

Recent *BABAR* Measurements of Hadronic *B* Branching Fractions

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Recent *BABAR* Measurements of Hadronic *B* Branching Fractions

This Talk

- The BaBar running era
- Recent Results on *B*-physics

$$\bar{B}^0 \rightarrow D^{(*)0} h^0$$

$$B \rightarrow \bar{D}^{(*)} D^{(*)} K$$

$$B \rightarrow D^{(*)} p\bar{p}(\pi)(\pi)$$

$$\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$$

Physics Reach

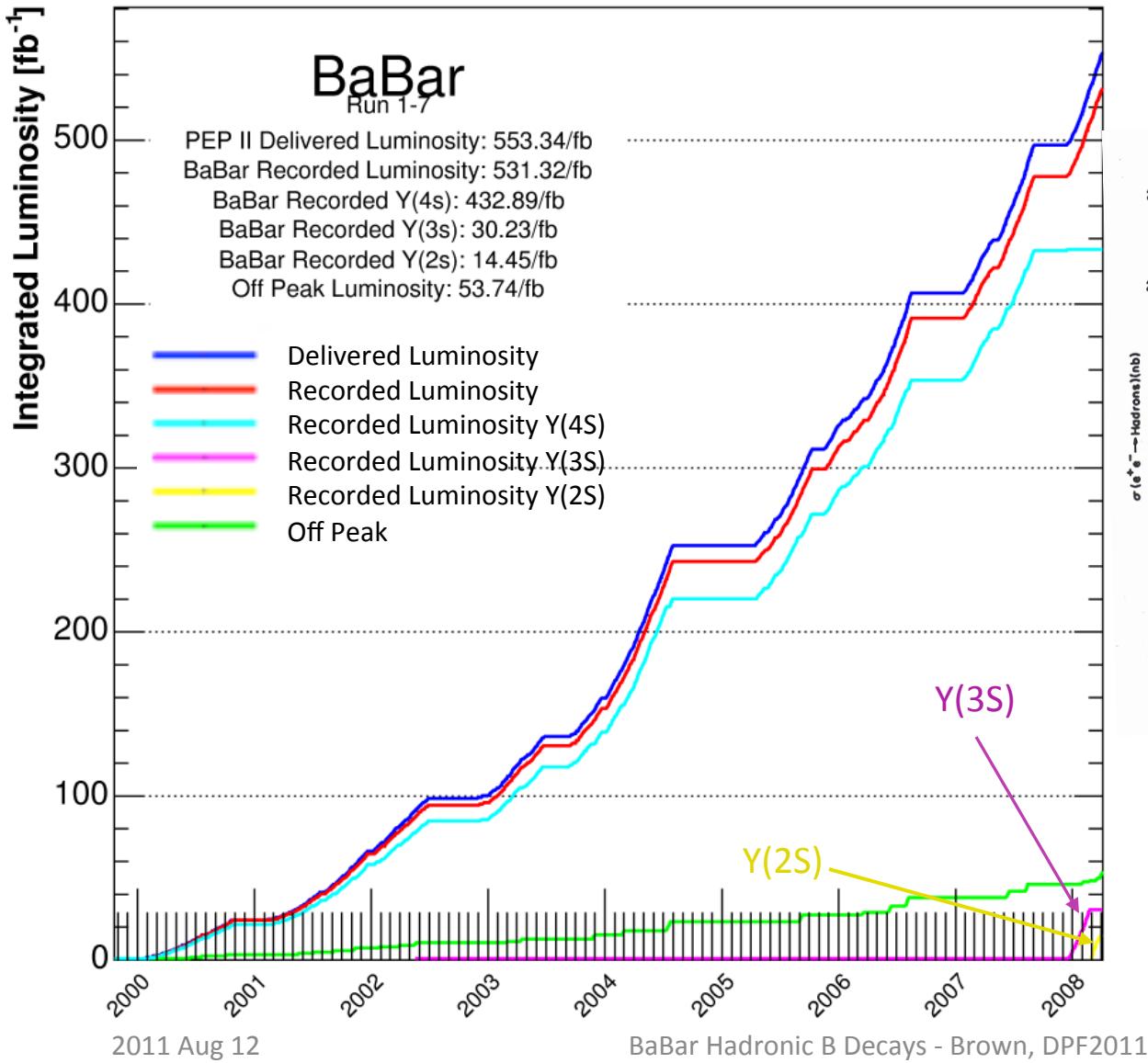
- *B*-physics
 - *CP Violation & Mixing, CKM matrix elements, hadronic, leptonic & semi-leptonic decays, penguin decays, etc*
- Charm and charmonium
- Tau physics
- Initial state radiation (ISR)
- Bottomonium spectroscopy
- Two-photon physics
- Beyond the Standard Model
- More

Motivation – Hadronic B Decays

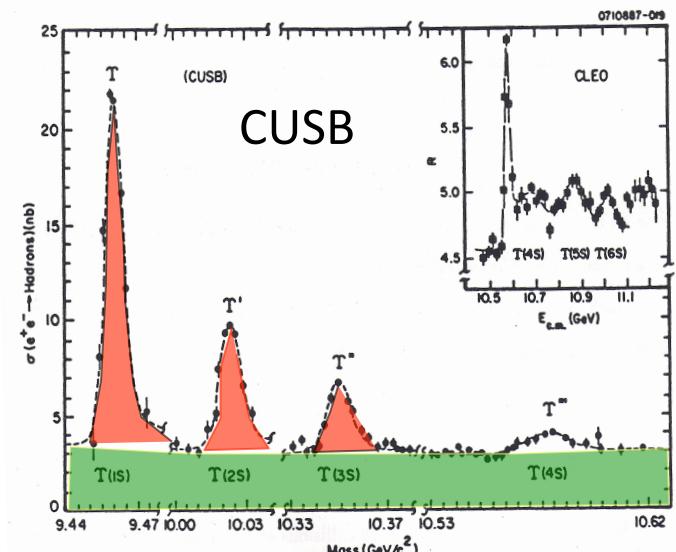
- In general, B decays provide an important platform for understanding CP -Violation and the CKM mechanism
- Hadronic B decays allow tests of Final State Interactions (FSI).
 - Implications for other measurements
 - Compare with predictions from perturbative QCD (pQCD), QCD factorization, and Soft Collinear Effective Theory (SCET)
- Baryons in the final state are not well-understood generally, so any measurements involving baryonic decays are particularly useful in developing models
- Measurements of rare modes improve our model constraints and can signal new physics



The *BABAR* Running Era



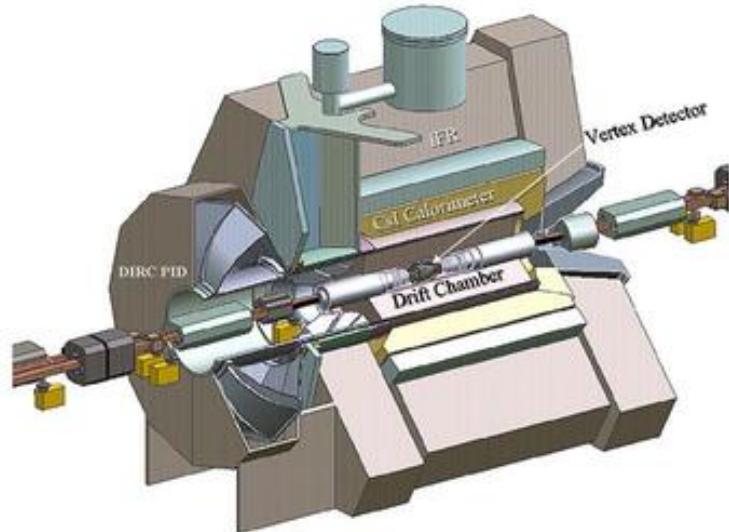
7 Runs over the course of 9 years



- First collisions with BaBar May 26, 1999
- Final data taken 12:43 p.m., April 7, 2008

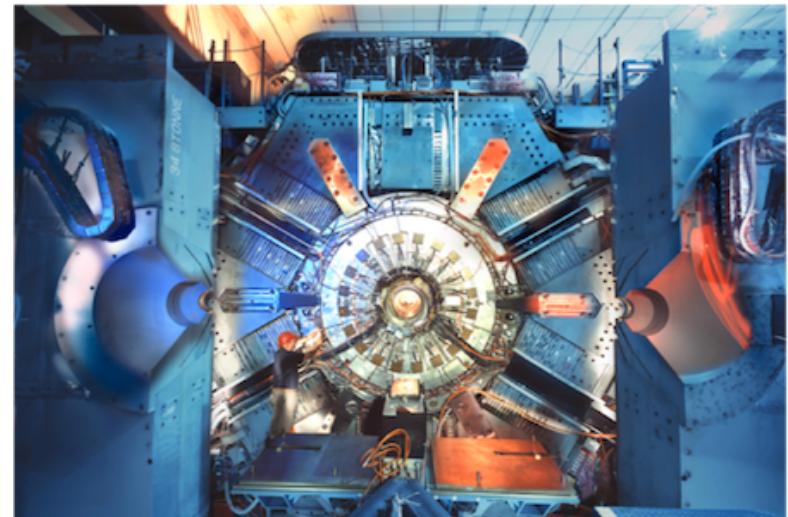


The *BABAR* Experiment at SLAC



- Primarily designed for study of CP -violation in B meson decays
- Quality and general-purpose design make it suitable for a large variety of studies

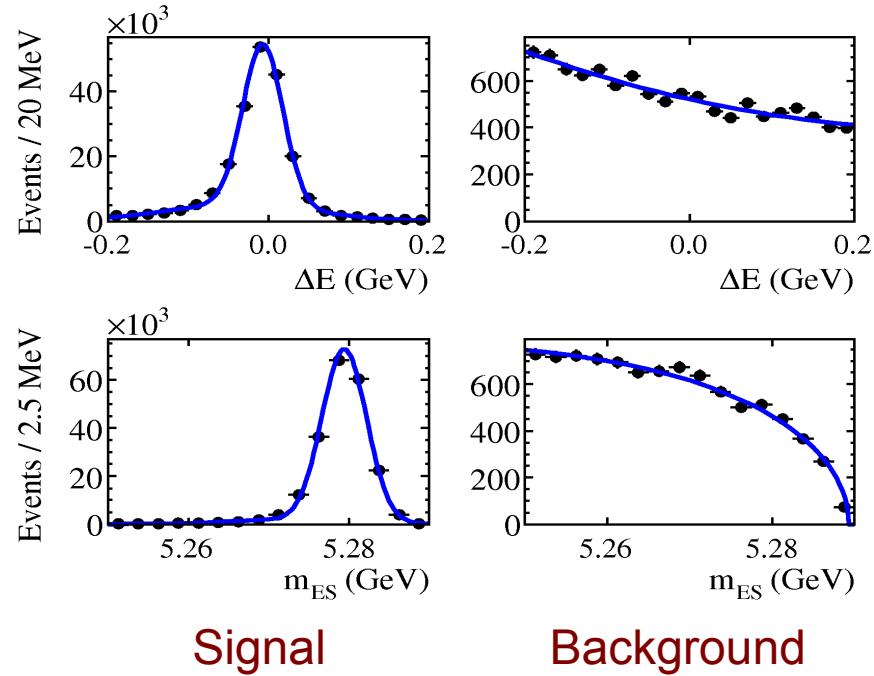
- Asymmetric-energy beams for boost
- Modern/state of the art detector
- 5 cylindrical subdetectors with a 40-layer drift chamber
- Excellent electromagnetic calorimetry
- Multiple measurements for particle identification
- Excellent momentum resolution



Kinematics of B Decays

- Fully reconstructed B mesons: two variables are commonly used (exploiting the precise knowledge of the beam energy):

$$\Delta E = E_{meas} - E_{beam}$$



$$m_{ES} = \sqrt{E_{beam}^2 - \mathbf{p}_{meas}^2}$$

- Dominant background: $q\bar{q}$ ($q = u, d, s, c$), exhibiting a jet-like topology ($B\bar{B}$ events are more “spherical”). We separate/suppress the continuum background, combining several variables sensitive to the event shape into a Fisher discriminant.

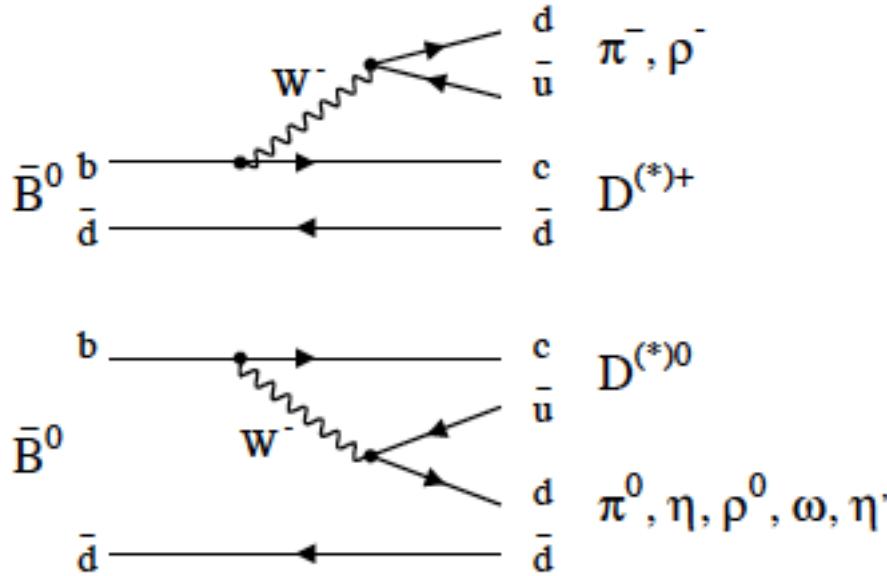


$$\bar{B}^0 \rightarrow D^{(*)0} h^0$$

$$h^0 : \pi^0, \eta, \omega, \eta'$$

arXiv: 1107.5751

New Result! To be submitted to Phys Rev D



- All-neutral modes involve color-suppressed internal W diagrams to highest order
- Large branching fractions point to non-factorizable contributions

Leganger & Eeg, PRD 82,
074007 (2010)

Strong interactions in final state (FSI) can modify decay dynamics

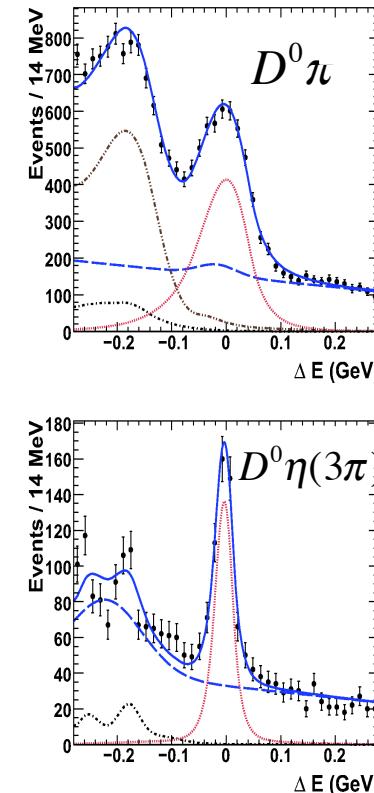
- Perturbative QCD (pQCD) e.g.: Keum *et al*, PRD 69, 094018(2004); Lu PRD 68, 097502 (2003)
- Soft Collinear Effective Theory (SCET)
e.g.: Bauer, *et al.*, PRD 65, 054022(2002); Mantry, *et al.*, PRD 68, 114009(2003);
Blechman, *et al.*, PLB 608, 77 (2005)

$$\bar{B}^0 \rightarrow D^{(*)0} h^0$$

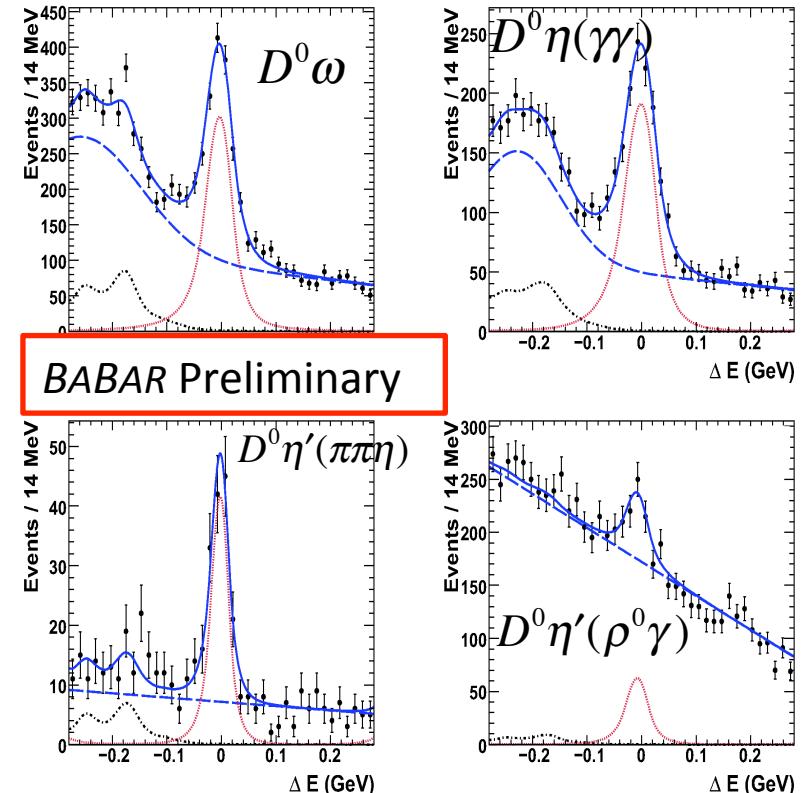
New!



- $\bar{B}^- \rightarrow D^{(*)0} h^-$; $h^- = \pi^-, \rho^-$
used in data and MC as control sample
- Cross-feed estimated with an iterative procedure
- Signal yields extracted with an unbinned maximum likelihood fit to the variable ΔE



D^0 modes



BABAR Preliminary

Data Sample: $454 \times 10^6 \bar{B}\bar{B}$ pairs

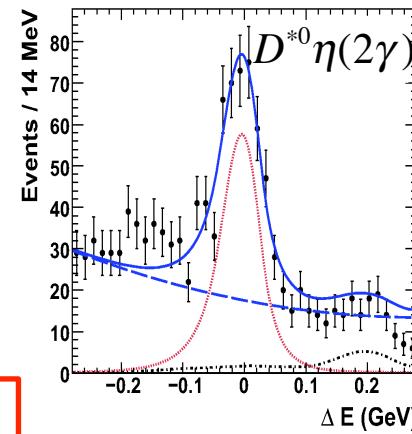
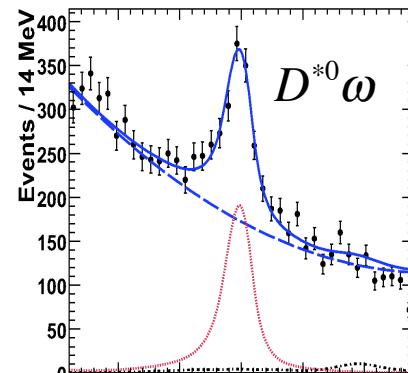
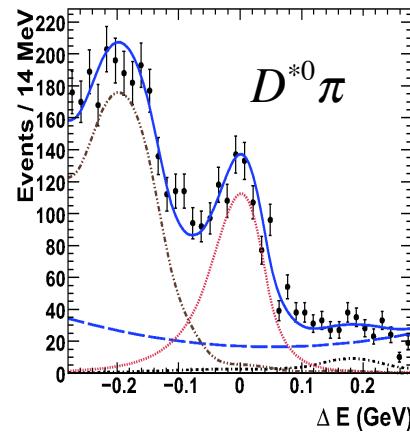


$$\bar{B}^0 \rightarrow D^{(*)0} h^0$$



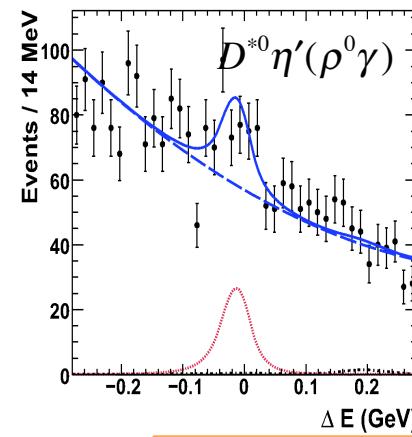
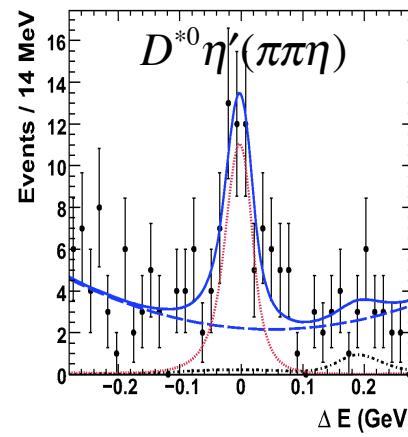
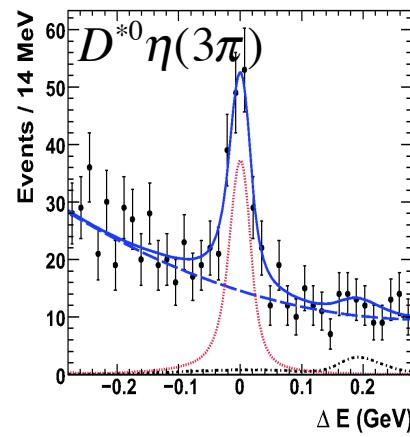
New!

D^{*0} modes



$D^{*0} \rightarrow D^0 \pi^0,$
 $D^0 \gamma$

BABAR Preliminary



D^0 reconstructed in
multiple modes

Data Sample: $454 \times 10^6 BB$ pairs



$$\bar{B}^0 \rightarrow D^{(*)0} h^0$$

New!

- Branching fractions consistent with other experiments
- $\mathcal{B}(\bar{B}^0 \rightarrow D^{*0} h^0) / \mathcal{B}(\bar{B}^0 \rightarrow D^0 h^0)$ is consistent with 1, to within 30%, as predicted by SCET – disagrees with pQCD

BABAR Preliminary

	$\mathcal{B}(\bar{B}^0 \rightarrow) (\times 10^{-4})$
$D^0\pi^0$	$2.69 \pm 0.09 \pm 0.13$
$D^{*0}\pi^0$	$3.05 \pm 0.14 \pm 0.28$
$D^0\eta$	$2.53 \pm 0.09 \pm 0.11$
$D^{*0}\eta$	$2.69 \pm 0.14 \pm 0.23$
$D^0\omega$	$2.57 \pm 0.11 \pm 0.14$
$D^{*0}\omega$	$4.55 \pm 0.24 \pm 0.39$
$D^0\eta'$	$1.48 \pm 0.13 \pm 0.07$
$D^{*0}\eta'$	$1.48 \pm 0.22 \pm 0.13$

To be submitted to Phys Rev D

2011 Aug 12

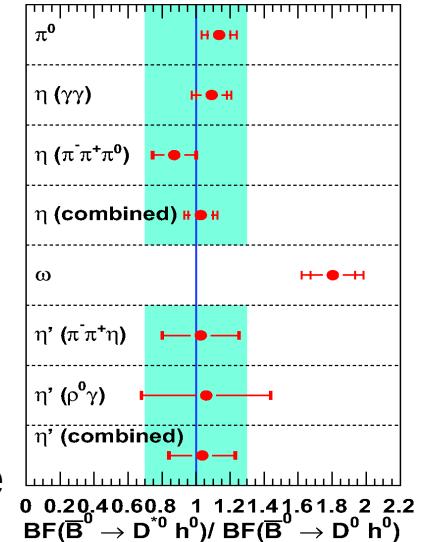
BaBar Hadronic B Decays - Brown, DPF2011

- For the $D^{*0}\omega$ mode, also measure longitudinal polarization

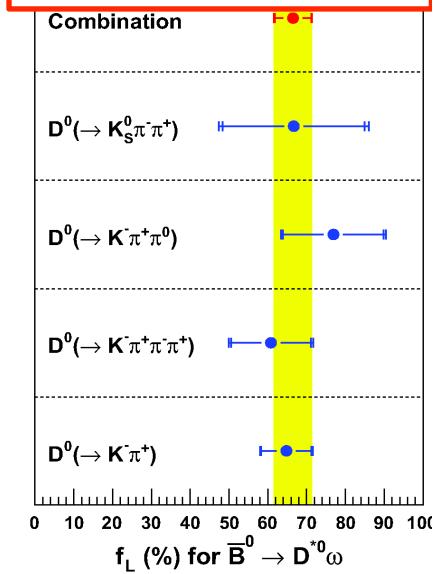
- Reconstruction efficiency
- SCET long-range contributions reduce longitudinal polarization

Result: $f_L = (66.5 \pm 4.7 \pm 1.5)\%$

- Much lower than HQET predictions



BABAR Preliminary





$$\bar{B} \rightarrow \bar{D}^{(*)} D^{(*)} K$$

PRD-RC 83, 032004 (2011)



$\bar{B} \rightarrow \bar{D}^{(*)} D^{(*)} K$



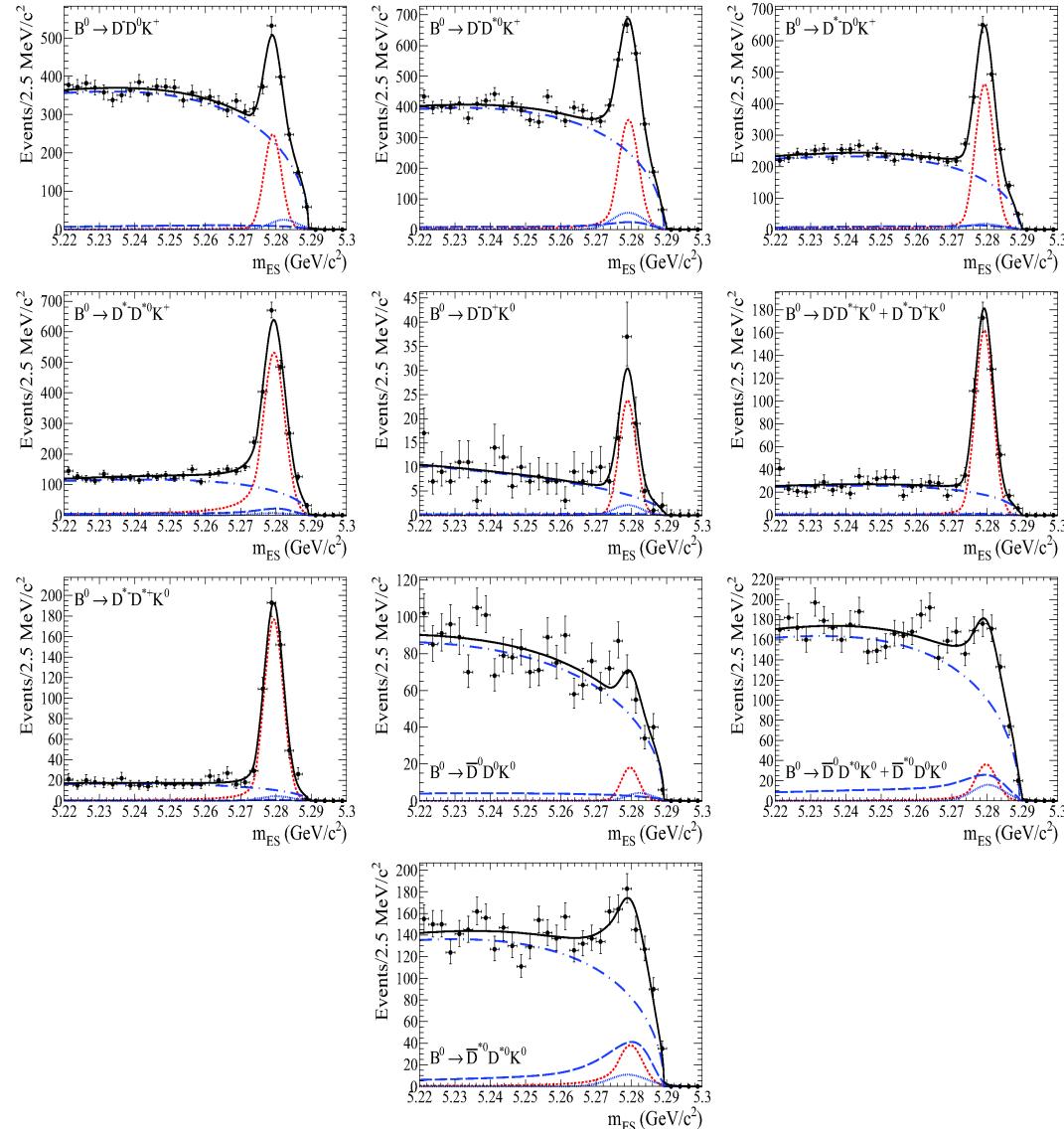
- Motivation: $B \rightarrow D^{(*)} D^{(*)} K$ decays have a sizable branching fraction (a few %), important to account for the inclusive hadronic branching fraction
- Several different amplitudes, important to verify that the pattern matches the predictions
- 22 decay modes:** since cross-feed is an issue it is fundamental to measure all the branching fractions in the same analysis
- Events selected with tight cuts on the masses of the intermediate resonances and ΔE
- Signal extracted through an unbinned ML fit on the m_{ES} variable.

Neutral B mode	Charged B mode
$B^0 \rightarrow D^- D^0 K^+$	$B^+ \rightarrow \bar{D}^0 D^+ K^0$
$B^0 \rightarrow D^- D^{*0} K^+$	$B^+ \rightarrow \bar{D}^0 D^{*+} K^0$
$B^0 \rightarrow D^{*-} D^0 K^+$	$B^+ \rightarrow \bar{D}^{*0} D^+ K^0$
$B^0 \rightarrow D^{*-} D^{*0} K^+$	$B^+ \rightarrow \bar{D}^{*0} D^{*+} K^0$
$B^0 \rightarrow D^- D^+ K^0$	$B^+ \rightarrow \bar{D}^0 D^0 K^+$
$B^0 \rightarrow D^- D^{*+} K^0 + D^{*-} D^+ K^0$	$B^+ \rightarrow \bar{D}^0 D^{*0} K^+$
	$B^+ \rightarrow \bar{D}^{*0} D^0 K^+$
$B^0 \rightarrow D^{*-} D^{*+} K^0$	$B^+ \rightarrow \bar{D}^{*0} D^{*0} K^+$
$B^0 \rightarrow \bar{D}^0 D^0 K^0$	$B^+ \rightarrow D^- D^+ K^+$
$B^0 \rightarrow \bar{D}^0 D^{*0} K^0 + \bar{D}^{*0} D^0 K^0$	$B^+ \rightarrow D^- D^{*+} K^+$
	$B^+ \rightarrow D^{*-} D^+ K^+$
$B^0 \rightarrow \bar{D}^{*0} D^{*0} K^0$	$B^+ \rightarrow D^{*-} D^{*+} K^+$

$$\bar{B} \rightarrow \bar{D}^{(*)} D^{(*)} K$$

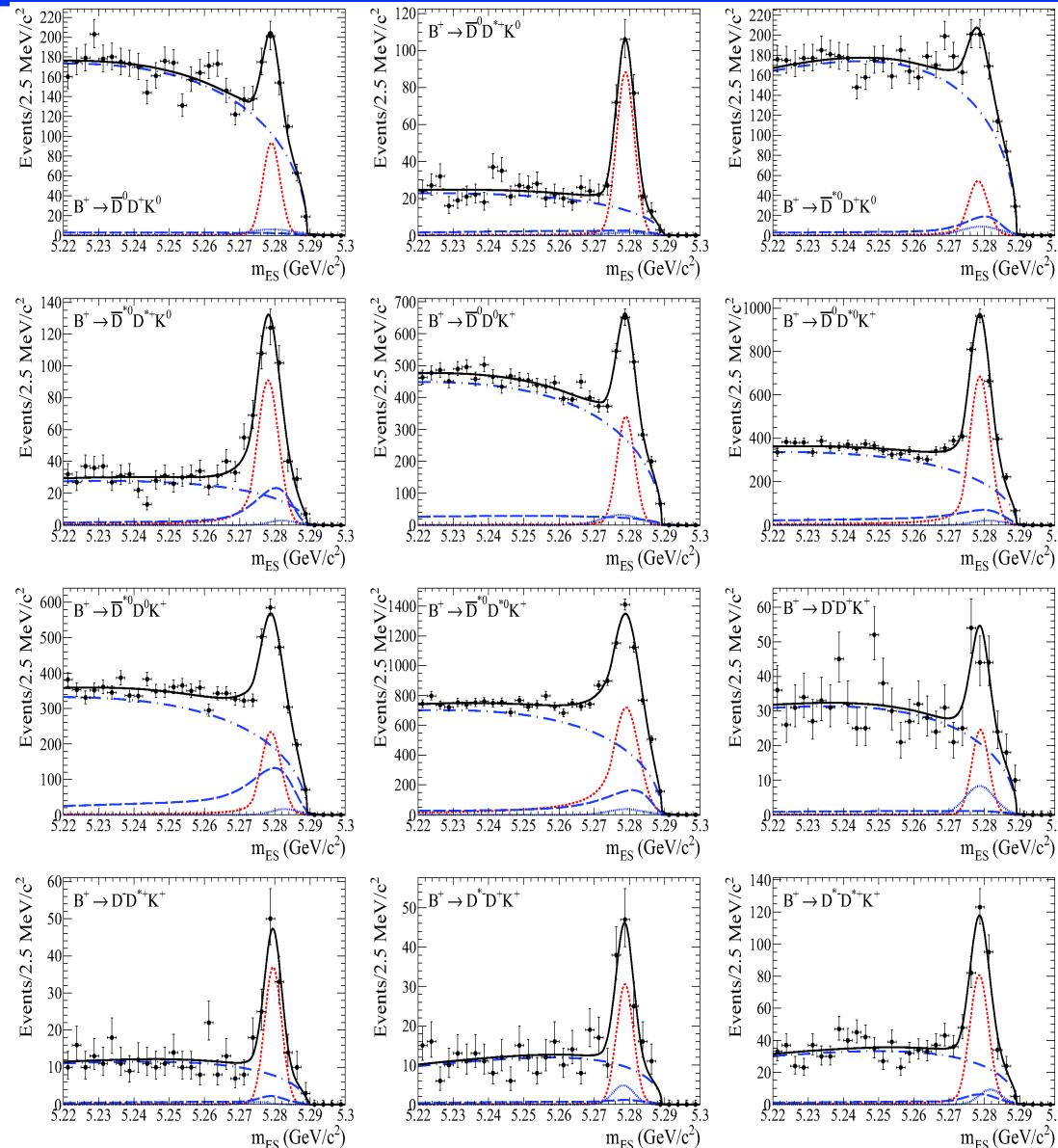


Neutral modes





$\bar{B} \rightarrow \bar{D}^{(*)} D^{(*)} K$



Charged modes



$\bar{B} \rightarrow \bar{D}^{(*)} D^{(*)} K$



- The amount of cross-feed in each channel is obtained with an iterative procedure which takes into account the branching fractions of all the other channels in the previous iteration;
- The peaking background is fixed using the MC predictions;
- Some decays proceed through resonances: in computing the BF's we take into account the variations of efficiency across the $D^{(*)}D^{(*)}K$ Dalitz Plot;
- Combining all modes:

$$\text{BF}(B^0 \rightarrow D^{(*)}D^{(*)}K) = (3.68 \pm 0.10 \pm 0.24)\%$$
$$\text{BF}(B^+ \rightarrow D^{(*)}D^{(*)}K) = (4.05 \pm 0.11 \pm 0.28)\%$$

PRD-RC 83, 032004 (2011)

- No evidence of isospin breaking has been observed.



$B \rightarrow baryons$

$\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$

and

$B \rightarrow D^{(*)} p\bar{p}(\pi)(\pi)$

To be submitted to PRD-RC

New!

To be submitted to PRD



$B \rightarrow baryons$

- $\text{BF}(B \rightarrow \text{baryons}) \sim 7\%$, but the sum of the known modes accounts for $\sim 1\%$
- In general, $B \rightarrow \text{baryons}$ decays are poorly understood theoretically, the study of as many exclusive decay modes as possible may provide insight on the different decay mechanisms
- $B \rightarrow \text{baryons}$ decays may provide evidence of new or poorly known resonances
- Threshold enhancement in the baryon-antibaryon invariant mass has been observed in several cases
- Today:

$$\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$$

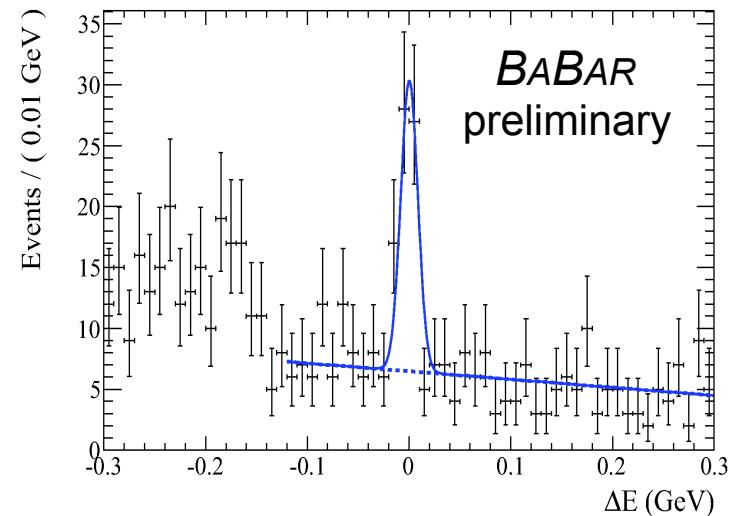
$$B \rightarrow D^{(*)} p \bar{p} (\pi)(\pi)$$

$$\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$$

New!



- Search for decay $\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$ with $\Lambda_c^+ \rightarrow p K^- \pi^+$, $\bar{\Lambda} \rightarrow \bar{p} \pi^+$
- Fit to ΔE yields signal of size 51 ± 9 events
- 8σ significance
- Peaking background from $\bar{B}^0 \rightarrow \Lambda_c^+ \bar{p} K^- \pi^+$ reduced by 99.6% with cut on $\bar{\Lambda}$ vertex distance of 0.4 cm. Remaining background from this mode estimated ~ 0.1 event. Same cut reduces combinatoric background 18%



Data Sample: $471 \times 10^6 B\bar{B}$ pairs

Charge conjugates implied

$\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-$

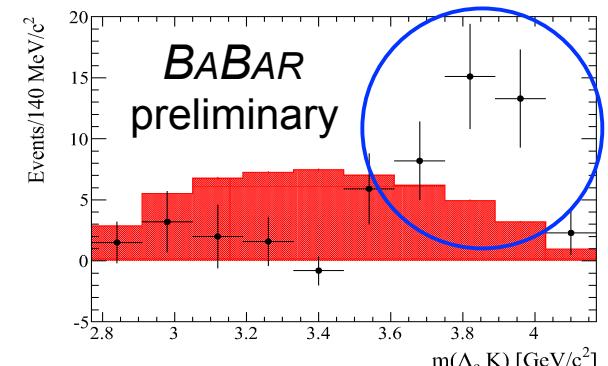
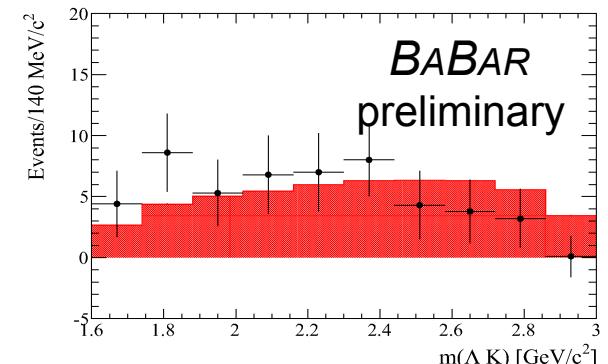
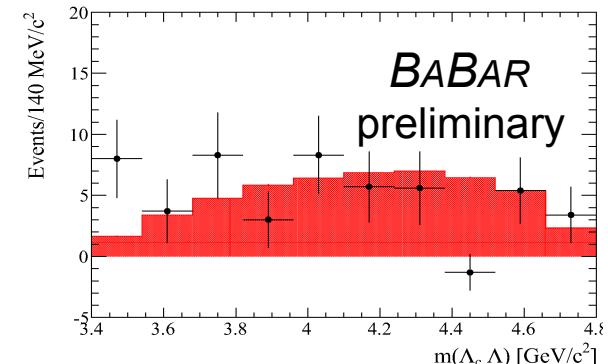

New!

- In the measurement of the branching fraction, the efficiency is corrected accounting for the distribution of the invariant masses that we observe on the data
- Within signal region, look at two-body invariant masses of decay products, note enhancement at high mass for $(\Lambda_c^+ K^-)$
- Result:

BABAR
preliminary

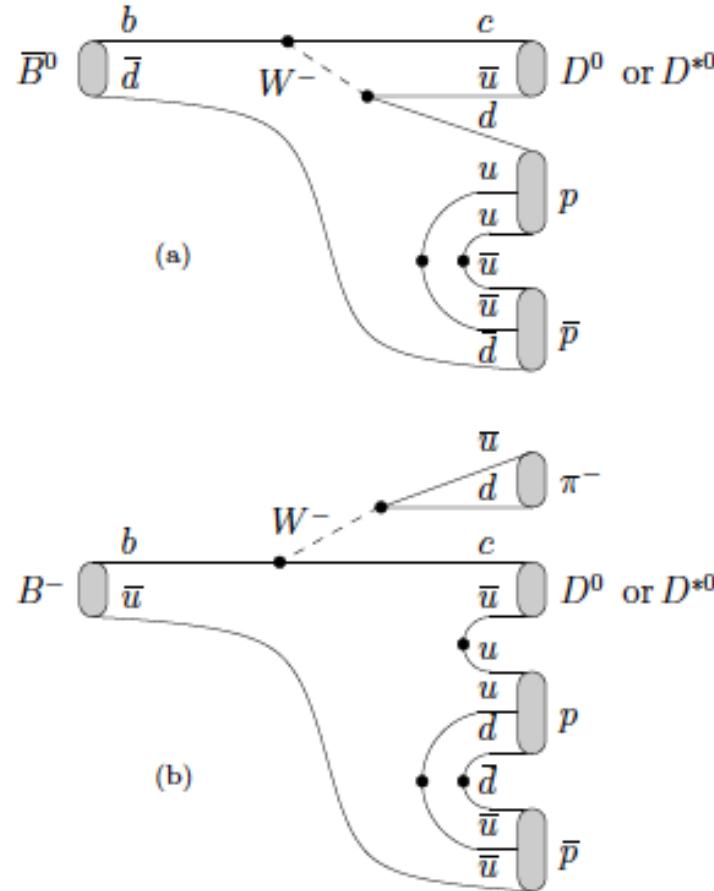
$$\mathcal{B}(\bar{B}^0 \rightarrow \Lambda_c^+ \bar{\Lambda} K^-) = (3.8 \pm 0.9_{\text{stat}} \pm 0.2_{\text{sys}} \pm 1.0_{\Lambda_c^+}) \times 10^{-5}$$

To be submitted to PRD-RC





New!



Charge conjugates implied

- Investigate branching fraction dependence on number of final state hadrons
- Total of 10 modes in 26 decay chains investigated
- Six modes not previously observed

$$\bar{B}^0 \rightarrow D^{(*)0} p\bar{p}$$

$$\bar{B}^0 \rightarrow D^{(*)+} p\bar{p}\pi^-$$

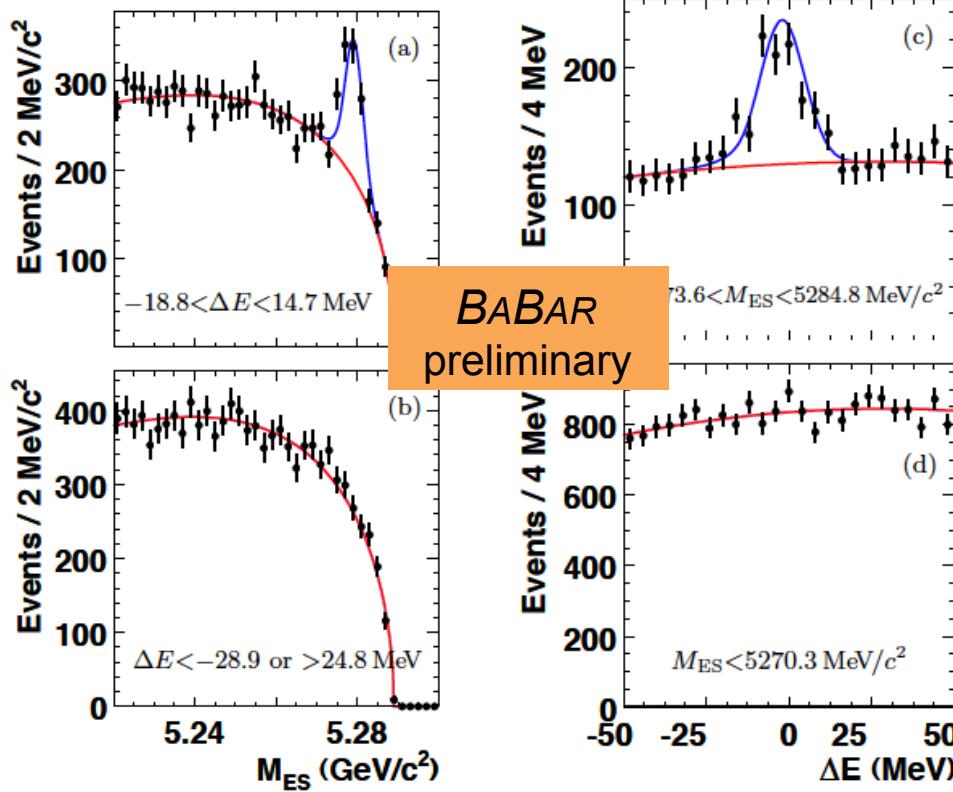
$$B^- \rightarrow D^{(*)0} p\bar{p}\pi^-$$

$$\bar{B}^0 \rightarrow D^{(*)0} p\bar{p}\pi^-\pi^+$$

$$B^- \rightarrow D^{(*)+} p\bar{p}\pi^-\pi^-$$

$B \rightarrow D^{(*)} p\bar{p}(\pi)(\pi)$


New!



- First observation for six modes – all 10 now observed

<i>N</i> -body	<i>B</i> -meson decay mode	$\mathcal{B} \pm \sigma_{\text{stat}} \pm \sigma_{\text{syst}}$ (10^{-4})
Three-body	$\bar{B}^0 \rightarrow D^0 p\bar{p}$	$1.02 \pm 0.04 \pm 0.06$
	$\bar{B}^0 \rightarrow D^{*0} p\bar{p}$	$0.97 \pm 0.07 \pm 0.09$
Four-body	$\bar{B}^0 \rightarrow D^+ p\bar{p}\pi^-$	$3.32 \pm 0.10 \pm 0.29$
	$\bar{B}^0 \rightarrow D^{*+} p\bar{p}\pi^-$	$4.55 \pm 0.16 \pm 0.39$
Five-body	$\bar{B}^0 \rightarrow D^0 p\bar{p}\pi^-\pi^+$	$3.72 \pm 0.11 \pm 0.25$
	$\bar{B}^0 \rightarrow D^{*0} p\bar{p}\pi^-\pi^+$	$3.73 \pm 0.17 \pm 0.27$
" "	$\bar{B}^0 \rightarrow D^+ p\bar{p}\pi^-\pi^-$	$2.99 \pm 0.21 \pm 0.45$
	$\bar{B}^0 \rightarrow D^{*+} p\bar{p}\pi^-\pi^-$	$1.91 \pm 0.36 \pm 0.29$
" "	$B^- \rightarrow D^0 p\bar{p}\pi^-\pi^+$	$1.66 \pm 0.13 \pm 0.27$
	$B^- \rightarrow D^{*0} p\bar{p}\pi^-\pi^-$	$1.86 \pm 0.16 \pm 0.19$

$$\mathcal{B}_{\text{3-body}} < \mathcal{B}_{\text{5-body}} < \mathcal{B}_{\text{4-body}}$$

Data Sample: $455 \times 10^6 B\bar{B}$ pairs

Charge conjugates implied



Summary

- *BABAR* continues producing interesting and competitive results.
- Hadronic B decays provide important information for constraining QCD models.
- Better precision will be gained from next generation of experiments.

