# First Physics Results from BABAR

**David Hitlin**
Caltech
for the *BABAR* Collaboration

XXX^th International Conference
on High Energy Physics
Osaka
July 31, 2000

# The *BABAR* Collaboration

**9 Countries**
**72 Institutions**
**554 Physicists**

## USA [35/276]
California Institute of Technology
UC, Irvine
UC, Los Angeles
UC, San Diego
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State
Florida A&M
U of Iowa
Iowa State U
LBNL
LLNL
U of Louisville
U of Maryland
U of Massachusetts, Amherst
MIT
U of Mississippi
Mount Holyoke College
Northern Kentucky U
U of Notre Dame
ORNL/Y-12
U of Oregon
U of Pennsylvania
Prairie View A&M
Princeton
SLAC
U of South Carolina
Stanford U
U of Tennessee
U of Texas at Dallas
Vanderbilt
U of Wisconsin
Yale

## Canada [4/16]
U of British Columbia
McGill U
U de Montréal
U of Victoria

## China [1/6]
Inst. of High Energy Physics, Beijing

## France [5/50]
LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris 6/7
Ecole Polytechnique
CEA, DAPNIA, CE-Saclay

## Germany [3/21]
U Rostock
Ruhr U Bochum
Technische U Dresden

## Italy [12/89]
INFN, Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova
INFN, Milano
INFN, Napoli
INFN, Padova
INFN, Pavia
INF, Pisa
INFNN, Roma and U "La Sapienza"
INFN, Torino
INFN, Trieste

## Norway [1/3]
U of Bergen

## Russia [1/13]
Budker Institute, Novosibirsk

## United Kingdom [10/80]
U of Birmingham
U of Bristol
Brunel University
U of Edinburgh
U of Liverpool
Imperial College
Queen Mary & Westfield College
Royal Holloway, University of London
U of Manchester
Rutherford Appleton Laboratory

# Outline of the talk

- PEP-II and *BABAR*
- Selected measurements
  - *B* lifetimes
  - *B* mixing
  - $J/\psi K^*$ polarization
  - $\pi\pi, K\pi, KK$ branching ratios
- Measurement of *CP*-violating asymmetries in *B* decays to *CP* eigenstates
  - Isolating and tagging the *CP* sample
  - Determining the $\Delta z$ resolution
  - Determining the mistag fractions
  - Determining the *CP*-violating asymmetries
- Conclusion

# PEP-II and *BABAR*

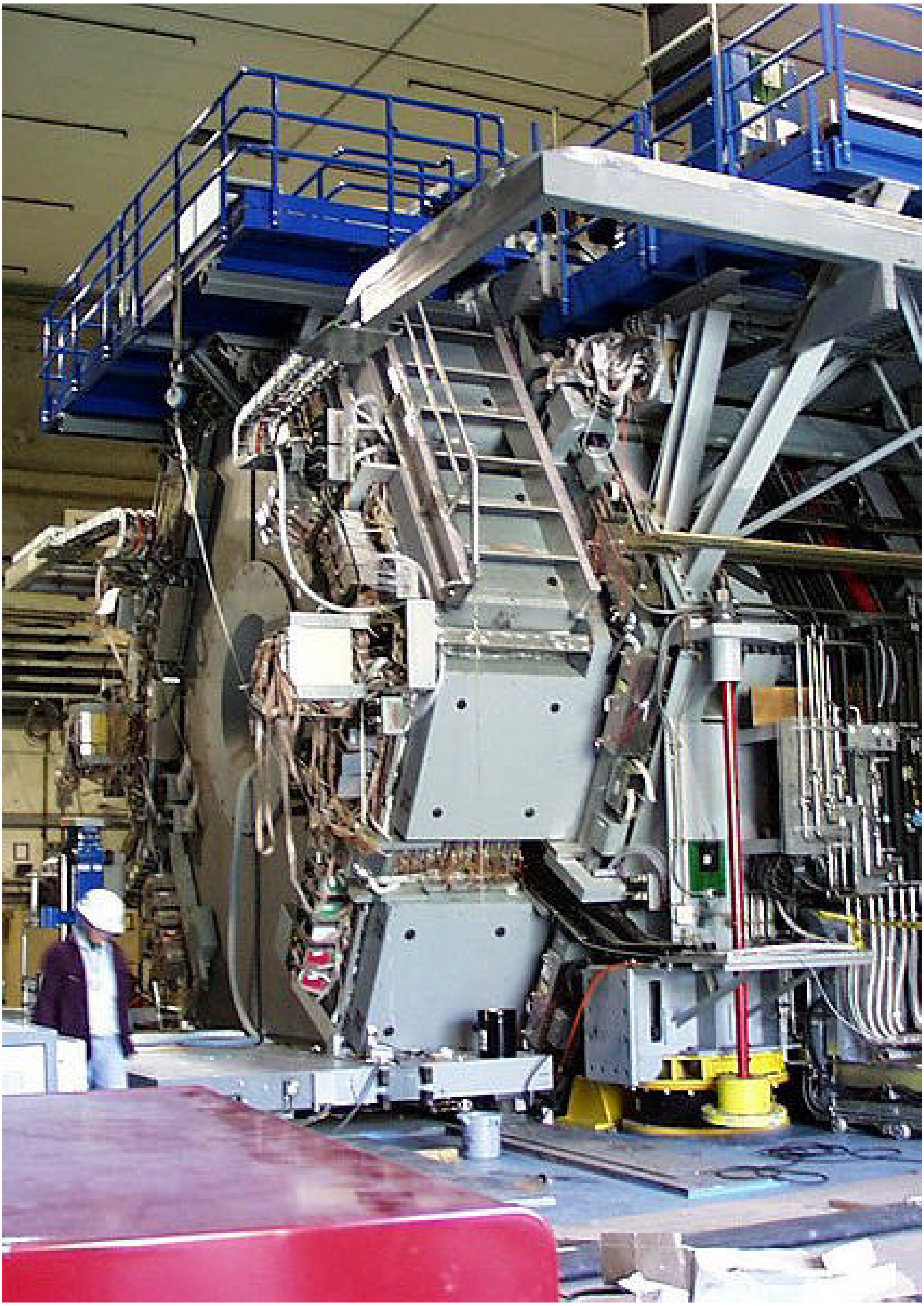
- With the goal of measuring *CP*-violating asymmetries in $B^0$ meson decay, construction of the PEP-II asymmetric storage ring and the associated *BABAR* detector were started in 1993 and 1994, respectively
- PEP-II had first collisions in the Summer of 1998
- *BABAR* was rolled onto the beamline in Spring 1999 and saw its first events on May 26, 1999
- PEP-II peak luminosity is

  $2.28 \times 10^{33}$ [$3 \times 10^{33}$ is design]

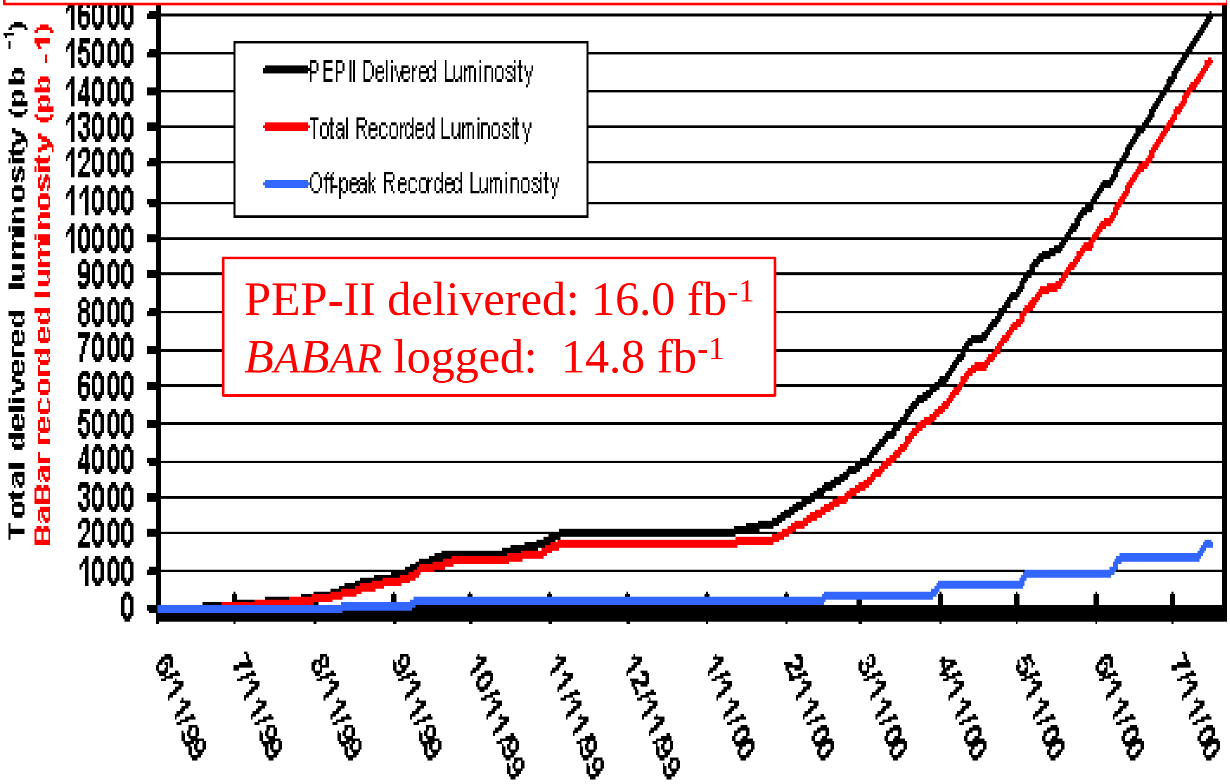
  using 606 bunches [1658 is design], with

  1286 ma $e^+$ and 751 ma $e^-$

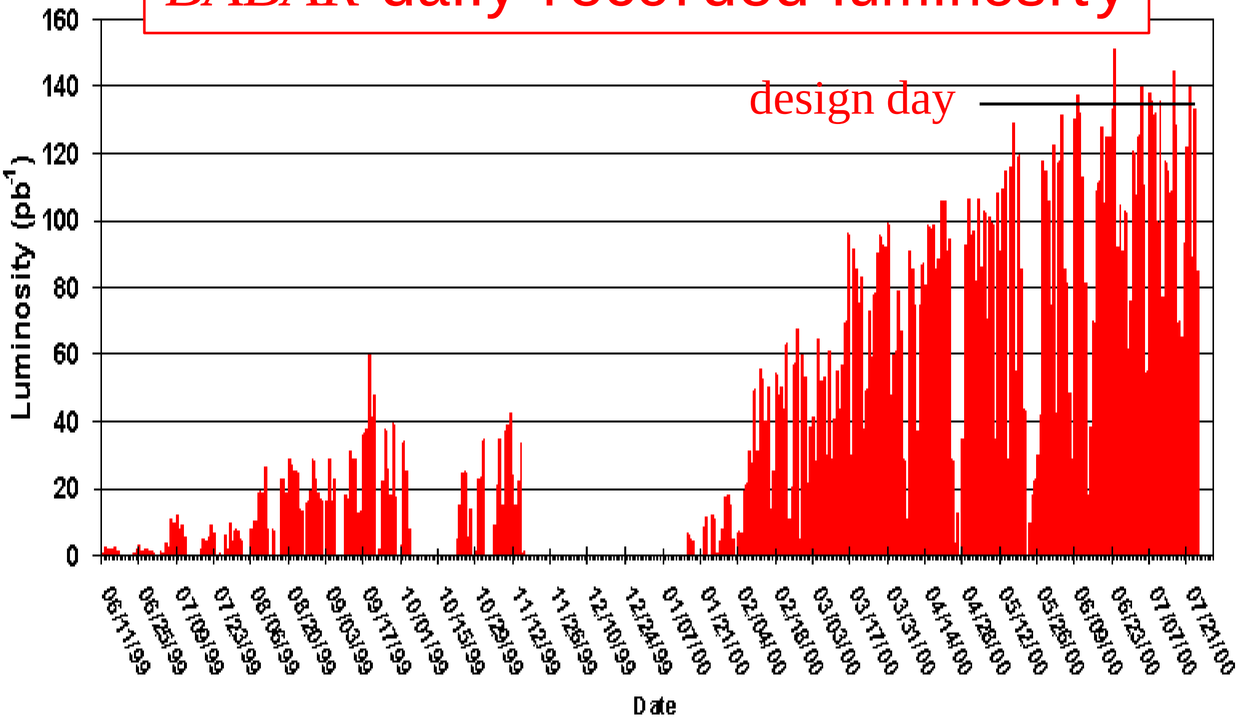
- PEP-II efficiency has been higher than expected and *BABAR* efficiency has typically been > 95%; the integrated "design day" luminosity of 135 $pb^{-1}$ (delivered) has been exceeded
- PEP-II has delivered 16 $fb^{-1}$ as of July 28
  - *BABAR* has recorded 14.8 $fb^{-1}$
    - The results presented today are based on ~10 $fb^{-1}$
    - Much of the early data requires reprocessing to improve calibration and alignment



# PEP-II delivered/*BABAR* recorded luminosity 1999+2000




# *BABAR* daily recorded luminosity

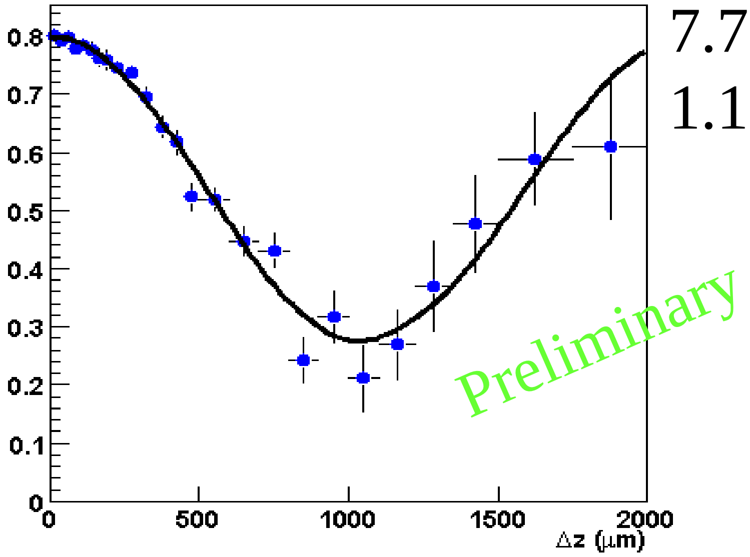


# *BABAR* talks at ICHEP2000

- Parallel Sessions
  - Study of inclusive and exclusive *B* decays to charmonium final states with *BABAR*.
    Gerhard Raven, UCSD
  - *BABAR* results on *B* decays to $D^*$ and $D_s^{(*)}$.
    Gloria Vuagnin, Universita' di Trieste
  - Study of *B* lifetime and mixing with fully-reconstructed $B^0$ decays with *BABAR*.
    Fernando Martinez-Vidal, Univ. Paris VI et VII
  - *BABAR* results on *B* lifetime and mixing with partially-reconstructed $B^0$ decays.
    Christophe Yeche, Saclay
  - *BABAR* study of the decays B->K*gamma, $B \to K l^+ l^-$ and $B \to K^* l^+ l^-$.
    Colin Jessop, SLAC
  - Study of charmless two-body, three-body and quasi-two-body *B* decays with *BABAR*.
    Theresa Champion, Univ. of Birmingham
  - DIRC - The particle identification system for *BABAR* .
    J. Schwiening, SLAC

- Plenary Session
  - First Physics Results from *BABAR*
    David Hitlin, Caltech

# Dilepton Mixing: Results

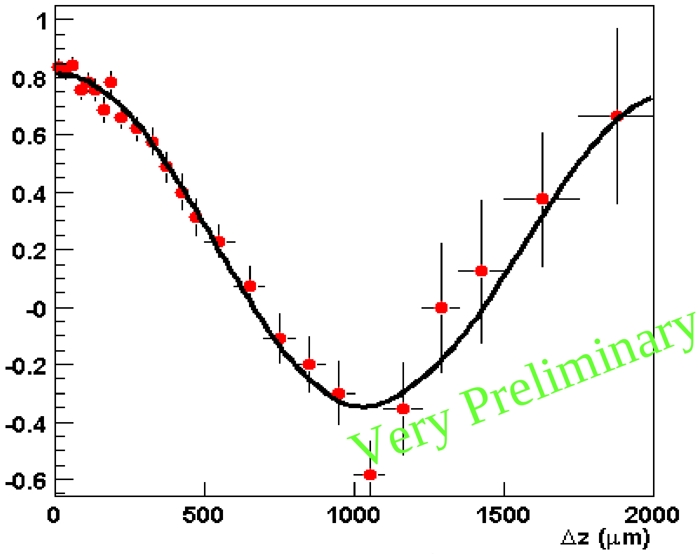



7.7 fb$^{-1}$ on-resonance
1.1 fb$^{-1}$ off-resonance

$\Delta m_d$ = (0.507 ± 0.015(stat) ± 0.022 (syst)) $\hbar$ ps$^{-1}$

[PDG: $\Delta m_d$ = (0.472 ± 0.017) $\hbar$ ps$^{-1}$ ]

PRELIMINARY




Dilepton sub-sample enriched in $B^0$ with partial reconstruction of $B^0 \rightarrow D^* l \nu$

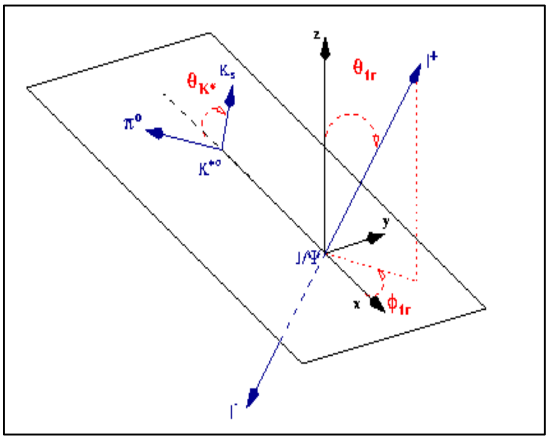
# $\pi\pi, K\pi, KK$ Branching Fraction Results

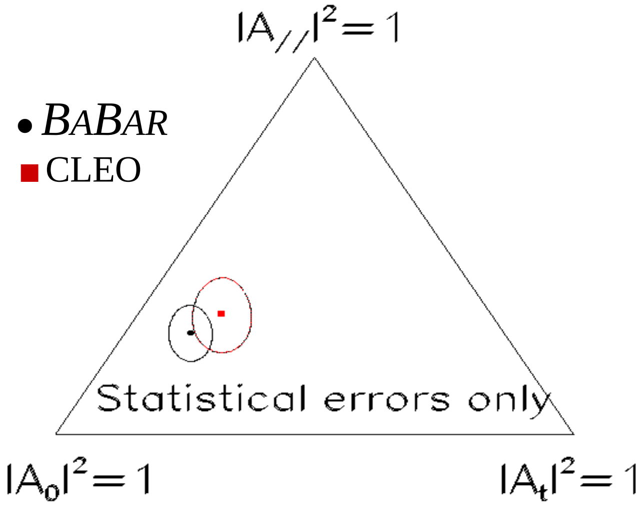
Global likelihood fit using $m_{ES}$, $\Delta E$, Fisher discriminant, and Cherenkov angle measured in DIRC

| Mode | $N_s$ | Stat. Sig. ($\sigma$) | $B$ ($10^{-6}$) | CLEO |
|---|---|---|---|---|
| $\pi^+\pi^-$ | $29^{+8+3}_{-7-4}$ | 5.7 | $9.3^{+2.6+1.2}_{-2.3-1.4}$ | $4.3^{+1.6}_{-1.4} \pm 0.5$ |
| $K^+\pi^-$ | $38^{+9+3}_{-8-5}$ | 6.7 | $12.5^{+3.0+1.3}_{-2.6-1.7}$ | $17.2^{+2.5}_{-2.4} \pm 1.2$ |
| $K^+K^-$ | $7^{+5}_{-4}$ ($<15$) | 2.1 | $<6.6$ | $<1.9$ |

PRELIMINARY

# Amplitude Analysis of $B \to J/\psi K^*$



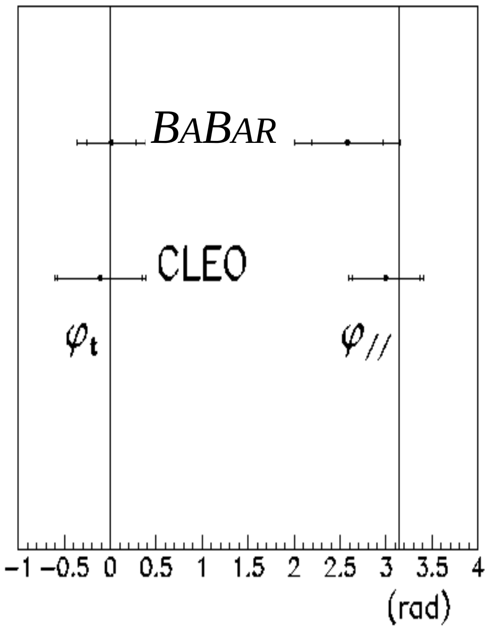




PRELIMINARY

Fraction of *CP* odd.

Longitudinal Polarization

| | |
|---|---|
| $\lvert A_\perp \rvert^2$ | $0.13 \pm 0.06 \pm 0.02$ |
| $\lvert A_0 \rvert^2$ | $0.60 \pm 0.06 \pm 0.04$ |
| $\phi_\parallel$ | $2.58 \pm 0.39 \pm 0.20$ |
| $\phi_\perp$ | $0.01 \pm 0.27 \pm 0.10$ |




Will be used for future $\sin(2\beta)$ measurement.

## The Wolfenstein parametrization of the CKM matrix

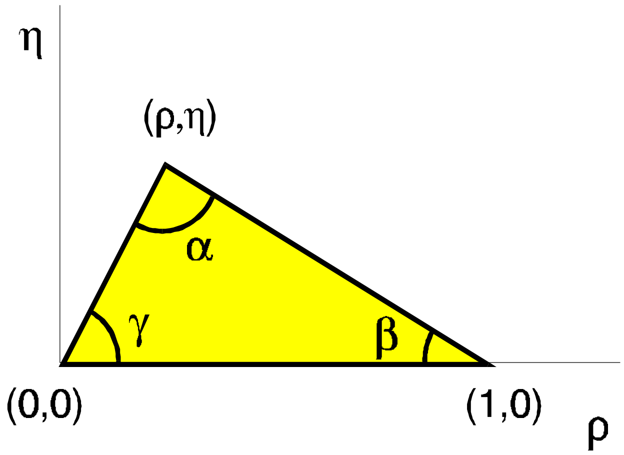
$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$\lambda$ and $A$ are well-determined; $\rho$ and $\eta$ are not

The unitarity of the CKM matrix provides six constraints, the most useful of which

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

is called the unitarity triangle:




The area of the unitarity triangle, the “Jarlskog Invariant”, is proportional to the strength of *CP* violation in the Standard Model:

# Overconstraining the Unitarity Triangle

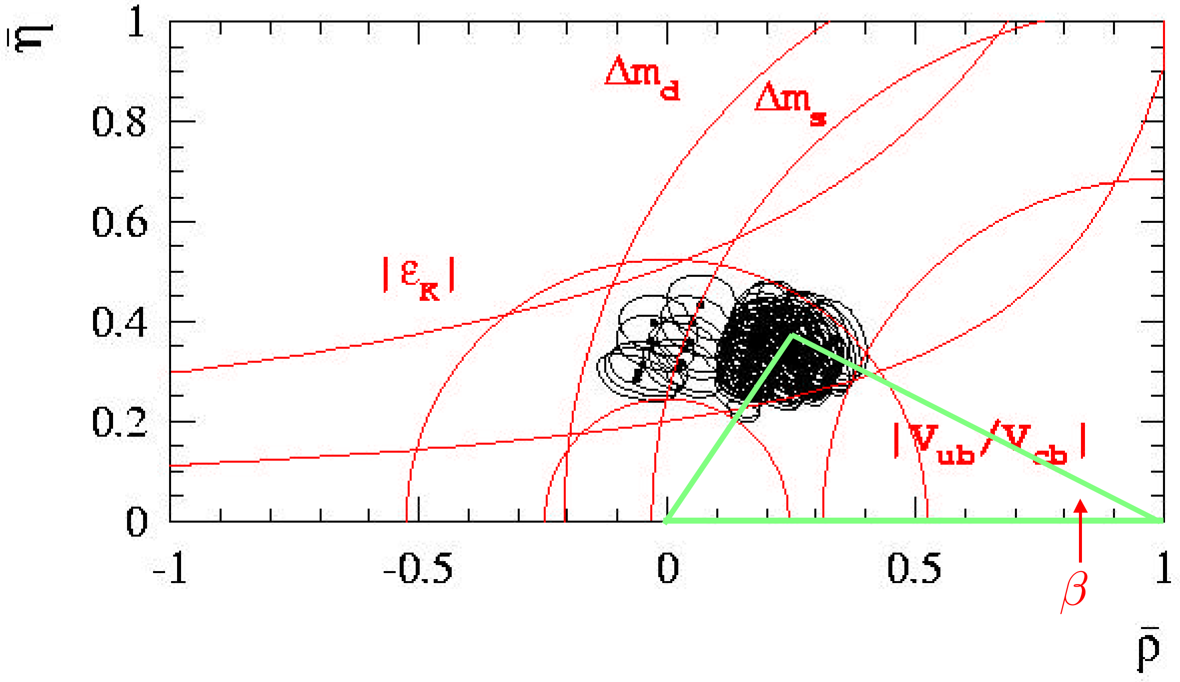
The sides of the unitarity triangle are determined by the magnitudes of the CKM matrix elements.

Uncertainties in theoretical models for $V_{ub}$, $f_B$, $B_K$, *etc* limit the determination of the triangle

The *CP* asymmetry in $B^0$ decays to *CP* eigenstates measures

$$\sin 2\beta = -\arg\left[\frac{V_{tt}V_{tt}^*}{V_{tt}V_{tt}^*}\right]$$

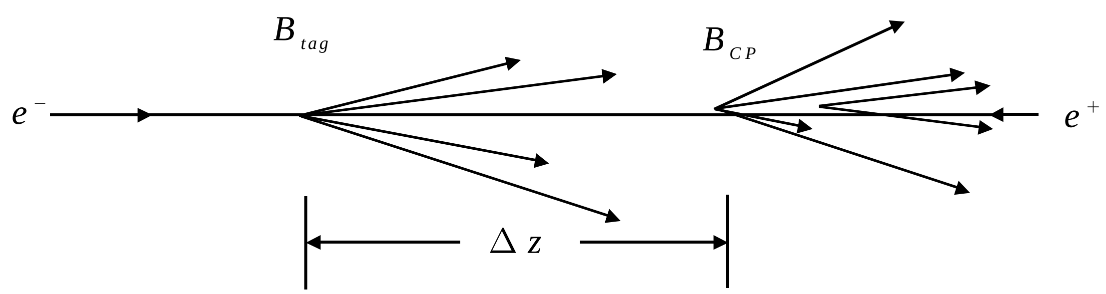
allowing us to overdetermine the Unitarity Triangle



# Measuring $CP$ violation at the $\Upsilon(4S)$

The $\Upsilon(4S)$ resonance decays to $B\bar{B}$ pairs in a coherent $L$=1 state

At PEP-II, with $e^-$ energy of 9 GeV and $e^+$ energy of 3.1 GeV, the $\Upsilon(4S)$ is produced with $\beta\gamma$=0.56




The mean decay distance $\Delta z$ between the $B$ decay vertices is ~250 μm, making it possible to ascertain the time order of the decays

If we can measure the flavor of a $B^0(\bar{B}^0)$ decay ($B_{tag}$) occurring at a time $t$, then at that time, the flavor of the other $\bar{B}^0(B^0)$ is known.

We then reconstruct the decay of the second $B^0$ at a time $\Delta t$=$t$-$t_0$ into a $CP$ eigenstate:

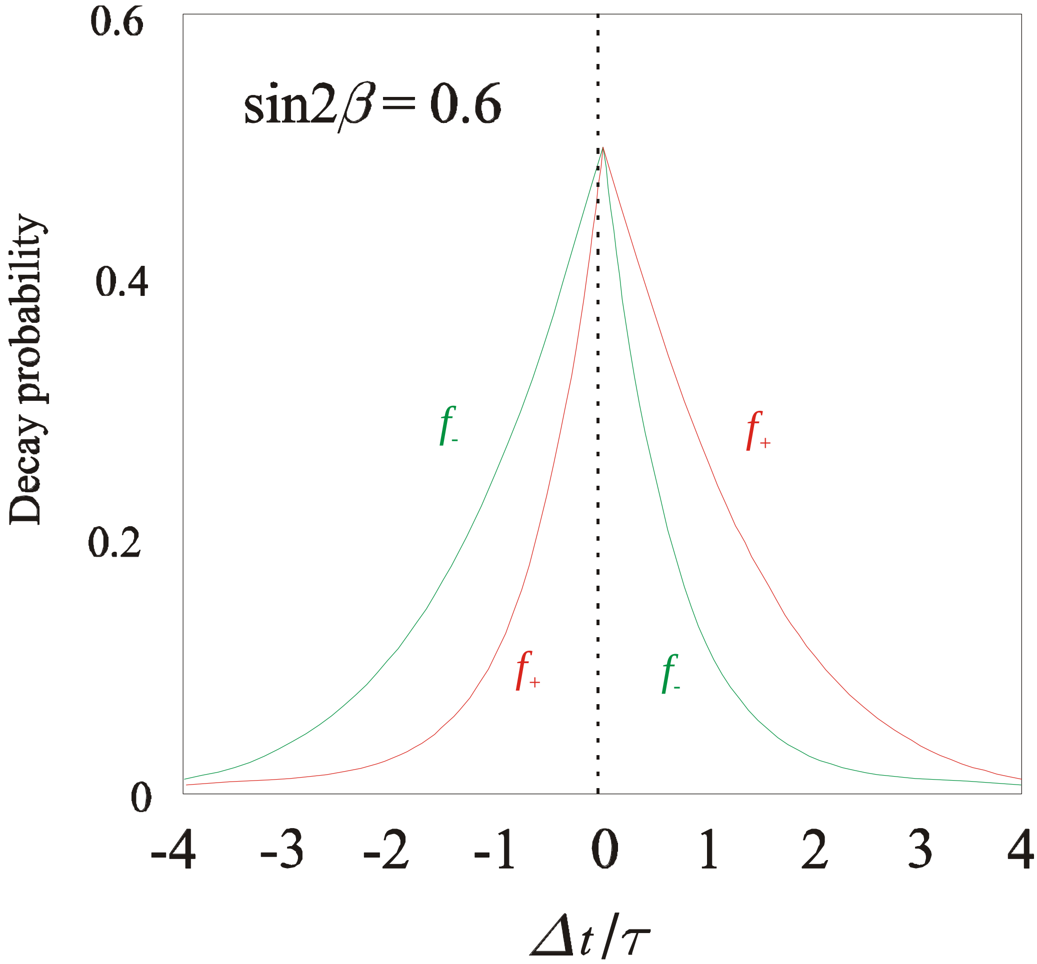
$$f_\pm(\Delta t;\Gamma,\Delta m_d,\mathcal{D}\sin 2\beta) = \frac{1}{4}\Gamma e^{-\Gamma|\Delta t|}\left[1 \pm \mathcal{D}\sin 2\beta \times \sin\Delta m_d \Delta t\right]$$

where the dilution $\mathcal{D}=(1-2w)$ is derived from the measured mistag fraction $w$

# Measuring $CP$ violation at the $\Upsilon(4S)$

There are four time distributions

$$f_+: \quad B_{tag} = B,\ \Delta t > 0$$
$$B_{tag} = B,\ \Delta t < 0$$
$$f_-: \quad B_{tag} = \bar{B},\ \Delta t > 0$$
$$B_{tag} = \bar{B},\ \Delta t < 0$$

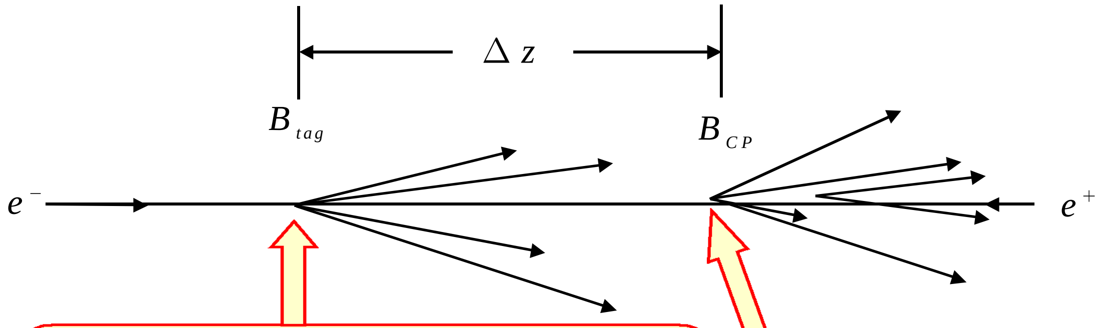



The $CP$ asymmetry is

$$\mathcal{A}_{CP} = \frac{f_+(\Delta t) - f_-(\Delta t)}{f_+(\Delta t) + f_-(\Delta t)} = \mathcal{D} \sin 2\beta \times \sin \Delta m_d \Delta t$$

# Overview of the analysis

Reconstruct the $B$ decays to $CP$ eigenstates and tag the flavor of the other $B$ decay




Select $B_{tag}$ events using, primarily, leptons and $K$'s from $B$ hadronic decays & determine $B$ flavor

Select $B_{CP}$ events ($B^0 \to J/\psi K^0_S$ , *etc.*)

Measure the mistag fractions $w_i$ and determine the dilutions $\mathcal{D}_i = 1 - 2\,w_i$

Measure $\Delta z$ between $B_{CP}$ and $B_{tag}$ to determine the signed time difference $\Delta t$ between the decays

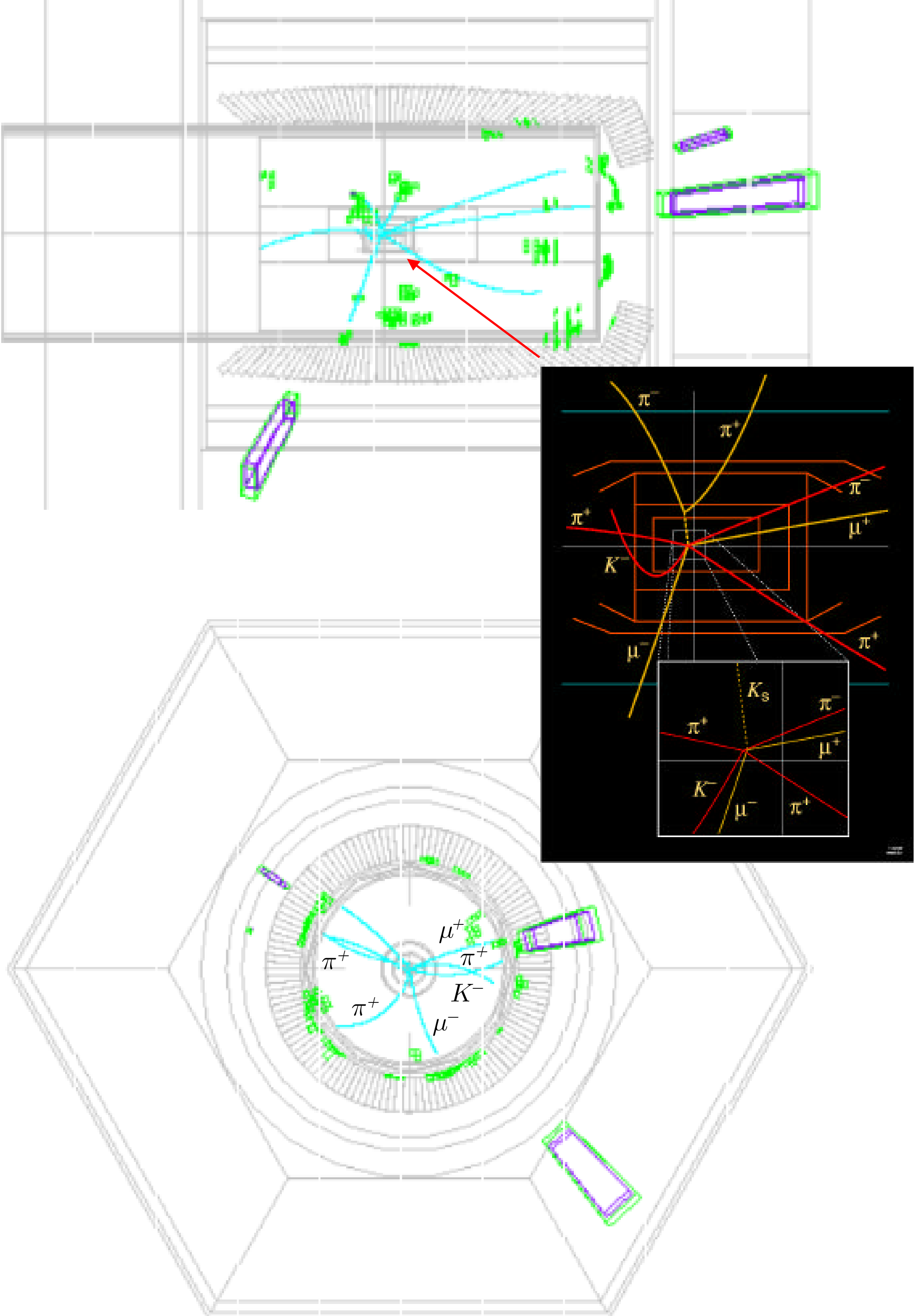
Determine the resolution function for $\Delta z$

$$\mathcal{R}(\Delta t;\hat{a})=\sum_{i=1}^{i=2}\frac{f_i}{\sigma_i\sqrt{2\pi}}\exp\left(-(\Delta t-\delta_i)^2\right)/2\sigma_i^2$$

$$\mathcal{F}_{\pm}(\Delta t;\Gamma,\Delta m_d,\mathcal{D}\sin 2\beta,\hat{a}) = f_{\pm}(\Delta t;\Gamma,\Delta m_d,\mathcal{D}\sin 2\beta)\otimes\mathcal{R}(\Delta t;\hat{a})$$

$$A_{CP}(\Delta t) \propto \frac{\mathcal{F}_+(\Delta t) - \mathcal{F}_-(\Delta t)}{\mathcal{F}_+(\Delta t) + \mathcal{F}_-(\Delta t)} \propto \mathcal{D}\sin 2\beta \times \sin \Delta m_d \Delta t$$

# A tagged $B^0 \to J/\psi K_S^0$ event



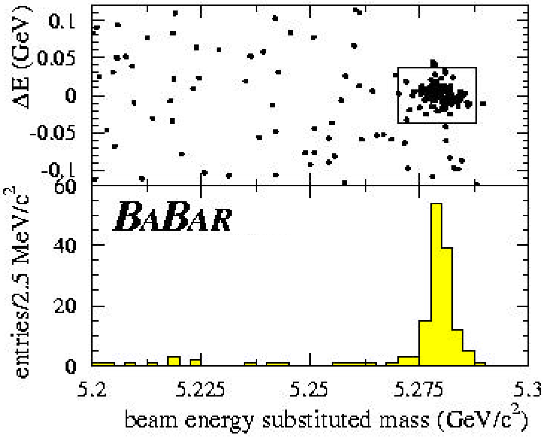
# The $B_{CP}$ sample

PRELIMINARY

$J/\psi\ K_S^0\ (K_S^0 \to \pi^+\pi^-)$

$124 \pm 12$ events

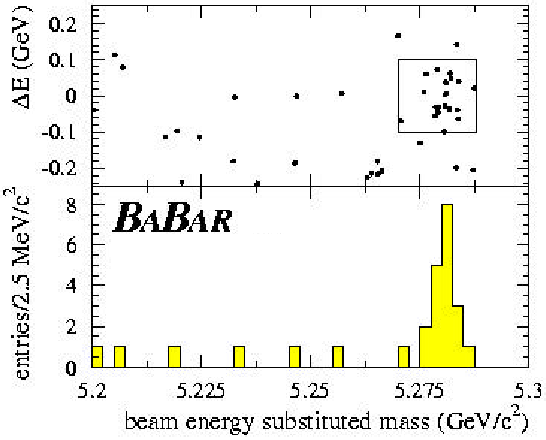
purity 96%




$J/\psi\ K_S^0\ (K_S^0 \to \pi^0\pi^0)$

$18 \pm 4$ events

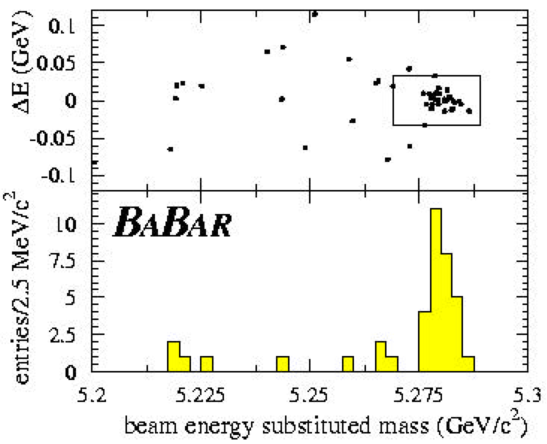
purity 91%




$\psi(2S)\ K_S^0$

$27 \pm 6$ events

purity 93%



# The resolution function for $\Delta t$

The time resolution is dominated by the *z* resolution of the tagging vertex

The vertex resolution function is well-described by a five-parameter sum of two gaussians

$$\mathcal{R}(\Delta t;\hat{a}) = \sum_{i=1}^{i=2} \frac{f_i}{\sigma_i\sqrt{2\pi}} \exp\left(-(\Delta t - \delta_i)^2/2\sigma_i^{\,2}\right)$$

In the likelihood fits, we use event-by-event time resolution errors. We introduce two scale factors $\mathcal{S}_1$ and $\mathcal{S}_2$:

$$\sigma_i = \mathcal{S}_i \times \sigma_{\Delta t}$$

To account for ~1% of events with very large $\Delta z$ a third gaussian with a fixed width of 8ps, is included

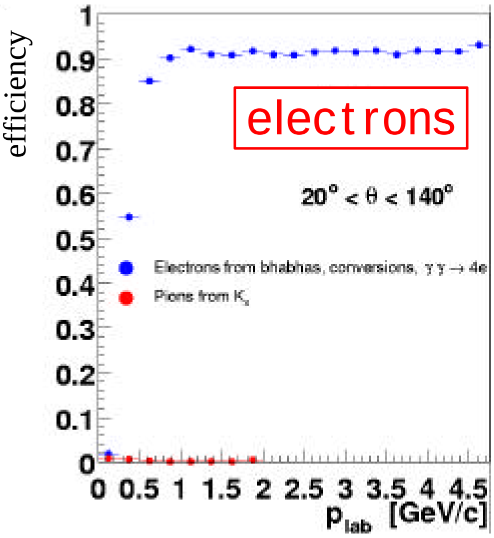
The parameters extracted from the fit are:

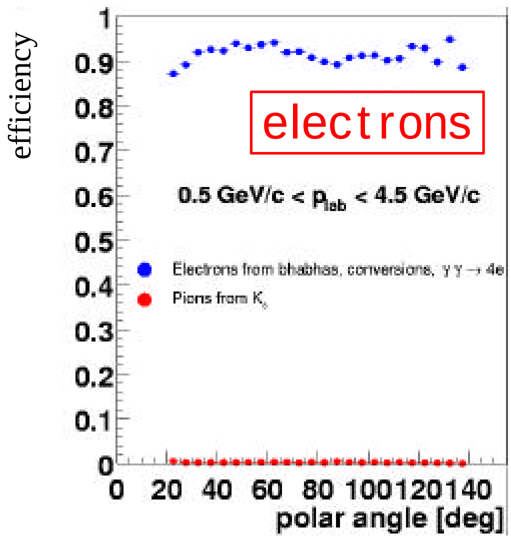
| parameter | | value | |
|---|---|---|---|
| $\delta_1$ | (ps) | _0.20 _ 0.06 | from fit |
| _1 | | 1.33 _ 0.14 | from fit |
| f_ | (%) | 1.6 _ 0.6 | from fit |
| $f_1$ | (%) | 75 | fixed |
| $\delta_2$ | (ps) | 0 | fixed |
| _2 | | 2.1 | fixed |

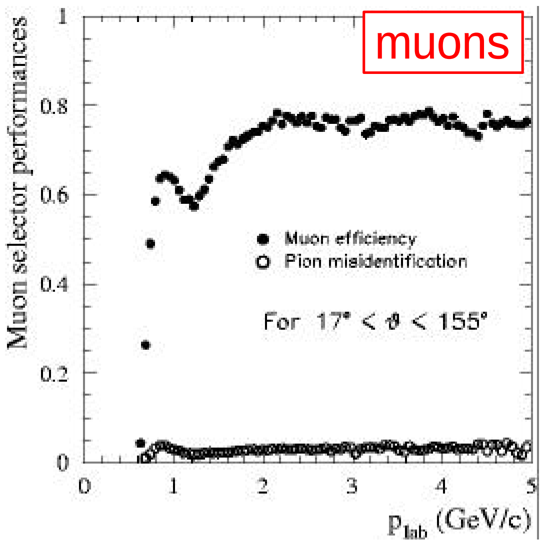
PRELIMINARY

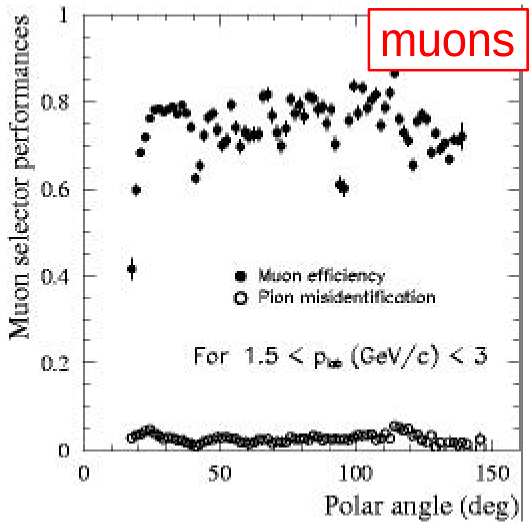
# Particle ID and mis-ID

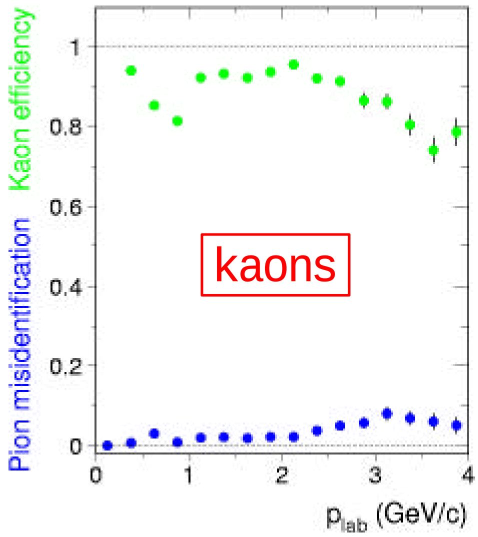
PRELIMINARY



# Measurement of mistag fractions & $\Delta m_d$

PRELIMINARY

- Mistag fractions and $\Delta m_d$ are directly measured
  - We use a large sample of events in which one $B^0$ candidate, called $B_{rec}$, is fully reconstructed in a flavor eigenstate mode
    - Hadronic sample: 2227 events
      $D^{*-}\pi^+, D^{*-}\rho^+, D^{*-}a_1^+, D^-\pi^+, D^-\rho^+, D^-a_1^+$
    - Semileptonic events: 7517 events $D^{*-}\ell^+\nu_\ell$
  - We apply flavor-tagging algorithms to the rest of the event, which constitutes the potential $B_{tag}$
  - Tagging categories:
    - Electron } Lepton
    - Muon } Lepton
    - Kaon
    - NT1 } Neural network
    - NT2 } Neural network
  - We classify tagged events as mixed or unmixed, depending on whether the $B_{tag}$ is tagged with the same or the opposite flavor as the $B_{rec}$
  - The time-dependent rate of mixing, which best exploits information at small values of $\Delta t = t_{rec} - t_{tag}$, is used to extract $w_i$ and $\Delta m_d$
  - The time-integrated rate of mixed events in each tagging category: $\chi_i = \chi_d + (1 - 2\chi_d) w_i$

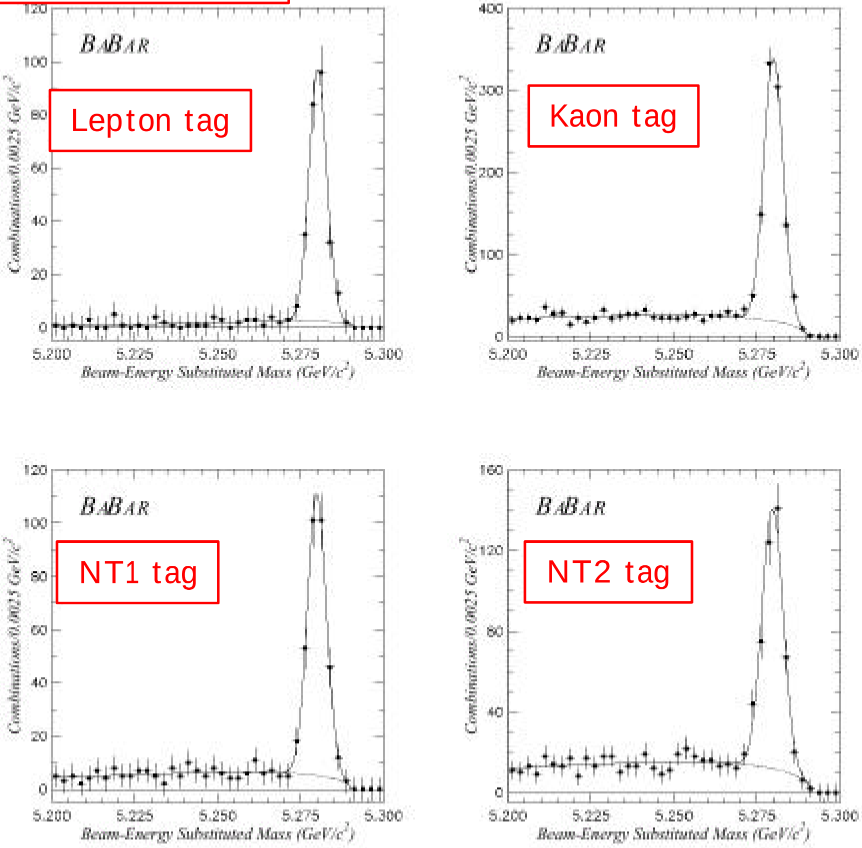
    where $\chi_d = \dfrac{x_d^2}{2(1+x_d^2)}$, $x_d = \dfrac{\Delta m_d}{\Gamma}$

    is used as a cross check

# Measurement of mistag fractions & $\Delta m_d$

PRELIMINARY

## Hadronic sample

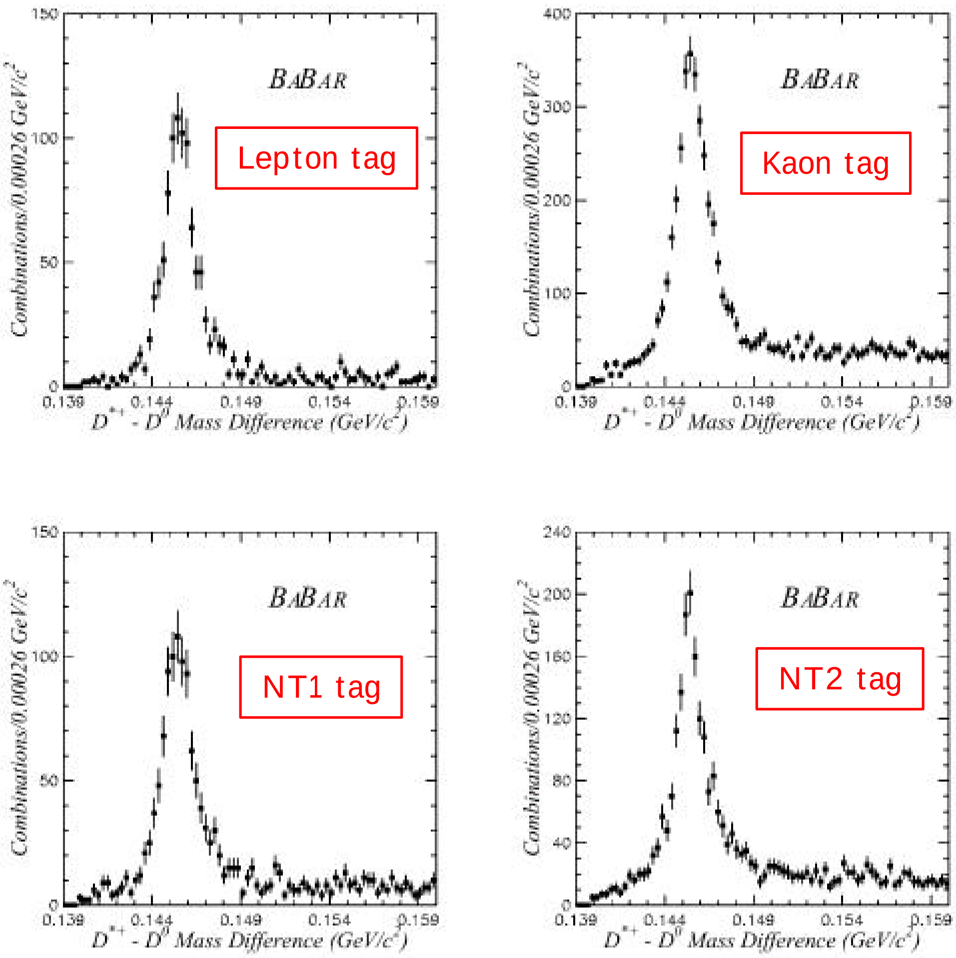



| Sample | Final State | Yield | Purity (%) |
|---|---|---|---|
| Hadronic | $D^{*-}\pi^+$ | $622 \pm 27$ | 90 |
| (neutral) | $D^{*-}\rho^+$ | $419 \pm 25$ | 84 |
| | $D^{*-}a_1^+$ | $239 \pm 19$ | 79 |
| | $D^-\pi^+$ | $630 \pm 26$ | 90 |
| | $D^-\rho^+$ | $315 \pm 20$ | 84 |
| | $D^{*-}\pi^+$ | $225 \pm 20$ | 74 |
| | total | $2438 \pm 57$ | 85 |
| Hadronic | $\bar{D}^0\pi^+$ | $1755 \pm 47$ | 88 |
| (charged) | $\bar{D}^*\pi^+$ | $543 \pm 27$ | 89 |
| | total | $2293 \pm 54$ | 88 |

# Measurement of mistag fractions & $\Delta m_d$

PRELIMINARY

## Semileptonic sample

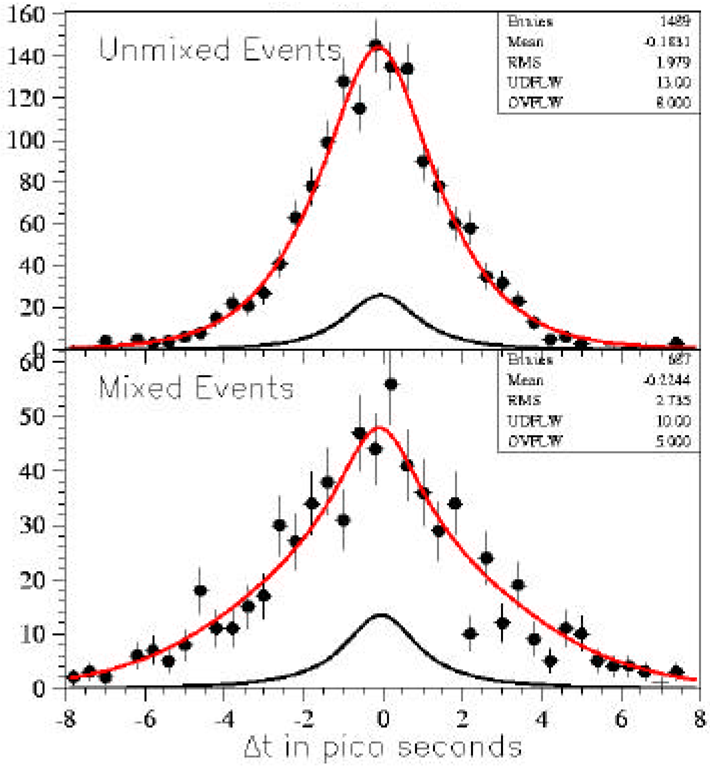



| Sample | Final State | Yield | Purity(%) |
|---|---|---|---|
| Semileptonic | $D^* l \nu$ | $7517 \pm 104$ | 84 |

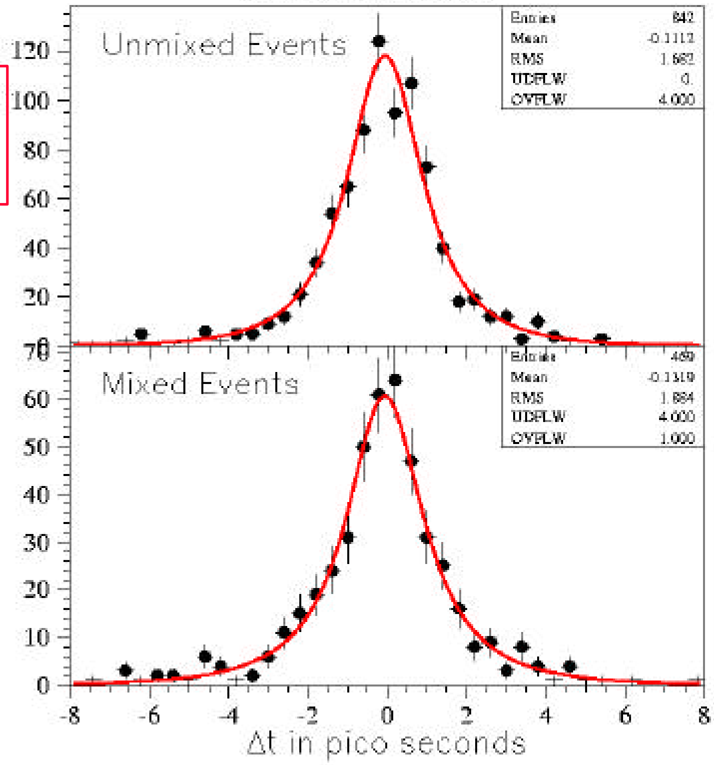
# Measurement of $\Delta m_d$

PRELIMINARY

**Signal region, all tags**




**Sideband region, all tags**






BABAR

# Time-dependent measurement of $w_i$ & $\Delta m_d$

PRELIMINARY

The time-dependence of mixed and unmixed events is

$$h_{\pm}(\Delta t;\Gamma,\Delta m_d,\mathcal{D}) = \frac{1}{4}\Gamma e^{-\Gamma|\Delta t|}[1 \pm \mathcal{D}\times\cos\Delta m_d\Delta t]$$

This is convoluted with the $\Delta z$ vertex resolution function

$$\mathcal{H}_{\pm}(\Delta t;\Gamma,\Delta m_d,\mathcal{D},\delta) = h_{\pm}(\Delta t;\Gamma,\Delta m_d,\mathcal{D}) \otimes R(\Delta t;\delta)$$

and used to form a likelihood function

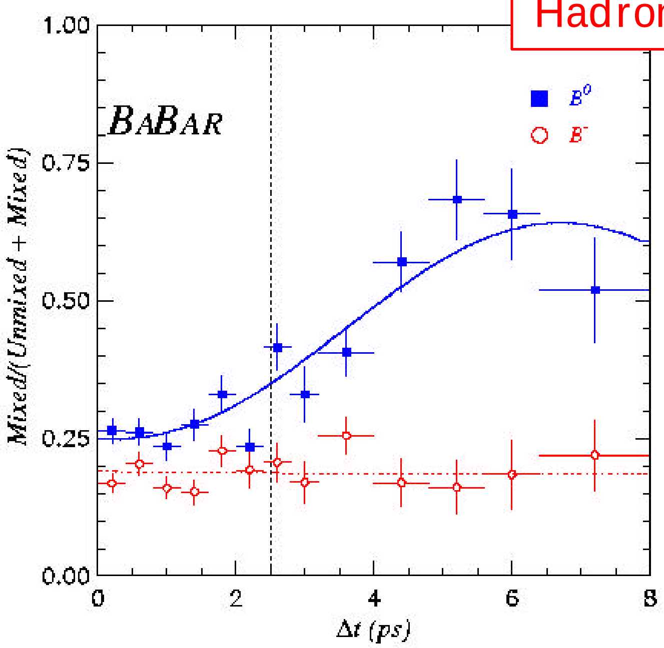
$$\ln\mathcal{L}_M = \sum_i \left[ \sum_{unmixed} \ln\mathcal{H}_+(t;\Gamma,\Delta m_d,\mathcal{D}_i,\delta) \quad \sum_{mixed} \ln\mathcal{H}_-(t;\Gamma,\Delta m_d,\mathcal{D}_i,\delta) \right]$$

from which we extract $w_i = (1-\mathcal{D}_i)/2$ and $\Delta m_d$

The period of the mixing rate $a(\Delta t) = \frac{N_{unmix}(\Delta t) - N_{mix}(\Delta t)}{N_{unmix}(\Delta t) + N_{mix}(\Delta t)}$ yields $\Delta m_d$

The amplitude yields $w_i$ for each tagging mode

Hadronic sample



# Results of the tag/mix likelihood fit

| Parameter | hadronic Fit Value | hadronic $Q = \epsilon(1-2w)^2$ | semileptonic Fit Value | semileptonic $Q = \epsilon(1-2w)^2$ |
|---|---|---|---|---|
| $\Delta m_d$ [$\hbar$ ps$^{-1}$] | $0.516 \pm 0.031$ | — | $0.508 \pm 0.020$ | — |
| $w$(Lepton) | $0.116 \pm 0.032$ | 0.062 | $0.084 \pm 0.020$ | 0.071 |
| $w$(Kaon) | $0.196 \pm 0.021$ | 0.136 | $0.199 \pm 0.016$ | 0.133 |
| $w$(NT1) | $0.135 \pm 0.035$ | 0.064 | $0.210 \pm 0.028$ | 0.066 |
| $w$(NT2) | $0.314 \pm 0.037$ | 0.023 | $0.361 \pm 0.025$ | 0.013 |
| $\text{scale}_{\text{core, sig}}$ | $1.33 \pm 0.13$ | — | $1.32 \pm 0.07$ | — |
| $\delta_{\text{core, sig}}$ [ps] | $-0.20 \pm 0.07$ | — | $-0.25 \pm 0.04$ | — |
| $f_{\text{outlier}}$ | $0.016 \pm 0.006$ | — | $0.000 \pm 0.002$ | — |

$$\sum_i Q_i = 0.285 \qquad \sum_i Q_i = 0.283$$

PRELIMINARY

# Tagged events and mistag fractions $w_i$

PRELIMINARY

## Mistag fractions (likelihood method) from the hadronic sample

| Tagging Category | $\varepsilon$ (%) | $w$ (%) | $Q$ (%) |
|---|---|---|---|
| Lepton | $11.2 \pm 0.5$ | $9.6 \pm 1.7 \pm 1.3$ | $7.3 \pm 0.3$ |
| Kaon | $36.7 \pm 0.9$ | $19.7 \pm 1.3 \pm 1.1$ | $13.5 \pm 0.3$ |
| NT1 | $11.7 \pm 0.5$ | $16.7 \pm 2.2 \pm 2.0$ | $5.2 \pm 0.2$ |
| NT2 | $16.6 \pm 0.6$ | $33.1 \pm 2.1 \pm 2.1$ | $1.9 \pm 0.1$ |
| all | $76.7 \pm 0.5$ | | $27.9 \pm 0.5$ |

The effective tagging efficiency is

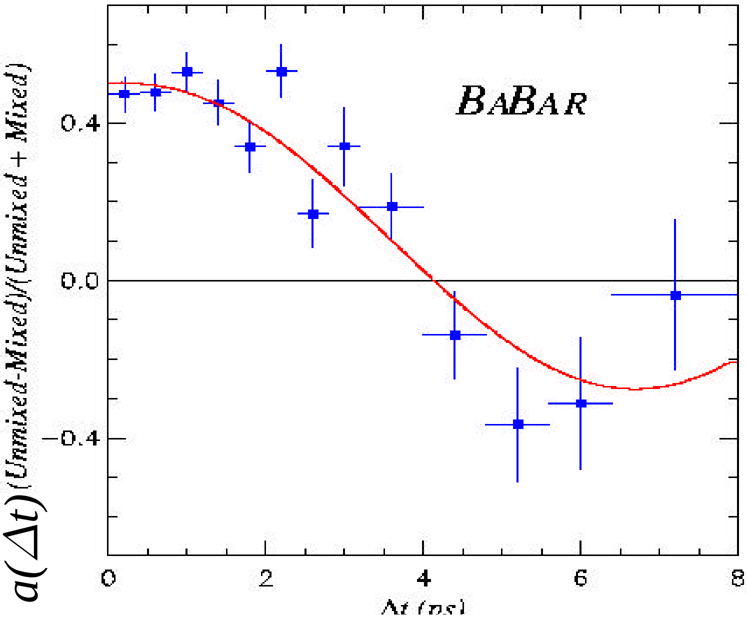
$$Q_i = \varepsilon_i (1 - 2 w_i)^2$$

## Tagged events by decay mode and tagging category

| Tagging Category | $J/\psi K_S^0$ $(K_S^0 \to \pi^+\pi^-)$ | | | $J/\psi K_S^0$ $(K_S^0 \to \pi^0\pi^0)$ | | | $\psi(2S)K_S^0$ $(K_S^0 \to \pi^+\pi^-)$ | | | $CP$ sample (tagged) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $B^0$ | $\overline{B}^0$ | all | $B^0$ | $\overline{B}^0$ | all | $B^0$ | $\overline{B}^0$ | all | $B^0$ | $\overline{B}^0$ | all |
| Electron | 1 | 3 | 4 | 1 | 0 | 1 | 1 | 2 | 3 | 3 | 5 | 8 |
| Muon | 1 | 3 | 4 | 0 | 0 | 0 | 2 | 0 | 2 | 3 | 3 | 6 |
| Kaon | 29 | 18 | 47 | 2 | 2 | 4 | 5 | 7 | 12 | 36 | 27 | 63 |
| NT1 | 9 | 2 | 11 | 1 | 0 | 1 | 2 | 0 | 2 | 12 | 2 | 14 |
| NT2 | 10 | 9 | 19 | 3 | 3 | 6 | 3 | 1 | 4 | 16 | 13 | 29 |
| Total | 50 | 35 | 85 | 7 | 5 | 12 | 13 | 10 | 23 | 70 | 50 | **120** |

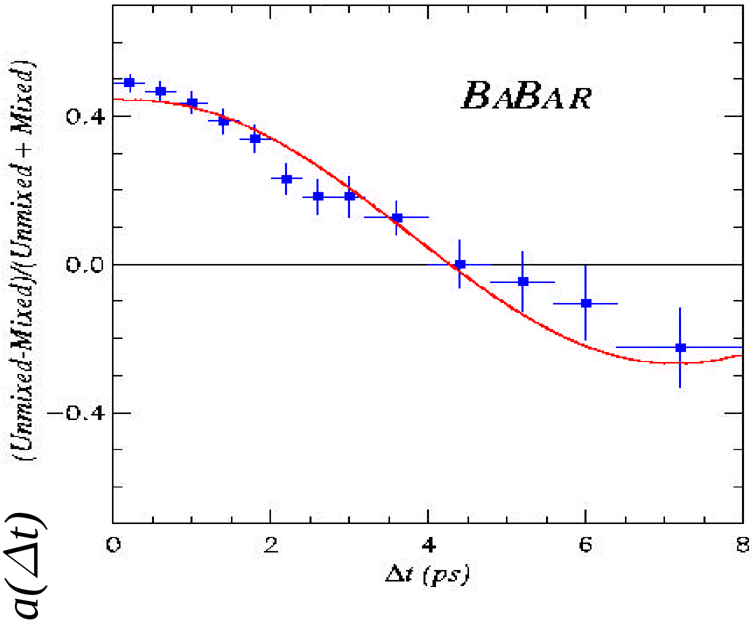
# $\Delta m_d$ from the tag/mix likelihood fit

PRELIMINARY




Hadronic decays

$\Delta m_d = 0.516$
$\pm 0.031$ (stat)
$\pm 0.018$ (syst) $\hbar$ ps$^{-1}$




Semileptonic decays

$\Delta m_d = 0.508$
$\pm 0.020$ (stat)
$\pm 0.022$ (syst) $\hbar$ ps$^{-1}$

Combined result

$$\Delta m_d = 0.512 \pm 0.017 \text{ (stat)} \pm 0.022 \text{ (syst)} \; \hbar \text{ ps}^{-1}$$

[PDG: $\Delta m_d = 0.472 \pm 0.017 \; \hbar$ ps$^{-1}$ ]

# Systematic uncertainties in $\Delta m_d$ & $w_i$

PRELIMINARY

## Hadronic decays

| Source | $\Delta m_d$ [$\hbar$ ps$^{-1}$] | Lepton | Kaon | NT1 | NT2 |
|---|---|---|---|---|---|
| $\Delta t$ Resolution | 0.011 | 0.004 | 0.004 | 0.004 | 0.004 |
| Background $\Delta t$ | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Background Resolution | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Background Fractions | 0.004 | 0.004 | 0.002 | 0.006 | 0.004 |
| $B^0$ lifetime | 0.005 | 0.001 | 0.001 | 0.001 | 0.001 |
| $z$ scale | 0.005 | — | — | — | — |
| $z$ boost | 0.003 | — | — | — | — |
| Monte Carlo Correction | +0.013 ± 0.011 | –0.001 ± 0.011 | 0.000 ± 0.008 | –0.010 ± 0.015 | –0.015 ± 0.014 |
| Total Systematic Error | 0.018 | 0.013 | 0.010 | 0.017 | 0.015 |
| Statistical Error | 0.031 | 0.032 | 0.021 | 0.035 | 0.037 |
| Total Error | 0.036 | 0.035 | 0.023 | 0.039 | 0.040 |

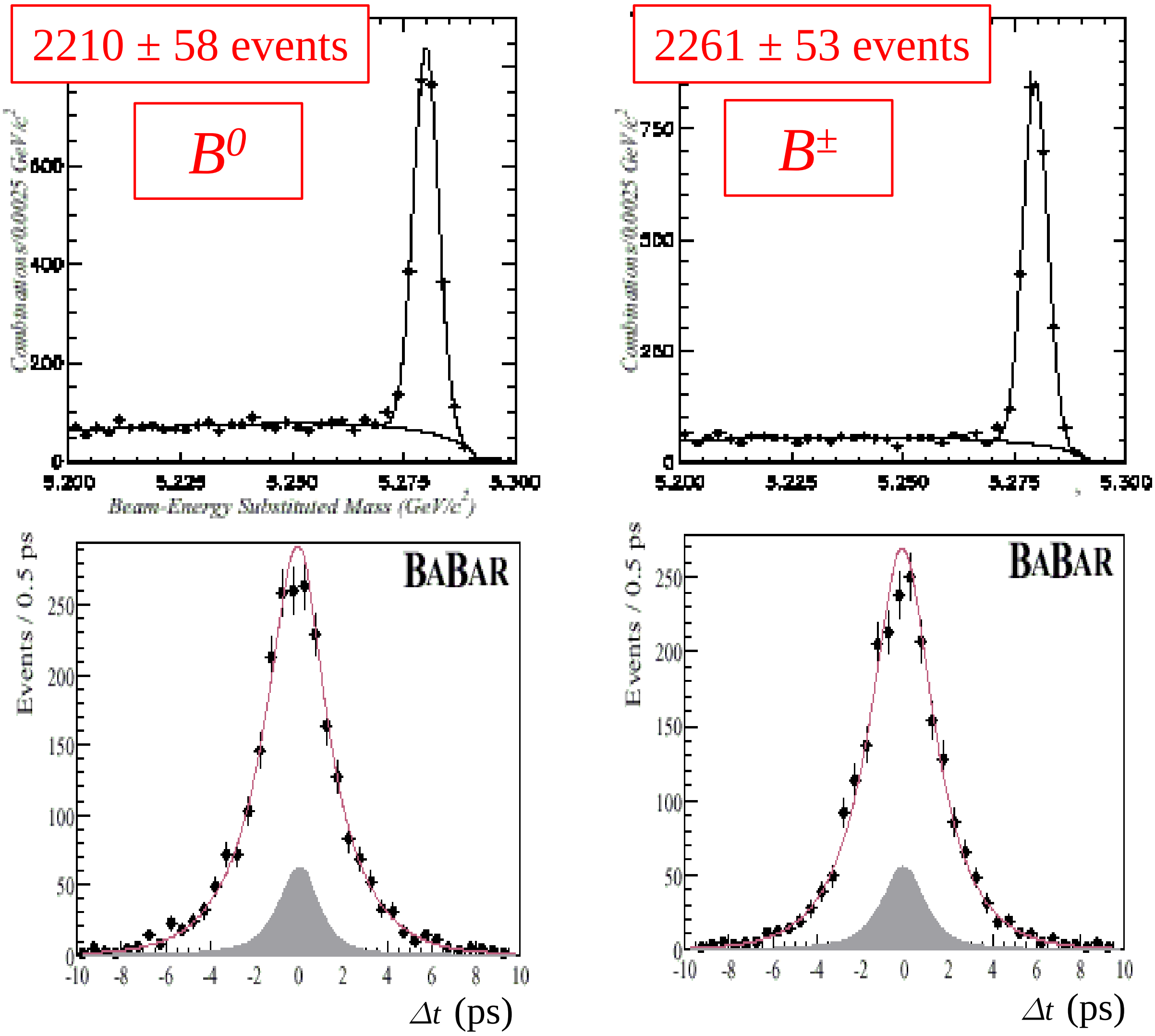
## $D^*l\nu$ decays

| Source | $\Delta m_d$ [$\hbar$ ps$^{-1}$] | Lepton | Kaon | NT1 | NT2 |
|---|---|---|---|---|---|
| $\Delta t$ Resolution | 0.012 | 0.005 | 0.009 | 0.012 | 0.005 |
| Background $\Delta t$ | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Background Resolution | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| Background Dilutions | 0.006 | 0.008 | 0.013 | 0.026 | 0.031 |
| Background Fractions | 0.006 | 0.009 | 0.011 | 0.017 | 0.032 |
| $B^+$ Backgrounds | 0.010 | 0.009 | 0.010 | 0.004 | 0.003 |
| $B^0$ lifetime | 0.006 | 0.001 | 0.001 | 0.001 | 0.001 |
| $z$ scale | 0.005 | — | — | — | — |
| $z$ boost | 0.003 | — | — | — | — |
| Monte Carlo Correction | +0.008 ± 0.009 | –0.010 ± 0.008 | –0.001 ± 0.006 | –0.002 ± 0.011 | –0.006 ± 0.011 |
| Total Systematic Error | 0.022 | 0.018 | 0.023 | 0.035 | 0.046 |
| Statistical Error | 0.020 | 0.020 | 0.016 | 0.028 | 0.025 |
| Total Error | 0.030 | 0.027 | 0.031 | 0.045 | 0.052 |

# $B^0$ and $B^{\pm}$ lifetimes using fully reconstructed hadronic decays

PRELIMINARY

Uses the same vertex fitting technique as the *CP* analysis




$\tau_{B0} = 1.506 \pm 0.052$ (stat) $\pm 0.029$ (syst) ps [PDG: $1.548 \pm 0.032$]

$\tau_{B+} = 1.602 \pm 0.049$ (stat) $\pm 0.035$ (syst) ps [PDG: $1.653 \pm 0.028$]

$\tau_{B+}/\tau_{B0} = 1.065 \pm 0.044$ (stat) $\pm 0.021$ (syst)

[PDG: $1.062 \pm 0.029$]

# Blind analysis

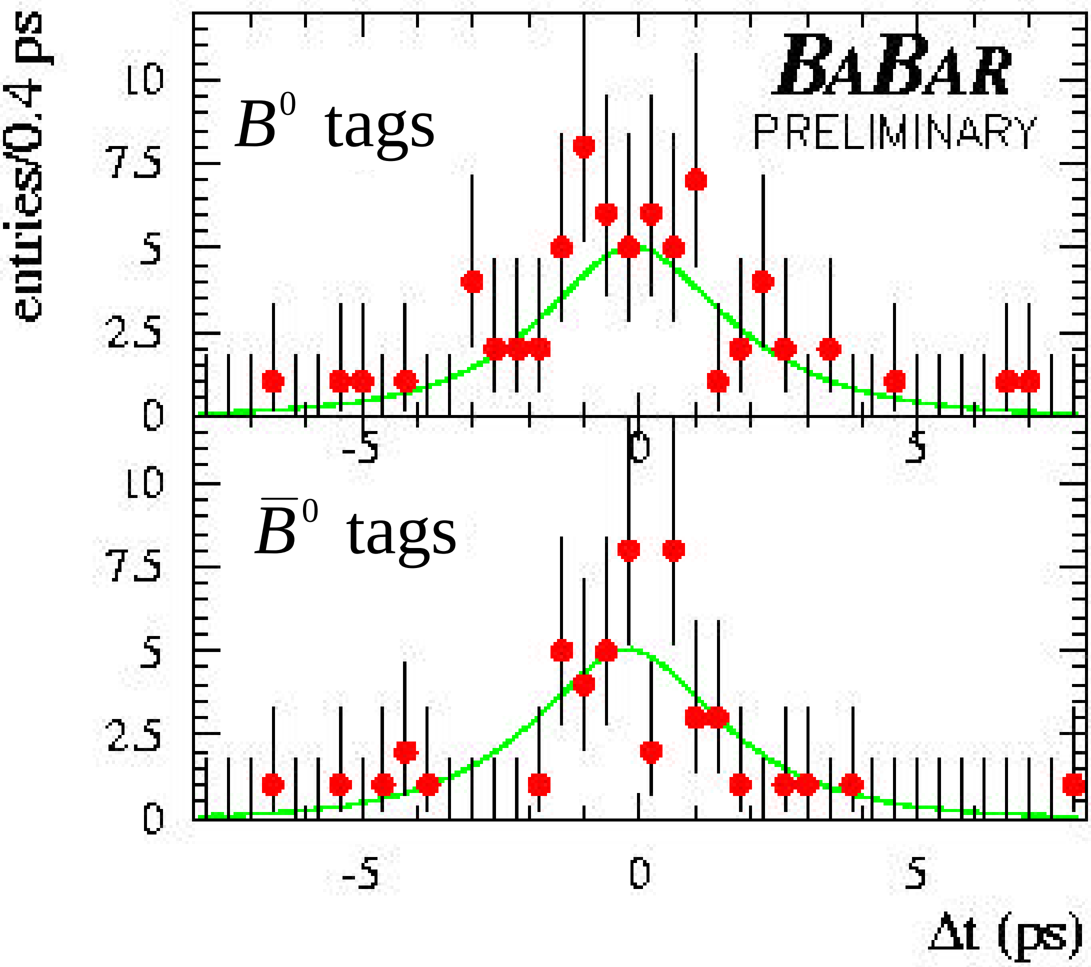
- The sin2$\beta$ analysis was done blind to eliminate experimenters' bias
  - The amplitude in the asymmetry $\mathcal{A}_{CP}(\Delta t)$ was hidden by arbitrarily flipping its sign and by adding an arbitrary offset
  - The *CP* asymmetry in the $\Delta t$ distribution was hidden by multiplying $\Delta t$ by the sign of the tag and by adding an arbitrary offset
  - The blinded aproach allows systematic studies of tagging, vertex resolution and their correlations to be done while keeping the value of sin2$\beta$ hidden
  - The result was unblinded two weeks ago

PRELIMINARY

# Extracting $\sin 2\beta$

- The $\Delta t$ distribution of the tagged *CP* eigenstate decays, which is analyzed using maximum likelihood to extract the asymmetry $\mathcal{A}_{CP}(\Delta t)$

## $B^0$ and $\bar{B}^0$ tags



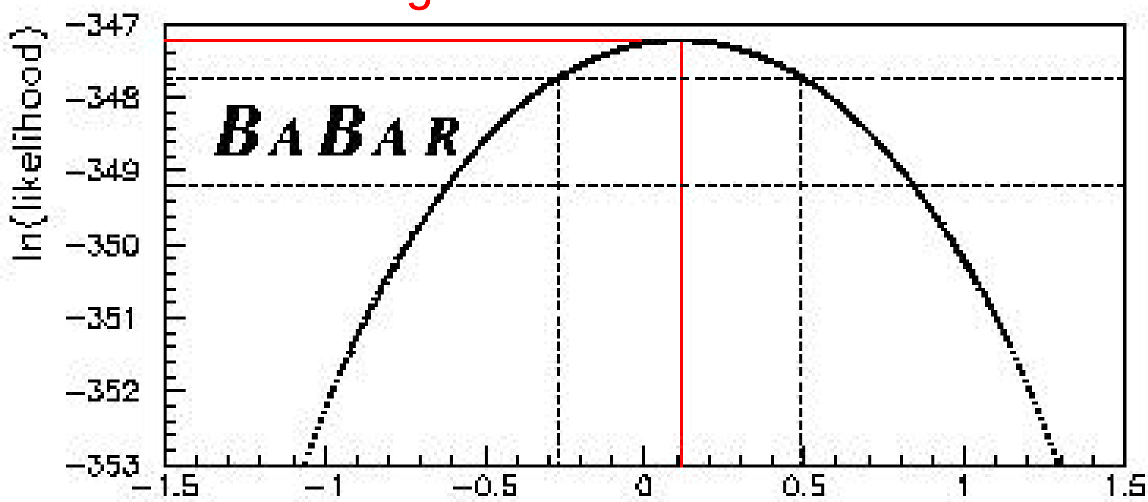
# Extracting $\sin 2\beta$

Results of the likelihood fit to the full sample and various subsamples

$$\sin 2\beta = 0.12 \pm 0.37 \text{ (stat) } \pm 0.09 \text{ (syst)}$$

PRELIMINARY

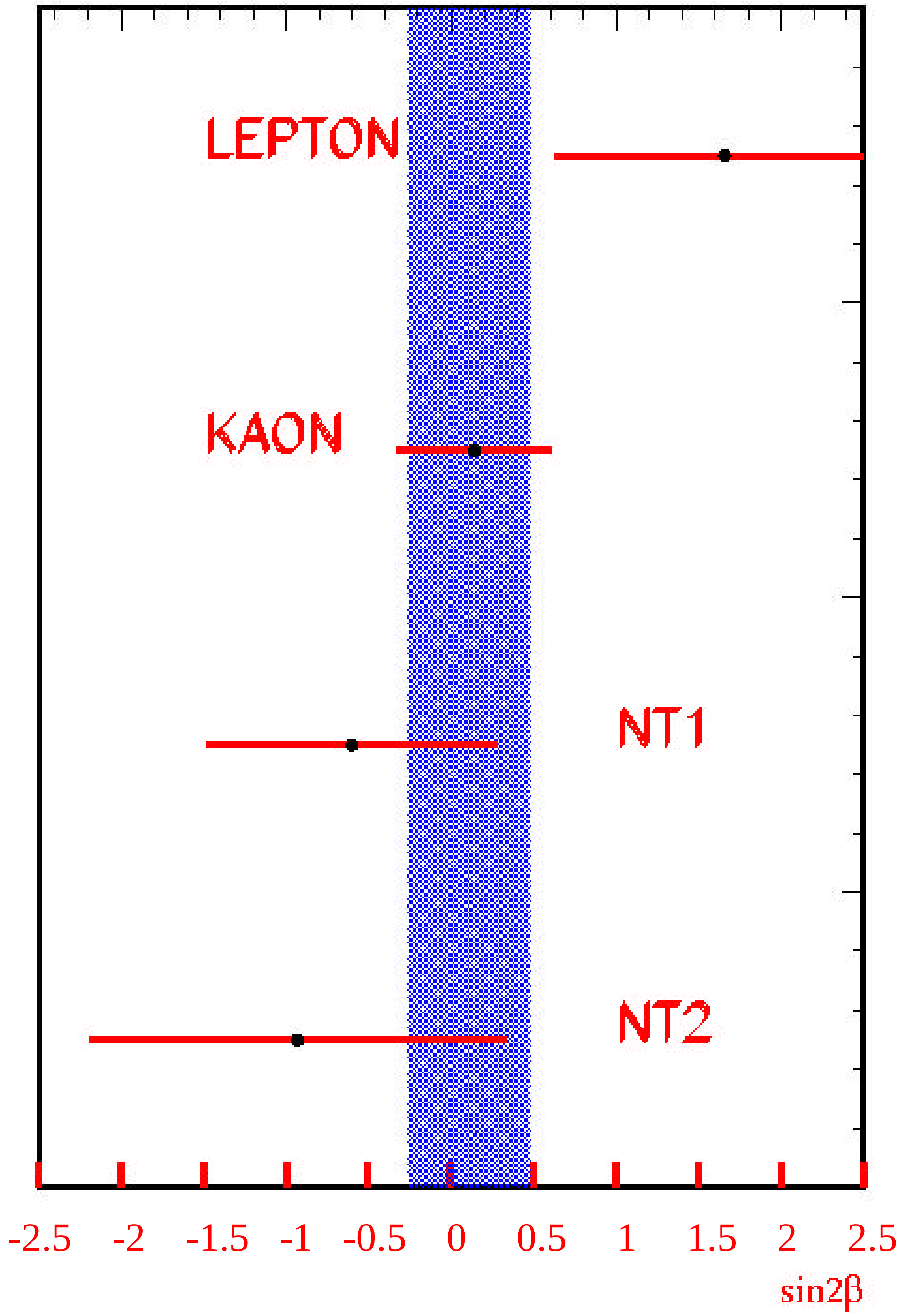
Log likelihood function




| sample | $\sin 2\beta$ |
|---|---|
| CP sample | $0.12 \pm 0.37$ |
| $J/\psi K^0_S$ ($K^0_S \to \pi^+\pi^-$) events | $-0.10 \pm 0.42$ |
| other CP events | $0.87 \pm 0.81$ |
| Lepton | $1.6 \pm 1.0$ |
| Kaon | $0.14 \pm 0.47$ |
| NT1 | $-0.59 \pm 0.87$ |
| NT2 | $-0.96 \pm 1.30$ |

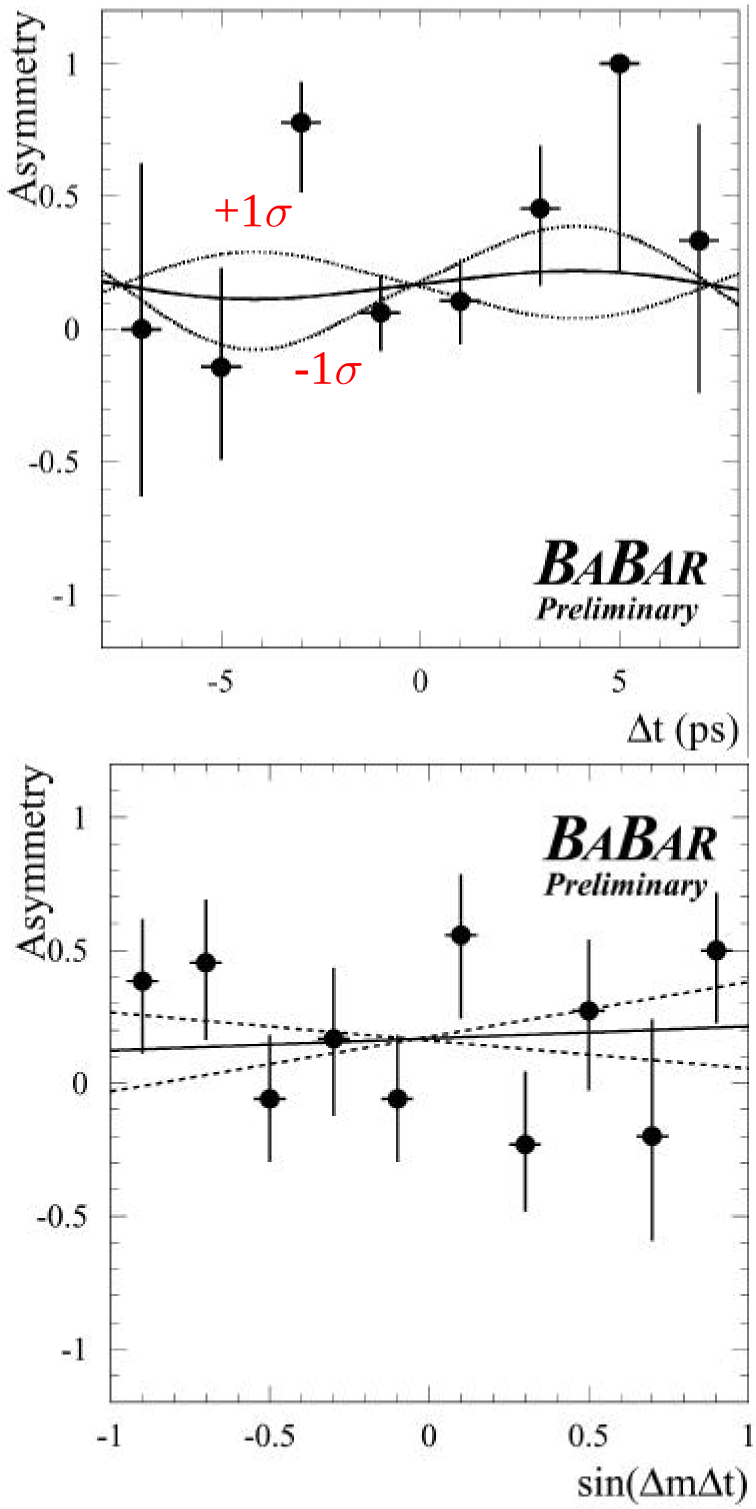
# sin2$\beta$ in different tagging categories

PRELIMINARY



# Extracting sin2$\beta$

$\sin 2\beta = 0.12 \pm 0.37$ (stat) $\pm 0.09$ (syst)




$\chi^2$ for the binned asymmetry and the likelihood fit is 9.2 for 7 df

PRELIMINARY

# Statistical error

- The probability of obtaining a 1$\sigma$ statistical error of 0.37 with a sample of 120 tagged *CP* eigenstate decays has been estimated by generating a large number of toy Monte Carlo experiments with a sample of this size
  - The errors are distributed around 0.32, with a standard deviation of 0.03
  - The probability of obtaining a statistical error larger than the one we observe is 5%
- Using a set of full Monte Carlo simulated experiments with the same number of events we observe, we estimate that the probability of finding a lower value of the likelihood than our observed value is 20%

# Checks

*CP* asymmetry of channels that should have none

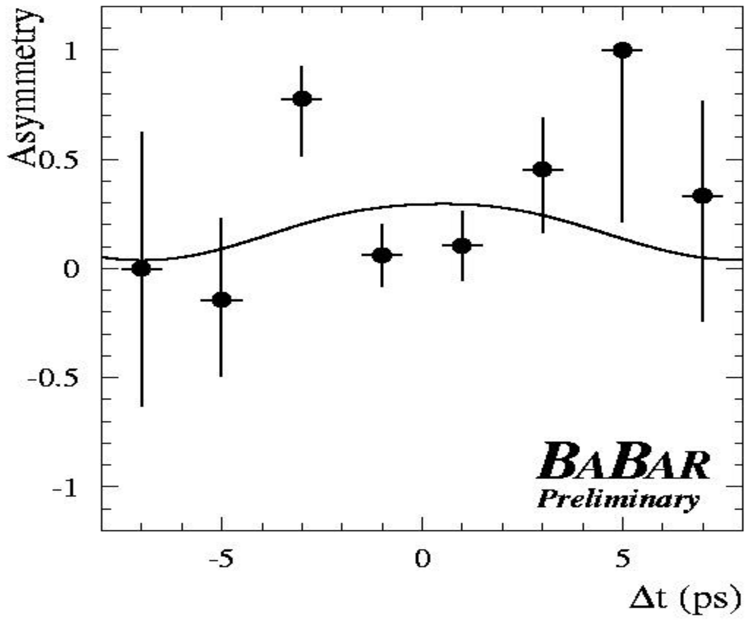
| Sample | Apparent *CP* asymmetry |
|---|---|
| hadronic charged | $0.03 \pm 0.07$ |
| hadronic neutral | $-0.01 \pm 0.08$ |
| $J/\psi\ K^+$ | $0.13 \pm 0.14$ |
| $J/\psi\ K^{*0}\ (K^{*0} \rightarrow K^+\pi^-)$ | $0.49 \pm 0.26$ |

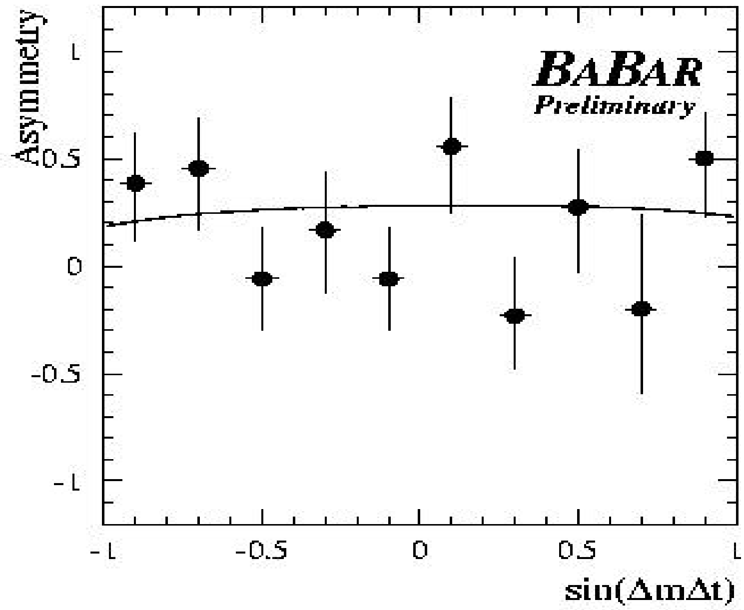
# Fit including direct *CP* violation

PRELIMINARY

$$\mathcal{A}_{CP} = \frac{\mathcal{D}\sin 2\beta \, \sin \Delta m_d \Delta t + \left(1 - |\lambda_{CP}|^2\right)\cos \Delta m_d \Delta t}{\left(1 + |\lambda_{CP}|^2\right)}$$

$$\sin 2\beta = 0.12 \pm 0.37 \qquad \frac{1 - |\lambda_{CP}|^2}{1 + |\lambda_{CP}|^2} = 0.26 \pm 0.19$$



# Systematic uncertainties

PRELIMINARY

Compute fractional systematic errors using the measured value of the asymmetry increased by $1\sigma$.
Different contributions are added in quadrature

| Source of uncertainty | Uncertainty on $\sin 2\beta$ |
|---|---|
| $\tau_{B^0}$ | 0.012 |
| $\Delta m_d$ | 0.015 |
| $\Delta z$ resolution for *CP* sample | 0.019 |
| Time resolution bias for *CP* sample | 0.047 |
| Measurement of mistag fraction | 0.059 |
| Different mistag fraction for *CP* and non *CP* samples | 0.050 |
| Different mistag fractions for $B^0$ and $\bar{B}^0$ | 0.005 |
| Background in *CP* sample | 0.015 |
| Total systematic uncertainty | 0.091 |

# Constraints on the Unitarity Triangle

PRELIMINARY

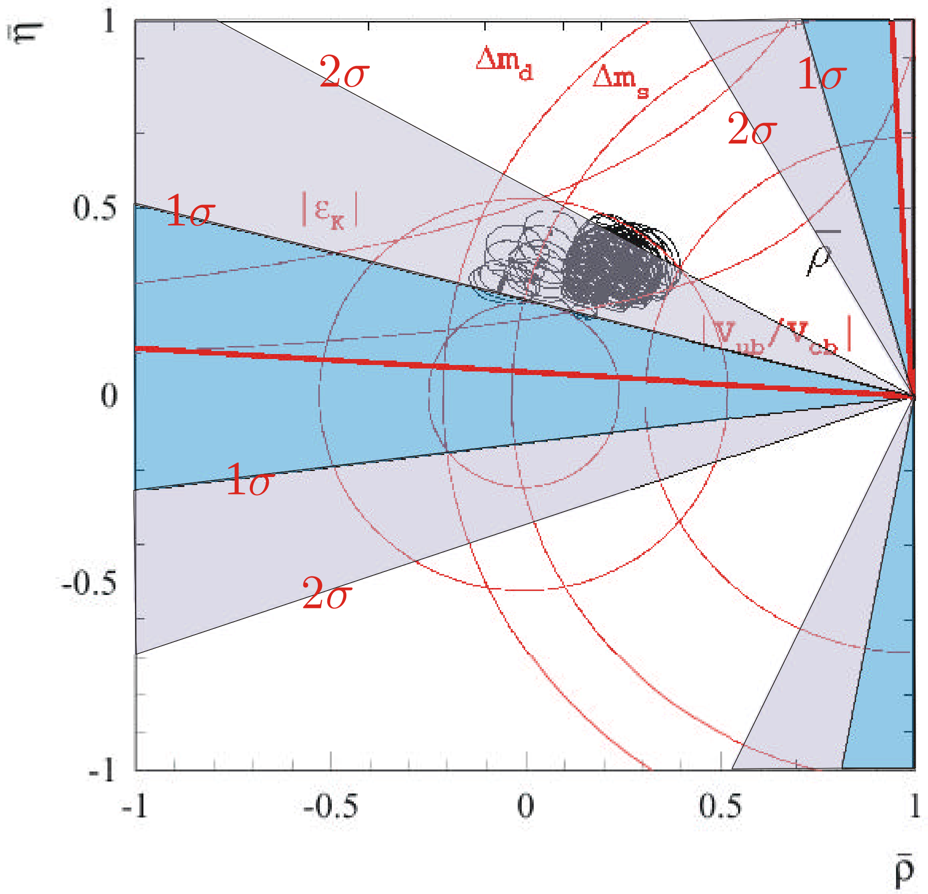
The set of ellipses represents the allowed range of $(\bar{\rho}, \bar{\eta})$ based on our knowledge of the magnitudes of CKM matrix elements, for a set of typical values of model-dependent theoretical parameters:

**Experimental inputs**

| measurement | central value | exp. error |
|---|---|---|
| $\lvert V_{cb}\rvert$ | .0402 | .0017 |
| $\lvert \frac{V_{ub}}{V_{cb}} \rvert$ | .085 | .008 |
| $\Delta m_{B_d}\ (ps)^{-1}$ | .472 | .017 |
| $\Delta m_{B_s}$ | from $\mathcal{A}$ (Moriond 2000) | $\sigma_{\mathcal{A}}$ |
| $\lvert\epsilon_K\rvert\ (10^{-3})$ | 2.271 | .017 |

**Theoretical inputs**

| Theoretical est. | lower bound | higher bound |
|---|---|---|
| $< \frac{V_{ub}}{V_{cb}} >$ | 0.070 | 0.100 |
| $f_{B_d}\sqrt{B_{B_d}}$ | 0.185 | 0.255 |
| $\xi_s^2$ | 1.14 | 1.46 |
| $B_K$ | 0.72 | 0.98 |




$\sin 2\beta = 0.12 \pm 0.37 \pm 0.09$ is NOT included in the fits

# Summary and Conclusions

PRELIMINARY

PEP-II and BaBar have had an exciting and productive first year, producing more than 15 fb$^{-1}$ in the $\Upsilon(4S)$ region and recording more than 14 fb$^{-1}$

In 9 fb$^{-1}$ we have reconstructed and tagged 120 decays of $B^0$ to $CP$ eigenstates

$$\sin 2\beta = 0.12 \pm 0.37\,(\text{stat}) \pm 0.09\,(\text{syst})$$

$\Delta m_d = 0.507 \pm 0.015 \pm 0.022$ di-lepton

$\Delta m_d = 0.516 \pm 0.031 \pm 0.018$ hadronic

$\Delta m_d = 0.508 \pm 0.020 \pm 0.022$ semileptonic

With 8 fb$^{-1}$ analyzed at the $\Upsilon(4S)$

$$\tau_{B^0} = 1.506 \pm 0.052\,(\text{stat}) \pm 0.029\,(\text{syst})\ \text{ps}$$

$$\tau_{B^+} = 1.602 \pm 0.049\,(\text{stat}) \pm 0.035\,(\text{syst})\ \text{ps}$$

$$\tau_{B^+}/\tau_{B^0} = 1.065 \pm 0.044\,(\text{stat}) \pm 0.021\,(\text{syst})$$

Measurements of $B(K^*\gamma)$, $B(\pi\pi)$, $B(K\pi)$, $B(KK)$, …

A wide variety of other results have been presented in parallel sessions and contributed papers

The PEP-II run has been extended to the end of October, with the goal of integrating 25 fb$^{-1}$

This should allow for a measurement of sin2*b* with interesting precision