

Hadronic B decays at the B-factories

(a selection of recent results)

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for the BaBar & Belle collaborations

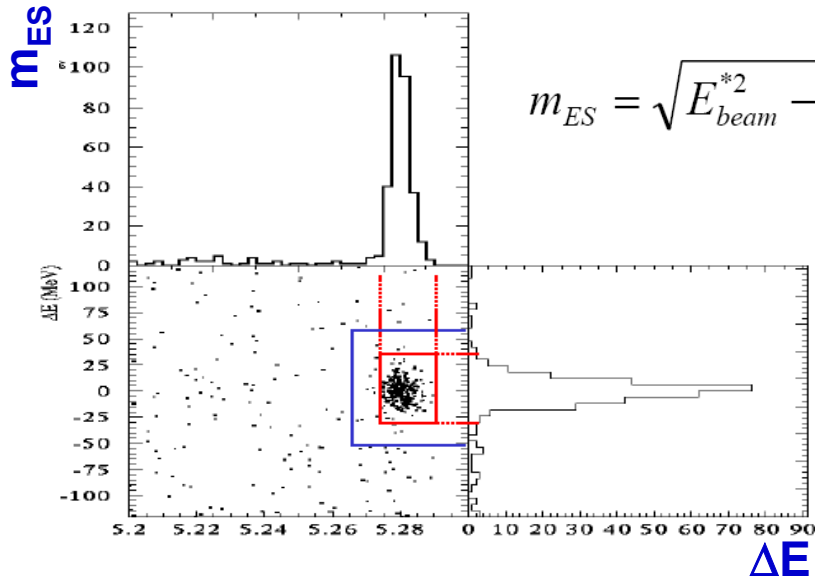
WIN'05, Delphi - Greece

June 6 –11 2005

Outline

- γ related measurements
 - $B \rightarrow D(\pi^+\pi^-\pi^0)K$
 - $B \rightarrow DK\pi$
 - $B \rightarrow D_s \pi^0$
 - $B \rightarrow D_s a_{0(2)}$
- Charmless 3 body
 - $B \rightarrow K\pi\pi, KKK$
 - Quasi-2-body Branching Fraction
 - Search for direct ~~CP~~
- Polarization in $B \rightarrow VV$
 - $B \rightarrow \phi K^*$ anomaly
- Investigating B meson wave function
 - $B \rightarrow J/\psi D$

Discriminating variables



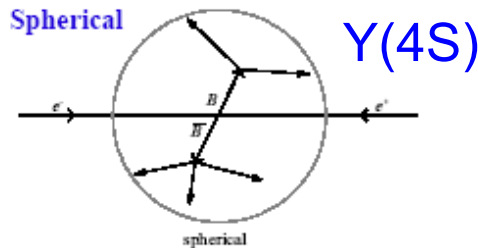
$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

Energy-substituted mass

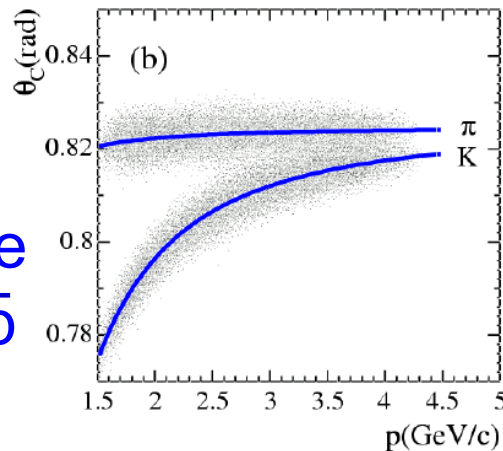
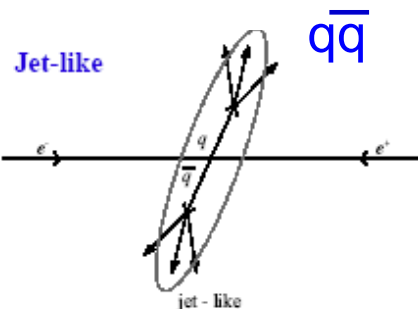
Energy difference

$$\Delta E = E_B^* - E_{beam}^*$$

Make use of precision kinematic information from the beams.



Event topology used to discriminate between $b\bar{b}$ and continuum

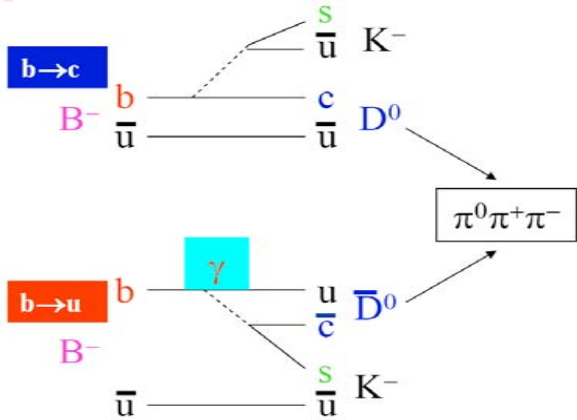


Cherenkov angle to separate Kaons from pions
(Belle: info from Aerogel Cherenkov counters)



$B \rightarrow D^0 K$ ($D^0 \rightarrow \pi^+ \pi^- \pi^0$)

motivation



- Measuring interference between $b \rightarrow c$ and $b \rightarrow u$ amplitudes to the same final state directly allows to extract γ

If $D \rightarrow 3$ body interference accessible via **Dalitz** analysis

Recently γ measured in $B \rightarrow D(K_s \pi \pi)K$

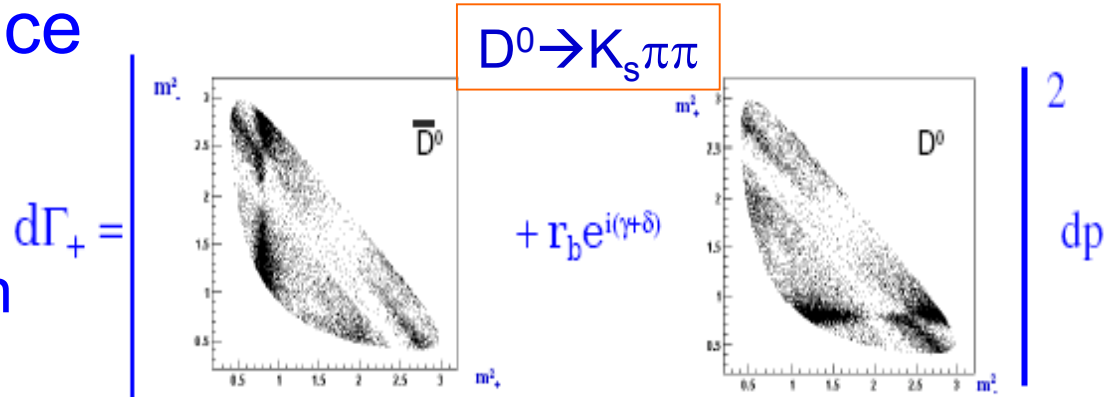
Babar (hep-ex/0504039)

Belle (hep-ex/0504013)

Trying out $B \rightarrow D(\pi \pi \pi)K$

Large interference 😊

Low statistics & high background 😞



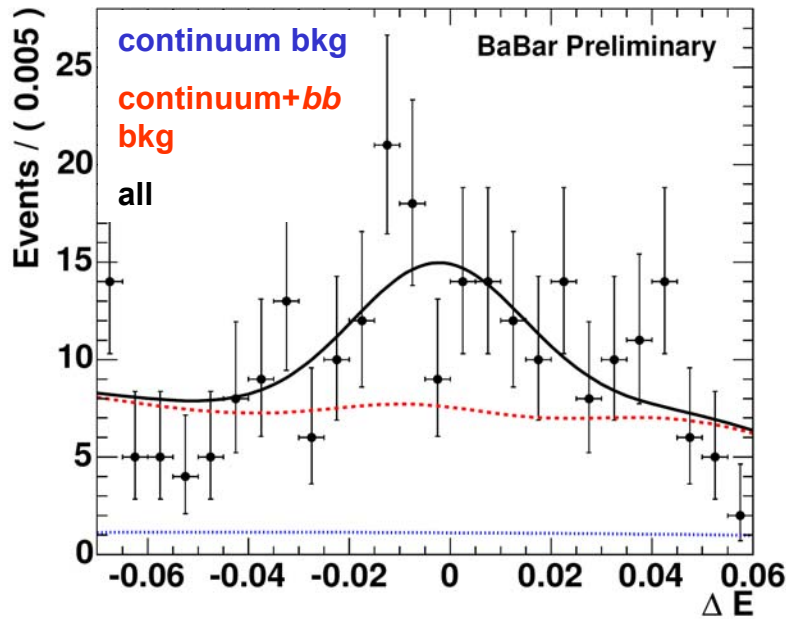
- First step: measure the Branching ratio and the CP asymmetry



$B \rightarrow D^0 K$ ($D^0 \rightarrow \pi^+ \pi^- \pi^0$)

results

$\mathcal{L} = 229 \times 10^6 \text{ BB pairs}$



- Neural Net used to discriminate signal from **continuum** and **combinatorial** (mis-reco π^0/D) background
- 3σ cut on m_{ES} and m_D
- ML fit on ΔE & NN output to extract the signal yield
- $N_{sig} = 133 \pm 23$

$$\mathcal{B} = (5.5 \pm 1.0 \pm 0.7) \times 10^{-6}$$

Working to evaluate potential for γ measurements

$$\frac{\mathcal{B}(B^+ \rightarrow (\pi^+ \pi^- \pi^0)_D K^+) - \mathcal{B}(B^- \rightarrow (\pi^+ \pi^- \pi^0)_D K^-)}{\mathcal{B}(B^+ \rightarrow (\pi^+ \pi^- \pi^0)_D K^+) + \mathcal{B}(B^- \rightarrow (\pi^+ \pi^- \pi^0)_D K^-)} = 0.02 \pm 0.16 \pm 0.03$$



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

motivation

- Studying feasibility for measuring γ from $B \rightarrow DK\pi$

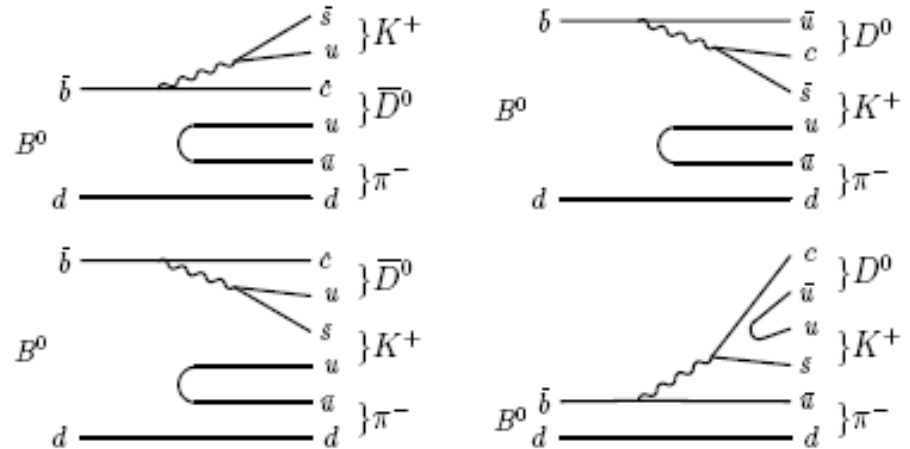
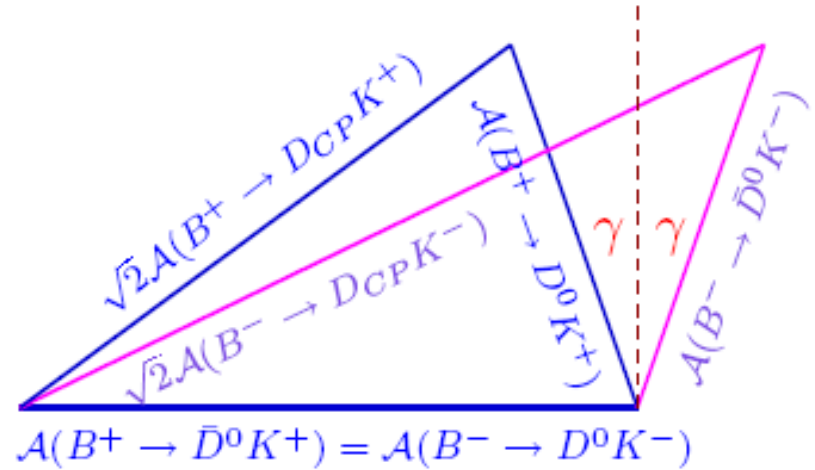
(Aleksan, Petersen, Soffer, PRD67, 096002)

- Same strategy as $B \rightarrow DK$

(Phys.Lett. B253,483 - Phys.Lett. B265,172)

but:

- C.K.M. suppressed amplitude is not color suppressed (large interference)
- 8-fold ambiguity (due to the strong phase) could be reduced to 2-fold by Dalitz Analysis

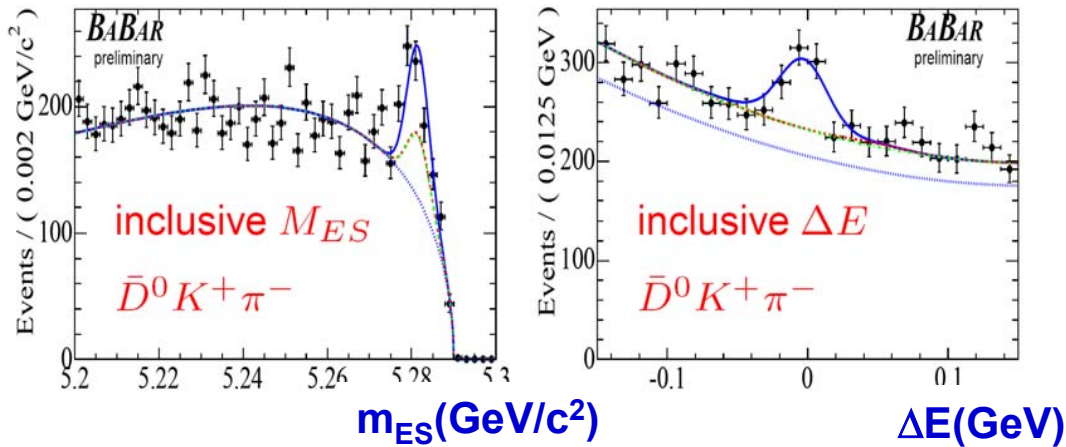




$B^0 \rightarrow \bar{D}^0(D^0) K^+ \pi^-$

results

$\mathcal{L} = 220 \text{ fb}^{-1}$



$D \rightarrow K\pi, K\pi\pi\pi, K\pi\pi^0$
2-dimensional $m_{ES}, \Delta E$ fit

Inclusive yields

$$N(B \rightarrow \bar{D}^0 K^+ \pi^-) = 244 \pm 35$$

$$N(B \rightarrow D^0 K^+ \pi^-) = 27 \pm 37$$

Measured B.R. (excluding $B \rightarrow D^* K$ contribution)

- $B(B \rightarrow \bar{D}^0 K \pi) = (8.6 \pm 1.5 \pm 1.0) \cdot 10^{-5}$

Identified two resonant contributions

- $B(B \rightarrow \bar{D}^0 K^*) \cdot B(K^* \rightarrow K \pi) = (3.9 \pm 0.6 \pm 0.4) \cdot 10^{-5}$

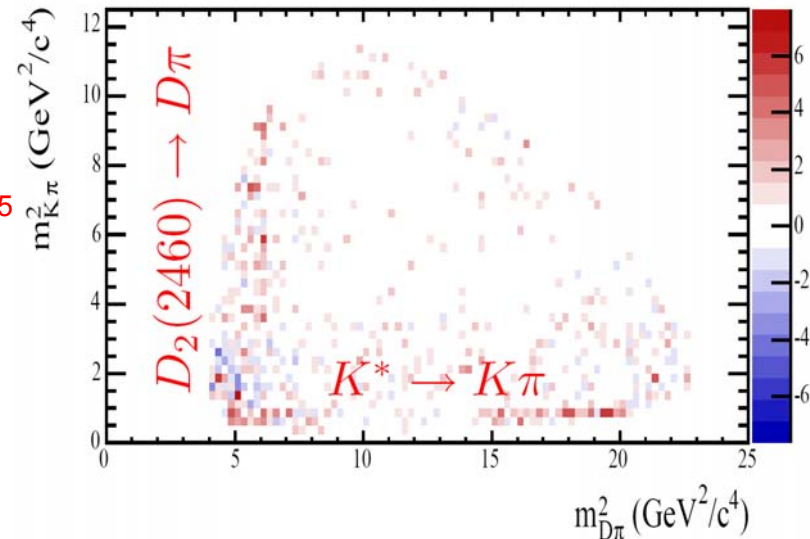
- $B(B \rightarrow D_2(2460) K) \cdot B(D_2(2460) \rightarrow D^0 K) = (1.9 \pm 0.4 \pm 0.3) \cdot 10^{-5}$

Non-resonant contribution

- $B(B \rightarrow \bar{D}^0 K \pi)_{\text{non-res}} = (2.6 \pm 0.8 \pm 0.4) \cdot 10^{-5}$

upper limit on the CKM suppressed

- $B(B \rightarrow D^0 K \pi) < 1.9 \cdot 10^{-5} @ 90\%$





$B \rightarrow D_s \pi^0$

motivation

- Extraction of $\sin(2\beta+\gamma)$ from time dependent analysis of $B \rightarrow D\pi$ requires knowledge of the ratio $r =$

$$r = \frac{\mathcal{A}(B^0 \rightarrow D^+ \pi^-)_{\text{CKM suppressed}}}{\mathcal{A}(\bar{B}^0 \rightarrow D^+ \pi^-)_{\text{CKM allowed}}}$$

- $B(B^0 \rightarrow D^+ \pi^-)$ not accessible
 - C.K.M. suppression
 - Large bkg from the C.K.M. allowed amplitude



Using SU(3) to obtain r

$$r \approx \sqrt{\frac{Br(B^0 \rightarrow D_s^+ \pi^-)}{Br(B^0 \rightarrow D^+ \pi^-)} \left| \frac{V_{cd}}{V_{cs}} \right| \frac{f_{D^+}}{f_{D_s^+}}}$$

- SU(3) verified at few % level for factorizable processes
- here a heavy meson is emitted and factorization does not apply.
- Measuring $B \rightarrow D^+ \pi^0$ and $B \rightarrow D_s^+ \pi^0$ will allow us to test SU(3) in this environment and reduce the theoretical uncertainties on r



$B \rightarrow D_s \pi^0$

results

$\mathcal{L} = 124 \times 10^6 \text{ BB pairs}$

- $D_s^+ \rightarrow \phi \pi^+, \bar{K}^{*0} K^+, K_s K^+$
- $N_{\text{tot}} = 27$
- $N_{\text{bkg}} = 14.7^{+4.76}_{-5.78}$
 - Combinatorial: $8.75^{+3.94}_{-5.20}$
 - From m_{ES} sideband
 - Peaking: $5.52^{+2.55}_{-2.52}$
 - from ΔE sideband
 - Probability of bkg fluctuation $\approx 3\%$

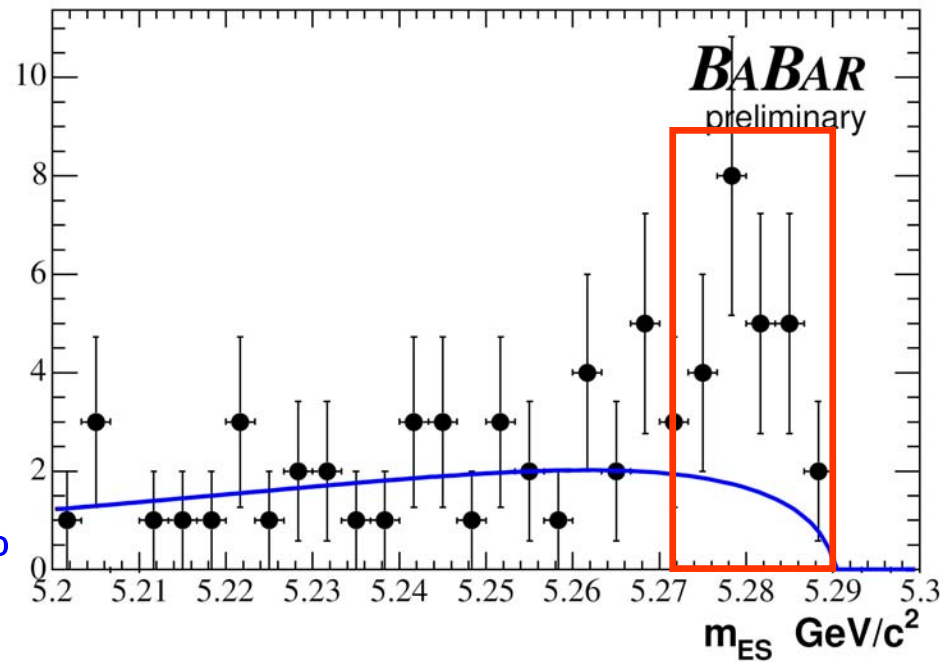
Upper Limit @ 90% CL:

$$\mathcal{B}(B^+ \rightarrow D_s^+ \pi^0) < 2.8 \times 10^{-5}$$

Consistent with SU(2) prediction from $\text{Br}(B^0 \rightarrow D_s^+ \pi^-)$:

$$\mathcal{B}(B^0 \rightarrow D_s^+ \pi^-) = (1.6 \pm 0.3 \pm 0.2) \times 10^{-5} \implies \mathcal{B}(B^+ \rightarrow D_s^+ \pi^0) \approx 0.9 \times 10^{-5}$$

SU(2)



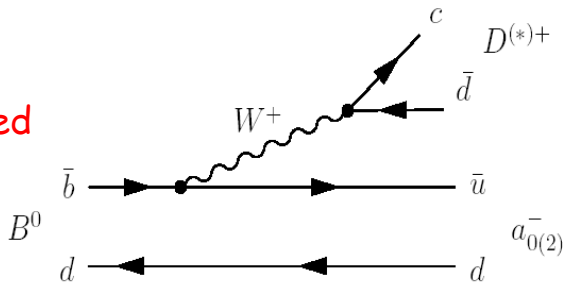


$B \rightarrow D_s a_{0(2)}$

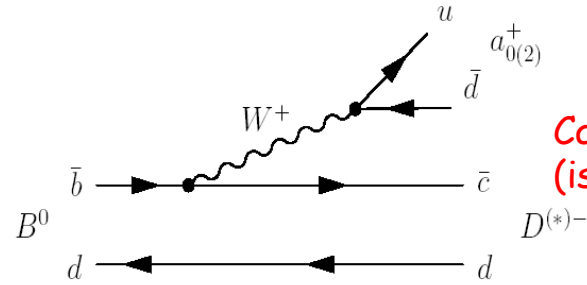
motivation

- Time dependent CP asymmetry in $B^0 \rightarrow D^+ a_{0(2)}^-$ to extract $\sin(2\beta + \gamma)$
- small value for $f_{a_{0(2)}}$
 - CKM allowed and CKM suppressed amplitudes expected of the same order
 - $r \approx 1 \rightarrow$ large interference

Cabibbo suppressed
(iso)spin favored



Cabibbo allowed
(iso)spin disfavored



- Studying $B^0 \rightarrow D_s a_{0(2)}$
 - SU(3) partner
 - Higher BR (no Cabibbo suppression)
 - Provide info on the $B \rightarrow a_{0(2)}$ form factor

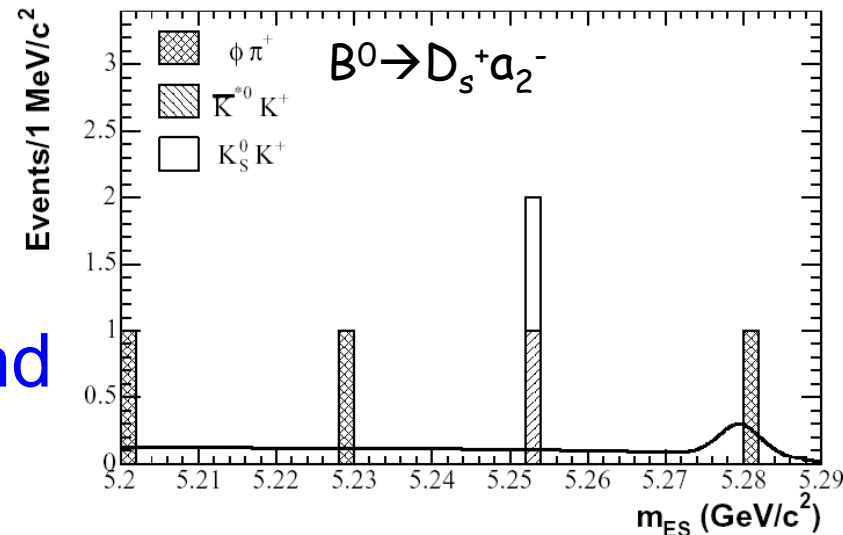
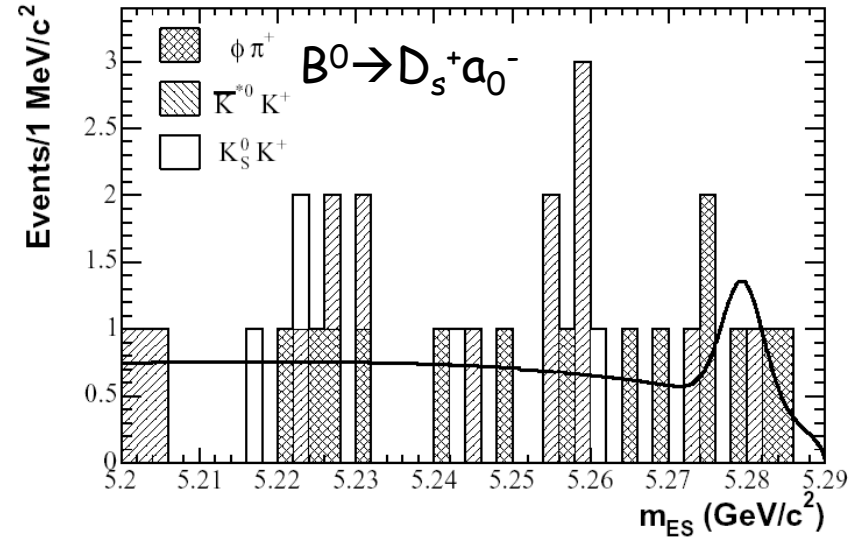


$B \rightarrow D_s a_{0(2)}$

results

$\mathcal{L} = 220 \text{ fb}^{-1}$

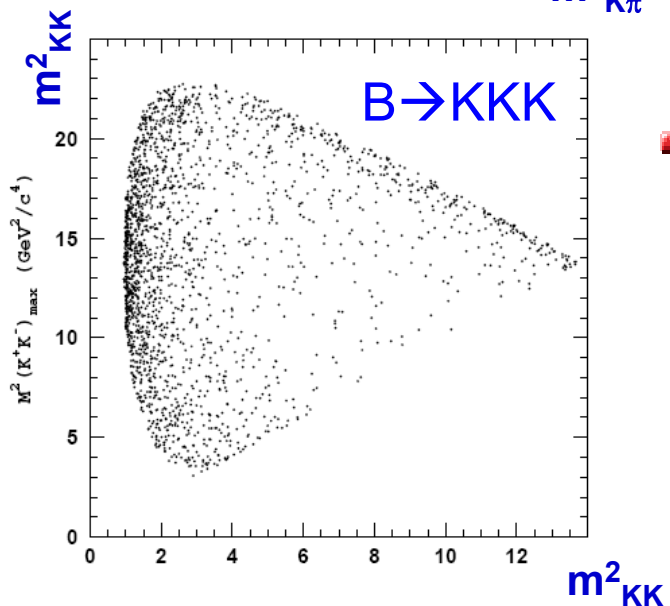
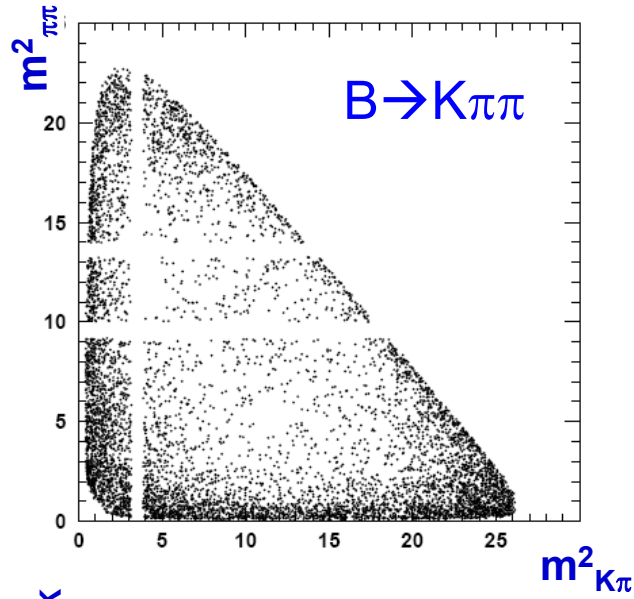
- $D_s^+ \rightarrow \phi \pi^+, K^{*0} K^+, K_S K^+$
- $a_{0(2)} \rightarrow \eta \pi^+$ 100%(15%)
- Background shape from MC
- No significant signal found



Mode	90% CL U.L.	Theory
$D_s^+ a_0^-$	$4.0 \cdot 10^{-5}$	$7.5 \cdot 10^{-5}$
$D_s^+ a_2^-$	$2.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-5}$

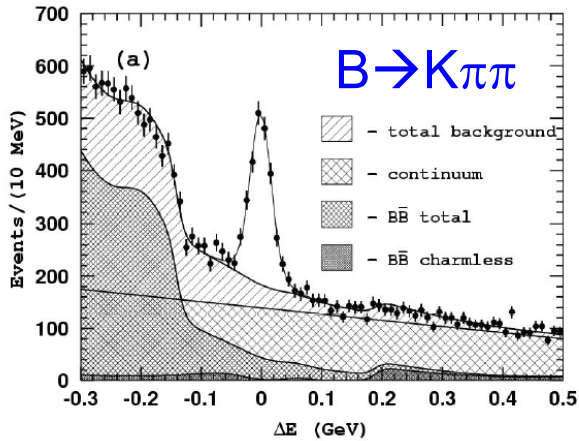
- $B(B^0 \rightarrow D_s a_0)$ found **lower** than expected from factorization and QCD sum rules

hep-ph/0105194
PRD 67,014011



- $B \rightarrow K \pi \pi$, KKK dominated by $b \rightarrow s$ penguin process
- Full amplitude Dalitz analysis allows to reliably measure quasi-two-body branching fractions ($B \rightarrow \rho K, K^* \pi \dots$)
- Search for direct CP violation
 - Looking for:
 - asymmetry in quasi two body Branching Ratios
 - Differences in relative phases

$\mathcal{L} = 140 \text{ fb}^{-1}$

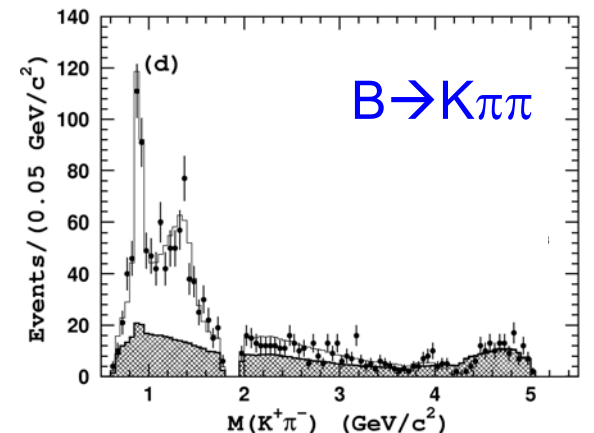
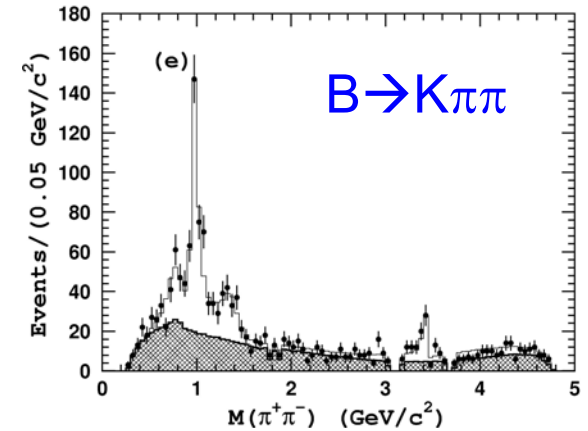


$$N_{\text{sig}}(K\pi\pi) = 1533 \pm 69$$

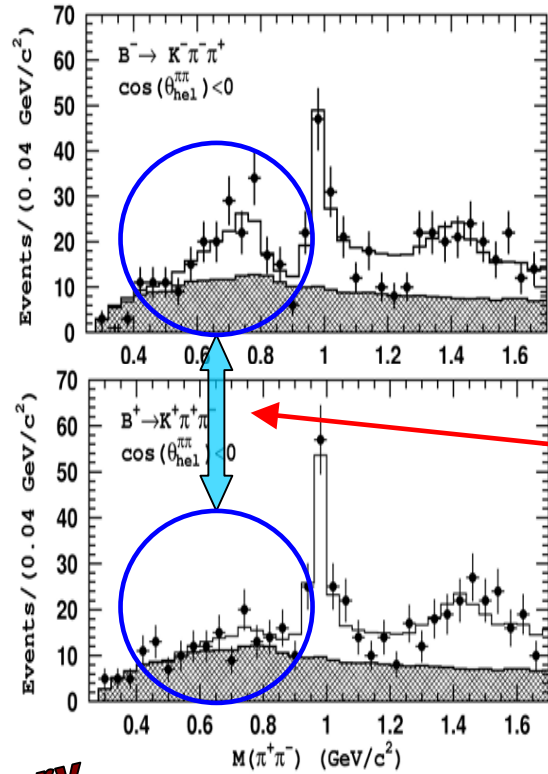
$$N_{\text{sig}}(KKK) = 1089 \pm 41$$

Non resonant amplitude needed in the Dalitz fit model

$$\begin{aligned} \text{Bf}[K^+ \pi^+ \pi^-] \text{ (charmless total)} &= (46.6 \pm 2.1 \pm 4.3) \times 10^{-6} \\ \text{Bf}[K^+ \pi^+ \pi^-] \text{ (non-resonant)} &= (17.3 \pm 1.7 \pm 1.6 \pm_{-7.8}^{+17.1}) \times 10^{-6} \\ \text{Bf}[K^{*0} \pi^+] &= (9.83 \pm 0.90 \pm 0.90 \pm_{-0.86}^{+0.57}) \times 10^{-6} \\ \text{Bf}[K^{*0}(1430) \pi^+] &= (45.0 \pm 0.2.9 \pm 6.2 \pm_{-8.7}^{+13.7}) \times 10^{-6} \\ \text{Bf}[\rho(770) K^+] &= (4.78 \pm 0.75 \pm 0.44 \pm_{-0.87}^{+0.91}) \times 10^{-6} \\ \text{Bf}[f_0(980) K^+] \times \text{Bf}[f_0 \rightarrow \pi^+ \pi^-] &= (7.55 \pm 1.24 \pm 0.69 \pm_{-0.96}^{+1.48}) \times 10^{-6} \\ \text{Bf}[K^+ K^+ K^-] \text{ (charmless total)} &= (30.6 \pm 1.2 \pm 2.3) \times 10^{-6} \\ \text{Bf}[K^+ K^+ K^-] \text{ (non-resonant)} &= (24.0 \pm 1.5 \pm 1.8 \pm_{-5.7}^{+1.9}) \times 10^{-6} \\ \text{Bf}[\phi K^+] &= (9.60 \pm 0.92 \pm 0.71 \pm_{-0.46}^{+0.78}) \times 10^{-6} \\ \text{Bf}[\chi_{c0} K^+] \text{ } (\chi_{c0} \rightarrow \pi^+ \pi^- + K^+ K^-) &= (1.96 \pm 0.35 \pm 0.33 \pm_{-0.26}^{+1.97}) \times 10^{-4} \end{aligned}$$



- Fit the B^+ and B^- samples individually to determine CP asymmetry for each quasi-two-body channel
- Model related uncertainty evaluated by repeating fit with different models

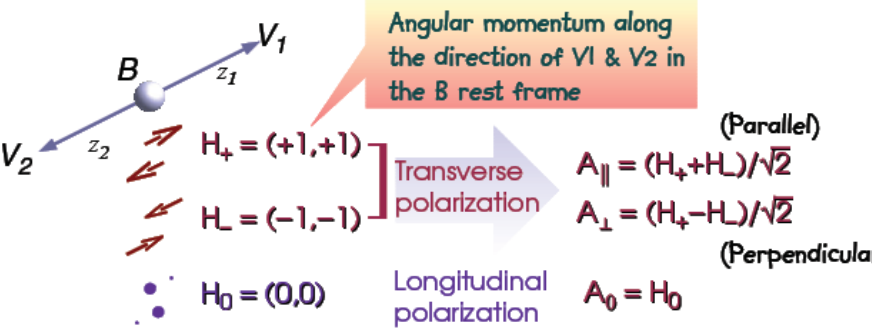


preliminary $\mathcal{L} = 253 \text{ fb}^{-1}$

Channel	A_{CP}
$K^\pm \pi^+ \pi^-$	$+0.046 \pm 0.030^{+0.017}_{-0.012}$
$K^*(892)^0 \pi^\pm$	$-0.14 \pm 0.08 \pm 0.02^{+0.03}_{-0.07}$
$K^*_0(1430)^0 \pi^\pm$	$+0.06 \pm 0.05 \pm 0.02^{+0.01}_{-0.32}$
$\rho(770)^0 K^\pm$	$+0.27 \pm 0.12 \pm 0.02^{+0.59}_{-0.03}$
$f_0(980) K^\pm$	$-0.13 \pm 0.11 \pm 0.02^{+0.16}_{-0.06}$
$\chi_{c0} K^\pm$	$-0.30 \pm 0.22 \pm 0.02^{+0.42}_{-0.00}$
Non-Res.	$-0.04 \pm 0.08 \pm 0.02^{+0.16}_{-0.03}$

preliminary

A 2.4σ hint for a Direct CP violation in $B^\pm \rightarrow \rho(770)^0 K^\pm$

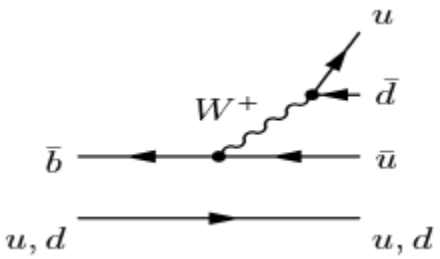


Standard Model prediction, with factorization assumption:

$$f_L = \frac{|A_0|^2}{|A_0|^2 + |A_{||}|^2 + |A_{\perp}|^2} = \frac{|A_0|^2}{|A_0|^2 + |A_+|^2 + |A_-|^2} = 1 - O\left(\left(\frac{m_V}{m_B}\right)^2\right) \sim 1$$

True for tree dominated decays

BaBar(89M)	$f_L(\rho^+\rho^-) = 0.99 \pm 0.03^{+0.04}_{-0.03}$
BaBar(89M)	$f_L(\rho^+\rho^0) = 0.97 \pm 0.03^{+0.03}_{-0.07} \pm 0.04$
Belle(85M)	$f_L(\rho^+\rho^0) = 0.95 \pm 0.11 \pm 0.02$
BaBar(89M)	$f_L(\rho^+\omega) = 0.88 \pm 0.12^{+0.12}_{-0.15} \pm 0.03$

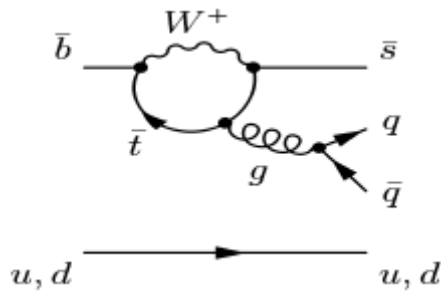


Many possible explanations:

- New Physics
- Transverse gluon
- Annihilation
- Rescattering

Not true in pure penguins

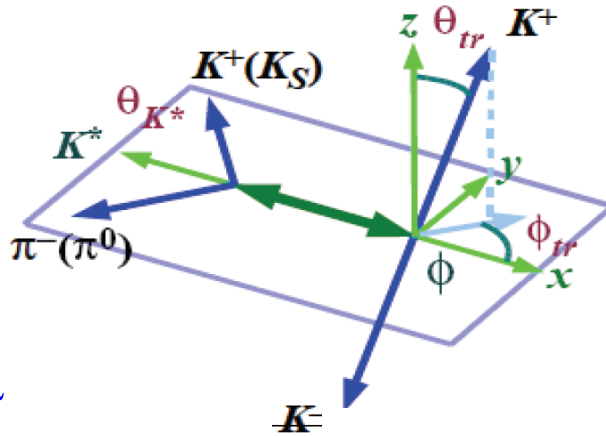
BaBar(227M)	$f_L(\phi K^{*0}) = 0.52 \pm 0.05 \pm 0.02$
Belle(152M)	$f_L(\phi K^{*0}) = 0.52 \pm 0.07 \pm 0.05$
BaBar(89M)	$f_L(\phi K^{*+}) = 0.46 \pm 0.12 \pm 0.03$
Belle(152M)	$f_L(\phi K^{*+}) = 0.49 \pm 0.13 \pm 0.05$



Y. Grossman, hep-ph/0310229
 W.-S. Hou et al., hep-ph/0408007
 A. Kagan, hep-ph/0405134
 P. Colangelo et al., hep-ph/0406162

- Full angular analysis allows to measure the polarization amplitudes A_λ

Angles in transversity basis



$$\frac{d^3R_{\phi K^*}}{d\phi_{tr} d\cos\theta_{tr} d\cos\theta_{K^*}} = F(A_{\parallel}, A_{\perp}, A_0; \phi_{tr}, \cos\theta_{tr}, \cos\theta_{K^*})$$

- Construct observables sensitive to New Physics and Final State Interaction

(D.London N.Shina R.Shina PRD69,114013 2004)

polarization

$$\Lambda_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 + |\bar{A}_\lambda|^2)$$

If non-zero possible FSI

$$\Sigma_{\perp i} = -\text{Im}(A_{\perp} A_i^* + \bar{A}_{\perp} \bar{A}_i^*)$$

$$\Lambda_{\parallel 0} = \text{Re}(A_{\parallel} A_0^* + \bar{A}_{\parallel} \bar{A}_0^*)$$

$$\Lambda_{\perp i} = -\text{Im}(A_{\perp} A_i^* - \bar{A}_{\perp} \bar{A}_i^*) \leftarrow \text{T-odd CP-violation}$$

$$\Sigma_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 - |\bar{A}_\lambda|^2)$$

$$\Sigma_{\parallel 0} = \text{Re}(A_{\parallel} A_0^* - \bar{A}_{\parallel} \bar{A}_0^*)$$

New Physics if $\neq 0$

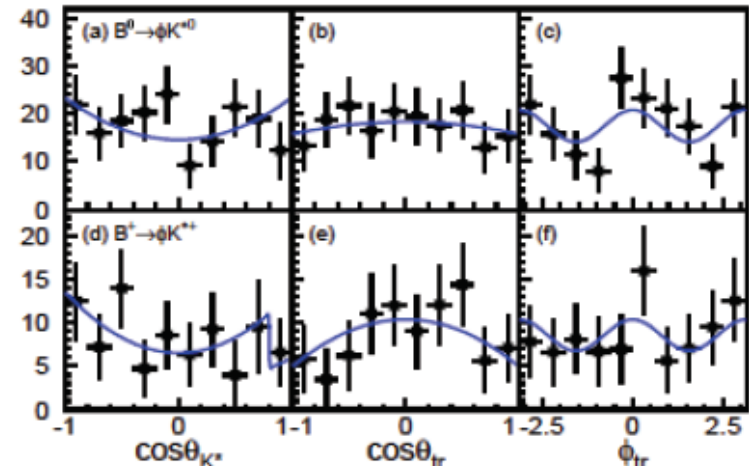
$\mathcal{L} = 253 \text{ fb}^{-1}$

$N_{\text{sig}}(B \rightarrow \phi K^{*0}) : 173 \pm 16$

$N_{\text{sig}}(B \rightarrow \phi K^{*+}) : 85^{+12}_{-11}$

$A_{CP}(B \rightarrow \phi K^{*0}) = 0.02 \pm 0.09 \pm 0.02$

$A_{CP}(B \rightarrow \phi K^{*+}) = -0.02 \pm 0.14 \pm 0.03$



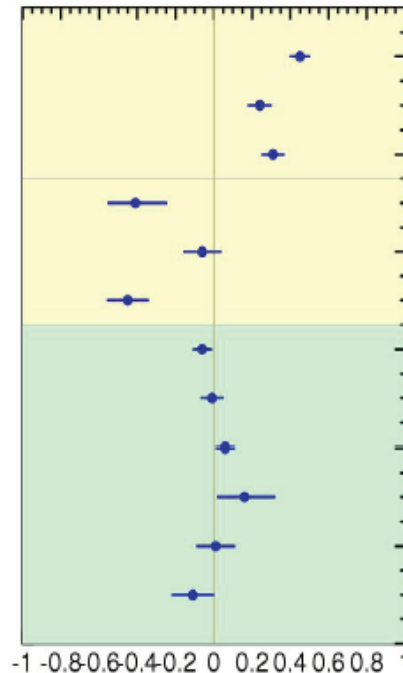
ϕK^* Anomaly

Non-0 value can be generated by FSI

$\neq 0$ if NP exists

Most of them are consistent with zero

- Λ_{00}
- $\Lambda_{\parallel\parallel}$
- $\Lambda_{\perp\perp}$
- $\Sigma_{\perp 0}$
- $\Sigma_{\perp\parallel}$
- $\Sigma_{\parallel 0}$
- Σ_{00}
- $\Sigma_{\parallel\parallel}$
- $\Sigma_{\perp\perp}$
- $\Lambda_{\perp 0} (= \overline{A_T^0} - A_T^0)$
- $\Lambda_{\perp\parallel} (= \overline{A_T^{\parallel}} - A_T^{\parallel})$
- $\Lambda_{\parallel 0}$



$0.45 \pm 0.05 \pm 0.02$

Longitudinal polarization $> 10\sigma$ away from 1

Indication of Final state interaction (also observed by BaBar)

No evidence of New Physics



$B \rightarrow J/\psi D$

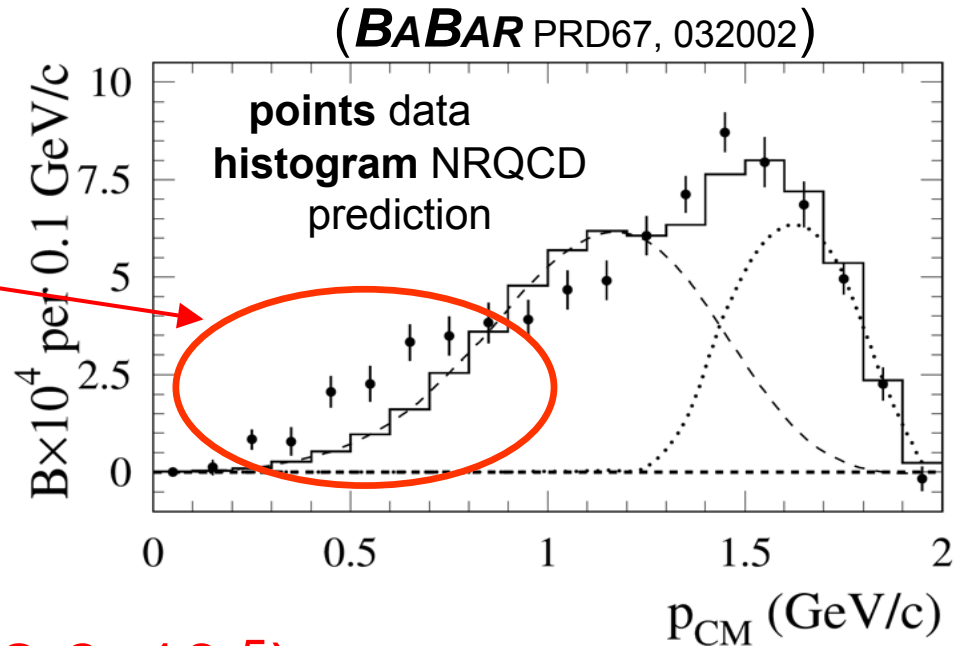
motivation

Inclusive $B \rightarrow J/\psi X$ spectrum

Excess at low momenta

$$m_X \approx 2 \text{ GeV}$$

$$B \approx 6 \times 10^{-4}$$



Possible explanations

- $B \rightarrow J/\psi \Lambda p$: ruled out ($< 2.6 \times 10^{-5}$)
- $B \rightarrow J/\psi + \text{Hybrid meson}$: No experimental evidence
- Search for $B \rightarrow J/\psi D$ to test the **intrinsic charm hypothesis**:
 - presence of $b\bar{u}c\bar{c}$ components in the B meson wave function
 - Expected $B(B \rightarrow J/\psi D(\pi)) \approx O(10^{-4})$



$B \rightarrow J/\psi D$

results

$\mathcal{L} = 112 \text{ fb}^{-1}$

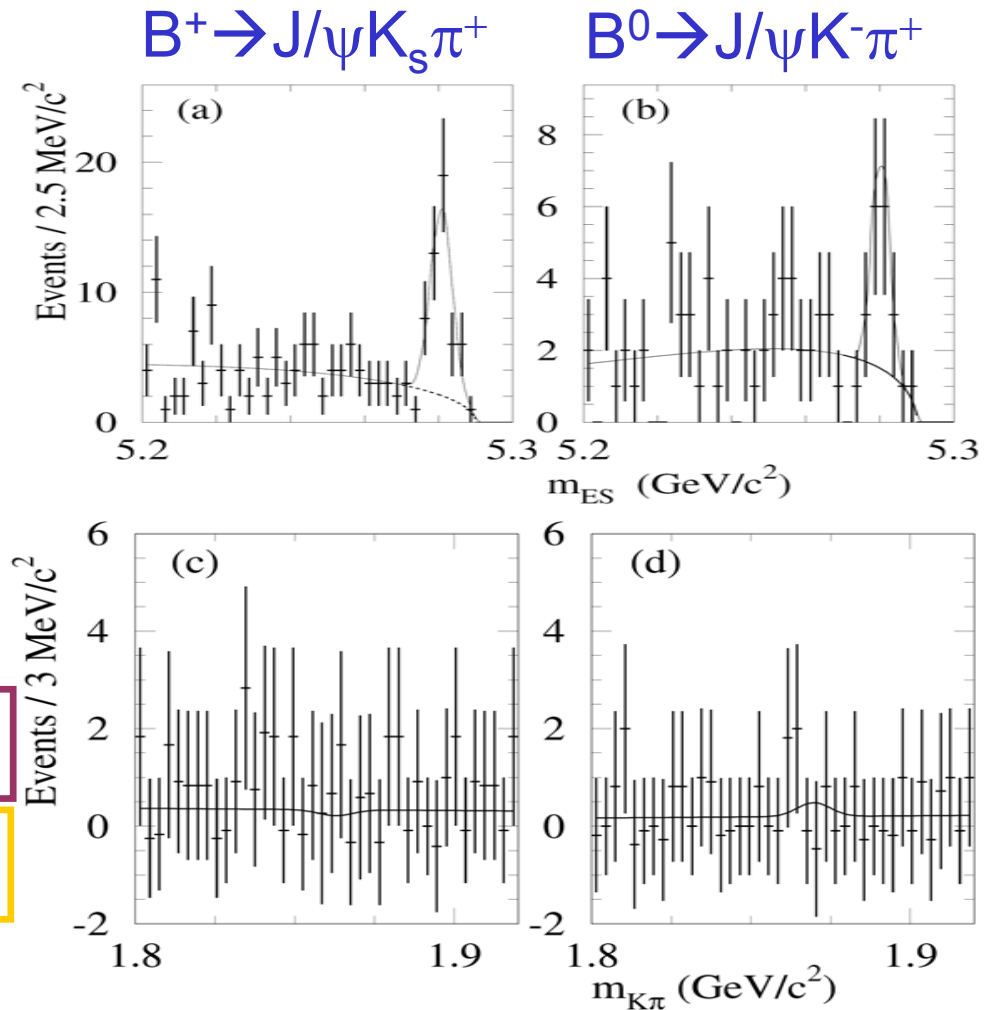
- $D^0 \rightarrow K^- \pi^+$
- $D^+ \rightarrow K_s \pi^+$
- $J/\psi \rightarrow e^+ e^-, \mu^+ \mu^-$

No significant signal coming from $D \rightarrow K\pi$

Upper Limit @ 90% CL:

$$\mathcal{B}(B^0 \rightarrow J/\psi D^0) < 0.64 \times 10^{-5}$$

$$\mathcal{B}(B^+ \rightarrow J/\psi D^+) < 6.2 \times 10^{-5}$$



Ruled out intrinsic charm hypothesis

Summary

A lot of interesting results from the *B-factories*:

- $B \rightarrow D(\pi^+\pi^-\pi^0)K$, $B \rightarrow DK\pi$:

trying new ways to measure γ

- $B \rightarrow D_s\pi^0$, $B \rightarrow D_s a_{0(2)}$:

testing factorization and SU(3) symmetry

- $B \rightarrow KKK$, $K\pi\pi$

Measured charmless quasi-two body BR
and looking for Direct CP violation

- $B \rightarrow \phi K^*$ polarization puzzle

Looking for New Physics and Final State Interaction

- $B \rightarrow J/\psi D$

intrinsic charm hypothesis ruled out.

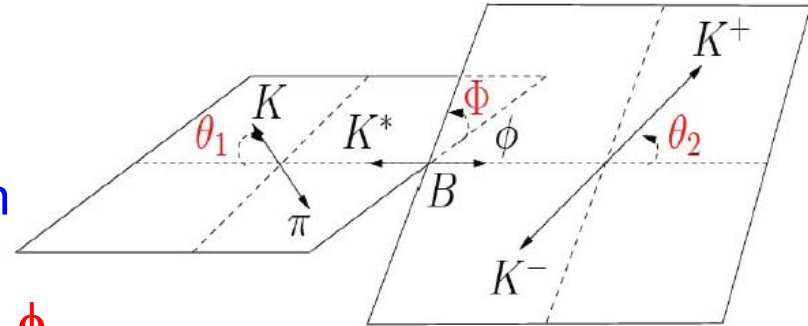
Lots of analyses are ongoing, more results are yet to come....

Backup slides



$B \rightarrow \phi K^*$

- Angular Analysis in helicity basis
- Fit for:
 - signal yield n_{sig}
 - Longitudinal and transverse polarization f_L, f_{\perp}
 - Longitudinal and transverse phases ϕ_L, ϕ_{\perp}
- Fit separately B^0 and B^0 samples
 - Look for CP asymmetries



- From fitted parameters derived the triple product asymmetries:

$$A_T^{\parallel,0} = \frac{1}{2} \left(\frac{\text{Im}(A_{\perp}^+ A_{\parallel,0}^{+*})}{\Sigma |A_m^+|^2} + \frac{\text{Im}(A_{\perp}^- A_{\parallel,0}^{-*})}{\Sigma |A_m^-|^2} \right)$$

sensitive to T-odd CP violation

$\phi_L, \phi_{\perp} \neq 0$ can be generated by Final State Interaction



$B \rightarrow \phi K^*$

$\mathcal{L} = 227 \times 10^6$ BB pairs

BABAR
Summer 2004

Angular Fit

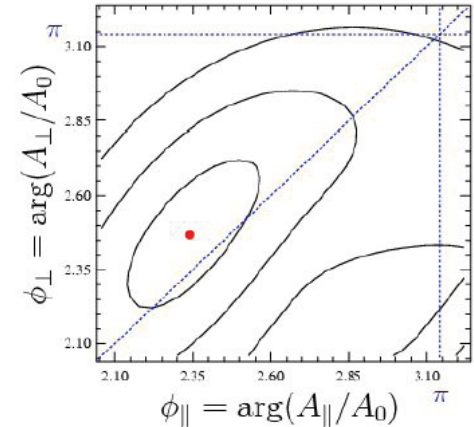
$$f_L = 0.52 \pm 0.05 \pm 0.02$$

$$f_{\perp} = 0.22 \pm 0.05 \pm 0.02$$

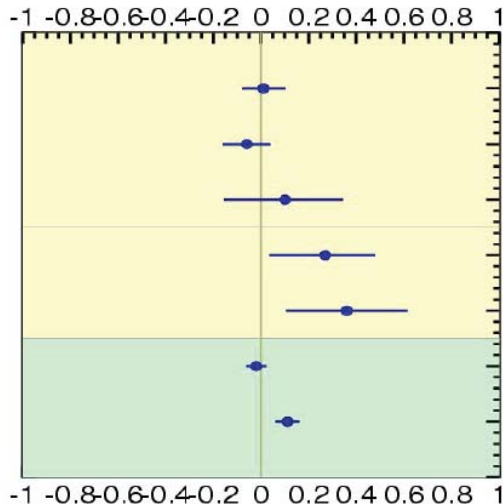
$$\phi_{\parallel} = 2.34^{+0.23}_{-0.20} \pm 0.05 \text{ (rad)}$$

$$\phi_{\perp} = 2.47 \pm 0.25 \pm 0.05 \text{ (rad)}$$

} Observed FSI $> 3\sigma$



CP Search



$$A_{CP} = -0.01 \pm 0.09 \pm 0.02$$

$$A_{CP}^0 = -0.06 \pm 0.10 \pm 0.01$$

$$A_{CP}^{\perp} = -0.10 \pm 0.24 \pm 0.05$$

$$\Delta\phi_{\parallel} = 0.27^{+0.20}_{-0.23} \pm 0.05 \text{ (rad)}$$

$$\Delta\phi_{\perp} = 0.36 \pm 0.25 \pm 0.05 \text{ (rad)}$$

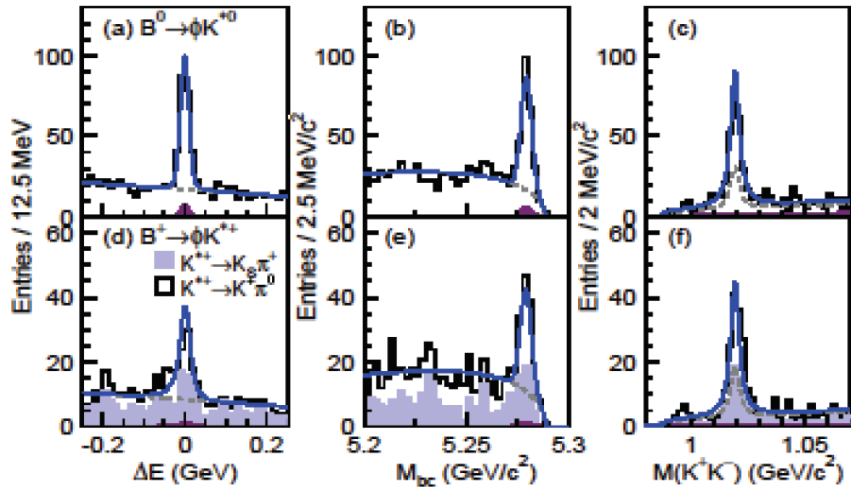
$$A_T^{\parallel} = -0.02 \pm 0.04 \pm 0.01$$

$$A_T^0 = +0.11 \pm 0.05 \pm 0.01$$

Direct CP Asymmetries

T-odd CP Asymmetries

$B \rightarrow \phi K^*$



$$\frac{d^3 R_{\phi K^*}(\phi_{\text{tr}}, \cos \theta_{\text{tr}}, \cos \theta_{K^*})}{d\phi_{\text{tr}} d \cos \theta_{\text{tr}} d \cos \theta_{K^*}} = \frac{9}{32\pi} \left[\begin{aligned} & |A_{\perp}|^2 2 \cos^2 \theta_{\text{tr}} \sin^2 \theta_{K^*} \\ & + |A_{\parallel}|^2 2 \sin^2 \theta_{\text{tr}} \sin^2 \phi_{\text{tr}} \sin^2 \theta_{K^*} \\ & + |A_0|^2 4 \sin^2 \theta_{\text{tr}} \cos^2 \phi_{\text{tr}} \cos^2 \theta_{K^*} \\ & + \sqrt{2} \text{Re}(A_{\parallel}^* A_0) \sin^2 \theta_{\text{tr}} \sin 2\phi_{\text{tr}} \sin 2\theta_{K^*} \\ & - \eta \sqrt{2} \text{Im}(A_0^* A_{\perp}) \sin 2\theta_{\text{tr}} \cos \phi_{\text{tr}} \sin 2\theta_{K^*} \\ & - 2\eta \text{Im}(A_{\parallel}^* A_{\perp}) \sin 2\theta_{\text{tr}} \sin \phi_{\text{tr}} \sin^2 \theta_{K^*} \end{aligned} \right],$$