Study of baryonic decays of B mesons

Lake Louise Winter Institute 2015

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Motivation to study baryonic decays of B mesons

- Decays of B mesons into final states with baryons: $\sim 7\%$ of the total decay width Z. Phys. C**56** (1992) 1
- Large mass of the B meson allows big variety of baryons in the final state

Hadronisation = Strong interaction

- Mechanism of the baryon production process unknown
- Study of baryonic B decays provides information for testing phenomenological models
- Investigation of quark fragmentation at low Q^2 values

Motivation to study baryonic decays of B mesons

Observed features

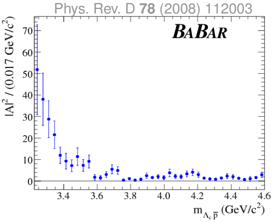
- Baryon-antibaryon threshold enhancement
  - Increased decay rate for low baryon-antibaryon invariant masses with respect to phase space model
- Large contributions to the total branching fraction from decays with intermediate states , e.g.

$$\frac{\mathcal{B}(\overline{B}^0 \to \Sigma_c(2455)^{++}\overline{p}\pi^-)}{\mathcal{B}(\overline{B}^0 \to \Lambda_c^+\overline{p}\pi^-\pi^+)} \approx 17\%$$

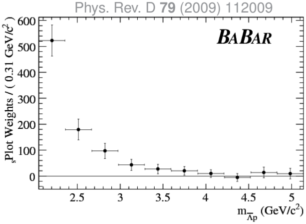
Phys. Rev. D **87** (2013) 9

Threshold enhancement

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

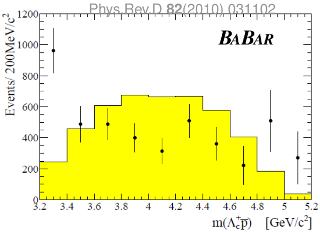


$\overline{B}^0 \to \Lambda \overline{p} \pi^+$



- Variety of models to describe threshold enhancement
  - Pole model
    e.g. Phys. Rev. D **66** (2002) 014020
  - Final-state interaction
    e.g. Phys. Rev. C **68** (2003) 052201
  - Glueball
    e.g. Phys. Rev. D **66** (2002) 054004
  - Bound state
    e.g. Phys. Lett. B **567** (2003) 273

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



Presented analysis: $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$

Phys. Rev. D **91 (2015) 031102 (R)**

- Comparison to similar decay: $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+$

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+) = (1.17 \pm 0.23) \times 10^{-3}$$

Chin. Phys. C **38** (2014) 090001

  - LUND model: The heavier mass of the s quark suggests a supression faction of $1/3$ for $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$ compared to $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+$ Phys. Rep. **97** (1983) 31
  - LUND model consistent for $\overline{B}^0 \to D^0 \Lambda \overline{\Lambda}$ relative to $\overline{B}^0 \to D^0 p \overline{p}$:

    expected: $$\frac{\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \overline{\Lambda})}{\mathcal{B}(\overline{B}^0 \to D^0 p \overline{p})} \sim \frac{1}{4} \cdot \frac{1}{3} = \frac{1}{12}$$

    measured : $$\frac{\mathcal{B}(\overline{B}^0 \to D^0 \Lambda \overline{\Lambda})}{\mathcal{B}(\overline{B}^0 \to D^0 p \overline{p})} = \frac{1}{10.6 \pm 3.8}$$

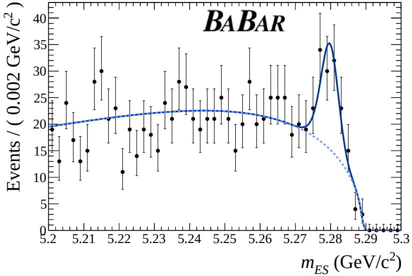
    Phys. Rev. D **89** (2014) 112002

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

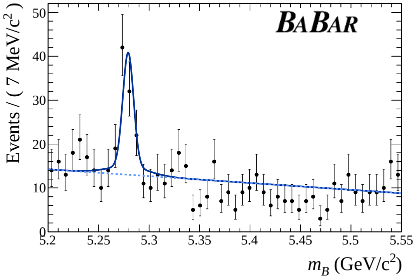
- Signal extraction via 2D fit to the energy-substituted mass m_{ES} versus invariant mass m_B

$$N = 66 \pm 12$$

m_{ES} projection



m_B projection

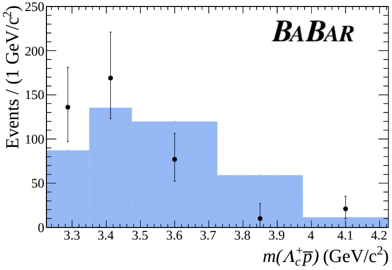


Statistical significance:

$$S = \sqrt{-2 \log \left(L_0 / L_{\mathsf{sig}} \right)} = 5.4\,\sigma$$

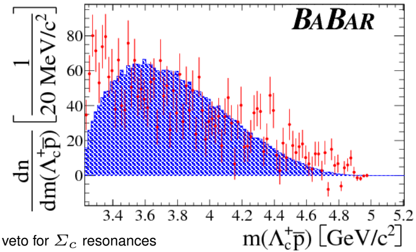
Threshold enhancement

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



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

Phys. Rev. D **87** (2013) 9, 092004



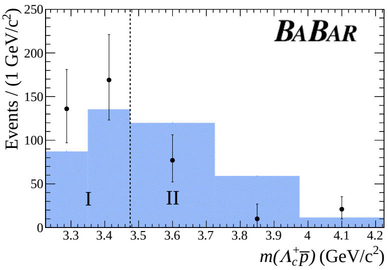
veto for Σ_c resonances

- Distribution of signal events compared to phase space model scaled to the same integral
- Enhancement not significant for $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$ but trend of data consistent with small threshold enhancement

$\Lambda_c^+\overline{p}$ invariant mass

- Division of the baryon-antibaryon invariant mass range into two regions
- Efficiencies:
  $\varepsilon_I = (10.93 \pm 0.08)\%$,
  $\varepsilon_{II} = (11.47 \pm 0.07)\%$

$m\left(\Lambda_c^+\overline{p}\right)$



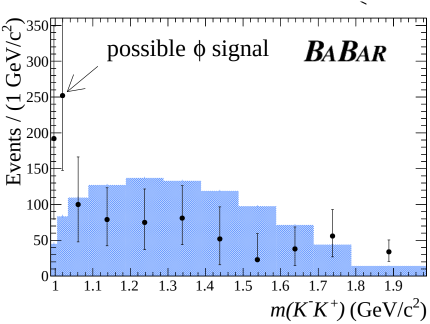
Branching fraction of $\overline{B}^0 \to \Lambda_c^+\overline{p}K^-K^+$:

$$\mathcal{B}\left(\overline{B}^0 \to \Lambda_c^+\overline{p}K^-K^+\right) = \left(2.5 \pm 0.4_{(\text{stat})} \pm 0.2_{(\text{syst})} \pm 0.6_{(\Lambda_c^+)}\right) \times 10^{-5}$$

Resonances

- Background substracted signal distribution compared to phase space model of $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$ scaled to the same integral
- Hint for resonance in the kaon-kaon invariant mass (ϕ)
- No evidence for other resonances, e.g. $\overline{\Lambda}(1520)$
- Calculate upper limit for the decay $\overline{B}^0 \to \Lambda_c^+ \overline{p} \phi$ at 90% confidence level

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



$$\mathcal{B}\left(\overline{B}^0 \to \Lambda_c^+ \overline{p} \phi\right) < 1.2 \times 10^{-5}$$

Interpretation

- Compare $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$ to $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+$
- Contribution of different intermediate resonant states

$$\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+)_{\mathrm{non-res}} \lesssim 50\% \cdot \mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+) = 6 \cdot 10^{-4}$$

$$\frac{\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+)}{\mathcal{B}(\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+)_{\mathrm{non-res}}} \gtrsim \frac{2.5 \cdot 10^{-5}}{6 \cdot 10^{-4}} = \frac{1}{24} < \frac{1}{3}$$

- Other contributions than $s\overline{s}$ suppression:
  - $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^- \pi^+$ has contributions from Feynman diagrams that are not possible for $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$

Summary

Phys. Rev. D **91 (2015) 031102(R)**

- First observation of the decay $\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+$ with a branching fraction of

$$\mathcal{B}\left(\overline{B}^0 \to \Lambda_c^+ \overline{p} K^- K^+\right) = \left(2.5 \pm 0.4_{\text{(stat)}} \pm 0.2_{\text{(syst)}} \pm 0.6_{\left(\Lambda_c^+\right)}\right) \times 10^{-5}$$

- Trend of a threshold enhancement in the baryon-antibaryon invariant mass
- Upper limit for the decay $\overline{B}^0 \to \Lambda_c^+ \overline{p} \phi$ at 90% confidence level

$$\mathcal{B}\left(\overline{B}^0 \to \Lambda_c^+ \overline{p} \phi\right) < 1.2 \times 10^{-5}$$

Backup

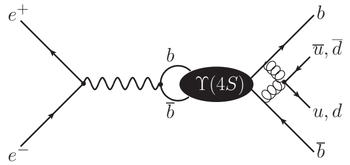
BACKUP

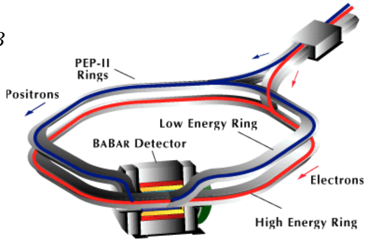
The *BABAR* experiment

- Investigation of features of B mesons and their decays

PEP-II: asymmetric B Factory

- e^+e^- storage ring:
  $E_{e^-} = 9.0\,\mathrm{GeV}$, $E_{e^+} = 3.1\,\mathrm{GeV}$
- Center-of-mass energy
  $\sqrt{s} \approx 10.58\,\mathrm{GeV} \sim m_{\Upsilon(4S)} \sim 2 \cdot m_B$
- $e^+e^- \to \Upsilon(4S) \to B\overline{B}$

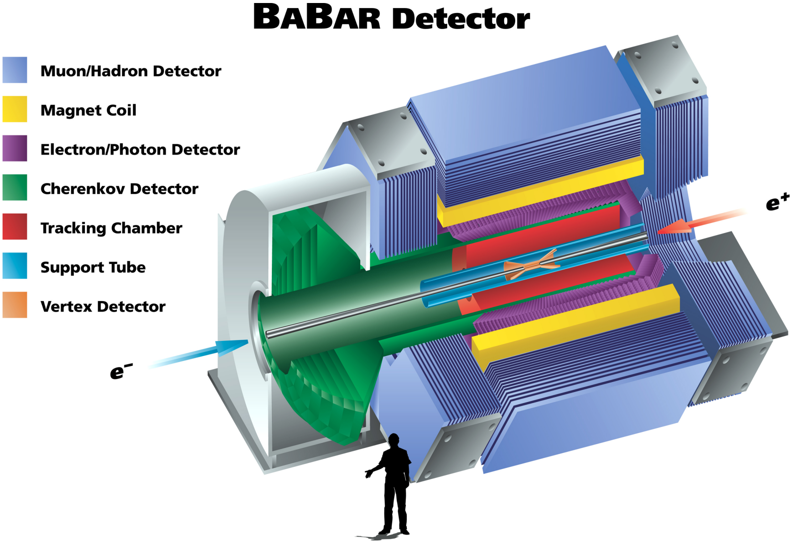




- $471 \cdot 10^6$ $B\overline{B}$ pairs (2000 - 2007)

The *BABAR* detector

- Measurement of decay products: p, K, π, e, μ und γ



BABAR variables

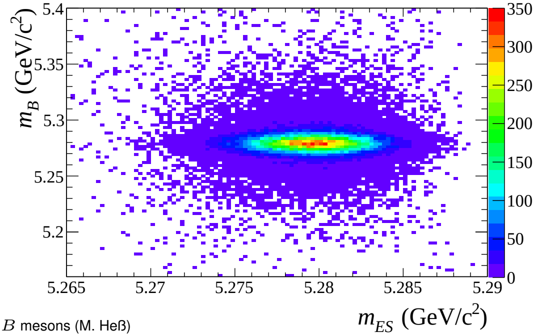
$$m_B = \sqrt{E_B^{*2} - \boldsymbol{p}_B^{*2}}$$

$$\sqrt{s} \sim m_{\Upsilon(4S)} \sim 2m_B$$

$$E_B^{*2} = \frac{\sqrt{s}}{2}$$

$$\Delta E = E_B^{*} - \frac{\sqrt{s}}{2} \qquad m_{\mathrm{ES}} = \sqrt{\left(\frac{\sqrt{s}}{2}\right)^2 - \boldsymbol{p}_B^{*2}}$$

m_{ES} and m_B are uncorrelated



Fit function

- Fit function used to determine the number of signal events

$$\begin{aligned} f_{\text{fit}} &= N_{\text{sig}} \cdot \mathcal{S}(m_{\text{ES}}, m_B) + N_{\text{bkg}} \cdot \mathcal{B}(m_{\text{ES}}, m_B) \\ &= N_{\text{sig}} \cdot f_{\text{2G}}(m_{\text{ES}}) \cdot f_{\text{2G}}(m_B) \\ &\quad + N_{\text{bkg}} \cdot f_{\text{ARGUS}}(m_{\text{ES}}) \cdot f_{\text{poly}}(m_B) \end{aligned}$$

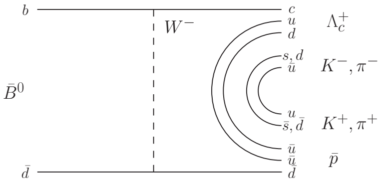
  - N_{sig} and N_{bkg} are the number of signal and background events
  - $\mathcal{S}$ and $\mathcal{B}$ the corresponding probability density functions

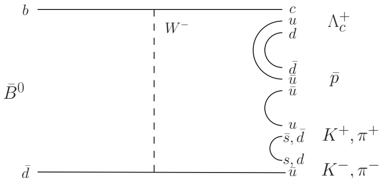
- Extended likelihood function

$$L(N_{\text{sig}}, N_{\text{bkg}}) = \frac{e^{-(N_{\text{sig}}+N_{\text{bkg}})}}{N!} \prod_{i=1}^{N} [N_{\text{sig}} \mathcal{S}_i(m_{\text{ES}i}, m_{Bi}) + N_{\text{bkg}} \mathcal{B}_i(m_{\text{ES}i}, m_{Bi})]$$

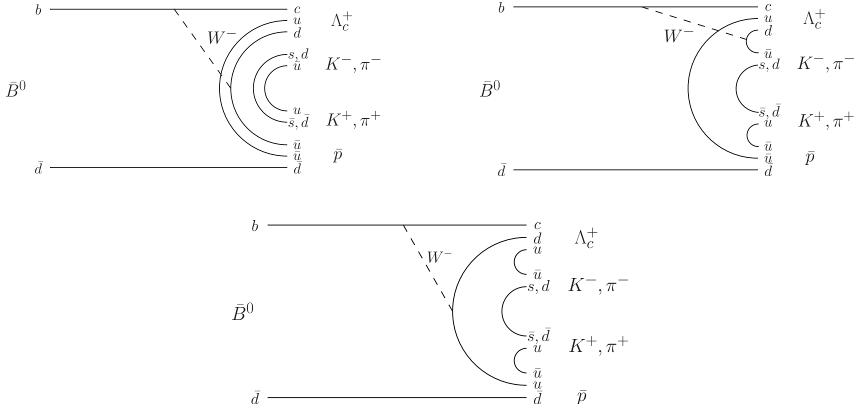
  - i denotes the ith candidate
  - N is the total number of events in the fit region

Feynman diagrams





Feynman diagrams



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