Charmless B Decays at CLEO

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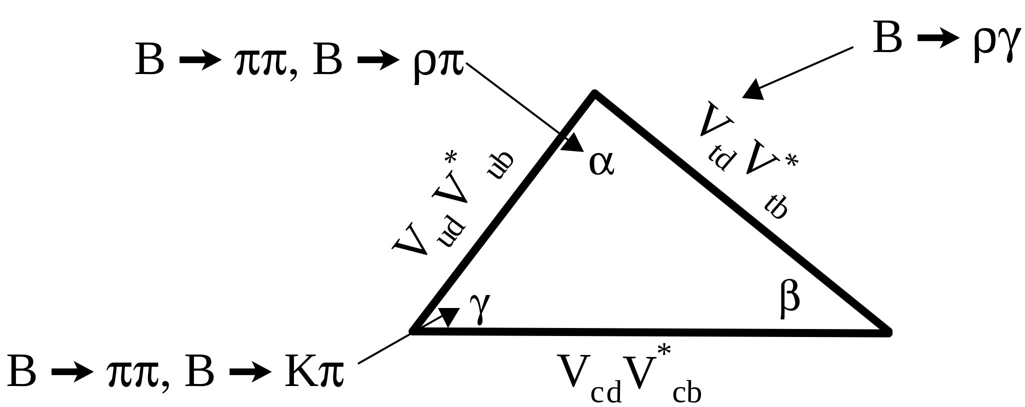
- Motivation
- New measurment on B $\rightarrow \Phi$ K
- Hadronic b-u transitions
- New limit on B $\rightarrow \pi^0 \pi^0$
- B $\rightarrow$ charmless PV states:
- B $\rightarrow$ charmless PP states:
- B decays with η and η' in final state
- First search for direct CP violation in B decays
- B $\rightarrow e^+e^-, \mu^+\mu^-, e^{\pm}\mu^{\mp}$
- Summary

Motivation

Rare B decay measurements will help to construct a description of the weak quark couplings and phases.

- Testing the unitarity of the CKM matrix:
  - Measurement of $\beta+\gamma$: $B \to \pi\pi, \rho\pi$
  - Measurement of γ: $B \to K\pi$



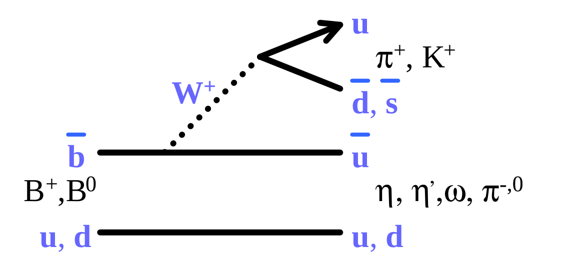
- CP-violation outside the Kaon sector:
  - direct: $B \to K\pi$, $B \to K^*\pi$
  - mixing induced: $B \to \pi\pi, \rho\pi$
- Search for non SM physics

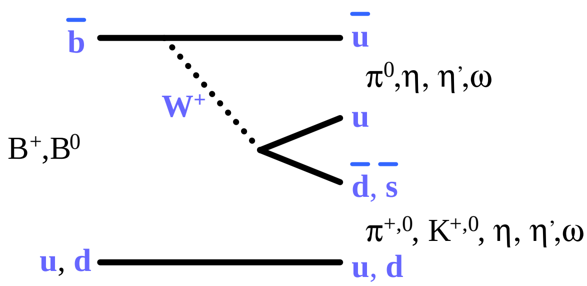
Introduction

Look for B ➞ PP or PV (P = pseudoscalar, V = vector)

Dominant diagrams:

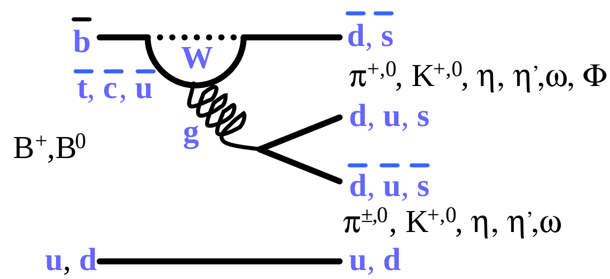
Tree



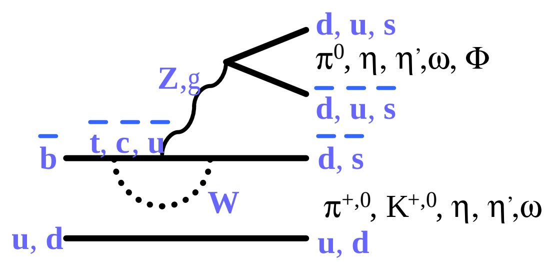


color suppressed

Penguin



gluonic



electroweak

Most modes have several interfering contributions.

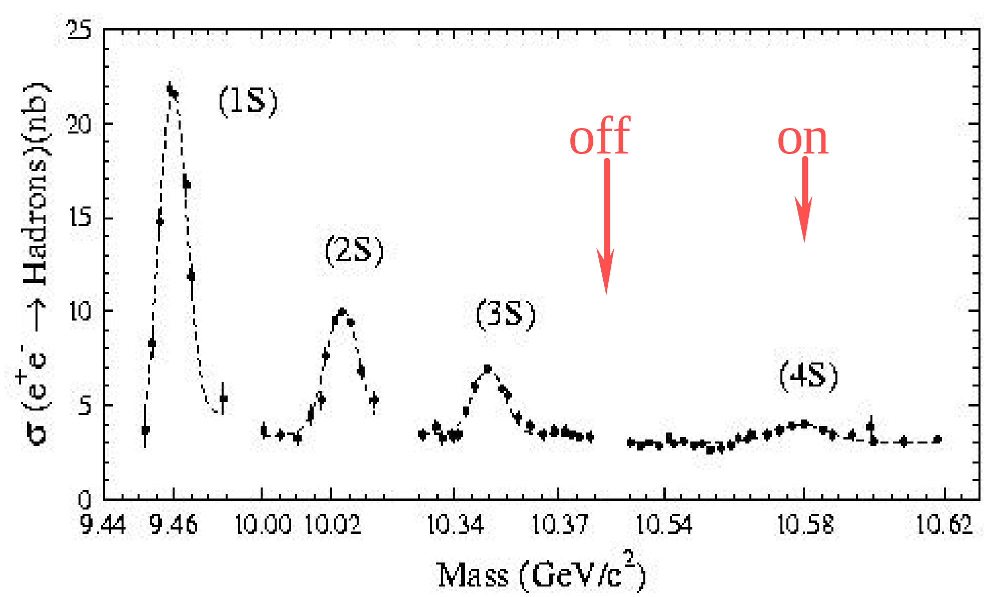
➩ Need to measure many related modes to disentangle the weak phases using isospin or SU(3) symmetries.

➩ May give rise to direct CP violation.

QCD corrections can obscure the weak physics.

The CLEO Experiment at the CESR Storage Ring

- All presented results use entire data sample:
- On Resonance:
  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$: 9.7×10^6 9.1 fb^{-1}
- Off Resonance:
  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow qq$: $\sim 3 \times 10^7$ 4.4 fb^{-1}
- Symmetric collider ⇒ $P_B \sim 300$ MeV/c
- CLEO II.V (about 2/3 of data): relevant change for rare B: DR gas ➞ better dE/dx



Observation of $B \to \phi K$ (preliminary)

- Final state is dominantly produced via the gluonic penguin.
- The ϕ is very narrow $\to$ nice signature
- $B \to \phi K \Rightarrow \sin 2\beta$
- Event Selection:
  - highest momentum ϕ and K ($K^{\pm}$or $K_s^0 \to \pi\pi$)
  - dE/dx of fast $K^{\pm}$ consistent with being a K.
  - cuts applied:

    ϕ-mass, K_s-mass, B-mass,

    R2 (event shape variable to reduce non resonant background).

	# events on res.	**# events off res.**	**Efficiency**
$K^{\pm}$	8486	4400	49 %
K^0	1024	505	31 %

Separation of Signal from Background

Unbinned maximum likelihood fit:

$$L(N_s, N_b) = e^{-(N_s+N_b)} \prod_{i}^{N_{on}} (N_s P_s^i + N_b P_b^i)$$

N_s: signal amplitude

N_b: background amplitude

Signal and Background Likelihoods P_s^i , P_b^i:

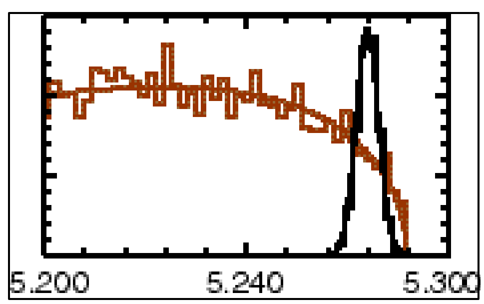
$$P_i = \prod_{j}^{6} p_j(x_j)$$

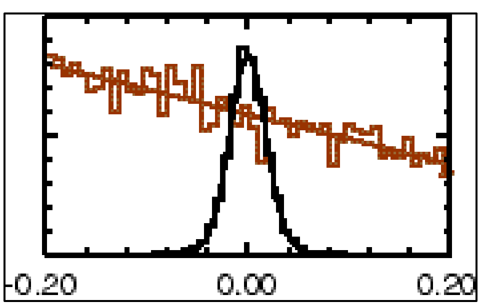
p_j : probability density functions from signal MC & off resonance data

Observables:

<u>Energy & Momentum Constraints</u>

- beam constrained mass of ΦK



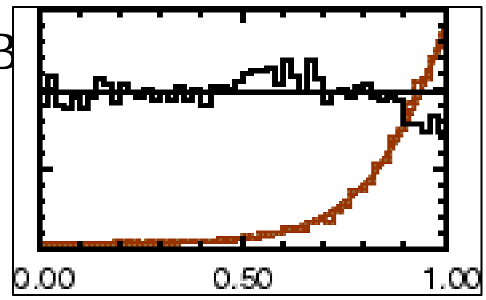


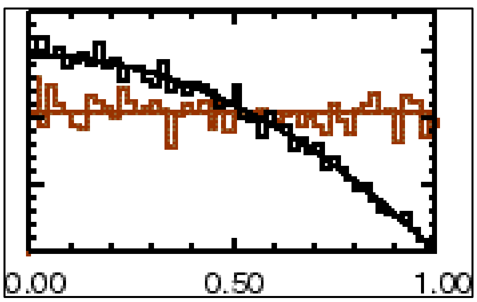
- energy difference E(ΦK)-E_{beam}

Observables

Event Shape:

- $|\cos \Theta_{tt}|$: ΦK thrust axis - other B

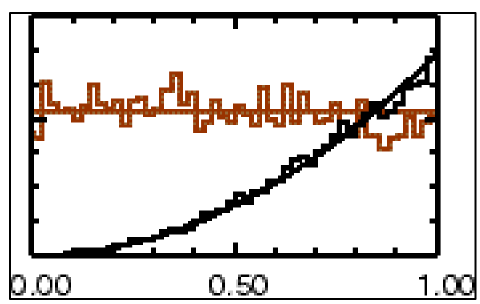


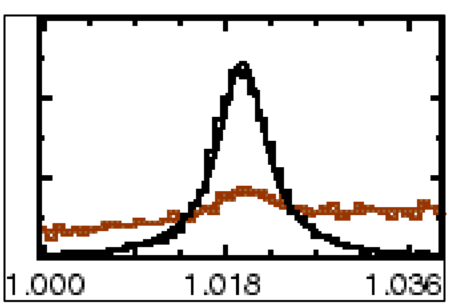


- $|\cos \Theta_B|$ polar angle of ΦK

Other Observables

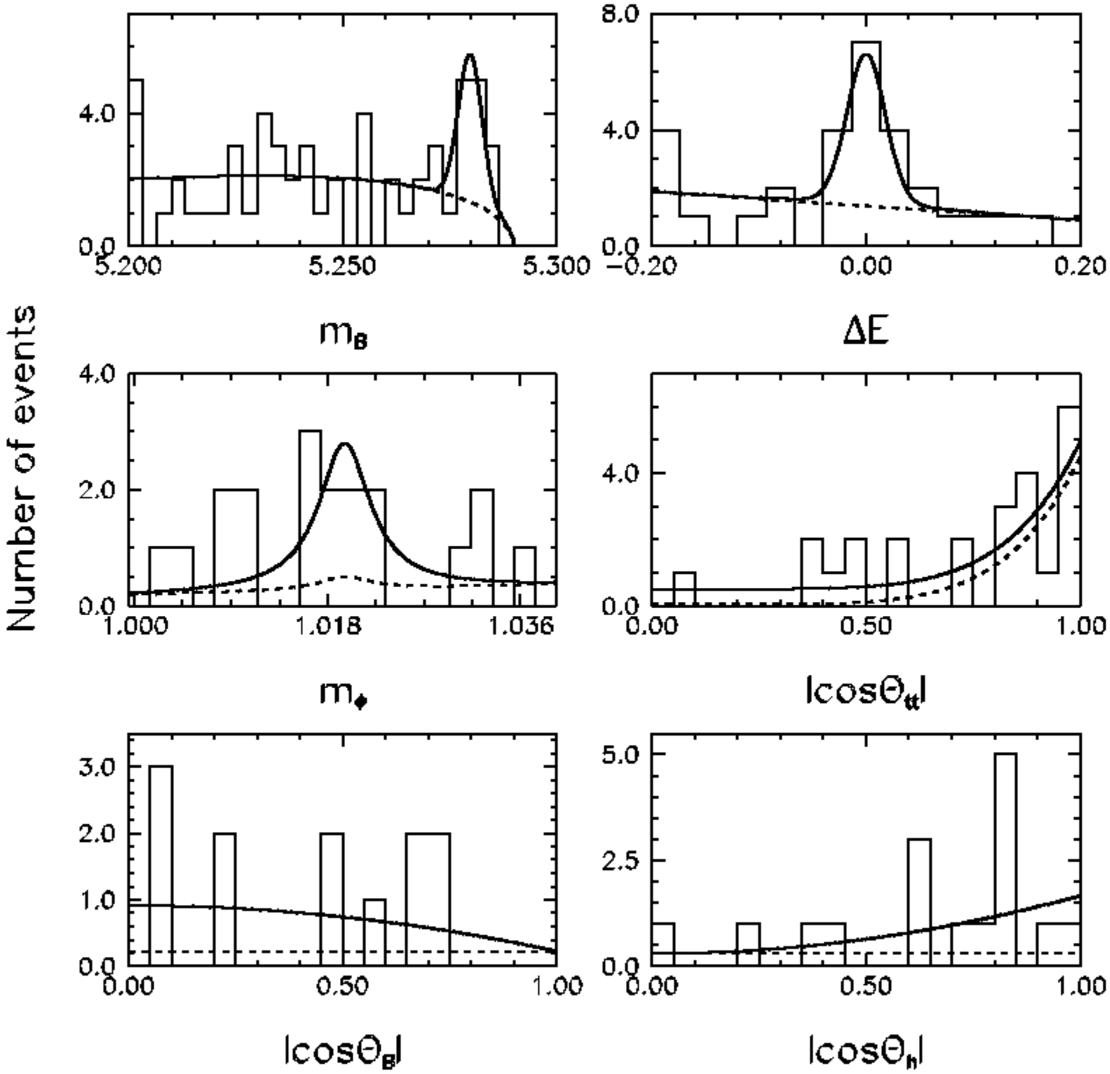
- $|\cos \Theta_h|$ - Φ helicity angle





- mass of Φ candidate

ΦK Data



solid line: Likelihood fit projection

dashed line: background projections only

B → F K Results (preliminary)

	$B^- \rightarrow$ F K^-	$B^0 \rightarrow$ F K_s^0	$B \rightarrow$ F K
signal yield (ev.):	$15.8\ ^{+6.1}_{-5.1}$	$4.3\ ^{+2.9}_{-2.1}$	
significance: $\sqrt{\Delta c^2 (N_s = 0)}$	4.7 σ	2.9 σ	5.6 σ
BR in units of 10^{-6}:	$6.4\ ^{+2.5}_{-2.1}\ ^{+0.5}_{-2.0}$	$5.9\ ^{+4.0}_{-2.9}\ ^{+1.1}_{-0.9}$	$6.2\ ^{+2.0}_{-1.8}\ ^{+0.7}_{-1.7}$
upper limit: (90 % CL)		1.2×10^{-5}	

Agreement with theory:

Deshpande+He:

inclusive $B \rightarrow \Phi X_s \sim (0.6 - 2.0) \times 10^{-4}$

ΦK Fraction of ΦX_s: ~ 10%

Hadronic b-u transitions

Motivation:

- Determine CKM angle α via isospin or time dependent daliz plot analysis.
- Determine CKM angle γ together with πK

First observation: $B \rightarrow \rho^0\pi^\pm$ (1998)

Followed by $B \rightarrow \rho^\pm\pi^\mp$

Further observations:

$B \rightarrow \omega\pi^\pm$

and finally $B \rightarrow \pi^+\pi^-$

But still looking for $B \rightarrow \pi^0\pi^0$:

New limit on B $\rightarrow \pi^0\pi^0$ (preliminary)

- Event selection:
  - selection of π^0:

    shape of showers photon like, photons distinct from tracks, $M(\gamma\gamma)$ within 2.5 σ of π^0 mass
  - beam constrained mass m(B),
  - $|E_{\pi^0\pi^0} - E_{beam}| < 400$MeV,
  - shape cut to reject jetty events
  - number of tracks >2,

  Selection efficiency for B $\rightarrow \pi^0\pi^0$: 32.1 %
- Background Monte Carlo studies:
  - 40 decay modes
  - 35 decay modes with $\varepsilon < 0.1\%$
  - large (7.57%) efficiency for $B_0 \rightarrow \rho^{\pm}\pi^0$

    ⇨ use $B_0 \rightarrow \rho^{\pm}\pi^0$ in Likelihood analysis

Maximum Likelihood Fit Results (Preliminary)

- Variables: M_B, ΔE, Fisher discriminant
- Components: Signal: $B^0 \rightarrow \pi^0\pi^0$

  Background: non $B\bar{B}$

  $B \rightarrow \rho^{\pm}\pi^0$

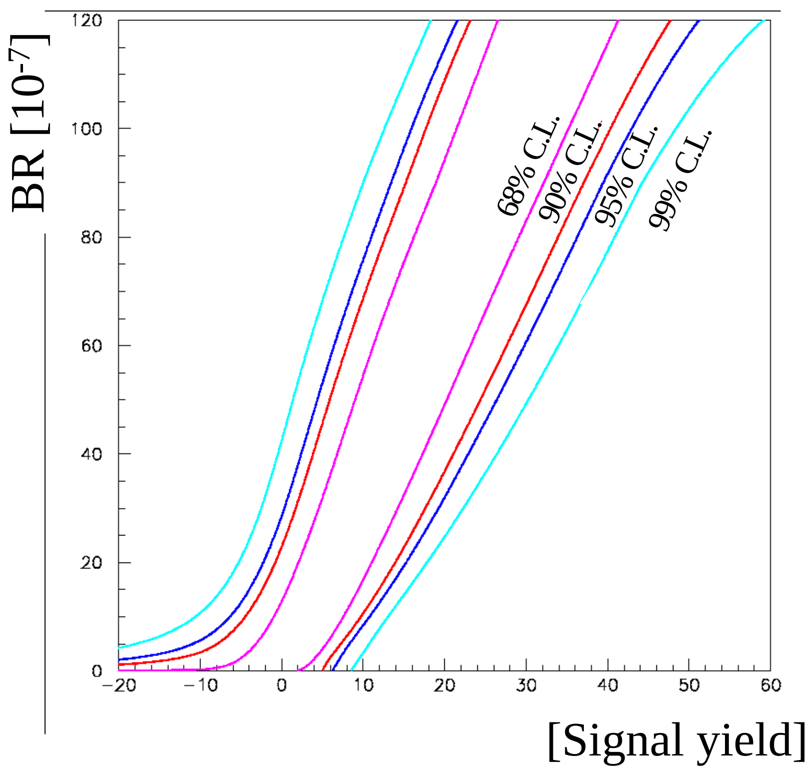
M.L. fit selection efficiency:

Decay Mode	$B^0 \rightarrow \pi^0\pi^0$	expected yield for On-resonance data
$B^0 \rightarrow \pi^0\pi^0$	$(28.79 \pm 0.27)\%$	
$B^0 \rightarrow \rho^{\pm}\pi^0$	0.023%	< 0.17
$B^0 \rightarrow f_0\pi^0$	<0.011%	< 0.01
$B^0 \rightarrow K_s^0\pi^0$	0.032%	< 0.24
$B^0 \rightarrow \eta\pi^0$	0.086%	< 0.10
$\tau\tau$	$(6.0\,^{+8.3}_{-5.3}) \times 10^{-8}$	< 0.5
Off resonance	$1.33^{+3.11}_{-1.33}$ ev.	

- Signal yield: $6.2\,^{+4.8}_{-3.7}$ events
- Significance ~ 2σ.

Check of Fit Behavior

- Test for probability that off-resonance background generates observed signal:
  - Generate off resonance Monte Carlo sample (same size as on resonance sample)
  - Use signal Monte Carlo events
  - apply M.L. fit for different signal sizes.



Preliminary Systematic Errors and Results for $B \to \pi^0\pi^0$

Systematic effects:

- $B^{\pm} \to \rho^{\pm}\pi^0$:

  cross feed ~ -0.3 ev. for largest BR($B^{\pm} \to \rho^{\pm}\pi^0$)

  other backgrounds (e.g. $B \to 3\pi$) feed into

  $B^{\pm} \to \rho^{\pm}\pi^0 \Rightarrow$ they do not contribute to $B \to \pi^0\pi^0$
- $\Delta N\tau\tau = -0.5^{+0.5}_{-0.7}$
- Prob. density functions ($\pm 1\sigma$) $\to {}^{+1.8}_{-1.3}$ events
- π^0 finding: $\pm 1\%$

$\Rightarrow$ $\mathbf{N = 5.7 \pm \left({}^{4.8}_{3.7}\right)_{sta} \pm \left({}^{1.9}_{1.8}\right)_{sys}}$ $- 7500 \times BR(B^{\pm} \to \rho^{\pm}\pi^0)$

Branching ratio:

$[2.1 \pm \left({}^{\mathbf{1.7}}_{\mathbf{1.3}}\right)_{sta} \pm \left({}^{\mathbf{0.7}}_{\mathbf{0.6}}\right)_{sys}] \times 10^{-6} - 0.0027 \bullet BR(B^{\pm} \to \rho^{\pm}\pi^0)$

Upper limit (90 % C.L.):

$BR(B^0 \to \pi^0\pi^0) < 5.6 \times 10^{-6}$

Theoretical Predictions: $0.3\text{-}4.6 \times 10^{-6}$

$B \rightarrow VP$

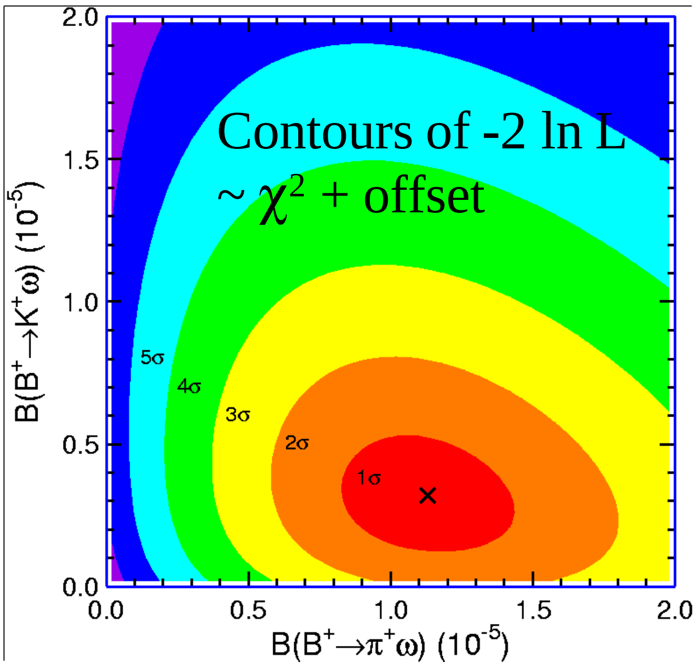
hep-ex/0006008 (accepted by PRL)

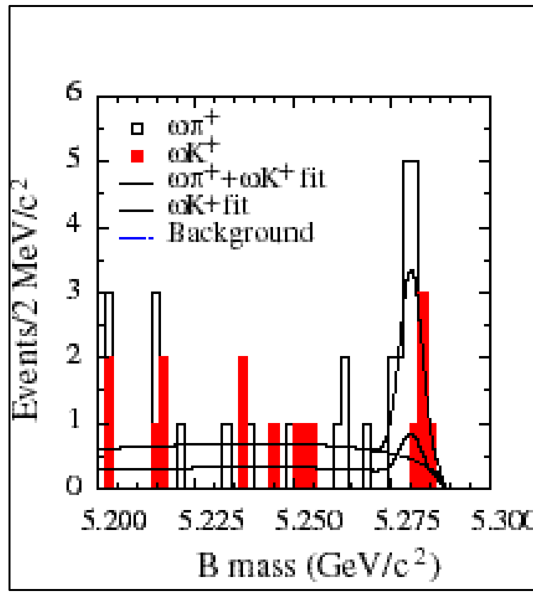
Mode	**Yield**	e(%)	**Signif.**	**BR(10^{-6})**	**Th.* (10^{-6})**
$B^0 \rightarrow \pi^\pm \rho^\mp$	$31.0^{+9.4}_{-8.3}$	12	5.6	$27.6^{+8.4}_{-7.4} \pm 4.2$	12 - 93
$B^- \rightarrow \pi^- \rho^0$	$29.8^{+9.3}_{-9.6}$	30	5.4	$10.4^{+3.3}_{-3.4} \pm 2.1$	0.4 - 13
$B^0 \rightarrow \pi^0 \rho^0$	$5.4^{+6.5}_{-4.8}$	34	1.2	< 5.5	0 - 2.5
$B^- \rightarrow \pi^0 \rho^-$	$23.7^{+8.4}_{-7.4}$ †	10	5.1	< 43	3 - 27
$B^0 \rightarrow K^\pm \rho^\mp$	$16.4^{+7.8}_{-6.6}$	11	3.5	< 32	0 - 12
$B^- \rightarrow K^- \rho^0$	$22.4^{+10.7}_{-9.1}$	28	3.7	< 17	0 - 6.1
$B^- \rightarrow \pi^- K^{*0}$	$13.4^{+6.2}_{-5.2}$	18	3.6	< 16	3.4 - 13
$B^0 \rightarrow \pi^0 K^{*0}$	$0.0^{+3.0}_{-0.0}$	25	0.0	< 3.6	0.7 - 6.1
$B^- \rightarrow \pi^0 K^{*-}$	$2.6^{+4.2}_{-2.6}$	4	1.0	< 31	0.5 - 24
$B^- \rightarrow K^- K^{*0}$	$0.0^{+2.2}_{-0.0}$	17	0.0	< 5.3	0.2 - 1
$B^- \rightarrow \pi^- \omega$	$28.5^{+8.2}_{-7.3}$	26	6.2	$11.3^{+3.3}_{-2.9} \pm 1.4$	0.6 - 24
$B^0 \rightarrow \pi^0 \omega$	$1.5^{+3.5}_{-1.5}$	19	0.6	< 5.5	0.0 - 12
$B^- \rightarrow K^- \omega$	$7.9^{+6.0}_{-4.7}$	26	2.1	< 7.9	0.2 - 14
$B^0 \rightarrow K^0_s \omega$	$7.0^{+3.8}_{-2.9}$	7	3.9	< 21	0.0 - 17

† non resonant contributions cannot be excluded

* [Chen,Cheng,Tseng,Yang, Phys Rev. D 60 094014]

Data and Interpretation





- Simultaneous fit for $\pi^{\pm}\rho^{\mp}/K^{\pm}\rho^{\mp}$, $\pi^{\pm}\rho^{0}/K^{\pm}\rho^{0}$, $\pi^{-}\omega/K^{-}\omega$
- $\Delta S = 0$ decay modes expected to be dominated by $b \rightarrow u$.
- No significant yields for $\Delta S = 1$ in contrast to $B \rightarrow PP$.
- Penguin play less role in $B \rightarrow PV$ than in $B \rightarrow PP$
- Consistent with prediction using factorization:
  - destructive interference between penguin operators of opposite chirality for $B \rightarrow K\rho \Rightarrow$ small penguin contrib.
  - constructive interference between penguin operators of opposite chirality for $B \rightarrow K\pi \Rightarrow$ large penguin contrib.

$B \rightarrow K\pi, \pi\pi$

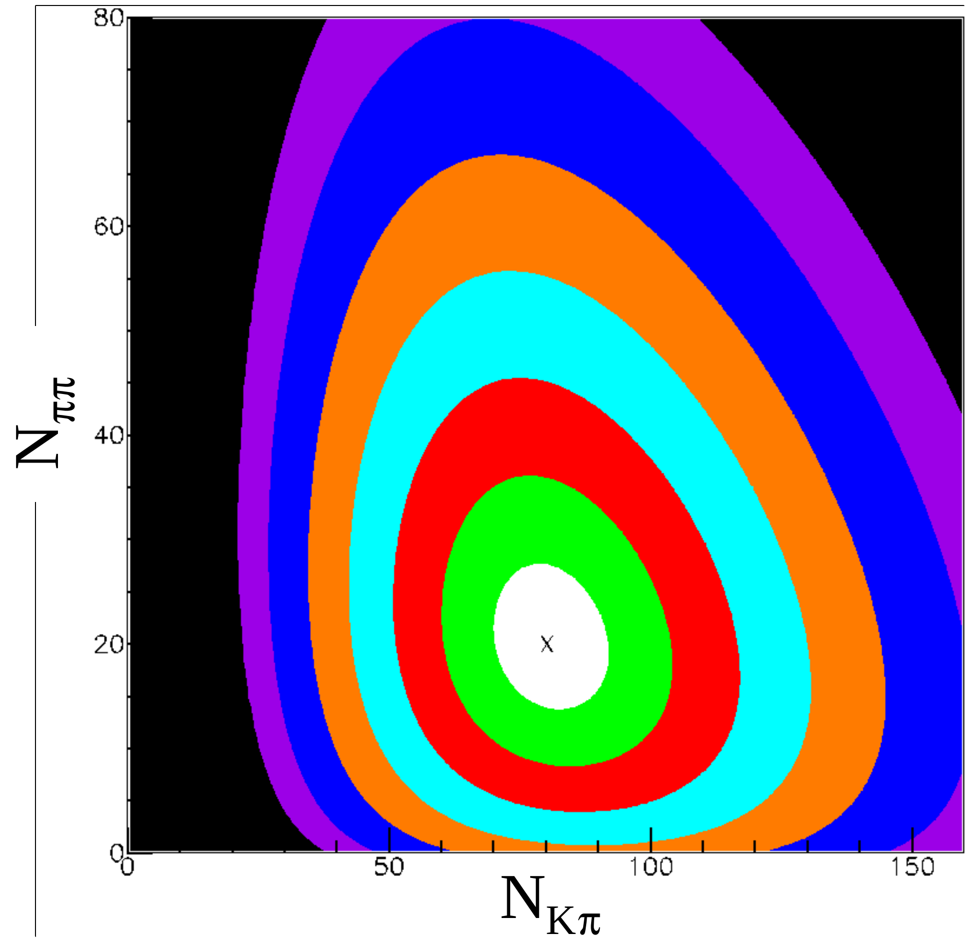
Mode	Sign.	ε(%)	Yield	$B(10^{-6})$
$K^{\pm}\pi^{\mp}$	11.7 σ	48	$80.2^{+11.8}_{-11.0}$	$17.2^{+2.5}_{-2.4} \pm 1.2$
$K^{0}\pi^{\pm}$	7.6 σ	14	$25.2^{+6.4}_{-5.6}$	$18.2^{+4.6}_{-4.0} \pm 1.6$
$K^{\pm}\pi^{0}$	6.1 σ	38	$42.1^{+10.9}_{-9.9}$	$11.6^{+3.0}_{-2.7}{}^{+1.4}_{-1.3}$
$K^{0}\pi^{0}$	4.9 σ	11	$16.1^{+5.9}_{-5.0}$	$14.6^{+5.9}_{-5.1}{}^{+2.4}_{-3.3}$
$\pi^{\pm}\pi^{\mp}$	4.2 σ	48	$20.0^{+7.6}_{-6.5}$	$4.3^{+1.6}_{-1.4} \pm 0.5$
$\pi^{\pm}\pi^{0}$	3.2 σ	39	$21.3^{+9.7}_{-8.5}$	<12.7 (90% CL)
$\pi^{0}\pi^{0}$	2.0 σ	29	$6.2^{+4.9}_{-3.7}$	<5.7 (90% CL)
$K^{\pm} K^{\mp}$	0.0 σ	48	$0.7^{+3.4}_{-0.7}$	<5.9 (90% CL)
$K^{\pm} K^{0}$ †	1.1 σ	14	$1.4^{+2.4}_{-1.3}$	<5.7 (90% CL)
$K^{0} K^{0}$ †	0.0 σ	5	0	<17 (90% CL)

For modes with K^0: yields are for K_s^0, other numbers for K^0

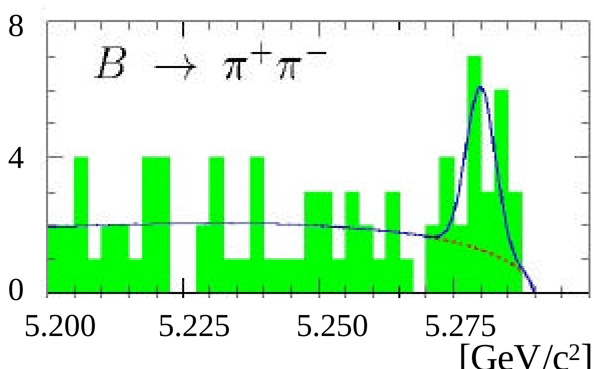
† Only 3.3M $B\overline{B}$ events used.

- New measurements of $B \rightarrow PV, PP$ decays by BaBar and Belle confirm our results.

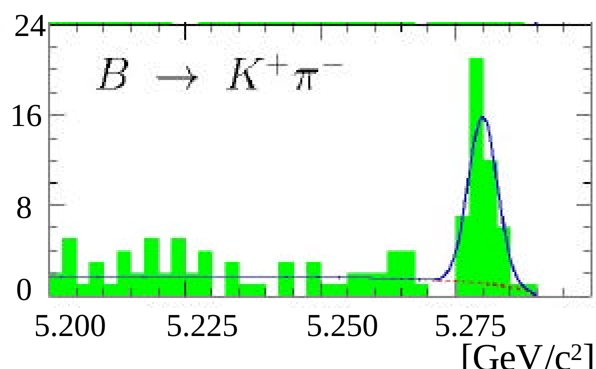
Selected Graphs of Fit Results



Contours of $-2 \ln L \sim \chi^2$ + offset



B Mass



B Mass

Interpretation of B ➙ PP

- Good agreement with theory
- small $\pi^+\pi^-$ rate & small upper limit for $\pi^0\pi^0$:
  - no strong phase enhancement
  - gluonic penguins are large
- No observed signals in B ➙ KK, B ➙ K^*K

  ⇨ No contribution from dominant diagrams: ideal probes of final state interactions.

  Rescattering in B ➙ $K^0\pi^\pm$ can be limited:

$$\left|\frac{A_{rescattering}}{P}\right| \cong l\sqrt{\frac{B(B \to K^+K^-)}{B(B \to K^0 p^\pm)}} < 9\%$$

  [Gronau and Rosner, hep-ph/9806348]

- Several constraints on angle γ :

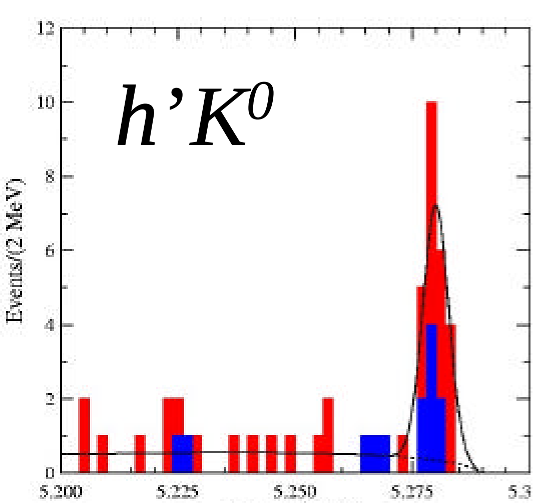
  [Fleischer-Mannel, hep-ph/9704423]

  [Neubert-Rosner, hep-ph/9808493]

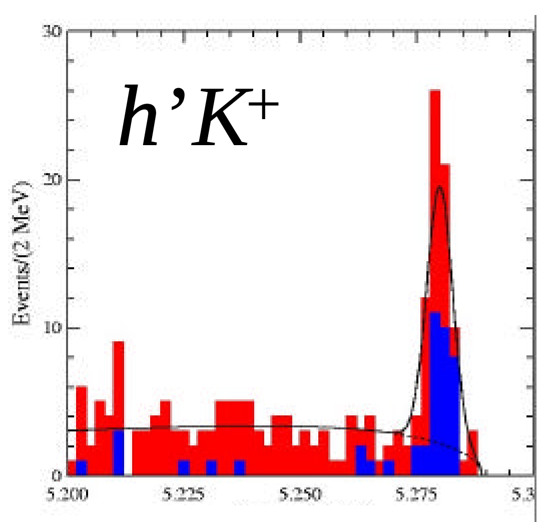
Modes with η and η'

Mode	e	Sign.	B (10^{-6})	Prediction
$\eta' K^{\pm}$	13	16.8 σ	$80\ ^{+10}_{-9} \pm 7$	21-41
$\eta' K^{0}$	4	11.7 σ	$89\ ^{+18}_{-16} \pm 9$	21-41
$\eta' \pi^{\pm}$	14	0.0 σ	< 12	0.3-0.4
$\eta' \pi^{0}$	12	0.0 σ	< 5.7	0.1-0.4
$\eta K^{*\pm}$	7	4.8 σ	$26.4\ ^{+9.6}_{-8.2} \pm 3.3$	2-4
ηK^{*0}	12	5.1 σ	$13.8\ ^{+5.5}_{-4.6} \pm 1.6$	2-4
$\eta \rho^{\pm}$	12	1.3 σ	< 15	2-3
$\eta \rho^{0}$	15	1.3 σ	< 10	2-3

No significant signals in other modes



B Mass (GeV/c^2)

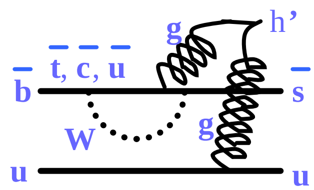


B Mass (GeV/c^2)

η' decay:
- *hpp*
- *rg*

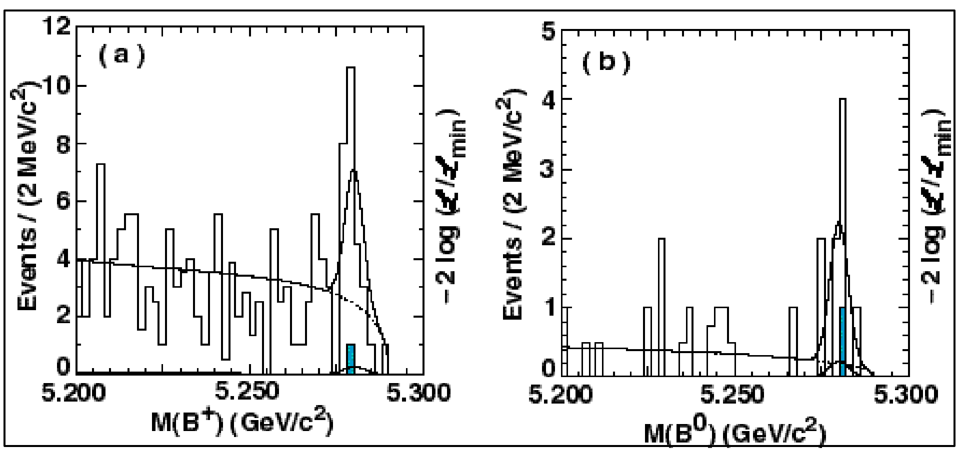
Interpretation

- Decays into η'K and η K^* are considerably higher than predicted by factorization [Ali, Kramer, Lu hep-ph/9804363]
- Hairpin diagram:



- glue content in η'
- new physics
- Intrinsic charm content of η' proposed. [E.V. Shuryak, A.R.Zhitnistsky, Phys. Rev. D 57, 2001 (1998)]

  No corresponding enhancement of BR($B \rightarrow \eta_c K$) over BR($B \rightarrow J/\psi K$) seen. [CLNS 00/1680, hep-ex/0007012], See Y.Gao's talk this conference.



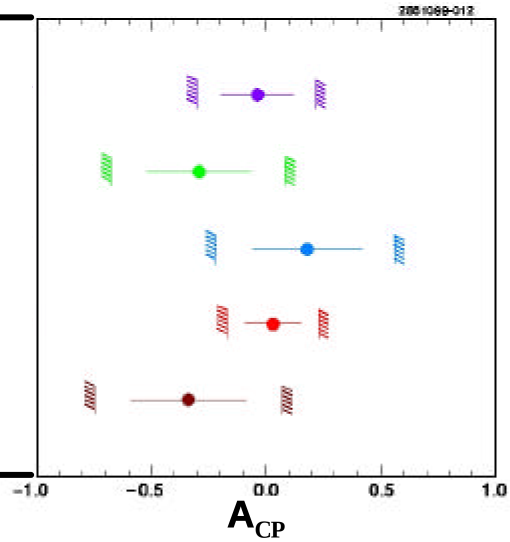
Direct CP Asymmetry Measurement

- Factorization model predictions small $A_{CP} < 0.1$

  [Ali, Kramer, Lu, hep-ph/9805403]
- Final state interaction or new physics can enhance strong phase [He, Hou, Yang, hep-ph/9809282]
- Combined CP-violating rate differences in

  $B^0 \rightarrow K^+\pi^-$ and $B^+ \rightarrow K^+\pi^0$ could be detectable.
  [Gronau, Rosner Phys Rev D 59 113002]
- Definition: $A_{CP} \equiv \dfrac{\Gamma(\bar{B} \to f) - \Gamma(B \to \bar{f})}{\Gamma(\bar{B} \to f) + \Gamma(B \to \bar{f})}$
- A_{CP} free parameter in Maximum Likelihood fits

Mode	Yield	A_{CP}
K$^\pm$p$^\mp$	$80.2^{+11.8}_{-11.0}$	-0.04±0.1
K$^\pm$p^0	$42.1^{+10.9}_{-9.9}$	-0.29±0.2
K^{0}p$^\pm$	$25.2^{+6.4}_{-5.6}$	+0.18±0.
K$^\pm$h'	100^{+13}_{-12}	+0.03±0.
wp$^\pm$	$28.5^{+8.2}_{-7.3}$	-0.34±0.2



$B \rightarrow e^+e^-, \mu^+\mu^-, e^{\pm}\mu^{\mp}$

Small helicity suppressed Standard Model Expectations:

- $BR(B^0 \rightarrow e^+e^-)$ ~ 2.6×10^{-15}
- $BR(B^0 \rightarrow \mu^+ \mu^-)$ ~ 1.1×10^{-10}
- $BR(B^0 \rightarrow e^{\pm} \mu^{\mp})$ forbidden

New physics can enhance cross section:

- Two Higgs doublet Models
- SUSY,
- Pati-Salam Leptoquark Models

$B \to e^+e^-, \mu^+\mu^-, e^{\pm}\mu^{\mp}$ cont.

Event Selection:

- 2 opposite charged tracks with correct lepton ID
- Beam Constrained B Mass
- Energy Constraint

Background Study:

- BB backgrounds: < 0.02 events
- $\tau^+\tau^-$ backgrounds < 0.5 events
- $e^+e^- \to q\bar{q}$ (q = u, d, s, c) < 0.2 event

Results:

Mode	**Efficiency**	**Evts.**	**UL (90% C.L.)**
$B^0 \to e^+e^-$	$31.3 \pm 0.4 \pm 2.4\%$	0	$< 8.3 \times 10^{-7}$
$B^0 \to \mu^+\mu^-$	$42.4 \pm 0.5 \pm 3.2\%$	0	$< 6.1 \times 10^{-7}$
$B^0 \to e^{\pm}\mu^{\mp}$	$43.6 \pm 0.5 \pm 7.1\%$	2	$< 15 \times 10^{-7}$

Summary

- Many modes $B \rightarrow PP, PV$ studied:
  - $B \rightarrow \Phi K$
  - limit on $B \rightarrow \pi^0\pi^0$
  - $B \rightarrow \pi^+\pi^-$
  - all modes of $B \rightarrow K\pi$
  - $B \rightarrow \pi\rho, \pi K^*, \pi\omega, K\rho, KK^*, K\omega$
  - larger than expected results in $B \rightarrow \eta'\pi, B \rightarrow \eta K^*$
- important to determine CKM angles α, β, γ
- Limits the possible range of direct CP Asymmetry values

- New limits on $B \rightarrow e^+e^-$, $B \rightarrow \mu^+\mu^-$, $B \rightarrow e^{\pm}\mu^{\mp}$

Simple Review of $K\pi$, $\pi\pi$, $K\Phi$ Results

Branching ratios: x 10^{-6}

Exp.	$K^{-}\pi^{+}$	$\pi^{-}\pi^{+}$	$K^{+}\Phi$
CLEO	$17.2^{+2.8}_{-2.7}$	$4.3^{+1.7}_{-1.6}$	$6.4\ ^{+2.6}_{-2.9}$
	} <1.0 σ	} <1.5 σ	} <1.4 σ
BaBar	$12.5^{+3.3}_{-3.1}$	$9.3^{+2.9}_{-2.7}$	
Belle	$17.4^{+5.1}_{-4.6}$		$17.2^{+6.9}_{-5.7}$
	15.6 ± 2.0	5.6 ± 1.4	8.0 ± 2.4

assuming gaussian errors!