Measurement of Time-dependent *CP* Asymmetries in Charmless Two-body *B* Meson Decays to Pions and Kaons at *BaBar*

Amir Farbin

(BABAR collaboration)

University of Maryland

Introduction- *Time-dependent CP asymmetries in B decays*

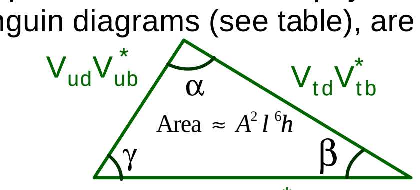
A primary goal of the asymmetric B factories is to search for inconsistencies in the Standard Model (SM) interpretation of CP violation (CPV) in the quark sector, which is encapsulated in a single complex phase in the CKM matrix. Two methods of testing the SM are:

1. *Unitarity of CKM matrix*: The unitarity condition can be expressed as a Unitarity Triangle (UT) whose angles (α, β, γ) are related to specific B decays. The goal is to measure α, β, γ and test closure: $\alpha+\beta+\gamma=180$. Having established CP violation in the B meson system by measuring sin 2β in decays of CP eigenstates with charmonium (*e.g.* $B^0 \to J/\psi K_s$), focus has shifted to measuring the other angles. $B^0 \to \pi^+\pi^-$ decays provide a means of extracting sin 2α (with theoretical uncertainties, see table).

2. *Search for new physics*: Measure UT angles in decays whose leading contributions are from loop diagrams, and may therefore deviate from SM prediction due to new physics. In the SM, $B^0 \to K_s \pi^0$ decays, whose amplitude is dominated by penguin diagrams (see table), are sensitive to sin 2β.

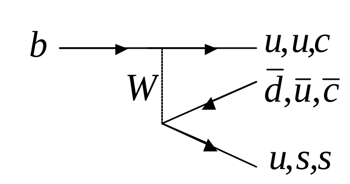
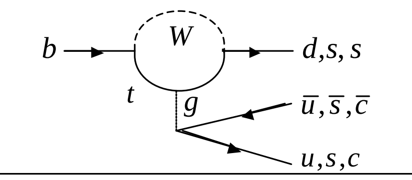
Primary method of measuring UT angles

Search for CP asymmetry in decay time:



$$A_{f_{CP}} = \frac{\Gamma(\bar{B}^0(t)\to f_{CP}) - \Gamma(B^0(t)\to f_{CP})}{\Gamma(\bar{B}^0(t)\to f_{CP}) + \Gamma(B^0(t)\to f_{CP})} = S_{f_{CP}} \sin\Delta m_d t - C_{f_{CP}} \cos\Delta m_d t$$

$$S_{f_{CP}} = \frac{2\,\mathrm{Im}\, l_{f_{CP}}}{1+|l_{f_{CP}}|^2} \qquad C_{f_{CP}} = \frac{1-|?_{f_{CP}}|^2}{1+|?_{f_{CP}}|^2}$$

B Meson Decay Mode to CP Eigenstate	Leading Tree Diagram (T)	Leading Loop "Penguin" Diagram (P)	Sensitivity to Unitarity Triangle
			$?_{f_{CP}} = \pm \frac{q}{p} \cdot \frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}$ (B Mixing; Decay Amp Ratio)
$B^0 \to \pi^+\pi^-$	$V_{ub}V_{ud}^* \propto l^3 e^{-ig}$ Same order as Penguin: |P/T| ~ .3	$V_{tb}V_{td}^* \propto l^3 e^{ib}$ $Br(B^0 \to K^+\pi^-) > Br(B^0 \to \pi^+\pi^-) \to$ Penguin is expected to be large	$l_{pp} = \|l_{pp}\| e^{2ia_{Eff}} \neq e^{2ia}$ $\Rightarrow \mathrm{Im}\, l_{pp} = \|l_{pp}\| \sin 2a_{Eff}$
$B^0 \to K_s \pi^0$	$V_{ub}V_{us}^* \propto l^4 e^{-ig}$ CKM Suppressed	$V_{tb}V_{ts}^* \propto l^2$ Dominant	$\mathrm{Im}\, l_{K_s p^0} = \sin 2b$
$B^0 \to J/\psi K_s$	$V_{cb}V_{cs}^* \propto l^2$ Dominant	$l^2 + O(l^4)e^{-ig}$ Same phase or CKM Suppressed	$\mathrm{Im}\, l_{J/y K_s} = \sin 2b$

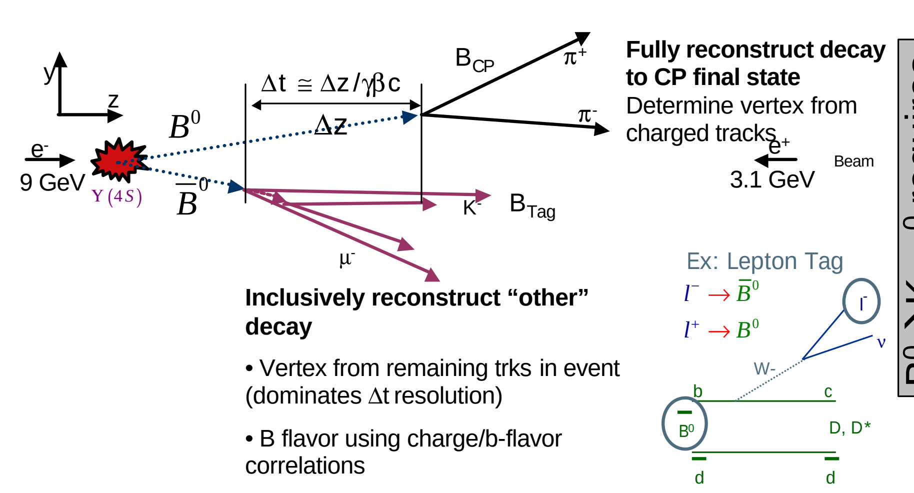
Requires measurement of decay time & B flavor

Vertexing/B Flavor Tagging

Measuring Time-dependent CP asymmetries at the B factories:

B mesons are produced in coherent pairs from $\Upsilon(4S) \to BB$ decays:

- Reconstruct 1 meson in CP eigenstate (B_{CP}), use other meson (B_{Tag}) for tagging/vertexing
- Asymmetry in $\Delta t = t_{CP} - t_{Tag}$
- Correlation between flavor of B_{CP} and B_{Tag} at time of decay.



Isolating signal decays

Charmless 2-body B Decay Analysis Issues

- Rare decays- Branching fractions ~ 10^{-6} → Perform loose selections to maximize efficiency
- Large backgrounds from continuum → Use Fisher discriminant (F) to combine information on event shape and "jettiness" to suppress continuum backgrounds.

→ Extract results from multivariate maximum likelihood fit.

B→p⁺p⁻

Must separate $B \to \pi^+\pi^-, K^+\pi^-, K^-\pi^+, K^+K^-$

→ Use the measurement of the Cherenkov angle θ_c from the Detector of Internally Reflected Cherenkov light (DIRC).

$B^0 \to K_s p^0$

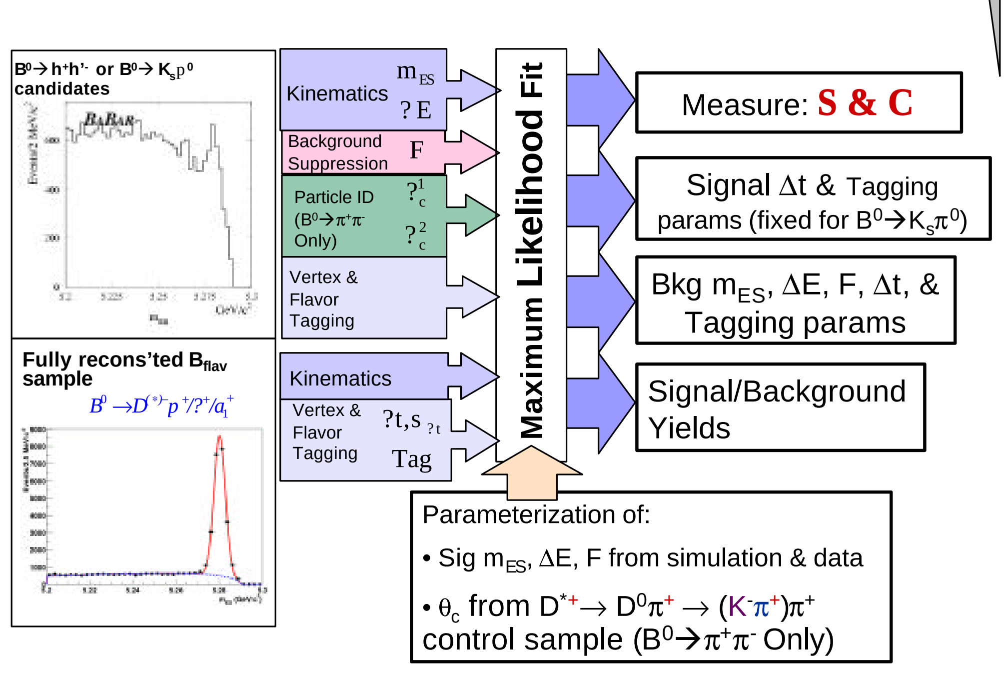
Only have Δt measurements for 65% of events.

→ Use all flavor-tagged events to extract the time-integrated CP asymmetry $C_{K_s\pi^0}$

Extracting Measurements

Maximum Likelihood Fit

- Multivariate fit maximally exploit kinematic, background suppression, particle identification, flavor tagging, and decay time information.
- Inclusion of large side-band regions permits simultaneous extraction of all background parameterizations along with the measurements from signal events.
- Inclusion of control samples permits simultaneous extraction of signal parameterizations.



Results

In 113/fb (124 Million $\Upsilon(4S) \to BB$ decays) we measure:

Preliminary

Decay Mode	# of Signal Events	S_f	C_f
$B^0 \to \pi^+\pi^-$	266 ± 24	$-0.40 \pm 0.22 \pm 0.03$	$-0.19 \pm 0.19 \pm 0.05$
$B^0 \to K_s \pi^0$	122 ± 16	$0.48^{+0.38}_{-0.47} \pm 0.11$	$0.40^{+0.27}_{-0.28} \pm 0.10$
		$0.41^{+0.41}_{-0.48} \pm 0.11$	Fixed to 0

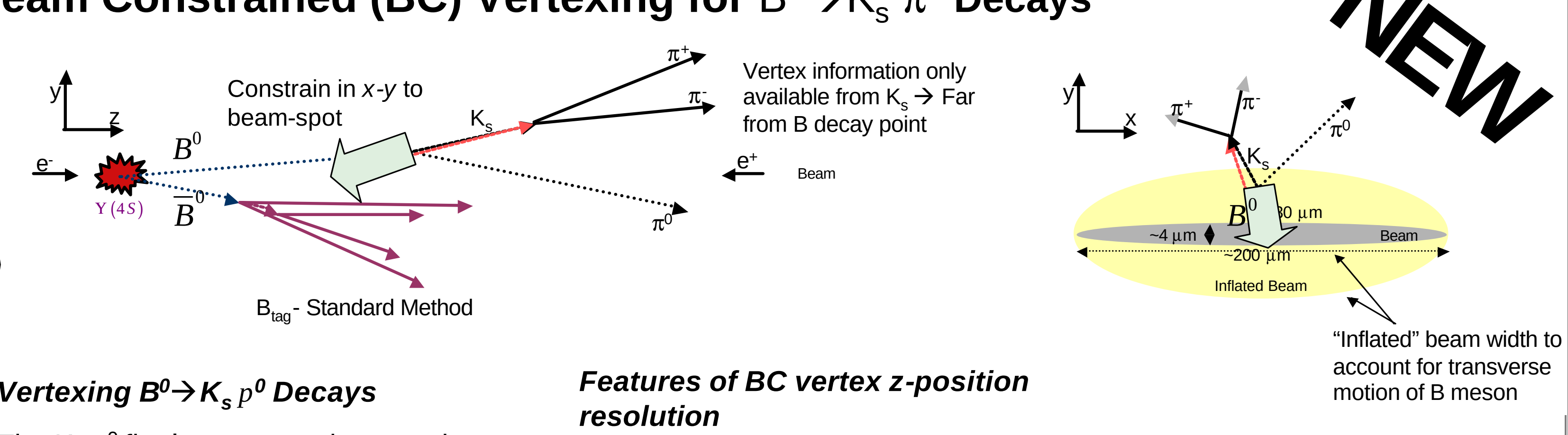
BaBar

$B^0 \to K_s \pi^0$ requires special technique

Isolating signal decays

Beam Constrained (BC) Vertexing for $B^0 \to K_s \pi^0$ Decays

NEW



Vertexing $B^0 \to K_s p^0$ Decays

The $K_s \pi^0$ final state contains no primary tracks from the B meson decay. We exploit:

- small transverse (*x-y*) motion (~ 30 μm) of B due to small decay length,
- small beam size (σ_x~200 μm, σ_y~4 μm),
- good beam-spot reconstruction,

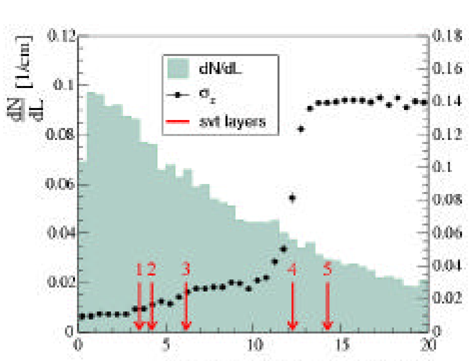
This constrains the B meson to originate from the interaction point in *x-y* and determines the *z*-position of the B decay point. The error on the *y* position of the beam is increased to account for the small transverse B motion.

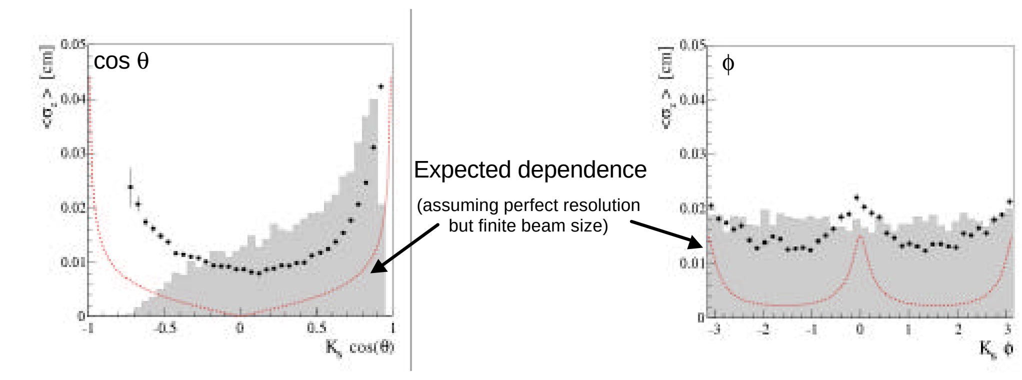
Features of BC vertex z-position resolution

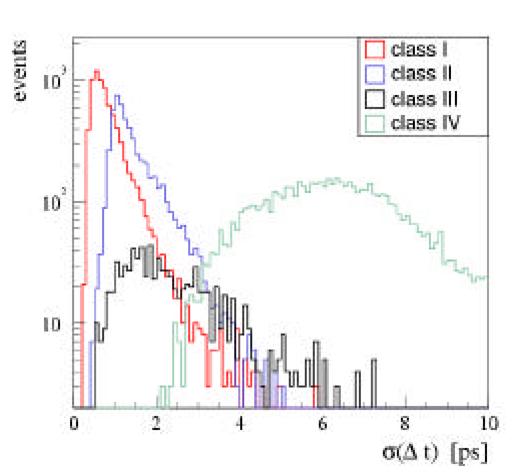
Resolution on the *z*-position varies with:

The number of Silicon Vertex Tracker (SVT) layers traversed by the charged pion decay products of the K_s.

The flight direction of the K_s, due to the geometry of intersecting its direction with the beam of finite width.







We identify 4 classes of events:

- Class I (Red)- 1 *z* & 1 φ hits in SVT layers 1-3 on both tracks from the K_s
- Class II (Blue)- Remaining events with 1 *z* & 1 φ hit in layers 1-5 on both tracks
- Class III (Black)- Only 1 SVT hit on either track
- Class IV (Green)- No SVT hits

→ We use Δt measurements from events in **classes I+II**

Selection Efficiency

class	$B^0 \to K_s^0\pi^0$	$B^0 \to J/\psi K_s^0$
I	0.373 ± 0.003	0.479 ± 0.003
II	0.273 ± 0.003	0.261 ± 0.002
III	0.045 ± 0.002	0.061 ± 0.002
IV	0.308 ± 0.003	0.198 ± 0.002

(Difference due to different K_s spectrum)

$B^0 \to J/y\, K_s$ as a control sample for $B^0 \to K_s\, p^0$

We may validate this technique by studying $B^0 \to J/\psi K_s$ reconstructed with the J/ψ removed from the B vertex. We then compare this with the standard reconstruction of $B^0 \to J/\psi K_s$ and find: 1. There is no bias on the vertex position. 2. We measure $\Delta S_{J/\psi Ks}$(nominal-BC)=-0.027 ± 0.064, $\Delta C_{J/\psi Ks}$(nominal-BC)=-0.034 ± 0.026, both of which are consistent with zero as expected.

Likelihood Projection Plots

Plots