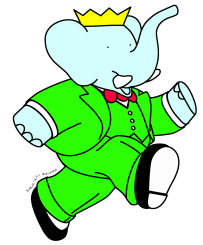
Baryonic B decays

(The very recent results)



$$\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$$
$$B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-$$
$$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$$
$$B^- \to p \overline{p} l^- \bar{\nu}$$
$$\overline{B}^0 \to \Lambda \overline{p} \pi^+ \gamma$$

Flavor Physics & CP Violation, Buzios, May 19-24, 2013

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baryonic B decays

Examples for baryonic B-decays (PDG values)

B^0/B^- decay mode	branching fraction $[\times 10^{-4}]$
$\Lambda_c^+ \overline{p}$	0.20 ± 0.04
$\Lambda_c^+ \overline{p}\pi^-$	2.8 ± 0.8
$\Lambda_c^+ \overline{p}\pi^0$	1.9 ± 0.5
$\Lambda_c^+ \overline{\Lambda}_c^- K^-$	8.7 ± 3.5
$\Lambda_c^+ \overline{p}\pi^+\pi^-\pi^-$	22 ± 7
$D^{*0} p\overline{p}$	1.0 ± 0.1
$D^{*+} p\overline{n}$	14 ± 4
$D^0 \overline{p}\Lambda$	0.14 ± 0.03
$\Lambda\overline{p}$	< 0.003
$\Lambda\overline{p}\pi^-$	0.031 ± 0.003
$p\overline{p}\overline{K}^0$	0.027 ± 0.003
$p\overline{p}K^-$	0.055 ± 0.005
$p\overline{p}$	< 0.001
$p\overline{p}\pi^-$	0.016 ± 0.002

- $(6.8 \pm 0.6)\%$ of all B meson decays with baryons in final state
- $(4.5 \pm 1.2)\%$ of all B meson decays with Λ_c in final state
- only about 10% of all baryonic B decays exclusively known

$\Rightarrow$ What about the other 90%??

study of baryon production

- "Pathways to rare baryonic B decays" (W.-S. Hou, A. Soni, 2001, Phys.Rev.Lett. **86**,4247)
  to have final states with baryons preferred, energy should be taken away by additional particle(s) $\Rightarrow$ invariant mass of baryon-antibaryon system should be low
  $\longrightarrow$ threshold enhancement in the baryon-antibaryon invariant mass distribution
  $\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}) = \mathcal{O}(10^{-5}) < \mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}\pi^0) = \mathcal{O}(10^{-4}) < \mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}\pi^+\pi^-) = \mathcal{O}(10^{-3})$
  $\mathcal{B}(B^- \to \Lambda \overline{p}\gamma) = \mathcal{O}(10^{-6}), \mathcal{B}(\overline{B}^0 \to \Lambda \overline{p}\pi^+\gamma) = \mathcal{O}(??)$

- influence of resonant substructure to baryon production
  $B^- \to \Lambda_c^+ \overline{p}\pi^-$: $\mathcal{B}_{\text{resonant}}/\mathcal{B}_{\text{total}} \geq (24.0 \pm 3.6)\%$
  $\overline{B}^0 \to \Lambda_c^+ \overline{p}\pi^+\pi^-$

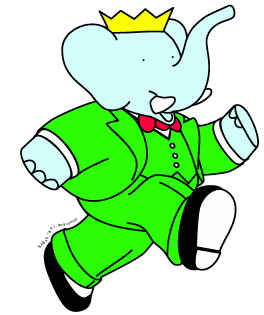
- $s\overline{s}$ suppression: $\overline{B}^0 \to D^0 p\overline{p}$ vs. $\overline{B}^0 \to D^0 \Lambda\overline{\Lambda}$

- influence of "spectator"-quark: $B^- \to \Lambda_c^+ \overline{p}\pi^-$ vs. $B_s \to \Lambda_c^+ \overline{\Lambda}\pi^-$

- contribution of "external" W-decay: $B^- \to p\overline{p}l^-\overline{\nu}$

$\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$

Phys. Rev. D **87**, 092004, May 2013



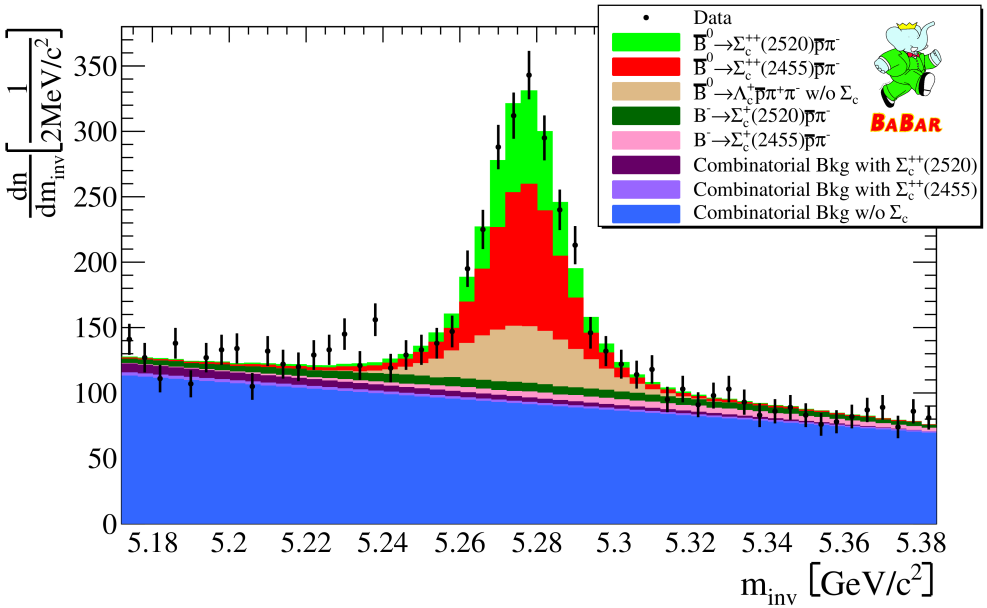
$\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$

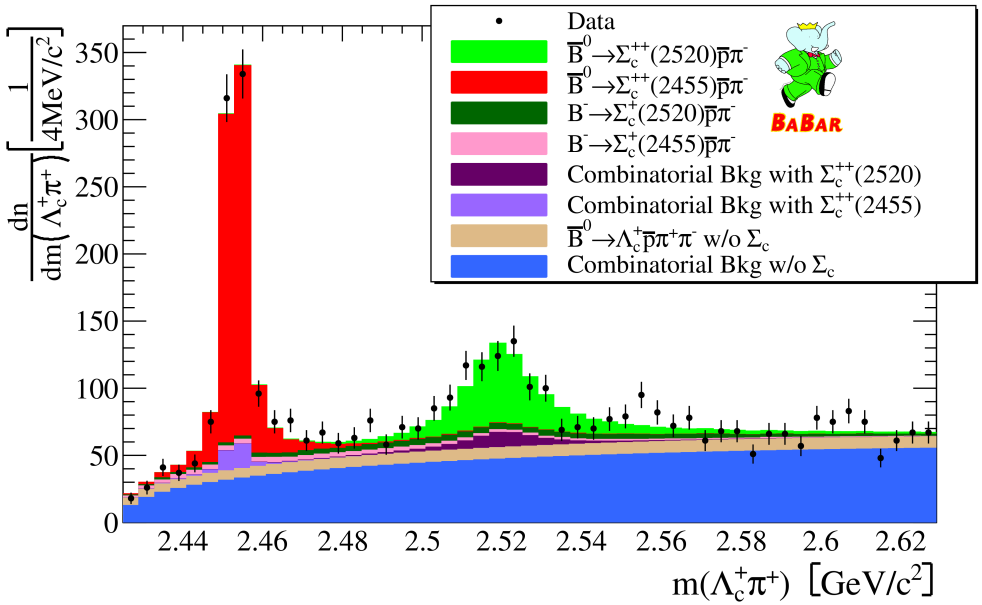
- many resonances possible
  - $\Sigma_c^{++}, \Sigma_c^0, N, \Delta, \rho, ...$
  - Influence on total branching fraction?
- difference between Σ_c^0 and Σ_c^{++} (with and without the quarks from the W decay)
  - Has it influence on a possible threshold enhancement in $m(\Sigma_c \overline{p})$?
- analysis based on $467 \times 10^6 B\overline{B}$

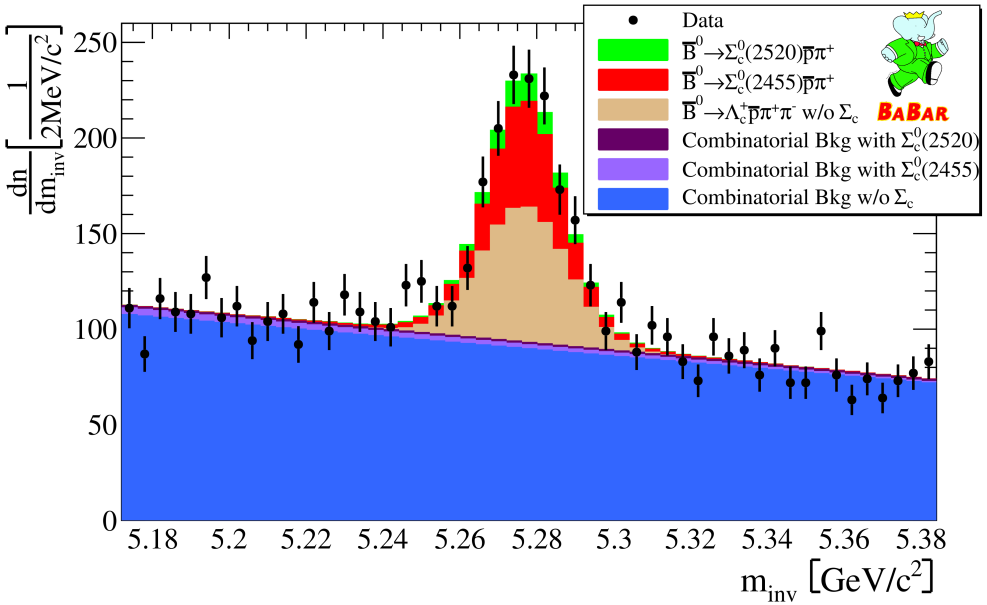
signal extraction

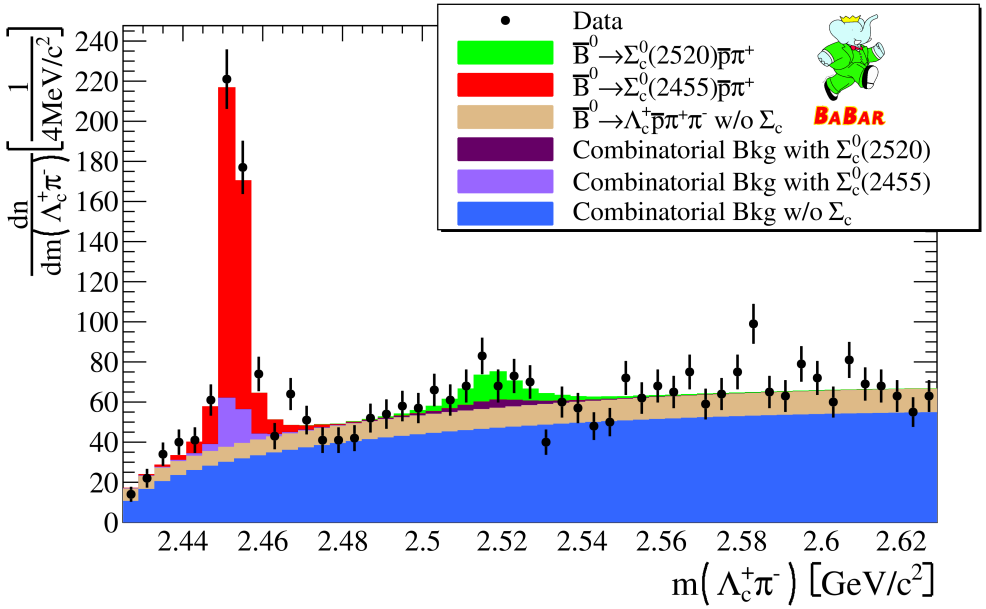
- consider possible peaking background sources not accounted for in previous studies
  $B \to Dp\bar{p}(n\pi)$ (same final state particles possible), $B^- \to \Sigma_c^+ \bar{p}\pi^-$
- for resonant subchannels: 2D fit to $m(B)$ and $m(\Lambda_c^+ \pi^\pm)$ with selection in m_{ES}
- for non-resonant decay mode: fit in $m(B)$ only and exclude $m(\Sigma_c)$
- use sPlot method to get signal distributions for 2-body and 3-body invariant mass distributions

fit to $m(B)$ and $m(\Lambda_c^+\pi^\pm)$









results

Decay mode	fitted signal yield	branching fraction $[10^{-4}]$
$\overline{B}^0 \to \Sigma_c^{++}(2455)\overline{p}\pi^-$	723 ± 32	$2.13 \pm 0.10 \pm 0.10 \pm 0.55$
$\overline{B}^0 \to \Sigma_c^{0}(2455)\overline{p}\pi^+$	347 ± 24	$0.91 \pm 0.07 \pm 0.04 \pm 0.24$
$\overline{B}^0 \to \Sigma_c^{++}(2520)\overline{p}\pi^-$	458 ± 38	$1.15 \pm 0.10 \pm 0.05 \pm 0.30$
$\overline{B}^0 \to \Sigma_c^{0}(2520)\overline{p}\pi^+$	87 ± 27	$0.22 \pm 0.07 \pm 0.01 \pm 0.06$
$(\overline{B}^0 \to \Lambda_c\overline{p}\pi^+\pi^-)_{\mathrm{non}-\Sigma_C}$	2728 ± 132	$7.9 \pm 0.4 \pm 0.4 \pm 2.0$

(uncertainties: statistical, systematic, and from $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$)

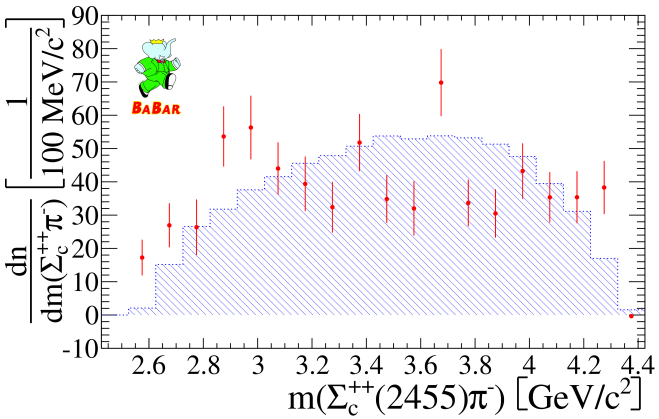
comparison: $\mathcal{B}(B \to \Sigma_c(2455)\overline{p}\pi\pi) \sim \mathcal{O}(10^{-4})$

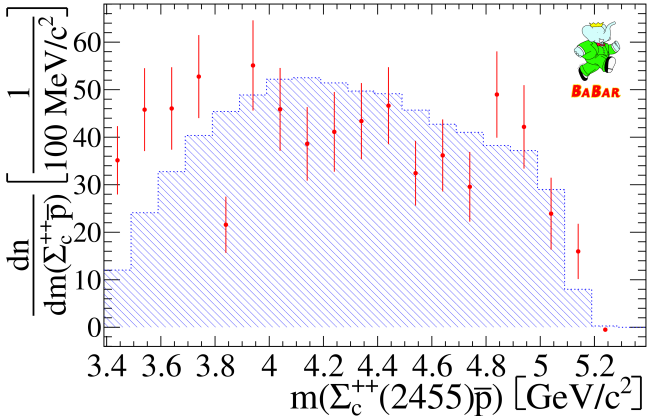
total branching fraction: $\mathcal{B}(\overline{B}^0 \to \Lambda_c\overline{p}\pi^+\pi^-)_{\mathrm{total}} = (12.3 \pm 0.5 \pm 0.7 \pm 3.2) \times 10^{-4}$

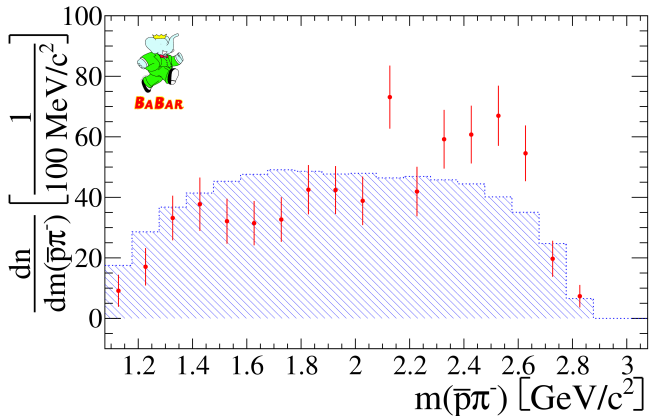
current PDG values (systematic+statistical uncertainties combined):

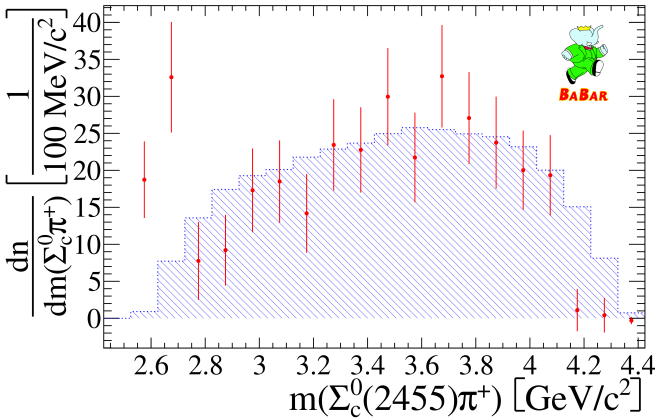
$\mathcal{B}(\overline{B}^0 \to \Sigma_c^{++}(2455)\overline{p}\pi^-)$	$=$	$(2.2 \pm 0.7) \times 10^{-4}$
$\mathcal{B}(\overline{B}^0 \to \Sigma_c^{0}(2455)\overline{p}\pi^+)$	$=$	$(1.5 \pm 0.5) \times 10^{-4}$
$\mathcal{B}(\overline{B}^0 \to \Sigma_c^{++}(2520)\overline{p}\pi^-)$	$=$	$(1.20 \pm 0.27) \times 10^{-4}$
$\mathcal{B}(\overline{B}^0 \to \Sigma_c^{0}(2520)\overline{p}\pi^+)$	$<$	0.38×10^{-4}
$\mathcal{B}(\overline{B}^0 \to \Lambda_c\overline{p}\pi^+\pi^-)_{\mathrm{non-resonant}}$	$=$	$(\ 6.4 \pm 1.0) \times 10^{-4}$
$\mathcal{B}(\overline{B}^0 \to \Lambda_c\overline{p}\pi^+\pi^-)_{\mathrm{total}}$	$=$	$(11.2 \pm 1.4) \times 10^{-4}$

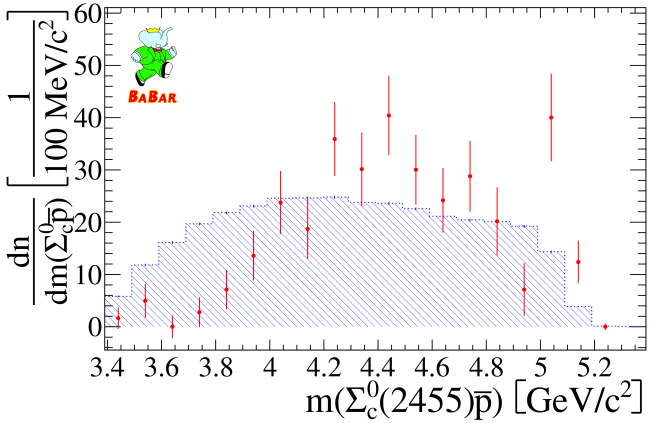
resonant substructure

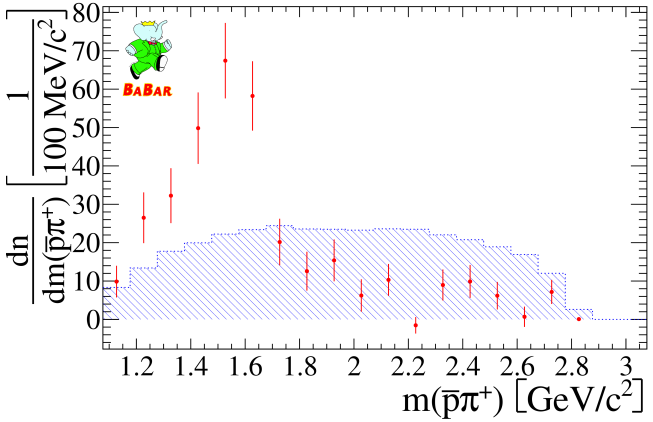


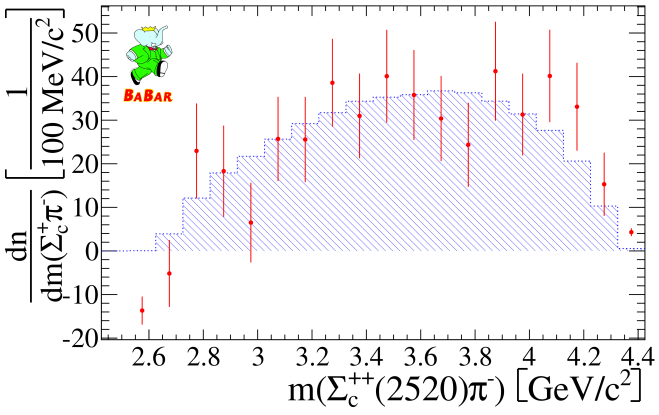


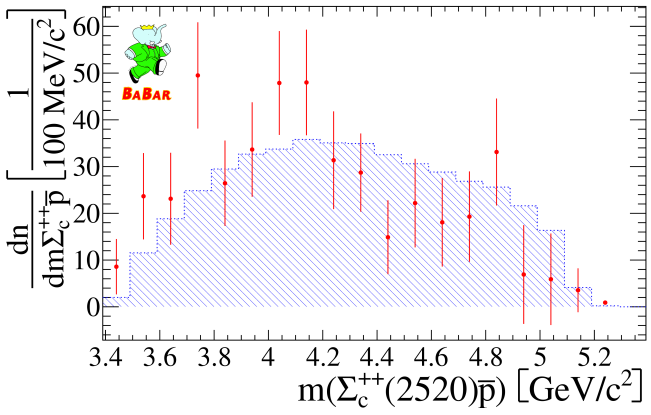


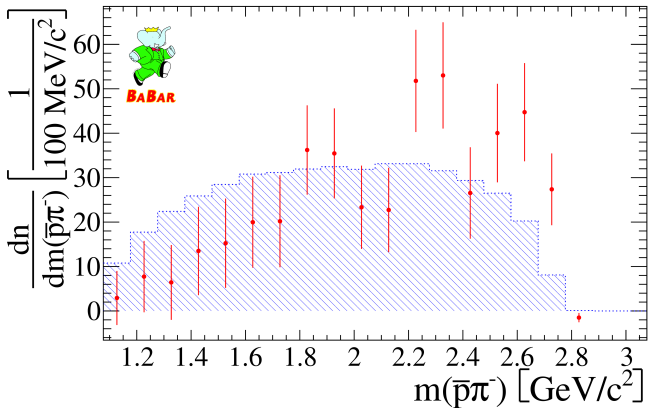




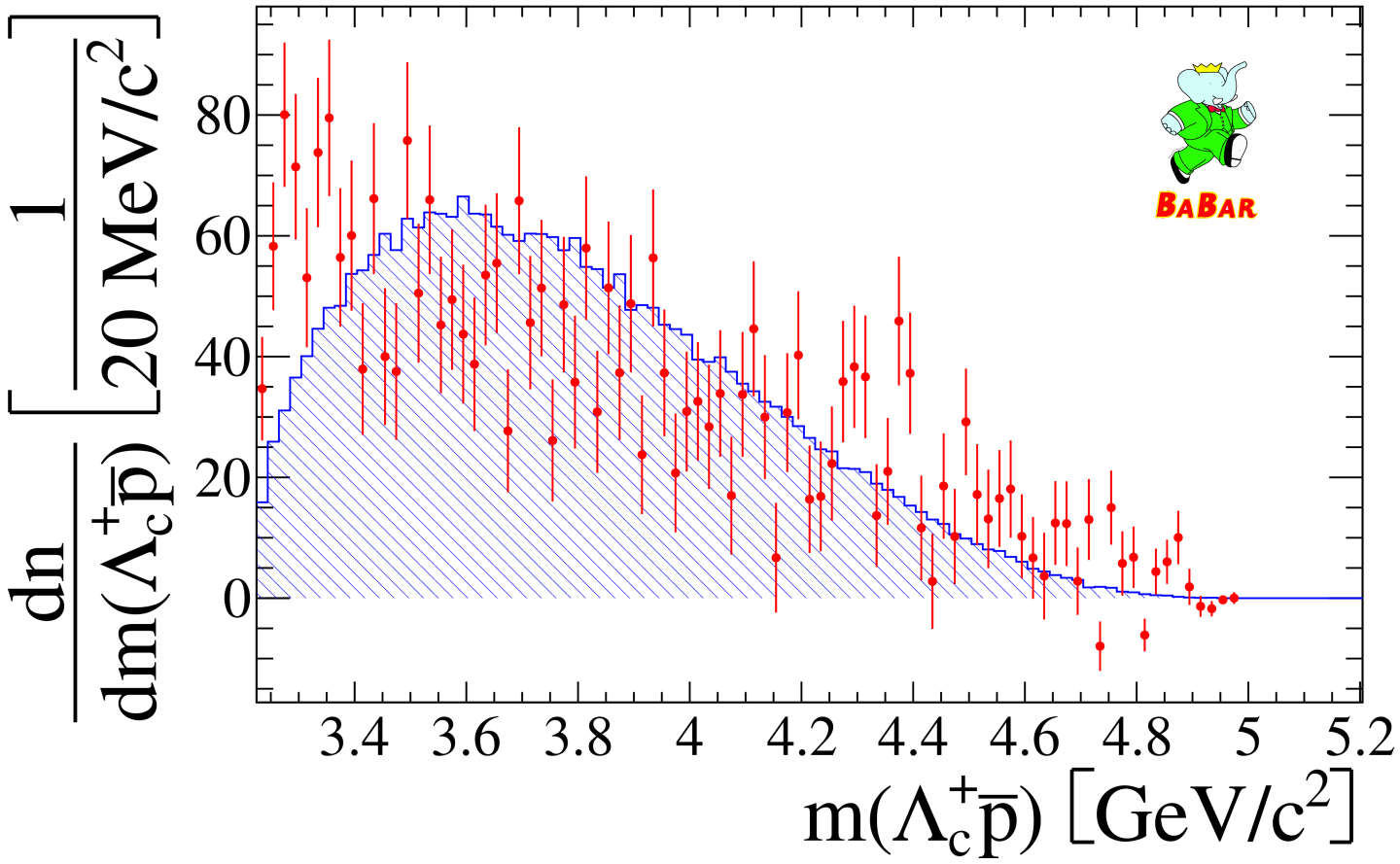








resonant substructure



- enhancement seen in $m\left(\Sigma_c^{++}(2455)\bar{p}\right)$ and $m\left(\Lambda_c\bar{p}\right)$ at threshold

- no threshold enhancement seen in $m\left(\Sigma_c^{0}(2455)\bar{p}\right)$ and in $m\left(\Sigma_c^{++}(2520)\bar{p}\right)$

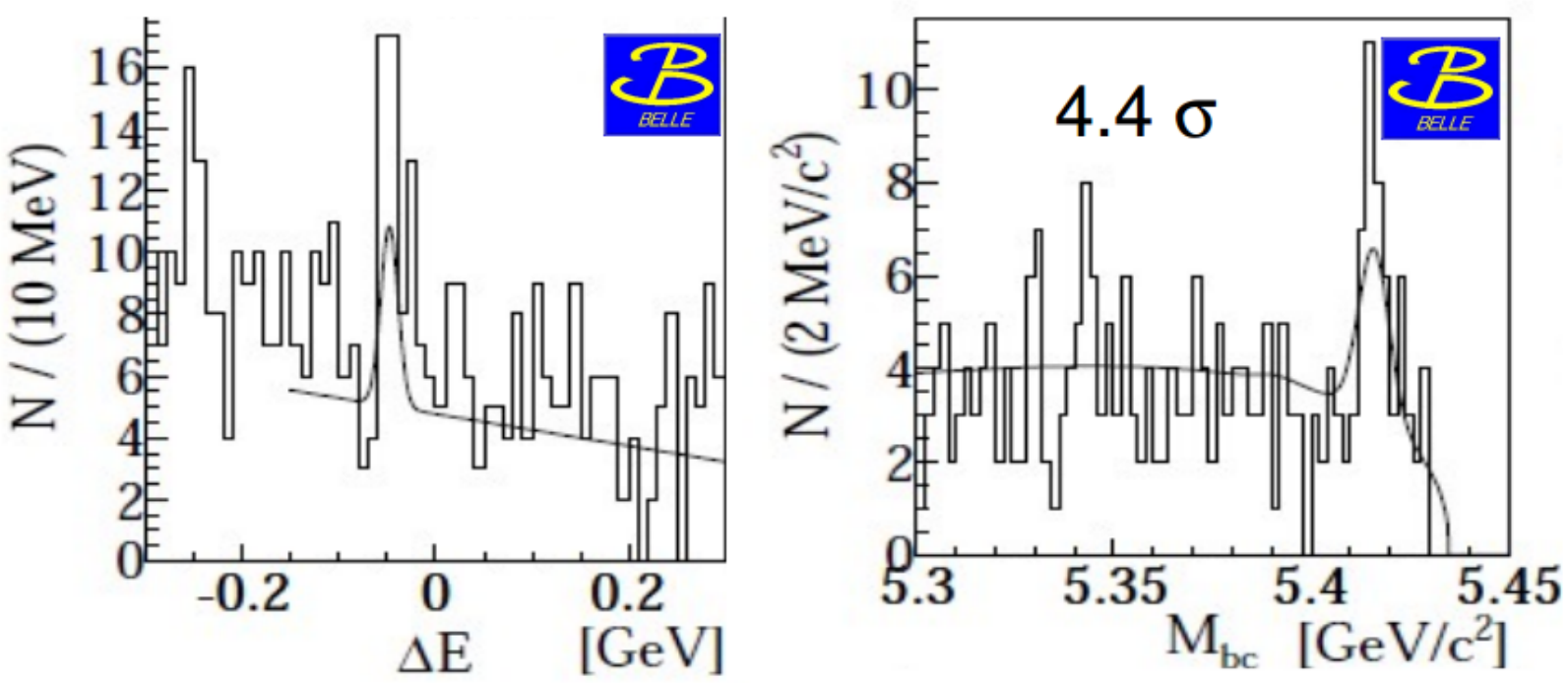
$B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-$

arXiv:1304.6931, submitted to Phys. Lett. B

$B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-$

- $e^+e^- \to \Upsilon(5S)$ dataset $((7.1 \pm 1.3) \times 10^6 B_s \bar{B}_s)$
- event-shape variables to suppress continuum events
- simultaneous fit in ΔE and M_{bc}
- can be compared with $B^- \to \Lambda_c^+ \bar{p} \pi^-$
  $\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-) = (2.8 \pm 0.8) \times 10^{-4}$
  $\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)_{\text{non-resonant}} < 2.1 \times 10^{-4}$

$B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-$

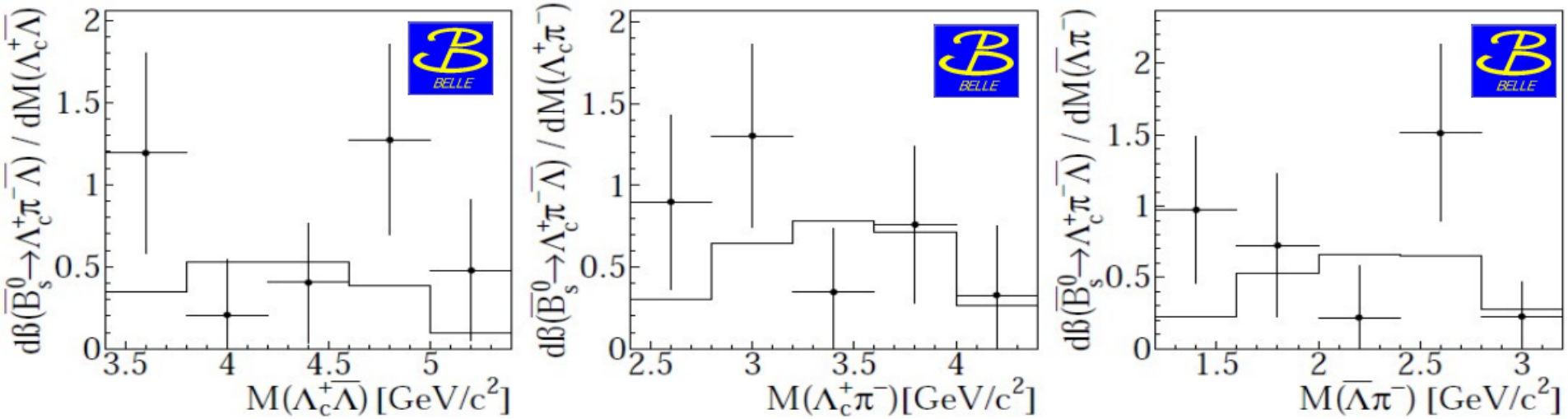


$$\mathcal{B}(B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-) = (3.6 \pm 1.1_{[\text{stat}]}\ ^{+0.3}_{-0.5[\text{syst}]} \pm 0.9_{[\mathcal{B}(\Lambda_c)]} \pm 0.7_{[N(B_s)]}) \times 10^{-4}$$

$$\mathcal{B}(B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-) \sim \mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)$$

$B_s \to \Lambda_c^+ \bar{\Lambda} \pi^-$

Phase space analysis



Unfortunately, not enough statistics to see resonances like $\Sigma_c^0(2455)$.

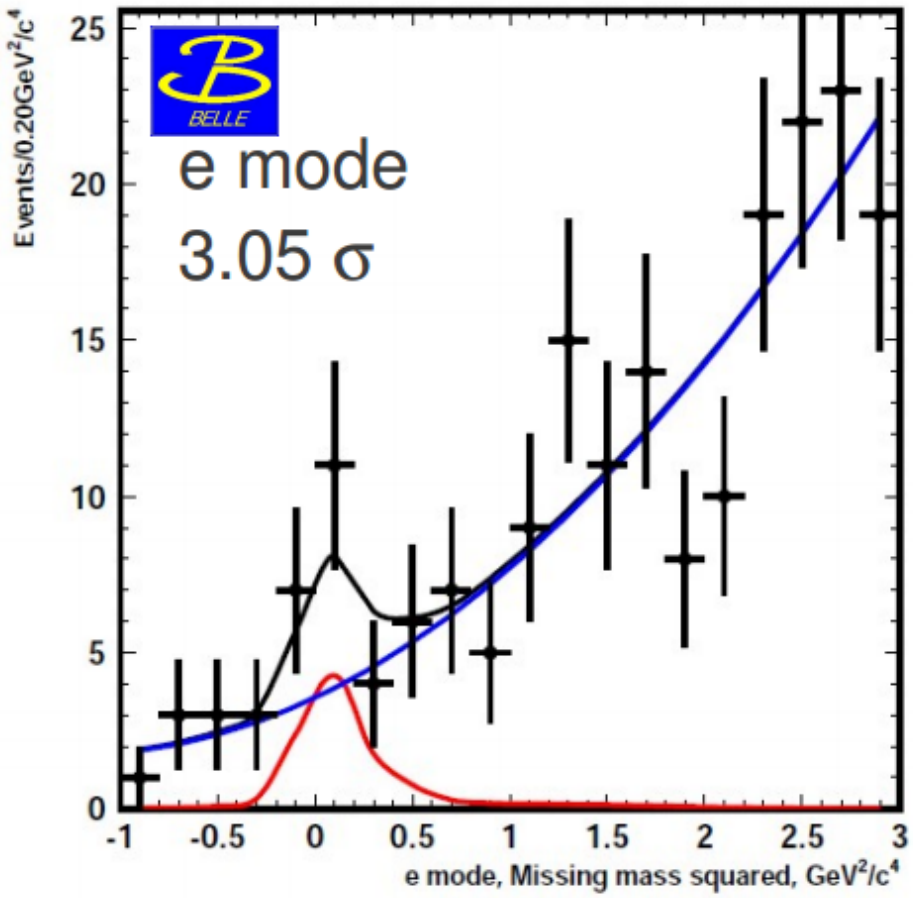
$$B^- \longrightarrow p\bar{p}l^-\bar{\nu}$$

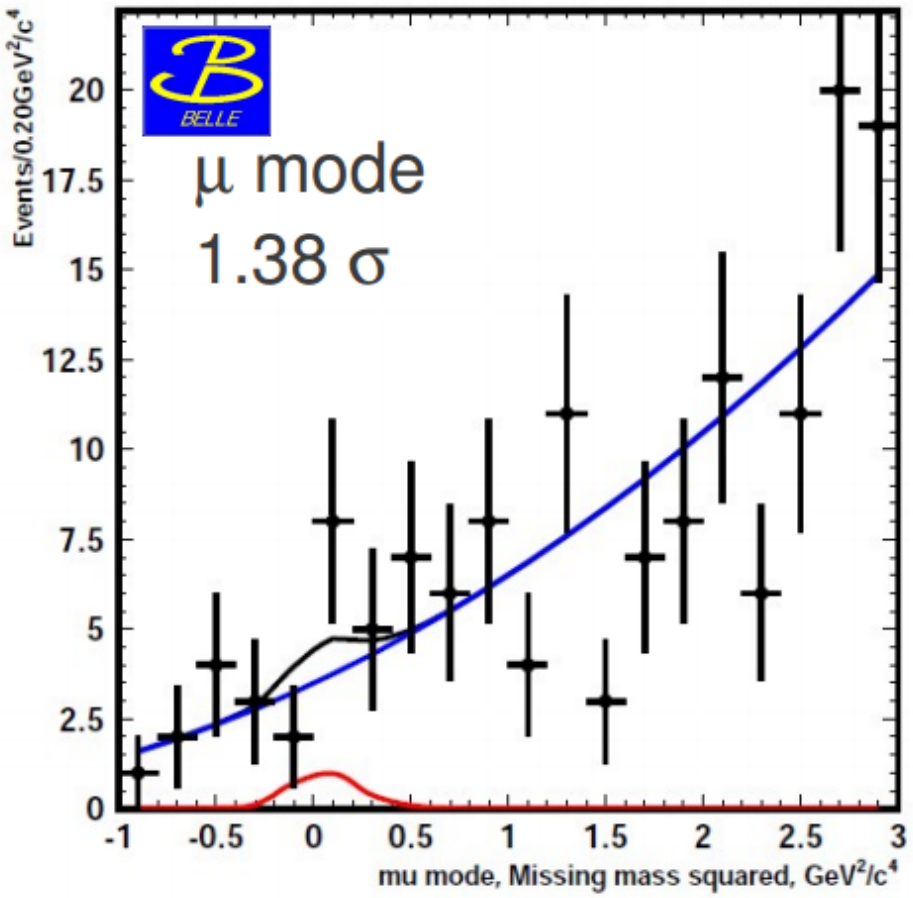
Preliminary

$B^- \longrightarrow p\overline{p}l^-\overline{\nu}$

- so far no semileptonic, baryonic B-decay mode observed
- very interesting since only one Feynman diagram contributes
- predictions
  - W.S. Hou, A. Soni, 2001, Phys. Rev. Lett. **86**,4247: $\mathcal{B} = \mathcal{O}(10^{-5})...\mathcal{O}(10^{-6})$
  - C.Q. Geng, Y.K.Hsiao, 2011,Phys. Lett. B **704**,495: $\mathcal{B} = (1.04 \pm 0.38) \times 10^{-4}$
- data sample of $772 \times 10^6 B\overline{B}$
- using tag B (charm mode)
- p, $\overline{p}$, and l identified
- recoil mass used for ν

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





$\mathcal{B}(B^- \to p\bar{p}e^-\bar{\nu}_e) = (8.22^{+3.74}_{-3.20} \pm 0.55) \times 10^{-6}$

$\mathcal{B}(B^- \to p\bar{p}\mu^-\bar{\nu}_\mu) = (3.13^{+3.10}_{-2.40} \pm 0.71) \times 10^{-6}$ $\quad \mathcal{B}(B^- \to p\bar{p}\mu\bar{\nu}_\mu^-) < 8.5 \times 10^{-6}$

$\mathcal{B}(B^- \to p\bar{p}l^-\bar{\nu}) = (5.78^{+2.42}_{-2.13} \pm 0.86) \times 10^{-6}$ $\quad \mathcal{B}(B^- \to p\bar{p}l^-\bar{\nu}) < 9.6 \times 10^{-6}$

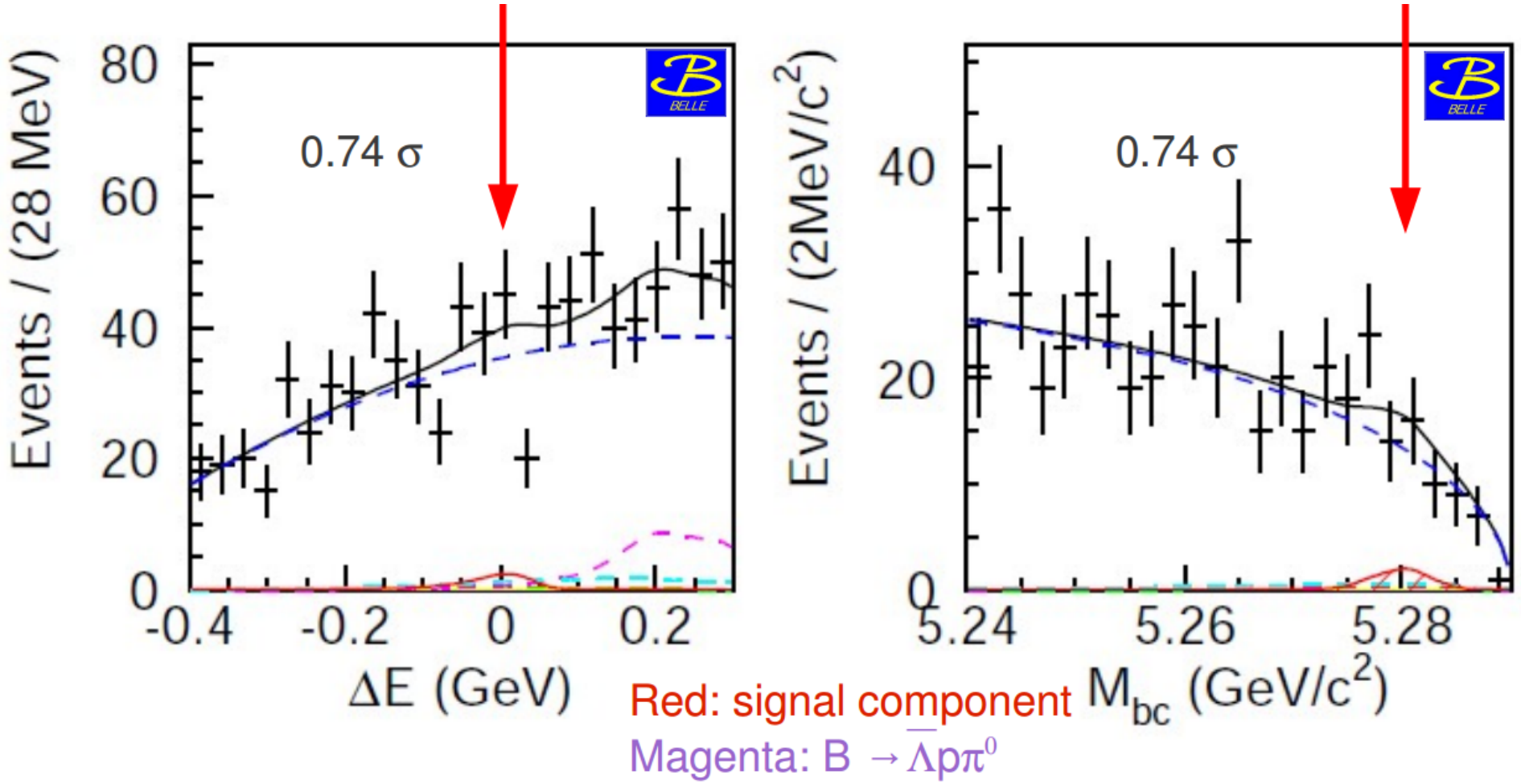
$\overline{B}^0 \to \Lambda \overline{p} \pi^+ \gamma$

Preliminary

$\overline{B}^0 \to \Lambda \overline{p} \pi^+ \gamma$

- $\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}) << \mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^0)$
- $\mathcal{B}$s for $B \to D^{(*)} p\overline{p}(\pi, \pi\pi)$ are all of the same order of magnitude
- $\mathcal{B}(B^- \to \Lambda \overline{p} \gamma) = (2.5^{+0.5}_{-0.4}) \times 10^{-6}$
- data sample of $772 \times 10^6 B\overline{B}$
- Continuum suppression with Fisher discriminant
- $E(\gamma) > 1.7$ GeV
- simultaneous fit in ΔE and M_{bc}

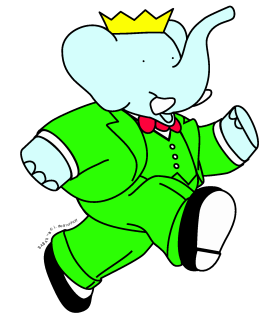
$\overline{B}^0 \to \Lambda\bar{p}\pi^+\gamma$



$\mathcal{B}(\overline{B}^0 \to \Lambda\bar{p}\pi^+\gamma) < 6.48 \times 10^{-7}$@90%$CL \sim \frac{1}{4}\mathcal{B}(\overline{B}^0 \to \Lambda\bar{p}\gamma)$

$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$

Preliminary

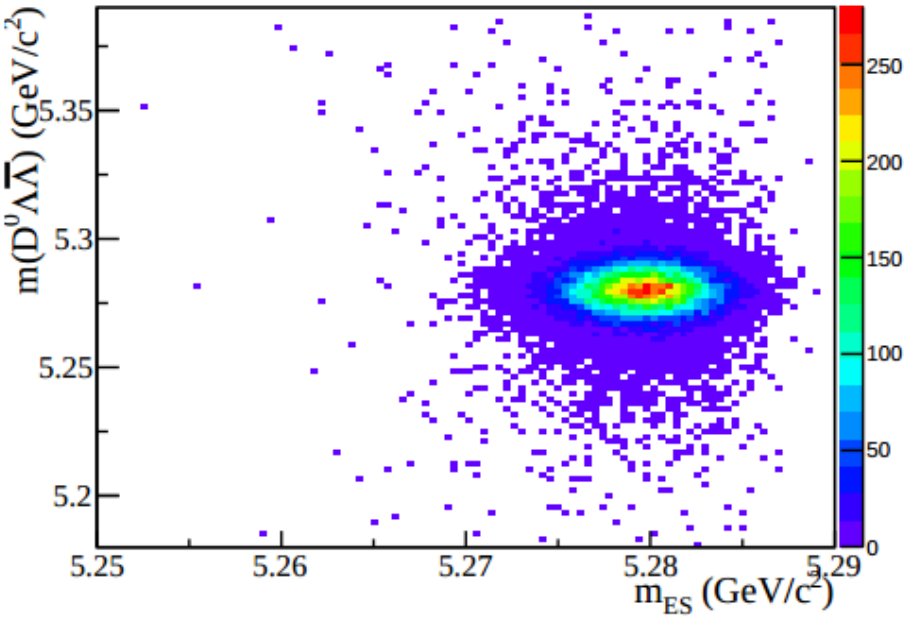


$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$

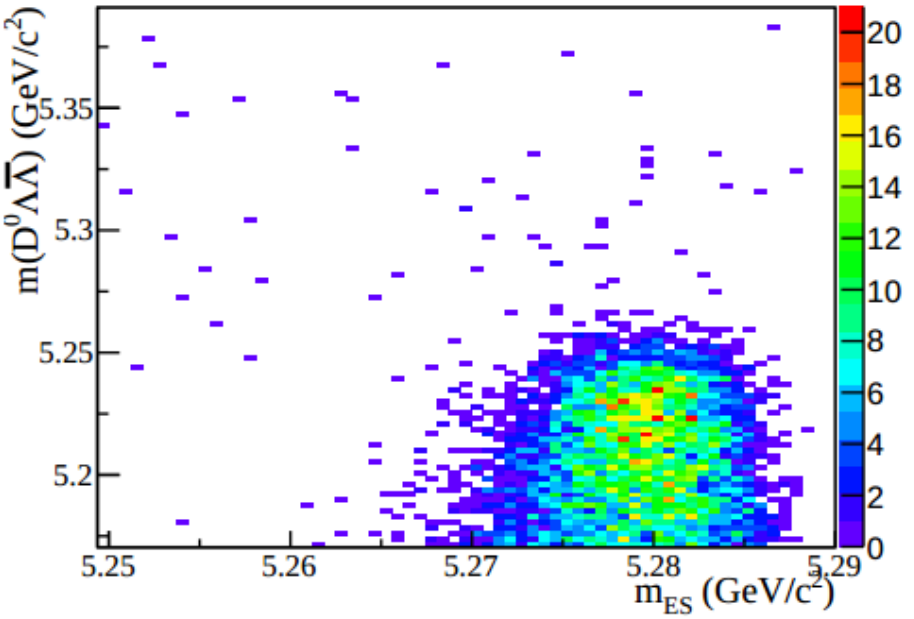
- $\mathcal{B}(\overline{B}^0 \to D^0 p\overline{p}) = (1.14 \pm 0.09) \times 10^{-4}$ already measured
- here we can study $s\overline{s}$ suppression
  fragmentation models: $s\overline{s}$ suppression by $1/12 = 0.083$
  Y.K.Hsiao, 2009, Int. J. Mod. Phys. A**24**, 3638: $\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}) = (2.3 \pm 0.8) \times 10^{-6}$
- data sample of $471 \times 10^6 B\overline{B}$
- consider $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, and $D^0 \to K^-\pi^+\pi^-\pi^+$
- problem: peaking background in m_{ES} from $\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}$

$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$

MC: $\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$



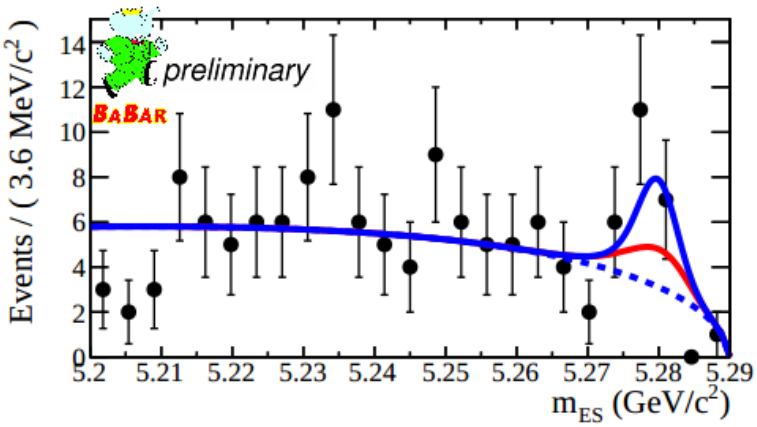
MC: $\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}$ reconstructed as $\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$

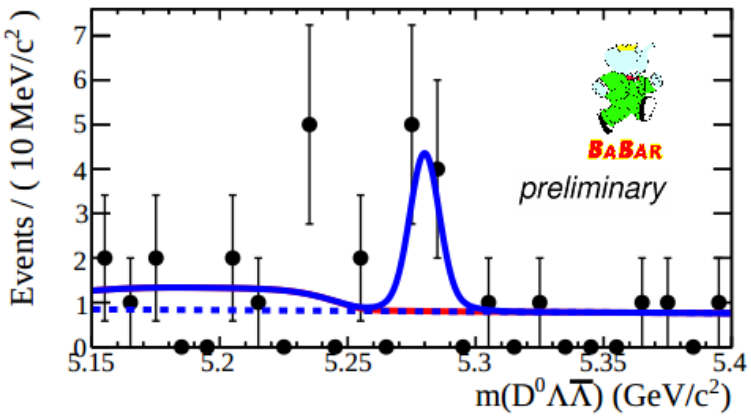


- take $\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}$ into account by adding an additional signal PDF

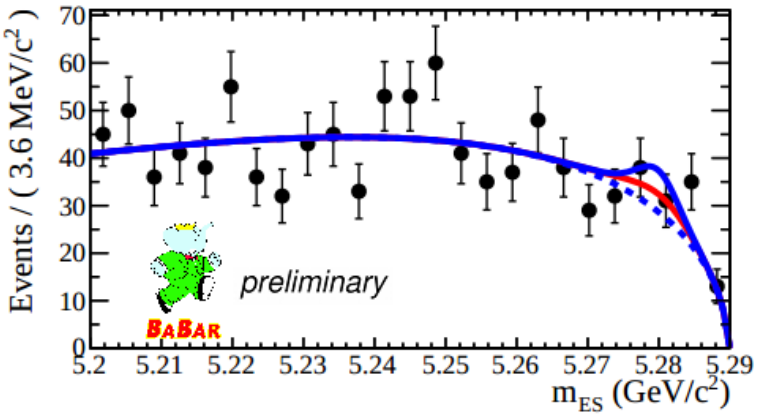
- final fit: 2D fit in m_{ES}:$m(B)$ simultaneously for all 3 D modes with signal PDFs for $\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$ and $\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}$

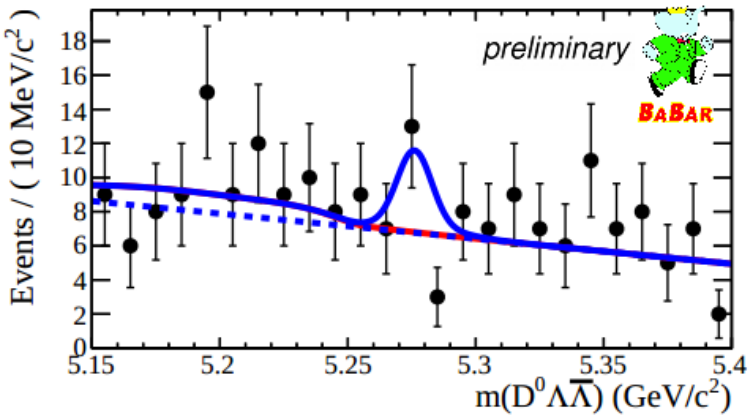
$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$



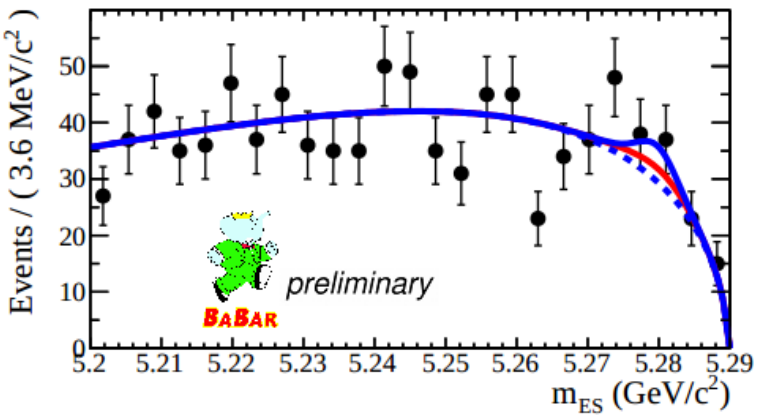


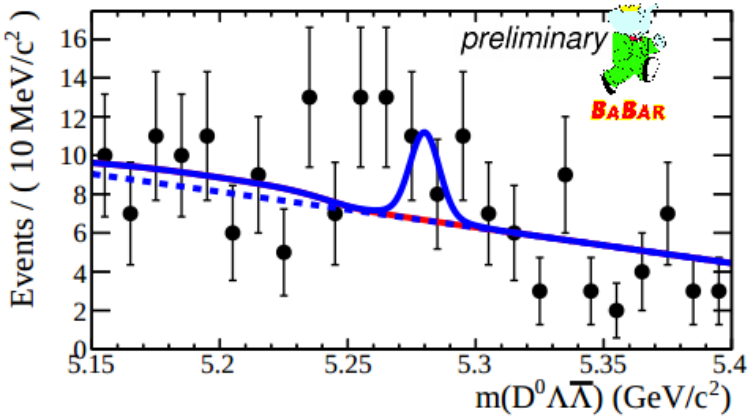
$D^0 \to K^-\pi^+$





$D^0 \to K^-\pi^+\pi^0$





$D^0 \to K^-\pi^+\pi^-\pi^+$

$\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}$

- $N_{\Lambda\bar{\Lambda}} = 1880^{+560}_{-500}$ $\quad \mathcal{B}(\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}) = (9.8^{+2.9}_{-2.6} \pm 1.9) \times 10^{-6}$

  Belle: $\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \bar{\Lambda}) = (10.5^{+5.7}_{-4.4} \pm 1.4) \times 10^{-6}$

  $\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \bar{\Lambda})_{\text{theory}} = (2.3 \pm 0.8) \times 10^{-6}$

- $\frac{\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \bar{\Lambda})}{\mathcal{B}(\overline{B}^0 \to D^0 p \bar{p})} = 0.087 \pm 0.032$ (expected: 0.083)

- $N_{\Sigma^0 \bar{\Lambda}} = 2870^{+1680}_{-1560}$ $\quad \mathcal{B}(\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}) = (1.5^{+0.9}_{-0.8}) \times 10^{-5}$

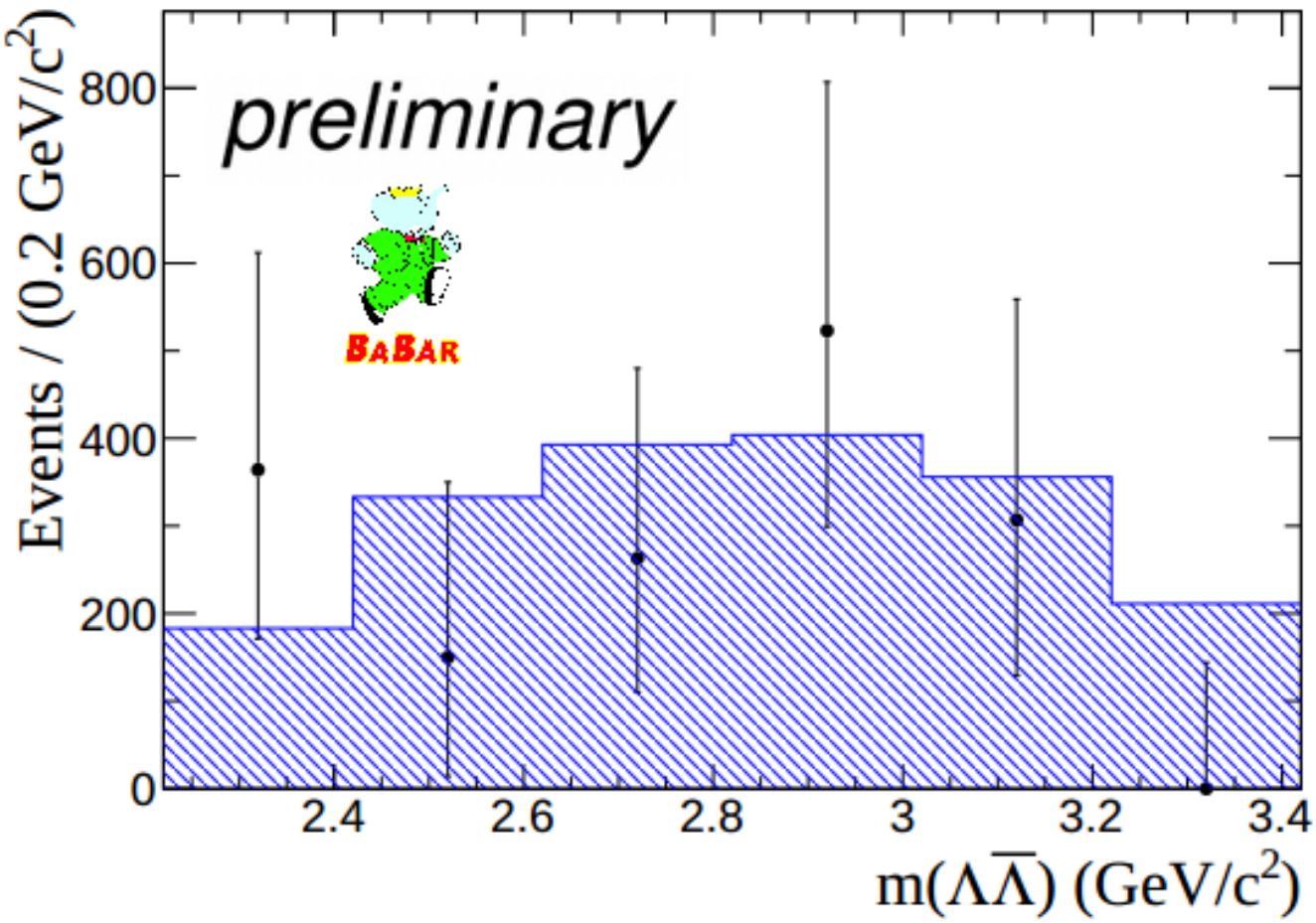
  $\mathcal{B}(\overline{B}^0 \to D^0 \Sigma^0 \bar{\Lambda}) < 3.1 \times 10^{-5}$

- significance for the combined fit: 3.9σ

- significance for Λ-mode only: 3.4σ

- significance for Σ-mode only: 1.2σ

$\overline{B}^0 \to D^0 \Lambda \overline{\Lambda}$



(histogram: phase space signal MC scaled to the same integral)

Not enough statistics to make a statement about a threshold enhancement.

summary

- *BABAR*: resonant substructure studied and branching fractions measured for $\overline{B}^0 \to \Lambda_c^+ \overline{p}\pi^+\pi^-$

  $\mathcal{B}(\overline{B}^0 \to \Sigma_c^0(2520)\overline{p}\pi^+)$ measured for the first time

  $\mathcal{B}$s for resonant decay modes are large fraction of total $\mathcal{B}$

  difference for Σ_c^0 and Σ_c^{++} modes observed

- Belle: first evidence for baryonic B_s decay, $B_s \to \Lambda_c^+ \bar{\Lambda}\pi^-$

  branching fraction measured to be consistent with $\mathcal{B}(B^- \to \Lambda_c^+ \overline{p}\pi^-)$

- Belle: first evidence for a baryonic, semileptonic decay mode, $B^- \to p\overline{p}l^-\bar{\nu}$

- Belle: study of $\overline{B}^0 \to \Lambda\overline{p}\pi^+\gamma$

  UL for the branching fraction already much lower than $\mathcal{B}(\overline{B}^0 \to \Lambda\overline{p}\gamma)$

- *BABAR*: study of $\overline{B}^0 \to D^0\Lambda\bar{\Lambda}$

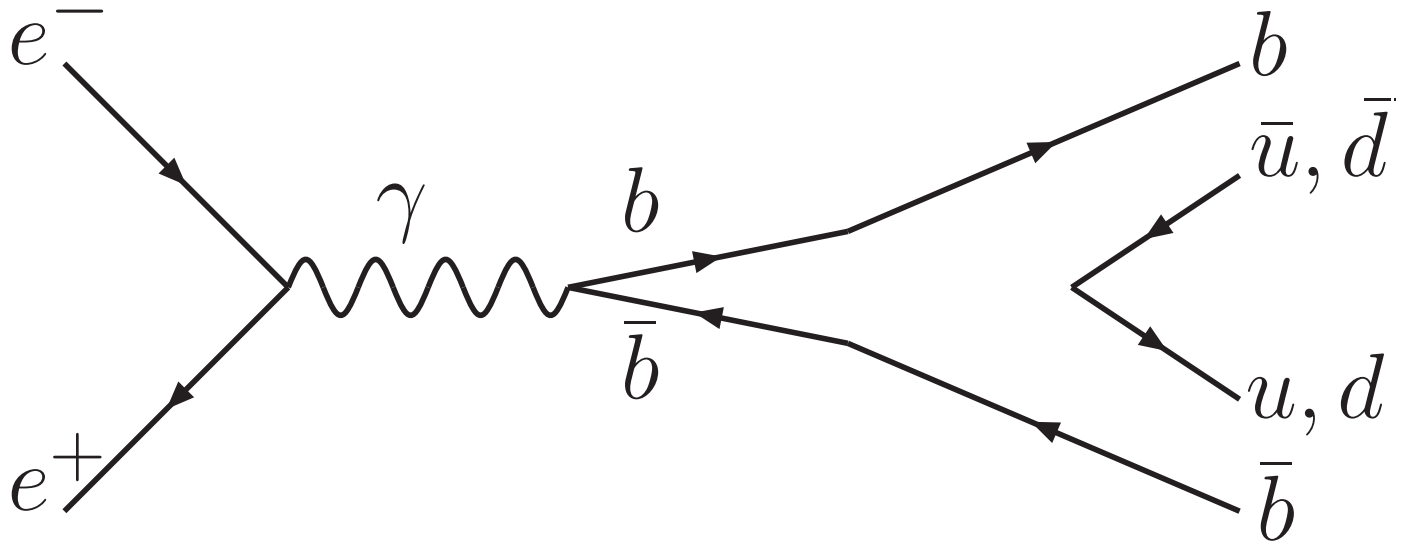
  branching fraction measured

  UL for the branching fraction of $\overline{B}^0 \to D^0\Sigma^0\bar{\Lambda}$ determined for the first time

  result consistent with $s\overline{s}$ suppression expected from fragmentation models

Backup

the experimental setup



$$e^+e^- \to b\bar{b} = \Upsilon(4S) \to B\overline{B}$$

$$E(e^+e^-) = \sqrt{s} \sim 10.58\,\text{GeV} = m(\Upsilon(4S)) \sim 2 \cdot m(B)$$

$$\Delta E = E^*(B) - \sqrt{s}/2 \qquad m_{\text{ES}} = M_{\text{BC}} = \tfrac{1}{c^2}\sqrt{s/4 - p^{*2}(B) \cdot c^2}$$