Charmless Hadronic B Decays at BaBar

Woochun Park
University of South Carolina

Representing the BaBar Collaboration

PHENO '07 @Univ of Wisconsin
May 7, 2007

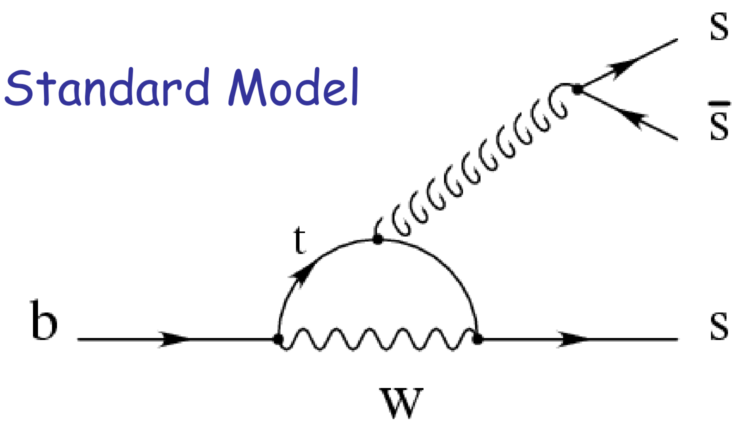
USC HEP
University of South Carolina
High Energy Physics Group

BABAR

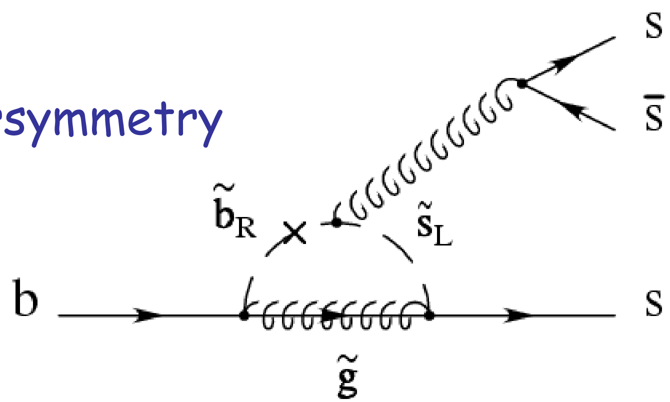
Introduction to Charmless Decays

- Dominated by SM-suppressed b→u tree amplitudes. Also, transitions involving b→s and b→d penguin amplitudes.
  - Small branching fractions, ~10^{-6} in Standard Model
  - Virtual loops sensitive to new physics contributions.
- Important probes of the CKM mechanism (α, β, and γ)
- Rich program at the B factories
  - Branching fractions and CP asymmetry measurements
  - Polarization measurements in vector-vector and vector-tensor modes.

Standard Model



Supersymmetry



Overview of This Talk

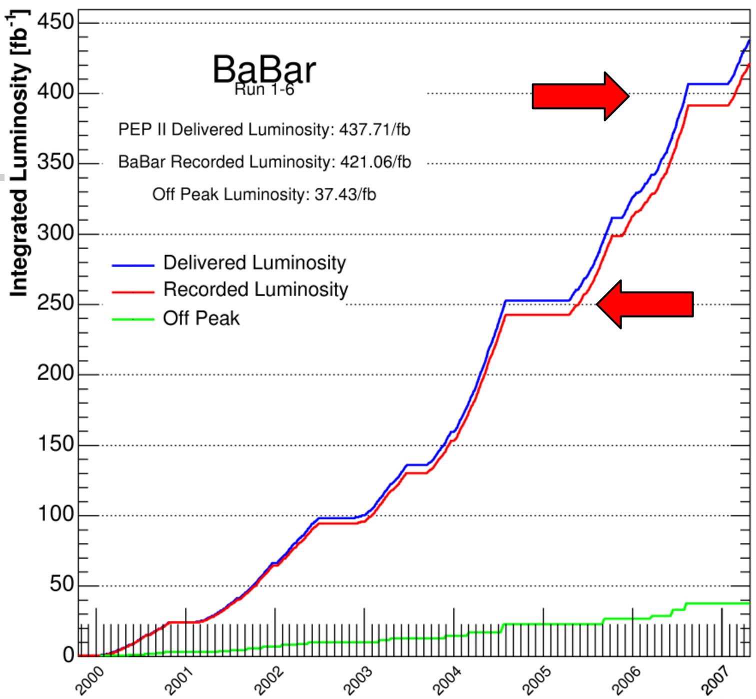
- Vector-Vector and Vector-Tensor modes
  - BR's, CP asymmetries, and polarization measurements
  - $B^0 \to \phi K^*(892)^0$ and $\phi K^*_2(1430)^0$ [PRL **98** 051801(2007)]
  - Search for $B^0 \to \phi (K\pi)^*$ with large $K\pi$ invariant mass [arXiv:0705.0398 [hep-ex]]
  - $B \to K^*\rho$ [PRL **97** 201801 (2006)]
- Search for $B^0 \to K_1(1270)^+ \pi^-$ and $B^0 \to K_1(1400)^+ \pi^-$ [Preliminary Result]
- Direct CP violation in $B^0 \to K^+ \pi^-$ [hep-ex/0703016]

α **angle** : See Marc Escalier's talk
β **angle**: See Roberto Covarelli's talk

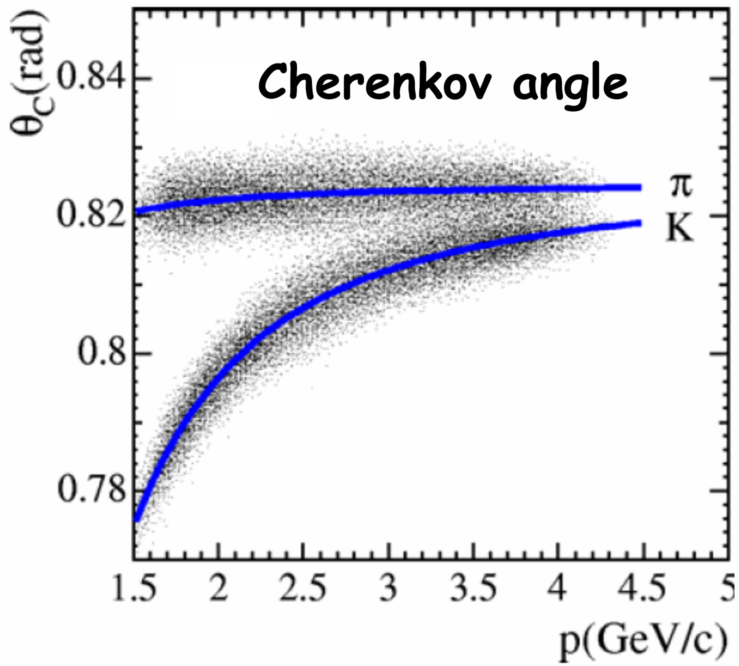
04/27/2007 04:15

BaBar Dataset and Detector

- Need large data samples to probe BF~10^{-6}
  - > 420 fb^{-1} delivered.
  - 223M or 384M B pair samples used for analyses presented here.



- BaBar Detector for Charmless B decay analyses
  - Good neutral energy resolution
  - Charged K/π separation more than 2σ with Cherenkov angle + dE/dx .

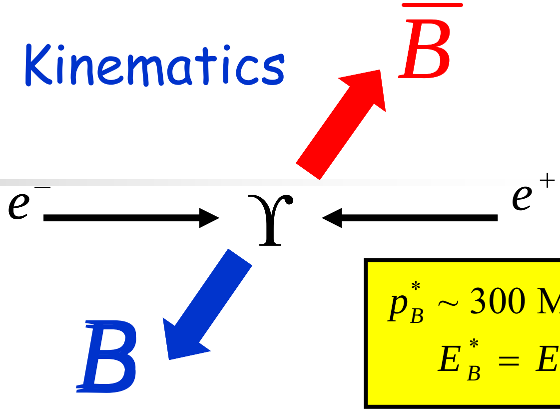


USC HEP
University of South Carolina
High Energy Physics Group

Analysis Method

- Perform maximum likelihood fit
  - Kinematic variables: beam energy substitute mass (m_{ES}), ΔE and resonance invariant masses
  - Event-shape variables to distinguish from continuum event
  - Fit for Branching fraction, CP asymmetries, and polarization parameters.

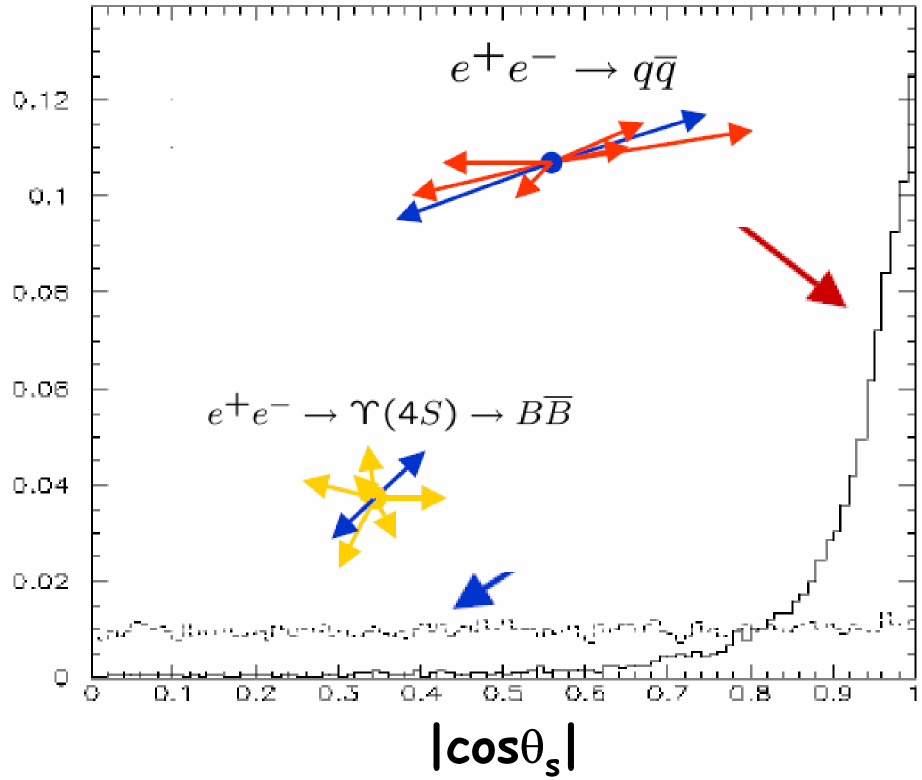
Kinematics



$p_B^* \sim 300\ \text{MeV}/c$

$E_B^* = E_{\text{beam}}^*$

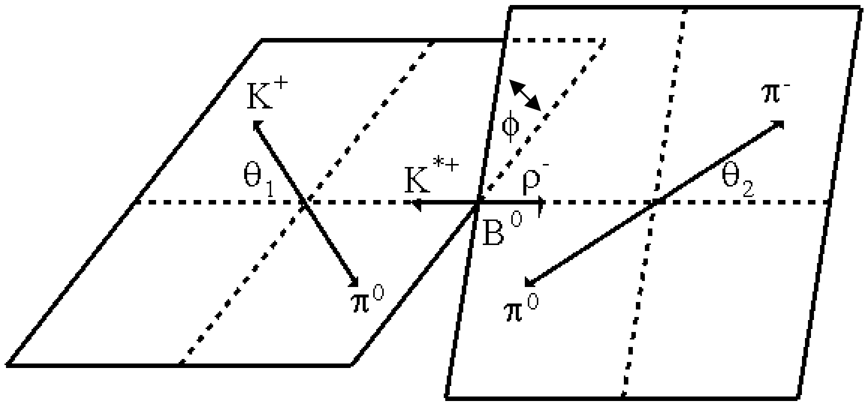
$m_{\text{ES}} = \sqrt{E_{\text{beam}}^{*2} - p_B^{*2}}$ $\Delta E = E_B^* - E_{\text{beam}}^*$



B→VV Decays : Helicity Amplitude and Angular analysis

- Full amplitude ananlysis can be simplified to separate longitudinal and transverse events with low statistics and measure:
  - Longitudinal polarization fraction f_L

$$f_L = \frac{|A_0|^2}{|A_0|^2 + |A_{+1}|^2 + |A_{-1}|^2}$$



- Analogous to H→ZZ→ $l^+l^-\, l^+l^-$ @ LHC.

$$\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\Phi} \propto \left| \sum_{|m|\le J_1,J_2} A_m \times Y_{J_1,m}(\theta_1,0) \times Y_{J_2,-m}(\pi-\theta_2,-\Phi) \right|^2$$

$$\propto \begin{cases} \frac{1}{4}\sin^2\theta_1 \sin^2\theta_2 (|A_{+1}|^2 + |A_{-1}|^2) + \cos^2\theta_1 \cos^2\theta_2 |A_0|^2 \\ +\frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 [\cos 2\Phi \Re(A_{+1}A_{-1}^*) - \sin 2\Phi \Im(A_{+1}A_{-1}^*)] \\ +\frac{1}{4}\sin 2\theta_1 \sin 2\theta_2 [\cos\Phi \Re(A_{+1}A_0^* + A_{-1}A_0^*) - \sin\Phi \Im(A_{+1}A_0^* - A_{-1}A_0^*) \end{cases}$$

Integrate over Φ

$$\frac{dN}{d\cos\theta_1 d\cos\theta_2} = f_L \times (\cos\theta_1 \cos\theta_2)^2 + (1 - f_L) \times \frac{1}{4} (\sin\theta_1 \sin\theta_2)^2$$

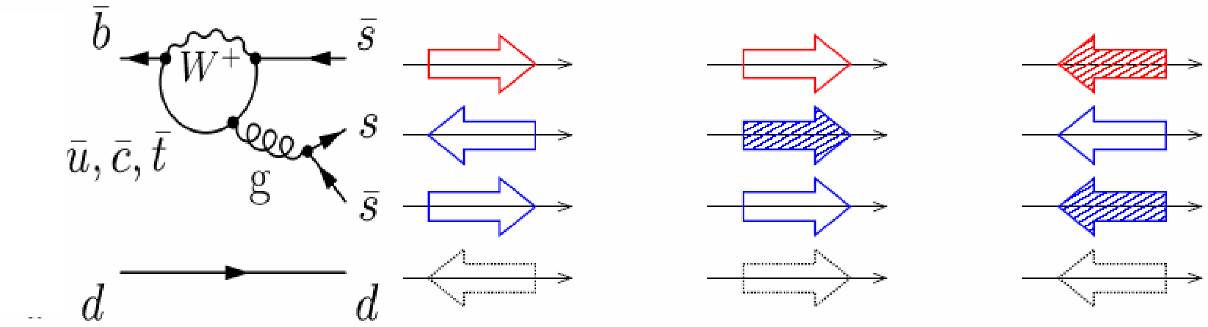
USC HEP
University of South Carolina High Energy Physics Group

Expectation of f_L

Standard Model:
left-handed quarks
and spin flip suppression:

$\bar{q}W^+ \rightarrow \bar{s} \Rightarrow \lambda_{\bar{s}} = +\frac{1}{2}$ $g \rightarrow s\bar{s} \Rightarrow \lambda_s = \pm\frac{1}{2},\ \lambda_{\bar{s}} = \mp\frac{1}{2}$

(A.Ali; M.Suzuki; A.Kagan,..) $A_0 \sim 1 \gg A_+ \sim \frac{m_V}{m_B} \gg A_- \sim \frac{m_V^2}{m_B^2}$

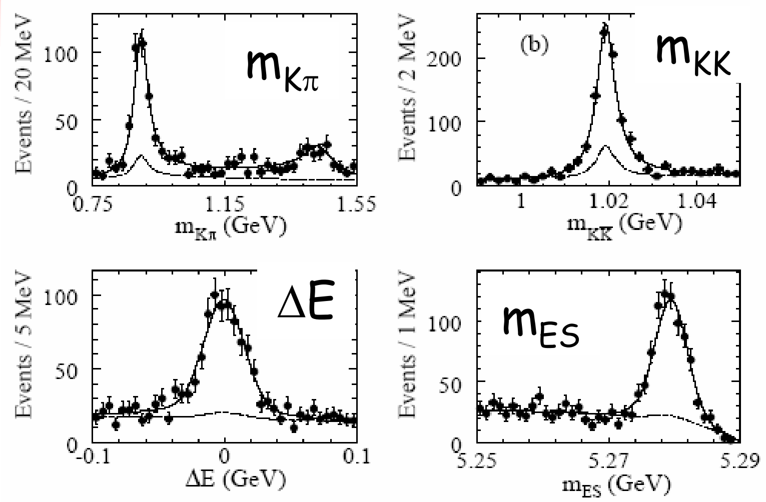


- We expect longitudinally polarized decays to dominate:
  - Confirmed (f_L ~ 0.82-0.98) in B→ρω, ρρ (tree-dominated).
  - We investigate penguin-dominated VV and VT decays.
- Other amplitudes could decrease f_L:
  - SM: annihilation contribution, re-scattering effect, magnetic penguin, small B→K* form factor……
  - NP: Right-handed supersymmetric mass insertions, tensor Z″,…

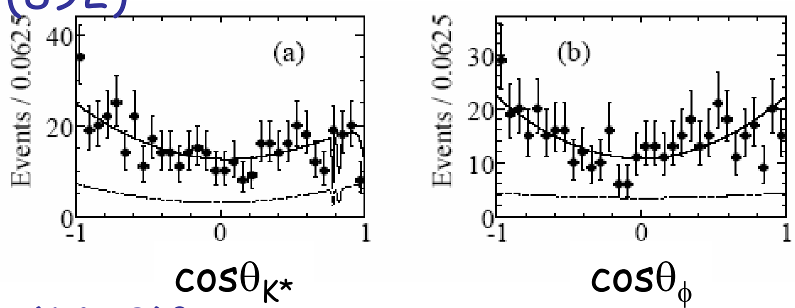
Previous VV results

	f_L
$\omega\rho^+$	0.82±0.11
$\rho^+\rho^0$	0.91±0.05
$\rho^0\rho^0$	0.86±0.13
$\rho^+\rho^-$	0.97±0.02

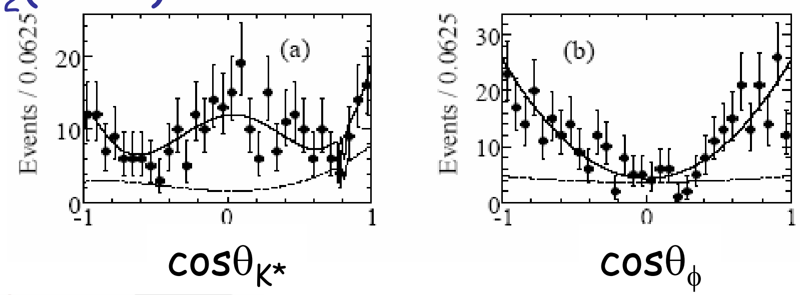
$B^0 \to \phi K^*(892)^0$ and $B^0 \to \phi K^*_2(1430)^0$ 384M BB PRL **98** 051801(2007)



$\phi K^*(892)^0$



$\phi K^*_2(1430)^0$



Full amplitude analysis

Mode	$\mathcal{S}$ (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{A}_{CP}$
$\phi K^*(892)^0$	21.0	$9.2 \pm 0.7 \pm 0.6$	$-0.03 \pm 0.07 \pm 0.03$
$\phi K^*_2(1430)^0$	9.7	$7.8 \pm 1.1 \pm 0.6$	$-0.12 \pm 0.14 \pm 0.04$
$\phi(K\pi)^{*0}_0$	9.8	$5.0 \pm 0.8 \pm 0.3$	$+0.17 \pm 0.15 \pm 0.03$
$\phi K^*_0(1430)^0$		$4.6 \pm 0.7 \pm 0.6$	

	$B^0 \to \phi K^*_2(1430)^0$	$B^0 \to \phi K^*(892)^0$
f_L	$0.853^{+0.061}_{-0.069} \pm 0.036$	$0.506 \pm 0.040 \pm 0.015$
$f_\perp$	$0.045^{+0.049}_{-0.040} \pm 0.013$	$0.227 \pm 0.038 \pm 0.013$
δ_0	$3.54^{+0.12}_{-0.14} \pm 0.06$	$2.78 \pm 0.17 \pm 0.09$

$$\delta_0 \propto \arg\left(\frac{A_{\text{S-Wave}}}{A_0}\right)$$

While VT shows large f_L values, VV shows f_L~0.5. (puzzle!!)

$B^0 \to \phi K^*(892)^0$ and $B^0 \to \phi K^*_2(1430)^0$ 384M BB PRL **98** 051801(2007)

	$B^0 \to \phi K^*(892)^0$	$B^0 \to \phi K_2^*(1430)^0$
$\phi_\parallel$	$2.31 \pm 0.14 \pm 0.08$	$2.90 \pm 0.39 \pm 0.06$
$\phi_\perp$	$2.24 \pm 0.15 \pm 0.09$	$5.72^{+0.55}_{-0.87} \pm 0.11$

$\phi_\parallel = \arg(\frac{A_\parallel}{A_0}) \quad \phi_\perp = \arg(\frac{A_\perp}{A_0})$

$\phi_\parallel$ and $\phi_\perp$ away from either π or zero.

➡ **Indicating the presence of final state interactions for VV and VT.**

VV $\phi_\parallel \simeq \phi_\perp$

$\Rightarrow |A_\parallel| \simeq |A_\perp|$ ➡ $|A_0| \simeq |A_{+1}| \gg |A_{-1}|$

$A_\parallel = \frac{A_{+1}+A_{-1}}{\sqrt{2}}$

$A_\perp = \frac{A_{+1}-A_{-1}}{\sqrt{2}}$

in VV ambiguity resolved

$|A_+| >> |A_-|$ vs. $|A_-| >> |A_+|$

While similar presence of FSI, still $f_L(VV) \neq f_L(VT)$ (puzzle)

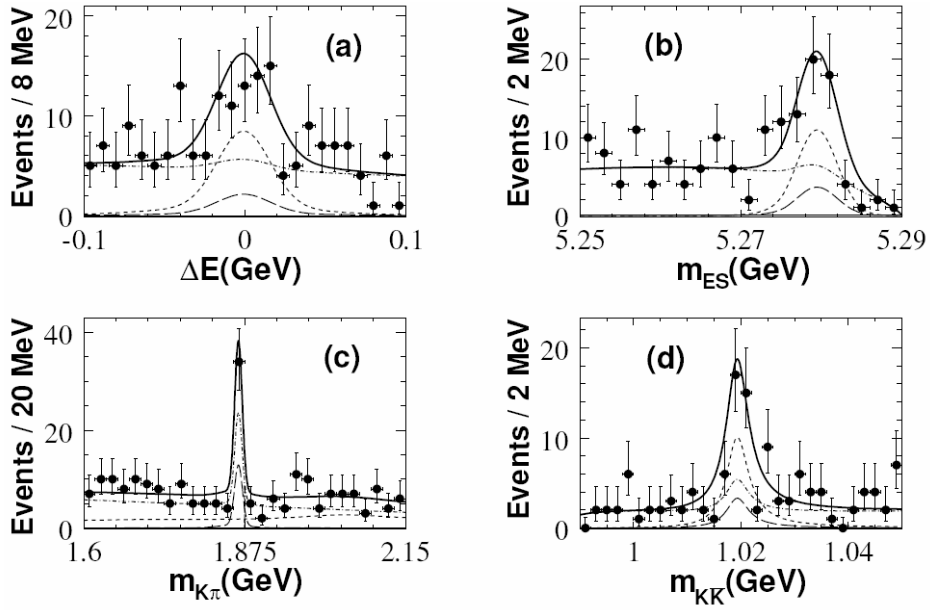
Indication of a new physics contribution???

$B^+ \to \phi K^*(892)^+$ analysis will be ready in FPCP'07.

Search for ϕ (Kπ)*0 with large Kπ invariant mass

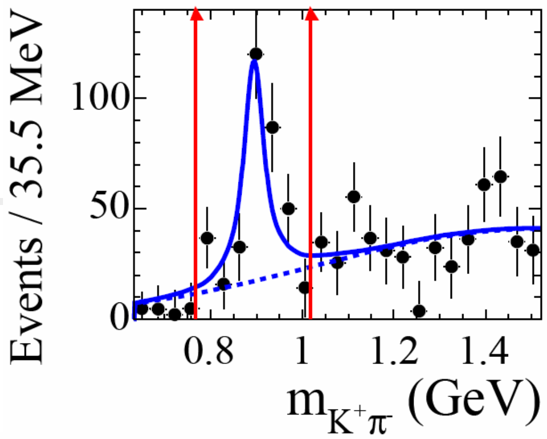
384 M BB arXiv:0705.0398 [hep-ex]

- We extend the B→ϕK*(892)0 analysis to higher-mass and higher-spin resonances.
- However, B→ϕD0 is highly suppressed in the SM.
- As a first measurement, we report several BF upper limits.
- D0 mass peak is predominantly due to f(980)0D0 and continuum.



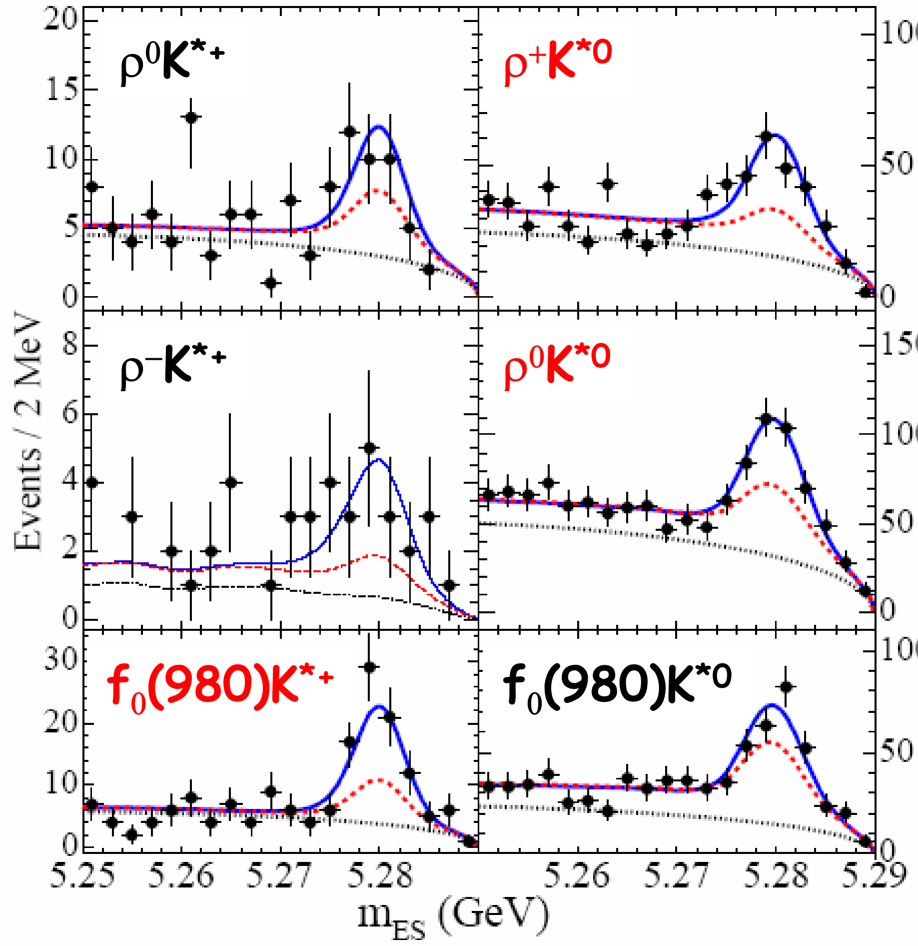
Mode	$\mathcal{S}$ (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ UL (10^{-6})
$\phi K^*(1680)^0$	0.6	$0.7^{+1.0}_{-0.7} \pm 1.1$	3.5
$\phi K_3^*(1780)^0$	0.0	$-0.9 \pm 1.4 \pm 1.1$	2.7
$\phi K_4^*(2045)^0$	1.2	$6.0^{+4.8}_{-4.0} \pm 4.1$	15.3
$\phi(K\pi)_0^{*0}$	2.2	$1.1 \pm 0.4 \pm 0.3$	1.7
$\phi\overline{D}^0$	2.4	$6.5^{+3.1}_{-2.7} \pm 1.4$	11.6

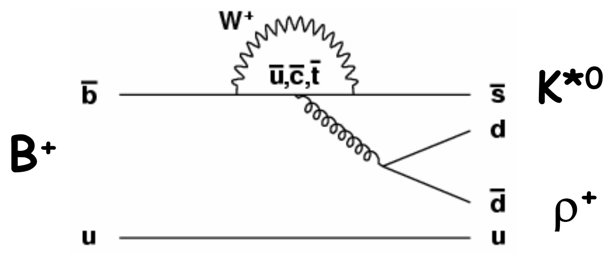
B→K(892)*ρ   232M BB PRL **97** 201801 (2006)

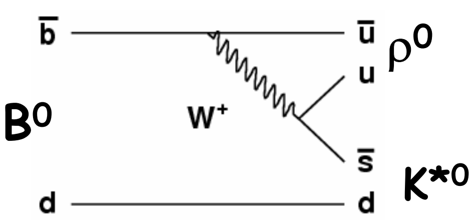


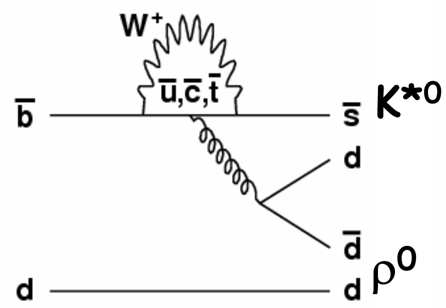
- The puzzle could be resolved by studying two other VV modes: $K^*(892)^0\rho^+$ and $K^*(892)^0\rho^0$

- As in the K(892)*φ mode, it is critical to understand the non-resonant background in these analyses such as $f_0(980)K^{*+}$.





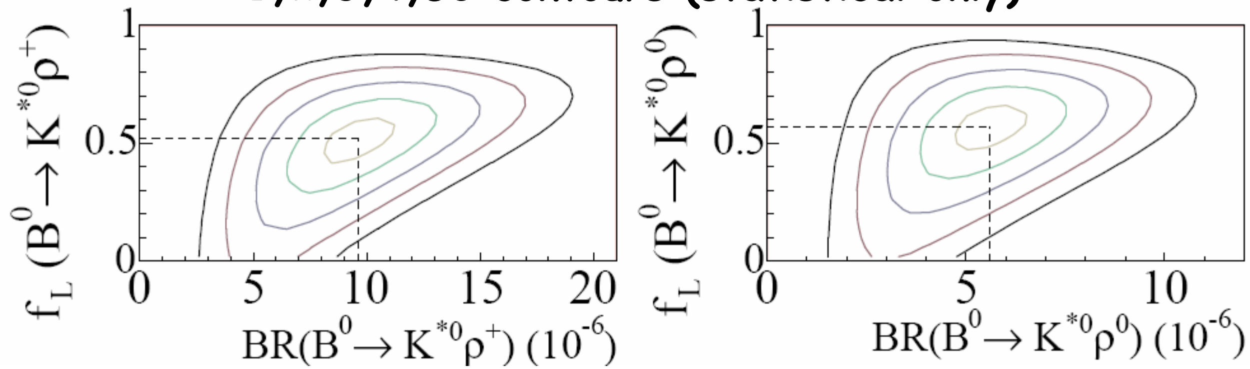




University of South Carolina High Energy Physics Group

B→K*ρ PRL 97 201801 (2006)

1,2,3,4,5σ contours (statistical only)



Mode	n_{sig}	$\varepsilon(\%)$	$\prod \mathcal{B}_i(\%)$	$S(\sigma)$	$\mathcal{B}(10^{-6})$	f_L	$\mathcal{A}_{CP}$
$\rho^0 K^{*+}$				2.5	$3.6^{+1.7}_{-1.6} \pm 0.8\ (6.1)$	$[0.9 \pm 0.2]$	–
$\rightarrow \rho^0 K^{*+}_{K^+\pi^0}$	19^{+16}_{-15}	7.9	32.9	1.3	$3.2^{+2.7}_{-2.4} \pm 0.9$	$[0.8^{+0.3}_{-0.5}]$	–
$\rightarrow \rho^0 K^{*+}_{K^0_S\pi^+}$	32^{+19}_{-17}	15.8	22.9	2.1	$3.8^{+2.2}_{-2.1} \pm 0.9$	$[1.0 \pm 0.3]$	–
$\rho^+ K^{*0}$	194 ± 29	13.5	66.7	7.1	$9.6 \pm 1.7 \pm 1.5$	$0.52 \pm 0.10 \pm 0.04$	$-0.01 \pm 0.16 \pm 0.02$
$\rho^- K^{*+}_{K^+\pi^0}$	60^{+25}_{-22}	15.2	32.5	1.6	$5.4^{+3.8}_{-3.4} \pm 1.6\ (12.0)$	$[-0.18^{+0.52}_{-1.74}]$	–
$\rho^0 K^{*0}$	185 ± 30	22.9	66.7	5.3	$5.6 \pm 0.9 \pm 1.3$	$0.57 \pm 0.09 \pm 0.08$	$0.09 \pm 0.19 \pm 0.02$
$f_0(980) K^{*+}$				5.0	$5.2 \pm 1.2 \pm 0.5$	–	$-0.34 \pm 0.21 \pm 0.03$
$\rightarrow f_0(980) K^{*+}_{K^+\pi^0}$	40^{+13}_{-12}	8.5	32.9	3.8	$6.2^{+2.1}_{-1.9} \pm 0.7$	–	$-0.50 \pm 0.29 \pm 0.03$
$\rightarrow f_0(980) K^{*+}_{K^0_S\pi^+}$	37^{+14}_{-12}	16.6	22.9	3.2	$4.2^{+1.5}_{-1.4} \pm 0.5$	–	$-0.13 \pm 0.30 \pm 0.01$
$f_0(980) K^{*0}$	83 ± 19	21.7	66.7	3.5	$2.6 \pm 0.6 \pm 0.9\ (4.3)$	–	$-0.17 \pm 0.28 \pm 0.02$

$B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$

Preliminary Result

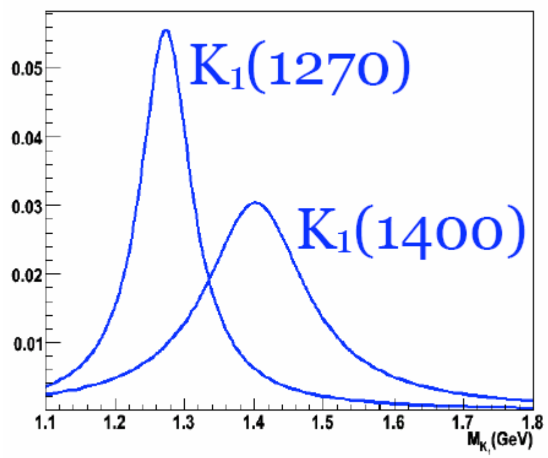
- Motivation:
  - CKM angle $\alpha_{eff}=(78.6\pm7.3)^\circ$ measured by time-dependent CP fit of $B^0\to a_1^+\pi^-$ @BaBar PRL 98 181803 (2007).
  - To bound $|\Delta\alpha|$ using flavor SU(3) symmetry, we need to measure BF($B\to K_1\pi$)

$$|\alpha - \alpha_{\rm eff}| \le \tfrac{1}{2}(|\alpha - \alpha^{+}_{\rm eff}| + |\alpha - \alpha^{-}_{\rm eff}|).$$

depends on BF($B\to K_1\pi$) — depends on BF($B\to a_1K$)

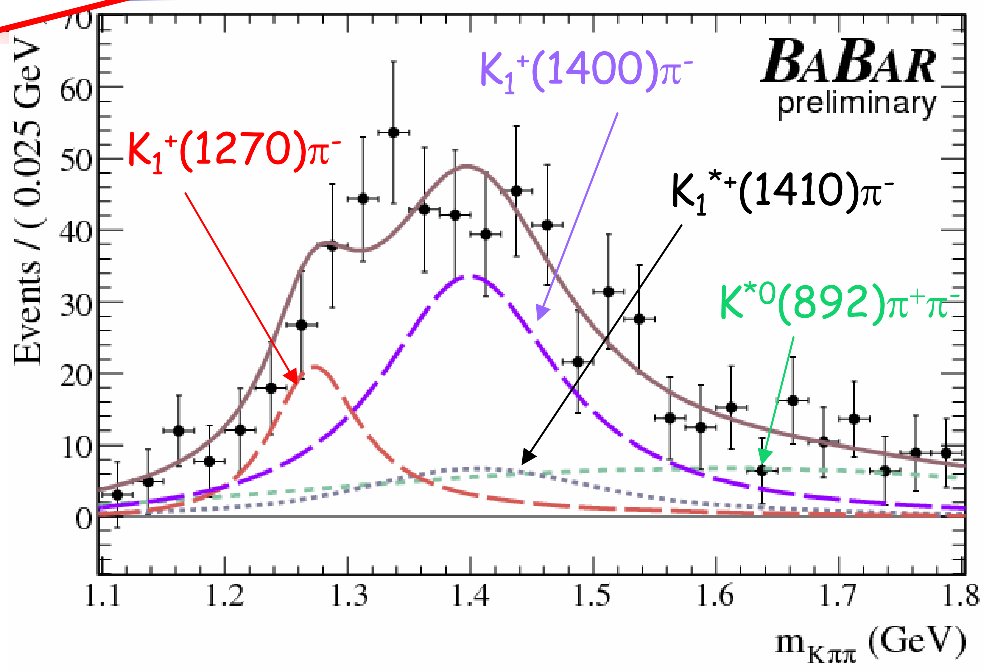
[Gronau & Zupan, Phys. Rev. D73, 057502 (2006)]

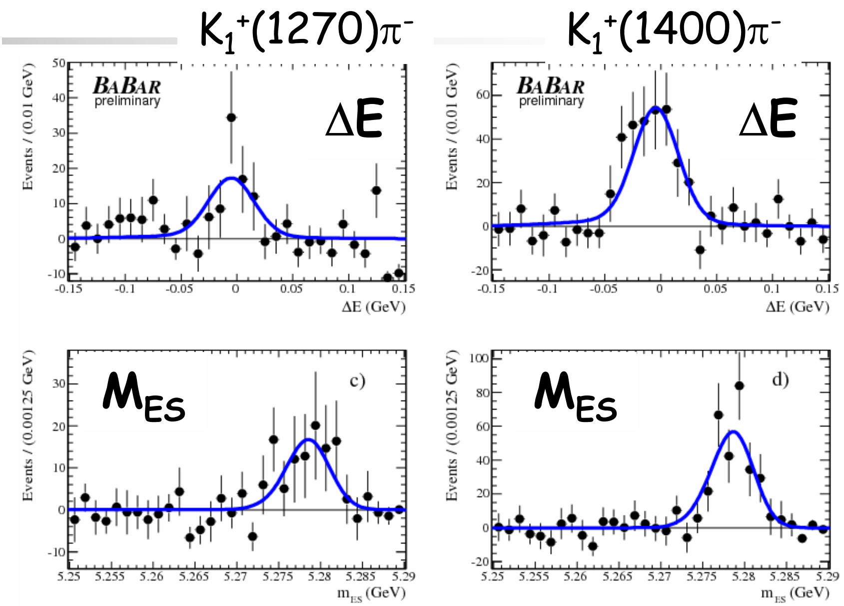
  - BF is also a test of factorization.



USC HEP University of South Carolina High Energy Physics Group

$B^0 \to K_1(1270)^+\pi^-$ and $K_1(1400)^+\pi^-$





Figures use sPlot background subtraction technique [Pivk, Le Diberder, NIM A 555, 356 (2005)]

Significance limited by interference uncertainty.

Possible Evidence for $K_1^+(1400)\pi^-$

Measured preliminary BF larger but not incompatible with factorization prediction.

	$K_1^+(1270)\pi^-$	$K_1^+(1400)\pi^-$
Signal yield	109 ± 29	318 ± 46
Significance	2.3σ	3.0σ
BF [10^{-6}]	$12.0 \pm 3.1^{+9.3}_{-4.5}$	$16.7 \pm 2.6^{+3.5}_{-5.0}$
90% C.L. UL	<25.2	<21.8

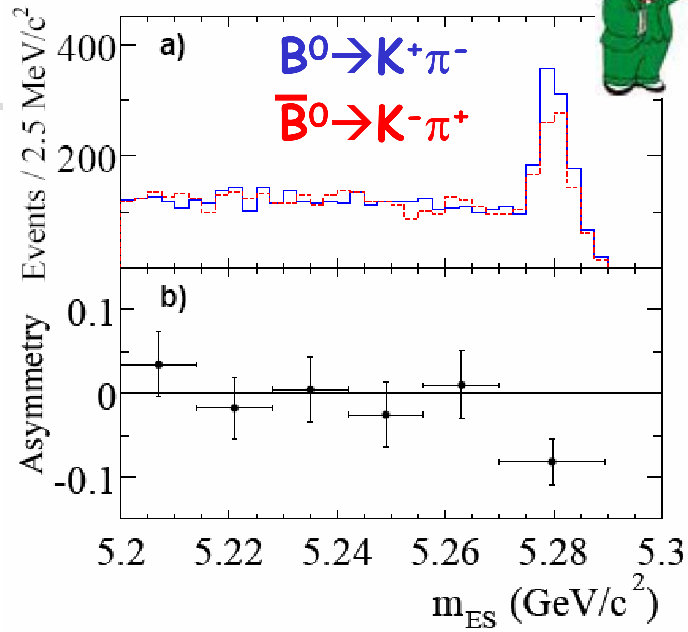
Factorization 7.6 4.0

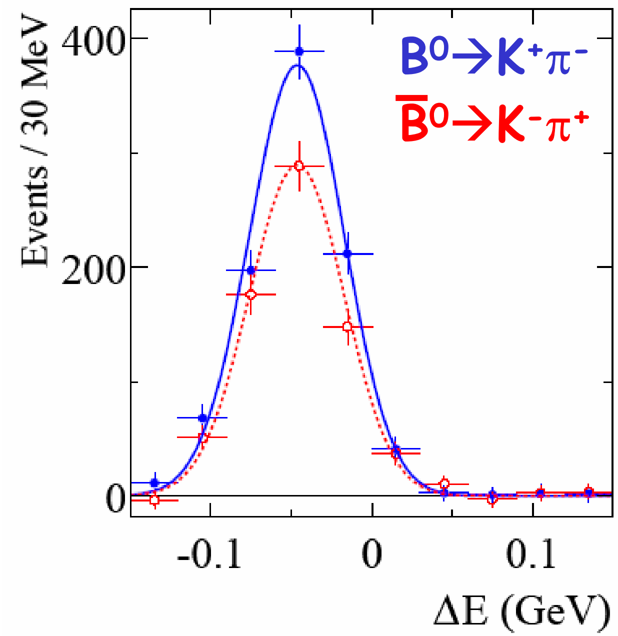
[Laporta et al. PRD 74, 054035 (2006)]

University of South Carolina High Energy Physics Group

Direct CP violation in B→$K^+\pi^-$

- Clear Direct CP violation signature
  - While background level is similar in sideband region, number of signal events is different.
- Updated with 384M B pairs [hep-ex/0703016].
  - $n(K^+\pi^-) = 4372 \pm 82$
  - 5.5σ significance to exclude CP-conserving hypothesis.





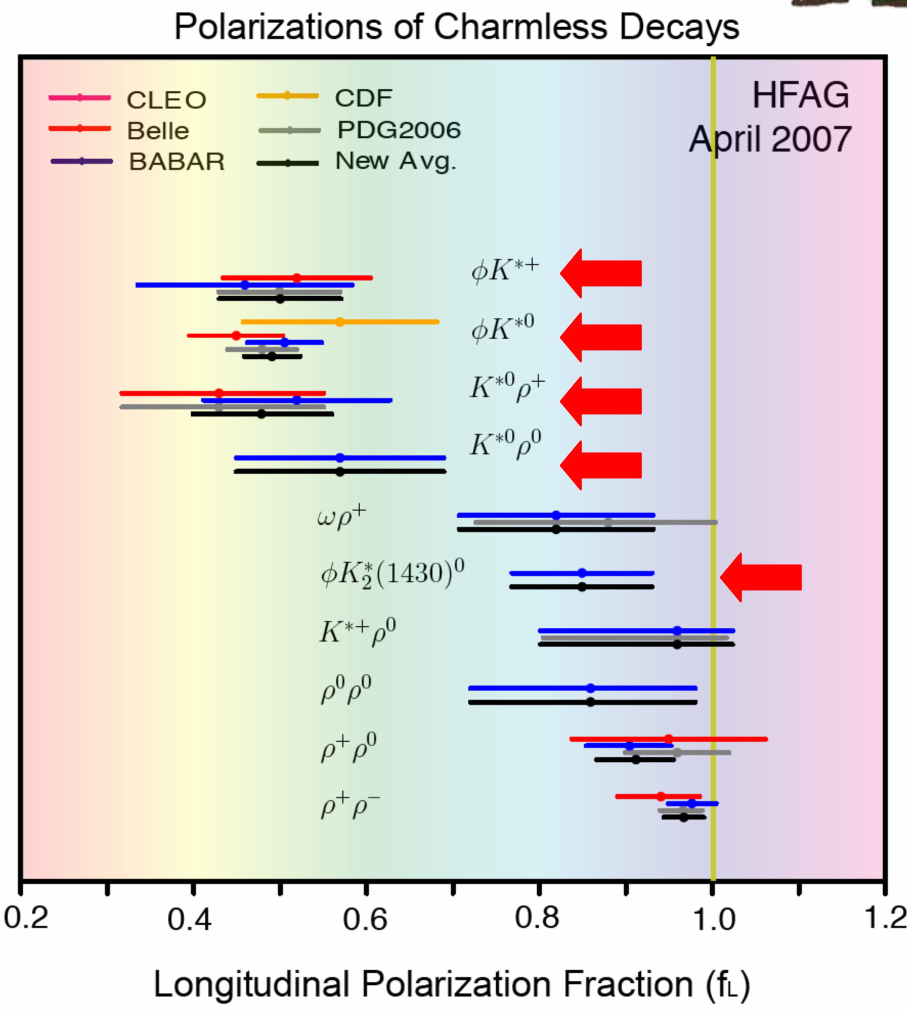
$$\mathcal{A}_{K\pi} = -0.107 \pm 0.018\,(\text{stat})^{+0.007}_{-0.004}\,(\text{syst})$$

USC HEP
University of South Carolina
High Energy Physics Group

Conclusion

- f_L measurements have been done in VV and VT decays and it's a puzzle.

	f_L
$\phi K^*(892)^+$	0.49 ± 0.06
$\phi K^*(892)^0$	0.51 ± 0.05
$\rho^+ K^*(892)^0$	0.52 ± 0.11
$\rho^0 K^*(892)^0$	0.57 ± 0.13
$\phi K^*_2(1430)^0$	0.85 ± 0.07



- New BF upper limits on
  - $K_1(1270)^+ \pi^-$ and $K_1(1400)^+ \pi^-$
- Direct CP violation becomes more significant 5.5 σ with updated $B^0 \rightarrow K^+\pi^-$ analysis.

Feynman Diagram