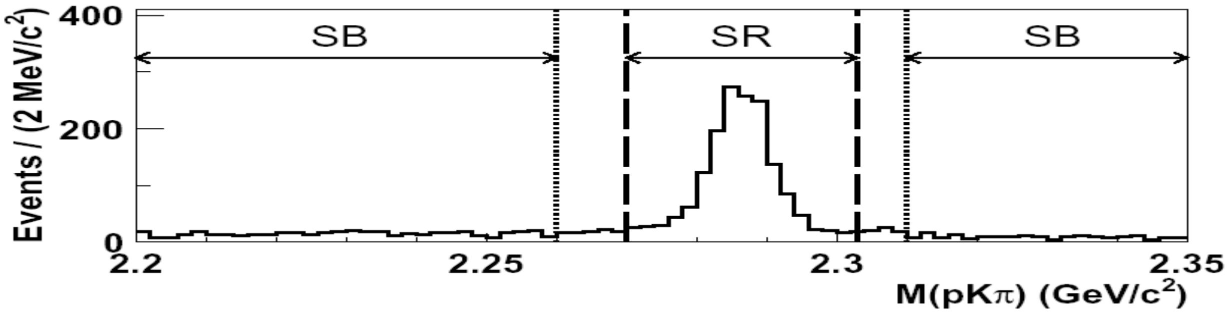
Right Sign: $D^{(*)-}\overline{p}\pi^+$

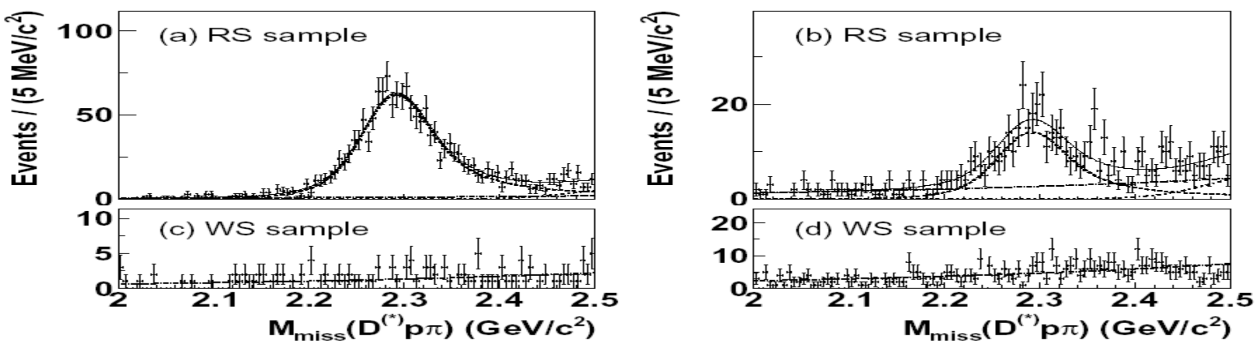
Wrong Sign: $D^{(*)-}p\pi^-$

$D^{(*)+}\overline{p}\pi^-$

Exclusive $\Lambda_c^+ \to pK^-\pi^+$ in inclusive Λ_c^+ sample

Sideband subtraction of inclusive Λ_c^+ yield





$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = \frac{N(\Lambda_c^+ \to pK^-\pi^+)}{N_{\rm inc}^{\Lambda_c} f_{\rm bias} \varepsilon(\Lambda_c^+ \to pK^-\pi^+)}$$

f_{bias} inclusive Λ_c^+ rec. ε bias due to signal mode

$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24(\mathrm{stat.})^{+0.21}_{-0.27}(\mathrm{syst.}))\%$$

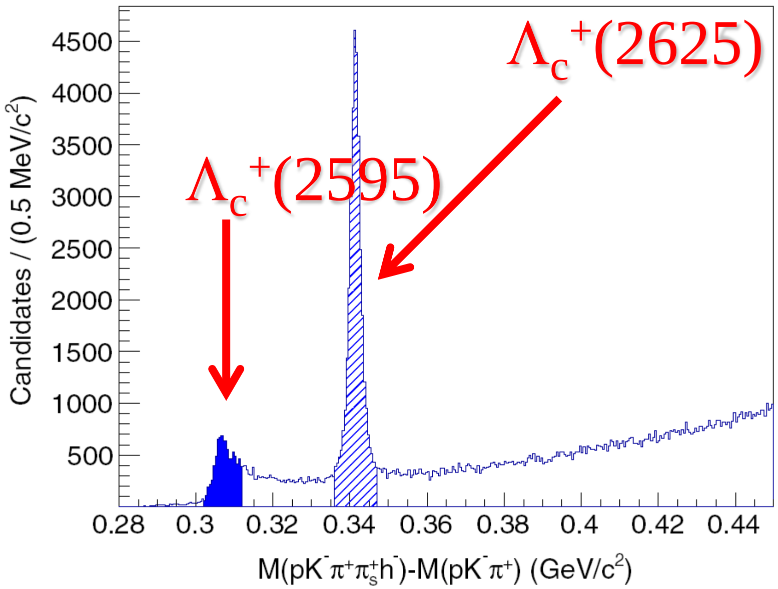
Mass and width of $\Sigma_c(2455)^{0/++}$, $\Sigma_c(2525)^{0/++}$

Phys.Rev.D89:091102

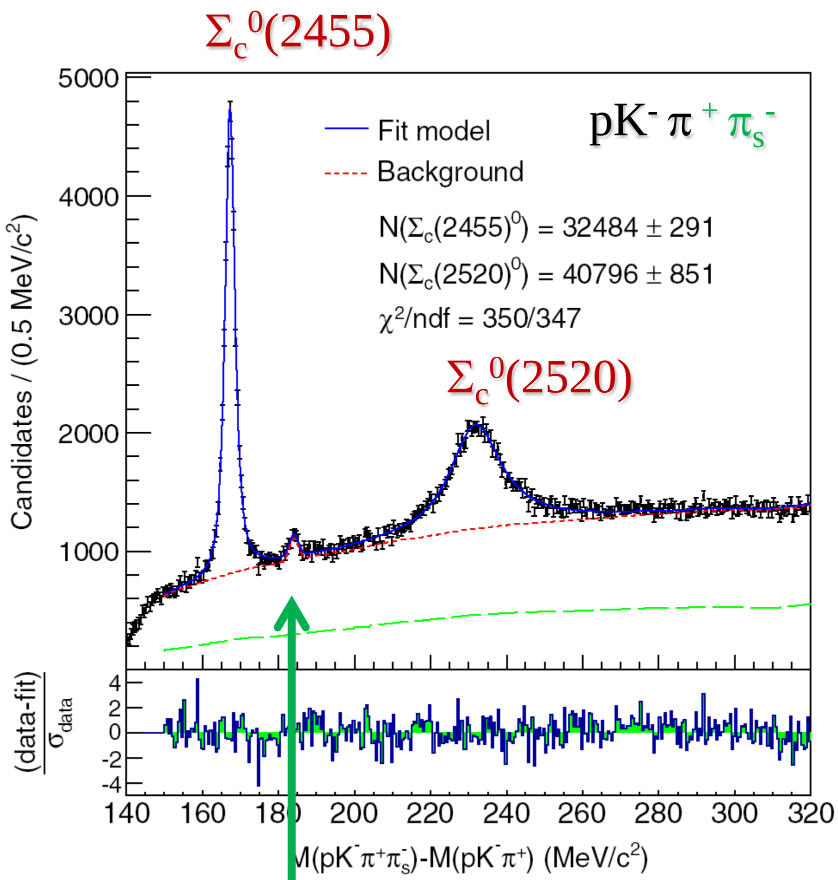
- Naïvely Σ_c^0 (ddc) heavier than Σ_c^{++}(uuc)
- Precise mass splitting measurement to test LQCD, HQET, Quark Model, QCD sum rule, Bag Model
- Use mass difference via $\Sigma_c^{0/++} \rightarrow \Lambda_c^+ (pK^- \pi^+) \pi_s^{-/+}$

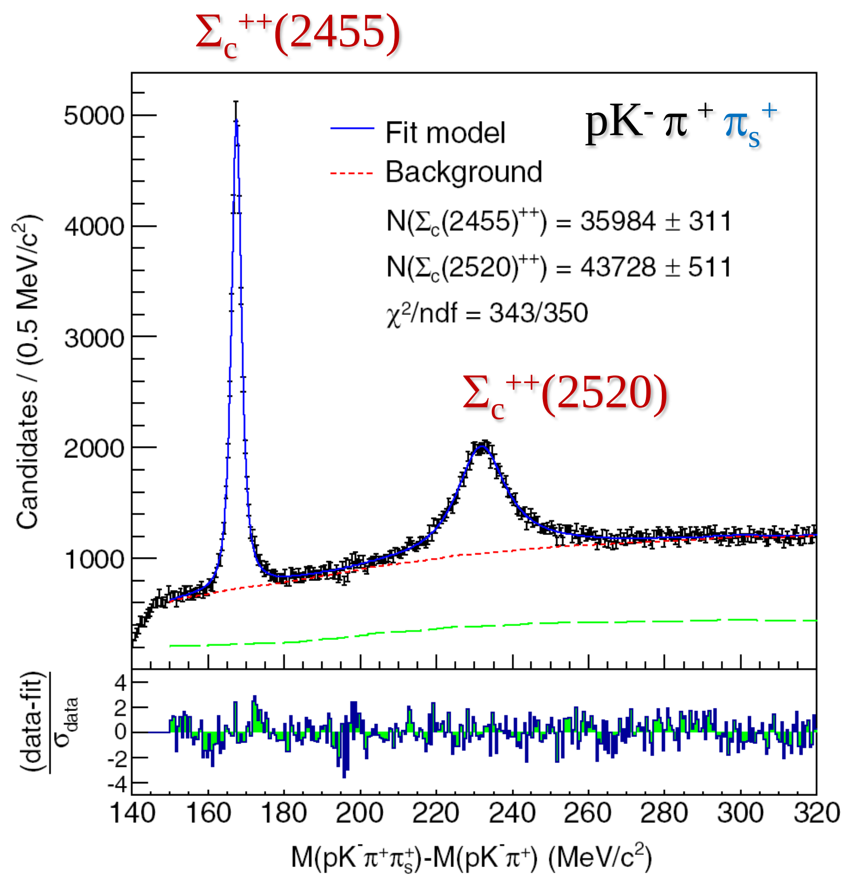
711 fb^{-1} Y(4S) data

Feed down background from excited Λ_c^{*+}



ΔM spect. after removing feed-down Λ_c^{*+}





Small bump: $\Xi_c^0 \to \Lambda_c^+ \pi^-$

ΔM spectrum Fit results

- Signal: relativistic Breit Wigner function convolved with detector response function
- Background: threshold function

	ΔM_0 (MeV/c^2)	Γ (MeV/c^2)	M_0 (MeV/c^2)
$\Sigma_c(2455)^0$	$167.29 \pm 0.01 \pm 0.02$	$1.76 \pm 0.04^{+0.09}_{-0.21}$	$2453.75 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2455)^{++}$	$167.51 \pm 0.01 \pm 0.02$	$1.84 \pm 0.04^{+0.07}_{-0.20}$	$2453.97 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2520)^0$	$231.98 \pm 0.11 \pm 0.04$	$15.41 \pm 0.41^{+0.20}_{-0.32}$	$2518.44 \pm 0.11 \pm 0.04 \pm 0.14$
$\Sigma_c(2520)^{++}$	$231.99 \pm 0.10 \pm 0.02$	$14.77 \pm 0.25^{+0.18}_{-0.30}$	$2518.45 \pm 0.10 \pm 0.02 \pm 0.14$

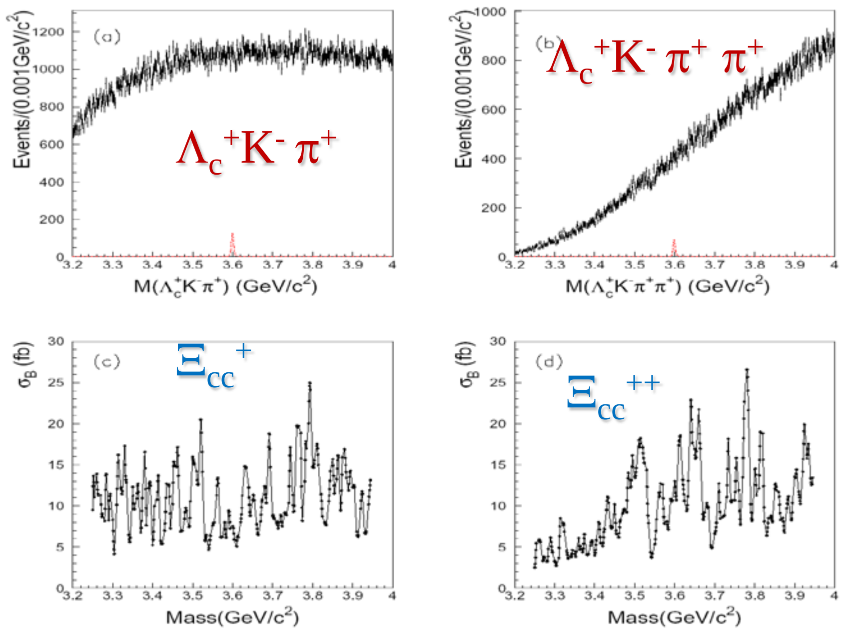
$$M_{\Sigma_c(2455)^{++}} - M_{\Sigma_c(2455)^0} = 0.22 \pm 0.01 \pm 0.01 \text{ MeV/c2}$$

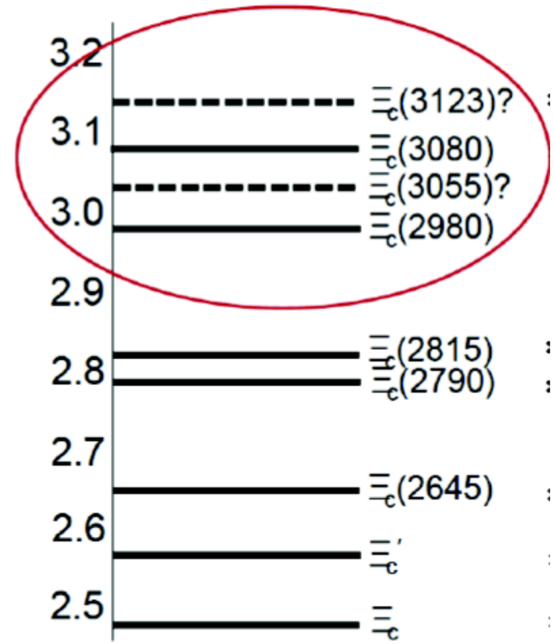
Search for $\Xi_{cc}^{+(+)}$, Ξ_c

Phys.Rev.D89:052003

- No confirmation of doubly charmed baryon (SELEX)
- Charmed strange baryon not fully understood

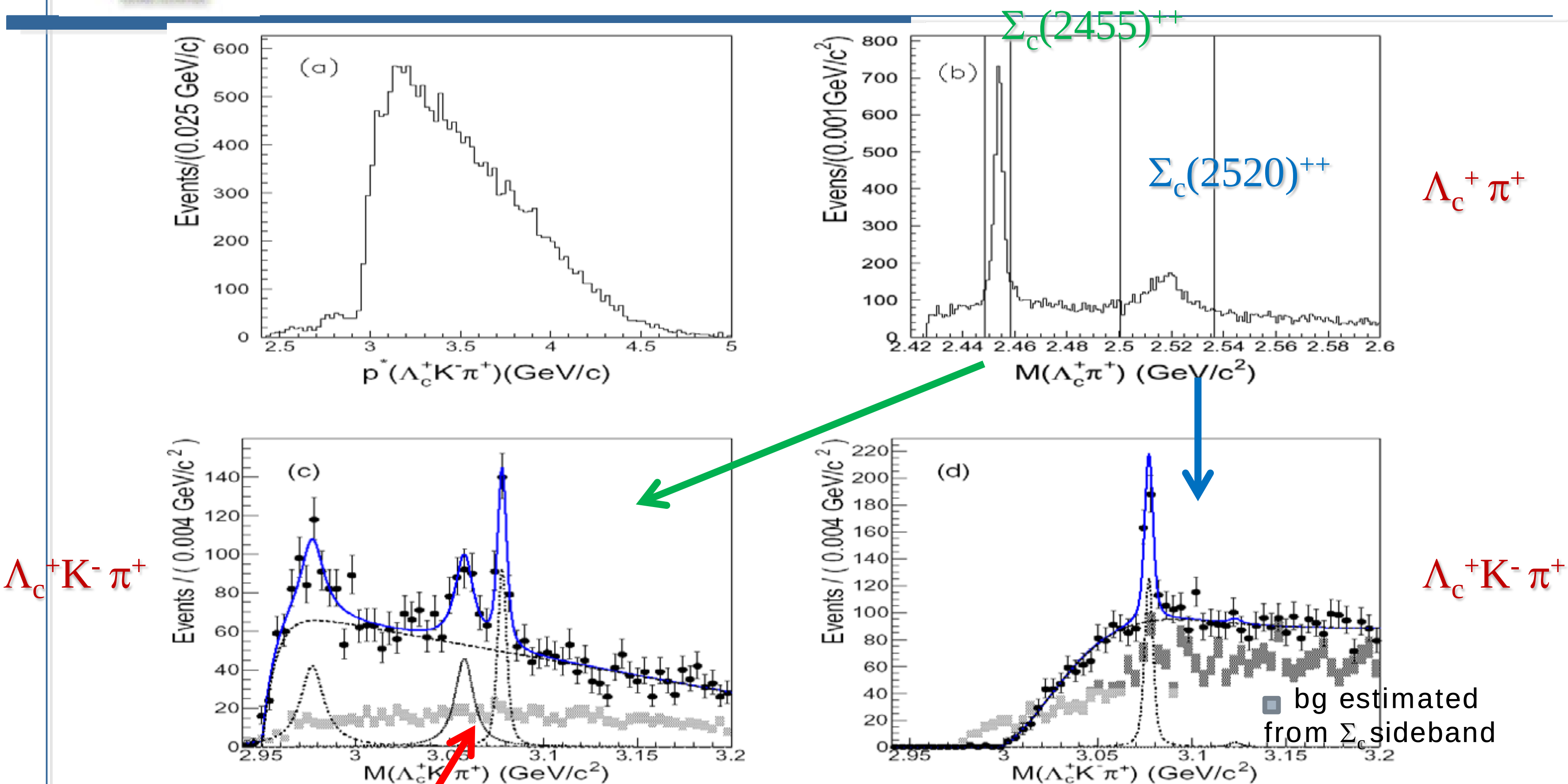
~980 fb^{-1}





No visible resonance peak found in both Ξ_{cc}^{+} and Ξ_{cc}^{++}

Fit results for Ξ_c

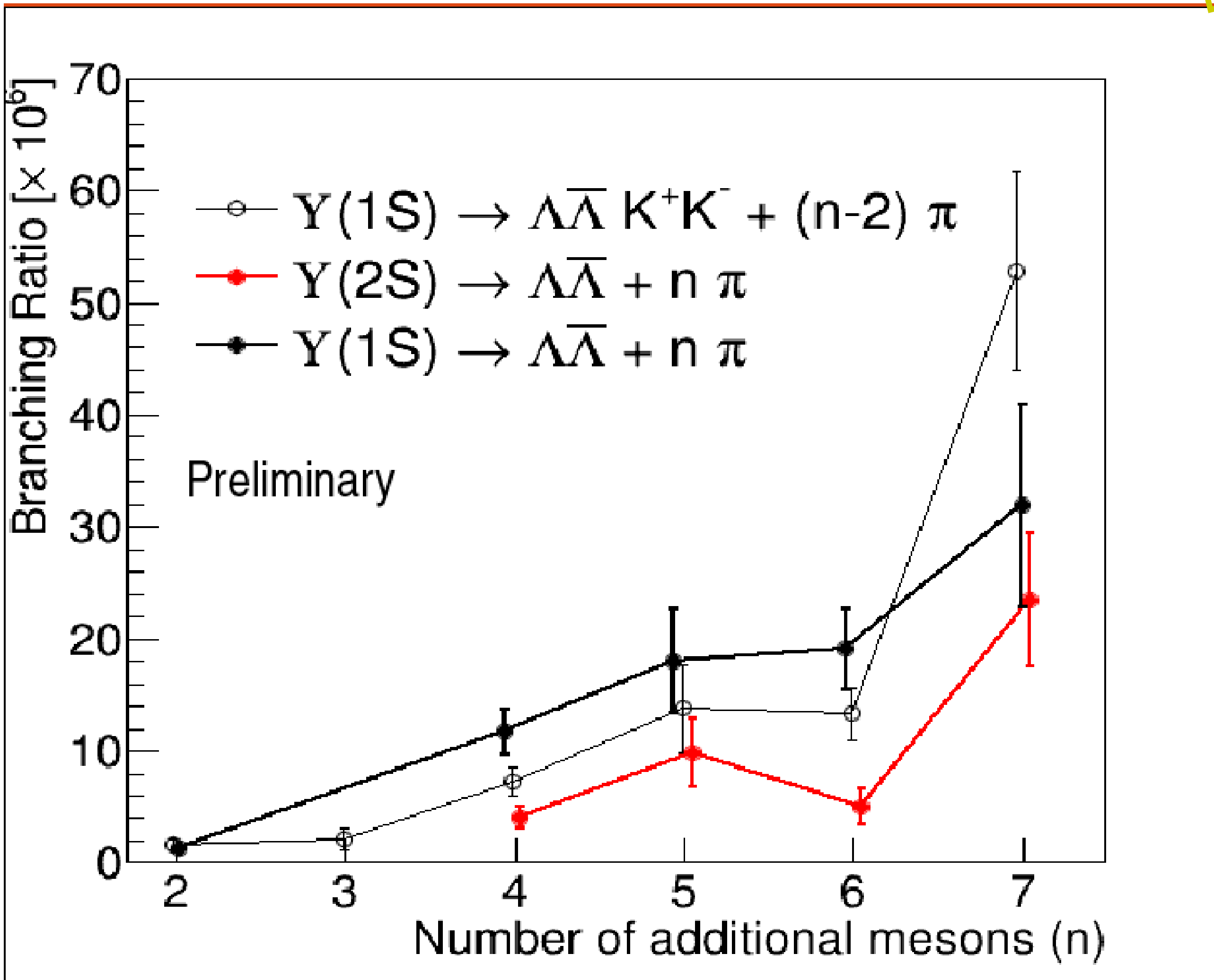


Particle	Mass (MeV/c^2)	Width (MeV/c^2)	Yield
$\Xi_c(2980)^+$	$2974.9 \pm 1.5 \pm 2.1$	$14.8 \pm 2.5 \pm 4.1$	244 ± 39
$\Xi_c(3055)^+$	$3058.1 \pm 1.0 \pm 2.1$	$9.7 \pm 3.4 \pm 3.3$	199 ± 46
$\Xi_c(3080)^+ (\Sigma_c)$	$3077.9 \pm 0.4 \pm 0.7$	$3.2 \pm 1.3 \pm 1.3$	185 ± 31
$\Xi_c(3080)^+ (\Sigma_c^*)$	$3076.9 \pm 0.3 \pm 0.2$	$2.4 \pm 0.9 \pm 1.6$	210 ± 30

Υ(1S,2S) → $\Lambda\bar{\Lambda}$X

X= combinations of K^+K^-, $\pi^+\pi^-$, maximum one π^0

preliminary

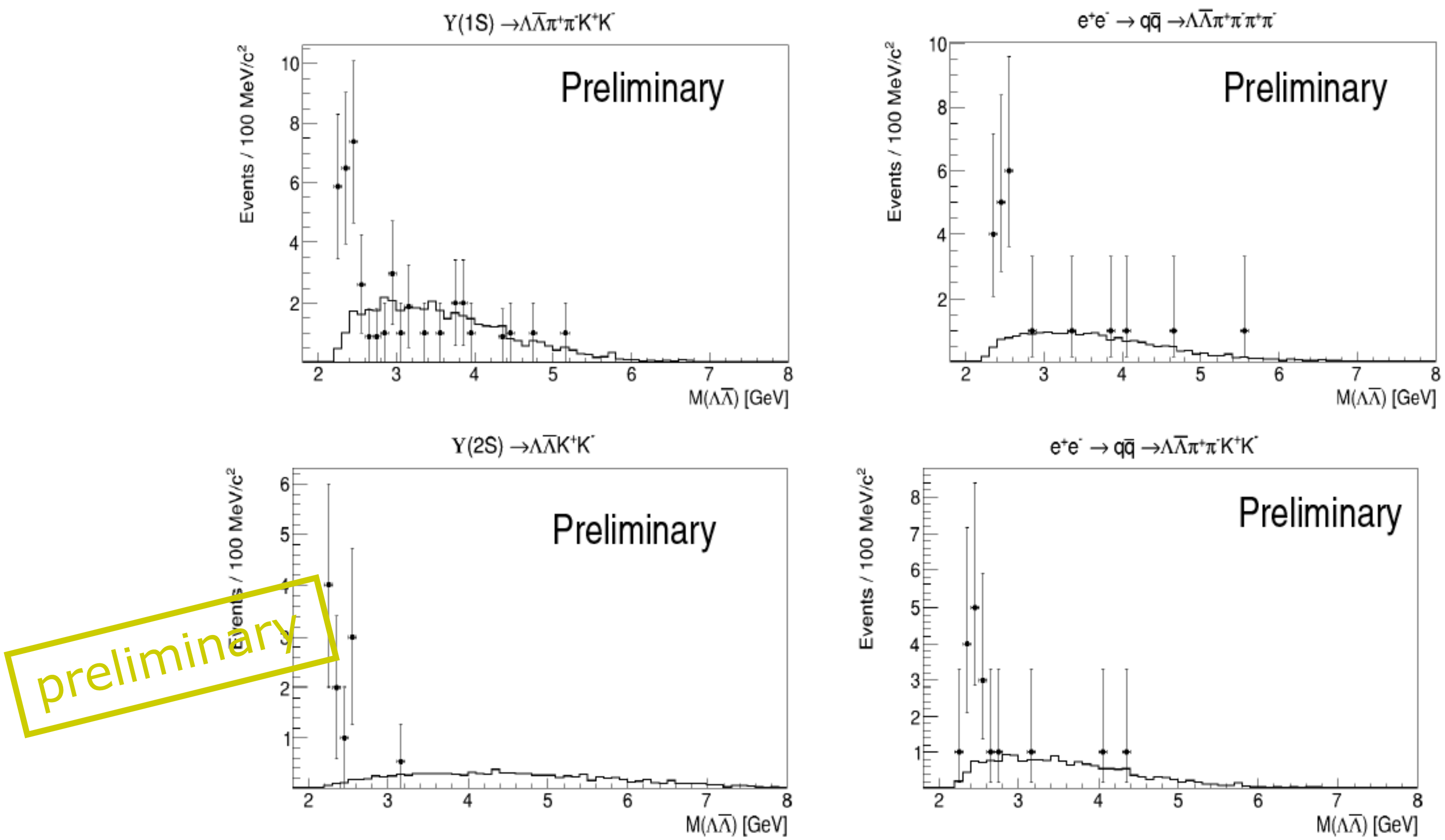


Check the $\Lambda\bar{\Lambda}$ mass spectrum

Dynamical interaction within the $\Lambda\bar{\Lambda}$ pair

→ Low threshold enhancement in $M(\mathcal{B}\bar{\mathcal{B}})$ is a common feature in B meson baryonic decays

Threshold Enhancement



Summary

- Angular asym. still a puzzle in $b \to s\, g$
- Evidence for $B^- \to p\bar{p} l^- \nu$
- No hierarchy BF(4 body)>BF(3 body) for $b \to s\, \gamma$
- Anti-deuteron productions at $\Upsilon(nS)$ mainly from gluon dominated decays
- Precise $\Lambda_c^+ \to pK^- \pi^+$ measurement
- Precise mass splitting for $\Sigma_c(2455)^{0/++}$
- Searched for $\Xi_{cc}^{+(+)}$, Ξ_c; observed $\Xi_c(3055)^+$
- Threshold enhancement for dibaryon production in $\Upsilon(1S,2S) \to \Lambda\Lambda X$
- More to come in the summer conferences

Back-up slide

preliminary

X = combination of K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ and π^0

Max 9 bodies, Max one π^0 → 48 channels

$$\sum_X BF[Y(1S)\rightarrow X] \simeq 2\,x\,10^{-4}$$
$$\sum_X BF[Y(2S)\rightarrow X] \simeq 0.7\,x\,10^{-4}$$

$$\frac{BF[Y(2S)\rightarrow X]}{BF[Y(1S)\rightarrow X]} \sim \frac{|\psi_{2S}(0)|^2}{|\psi_{1S}(0)|^2} = \mathbf{0.77}$$

Channel	$\mathcal{B}[\Upsilon(1S)\to X]$ [$\times10^{-6}$]	$\mathcal{B}[\Upsilon(2S)\to X]$ [$\times10^{-6}$]	Q
$\Lambda\bar{\Lambda}+\pi^+\pi^-$	1.43 ± 0.48 ± 0.23		
$\Lambda\bar{\Lambda}+K^+K^-$	1.29 ± 0.51 ± 0.20	1.27 ± 0.47 ± 0.20	0.98 ± 0.53 ± 0.11
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)$	6.99 ± 1.28 ± 1.11	3.81 ± 0.97 ± 0.61	0.55 ± 0.17 ± 0.06
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-$	11.83± 2.01 ± 1.87		
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}$	2.99 ± 0.86 ± 0.47		
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)$	13.14± 2.36 ± 2.10	4.72 ± 1.64 ± 0.75	0.36 ± 0.14 ± 0.04
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-$	18.99± 3.60 ± 3.04		
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}$	6.03 ± 1.67 ± 0.96		
$\Lambda\bar{\Lambda}+\pi^+\pi^-2(K^+K^-)$		2.93 ± 1.49 ± 0.47	
$\Lambda\bar{\Lambda}+\pi^+\pi^-\ \pi^0$	2.00 ± 0.97 ± 0.34		
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)\ \pi^0$	13.86± 3.96 ± 2.35	9.76 ± 3.06 ± 1.66	0.70 ± 0.30 ± 0.08
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-\ \pi^0$	18.26 ± 4.68 ± 3.11		
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}\ \pi^0$	5.85 ± 2.35 ± 0.99		
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)\ \pi^0$	52.83 ± 8.93 ± 9.07	23.35 ± 5.97 ± 4.02	0.44 ± 0.14 ± 0.05
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-\ \pi^0$	31.78 ± 9.35 ± 5.54	30.70 ± 8.60 ± 5.36	0.97 ± 0.39 ± 0.12
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}\ \pi^0$	15.95 ± 5.81 ± 2.76		