Towards sin(2α) with BABAR

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On behalf of the BABAR Collaboration

XIVth Rencontres de Blois
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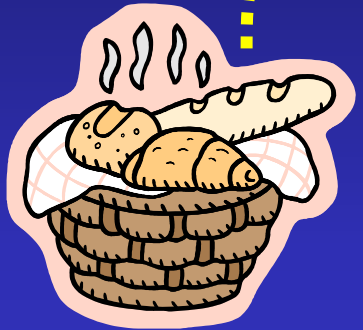
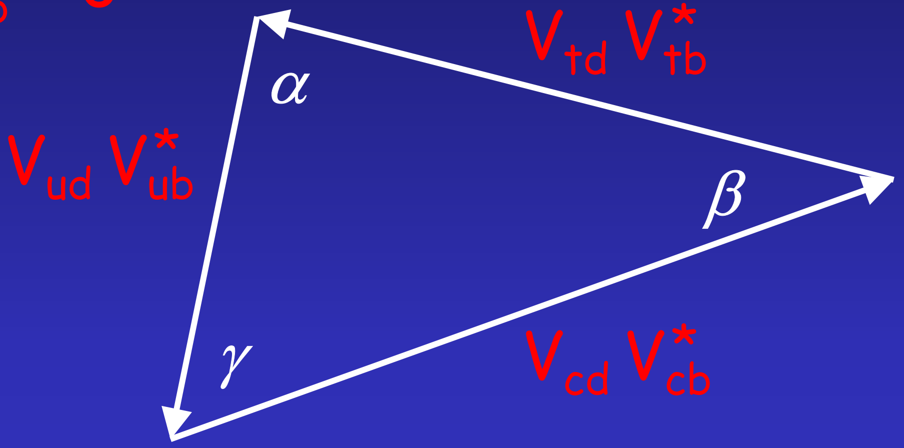


The CKM Matrix & Unitarity Triangle

Cabibbo-Kobayashi-Masakawa matrix U of $W^\pm$ couplings to quarks is unitary $U^\dagger U = 1$:

$$\begin{pmatrix} V^*_{ud} & V^*_{cd} & V^*_{td} \\ V^*_{us} & V^*_{cs} & V^*_{ts} \\ V^*_{ub} & V^*_{cb} & V^*_{tb} \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Rightarrow V_{ud} V^*_{ub} + V_{cd} V^*_{cb} + V_{td} V^*_{tb} = 0$$



CP violation in SM due to single observable phase of CKM matrix ~ invariant area of unitarity triangles.

$\sin 2\beta = 0.78 \pm 0.08$

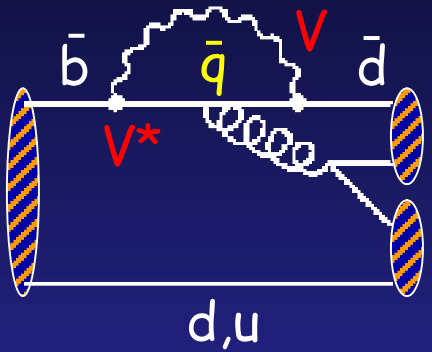
Penguins & Trees

Two general classes of weak diagrams describe main contributions to decay amplitudes:

Penguin

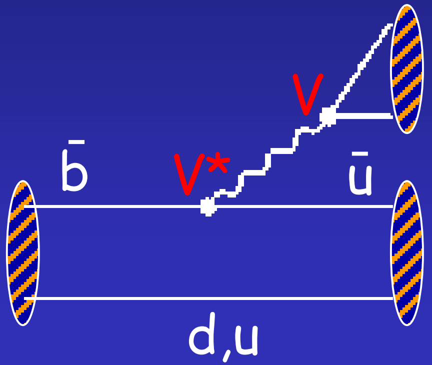
P_q

$q = u,c,t$

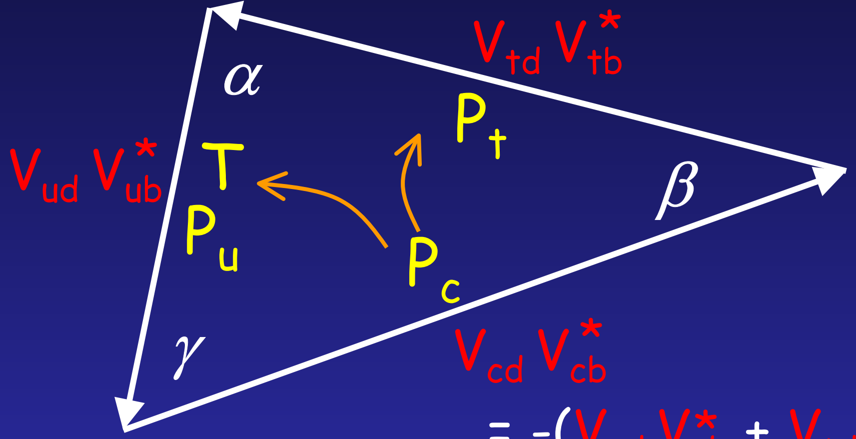


Tree

T



E.g., $B^0 \rightarrow \pi^+\pi^-$:



$$= -(V_{ud} V_{ub}^* + V_{td} V_{tb}^*)$$

Direct $B^0 \rightarrow \pi^+\pi^-$ amplitude =

$$V_{ud} V_{ub}^* (T+P_u-P_c) + V_{td} V_{tb}^* (P_t-P_c)$$

weak phases

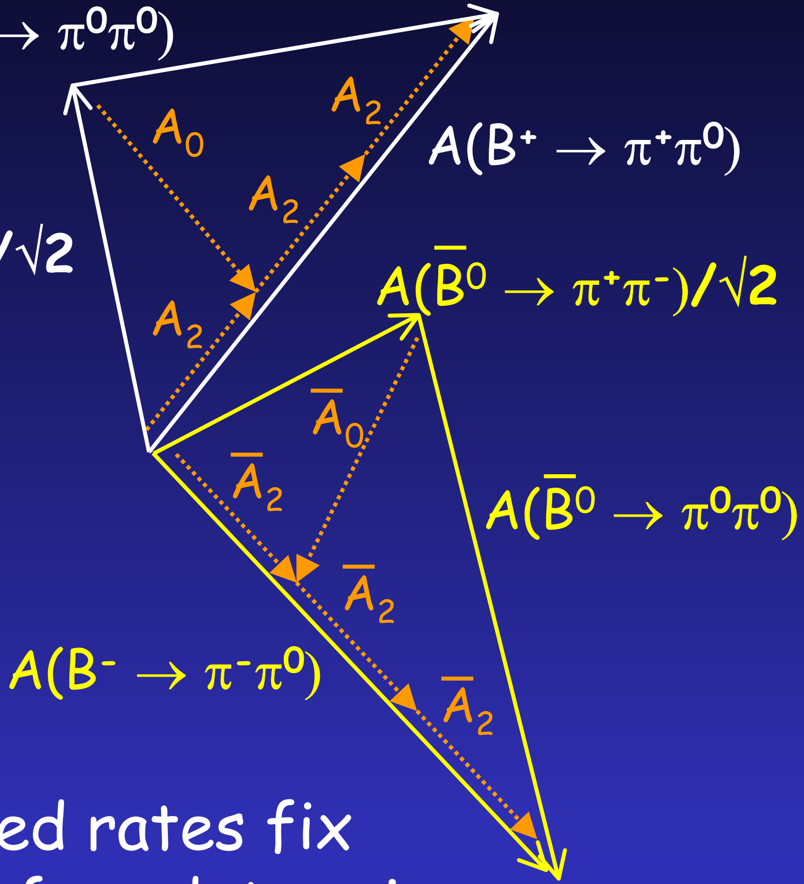
hadr. phases, matrix elts.

Isospin Analysis

The 3 $B^0, B^+ \to \pi\pi$ amplitudes proceed via 2 isospin amplitudes A_0, A_2 :

$\overline{B}^0, B^- \to \pi\pi$ proceed via the CP-conjugated $\overline{A}_0$, $\overline{A}_2$:

$$|A(B^- \to \pi^-\pi^0)| = |A(B^+ \to \pi^+\pi^0)|$$



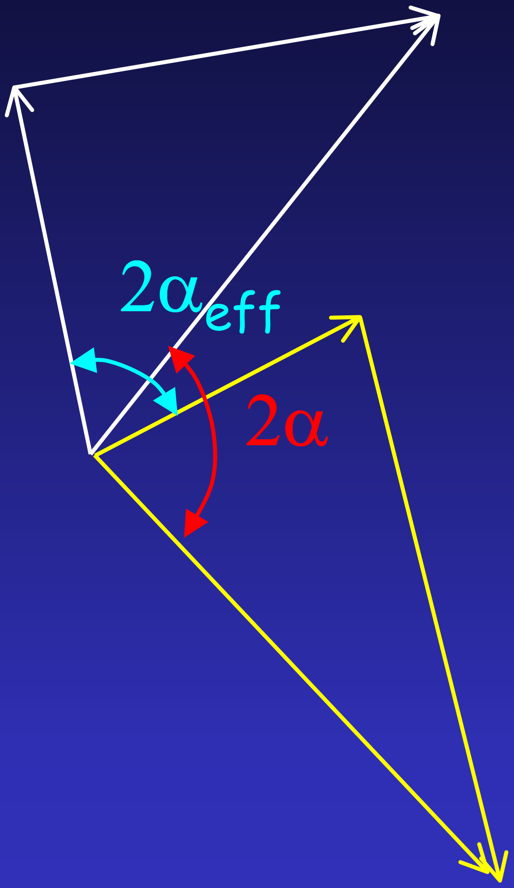
Measurements of 5 time-averaged rates fix the lengths of each side & therefore determine interior angles but <u>not</u> relative orientation of triangles.

Putting it all Together

The interior angles of the 2 isospin triangles do not directly measure α.

The relative mixing-decay phase α_{eff} also does not directly measure α.

Instead, α_{eff} fixes the relative orientation of the isospin triangles necessary to directly determine α:

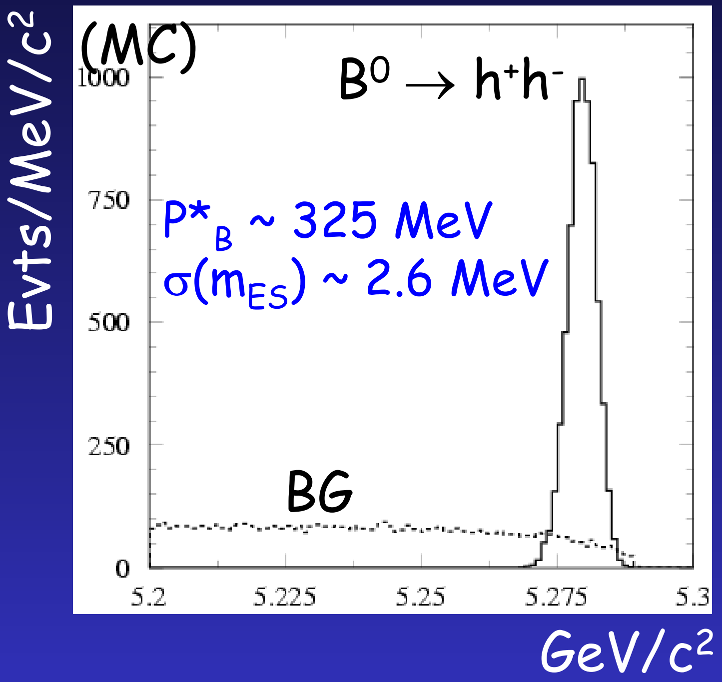


Select 2-Body B Decays

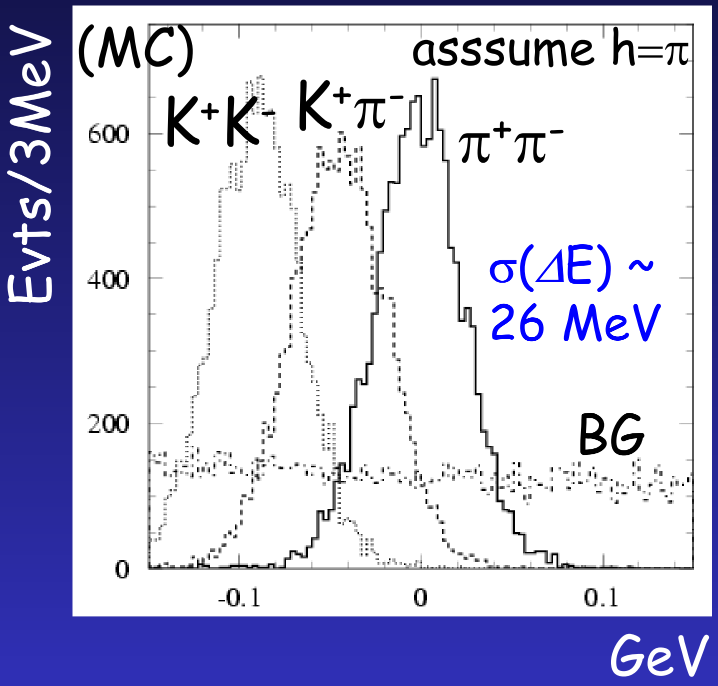
Identify candidate 2-body B decays with expected invariant mass and CM energy, e.g. for $B^0 \rightarrow h^+h^-$ $(h=K,\pi)$

$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$

$$\Delta E = E^*_B - E^*_{beam}$$



P^*_B ~ 325 MeV
$\sigma(m_{ES})$ ~ 2.6 MeV



$\sigma(\Delta E)$ ~ 26 MeV

Use similar techniques for B decays to K^0 $(\rightarrow\pi^+\pi^-)$, π^0 $(\rightarrow\gamma\gamma)$

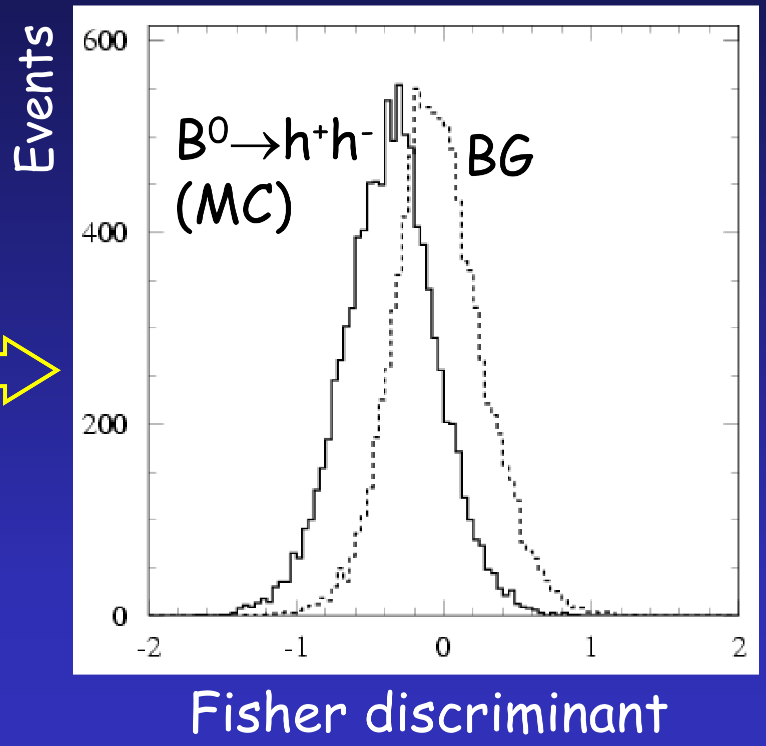
Continuum Backgrounds

Dominant B decays to charm final states removed by 2-body requirement. Main background is therefore due to continuum hadronic final states:

$$e^+e^- \to \gamma \to q\bar{q} \to \text{jets}$$

Use event shape variables to distinguish jet-like events (BG) from more spherical $\Upsilon(4S) \to BB$ events.

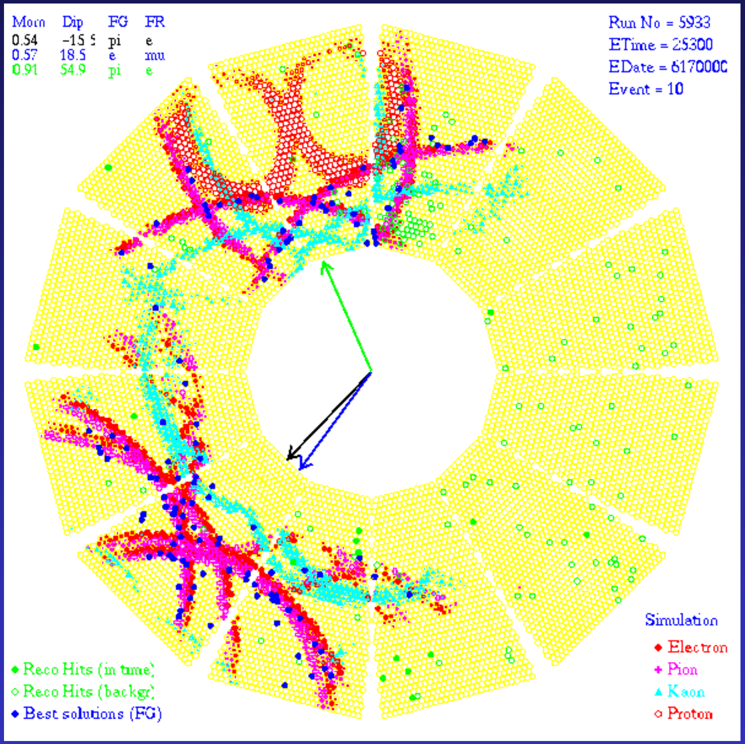
E.g. weighted momentum flow (“Fisher discriminant”)

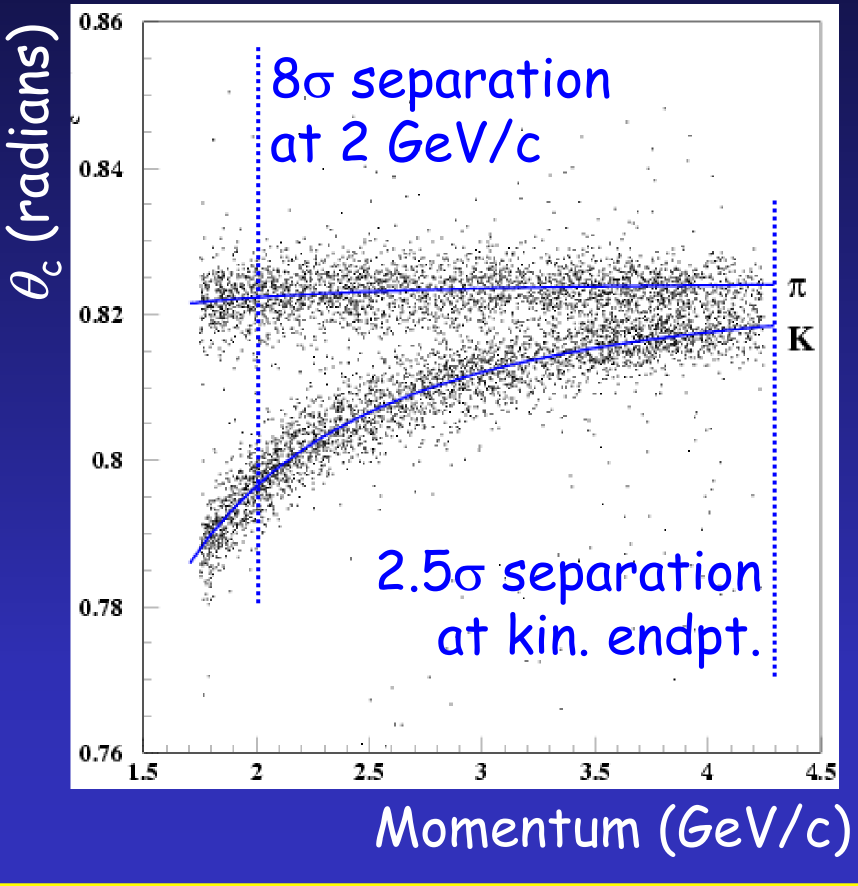


Use m_{ES}, ΔE sidebands in data for BG characterization.

Kaon-Pion Discrimination

$B^0 \rightarrow \pi^+\pi^-, K^+\pi^-, K^+K^-$ decays cannot be disentangled cleanly using kinematics alone. Use angle of Cerenkov emission $\cos\theta_c = 1/n\beta$ in quartz bars to distinguish $K^\pm, \pi^\pm$ of known momentum:





8σ separation at 2 GeV/c

2.5σ separation at kin. endpt.

Preliminary Branching Ratio Results

Fit distributions of signal candidates with shapes fixed by sideband data (BG) and MC (signal) to obtain yields from 60M $\Upsilon(4S) \rightarrow BB$ decays recorded by BABAR (2000-01).

E.g., a selection of results most relevant to sin(2α):

Mode	Yield	BR ($x10^{-6}$)
$B^0 \rightarrow \pi^0\pi^0$	9.8 ± 8.7	< 3.4 (90%CL)
$B^+ \rightarrow \pi^+\pi^0$	$62^{+17}_{-16}{}^{+10}_{-11}$	$4.1^{+1.1}_{-1.0}{}^{+0.8}_{-0.7}$
$B^0 \rightarrow \pi^+\pi^-$	124^{+16}_{-15}	$5.4 \pm 0.7 \pm 0.4$
$B^0 \rightarrow K^+\pi^-$	403 ± 24	$17.8 \pm 1.1 \pm 0.8$
$B^+ \rightarrow K^0\pi^+$	$172 \pm 17 \pm 9$	$17.5^{+1.8}_{-1.7} \pm 1.8$

isospin analysis

strong phase

|(penguin amplitude)|

PRELIMINARY

Main systematic uncertainties: assumed distributions for θ_c ($\pi^+\pi^-$, $K^+\pi^-$), m_{ES} ($\pi^+\pi^0$), ΔE ($K^0\pi^+$) and Fischer discriminant ($K^0\pi^+$, $\pi^+\pi^0$).

Separation of B^0 and $\overline{B}^0$ Decays to $\pi^+\pi^-$

In order to be sensitive to CP violation, must separately analyze B^0, $\overline{B}^0$ decays.

Use charge correlations between parent b-quark and primary decay products to "flavor tag" events:

- $b \to c l^- \nu$ (e^-, μ^-)
- $b \to c \to s$ (K^-)

try first

category hierarchy

Identified K,e,μ

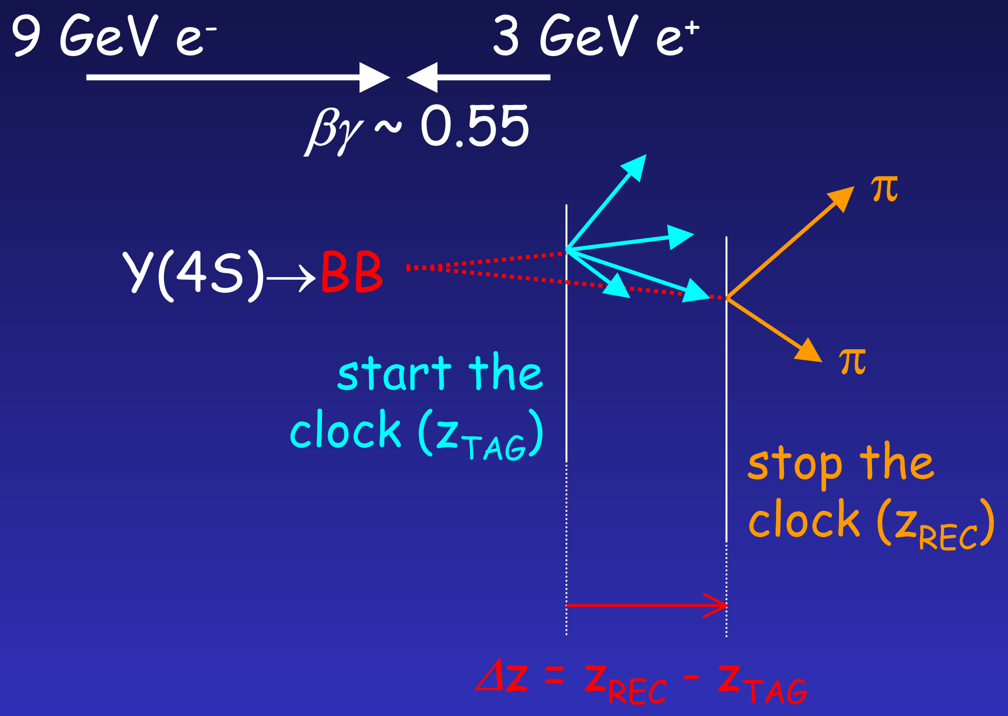
Inclusive Neural Network analysis

	ε	ω	$\varepsilon(1-2\omega)^2$
Tagging Category	Efficiency on Signal	Prob. Of Wrong Tag	Overall Quality Factor
Lepton	11.1%	8.6%	8%
Kaon	34.7%	18%	14%
NT1	7.6%	22%	2%
NT2	14.0%	37%	1%

Measured with independent control sample ⮤

Measurement of B Decay Time Difference

Use boost of asymmetric-energy collisions to estimate B decay-time difference $\Delta t \sim \Delta z / (c\beta\gamma)$:



9 GeV e^-

3 GeV e^+

$\beta\gamma \sim 0.55$

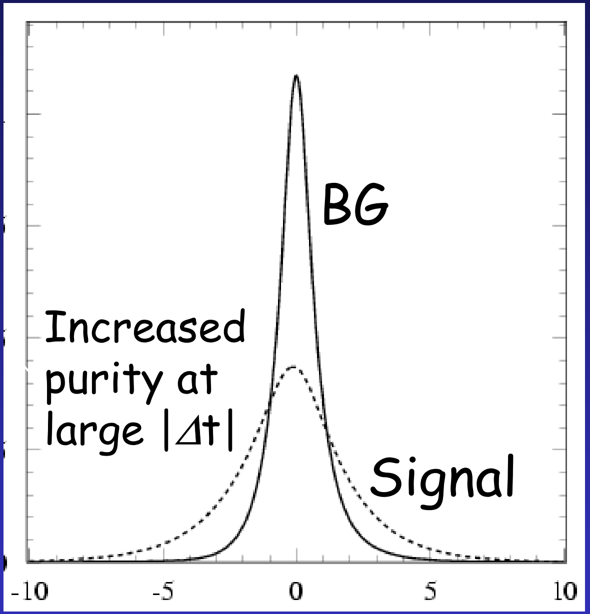
$\Upsilon(4S) \rightarrow BB$

start the clock (z_{TAG})

stop the clock (z_{REC})

$\Delta z = z_{REC} - z_{TAG}$

$\langle|\Delta z|\rangle = c\beta\gamma\,\tau_B \sim 0.25\text{mm}$



Decay-time difference, Δt (ps)

$\sigma(\Delta t_{rec}-\Delta t_{tru})$ measured with indep. control samples

Preliminary Time-Dependent Fit Results

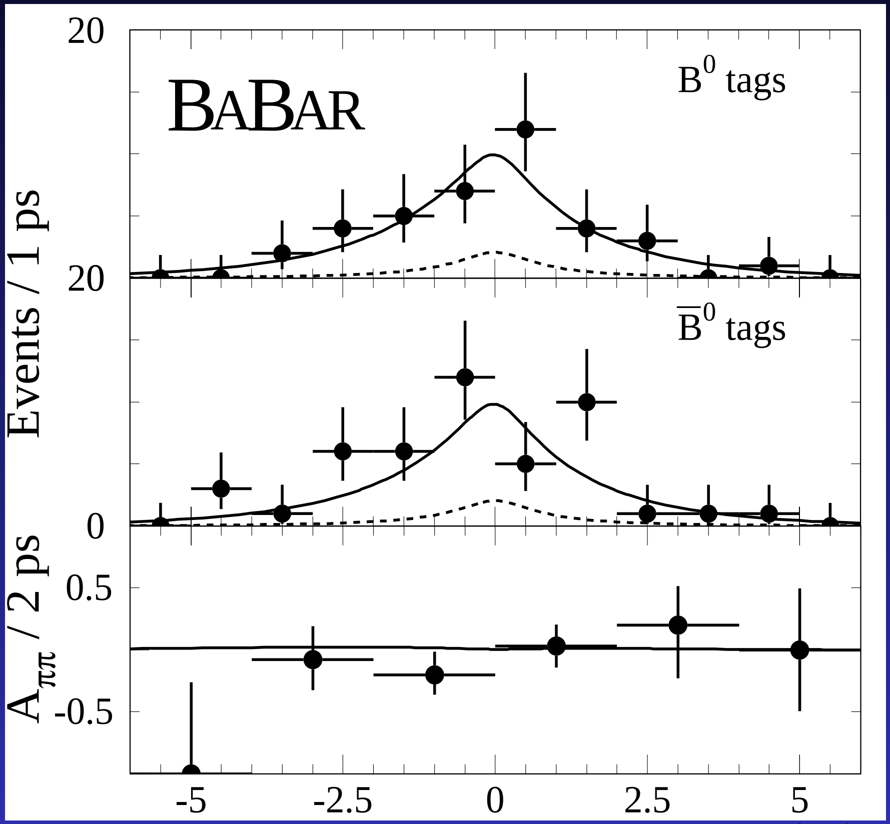
Fit coefficients $S_{\pi\pi}$, $C_{\pi\pi}$ to measured B^0, $\overline{B}^0$ decay-time distributions:

$$S_{\pi\pi} = -0.01 \pm 0.37 \pm 0.07$$
$$C_{\pi\pi} = -0.02 \pm 0.29 \pm 0.07$$

PRELIMINARY

No significant CP asymmetry observed in 60M $\Upsilon(4S) \rightarrow BB$ decays

$$A_{\pi\pi}(\Delta t) = \frac{N(\Delta t) - \overline{N}(\Delta t)}{N(\Delta t) + \overline{N}(\Delta t)}$$



Decay-time difference, Δt (ps)

Main systematic uncertainty: shape of θ_c distributions.

Interpretation of Results

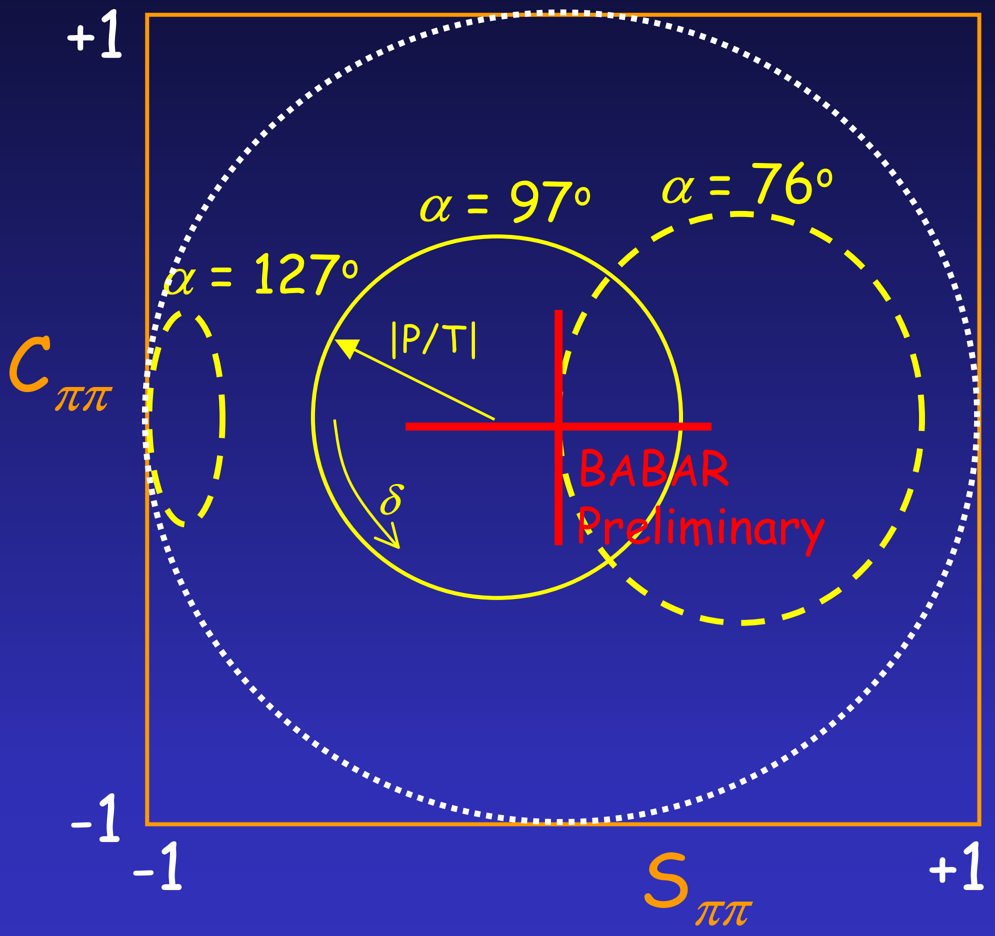
Results of time-dependent $B^0 \rightarrow \pi^+\pi^-$ analysis are consistent with Standard Model expectations.

E.g., take $\alpha = (97^{+30}_{-21})^o$,
$|P/T| = 0.28$, $|\delta| < \pi$:

(following Gronau, Rosner in hep-ph/0202170)

Unitarity limit:

$$C_{\pi\pi}^{2} + S_{\pi\pi}^{2} \leq 1$$



Summary & Prospects

BABAR has studied complete set of $B^0, B^+ \rightarrow h'h$ decays ($h', h = \pi^\pm, \pi^0, K^\pm, K^0$). Results are generally in good agreement with CLEO & BELLE.

Results obtained with 60M $\Upsilon(4S) \rightarrow BB$ decays are statistics limited. Errors expected for summer (~95M) will be ~35% smaller.

Much larger samples required for separate rate measurements of $B^0 \rightarrow \pi^0\pi^0$, $\overline{B}^0 \rightarrow \pi^0\pi^0$:

$$\text{Rate} \sim \underset{\text{reconstruction eff.}}{18\%} \times \overset{\text{flavor tagging eff.}}{10\%} \times (\underset{\text{branching ratio}}{<3.4\times10^{-6}}) = O(10^{-8})$$

We expect to record ~500/fb by 2006 with projected error on $\alpha \sim 30^o$ (SLAC-PUB-8970).