Initial Physics Results from *BABAR*

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*For the **BABAR** Collaboration*

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The *BABAR* Collaboration

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LAL Orsay
LPNHE des Universités Paris 6/7
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CEA, DAPNIA, CE-Saclay

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MIT
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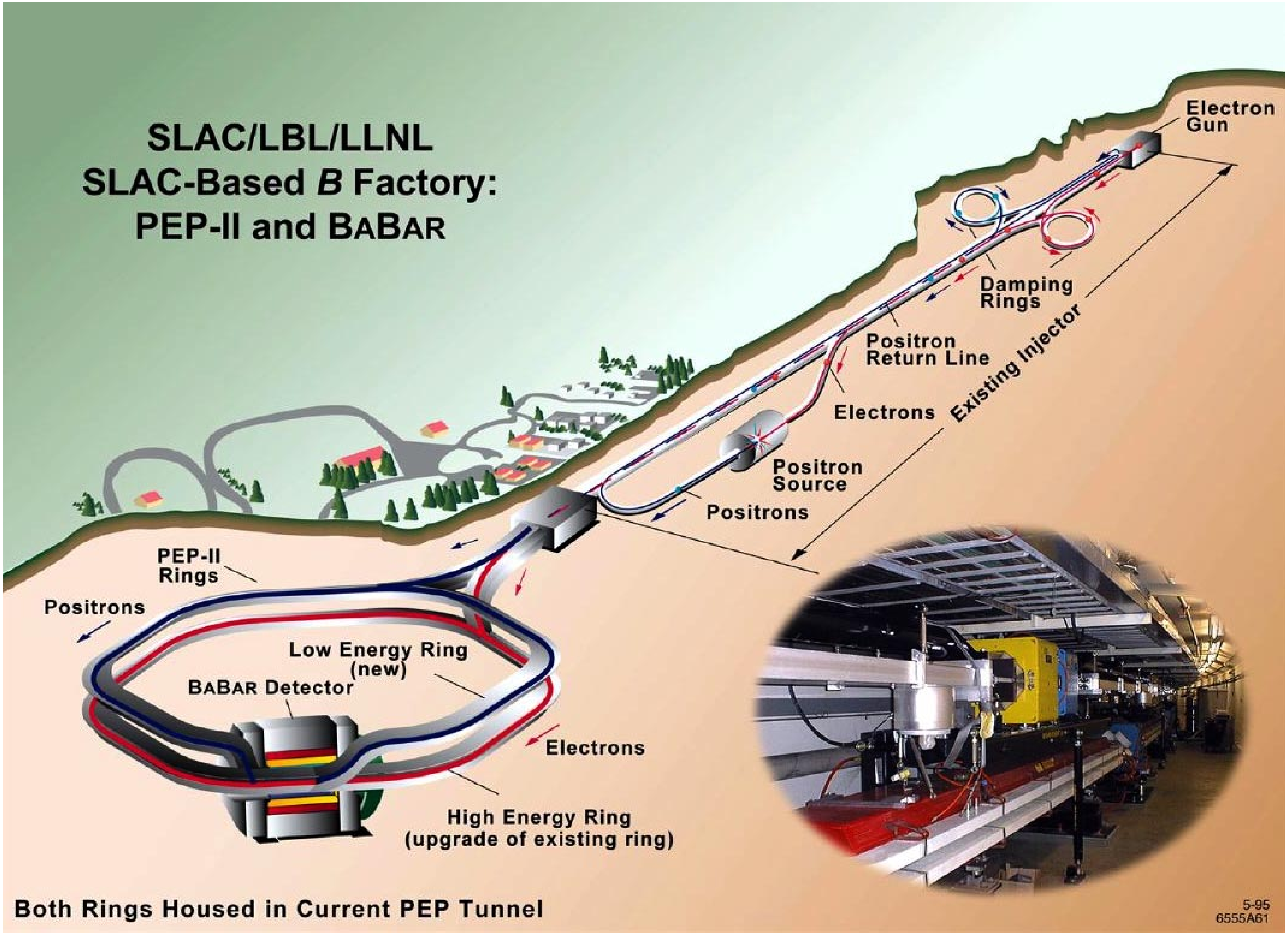
Mount Holyoke College
Northern Kentucky U
U of Notre Dame
ORNL/Y-12
U of Oregon
U of Pennsylvania
Prairie View A&M
Princeton
SLAC
U of South Carolina
Stanford U
U of Tennessee
U of Texas at Dallas
Vanderbilt
U of Wisconsin
Yale

- 9 Countries, 72 Institutions, 554 Physicists

Introduction

- ***BaBar*** recorded first colliding beam data in June 1999.
- 13 physics papers submitted to ICHEP (Osaka) July 2000.
  - » For details, see BaBar conference papers on web: http://www.slac.stanford.edu/BFROOT/www/doc/public/conf_pubs/index.html


SLAC/LBL/LLNL
SLAC-Based B Factory:
PEP-II and BABAR
Electron Gun
Damping Rings
Positron Return Line
Existing Injector
Electrons
Positron Source
Positrons
PEP-II Rings
Positrons
Low Energy Ring (new)
BABAR Detector
Electrons
High Energy Ring (upgrade of existing ring)
Both Rings Housed in Current PEP Tunnel
5-95
6555A61

PEP-II

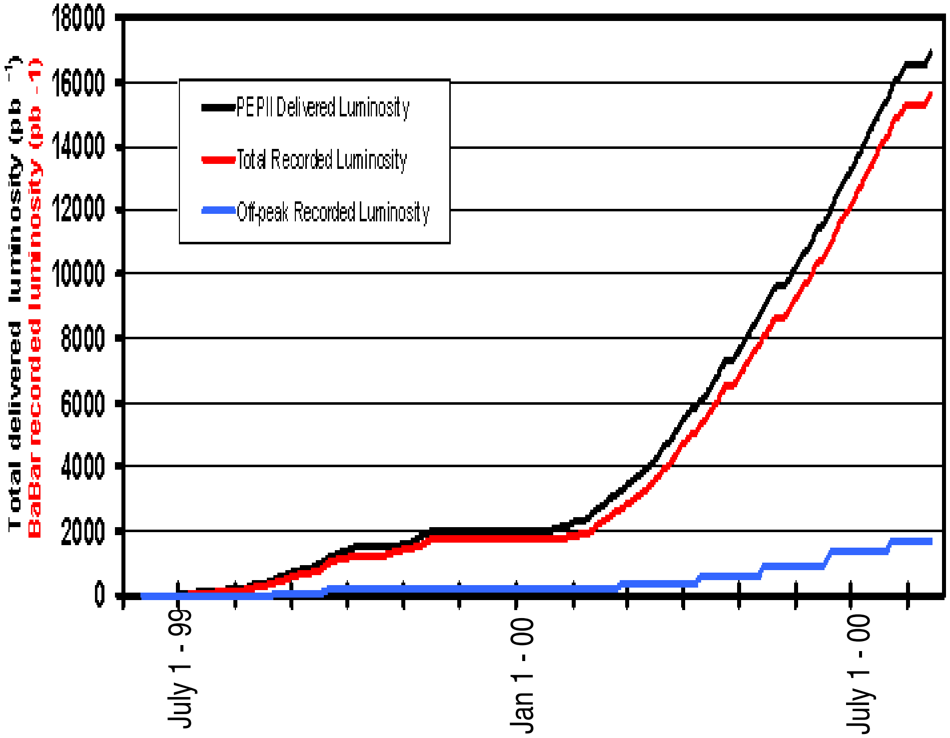
- 3.1 GeV e^+ on 9.0 GeV e^-.
- Good luminosity and efficiency; backgrounds better than expected.

Item		*Design*	*Achieved*
e^- Current	mA	750	751
e^+ Current	mA	2150	1286
Bunches		1658	606
Peak L	$cm^{-2}s^{-1}$	3.0×10^{33}	2.3×10^{33}
Daily L	pb^{-1}	135	135
Yearly L 10 month	fb^{-1}	30	13.6 in 7 months

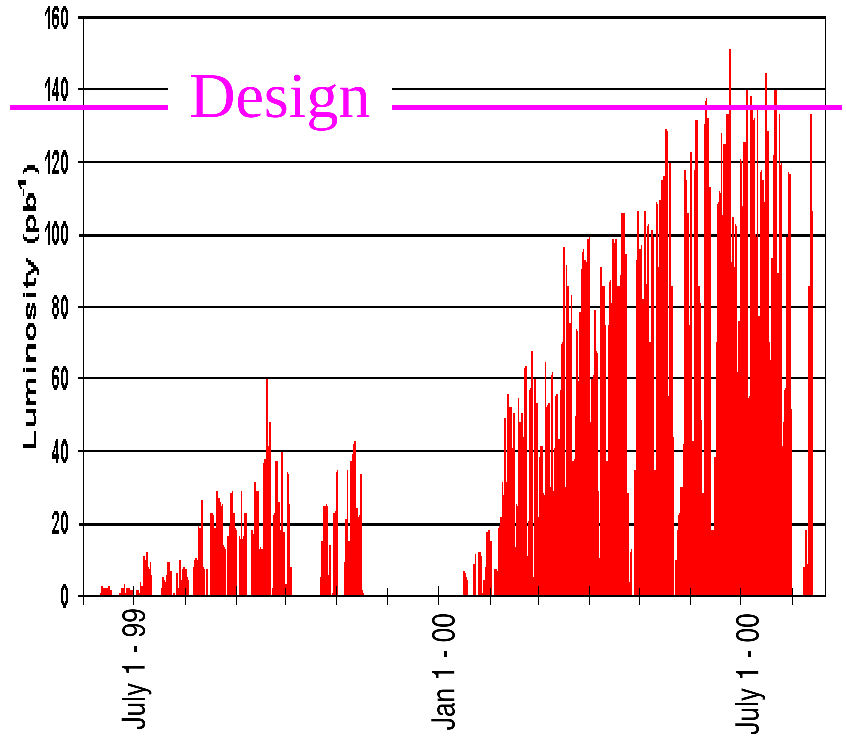
Integrated Luminosity

- Results today on 8 – 9 fb^{-1} out of 15 fb^{-1} recorded on-peak & 1 fb^{-1} of 1.8 fb^{-1} below $B\bar{B}$ threshold.

Integrated Luminosity

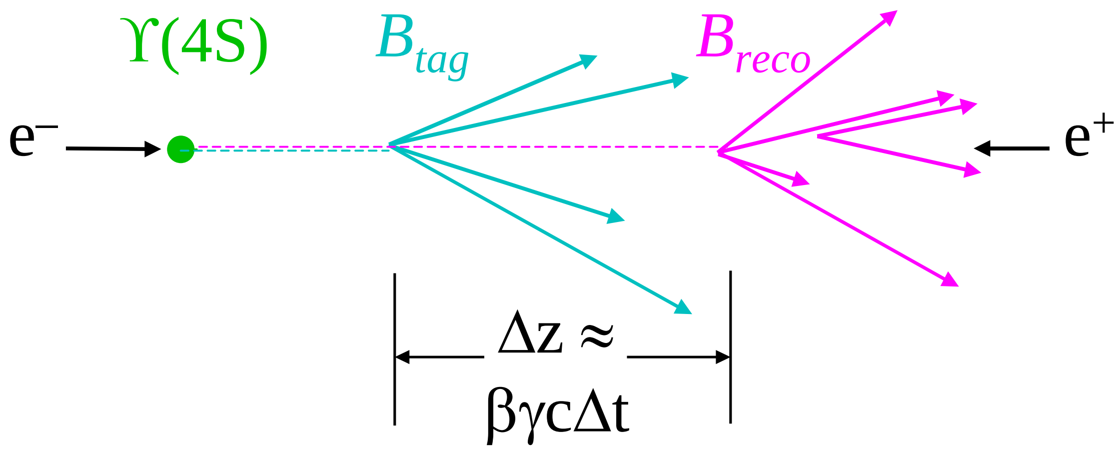


Daily Recorded Luminosity



B Physics at the $\Upsilon(4S)$

- $\sigma_{\Upsilon(4S)} \sim$ 30% of σ_{qq}.
- $\beta\gamma$ of $\Upsilon(4S)$ = 0.56.
- Decays 100% to $B\overline{B}$ in coherent L=1 state.



- When 1st B decays, other B is fixed to be other flavor. Neutral B can subsequently oscillate.
- Fully reconstruct at most 1 B; vertex and flavor of other B can be determined for sin2β, Δm_{B0} and lifetimes.

CP Violation from $B^0\overline{B}^0$

- Reconstruct B_{reco} in a CP eigenstate. Look for CP violation via an asymmetry in the decay rate of B_{reco} as a function of Δt:

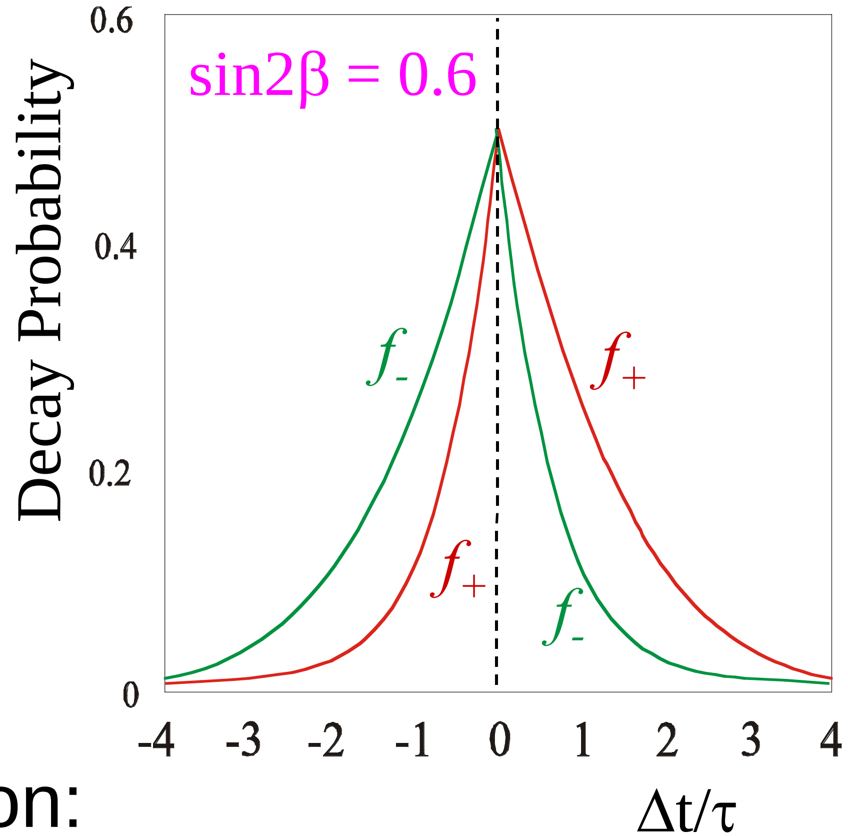
$$f_{\pm}(\Delta t;\Gamma,\Delta m_{B0},D\sin 2\beta)=\tfrac{1}{4}\Gamma e^{-|\Delta t|}\left(1\pm D\sin 2\beta\cdot\sin\Delta m_{B0}\Delta t\right)$$

  - » Where "+" means B_{tag} is a B^0; "-" = $\overline{B}^0$;
  - » Γ, Δm_{B0} are lifetime and oscillation parameter;
  - » D = "dilution": reduction in effect due to incorrect tags; D = (1 - 2w), w = mistag fraction.
  - » Sin 2β = unitarity triangle angle (CKM matrix).

CP Asymmetry

- Asymmetry is:

$$A_{CP} = \frac{f_+(\Delta t) - f_-(\Delta t)}{f_+(\Delta t) + f_-(\Delta t)}$$
$$= D\sin 2\beta \cdot \sin \Delta m_{B0} \Delta t$$

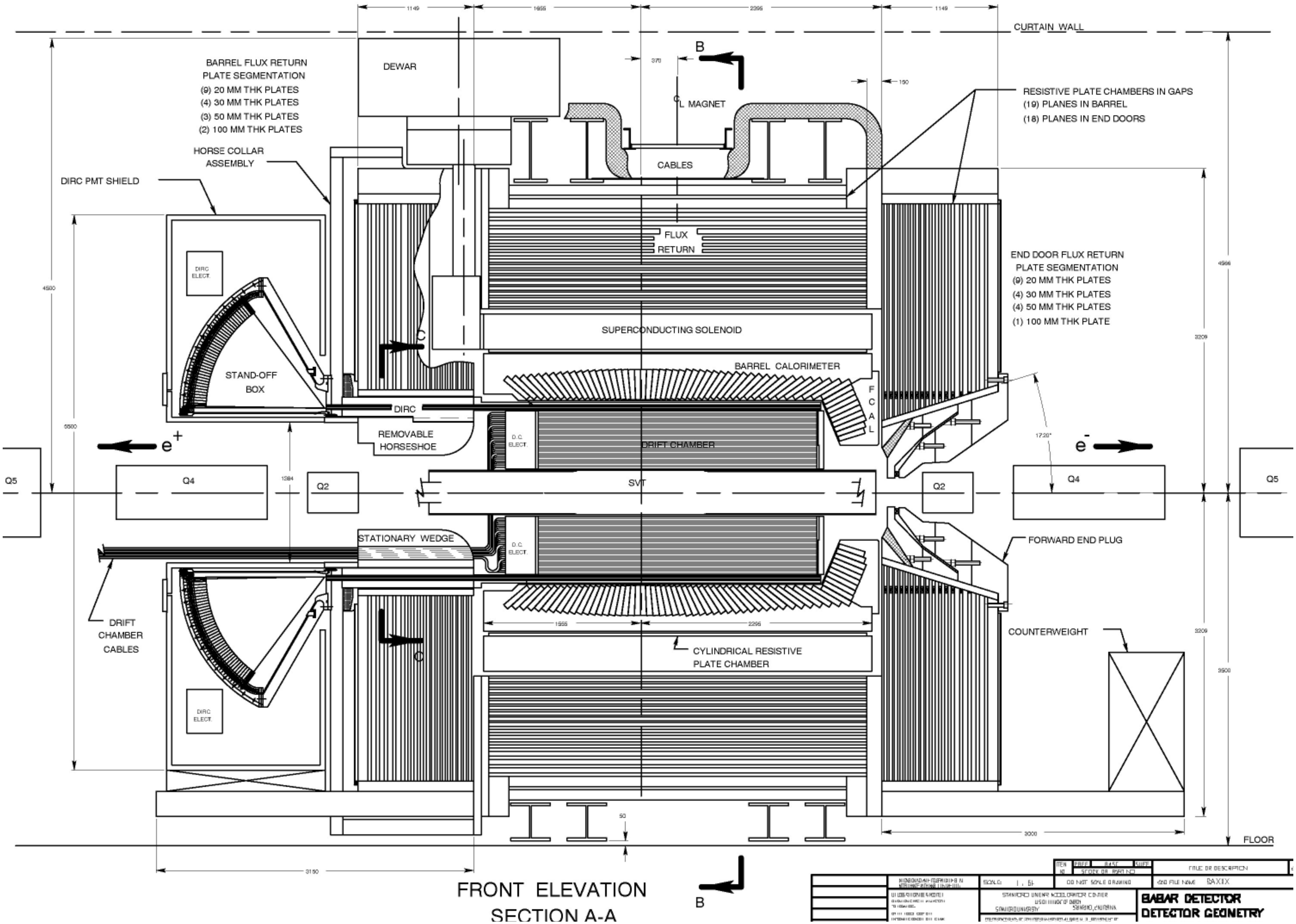


- Need to include Δt resolution:

$$F_\pm(\Delta t; \Gamma, \Delta m_{B0}, D\sin 2\beta, \hat{a}) = f_\pm(\Delta t; \ldots) \otimes R(\Delta t; \hat{a})$$

Sin 2β Issues

- For each event:
  - » Selection of event and reconstruction of B_{reco};
  - » Vertexing/determination of Δt;
  - » Tagging of other B.
- For ensemble of events:
  - » Determination of mistag fractions;
  - » Likelihood fit to extract sin2β.
- Discuss these, but generalize to include other ***BABAR*** analyses.


CURTAIN WALL
BARREL FLUX RETURN
PLATE SEGMENTATION
(9) 20 MM THK PLATES
(4) 30 MM THK PLATES
(3) 50 MM THK PLATES
(2) 100 MM THK PLATES
DEWAR
HORSE COLLAR
ASSEMBLY
DIRC PMT SHIELD
B
CL MAGNET
CABLES
RESISTIVE PLATE CHAMBERS IN GAPS
(19) PLANES IN BARREL
(18) PLANES IN END DOORS
FLUX
RETURN
END DOOR FLUX RETURN
PLATE SEGMENTATION
(9) 20 MM THK PLATES
(4) 30 MM THK PLATES
(4) 50 MM THK PLATES
(1) 100 MM THK PLATE
SUPERCONDUCTING SOLENOID
BARREL CALORIMETER
STAND-OFF
BOX
DIRC
FCAL
REMOVABLE
HORSESHOE
DRIFT CHAMBER
e+
e-
Q5
Q4
Q2
SVT
STATIONARY WEDGE
FORWARD END PLUG
DRIFT
CHAMBER
CABLES
COUNTERWEIGHT
CYLINDRICAL RESISTIVE
PLATE CHAMBER
FLOOR
FRONT ELEVATION
SECTION A-A
BABAR DETECTOR
DETECTOR GEOMETRY

Common Analysis Features – Reconstruction

- Track vertex and angles reconstructed using 5 layer silicon vertex tracker; p_t measured by 40 layer drift chamber (1.5 T field).
  - » Typical fiducial $0.41 < \theta < 2.54$ in lab;
  - » Typical $\sigma_{pt}/p_t = 0.45\% + 0.14\% \times p_t$;
  - » Impact parameter resolution ~60μ @ 1 GeV/c.
- Photon energy and location using 6600 CsI crystal calorimeter.
  - » $\sigma_E/E = 1.33\% \cdot E^{-1/4} \oplus 2.1\%$

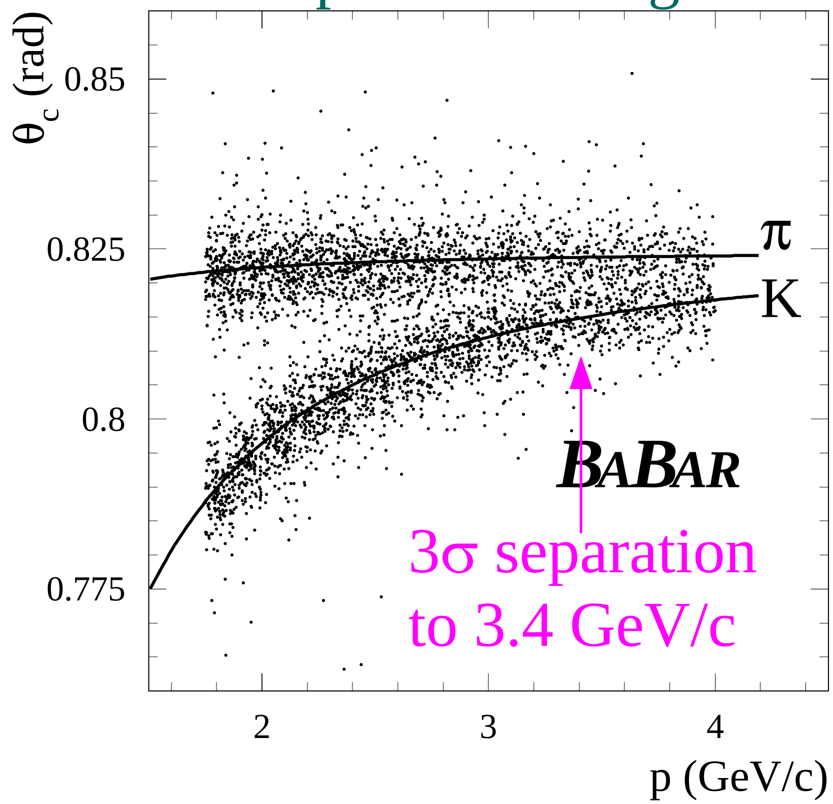
Charged Particle Identification

- $e^{\pm}$ are identified primarily by magnitude (E/p) and shape of energy deposition in EMC.
  - » Also require dE/dx in drift chamber.
  - » Use eeγ, eeee control samples to characterize as a function of p and angle; π from τ decays.
  - » Typical performance: ε = 92%, π misID = 0.3%.
- Identify $\mu^{\pm}$ by the amount of material penetrated and pattern of hits in IFR.
  - » ee$\mu\mu$ and $\mu\mu\gamma$ control samples.
  - » Typical: ε = 75%, π misID = 2.6%.

Particle ID Performance

- $K^{\pm}$ identified by number of photons and Cherenkov angle in DIRC.
  - » dE/dx dominant below ~0.7 GeV.
  - » Likelihood analysis.
  - » $D^{*+} \rightarrow \pi^{+} D^{0} \rightarrow K^{-} \pi^{+}$ control sample.

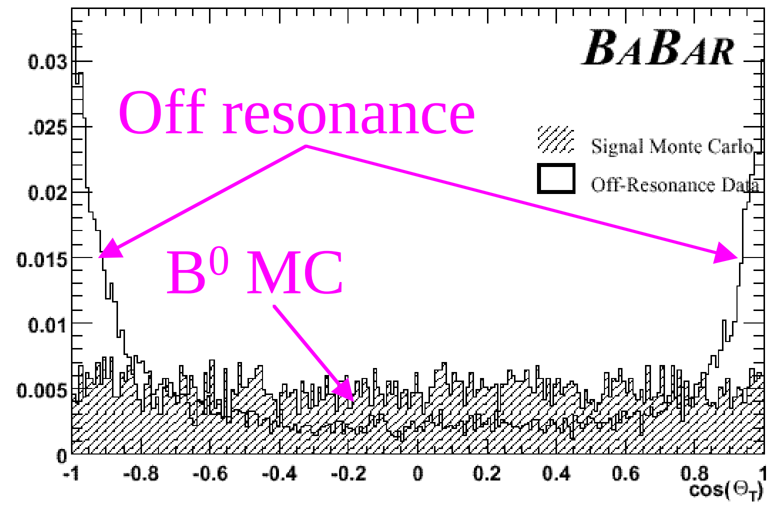
π/K Separation using DIRC



$B\bar{B}$ Event Selection

- Typical variables to distinguish $B\bar{B}$ events from $q\bar{q}$:
- R_2: tighten cut.
- θ_T: angle between thrust axis of B_{reco} and other tracks and clusters.
  - » Flat for $B\bar{B}$, peaked for $q\bar{q}$.

$\cos\theta_T$ for $B^0 \rightarrow K^{(*)}\gamma$
MC and off-resonance data



- θ^*_B: angle of B in CM system $\propto 1-\cos^2\theta^*_B$; flat for background.

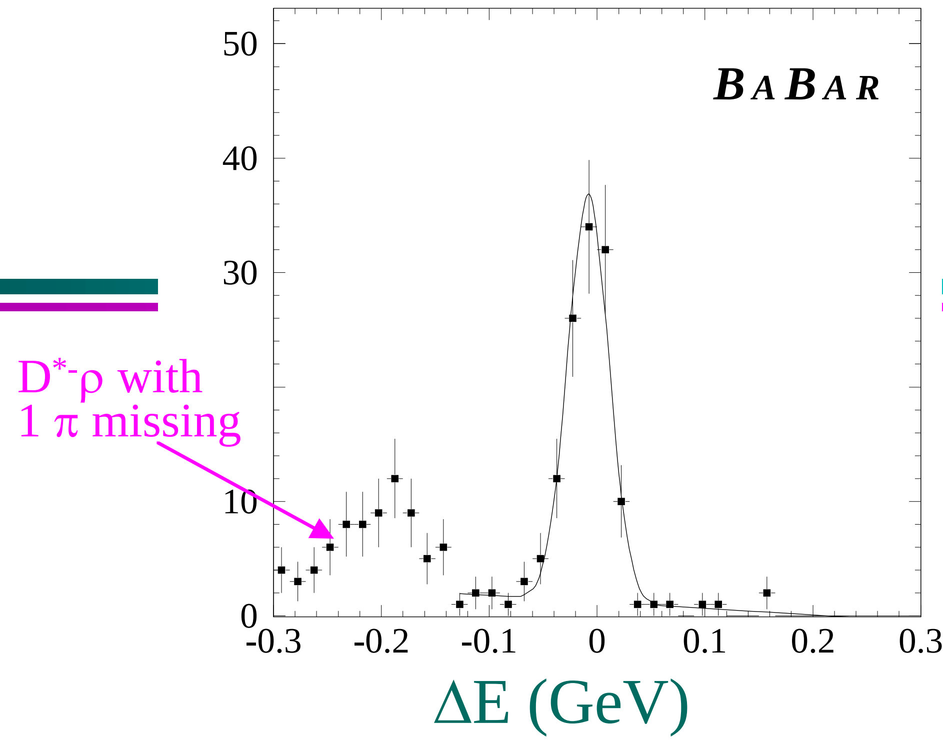
B Reconstruction

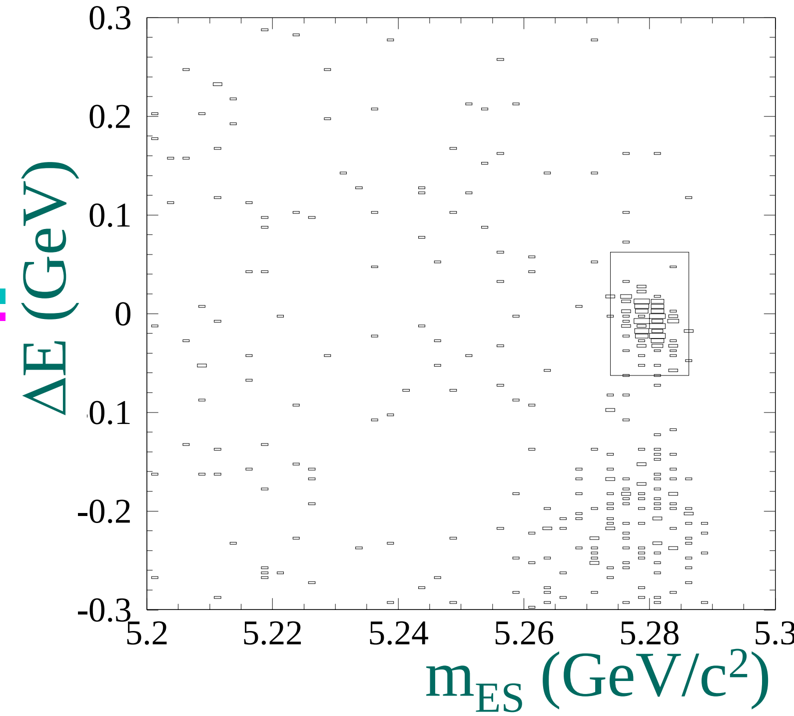
- Two kinematic variables used to reject backgrounds to fully-reconstructed B:
- $\Delta E = E^{*}_{reco} - E^{*}_{beam}$
  - » Peaked at 0 for correctly-reconstructed B; width 19 – 40 MeV depending on mode.
- Beam-energy substituted mass:

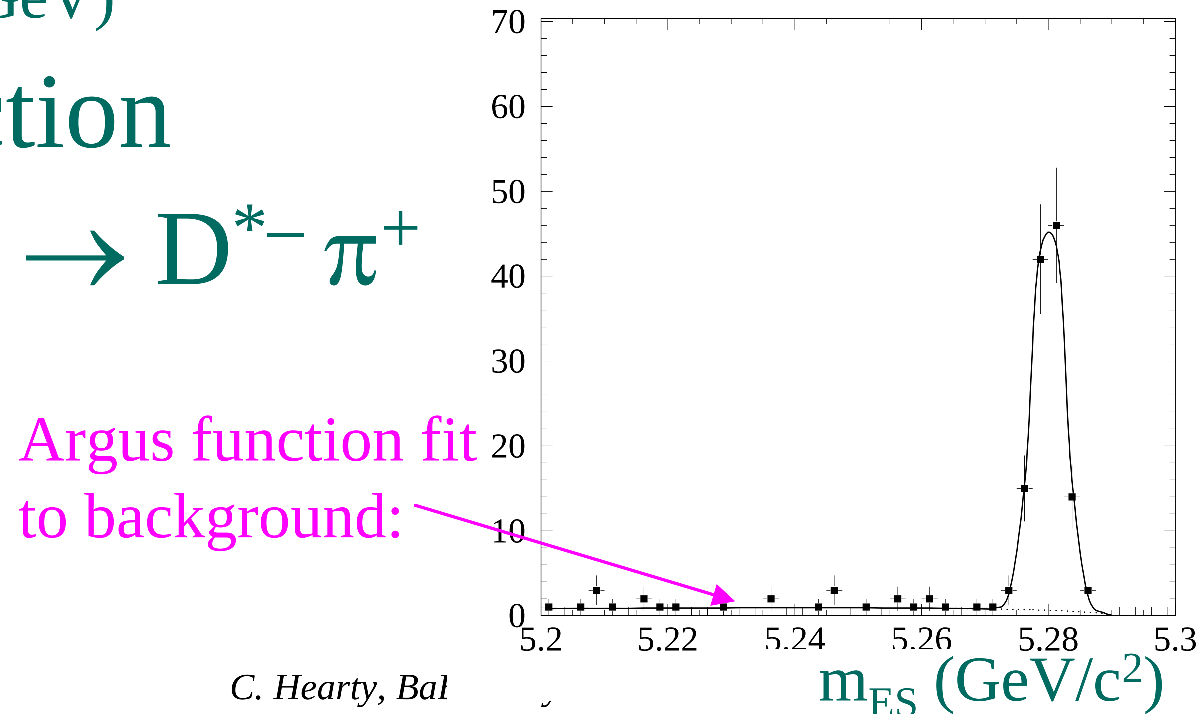
$$m_{ES} = \sqrt{E^{*\,2}_{beam} - \vec{p}^{\,*\,2}_{reco}}$$

  - » m_{ES} resolution ≈ 3 MeV/c^2 dominated by beam energy spread.

B Reconstruction Variables, $B^0 \rightarrow D^{*-} \pi^+$

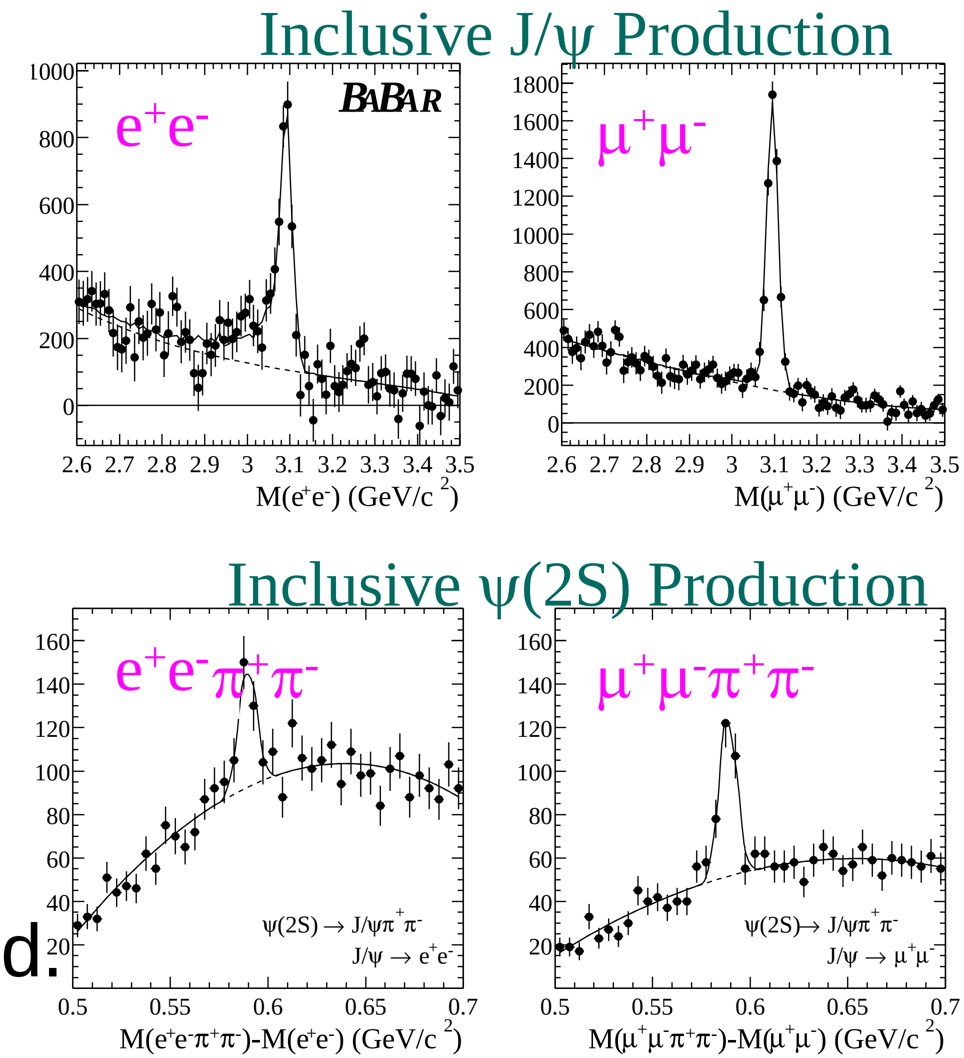




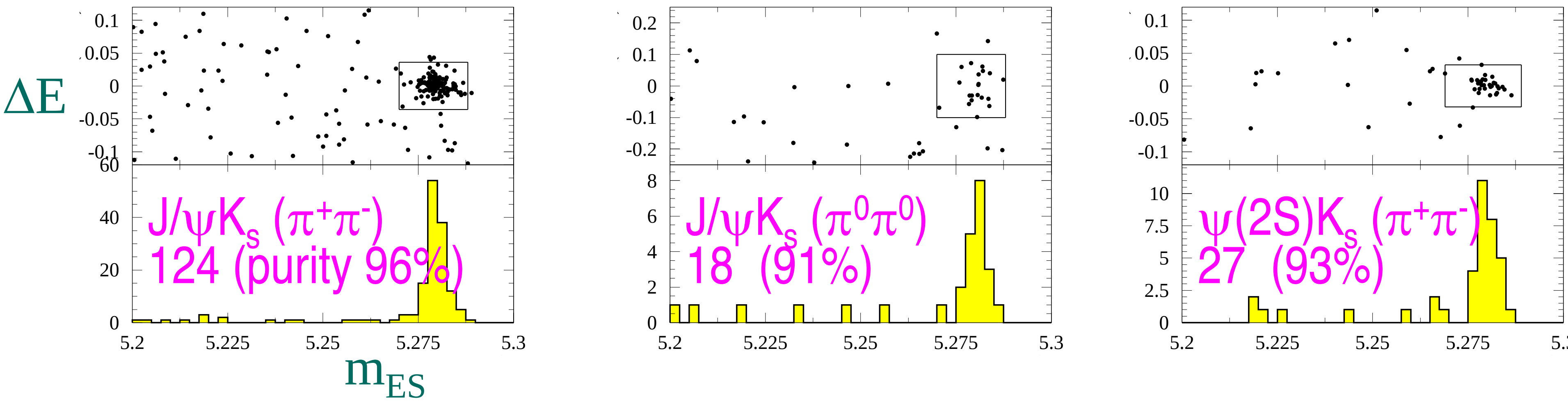


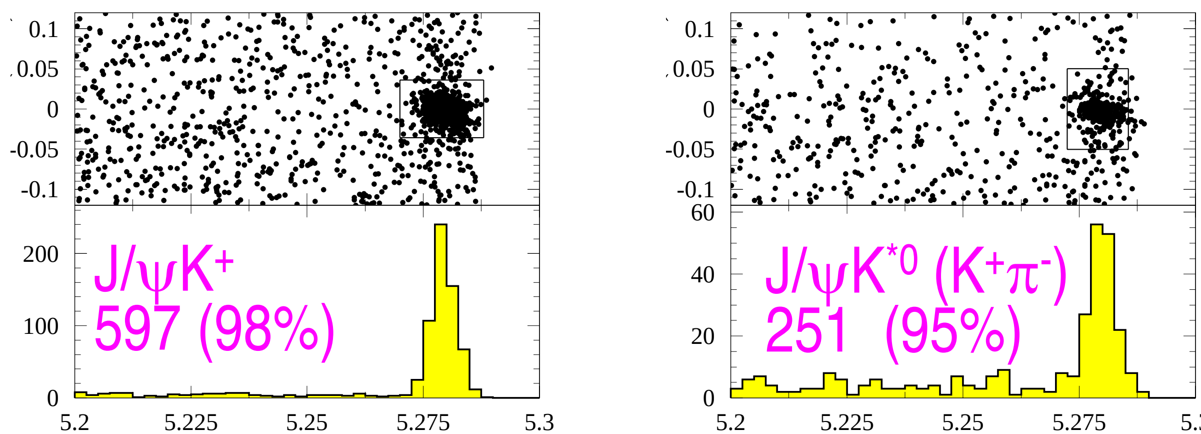
sin2β Event Sample

- Signal:
  $B^0 \to J/\psi K_s;\ K_s \to \pi^+ \pi^-$
  $B^0 \to J/\psi K_s;\ K_s \to \pi^0 \pi^0$
  $B^0 \to \psi(2S) K_s;\ (\pi^+ \pi^-)$
- Charmonium control samples:
  $B^+ \to J/\psi K^+;\ \psi(2S) K^+$
  $B^0 \to J/\psi K^{*0};\ (K^+ \pi^-)$
  - » No CP violation expected.



Charmonium Reconstruction, Exclusive Final States





168 total candidates
848 control events

Vertexing

- Average Δ_z between B's = 260μm. Beam spot: σ_x = 150μm; $\sigma_y \approx$ 4μm; σ_z = 1cm.
  - » Use σ_y = 40μm to allow for B flight in y.
- Fit full decay tree of reconstructed B;
  - » constrain daughter masses and vertices, not B mass or energy.
  - » $\sigma_z \sim$ 45–65 μm.

Vertexing / Δt Resolution

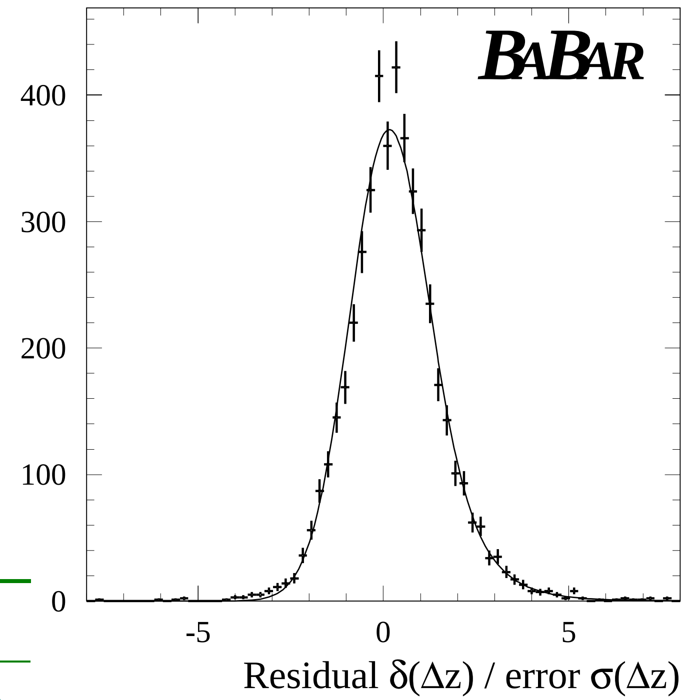
- Use remaining tracks to vertex other B with production point & direction from B_{reco} and beam spot.
  - » Remove tracks with poor fit; fit K_s if possible.
  - » σ_z ~ 115 μm; bias (charm) ~ 25 μm.
- Model Δt resolution by two Gaussians with $\sigma_{1,2} = S_{1,2} \cdot \sigma_{fit}$, where σ_{fit} is the uncertainty from fit. Additional wide Gaussian for outliers.

Δt Resolution

- Fit S_1, δ_1, and f_w to data; fix others or obtain from MC.
- Same for all reconstructed final states (dominated by tag B).

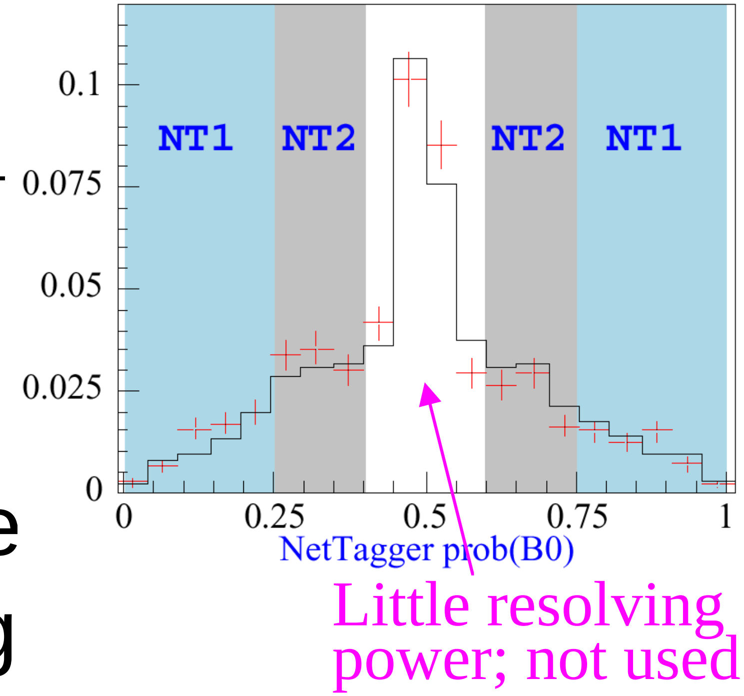
	Core	*2nd*	*Wide*
f (%)	75	$1 - f_1 - f_w$	1.6 ± 0.6
δ (ps)	-0.20 ± 0.07	0	0
σ (ps)	$(1.33 \pm 0.13) \cdot \sigma_{fit}$	$2.1 \cdot \sigma_{fit}$	8

$B^0 \to D^- \pi^+$ MC



B Flavor Tagging

- Identify flavor of B_{tag} using electrons or muons (p^*>1.1 GeV/c), or charged kaons.
- Otherwise, use neural net.
  - » Charge of slow pion from D^{*-}
  - » Lower momentum leptons;
  - » p^* of charged particles.
- sin2β error $\propto 1/\sqrt{\Sigma Q_i}$, where $Q_i = \varepsilon_i(1 - 2 \cdot w_i)^2$, w = mistag
- Of 168 events, 70 tagged as B^0; 50 $\overline{B}^0$.



B^0 Oscillations and Dilutions

- Fully reconstruct hadronic and semileptonic B^0 decays; tag other B as per CP analysis.
  - » $D^-\pi^+$, $D^-\rho^+$, $D^-a_1^+$, $D^{*-}\pi^+$, $D^{*-}\rho^+$, $D^{*-}a_1^+$, $J/\psi K^{*0}$ (2577 ± 59 events)
  - » $D^{*-}\ell^+\nu$ (7517 ± 104 events).
- Look at rate of same flavor/opposite flavor as a function of Δt. Same flavor due to mixing or mistags. (+ = opposite, - = same):

$$h_{\pm}(\Delta t;\Gamma,\Delta m_{B0},D)=\tfrac{1}{4}\Gamma e^{-\Gamma|\Delta t|}\left(1\pm D\cos\Delta m_{B0}\Delta t\right)$$

Dilutions and Oscillation II

- Look at difference/sum vs time:

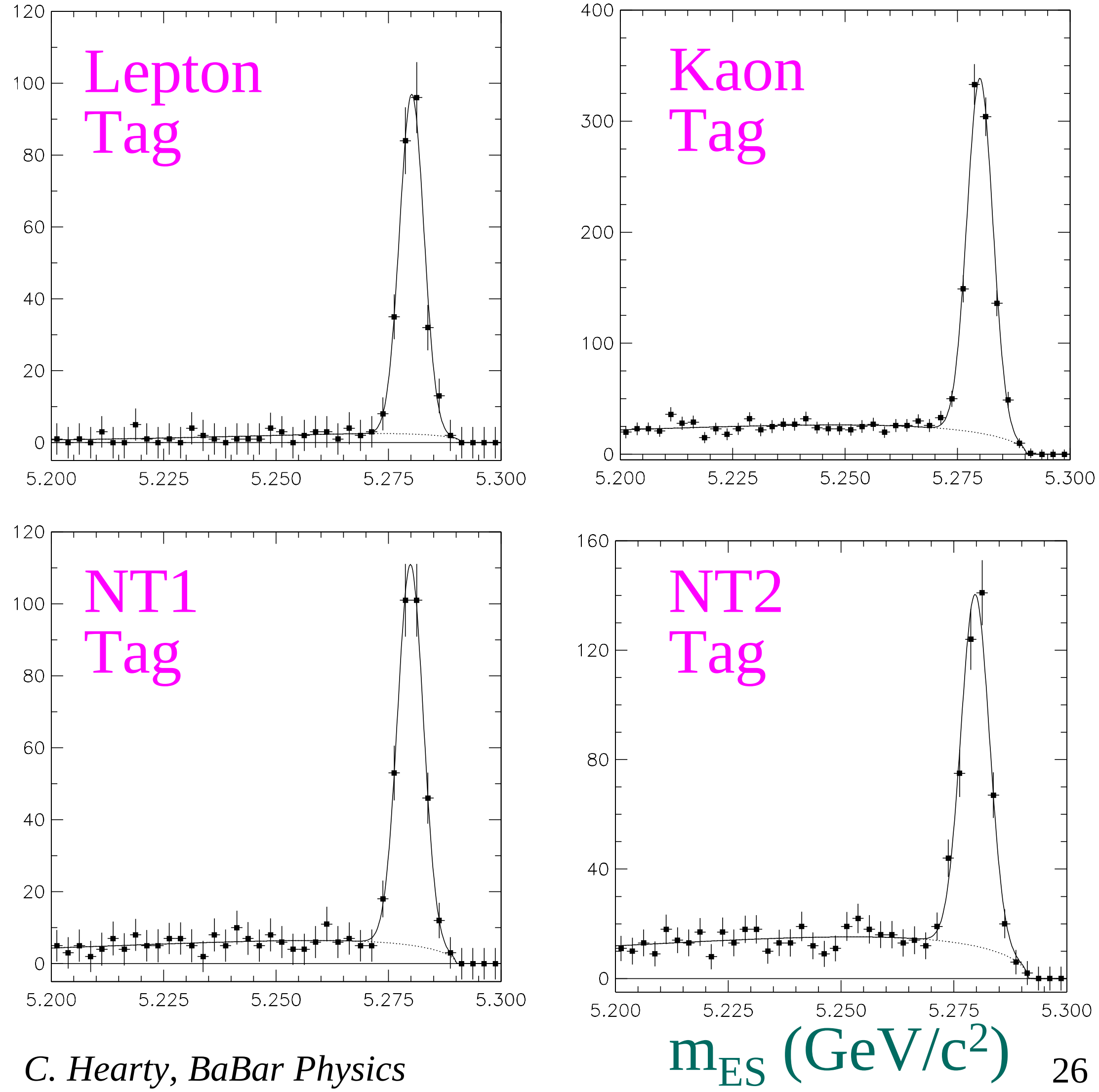
$$\left(h_{+} - h_{-}\right) / \left(h_{+} + h_{-}\right) = D \cos \Delta m_{B0} \Delta t$$

  » D is most sensitive to Δt ~ 0; Δm_{B0} to Δt where difference = 0.

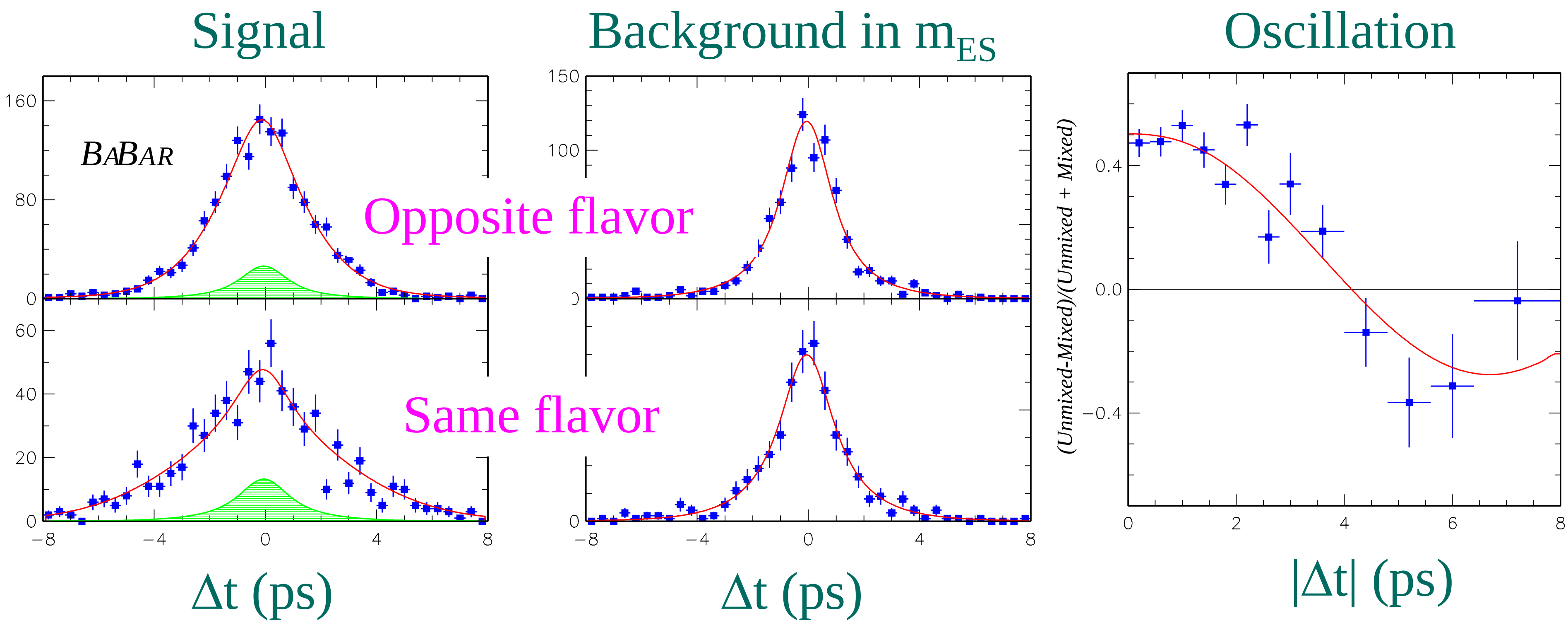
- Include Δt resolution: $H_{\pm} = h_{\pm} \otimes R$
- Include pdf for backgrounds;
  » Three components: zero lifetime; non zero lifetime with mixing; no mixing.

Fully-Reconstructed Hadronic Event Sample

- Efficiency for each tag from N_{sig} in plot.
- Use m_{ES} sidebands to characterize backgrounds.



Fit Results, Hadronic Events



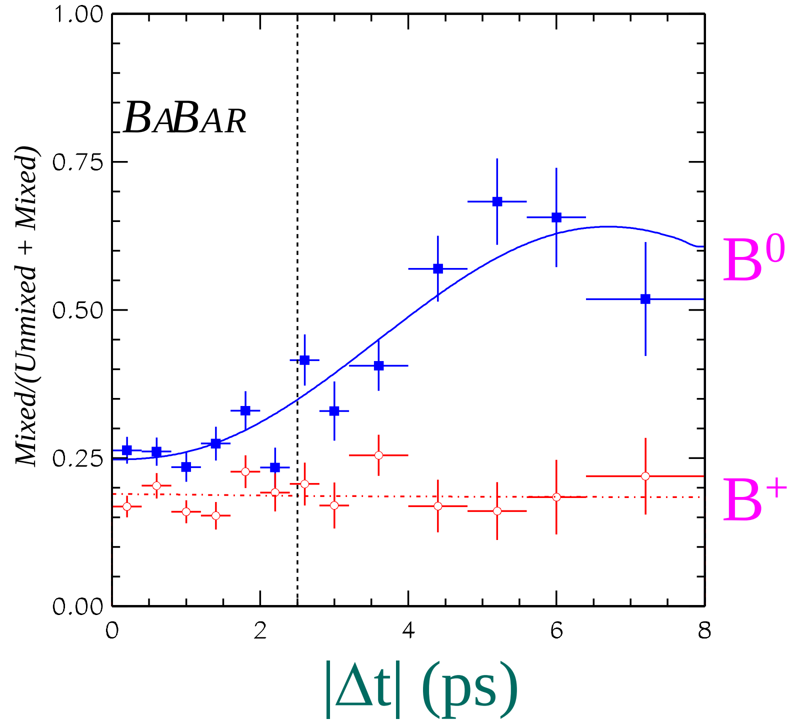
- Good agreement between hadronic and $D^{*-}\,\ell^{+}\nu$ samples.

Time-Integrated Extraction of Dilutions

- Extract mistag rate by looking at:

$$\chi_{obs} = N_{mix} / \left(N_{mix} + N_{unmix} \right)$$

- Sum over $|\Delta t| < 2.5$ ps, where mistags dominate same-sign sample.



Summary of Dilutions

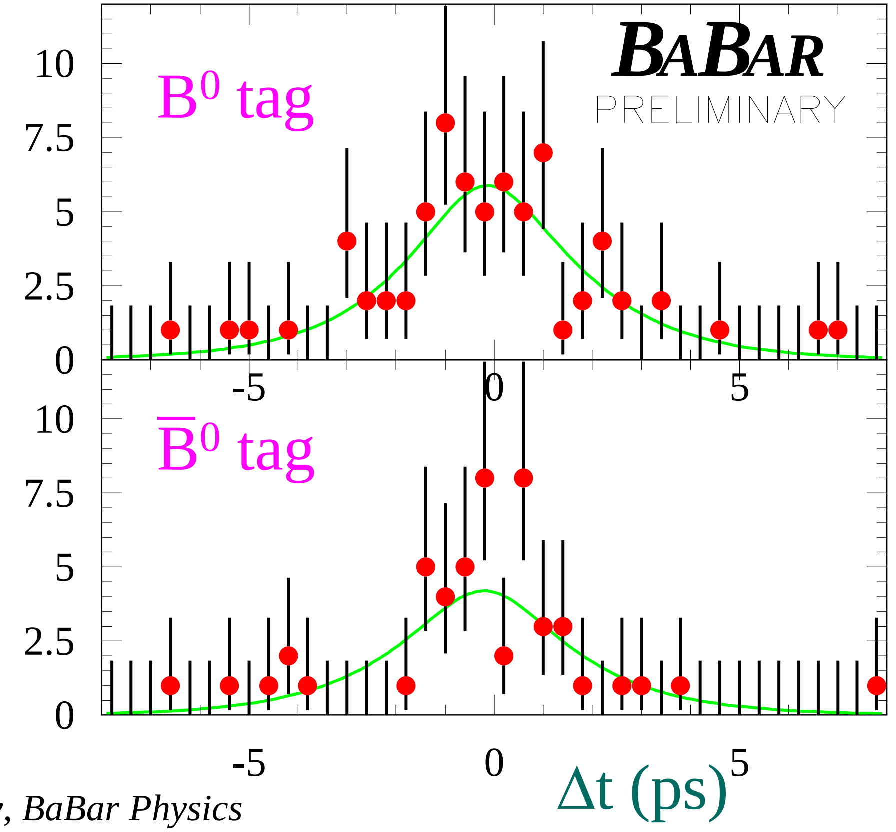
- Good agreement between likelihood (combined hadronic and $D^{*-} \ell^+ \nu$) and time-integral methods.
- Use likelihood values in CP analysis.

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

$Q_{sum} = 28\%$

sin2β Analysis

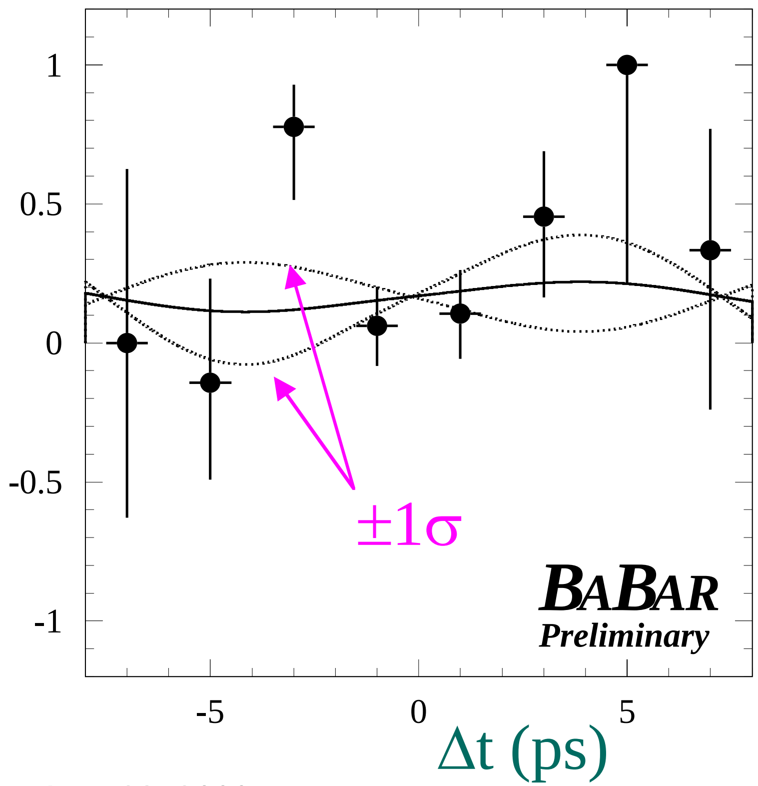
- sin2β analysis was done "blind" to avoid bias — value was hidden until shortly before ICHEP 2000.
- sin2β extracted by likelihood fit to Δt distribution.
  - » Γ and Δm_{B0} fixed to PDG values.



Result

- Sin 2β = 0.12±0.37±0.09

Raw Asymmetry =
$(N_{B0}-N_{\overline{B}0})/(N_{B0}+N_{\overline{B}0})$



Breakdown into categories

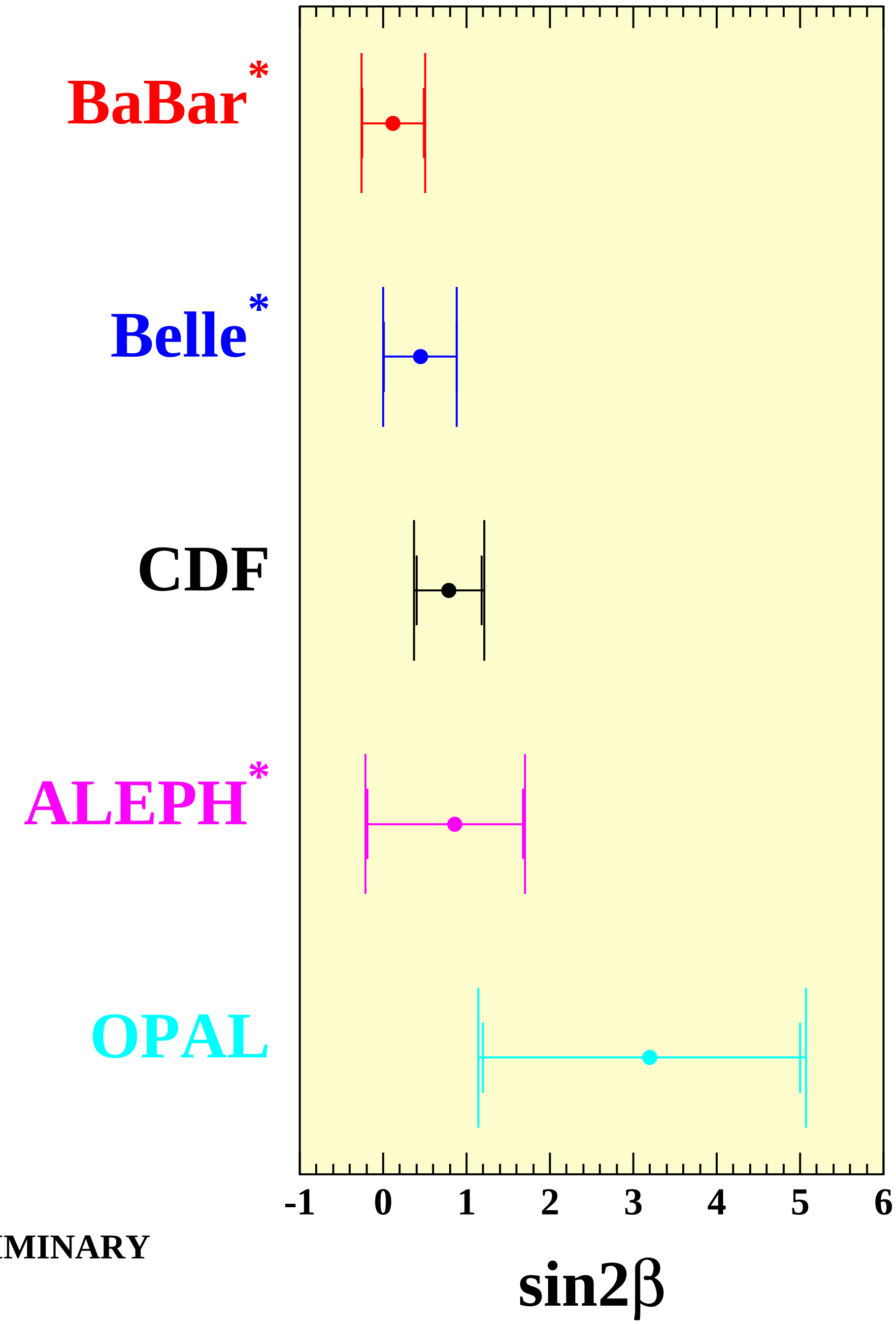
Sample	*sin2β*
CP sample	**0.12 ± 0.37**
J/ψ K^0_s ($\pi^+\pi^-$)	-0.10 ± 0.42
Other CP events	0.87 ± 0.81
Lepton	1.6 ± 1.0
Kaon	0.14 ± 0.47
NT1	-0.59 ± 0.87
NT2	-0.96 ± 1.30

Systematic Error and Studies

- Primary systematic errors from Δt resolution function and uncertainty in mistag fractions.
- Measure "CP Asymmetry" in charmonium control samples and hadronic samples.
  - » Results consistent with no asymmetry.

Sample	*Apparent CP Asymmetry*
Hadronic charged B decays	0.03 ± 0.07
Hadronic neutral B decays	-0.01 ± 0.08
$J/\psi\ K^+$	0.13 ± 0.14
$J/\psi\ K^{*0}\ (K^+\pi^-)$	0.49 ± 0.26

sin2β Summary



$0.12 \pm 0.37 \pm 0.09$

$0.45^{+0.43}_{-0.44}{}^{+0.07}_{-0.09}$

$0.79 \pm 0.39 \pm 0.1$

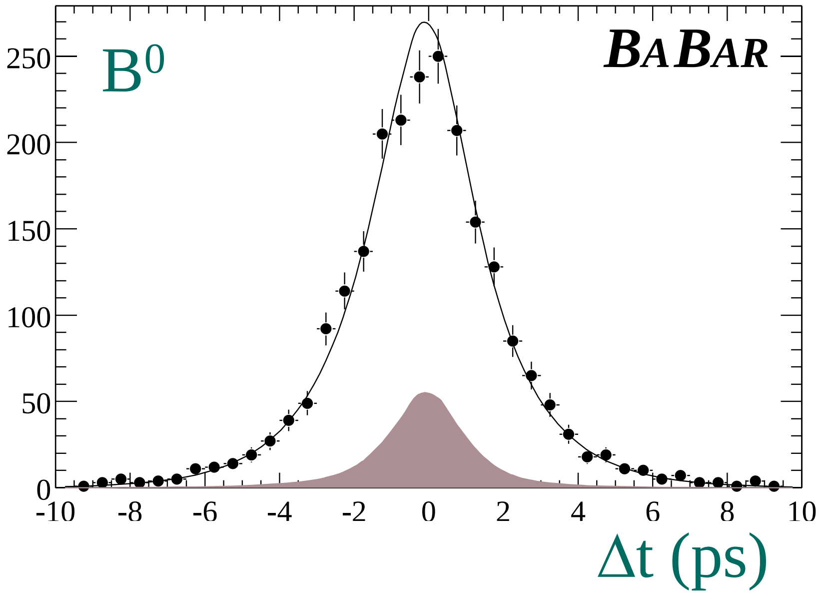
$0.86^{+0.82}_{-1.05} \pm 0.20$

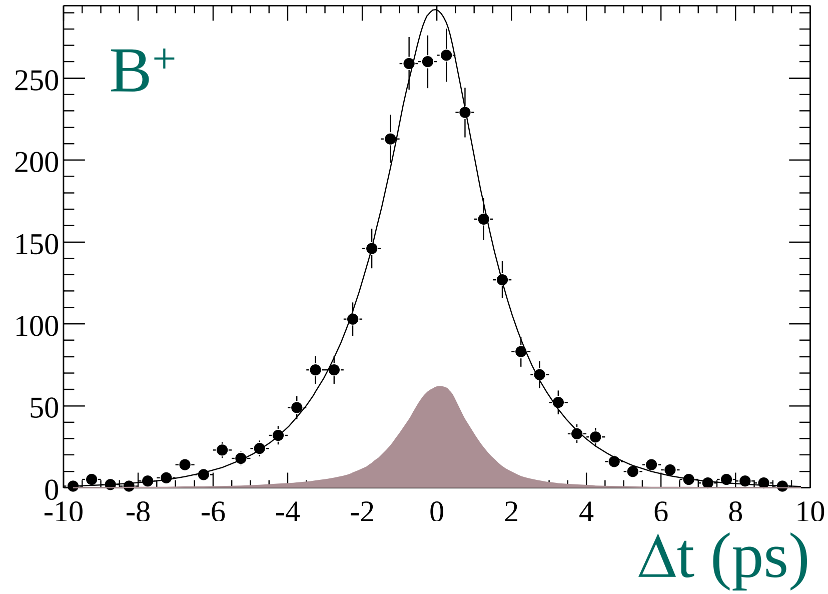
$3.20^{+1.8}_{-2.0} \pm 0.5$

* PRELIMINARY

B Lifetimes, Fully Reconstructed B Mesons

- Knowledge of Δt resolution is critical.





- τ_{B0} = 1.506±0.052±0.029 (PDG 1.548±0.032)
  τ_{B+} = 1.602±0.049±0.035 (1.653±0.028)
  τ_{B+} / τ_{B0} = 1.065±0.044±0.021 (1.062±0.029)

B^0 Oscillation Frequency Δm_{B0}

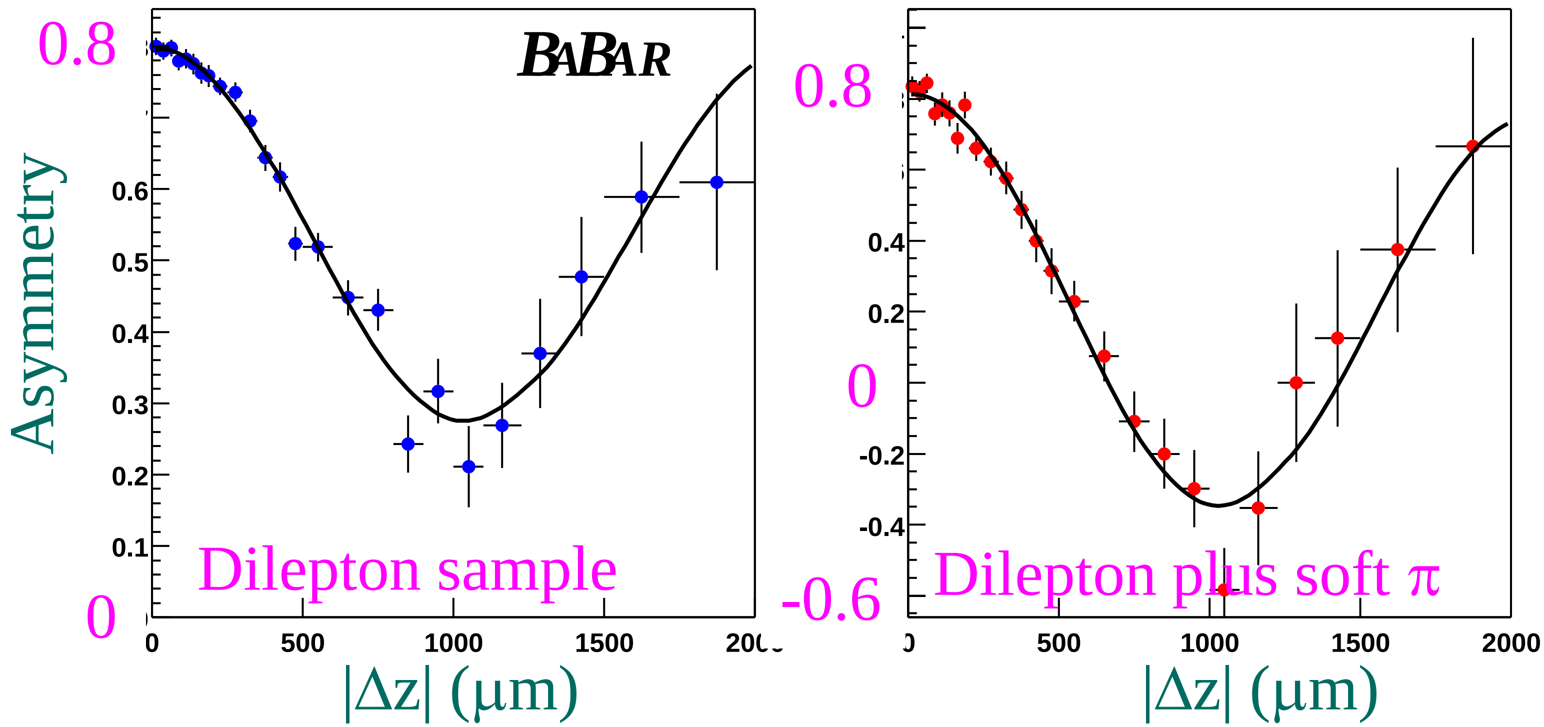
- Hadronic sample:
  $\Delta m_{B0} = 0.516 \pm 0.031 \pm 0.018\ \hbar\ \mathrm{ps}^{-1}$
  - » Systematic error from Δt function and MC study.
- $D^{*-}\ell^{+}\nu$: $\Delta m_{B0} = 0.508 \pm 0.020 \pm 0.022\ \hbar\ \mathrm{ps}^{-1}$
  - » Additional systematic from B^{+} backgrounds.

Δm_{B0} From Dilepton Sample

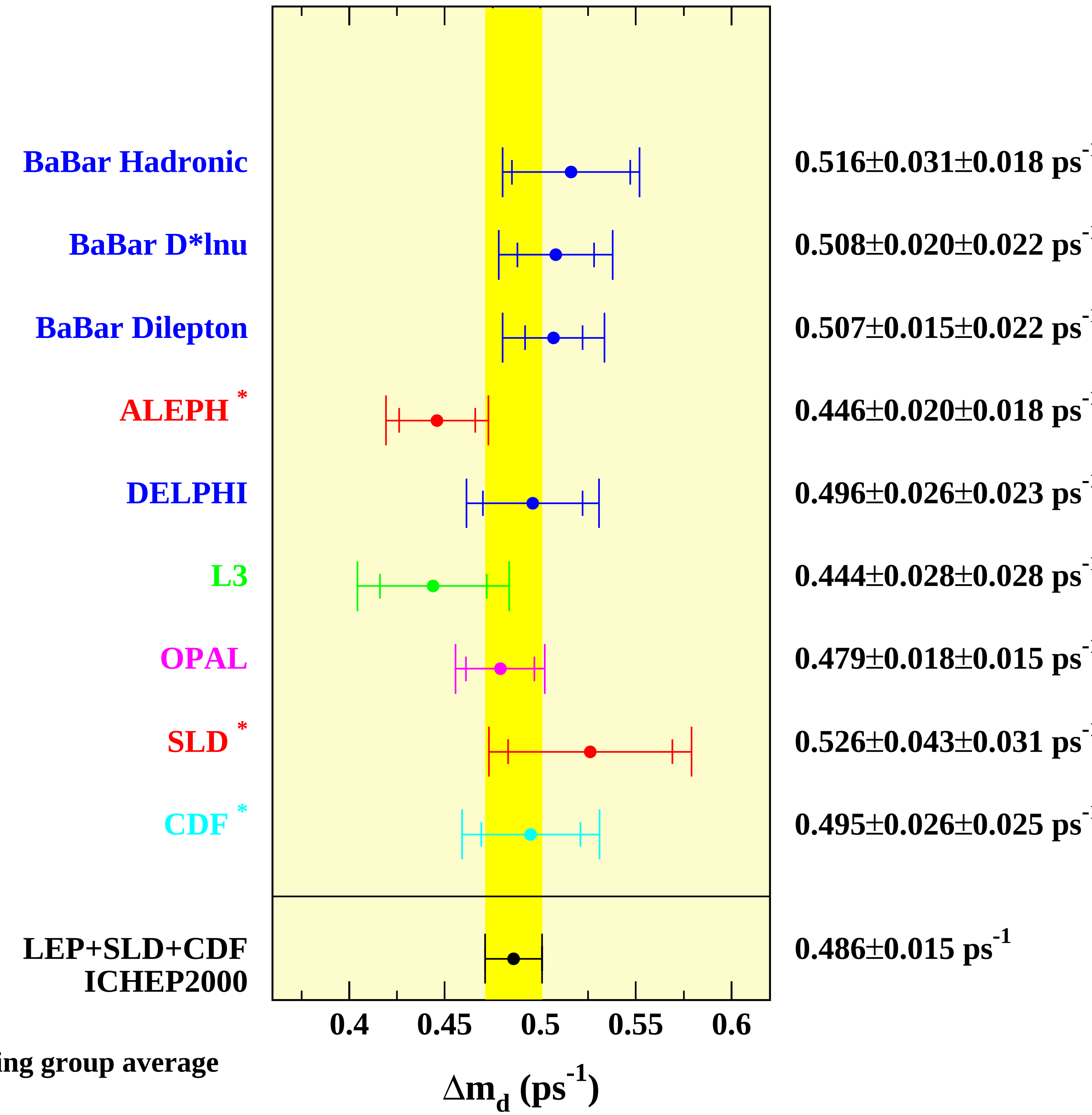
- Identify B^0 oscillations by comparing events with same-sign leptons to opposite sign.
- Can also get opposite sign lepton from $b \rightarrow c \rightarrow \ell$ decays. Use neural net with lepton momenta, E_{tot}, p_{miss}, and θ_{12}.
- 36,631 events; 78% purity; ε = 9%.
- Δt from two leptons and beamspot.
- Alternative: look for soft π^- from $D^{*-}\ell^+\nu$ to enhance B^0 purity.

Dilepton Δm_{B0} Results

- $\Delta m_{B0} = 0.507 \pm 0.015 \pm 0.022\ \hbar\ ps^{-1}$
  - » $\Delta m_{B0} = 0.518 \pm 0.017\ \hbar\ ps^{-1}$ in enriched sample.



Δm_{B0} Summary

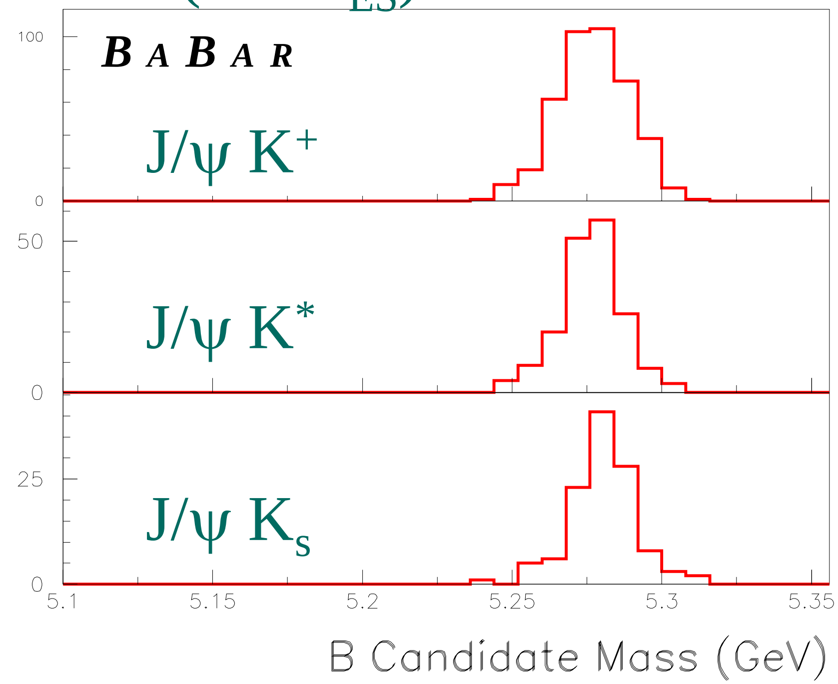


* working group average

B^0 and B^+ Masses from Exclusive Charmonium Modes

- Correct for alignment & B field using $J/\psi \rightarrow \mu^+\mu^-$ & $K_s \rightarrow \pi^+\pi^-$
- 2–4% background produces 0.3–0.7 MeV uncertainty.
- $m(B^0) = 5279.0 \pm 0.8 \pm 0.8$ MeV/c^2
  $m(B^+) = 5278.8 \pm 0.6 \pm 0.4$ MeV/c^2
- $m(B^0) - m(B^+)$ (from m_{ES}) $= 0.28 \pm 0.21 \pm 0.04$ MeV/c^2

Mass (not m_{ES}) of B Candidates

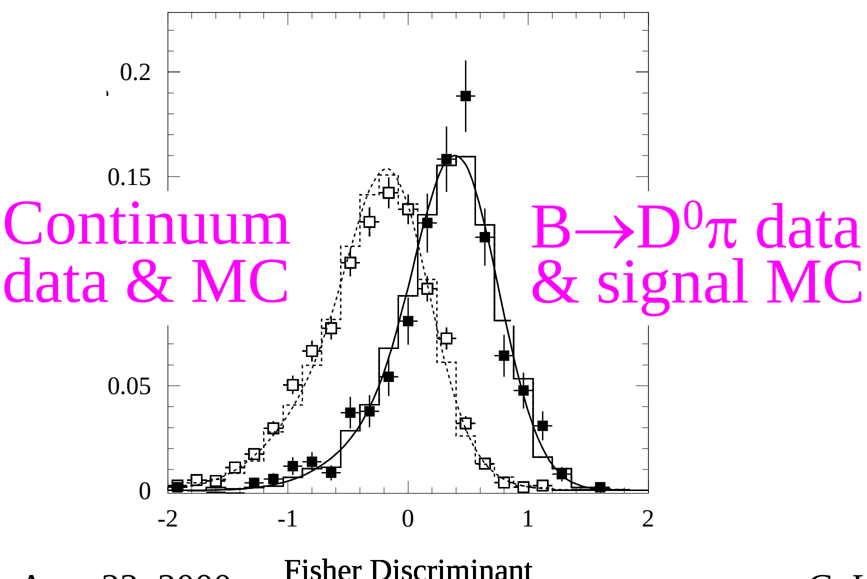


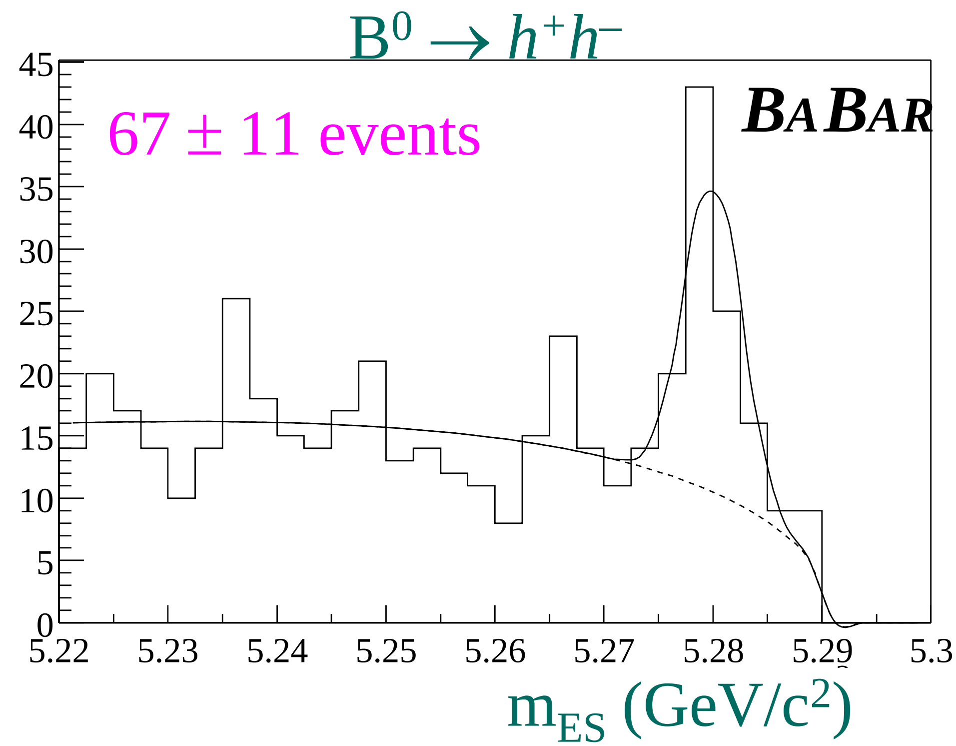
Branching Fraction Measurements

- Large luminosity sample permits numerous interesting branching ratio measurements.
  - » Inclusive Charmonium
  - » Exclusive Charmonium + K
  - » $D^{*-}\pi^{+}$, $D^{*-}\rho^{+}$
  - » $K^{*0}\gamma$
  - » D_s^{*+}
  - » Charmless 3 body & quasi-two-body
  - » $K^{*}\ell^{+}\ell^{-}$ limit

Rare Charmless Decays
$B^0 \rightarrow h^+h^-$

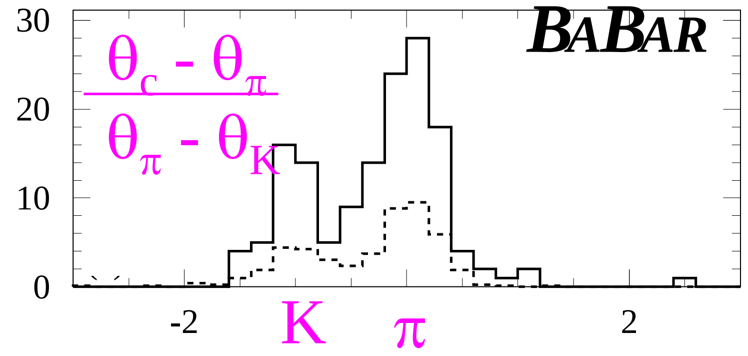
- $B^0 \rightarrow \pi^+\pi^-$ interesting for sin2α, but depends on size of "penguin" contribution. $B^0 \rightarrow K^+\pi^-$ rate provides estimate.
- Continuum background; use Fisher discriminant.

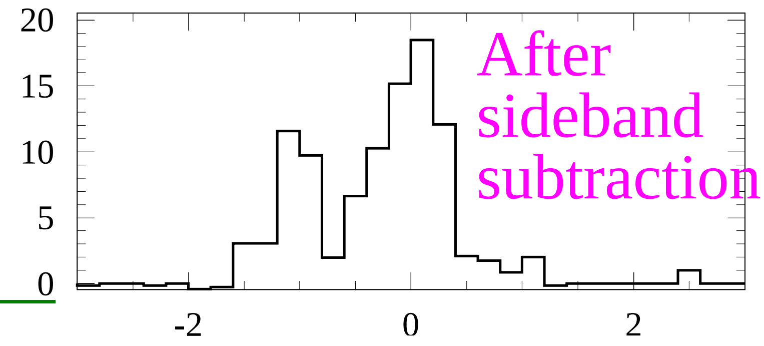




Branching Fractions, $B^0 \rightarrow \pi^+\pi^-$ and $B^0 \rightarrow K^+\pi^-$

- 1st method: Kaon ID cuts. Correct for ε & misID.
- Likelihood analysis of h^+h^- sample using m_{ES}, ΔE, Fisher discriminant and DIRC θ_c
  - » Acceptable agreement.

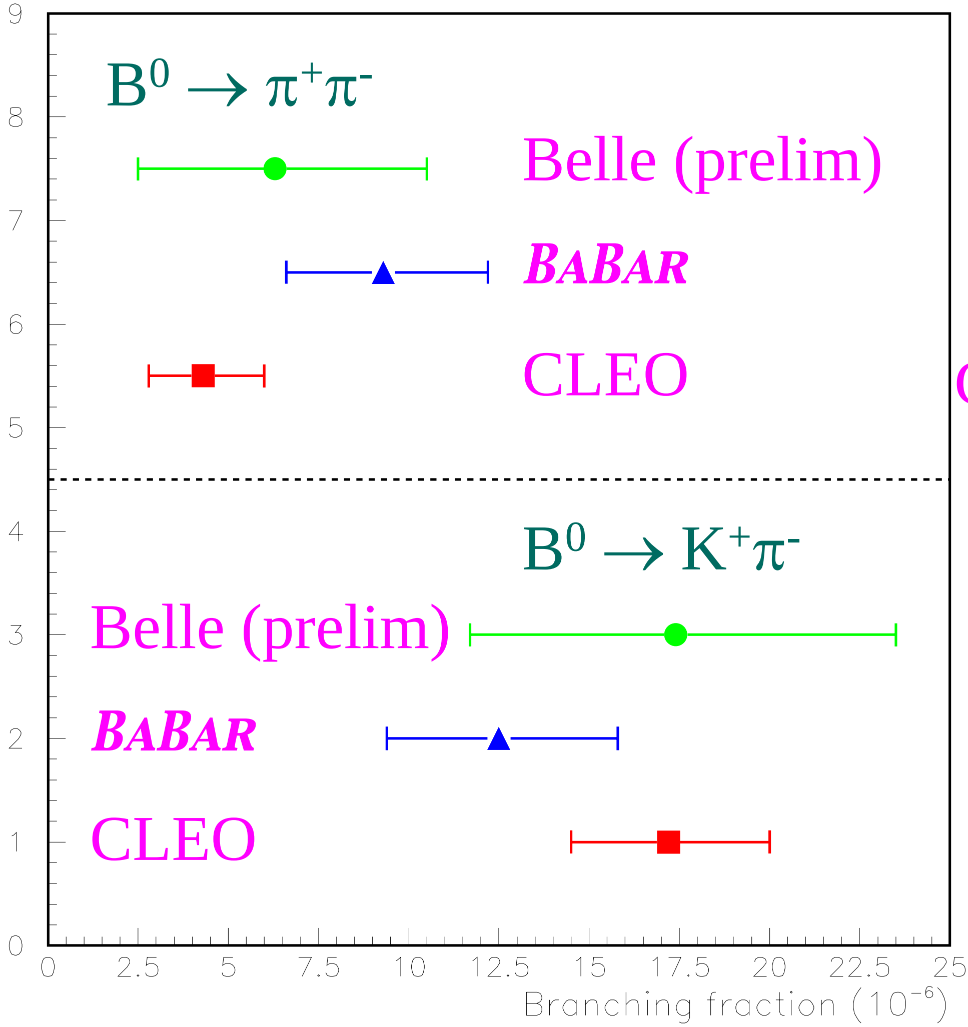


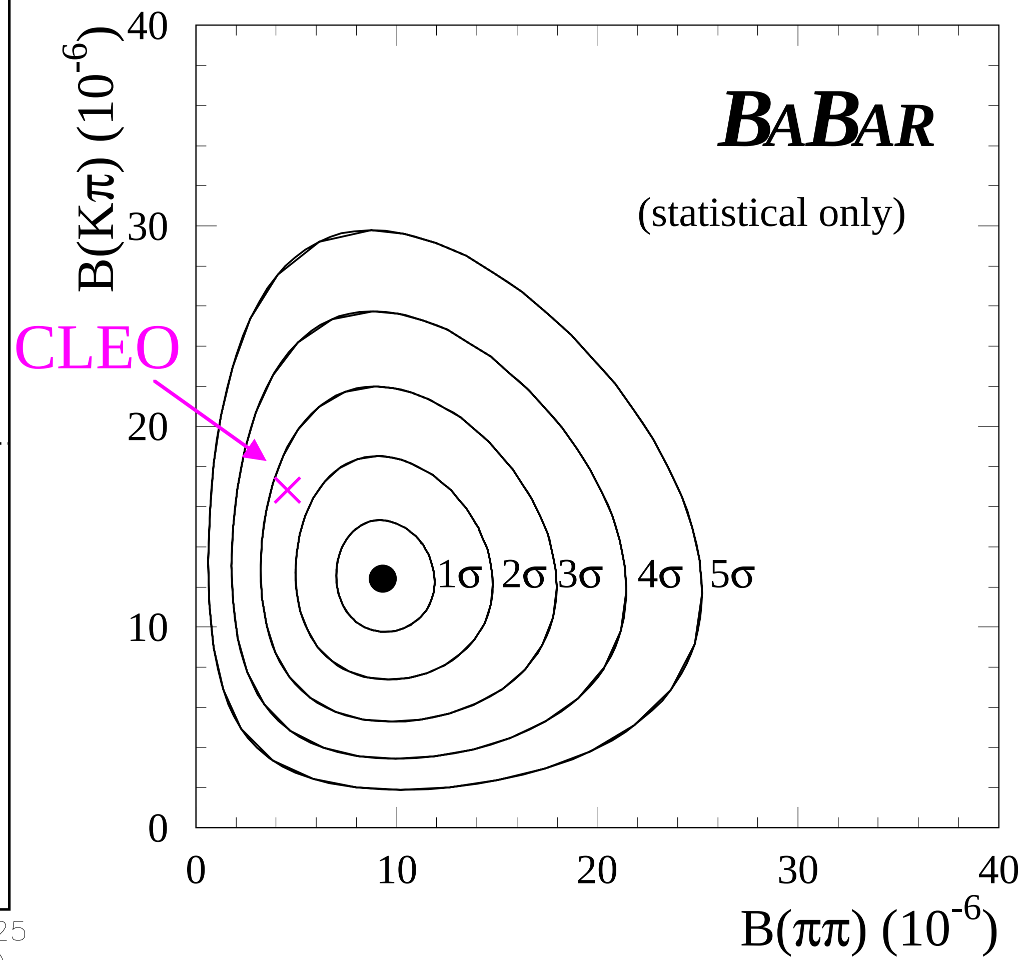


Summary — from Likelihood

Mode	N_S	*Stat. Sig (σ)*	$B\ (10^{-6})$
π+π-	$29^{+8\,+3}_{-7\,-4}$	5.7	$9.3^{+2.6\,+1.2}_{-2.3\,-1.4}$
K+π-	$38^{+9\,+3}_{-8\,-5}$	6.7	$12.5^{+3.0\,+1.3}_{-2.6\,-1.7}$
K+K-	7^{+5}_{-4} (<15)	2.1	< 6.6

Comparison with CLEO and Belle





Summary and Outlook

- Good performance of PEP-II and BaBar have produced numerous preliminary physics results.
- Highlight: $\sin 2\beta = 0.12 \pm 0.37 \pm 0.09$
- Current run will continue until end of October. Aim for 25 fb^{-1}.
  - » Reblind $\sin 2\beta$ analysis;
  - » Additional channels.