Hadronic B Decays

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- B to Single Charm
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- Summary

Introduction

- Motivation
  - Provide large data sample to search for indirect or direct CP violation
  - Study on hadronic B decays help understand the underlying quark decay mechanism.
  - Measured exclusive branching fractions are a small fraction of the inclusive one.

- Experimental Technique

	$\Upsilon(4S)$	LEP, CDF, SLD
B Idenf.	$M_{bc}(M_{ES})$ ΔE	Reconstructed mass
Bkg. Supp.	Various event shape variables	Distinct decay vertex
	$R_2, \cos\theta_B$,helicity ...	large B momentum
	PID.	Di-leptons (CDF)

- Summarize recent results mainly from B factory experiments
  - CLEO (9.7 M $B\bar{B}$); Belle (23 M $B\bar{B}$); BaBar (23 M $B\bar{B}$)

B Decays to Charmonium

- Extensive studies were made to study two body B decays to charmonium: $J/\psi \to l^+l^-, \psi(2S) \to l^+l^-, \psi(2S) \to J/\psi\pi^+\pi^-, \chi_{c1} \to J/\psi\gamma$
- Some were used to study CP violation and some were for calibration. **See $\sin 2\phi_1(2\beta)$ talks given by Jan Stark, Martin Sevior and Zhi-zhong Xing**

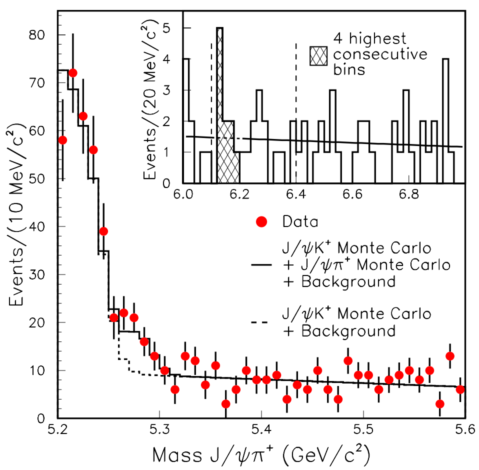
Channel	BaBar ($\times 10^{-4}$)	Belle ($\times 10^{-4}$)	Previous ($\times 10^{-4}$)
$B^0 \to J/\psi K^0 (K^0_S \to \pi^+\pi^-)$	$8.5 \pm 0.5 \pm 0.6$	$7.7 \pm 0.4 \pm 0.7$	9.6 ± 0.9 *
$(K^0_S \to \pi^0\pi^0)$	$9.6 \pm 1.5 \pm 0.7$	-	-
K^0_L	$6.8 \pm 0.8 \pm 0.8$	-	-
All	$8.3 \pm 0.4 \pm 0.5$	-	-
$B^+ \to J/\psi K^+$	$10.1 \pm 0.3 \pm 0.5$	$10.1 \pm 0.3 \pm 0.8$	10.1 ± 1.0 *
$B^0 \to \psi(2S) K^0$ (l^+l^-)	-	$6.0 \pm 1.1 \pm 0.7$	-
$(J/\psi\pi^+\pi^-)$	-	$7.2 \pm 1.1 \pm 1.1$	-
All	$6.9 \pm 1.1 \pm 1.1$	-	5.0 ± 1.3 ◊
$B^+ \to \psi(2S) K^+$ (l^+l^-)	-	$6.7 \pm 0.6 \pm 0.7$	-
$(J/\psi\pi^+\pi^-)$	-	$5.7 \pm 0.5 \pm 0.8$	-
All	$6.4 \pm 0.5 \pm 0.8$	-	5.8 ± 1.0 *
$B^0 \to \chi_{c1} K^0$	$5.4 \pm 1.4 \pm 1.1$	$3.1 \pm 0.9 \pm 0.4$	$3.9^{+1.9}_{-1.4}$ *
$B^+ \to \chi_{c1} K^+$	$7.5 \pm 0.8 \pm 0.8$	$6.1 \pm 0.6 \pm 0.6$	10.0 ± 4.0 *
$B^0 \to \chi_{c1} K^{*0}$	$4.8 \pm 1.4 \pm 0.9$	-	< 21 *

* PDG (http://pdg.lbl.gov); ◊ CLEO Collaboration PRD 63, 031003 (2001).

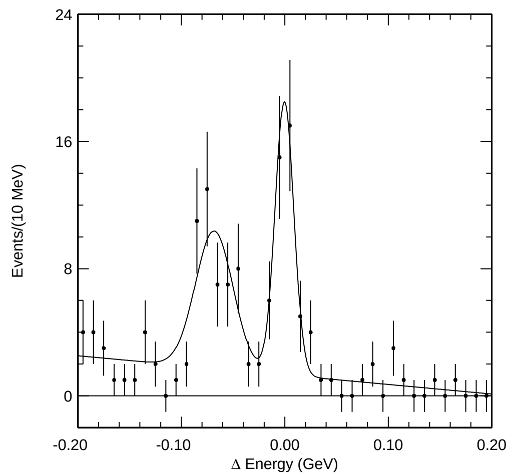
Measurement of $B \to J/\psi\pi$

Channel	BaBar ($\times 10^{-4}$)	Belle ($\times 10^{-4}$)	Previous ($\times 10^{-4}$)
$B^0 \to J/\psi\pi^0$	$0.20 \pm 0.06 \pm 0.02$	$0.24 \pm 0.06 \pm 0.02$	$0.25^{+0.11}_{-0.09}$
$B^+ \to J/\psi\pi^+$	0.39 ± 0.08	$0.52 \pm 0.07 \pm 0.07$	0.51 ± 0.15

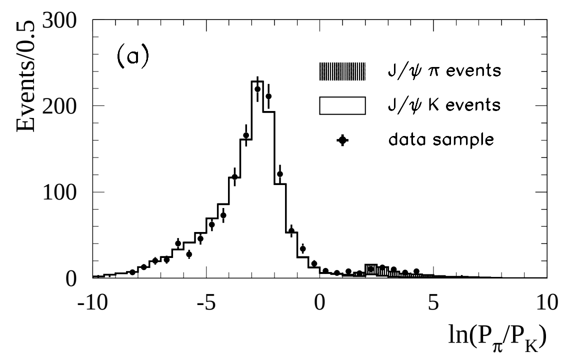
- Both Cabbibo suppressed and color suppressed $\Rightarrow$ could have large direct CP violation
- Provide a good test for factorization. 5% of Cabbibo allowed decays



CDF, 28^{+10}_{-9}



Belle, 45.3 ± 6.9



BaBar, 52 ± 10

- Experimental results agree with factorization hypothesis: $Br(B^+ \to J/\psi\pi^+)/Br(B^+ \to J/\psi K^+) \sim 5\%$.
- Support SU(3) symmetry: $Br(B^+ \to J/\psi\pi^+) \sim 2 \times Br(B^0 \to J/\psi\pi^0)$.

Polarization in $B \to J/\psi K^*$

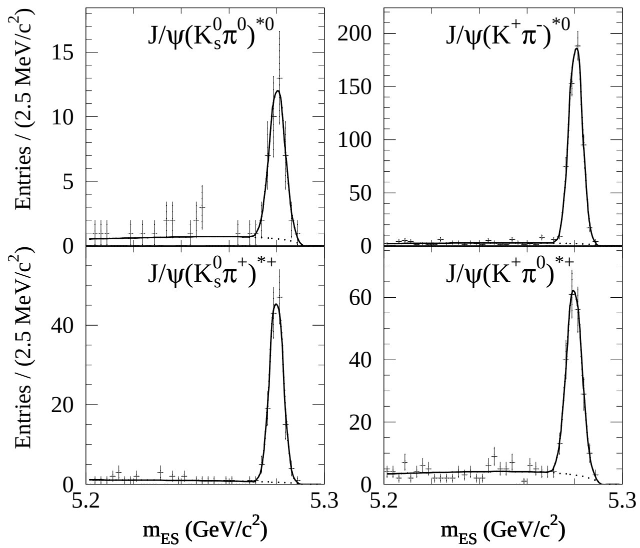
- Pseudo-scalar to vector-vector decays have orbital angular momentum 0, 1, 2.
  Three decay amplitudes govern the transition
- Measure $\sin 2\phi_1(\beta)$ using the decay, $B^0 \to J/\psi K^{*0}, K^{*0} \to K_S^0 \pi^0$
  Need angular information to extract the CP content
- Provide a test of factorization hypothesis
  The decay amplitudes should have relative phase 0 or π $\to$ No final state interactions
- Reconstruct $K^{*0} \to K^+\pi^-, K_S^0\pi^0,$
  $K^{*+} \to K^+\pi^0, K_S^0\pi^+$

	$Br(B^0 \to J/\psi K^{*0})$ (10^{-3})	$Br(B^+ \to J/\psi K^{*+})$ (10^{-3})
CLEO	$1.32 \pm 0.15 \pm 0.17$	$1.41 \pm 0.20 \pm 0.24$
BaBar	$1.24 \pm 0.05 \pm 0.08$	$1.37 \pm 0.09 \pm 0.11$
Belle	$1.25 \pm 0.06 \pm 0.08$	$1.29 \pm 0.08 \pm 0.12$

* BaBar and Belle results are preliminary

- Decay amplitudes have been measured by CLEO, CDF, BaBar and Belle.

BaBar

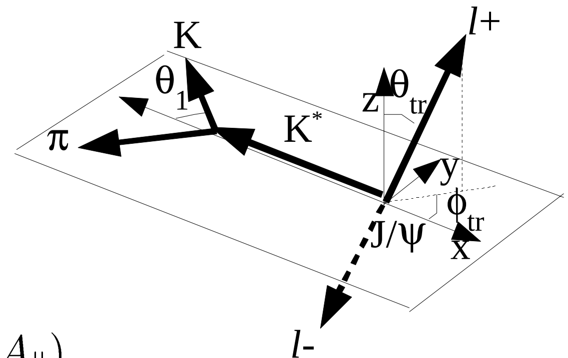


$B \to J/\psi K^*$ Cont.

- Express in transversity basis:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{tr}d\cos\theta_1 d\phi} = \frac{9}{32\pi}\times$$

$$[2\cos^2\theta_1(1-\sin^2\theta_{tr}\cos^2\phi_{tr})|A_0|^2$$
$$+\sin^2\theta_1(1-\sin^2\theta_{tr}\sin^2\phi_{tr})|A_\parallel|^2$$
$$+\sin^2\theta_1\sin^2\phi_{tr}|A_\perp|^2$$
$$+\sin^2\theta_1\sin^2\phi_{tr}\sin^2\phi_{tr}Im(A_\parallel^* A_\perp)$$
$$+\frac{1}{\sqrt{2}}\sin 2\theta_1\sin^2\phi_{tr}\sin 2\phi_{tr}Re(A_0^* A_\parallel)$$
$$-\frac{1}{\sqrt{2}}\sin 2\theta_1\sin 2\theta_{tr}\cos\phi_{tr}Im(A_0^* A_\perp)]$$



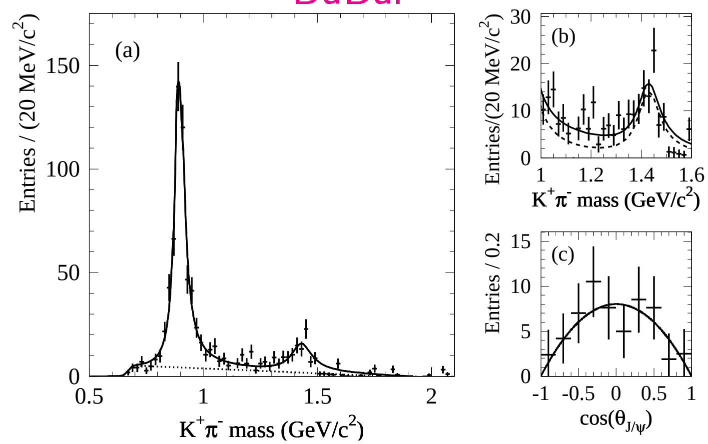
$$|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$$

- $|A_0|$ is the lognitudinal polarization of J/ψ
- $|A_\perp|$ is the CP odd components for $J/\psi K^{*0}(K^{*0}\to K^0_S\pi^0)$
- Four parameters from the fit: $|A_0|^2, |A_\perp|^2, arg(A_\parallel), arg(A_\perp).$

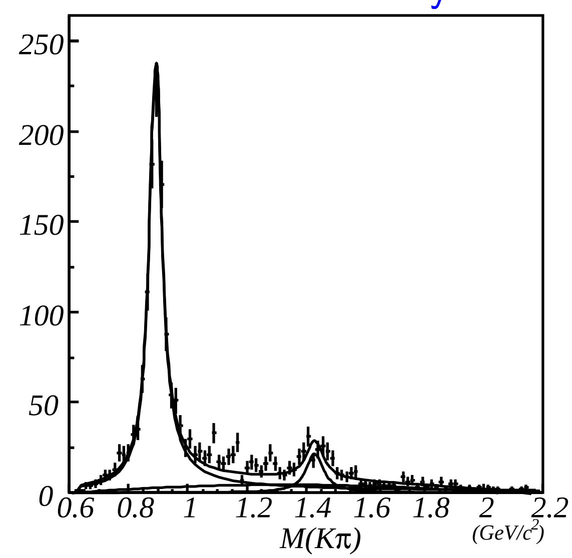
Results on $B \to J/\psi K^*$

- Observe higher mass $K\pi$ state ($K_2^*(1430)$) by BaBar and Belle
- Besides $K^*(892)$ and $K_2^*(1430)$, there exists a S-wave (non-resonant) contribution. Estimate the non-resonant contribution in $K^*(892)$ region from $K^*(892)$ sideband.
- Perform an un-binned likelihood on events with PDFs from signals, combinatoric background, feed-down component and non-resonant part.
- Assign 100% error on non-resonant contribution (BaBar and Belle)
- CDF used $K^{*0} \to K^+\pi^-$ decays only but also studied $B_s \to J/\psi\phi$.

BaBar



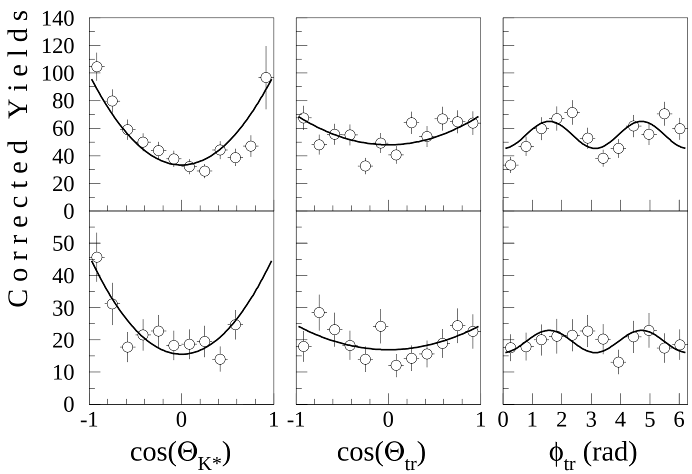
Belle Preliminary



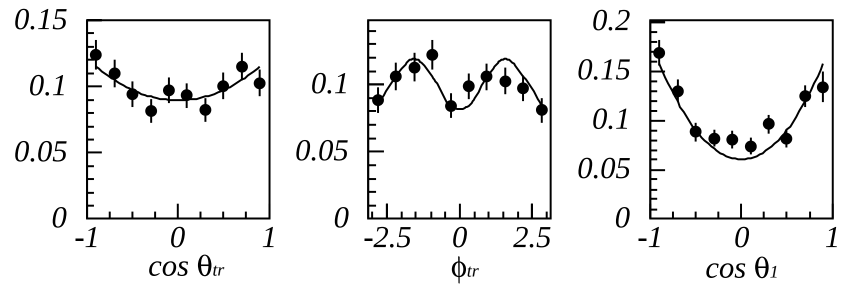
Polarization Results

	$\|A_0\|^2$	$\|A_\perp\|^2$	$arg(A_\parallel)$	$arg(A_\perp)$
CLEO	$0.52 \pm 0.07 \pm 0.04$	$0.16 \pm 0.08 \pm 0.04$	$3.00 \pm 0.37 \pm 0.04$	$-0.11 \pm 0.46 \pm 0.03$
CDF	$0.59 \pm 0.06 \pm 0.01$	$0.13^{+0.12}_{-0.09} \pm 0.06$	$2.2 \pm 0.5 \pm 0.1$	$-0.6 \pm 0.5 \pm 0.1$
BaBar	$0.60 \pm 0.03 \pm 0.02$	$0.16 \pm 0.03 \pm 0.01$	$2.50 \pm 0.20 \pm 0.08$	$-0.17 \pm 0.16 \pm 0.07$
Belle	$0.60 \pm 0.03 \pm 0.04$	$0.19 \pm 0.04 \pm 0.04$	$2.86 \pm 0.25 \pm 0.05$	$0.01 \pm 0.19 \pm 0.08$
CDF $(J/\psi\phi)$	$0.61 \pm 0.14 \pm 0.02$	$0.23 \pm 0.19 \pm 0.04$	$1.1 \pm 1.3 \pm 0.2$	-

BaBar



Belle Preliminary

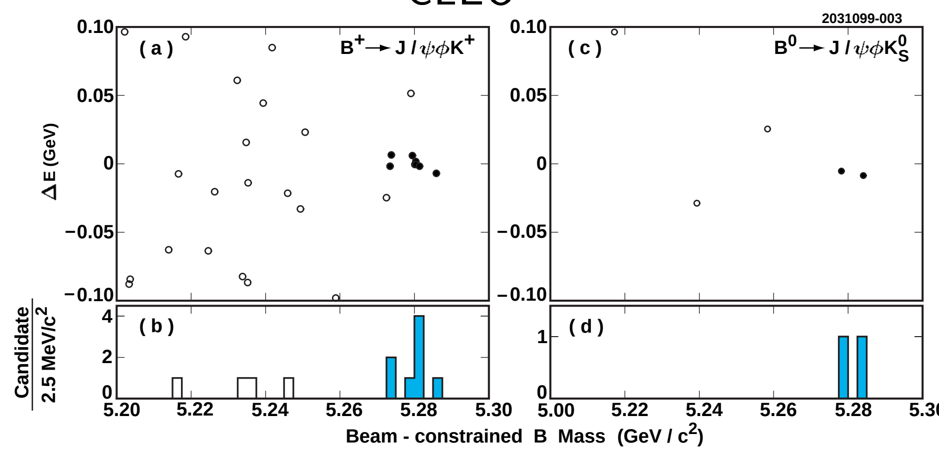


- Results on four experiments are consistent with each other.
- Lognitudal polarization ($|A_0|^2 = \frac{\Gamma_L}{\Gamma}$) is dominant; parity-odd fraction is small.
- $arg(A_\parallel)$ seems to be differ from π, indicating the presence of final state interactions.

Observation of $B \to J/\psi \phi K$, $B^+ \to \chi_{c0} K^+$

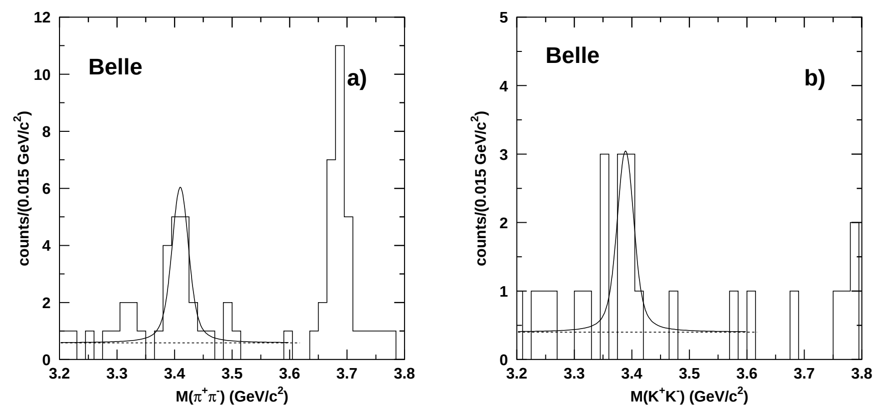
- Observe $B \to J/\psi \phi K$ by CLEO
  1. Need additional $s\bar{s}$ quark pair
  2. Reconst. $\phi \to K^+K^-$ with dE/dx
  3. Assume uniform Dalitz distribution and isotropic decays of J/ψ and ϕ
  4. $Br = (8.8^{+3.5}_{-3.0} \pm 1.3) \times 10^{-5}$

CLEO



- Observe $B^+ \to \chi_{c0} K^+$ by Belle
  1. Identify B candidates in $K^+\pi^+\pi^-$ and $K^+K^+K^-$ channels.
  2. Clear peaks in $\chi_{c0} \to \pi^+\pi^-$ and $\chi_{c0} \to K^+K^-$. Second Peak in a) corresponds to $\psi(2S) \to \mu^+\mu^-$
  3. Normalize to $B^+ \to J/\psi K^+$
  4. $Br = (6.0^{+2.1}_{-1.8} \pm 1.1) \times 10^{-4}$

Belle

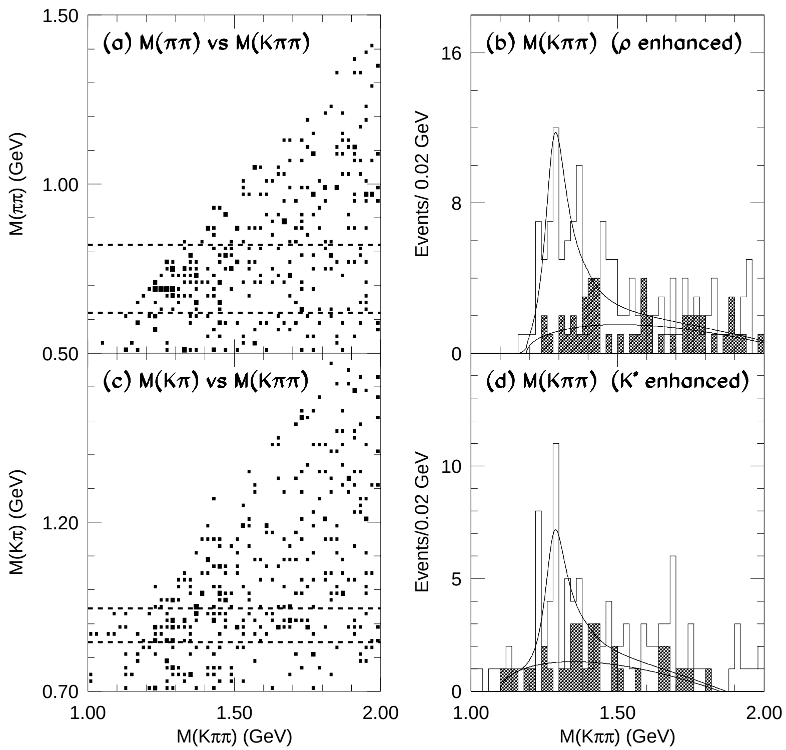


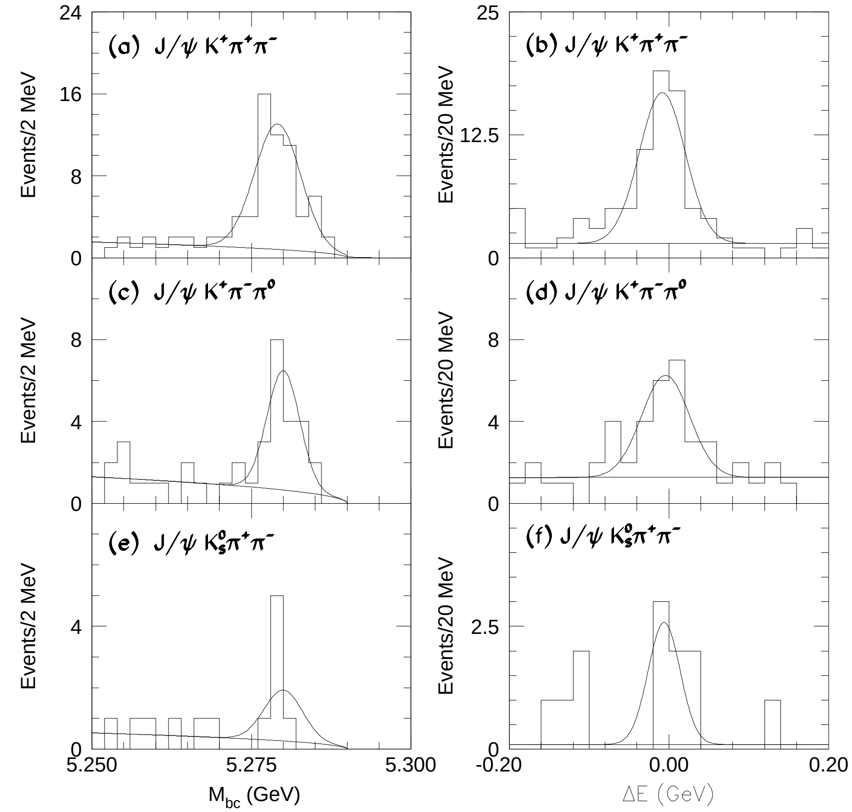
Observation of $B \to J/\psi K_1(1270)$

- Observe $B \to J/\psi K_1(1270)$ by Belle

  Consider $J/\psi K^+\pi^+\pi^-, J/\psi K^+\pi^-\pi^0, J/\psi K^0\pi^+\pi^-$

Belle





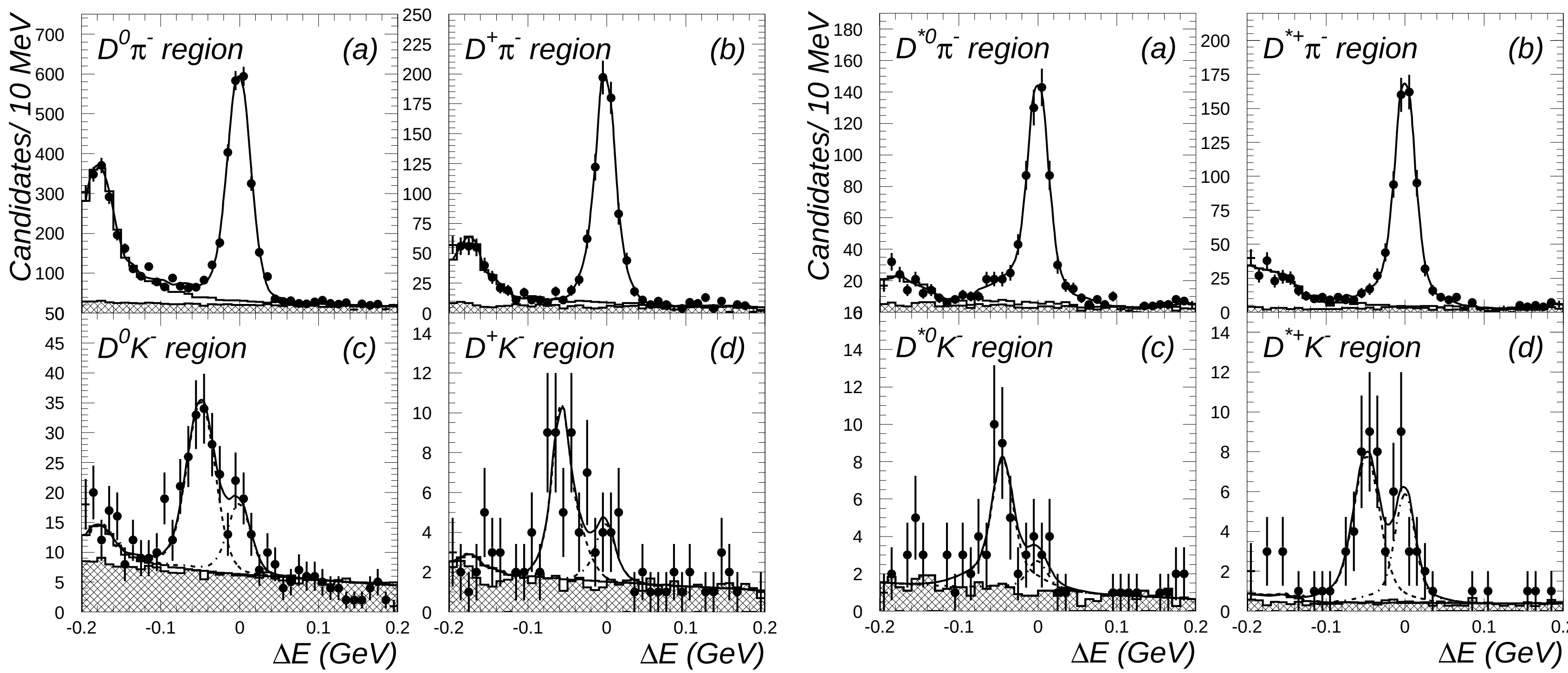
- $Br(B^0 \to J/\psi K_1^0(1270)) = (1.30 \pm 0.34 \pm 0.32) \times 10^{-3}$
- $Br(B^+ \to J/\psi K_1^+(1270)) = (1.80 \pm 0.34 \pm 0.39) \times 10^{-3}$
- $Br(B^+ \to J/\psi K_1^+(1400))/Br(B^+ \to J/\psi K_1^+(1270)) < 0.3$

B Decays to Single Charm

- Observation of Cabbibo Suppressed Decays (Belle, 11.1 M $B\bar{B}$)
- Naive Tree Level Expectation

$$R_C \equiv \frac{Br(B \to D^{(*)}K^-)}{Br(B \to D^{(*)}\pi^-)} \simeq \tan^2\theta_C (f_K/f_\pi)^2 \sim 0.074$$

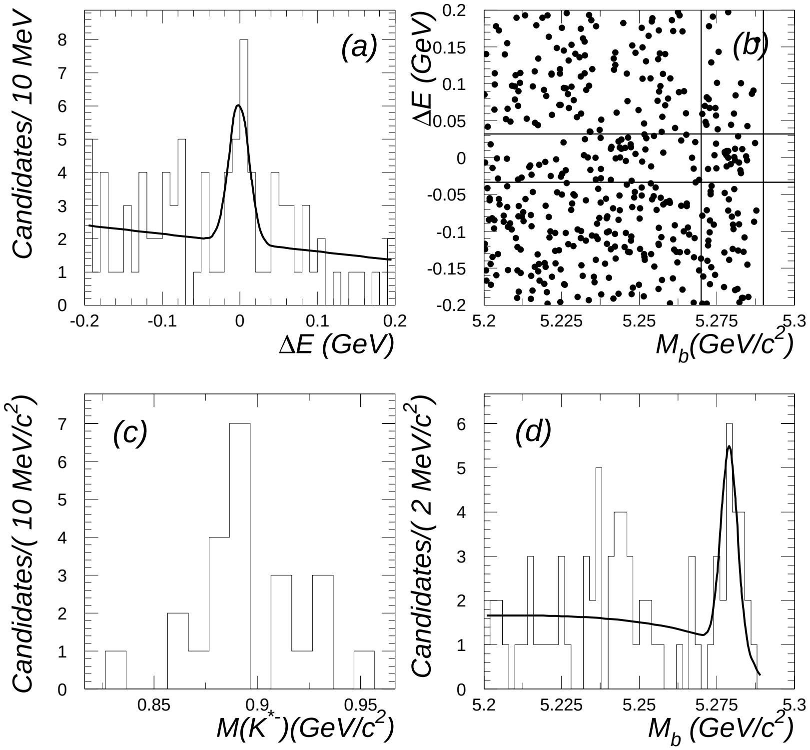
$$R'_C \equiv \frac{Br(B^- \to D^0 K^{*-})}{Br(B^- \to D^0\pi^-)} = \frac{Br(B^- \to D^0 K^{*-})}{Br(B^- \to D^0 K^-)} \frac{Br(B^- \to D^0 K^-)}{Br(B^- \to D^0\pi^-)} \sim 0.19$$



$B \to D^{(*)}\pi^-, D^{(*)}K^-$, *Belle*

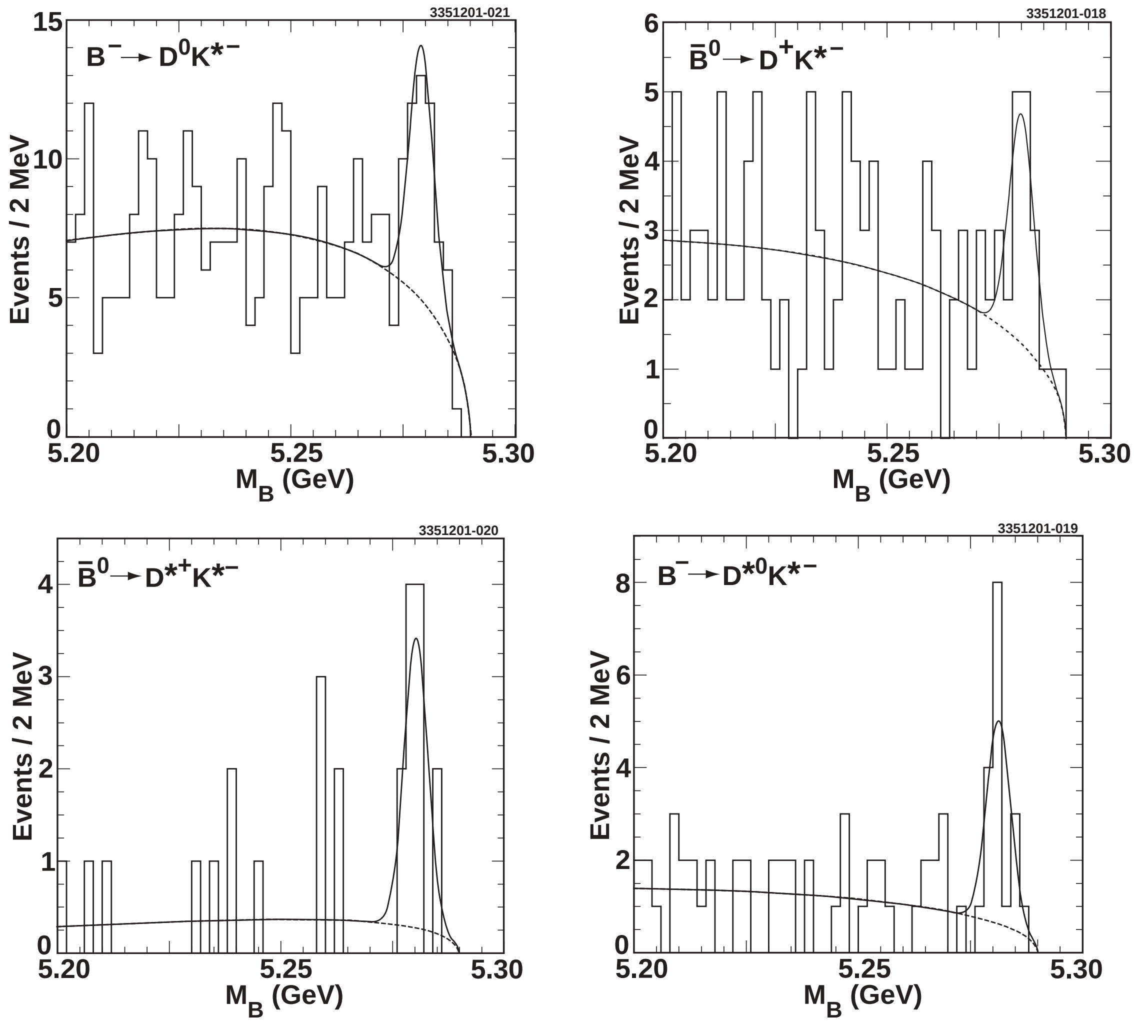
	PID(K)<0.8	PID(K)>0.8		Sig.	Br(DK)/Br($D\pi$)
	$N(D\pi)$	$N(DK)$	$N(D\pi)$		
D^0h^-	2402.8 ± 97.8	135.7 ± 15.6	49.0 ± 11.3	11.3	$0.0770 \pm 0.0094 \pm 0.0058$
D^+h^-	681.9 ± 32.1	32.9 ± 7.3	10.1 ± 4.9	6.0	$0.066 \pm 0.015 \pm 0.007$
$D^{*0}h^-$	584.8 ± 32.4	32.3 ± 7.7	6.5 ± 4.9	5.7	$0.076 \pm 0.019 \pm 0.009$
$D^{*+}h^-$	640.9 ± 30.8	35.4 ± 7.1	20.6 ± 5.7	7.5	$0.072 \pm 0.015 \pm 0.006$

- Ratio agrees with theoretical prediction. Earlier CLEO result (3.3 M $B\bar{B}$):
  $Br(D^0K^-)/Br(D^0\pi^-)$
  $= 0.055 \pm 0.015 \pm 0.005$
- First observation of $\bar{B}^0 \to D^+K^-$, $B^- \to D^{*0}K^-, \bar{B}^0 \to D^{*+}K^-$
- First observation of $B^- \to D^0K^{*-}$
  1. Reconstruct $K^{*-} \to K^0_S\pi^-$
  2. $N = 15.0 \pm 4.6$
  3. Br($B^- \to D^0K^{*-}$)/Br($B^- \to D^0\pi^-$) $= 0.116 \pm 0.036 \pm 0.015$



Observation of $\bar{B} \to D^{(*)} K^{*-}$, CLEO

- Reconstruct $D^{*0} \to D^0\pi^0, D^0\gamma, \quad D^{*+} \to D^0\pi^+, \quad K^{*-} \to K^0_S\pi^-$
- Fit M_{bc} to obtain singal yields.



- $\mathcal{B}(B^- \to D^0K^{*-}) = (6.1\pm1.6\pm1.7)\times10^{-4}$
- $\mathcal{B}(\bar{B}^0 \to D^+K^{*-}) = (3.7\pm1.5\pm1.0)\times10^{-4}$
- $\mathcal{B}(\bar{B}^0 \to D^{*+}K^{*-}) = (3.8\pm1.3\pm0.8)\times10^{-4}$
- $\mathcal{B}(B^- \to D^{*0}K^{*-}) = (7.7\pm2.2\pm2.6)\times10^{-4}$
- $\frac{\mathcal{B}(B\to D^*K^{*-})}{\mathcal{B}(B\to D^*\rho^{*-})} \sim 5\%$ consistent with $|\frac{V_{us}}{V_{ud}}|^2(\frac{f_{K^{*-}}}{f_{\rho^{*-}}})^2$

Direct CPV on $B^- \to D_{CP}K^-$, Belle

- Extract $\phi_3(\gamma)$ from $B^- \to D^0_{1,2}K^-$, D_1 and D_2 are CP even and CP odd eigenstates.
- Ignore $D^0 - \bar{D}^0$ mixing:

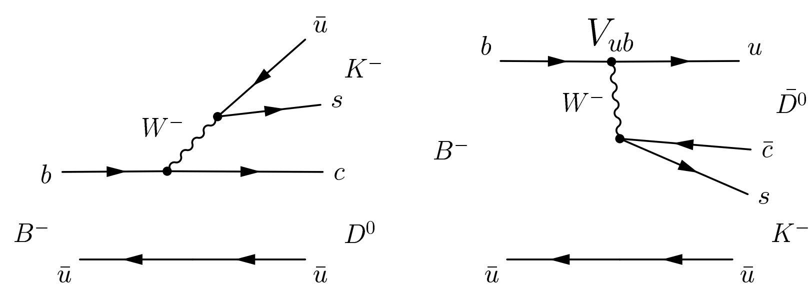
$$A_{1,2} = \frac{\mathcal{B}(B^- \to D_{1,2}K^-) - \mathcal{B}(B^+ \to D_{1,2}K^+)}{\mathcal{B}(B^- \to D_{1,2}K^-) + \mathcal{B}(B^+ \to D_{1,2}K^+)} = \frac{2r\sin\delta'\sin\phi_3}{1 + r^2 + 2r\cos\delta'\cos\phi_3}$$

$$R_{1,2} = \frac{\frac{\mathcal{B}(B^- \to D_{1,2}K^-)+\mathcal{B}(B^+ \to D_{1,2}K^+)}{\mathcal{B}(B^- \to D_{1,2}\pi^-)+\mathcal{B}(B^+ \to D_{1,2}\pi^+)}}{\frac{\mathcal{B}(B^- \to D^0K^-)+\mathcal{B}(B^+ \to D^0K^+)}{\mathcal{B}(B^- \to D^0\pi^-)+\mathcal{B}(B^+ \to D^0\pi^+)}} = 1 + r^2 + 2r\cos\delta'\cos\phi_3$$

$$\delta' = \begin{cases} \delta & \text{for } D_1 \\ \delta + \pi & \text{for } D_2 \end{cases},$$

where r is the ratio of amplitudes, $r \equiv A(B^- \to \bar{D}^0K^-)/A(B^- \to D^0K^-)$;

δ is the strong phase. Interference between $b \to c$ and $b \to u$



Results on $B^- \to D_{CP}K^-$, Belle

Preliminary

	CP $+$	CP $-$
A_{CP}	$A_1 = 0.29^{+0.29}_{-0.24} \pm 0.05$ $-0.14 < A_1 < 0.79$	$A_2 = -0.22^{+0.26}_{-0.22} \pm 0.04$ $-0.60 < A_2 < 0.21$
R_{CP}	$R_1 = 1.38 \pm 0.38 \pm 0.15$	$R_2 = 1.37 \pm 0.36 \pm 0.12$

CP $+$: $K^+K^-, \pi^+\pi^-$

CP $-$: $K_s\pi^0, K_s\omega, K_s\eta, K_s\eta'$

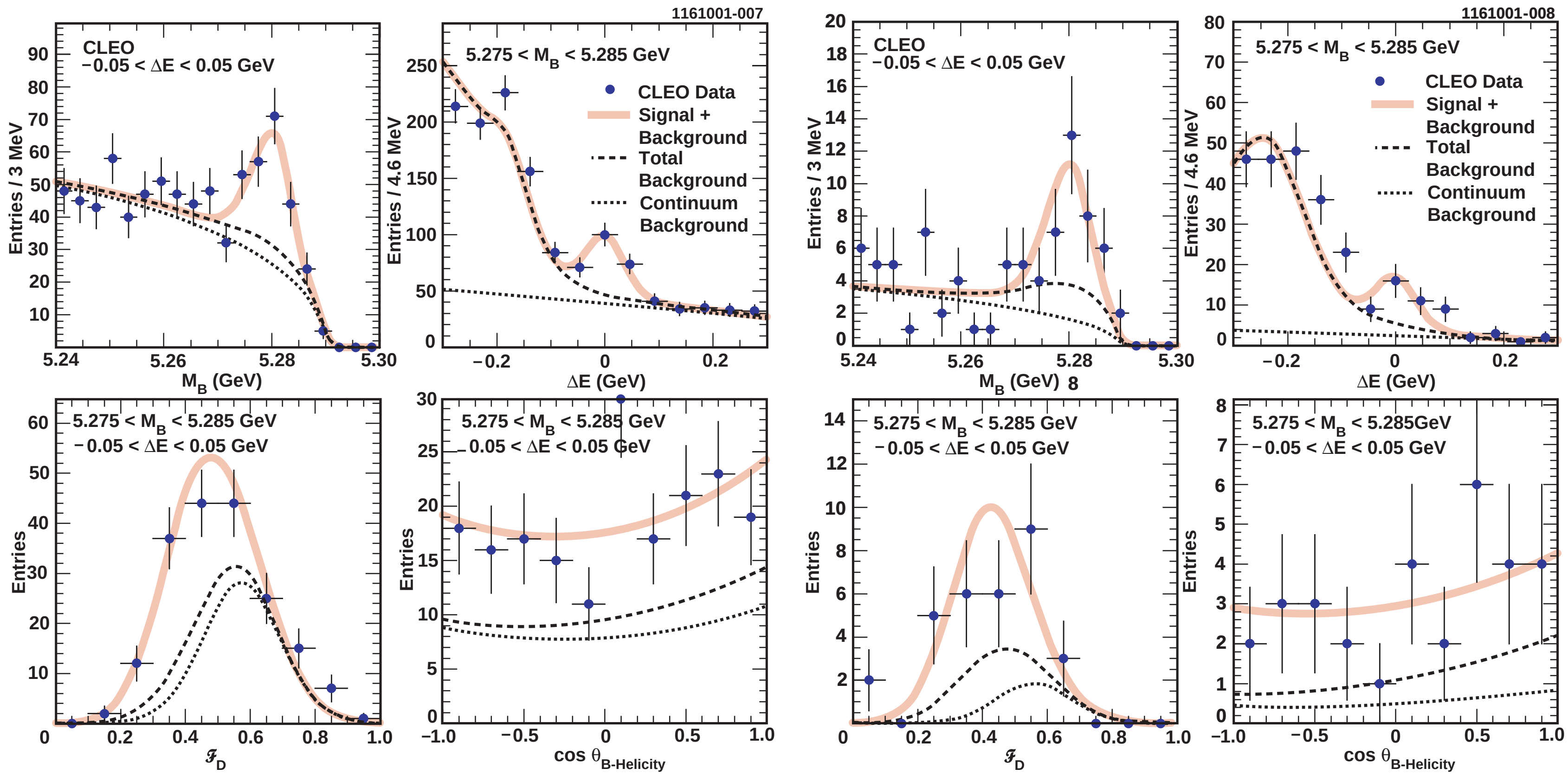
Data sample: 29.1 fb^{-1}

$$\Rightarrow \frac{R_{1,2}}{2}(1 - \sqrt{1 - A_{1,2}^2}) \leq \sin^2\phi_3 \leq \frac{R_{1,2}}{2}(1 + \sqrt{1 - A_{1,2}^2}) \leq R_{1,2}$$

Provide a constraint to ϕ_3 in the future with more data.

Observation of Color Suppressed Decays

- CLEO results on $\bar{B}^0 \to D^0\pi^0, D^{*0}\pi^0$
  1. Multivariable unbinned maximum likelihood fit
  2. Large bkg. in both M_{bc} and ΔE
  3. Signal Yields: N$(D^0\pi^0) = 124.2^{+15.7}_{-15.0}$ (12.1σ), N$(D^{*0}\pi^0) = 28.5^{+7.3}_{-6.5}$ (5.9σ).



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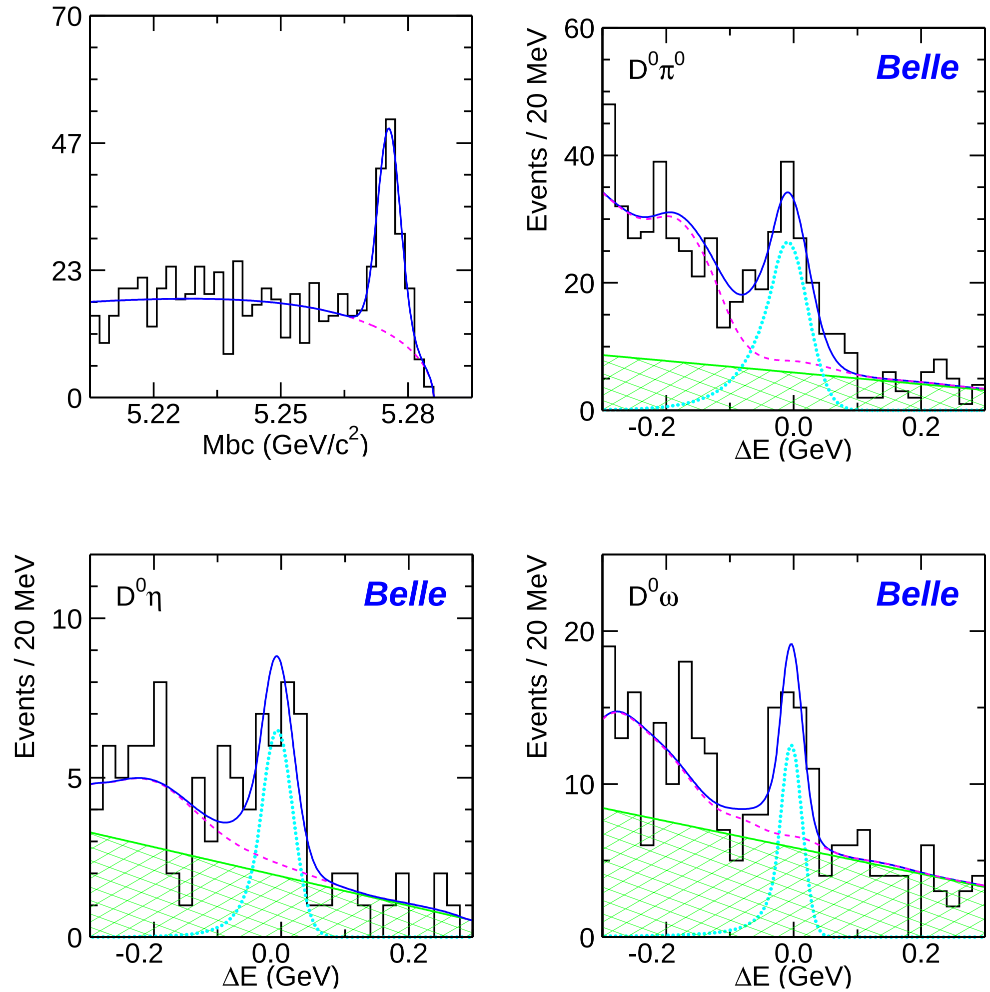
Belle Results on Color Suppressed Decays

- Observe significant yields on $\bar{B}^0 \to D^0\pi^0, D^0\eta, D^0\omega$
- Obtain $B\bar{B}$ background from MC; Fit ΔE to obtain signal yields.

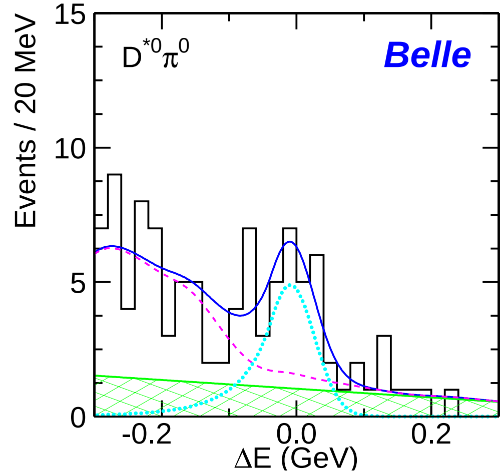
1. $D^0\pi^0$
   $N = 126.2^{+16.1+7.2}_{-15.5-5.2}$
   Sig. $= 9.3\ \sigma$
2. $D^0\eta$
   $N = 22.1^{+7.0+2.0}_{-6.3-1.8}$
   sig. $= 4.2\ \sigma$
3. $D^0\omega$
   $N = 32.5^{+9.4+4.0}_{-8.6-3.1}$
   sig. $= 4.4\ \sigma$



Color Suppressed Cont.

- Significant signal yields observed in $\overline{B} \to D^{*0}\pi^0$, $D^{*0}\eta$, or $D^{*0}\omega$.

- Yields =
  $D^{*0}\pi^0$: $26.4\ ^{+7.7}_{-7.1}\ ^{+1.6}_{-2.2}\ (4.1\sigma)$
  $D^{*0}\eta$: $7.8\ ^{+3.6}_{-3.0} \pm 0.7\ (3.3\sigma)$
  $D^{*0}\omega$: $16.1\ ^{+6.8}_{-6.0} \pm 2.4\ (3.0\sigma)$



Branching Fraction $(\times 10^{-4})$

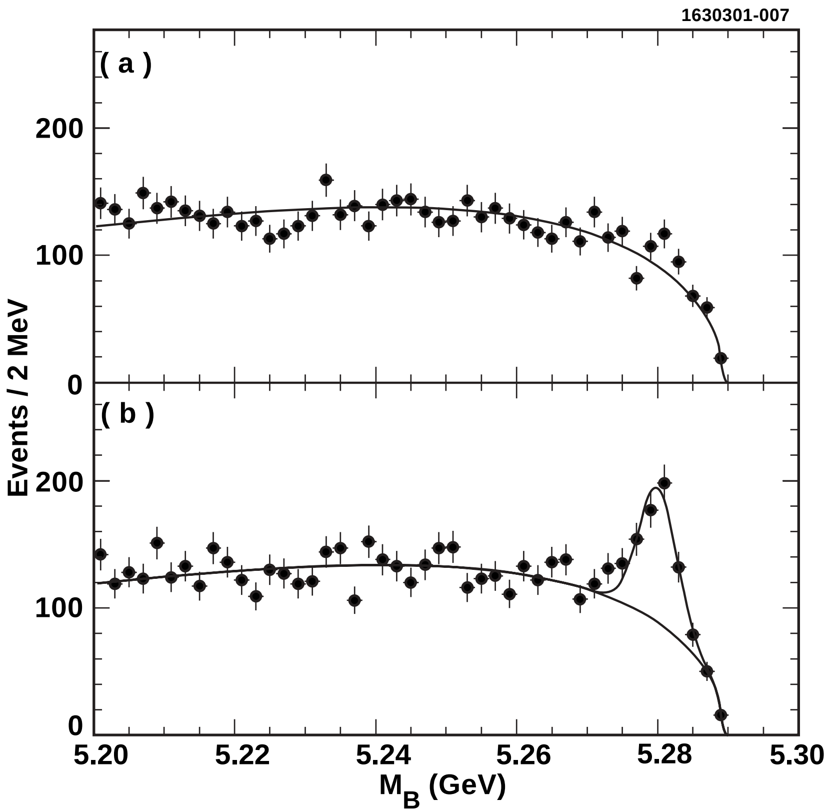
Mode	Belle	UL	CLEO 98	CLEO 01	TH
$D^0\pi^0$	$3.1 \pm 0.4 \pm 0.5$	–	< 1.2	$2.6 \pm 0.3 \pm 0.6$	0.7
$D^{*0}\pi^0$	$2.7\ ^{+0.8}_{-0.7}\ ^{+0.5}_{-0.6}$	–	< 4.4	$2.0 \pm 0.5 \pm 0.7$	1.0
$D^0\eta$	$1.4\ ^{+0.5}_{-0.4} \pm 0.3$	–	< 1.3	–	0.5
$D^{*0}\eta$	$2.0\ ^{+0.9}_{-0.8} \pm 0.4$	< 4.6	< 2.6	–	0.6
$D^0\omega$	$1.8 \pm 0.5\ ^{+0.4}_{-0.3}$	–	< 5.1	–	0.7
$D^{*0}\omega$	$3.1\ ^{+1.3}_{-1.1} \pm 0.8$	< 7.9	< 7.4	–	1.7

- Need additional corrections to the model:

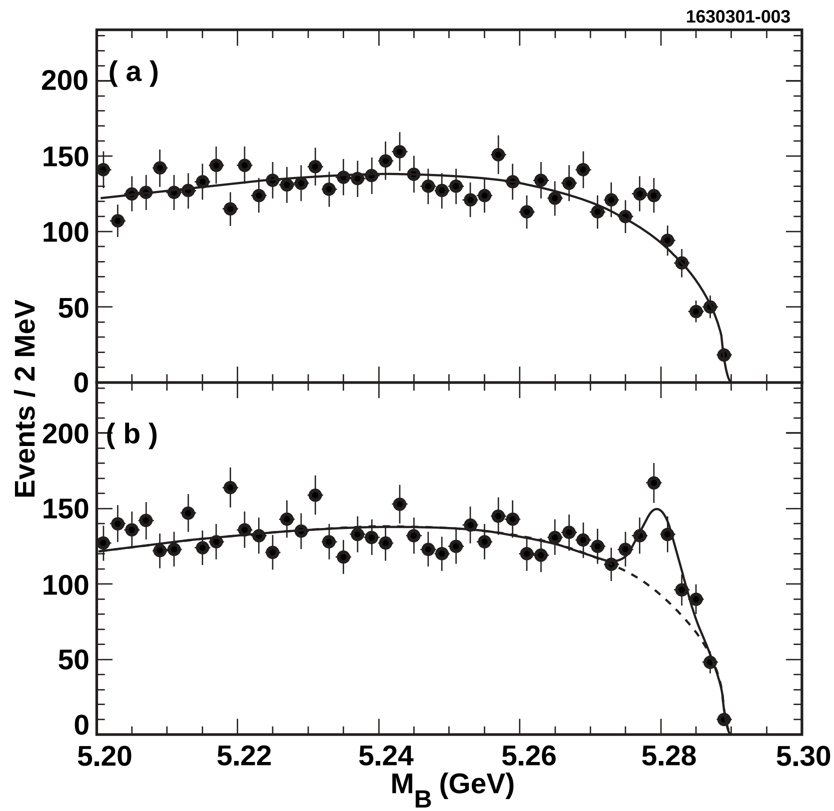
  class-2 a_2 is process dependent or final state rescatterings.

$B \to D^* 4\pi$, CLEO

- $\overline{B}^0 \to D^{*+}\pi^+\pi^-\pi^-\pi^0$
  - $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$
  - Obtain eff. as a function of 4π mass
  - $\mathcal{B} = (1.72 \pm 0.14 \pm 0.24)\%$



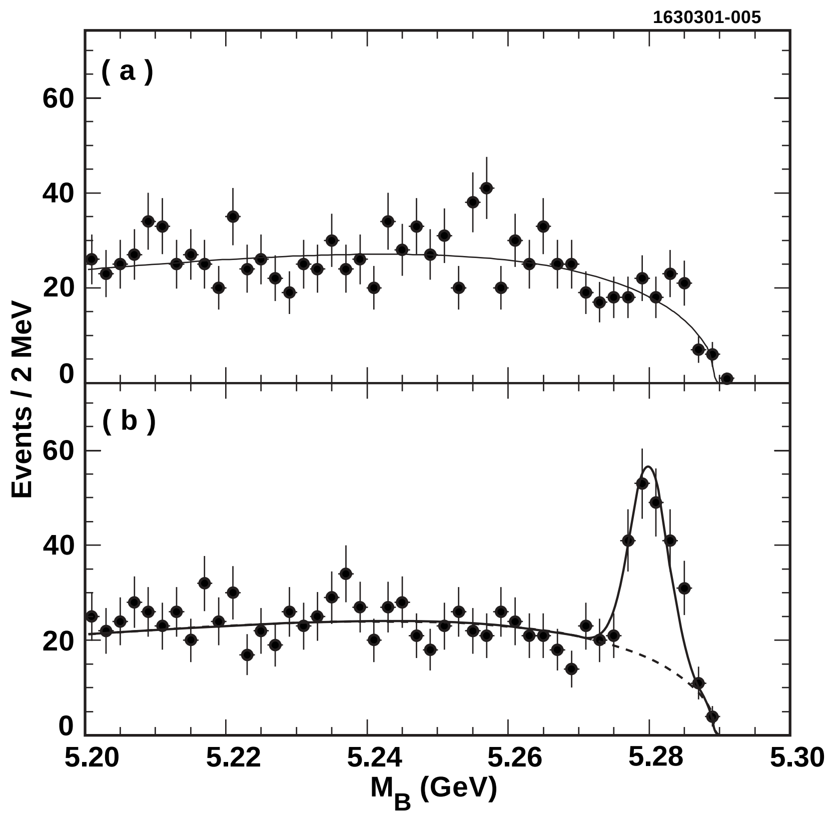
- $\overline{B}^- \to D^{*0}\pi^+\pi^-\pi^-\pi^0$
  - $D^0 \to K^-\pi^+$
  - Obtain eff. as a function of 4π mass
  - $\mathcal{B} = (1.80 \pm 0.24 \pm 0.27)\%$



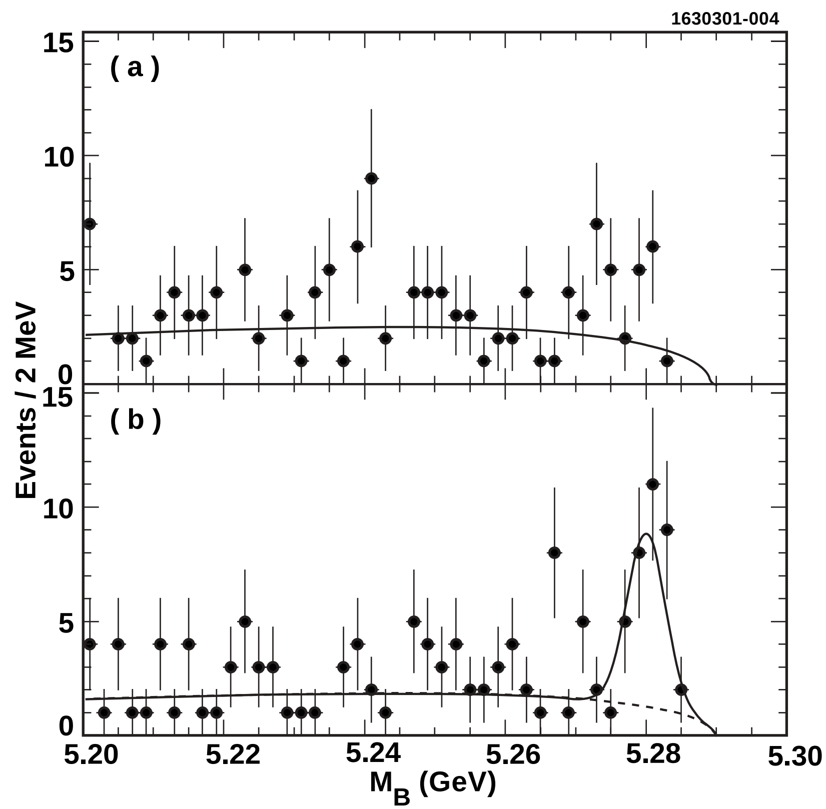
- $Br.$ is measured from $K\pi$ mode only. (a) ΔE sideband; (b) ΔE signal.

$D^*4\pi$ cont, CLEO

- $\overline{B}^0 \to D^{*+}\omega\pi^-$
  - See ω peak in 3π mass
  - Obtain eff. as a function of $\omega\pi$ mass
  - $\mathcal{B} = (0.29 \pm 0.03 \pm 0.04)\%$



- $\overline{B}^- \to D^{*0}\omega\pi^-$
  - See ω peak in 3π mass
  - Obtain eff. as a function of $\omega\pi$ mass
  - $\mathcal{B} = (0.45 \pm 0.10 \pm 0.07)\%$

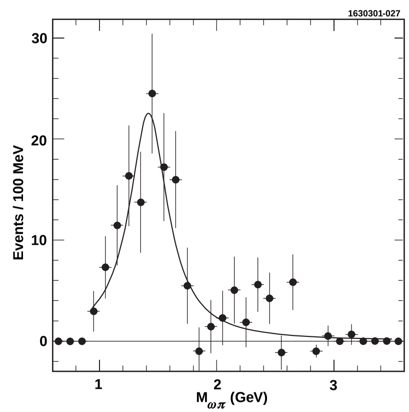


- (a) ΔE sideband; (b) ΔE signal region

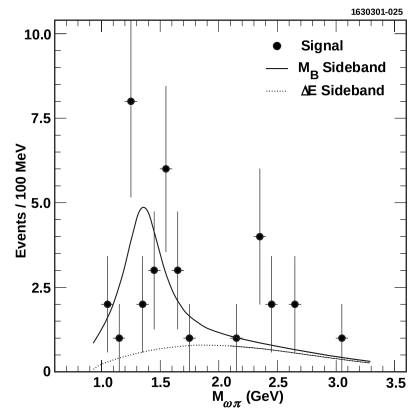
$D\omega\pi$, CLEO

- See enhancement on $\omega\pi$ mass around 1400 MeV$/c^2$ with 400 MeV$/c^2$ width

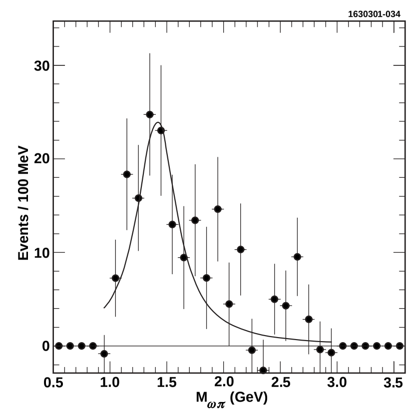
$D^{*+}\omega\pi^-$



$D^{*0}\omega\pi^-$



$D\omega\pi^-$



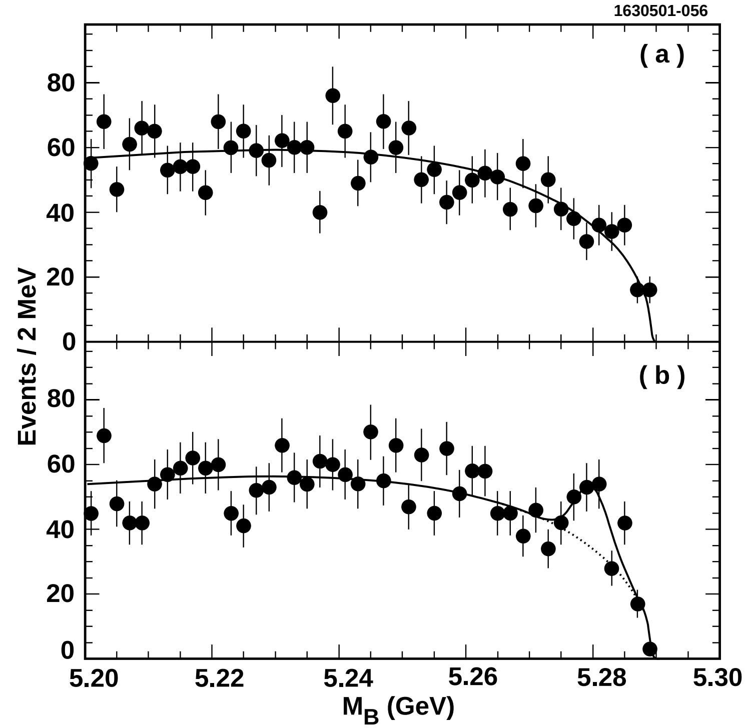
- Check $B \to D\omega\pi^-$ final state with $D^0 \to K^-\pi, D^+ \to K^-\pi^+\pi^+$
  - $\mathcal{B}(B^0 \to D^+\omega\pi^-) = (0.28 \pm 0.05 \pm 0.04)\%$
  - $\mathcal{B}(B^- \to D^0\omega\pi^-) = (0.41 \pm 0.07 \pm 0.06)\%$
- The same enhancement appears also in $\omega\pi^-$ mass spectrum in $D\omega\pi^-$ sample
- Perform angular analysis on $D\omega\pi^-$ events and the $\omega\pi^-$ peak is identified as $\rho^-(1450)$

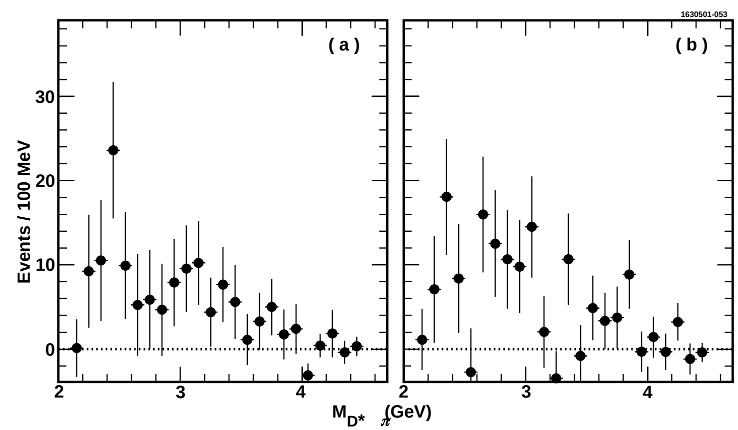
$\overline{B}^0 \to D^{*0}\pi^+\pi^+\pi^-\pi^-$, CLEO

- Same procedure as the previous one.
- Use $D^0 \to K^-\pi^+$ mode
- $\mathcal{B} = (0.30 \pm 0.07 \pm 0.06)\%$

$$R_{0-} = \frac{\Gamma(\overline{B}^0 \to D^{*0}\pi^+\pi^+\pi^-\pi^-)}{\Gamma(\overline{B}^0 \to D^{*+}\pi^+\pi^-\pi^-\pi^0)} = 0.17 \pm 0.04 \pm 0.02$$

- Check $D^{*0}\pi^+$ and $D^{*0}\pi^-$ masses
  See enhancement around $D^{**+}(2400)$
  No structure on $D^{*0}\pi^-$ as expected.
  No feature on $\pi^+\pi^+\pi^-$ mass
  from $D^{*0}\pi^-$ peak.





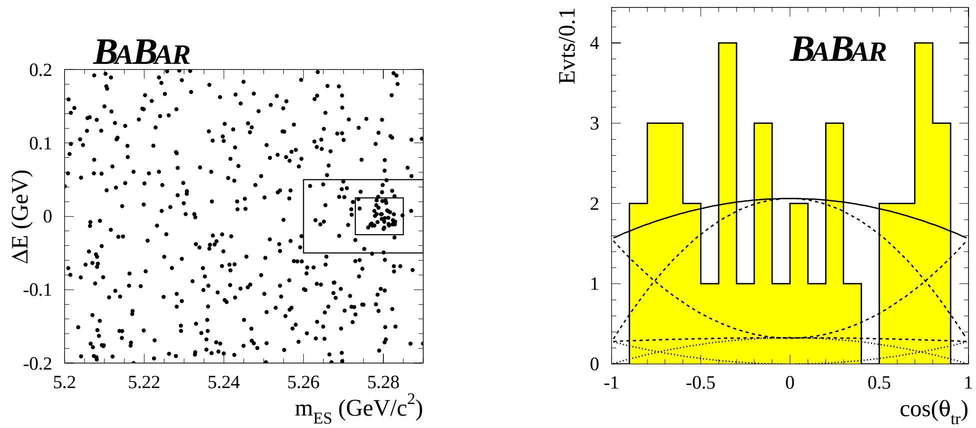
$B \to D^{(*)}\bar{D}^{(*)}$

- $B \to D^{(*)}\bar{D}^{(*)}$ can be used to probe the parameter $\sin 2\phi_1(\beta)$.
- $\mathcal{B}(B \to D^{(*)}\bar{D}^{(*)}) \approx (\frac{f_{D^{(*)}}}{f_{D_s^{(*)}}}) \tan^2\theta_c \times \mathcal{B}(B \to D_s^{(*)}\bar{D}^{(*)}) \sim 0(10^{-3})$

♣ BaBar preliminary on $D^{*+}D^{*-}$

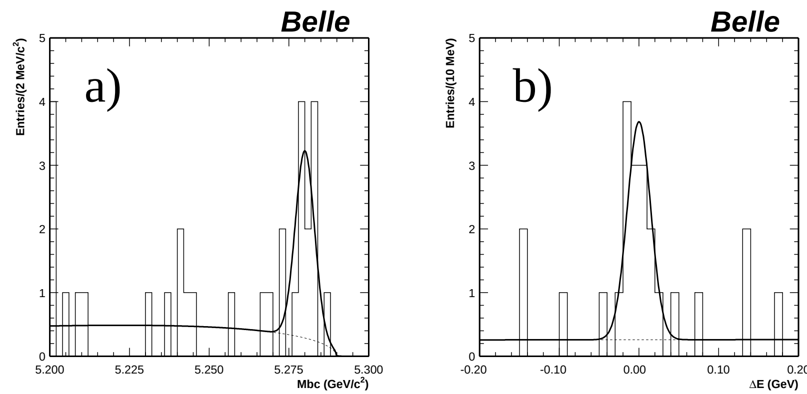
1. Reconstruct $D^{*+}D^{*-}$ to $(D^0\pi^+, D^0\pi^-)$ and $(D^0\pi^+, D^-\pi^0)$
2. $N = 38$ in signal box with $6.24 \pm 0.33 \pm 0.36$ bkg. estimated from sideband data.
3. $(\mathcal{B} = 8.0 \pm 1.6 \pm 1.2) \times 10^{-4}$
4. Perform angular analysis
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{tr}} = \frac{3}{4}(1 - R_t)\sin^2\theta_{tr} + \frac{3}{2}R_t\cos^2\theta_{tr}$$

R_t (CP-add) $= 0.22 \pm 0.18 \pm 0.03$



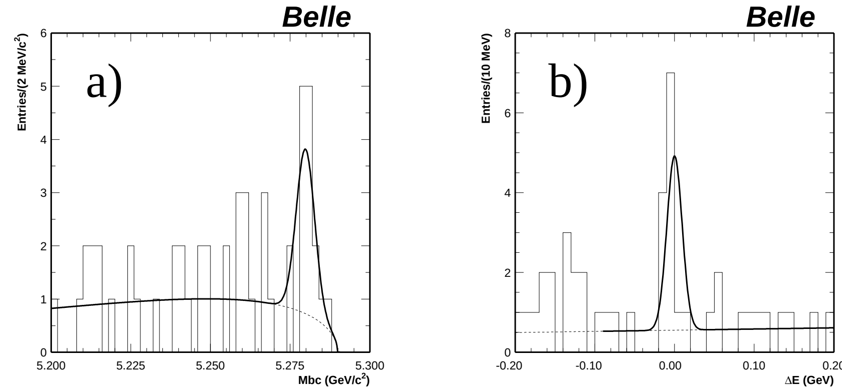
♠ Belle preliminary on $D^{*+}D^{*-}$

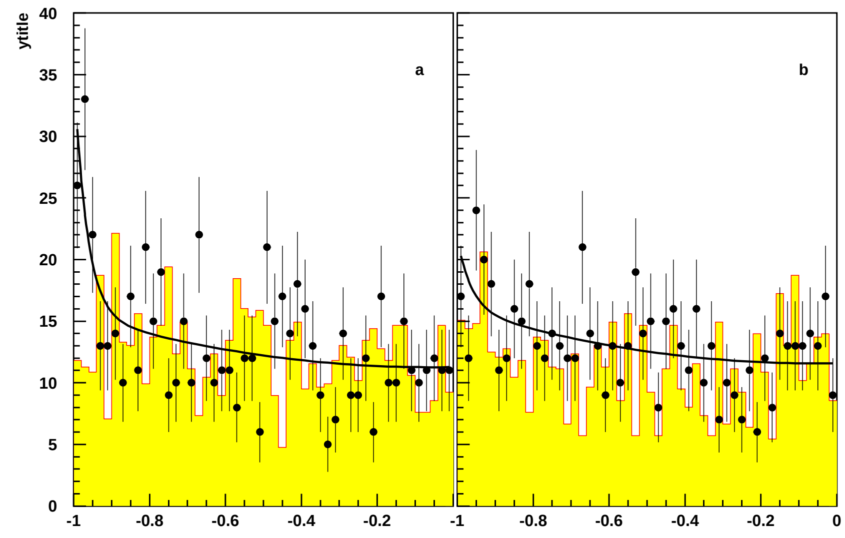
1. $D^{*+}D^{*-}$ to $(D^0\pi^+, D^0\pi^-)$
2. $N = (11.0 \pm 3.7)$ from M_{bc} fit
3. $(\mathcal{B} = (12.1 \pm 4.1 \pm 2.7) \times 10^{-4}$



$B^0 \to D^\pm D^{*\mp}$, *Belle preliminary*

- Full reconstruction
  - $N = 11.2 \pm 4.0\ (4.1\sigma), M_{bc}$ fit
  - $\mathcal{B} = (10.4 \pm 3.8 \pm 2.2) \times 10^{-4}$
- Partial reconstruction
  - Reconst. D^+ and π_s from D^{*-}
  - Extract yields from $\cos\alpha$, α is the angle between D^+ and π_s in CM frame
  - Use polarization angle (θ) from kinematics: $|\cos\theta| > 0.5 \to$ signal enriched region
  - Estimate background from large MC
  - Divide sample into lepton tagged and non-tagged
  - $\mathcal{B} = (18.4 \pm 4.3^{+6.8}_{-6.3}) \times 10^{-4}$





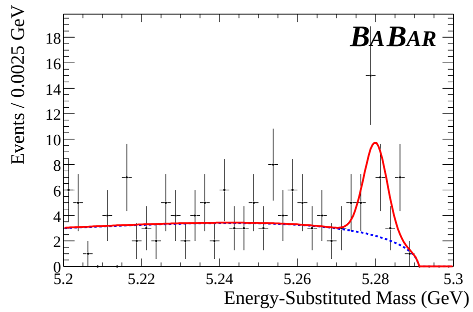
$\cos\alpha$ with lepton tag

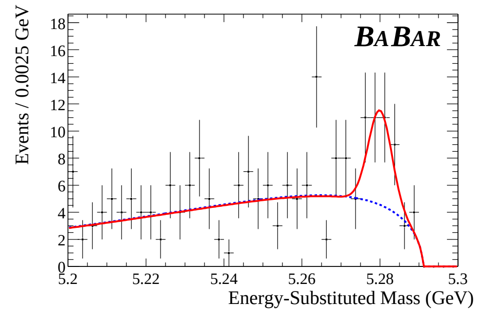
$|\cos\theta| > 0.5$ $\qquad$ $|\cos\theta| < 0.5$

$B^0 \to D^\pm D^{*\mp}$, $B^+ \to D^{*+} D^{*0}$, *BaBar preliminary*

- See signals in both channels

  1. $N(D^\pm D^{(*\mp)}) = 31$
     Bkg $= 10.5 \pm 1.7$
     Sig. $= 4.3\sigma$
  2. $N(D^{*+} D^{*0}) = 39$
     Bkg $= 20.3 \pm 0.5$
     Sig. $= 4.1\sigma$





Decay	BaBar $Br(\times 10^{-4})$	Belle $Br(\times 10^{-4})$	Previous $Br(\times 10^{-4})$
$B^0 \to D^{*+} D^{*-}$	$8.0 \pm 1.6 \pm 1.2$	$12.1 \pm 3.8 \pm 2.2$	$9.9^{+4.2}_{-3.3} \pm 1.2$ (CLEO)
$B^0 \to D^\pm D^{*\mp}$	seen	(full) $10.4 \pm 3.8 \pm 2.2$	< 6.3 (CLEO)
		(part.) $18.4 \pm 4.3^{+6.8}_{-6.3}$	
$B^+ \to D^{*+} D^{*0}$	seen	-	< 110 (ALEPH)

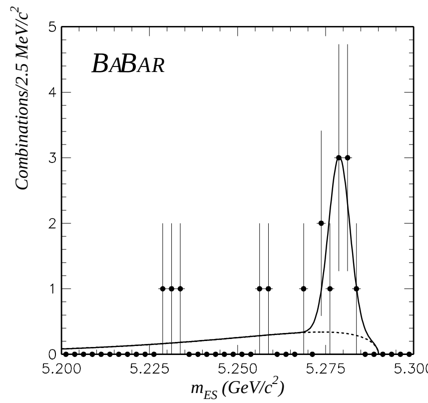
$B \to D^{(*)} D^{(*)} K$

- Smaller $\mathcal{B}(b \to c\bar{c}s)$ from $B \to D_s X, B \to (c\bar{c})X, B \to \Xi_c X$ than theory.
- $B \to D^{(*)} D^{(*)} K$ decays are due to $b \to c\bar{c}s$ process. $\Rightarrow$ could be large

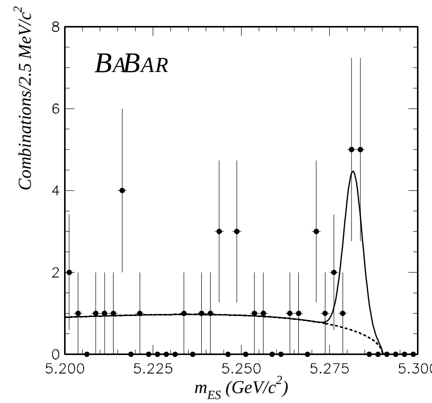
♣ BaBar preliminary results

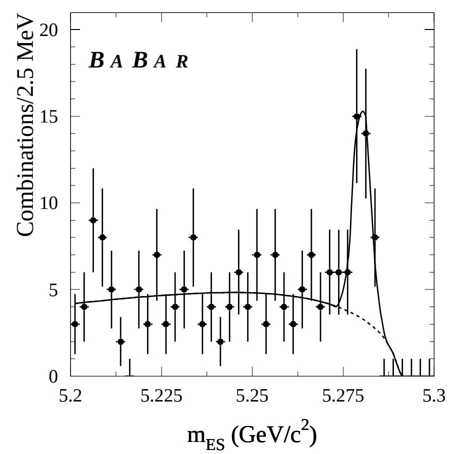
1. Reconstruct $D^{*+} \to D^0 \pi^+$.
2. $N(D^{*-}D^{*+}K^+) = 8.2 \pm 3.5$
   $\mathcal{B} = (3.4 \pm 1.6 \pm 0.9) \times 10^{-3}$
3. Use $D^{*-}D^0K^+$ events for $B \to D^{*-}D^{(*)0}K^+$ search
   - Distinguish $D^{*-}D^0K^+$ and $D^{*-}D^{*0}K^+$ from ΔE
   - $\mathcal{B}(D^{*-}D^0K^+)$
     $= (2.8 \pm 0.7 \pm 0.5) \times 10^{-3}$
   - $\mathcal{B}(D^{*-}D^{*0}K^+)$
     $= (6.8 \pm 1.7 \pm 1.7) \times 10^{-3}$
4. Observe significant yield in $D^{(*)+}D^{(*)-}K_S^0$

$B^+ \to D^{*-}D^{*+}K^+$

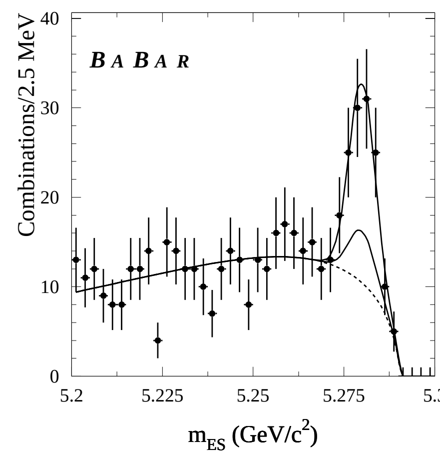


$B^0 \to D^{(*)-}D^{(*)+}K_S^0$





$B^0 \to D^{*-}D^0K^+$



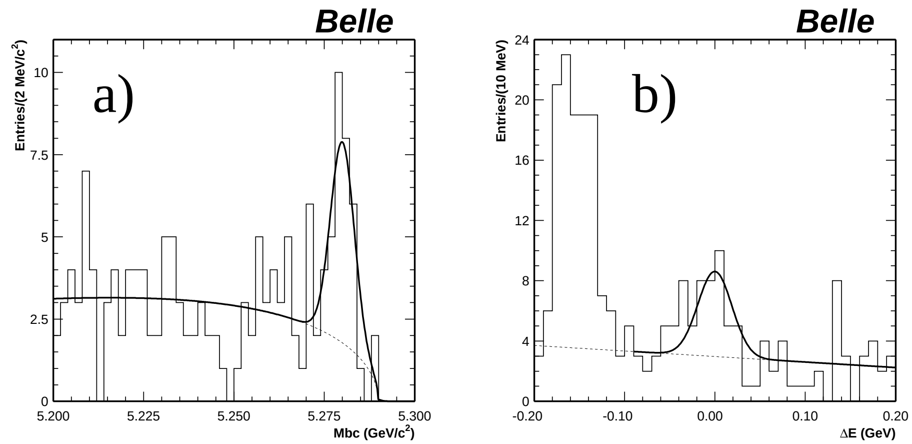
$D^{*-}D^0K^+$

$B \to D^{(*)} D^{(*)} K$ cont.

♠ Belle preliminary results

$N(D^{*-} D^0 K^+) = 25.2 \pm 6.5$

$\mathcal{B} = (3.2 \pm 0.8 \pm 0.7) \times 10^{-3}$



Branching Fraction ($\times 10^{-3}$)

Mode	BaBar	Belle	CLEO
$D^{*-} D^0 K^+$	$2.8 \pm 0.7 \pm 0.5$	$3.2 \pm 0.8 \pm 0.7$	$4.5^{+2.5}_{-1.9} \pm 0.08$
$D^{*-} D^{*0} K^+$	$6.8 \pm 1.7 \pm 1.7$	-	$13.0^{+7.8}_{-4.7} \pm 2.7$
$D^{*-} D^{*+} K^+$	$3.4 \pm 1.6 \pm 0.9$	-	< 7
$D^{(*)+} \overline{D}^{(*)-} K^0_S$	Seen	-	-

- Branching fraction becomes more precise.
- It's a good start. More will come.

Summary

- More precise and new measurements on B decays to charmonium.
  - $\mathcal{B}(J/\psi\pi)$ agrees with naive expectation
  - Suggesting FIS in $B \to J/\psi K^*(892)$; Observe S-wave contribution.
  - Observations of $B^+ \to J/\psi\phi K^+, \chi_{c0}K^+, B \to J/\psi K_1(1270)$
- Observe many new B decays to single charm
  - All B decays to $D^{(*)}K^{(*)-}$ are measured $\Rightarrow$ agree with prediction
  - First attempt of CPV on $B^- \to D_{CP}K^- \Rightarrow$ constrain $\phi_3(\gamma)$
  - Large Bf. on $D^{(*)0}\pi^0, D^0\eta, D^0\omega \Rightarrow$ FIS. or modification of a_2
  - Observation of $\overline{B} \to D^{(*)}\rho'^-, \rho'^- \to \omega\pi^-$
- Search for B decays to double charm
  - Precise measurements on $B^0 \to D^{*+}D^{*-}, Bf. \sim 10^{-3}$
  - First observation of $B^0 \to D^\pm D^{*\mp}, Bf. \sim 10^{-3}$
  - More precise results on $B \to D^{*-}D^{(*)}K^+$, confirm $b \to c\bar{c}s$ can proceed through $B \to D^{(*)}\overline{D}^{(*)}K$