# Baryonic $B$ decays

# at BABAR

$$B^0 \to \bar{\Lambda} p \pi^-$$
$$\bar{B}^0 \to \Lambda_c^+ \bar{p} K^- \pi^+$$

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

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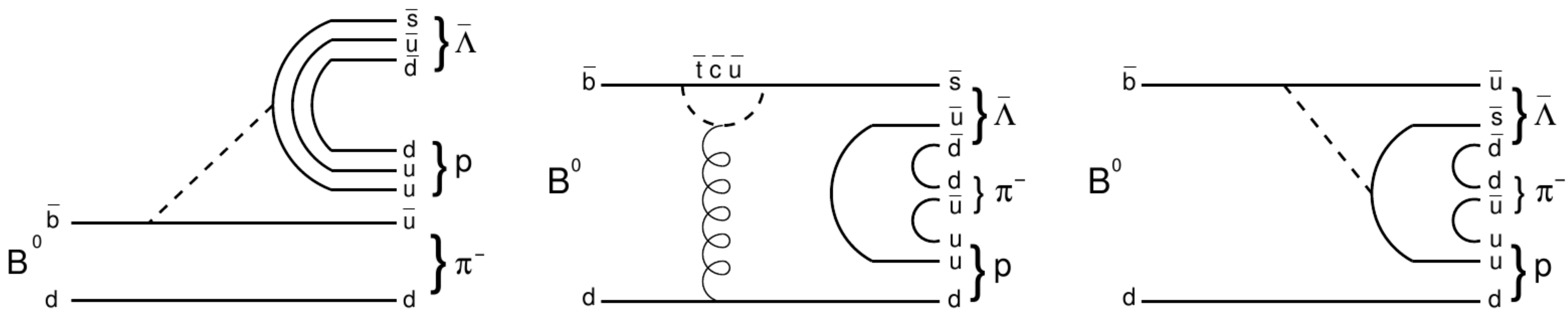



reconstruction, background reduction and signal extraction

branching fraction

asymmetry

$\bar{\Lambda}$ polarization

# $B^0 \to \overline{\Lambda} p \pi^-$ reconstruction

- 426 fb$^{-1}$ data taken at $\Upsilon(4S)$ corresponding to 467 million $B\overline{B}$ pairs analyzed
- $\overline{\Lambda} \to \overline{p}\pi^+$ decay mode used
  - $1.111\,\text{GeV}/c^2 < m(\overline{p}\pi^+) < 1.121\,\text{GeV}/c^2$
  - mass constraint fit requiring common vertex for $p$ and $\pi$ candidates
- $\overline{\Lambda}$ candidate combined with two oppositely charged tracks
  - full decay chain fitted to reconstruct the $B^0$ vertex using total beam energy and position of beam spot as constraints ; $P_{vtx} > 10^{-6}$

# $B^0 \to \overline{\Lambda} p \pi^-$ background reduction

- event shape variables against $e^+e^- \to q\overline{q} \quad (q = u, d, s, c)$
  combined in a Fisher discriminat (92% of this background removed but only 28% of signal)

- flight length of the $\overline{\Lambda}$ candidate divided by its error $\frac{\beta\tau}{\sigma_{\beta\tau}} > 20$

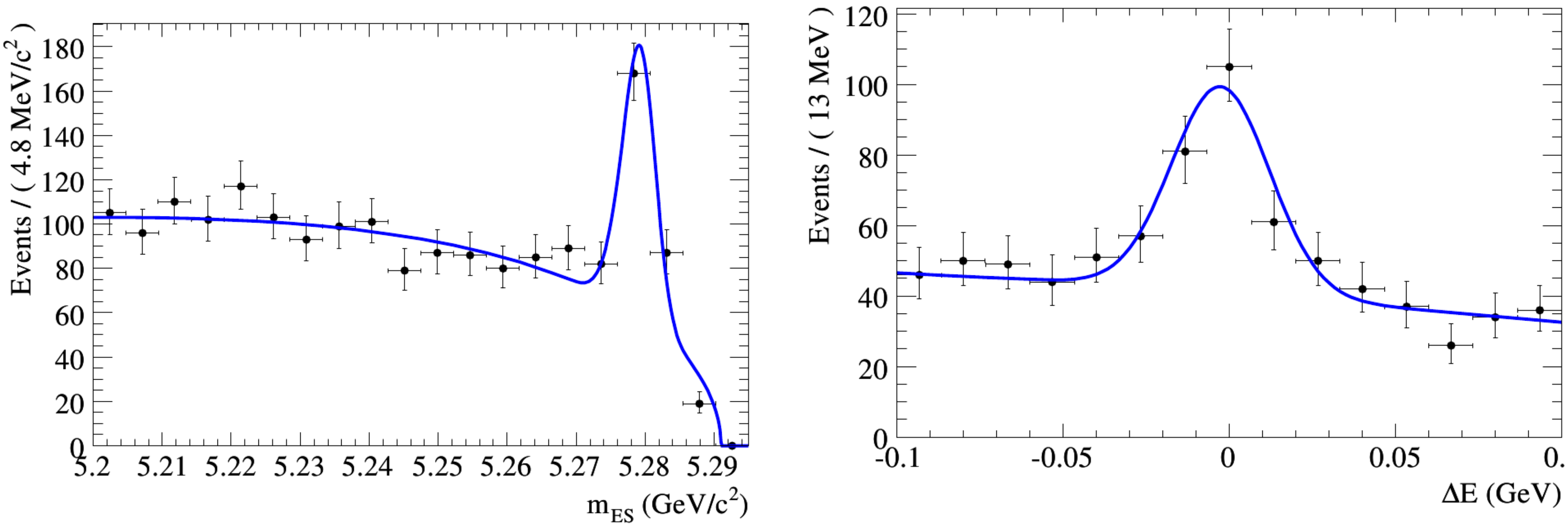
- $\overline{B}^0 \to \Lambda_c^+ \overline{p}$, $\Lambda_c^+ \to \Lambda \pi^+$ removed by requiring
  $|m(\overline{\Lambda}\pi^+) - m(\Lambda_c)_{PDG}| > 20\,\mathrm{MeV}/c^2$ (five standard deviations)

# $B^0 \to \bar{\Lambda} p \pi^-$ signal extraction

- 2D maximum likelihood fit to $\Delta E$-$m_{\mathrm{ES}}$
  - signal PDF: 2xGaussians for $m_{\mathrm{ES}}$ and 2xGaussians for $\Delta E$
    background PDF: ARGUS function (Z.Phys. C**48**,543 (1990) ) for $m_{\mathrm{ES}}$ and first order polynomial for $\Delta E$
  - only means of narrow $\Delta E$ and $m_{\mathrm{ES}}$ signal Gaussians, parameter of the ARGUS function, linear coefficient of $\Delta E$ background and the event yields for signal and background are fitted
- ${}_s\mathcal{P}$lot technique (Nucl. Instrum. Methods A**555**,356 (2005) ) used to determine the $m(\bar{\Lambda} p)$ distribution
- $\bar{\Lambda}$ polarisation measured as function of $E^*_{\bar{\Lambda}}$ using 4D maximum likelihood fit in $m_{\mathrm{ES}}$, $\Delta E$, $E^*_{\bar{\Lambda}}$ and $\cos\theta_h$

# $\mathcal{B}(B^0 \to \bar{\Lambda} p \pi^-)$ results

$|\Delta E| < 0.027$ GeV $m_{\text{ES}} > 5.274$ GeV$/c^2$



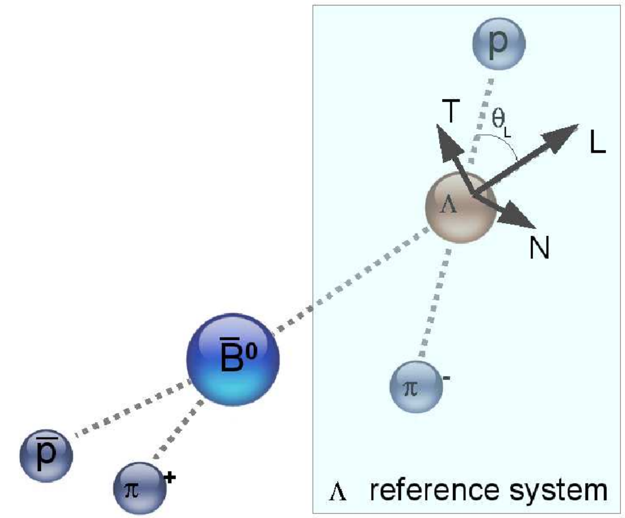

$$\mathcal{B}(B^0 \to \bar{\Lambda} p \pi^-) = \frac{N_s}{N_{B\bar{B}} \cdot \mathcal{B}(\bar{\Lambda} \to \bar{p} \pi^+)} = (3.07 \pm 0.31_{\text{stat.}} \pm 0.23_{\text{syst.}}) \times 10^{-6}$$

(Belle: $\mathcal{B}(\bar{B}^0 \to \Lambda \bar{p} \pi^+) = (3.2 \pm^{+0.33}_{-0.29} \pm 0.29) \times 10^{-6}$ ($414\,\text{fb}^{-1}$) Phys.Rev.D**76**,052004 (2007) )

$$\mathcal{A} = \frac{\mathcal{B}(\bar{B}^0 \to \Lambda \bar{p} \pi^+) - \mathcal{B}(B^0 \to \bar{\Lambda} p \pi^-)}{\mathcal{B}(\bar{B}^0 \to \Lambda \bar{p} \pi^+) + \mathcal{B}(B^0 \to \bar{\Lambda} p \pi^-)} = -0.10 \pm 0.10_{\text{stat}} \pm 0.02_{\text{syst.}}$$

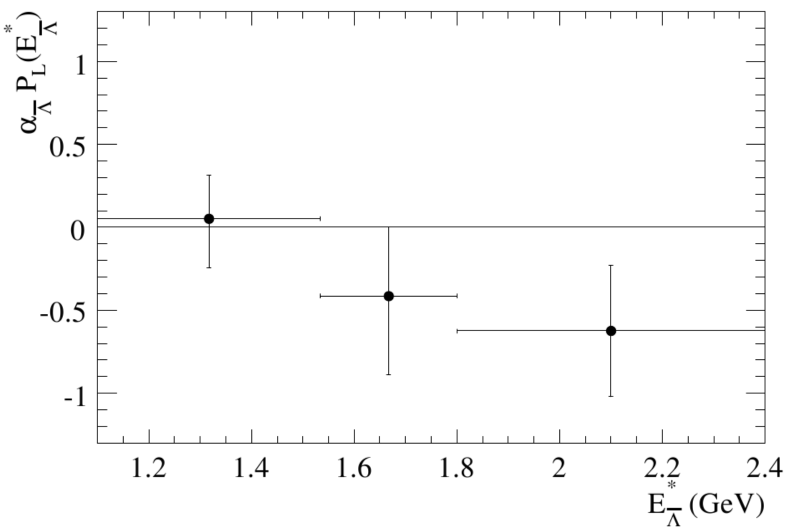
# $B^0 \to \bar{\Lambda} p \pi^-$ polarisation measurement

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{\mathrm{H}}} = \frac{1}{2}\left[1 + \alpha_{\bar{\Lambda}} P\left(E^*_{\bar{\Lambda}}\right)\cos\theta_{\mathrm{H}}\right]$$




$\alpha_{\bar{\Lambda}} = -0.642 \pm 0.013$ ($\bar{\Lambda}$ decay-asymmetry parameter)

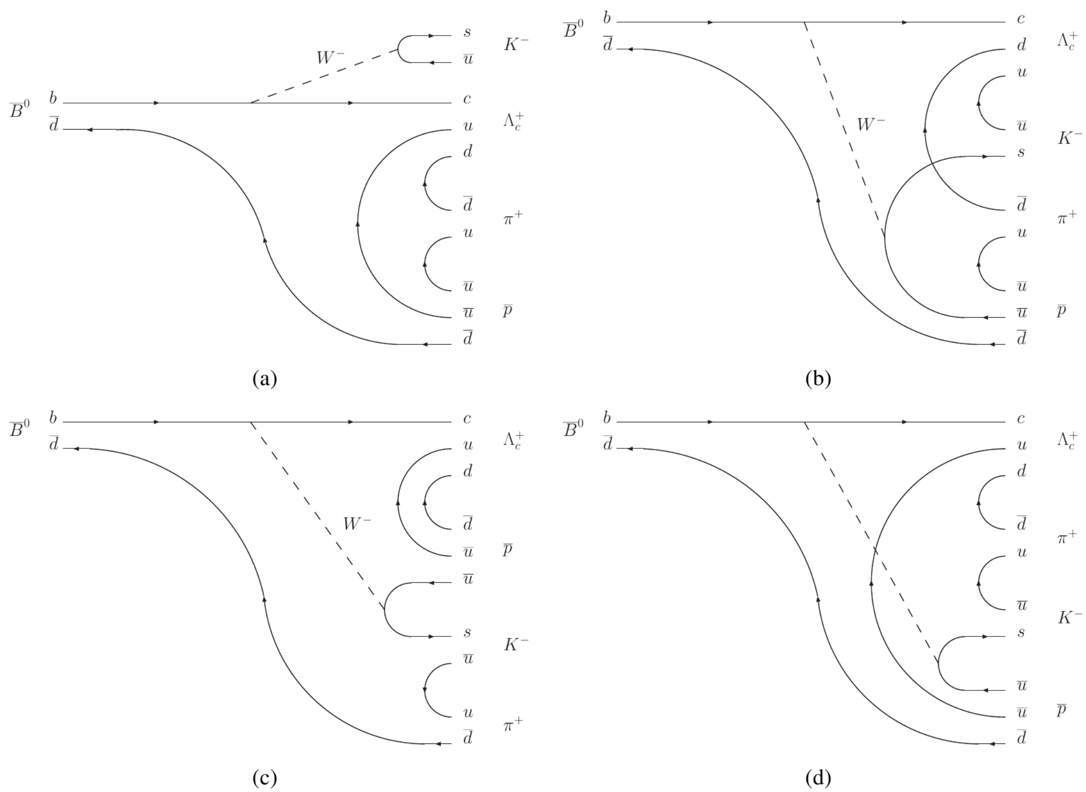
Phys.Lett. B667,1 (2008)




| | $E^*_{\bar{\Lambda}}$ range (GeV) | | |
|---|---|---|---|
| | $1.10 - 1.53$ | $1.53 - 1.80$ | $1.80 - 2.40$ |
| $N_{\mathrm{S}}$ | $63 \pm 9$ | $51 \pm 9$ | $55 \pm 11$ |
| $N_{\mathrm{B}}$ | $519 \pm 23$ | $643 \pm 26$ | $2663 \pm 52$ |
| $P_L$ | $-0.08^{+0.47}_{-0.40} \pm 0.09$ | $+0.64^{+0.73}_{-0.65} \pm 0.12$ | $+0.97^{+0.62}_{-0.62} \pm 0.08$ |
| $P_T$ | $+0.25^{+0.53}_{-0.58} \pm 0.09$ | $+0.56^{+0.42}_{-0.48} \pm 0.12$ | $+0.05^{+0.61}_{-0.60} \pm 0.08$ |
| $P_N$ | $-0.64^{+0.34}_{-0.33} \pm 0.09$ | $-0.78^{+0.39}_{-0.36} \pm 0.12$ | $+0.26^{+0.53}_{-0.53} \pm 0.08$ |

$\Rightarrow$ consistent with full longitudinal right-handed polarization of $\bar{\Lambda}$ at large $E^*_{\bar{\Lambda}}$

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




reconstruction and signal extraction

branching fraction

resonant subchannels

# $\overline{B}^0 \rightarrow \Lambda_c^+ \overline{p} K^- \pi^+$ reconstruction

- 426 fb$^{-1}$ data taken at $\Upsilon(4S)$ corresponding to 467 million $B\overline{B}$ pairs analyzed

- $\Lambda_c^+ \rightarrow p K^- \pi^+$ decay mode used ($\mathcal{B} = 0.050 \pm 0.013$ Phys.Lett. B667,1 (2008) )
  - $2.277\,\mathrm{GeV}/c^2 < m(pK^-\pi^+) < 2.295\,\mathrm{GeV}/c^2$

- $\Lambda_c^+$ candidate combined with $\overline{p}$, $K^-$ and $\pi^+$ candidates
  - decay chain fitted requiring common vertex for $\Lambda_c^+$, $\overline{p}$, $K^-$ and $\pi^+$ and with mass of $\Lambda_c^+$ candidate constraint to the nominal one; $P_{vtx} > 0.002$

- for multiple $\overline{B}^0$ candidates in an event use the one with $m(pK^-\pi^+)$ closest to $m(\Lambda_c^+)$; for multiple $\overline{B}^0$ candidates with the same $\Lambda_c^+$ candidate use the one with the highest vertex fit probability

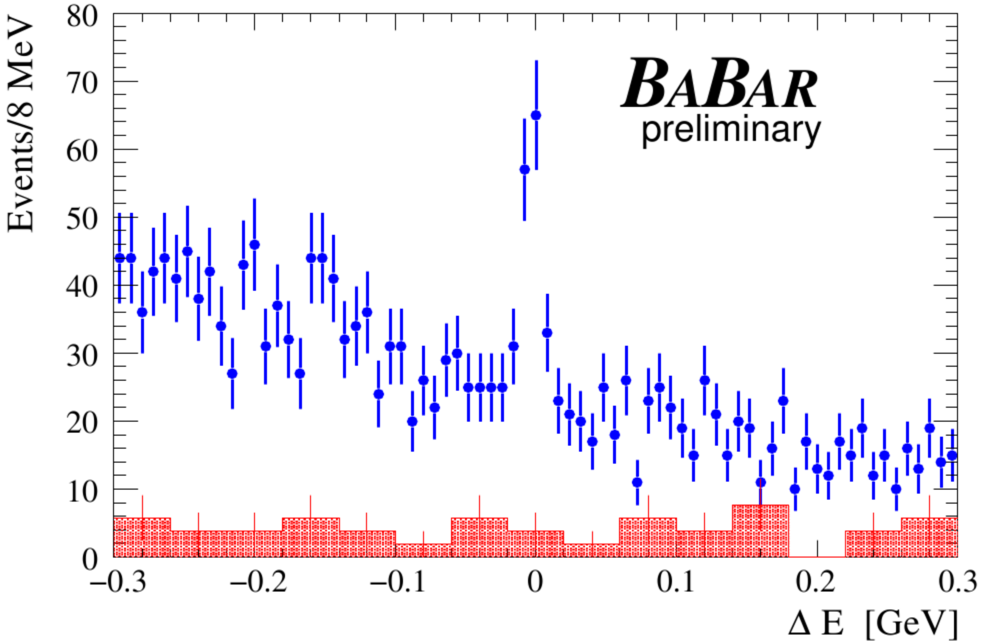
# $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+$ signal extraction

- phase space divided into different regions to account for resonances and efficiency variation
  (1) $2.447\ \mathrm{GeV}/c^2 < m(\Lambda_c^+ \pi^+) < 2.461\ \mathrm{GeV}/c^2$
  (2) $0.8\ \mathrm{GeV}/c^2 < m(K^- \pi^+) < 1.1\ \mathrm{GeV}/c^2$ excluding (1)
  rest divided into five bins according to $m(\Lambda_c^+ \overline{p} \pi^+)$

- signal yield extracted from $\Delta E$ distribution in these regions
  ($5.275\ \mathrm{GeV}/c^2 < m_{\mathrm{ES}} < 5.286\ \mathrm{GeV}/c^2$)
  - only background fitted with first order polynomial and $|\Delta E| < 0.12\ \mathrm{GeV}$
  - $|\Delta E| < 0.024$ excluded from the fit and later extrapolated to this region
  - difference between observed events and expected background in $|\Delta E| < 0.024\ \mathrm{GeV}$ used as signal yield

- resonant fraction for $\overline{B}^0 \to \Sigma_c^{++}(2455) \overline{p} K^-$ and $\overline{B}^0 \to \Lambda_c^+ \overline{p} \overline{K}^{*0}$ extracted from $\Delta E$ sideband subtracted $m(\Lambda_c^+ \pi^+)$ and $m(K^- \pi^+)$ distributions

# $\mathcal{B}\left(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+\right)$ **result**




| Region | $N_{\text{sig}}$ | $\epsilon$ [%] |
|---|---|---|
| 1 | $17.3 \pm 4.6$ | $6.64 \pm 0.04$ |
| 2 | $26.5 \pm 9.7$ | $8.60 \pm 0.07$ |
| 3-7 | $39.7 \pm 12.2$ | $8.94 \pm 0.25$ |

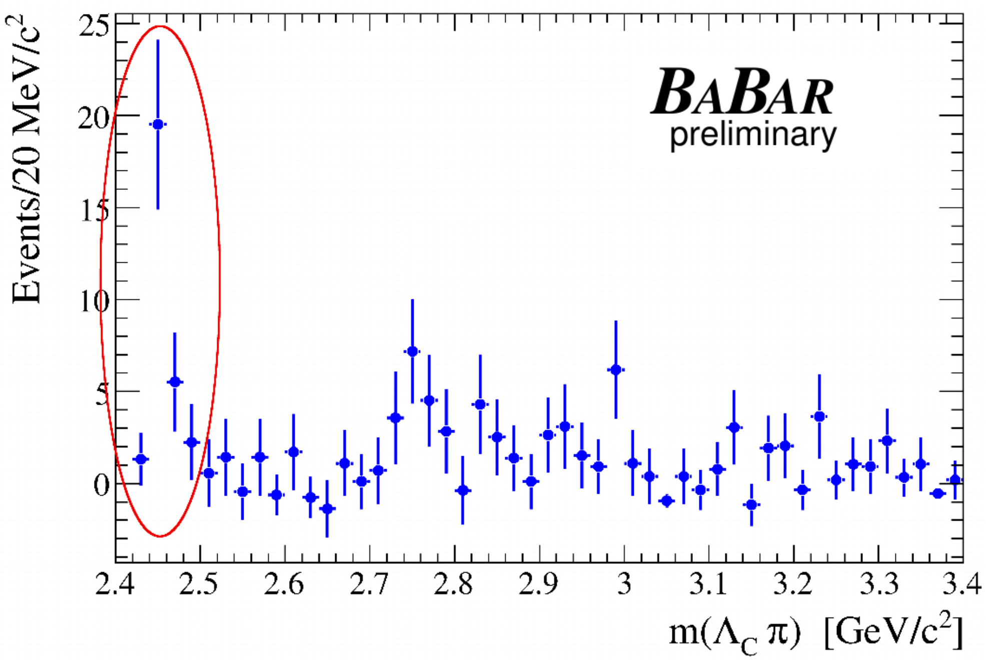
$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+) = \frac{1}{\mathcal{B}(\Lambda_c^+ \to p K^- \pi^+) \cdot N_{B\overline{B}}} \cdot \sum_{i=1}^{7} \frac{N_{\text{sig},i}}{\epsilon_i}$$

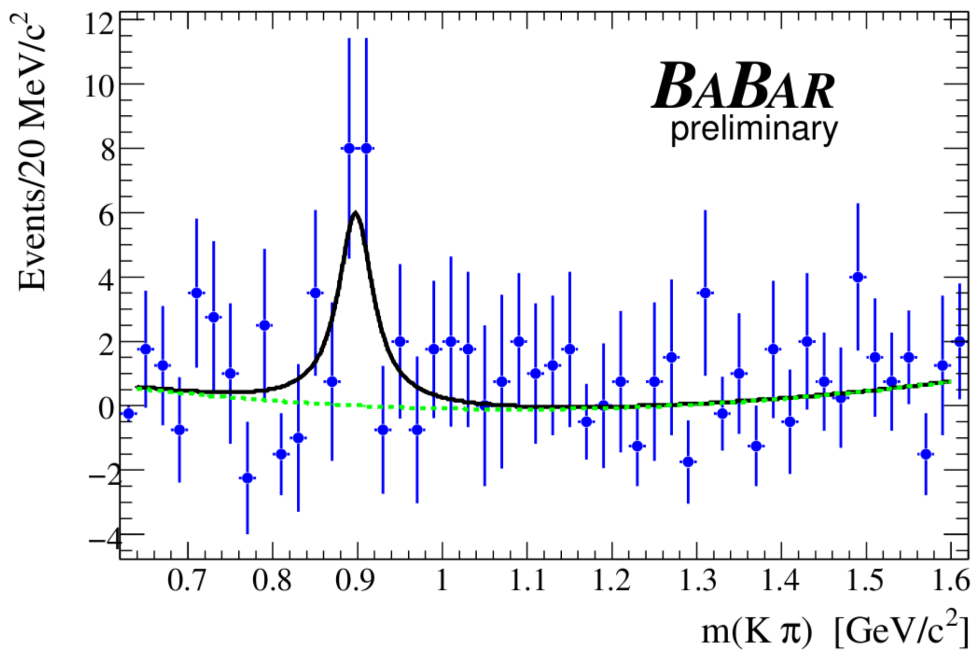
$$= (4.33 \pm 0.82_{\text{stat.}} \pm 0.31_{\text{syst.}} \pm 1.13_{\mathcal{B}(\Lambda_c)}) \times 10^{-5}$$

preliminary!

$\Rightarrow$ first observation ! (significance of 8.8 standard deviations)

# study of resonant subchannels




$N_{\text{sig}}\left(\Sigma_c(2455)^{++}\right) = 16.0 \pm 4.3$

$\epsilon_1 = (6.15 \pm 0.04)\%$

$\mathcal{B}(\overline{B}^0 \to \Sigma_c(2455)^{++}\overline{p}K^-)$
$= \left(1.11 \pm 0.30_{\text{stat}} \pm 0.09_{\text{syst}} \pm 0.29_{\mathcal{B}(\Lambda_c)}\right) \times 10^{-5}$

preliminary!

$N_{\text{sig}}(\overline{K}^{*0}) = 20.9 \pm 7.9$

$\epsilon_2 = (8.38 \pm 0.05)\%$

$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p}\overline{K}^{*0}) < 2.41 \times 10^{-5}$ @90% $C.L.$

preliminary!

# baryonic $B$ decays

| $B^0/B^-$ decay mode | branching fraction $[\times 10^{-4}]$ |
|---|---|
| $\Lambda\overline{p}$ | $< 0.0032$ |
| $\Lambda\overline{p}\pi^-$ | $0.031 \pm 0.003$ |
| $\Lambda\overline{p}\pi^0$ | $0.030^{+0.007}_{-0.006}$ |
| $p\overline{p}\overline{K}^0$ | $0.027 \pm 0.004$ |
| $p\overline{p}K^-$ | $0.029^{+0.01}_{-0.008}$ |
| $p\overline{p}$ | $< 0.0017$ |
| $p\overline{p}\pi^-$ | $0.0162 \pm 0.0020$ |
| $\Lambda_c^+\overline{p}$ | $0.2 \pm 0.04$ |
| $\Lambda_c^+\overline{p}\pi^-$ | $2.1 \pm 0.6$ |
| $\Lambda_c^+\overline{\Lambda_c^+}K^-$ | $7 \pm 4$ |
| $\Lambda_c^+\overline{p}\pi^+\pi^-$ | $11.2 \pm 3.2$ |
| $\Lambda_c^+\overline{p}\pi^-\pi^0$ | $18 \pm 6$ |

- $\mathcal{B}(\text{2body}) < \mathcal{B}(\text{3body}) < \mathcal{B}(\text{4body})$
- Hou and Soni Phys.Rev.Lett. **86**,4247 (2001)
  *"One has to reduce the energy release and at the same time allow for baryonic ingredients to be present in the final state"*
- energy taken away by additional particles

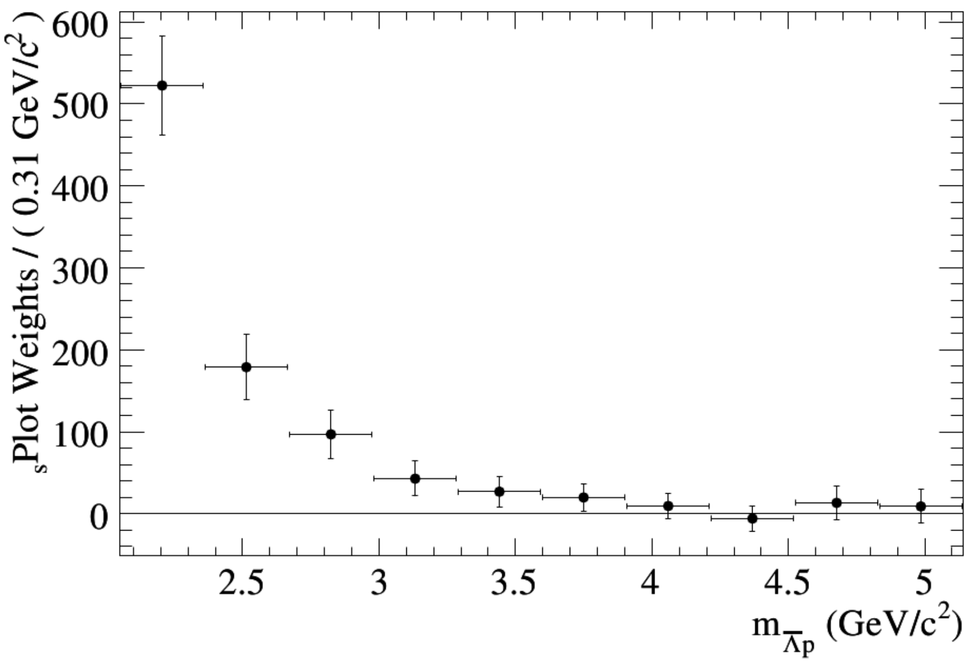
$\Rightarrow$ invariant mass of baryon-antibaryon system should be low $\longrightarrow$ threshold enhancement

- seen in many baryonic $B$ decays
  $B^- \to \Lambda_c^+\overline{p}\pi^-$, $B^- \to p\overline{p}K^-$
- but also in totaly different reactions like $e^+e^- \to \gamma\Lambda\overline{\Lambda}$

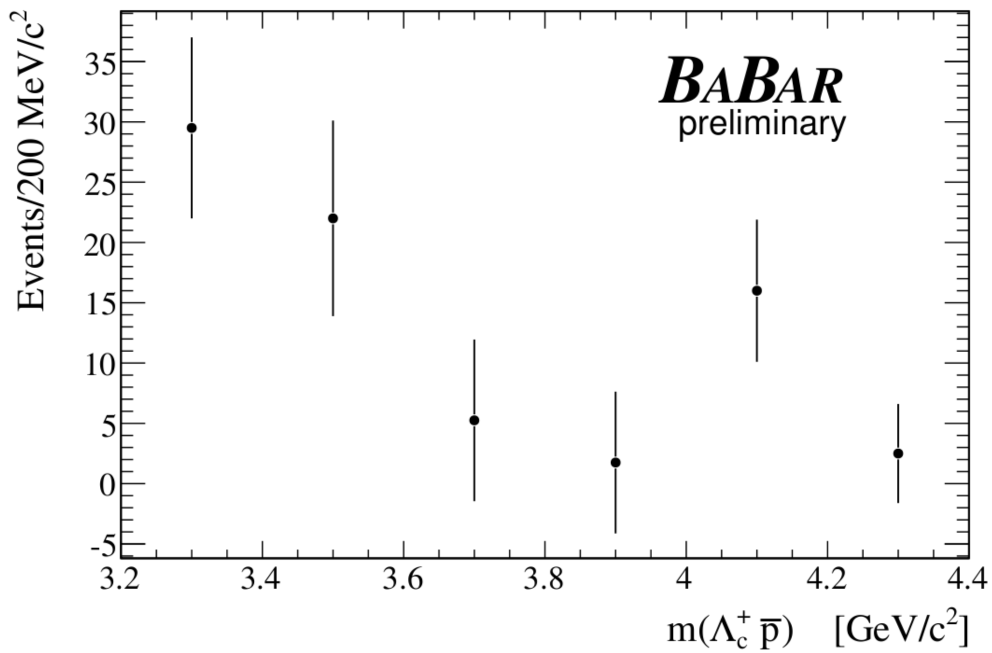
other explanations: Rosner Phys.Rev.D**68**,014004

# baryon-antibaryon mass distribution

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




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




$\Rightarrow$ threshold enhancement for both decay modes visible

# Conclusion

- decay $B^0 \to \bar{\Lambda} p \pi^-$ studied (PRD 79, 112009 (2009))
  - $\mathcal{B}(B^0 \to \bar{\Lambda} p \pi^-) = (3.07 \pm 0.31 \pm 0.23) \times 10^{-6}$
  - no hint for CP-violating branching fraction asymmetry
  - $\bar{\Lambda}$ polarisation consistent with full longitudinal right-handed polarisation at large $E^*_{\bar{\Lambda}}$
- decay $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+$ also studied; preliminary results :
  - $\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- \pi^+) = (4.33 \pm 0.82 \pm 0.31 \pm \pm 1.13) \times 10^{-5}$
  - $\mathcal{B}(\overline{B}^0 \to \Sigma_c^+(2455)^{++} \overline{p} K^-) = (1.11 \pm 0.30 \pm 0.09 \pm 0.29) \times 10^{-5}$
  - $\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \bar{K}^{*0}) < 2.41 \times 10^{-5} \quad @90\% C.L.$
- threshold enhancement in the baryon-antibaryon mass distribution for both decay modes found

# BACKUP SLIDES

# ${}_s\mathcal{P}lot$ technique used for $B^0 \to \bar{\Lambda} p \pi^-$

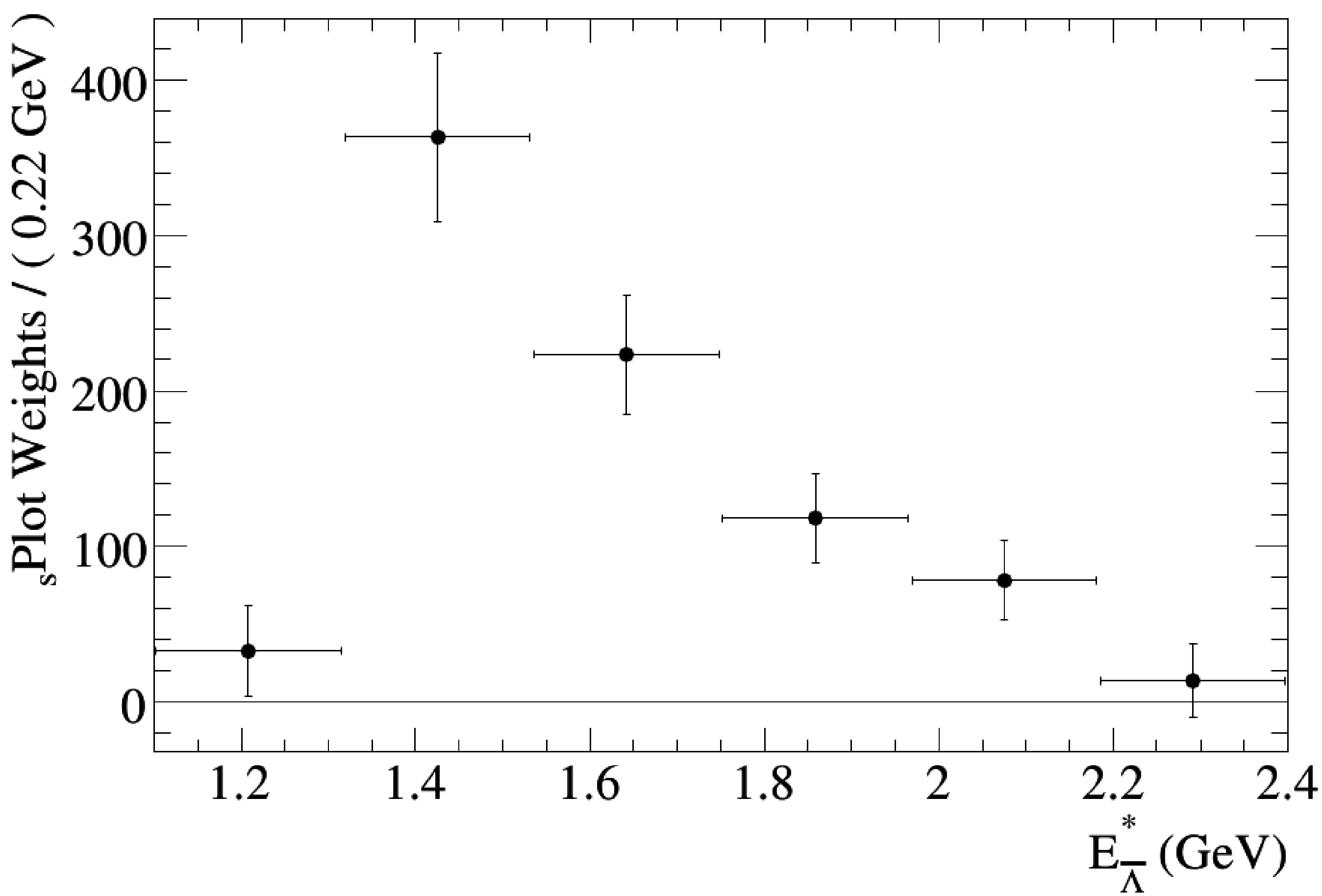
$$\mathcal{L} = \frac{1}{N!} e^{-(N_{\mathrm{S}}+N_{\mathrm{scf}}+N_{\mathrm{B}})} \prod_{e=1}^{N} \{ N_{\mathrm{S}} \mathcal{P}_{\mathrm{S}}(y_e) + N_{\mathrm{scf}} \mathcal{P}_{\mathrm{scf}}(y_e) + N_{\mathrm{B}} \mathcal{P}_{\mathrm{B}}(y_e) \}, \quad (1)$$

$${}_s\mathcal{P}_n(y_e) = \frac{\sum_{j=1}^{n_c} \mathbf{V}_{nj} \mathcal{P}_j(y_e)}{\sum_{k=1}^{n_c} N_k \mathcal{P}_k(y_e)}, \quad (2)$$

$$\tilde{N}_{S,J} = \sum_{e \in J} \frac{{}_s\mathcal{P}_S(y_e)}{\varepsilon(x_e)}, \quad (3)$$

$$\tilde{N}_S = \sum_J \tilde{N}_{S,J}$$

# $E^*_{\overline{\Lambda}}$ distribution



# Systematics for $B^0 \to \bar{\Lambda} p \pi^-$

| | source | uncertainty (%) |
|---|---|---|
| Overall | Tracking efficiency | 2.4 |
| | PID efficiency | 1.4 |
| | MC statistics | 0.4 |
| | $B\bar{B}$ counting | 1.1 |
| | $B^0\bar{B}^0/B\bar{B}$ fraction | 3.2 |
| | $\Lambda \to p\pi$ branching fraction | 0.8 |
| Event Selection requirements | Event shape | 1.0 |
| | Fit probability | 1.0 |
| | $\Lambda$ flight length | 2.8 |
| | $\Lambda$ mass | 2.4 |
| | $\Lambda_c$ veto | 0.5 |
| Fit Procedure | Likelihood parameters | 3.9 |
| | $\Delta E$ resolution | 1.7 |
| | Self cross-feed fraction | 0.8 |
| | ${}_s\mathcal{P}$lot bias | 0.6 |
| Total | | 7.4 |

# Systematics for $\overline{B}^0 \rightarrow \Lambda_c^+ \overline{p} K^- \pi^+$

| Source | contribution (%) |
|---|---|
| tracking | 1.4 |
| PID | 2.4 |
| $N_{B\overline{B}}$ | 1.1 |
| signalband definition | 3.3 |
| $\Delta E$ background shape | 4.7 |
| MC statistics | 0.4 |
| MC generation model | 1.0 |
| $m(\Lambda_c^+)$ cut | 3.4 |
| $P(\chi^2)$ cut | 0.8 |
| sum | 7.5 |