

CP Violation

Status of Experimental Measurements

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Outline

- CP violation in K mesons decays
 - NA48, KTeV
- CP asymmetries in B decays
 - B factories and hadron colliders
- Experimental issues in $\sin 2\beta$ measurement
- Future and perspective

Ringraziamenti

- Per i risultati presentati in questa review
ringrazio
 - L.Lanceri,D.Kirkby (BaBar)
 - J.Alexander (Cleo)
 - M.Sozzi,A.Ceccucci (NA48)
 - H.Nguyen (KTeV)
 - D.Bortoletto (CDF)
 - S. Schrenk (*Belle*)

Osservabili della matrice CKM

Oss.	Determina	Teo.	Sper.
$ V_{ub}/V_{cb} ^2$	$\lambda^2(\rho^2 + \eta^2)$	***	***
ϵ	$\eta \left((1 - \rho) A^2 + 0.2 \right)^{\frac{ABK}{0.65}}$	**	***
x_d	$(\rho - 1)^2 + \eta^2$	**	***
$A_{CP}\psi K_s^0$	$\sin 2\beta$	***	***
$A_{CP}\pi^+\pi^-$	$\sin 2\alpha$	**	***
$A_{CP}\rho K_s^0$	$\sin 2\gamma$	**	*
$A_{CP}B^\pm \rightarrow D_{CP}^0 K^\mp$	$\sin 2\gamma$	***	*
ϵ'/ϵ	η	**	**
$B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})$	η	***	*
$B(K^+ \rightarrow \pi^+ \nu \bar{\nu})$	$(\rho - 1)^2 + \eta^2$	**	**
$B \rightarrow X_d \nu \bar{\nu} / B \rightarrow X_s \nu \bar{\nu}$	$(V_{td} / V_{ts})^2$	***	*
$B \rightarrow X_d \mu^+ \mu^- / B \rightarrow X_s \mu^+ \mu^-$	$(V_{td} / V_{ts})^2$	**	**
x_d/x_s	$(V_{td} / V_{ts})^2$	**	**



BABAR.

M.Carpinelli

Double ratio technique

$$\eta_{+-} \equiv \frac{A(K_L \rightarrow \pi^+ \pi^-)}{A(K_S \rightarrow \pi^+ \pi^-)} \simeq \varepsilon + \varepsilon'$$

$$\eta_{00} \equiv \frac{A(K_L \rightarrow \pi^0 \pi^0)}{A(K_S \rightarrow \pi^0 \pi^0)} \simeq \varepsilon - 2\varepsilon'$$

$$Re(\varepsilon'/\varepsilon) \simeq \frac{1}{6} \left\{ 1 - \frac{\Gamma(K_L \rightarrow \pi^0 \pi^0)}{\Gamma(K_S \rightarrow \pi^0 \pi^0)} / \frac{\Gamma(K_L \rightarrow \pi^+ \pi^-)}{\Gamma(K_S \rightarrow \pi^+ \pi^-)} \right\} = \frac{1}{6} (1 - R)$$

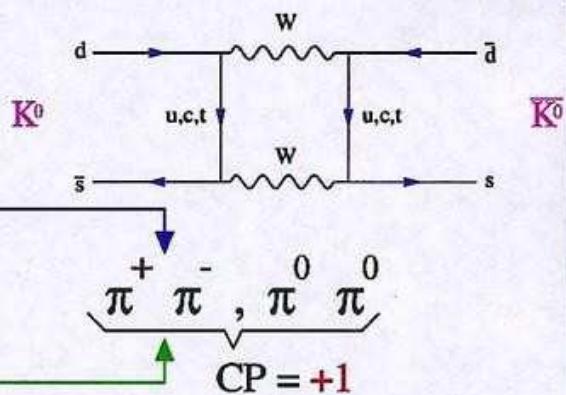
$R = \frac{N_L^{00}}{N_S^{00}} / \frac{N_L^{+-}}{N_S^{+-}}$ Provided at least K_S / K_L or $\pi^+ \pi^- / \pi^0 \pi^0$ are collected at the same time

NA31	$(23.0 \pm 6.5) \times 10^{-4}$
E731	$(7.4 \pm 5.9) \times 10^{-4}$

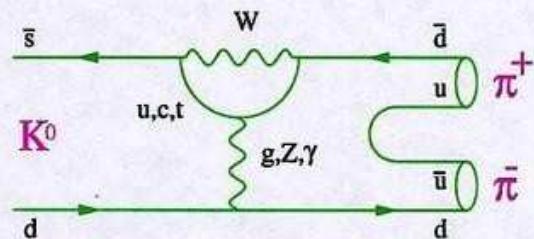
KTEV	$(28.0 \pm 4.1) \times 10^{-4}$
NA48 97	$(18.5 \pm 7.3) \times 10^{-4}$
NA48 98	$(12.2 \pm 4.9) \times 10^{-4}$

Physics motivation, contd.

$\varepsilon \Rightarrow$ Indirect CP violation
via K^0/\bar{K}^0 mixing



Direct CP violation:



$$\varepsilon' = \frac{i}{\sqrt{2}} \Im \frac{A_2}{A_0} \exp(i(\delta_2 - \delta_0))$$

$$A(K^0 \rightarrow \pi \pi, I) = A_I \exp(i\delta_I)$$

$$A(\bar{K}^0 \rightarrow \pi \pi, I) = A_I^* \exp(i\delta_I)$$

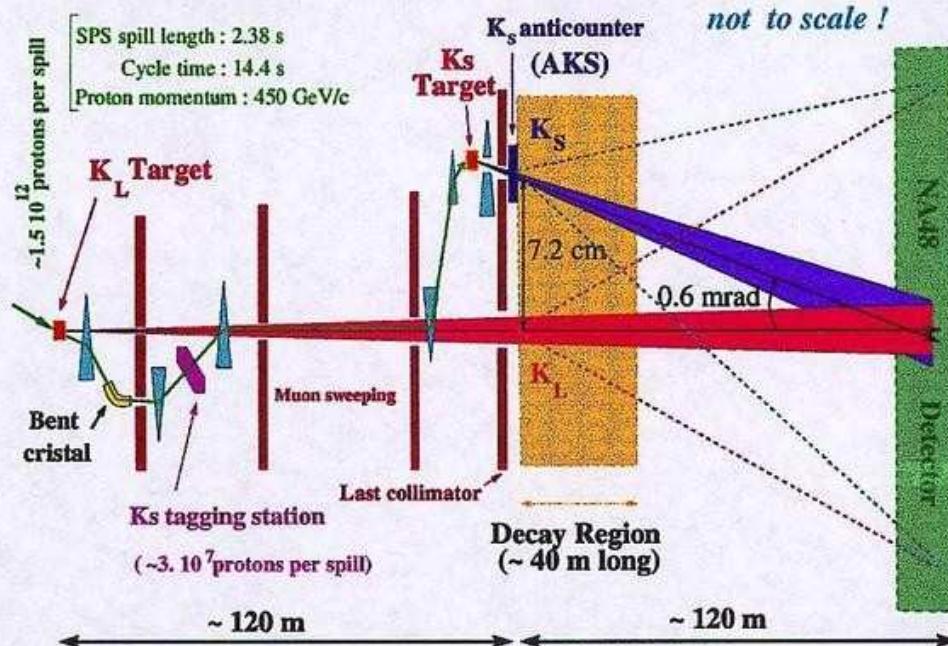
Overview of NA48 method

To achieve the required statistical precision *several* $10^6 K_L \rightarrow \pi^0 \pi^0$ decays (limiting mode) have to be collected.

To maximize systematic accuracy and to have minimal corrections, NA48 uses:

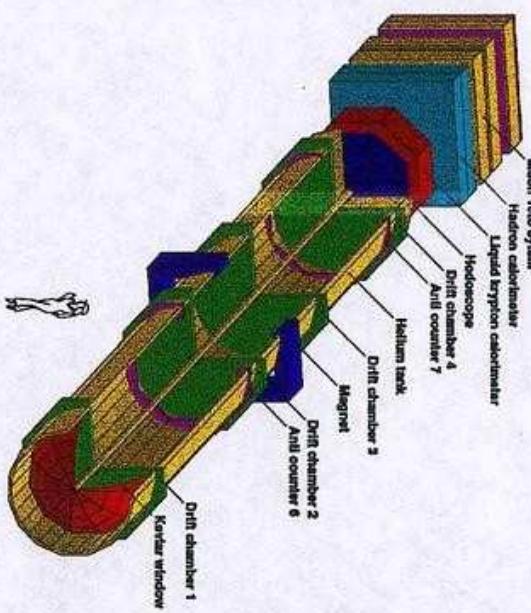
- ▷ simultaneous, almost collinear K_L and K_S beams, allowing for
- ▷ concurrent detection of the four decay modes in the same decay region to have cancellation of fluxes, acceptances, inefficiencies, dead time, accidental losses;
- ▷ K_S identification by proton tagging upstream of K_S production target;
- ▷ a detector based on a magnetic spectrometer and a quasi-homogeneous liquid Krypton calorimeter, to achieve good resolutions and minimize the background;
- ▷ lifetime weighting procedure to minimize acceptance corrections by making K_S and K_L decay distributions similar.

Simultaneous K_S and K_L Beams



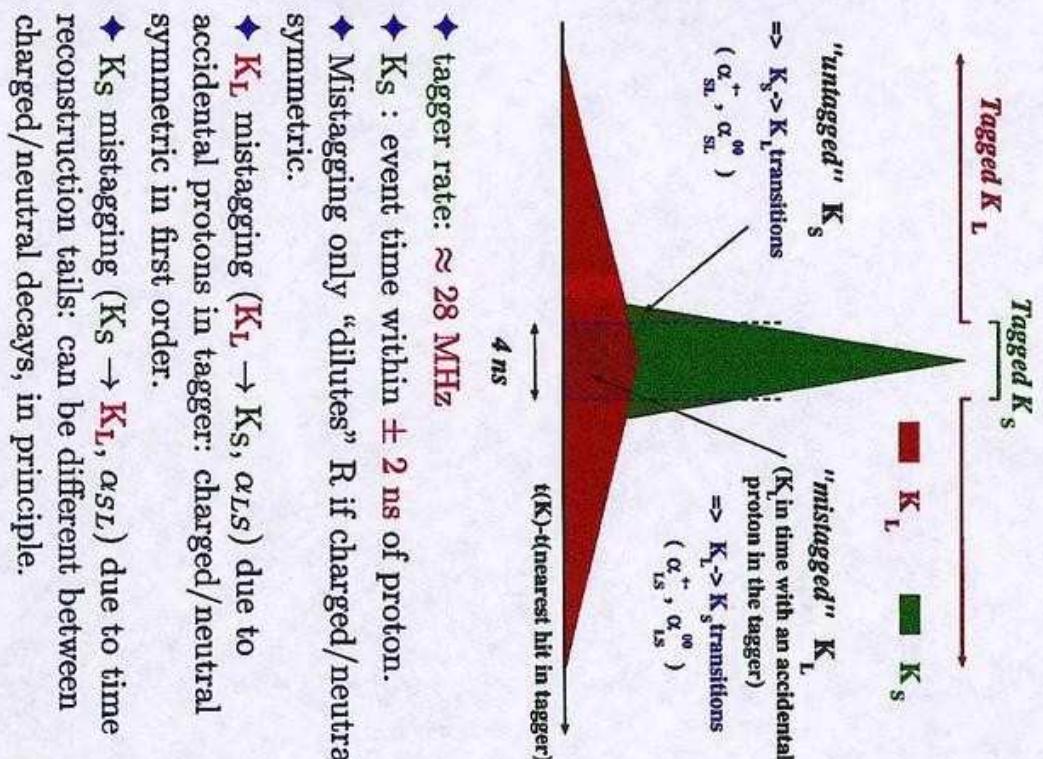
K_S are distinguished from K_L by tagging the protons upstream of their production target.

The NA48 detector



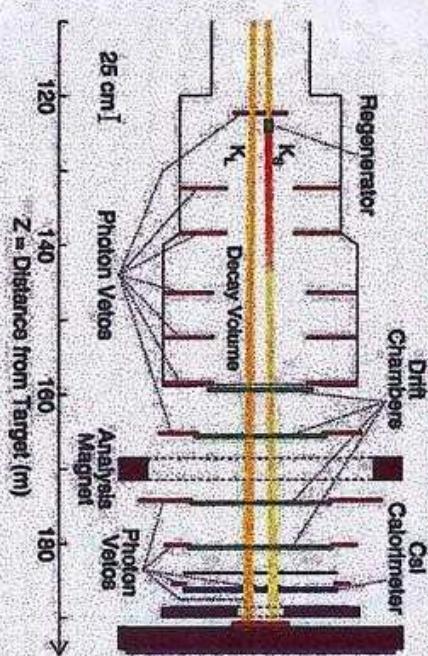
- ◆ $K_{L,S} \rightarrow \pi^+ \pi^-$: magnetic spectrometer (P_T kick ~ 265 MeV/c); event time measured with scintillator hodoscope
- ◆ $K_{L,S} \rightarrow \pi^0 \pi^0$: quasi-homogeneous liquid Krypton e.m. calorimeter with **high granularity** (13212 2×2 cm 2 cells) and **projective geometry**
- ◆ $K_{\mu 3}$ rejection: muon veto counters
- ◆ K_{e3} rejection: E(LKr)/P(spectrometer)
- ◆ $K_L \rightarrow 3\pi^0$ rejection: high resolution e.m. calorimeter

Tagging - Principle

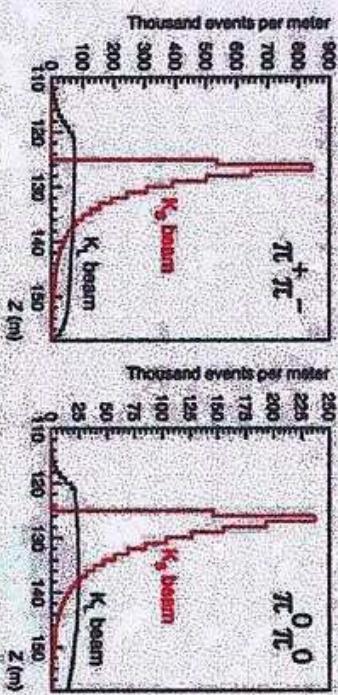


- ♦ tagger rate: $\approx 28 \text{ MHz}$
- ♦ K_S : event time within $\pm 2 \text{ ns}$ of proton.
- ♦ Mis-tagging only "dilutes" R if charged/neutral symmetric.
- ♦ K_L mis-tagging ($K_L \rightarrow K_S, \alpha_{LS}$) due to accidental protons in tagger: charged/neutral symmetric in first order.
- ♦ K_S mis-tagging ($K_S \rightarrow K_L, \alpha_{SL}$) due to time reconstruction tails: can be different between charged/neutral decays, in principle.

Collect K_L and K_S Decays Simultaneously

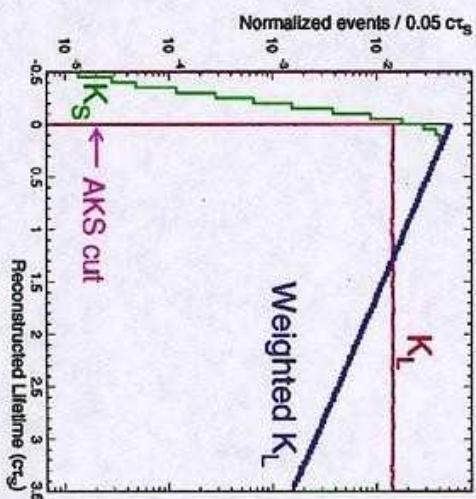


Vertex Z Distributions



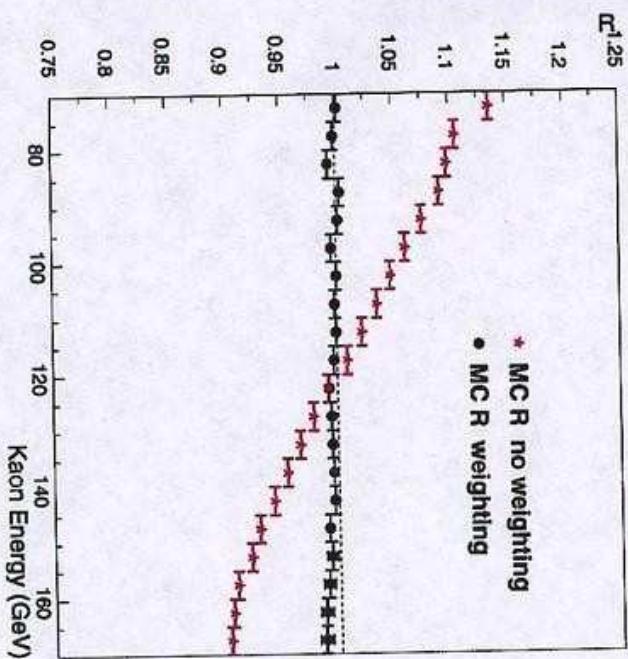
Lifetime weighting

- ◆ K_S and K_L are collected in the same fiducial region
- ◆ Weighting K_L events as a function of decay proper time, according to expected ratio of $\pi\pi$ rates \Rightarrow very similar lifetime distributions
- ◆ Accounts for small terms due to K_S and K_L interference and K^0/\bar{K}^0 production difference
- ⇒ Reduces potentially large acceptance corrections to $< 0.5\%$
- ◆ Increases statistical error



Acceptance

The increase of the statistical error due to weighting is 35%



$$\Delta R = (+31 \pm 6(\text{stat}) \pm 6(\text{syst})) \times 10^{-4}$$

Measurement Technique for $\text{Re}(\epsilon'/\epsilon)$

$$R = \frac{\Gamma(K_L \rightarrow \pi^+ \pi^-) / \Gamma(K_S \rightarrow \pi^+ \pi^-)}{\Gamma(K_L \rightarrow \pi^0 \pi^0) / \Gamma(K_S \rightarrow \pi^0 \pi^0)} = 1 + \delta \text{Re}(\epsilon'/\epsilon)$$

Must Control $\delta R/R$ to 0.1% Level in the Presence of:

Correction	Approximate Size
Acceptance	4 %
K_L, K_S Scattering	1 %
Background	0.4 %
Rate Effects	0.2 %
Energy Scale	0.1 %

Measurement of Corrections:

Acceptance:

Estimated From Monte Carlo

Cross checked with Ke3, $\pi^+ \pi^- \pi^0$, $\pi^0 \pi^0 \pi^0$ events
Constraints from detector apertures and edges
Detailed simulation of detector inefficiencies

Energy Scale:

Momentum Analyzed Ke3's and $\pi^+ \pi^- \pi^0$

Rate Effects:

Random triggers which scale with beam intensity

Scattering:

Studied with known scattered kaons

Detailed modeling of scattering

Background:

Extrapolated from mass sidebands

Detailed modeling of background

Comparison of the 1997 and 1998 results

Corrections and syst. uncertainties on R (Units = 10^{-4})

Source	1997 sample		1998 sample	
Charged trigger	+9	± 23	-1	± 11 <small>stat.</small>
Mistagging probability	+18	± 9	+1	± 8 <small>stat.</small>
Tagging efficiency	-	± 6	-	± 3
Neutral scale	-	± 12	-	± 10
Charged vertex	-	± 5	+2	± 2
Acceptance	+29	± 12	+31	± 9 <small>MC stat.</small>
Neutral BG	-8	± 2	-7	± 2
Charged BG	+23	± 4	+19	± 3
Beam scattering	-12	± 3	-10	± 3
Accid. activity	-2	± 14	+2	± 12 <small>stat.</small>
Total	+57	± 35	+37	± 24

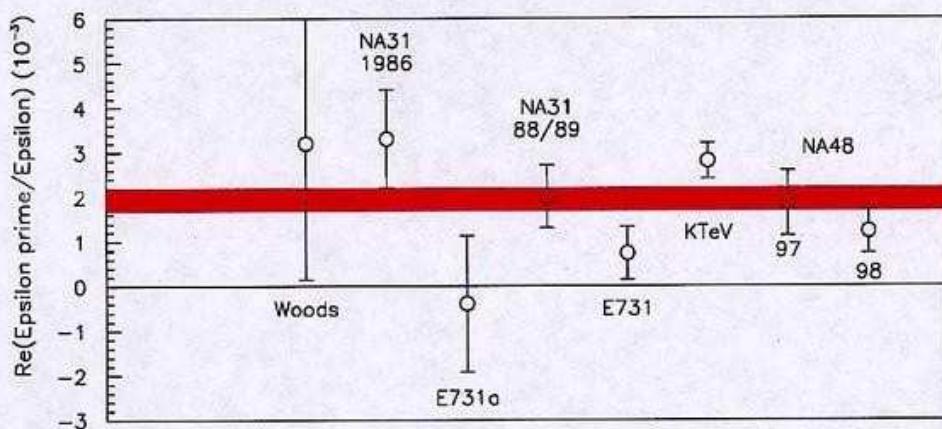
Summary of Systematic Uncertainties

Systematic	$\pi^+\pi^-$ Analysis ($\times 10^{-4}$)	$\pi^0\pi^0$ Analysis ($\times 10^{-4}$)
Trigger (L1/L2/L3)	0.50	0.29
Detector Resolution	0.35	<0.10
Calibration/Alignment	0.25	0.38
Energy Scale	0.12	0.70
DC simulation	0.63	—
Csi non-linearity	—	0.60
Apertures	0.26	0.48
(incl Reg Edge)		
Analysis Cuts	0.59	0.78
Backgrounds	0.20	0.81
Overall Acceptance	1.59	0.68
Monte Carlo Statistics	0.50	0.90
Attenuation Slope	0.24	
Movable Absorber	0.20	
External Parameters	0.19	

Total systematic uncertainty on $Re(\epsilon'/\epsilon) =$

$$2.80 \times 10^{-4}$$

New world average



New world average:

$$\text{Re}(\epsilon'/\epsilon) = (19.3 \pm 2.4) \times 10^{-4}$$
$$(\chi^2/ndf = 11.1/5)$$

CP Violation in B Mesons

- Three different categories of CP violating observables
- Direct CP Violation in B decays
- CP Violation due to $B^0/\text{anti-}B^0$ mixing
- CP Violation due to interplay of B decay and $B^0/\text{anti-}B^0$ mixing

CP Violation due to B^0 mixing

$$A = \frac{N(l+l+) - N(l-l-)}{N(l+l+) + N(l-l-)}$$

$$(\delta A)^2 = \frac{1-A^2}{N_{b\bar{b}} \chi f_0^2 (Br\varepsilon)^2}$$

$$A \approx 0.1\% \quad \chi \approx 18\%, Br \approx 20\%, \varepsilon \approx 50\%$$

$$\delta A \leq A \Rightarrow N_{b\bar{b}} \approx 10^9$$

- Very small asymmetries 0.1%; extremely difficult to measure, very good understanding of systematic

Direct CP Violation in B decays

- CP violation evidence from the asymmetry of $B \rightarrow f$ vs anti- $B \rightarrow$ anti f
- Number of B decays required for the observation of an asymmetry A with S standard deviation

$$(\delta A)^2 = \frac{1-A^2}{N_B Br\varepsilon} \left(1 + \frac{N_{bg}}{N_{sig}} \right)$$

$A \approx 1\%$, $Br \approx 3 \cdot 10^{-5}$, $\varepsilon \approx 30\%$ $\delta A \leq A \Rightarrow N_B \approx 10^9$

Searches for Direct CP Violation in B Decay

Jim Alexander, Cornell University

- CLEO Dataset, 9.7M $B\bar{B}$ events
- Modes:

$$B \rightarrow K^\pm \pi^\mp$$

$$B \rightarrow K^\pm \pi^0$$

$$B \rightarrow K^0 \pi^\pm$$

$$B \rightarrow K^\pm \eta'$$

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

$$B^\pm \rightarrow \psi^{(\prime)} K^\pm$$

- Sign convention:

$$A_{CP} = \frac{Br(b \rightarrow f) - Br(\bar{b} \rightarrow \bar{f})}{Br(b \rightarrow f) + Br(\bar{b} \rightarrow \bar{f})}$$

- See also talks by

• Jim Smith

• Tomasz Skwarnicki

• David Asner

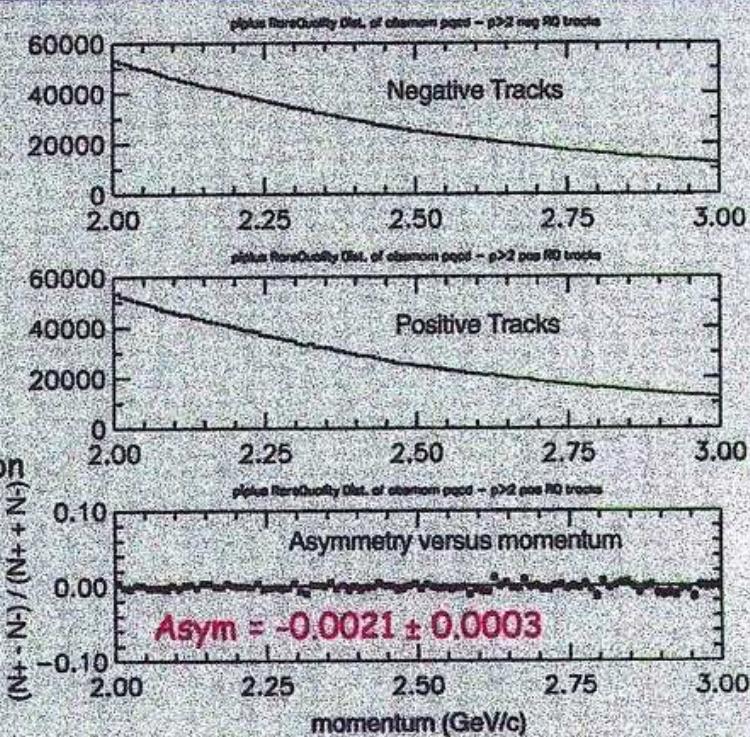
Results

Mode	Yield	B/S	Acp (Bkg)	Acp (Signal)
$K^\pm\pi^\pm$	80.2 ± 11.4	0.6	-0.02 ± 0.04	-0.04 ± 0.16
$K^\pm\pi^0$	42.1 ± 10.4	1.6	-0.00 ± 0.03	-0.29 ± 0.23
$K^0\pi^\pm$	25.2 ± 6.0	0.4	-0.02 ± 0.04	$+0.18 \pm 0.24$
$K^\pm\eta'$	100 ± 12.5	0.6	-0.01 ± 0.07 -0.01 ± 0.02	$+0.03 \pm 0.12$
$\omega\pi^\pm$	28.5 ± 7.8	1.1	-0.00 ± 0.01	-0.34 ± 0.25

Limit on +- asymmetries in CLEO

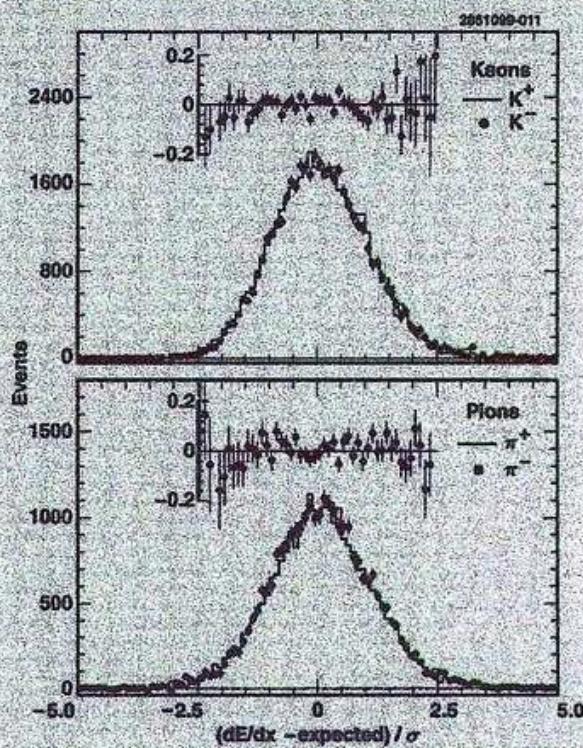
Acp measurements presented here all depend on a high momentum charged track to tag the b-quark flavor.

Same track selection criteria as for rare B analyses.



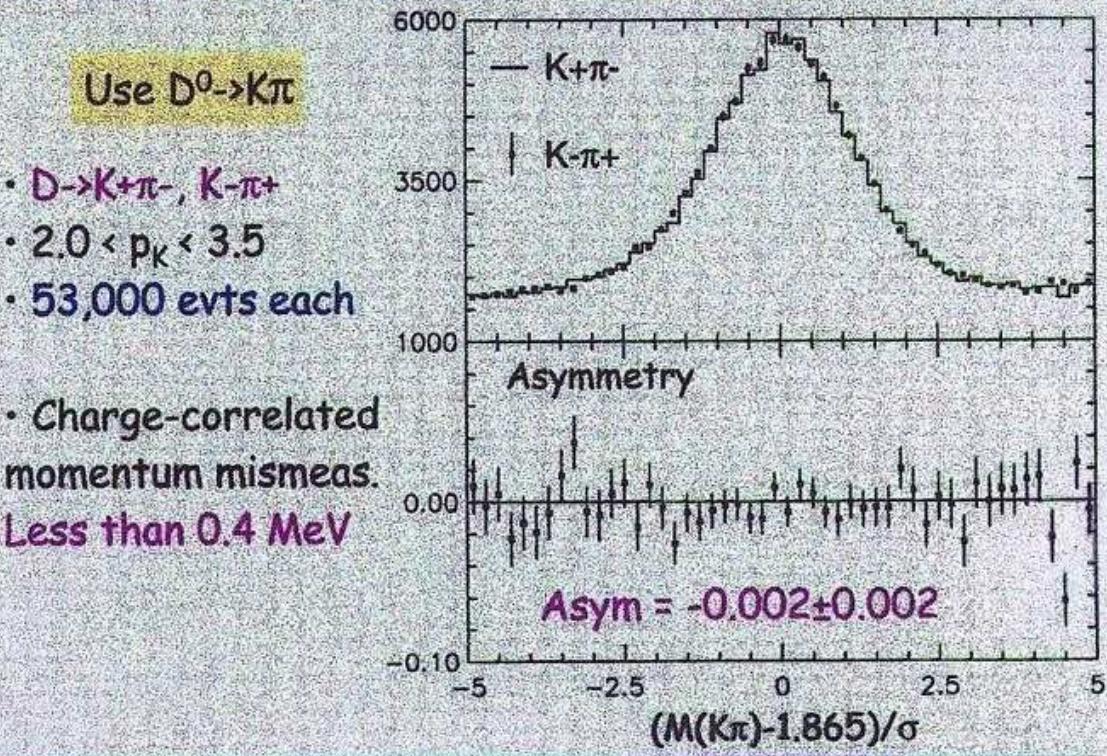
Limit on +- asymmetries in CLEO (continued)

Can use D0 decays to check whether there is any charge bias in $K\pi$ identification by dE/dx



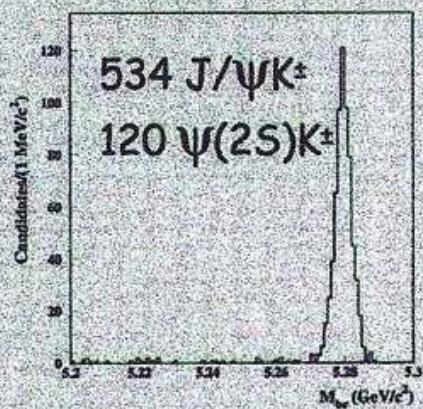
Upper limit effect on A_{CP} in $B \rightarrow K^*\pi^-$ is ± 0.01 .

Limit on +- asymmetries in CLEO (continued)



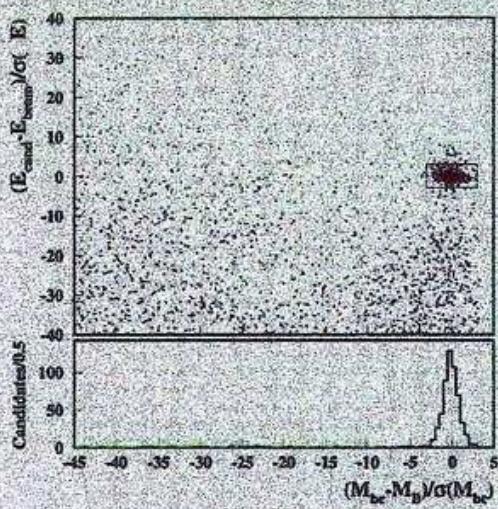
$B^\pm \rightarrow \psi K^\pm$ asymmetry

- 654 events total
- background = 6±1 events

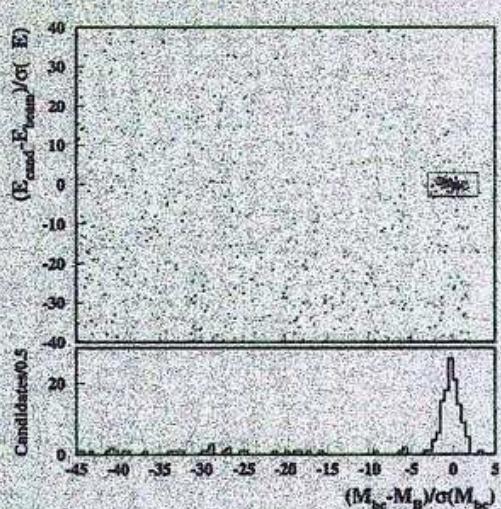


$$A_{CP} = \frac{N^+ - N^-}{N^+ + N^-} = \frac{322 - 332}{322 + 332} = -0.0015 \pm 0.0039$$

$B^{\pm} \rightarrow \psi K^{\pm}$ and $B^{\pm} \rightarrow \psi' K^{\pm}$



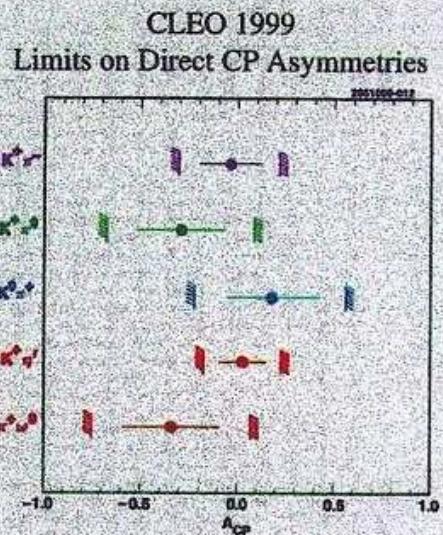
534 ψK events



120 $\psi' K$ events

Conclusions

- A_{CP} measurements are just now becoming feasible
- Statistics limited: ± 0.12 (+)
- Systematic error: ± 0.02
- No significant A_{CP} in these five rare hadronic modes
- But large chunks of A_{CP} space are ruled out.
- No significant asym in ψK^\pm ; statistical precision is ± 0.04
- Precision A_{CP} m's'ts will require very large datasets...





was definitely a B^0

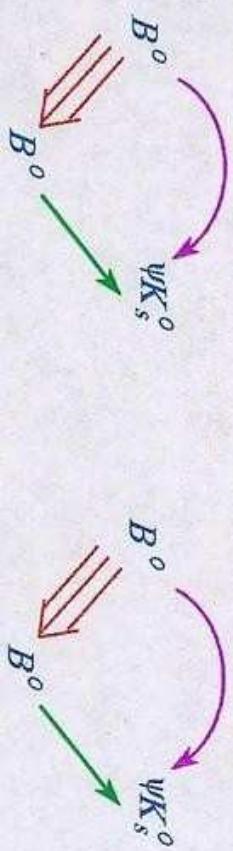
Coherence: The other B^0 evolves as if it was a pure B^0 at time t_1 .

Process

$$B_{phys}^0 \rightarrow \psi K_s^0$$

CP conjugated process

$$B_{phys}^0 \rightarrow \psi K_s^0$$



Because of interference

Rate of process \neq rate of CP conjugated process

CP Violation!

Mixing is Essential Here

CP violation observable in B decays

$$A_{OBS}(\Delta z) \equiv \frac{N(\Delta z) - \bar{N}(\Delta z)}{N(\Delta z) + \bar{N}(\Delta z)}$$

$N(\Delta z)$ [$\bar{N}(\Delta z)$] = n. of B [\bar{B}] decaying to
a final state $f[\bar{f}]$; usually $f = \bar{f}$

$A_{OBS}(\Delta z) = D \sin(2\phi)$; $D < 1$ is a dilution factor

depends upon :
mixing,
tagging,
vertexing resolution,
background

$\sin(2\beta)$ sensitivity

The observed time integrated asymmetry A (splitting events in $\Delta z > 0$ and $\Delta z < 0$, B^0 and anti B^0) can be written as

$$A = D \sin(2\beta) \quad D = d_{mix} d_{vtx} d_{tag} d_{bg} < 1 \quad d_{mix} = \frac{x_d^2}{1+x_d^2} = 0.48$$

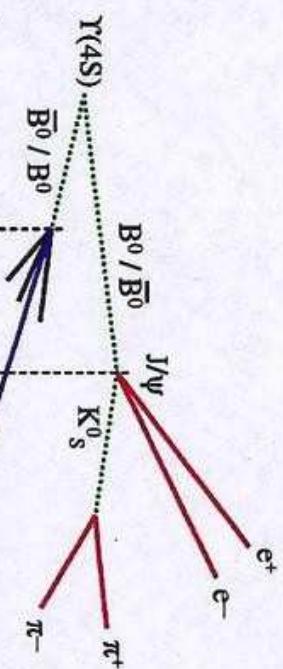
And the expected error on $\sin(2\beta)$ is

$$\delta \sin(2\beta) = \frac{\sigma_0}{\sqrt{N_{SIG}}} \frac{1}{d_{mix}} \frac{1}{d_{bg}} \frac{1}{d_{vtx}} \frac{1}{d_{tag}}$$
$$\sigma_0 = \sqrt{(1-A^2)} \quad \text{Not using the time dependence}$$

Fitting the time dependent asymmetry
will reduce σ_0 by a factor between 0.8 and 0.7
depending from the value of $\sin(2\beta)$

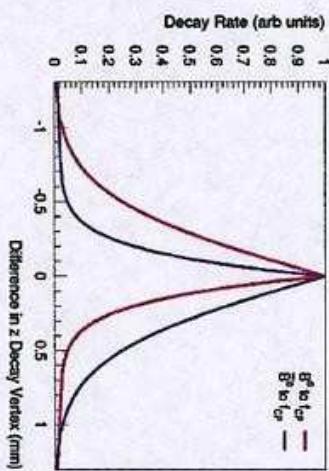
What are the experimental challenges for this mode?

$B^0 \bar{B}^0$ pairs are produced coherently in a B factory:



The key ingredients for a measurement of $\sin 2\beta$ are:

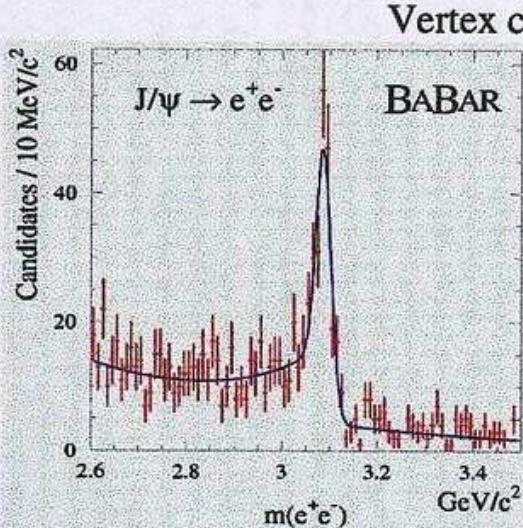
- full reconstruction of B^0/\bar{B}^0 decays into $J/\Psi K_S^0$
- tagging to distinguish between B^0 and \bar{B}^0 decays
- vertex reconstruction to measure $c \Delta t = \Delta z / \beta_z \gamma$



Inclusive J/psi reconstruction

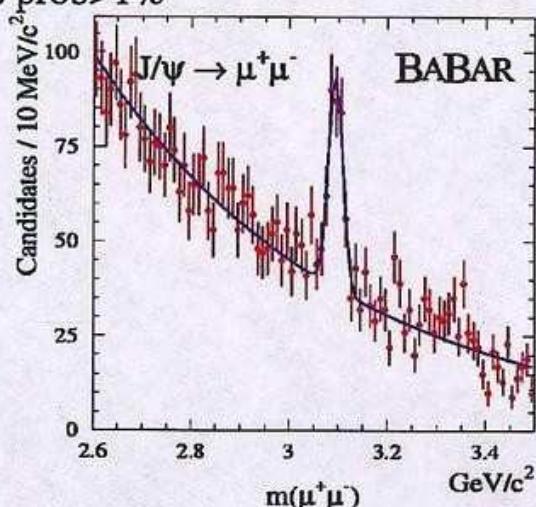
$0.8 < E/p < 1.4$

$E/p < 0.4$
 $n. \text{ layer} > 4; 0 < n. \text{ hit} < 7$
for at least one muon



$L = 540 \text{ pb}^{-1}$

Mass resolution $\sim 15 \text{ MeV}$



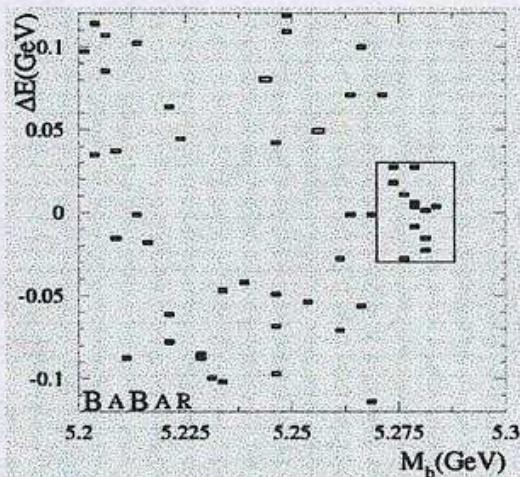
$L = 380 \text{ pb}^{-1}$

XXXV Rencontres de Moriond, March 2000

Massimo Carpinelli University of Pisa & I.N.F.N

B->J/psi K_S signal

38.1 B->J/psi K_S ($\pi^+ \pi^-$)/fb⁻¹
are produced.

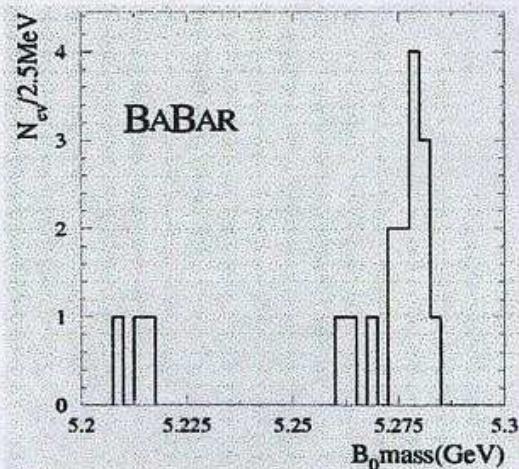


$$\Delta E = \sqrt{s/2} - E_{\text{meas}}$$

$$M_B = \sqrt{s/2 - p_{\text{meas}}^2}$$

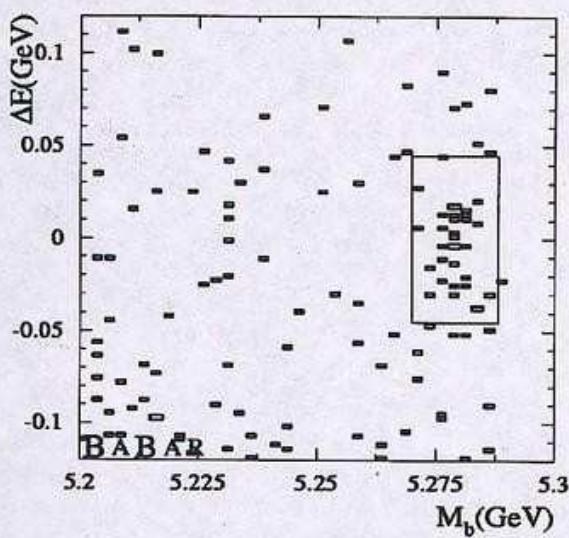
- $\sigma(M_B) = 2.5(e) - 2.3(\mu) \text{ MeV}$

- Luminosity 620 pb⁻¹
- 12 signal events observed in the signal box
- 1.4 bg events (higher than expected)

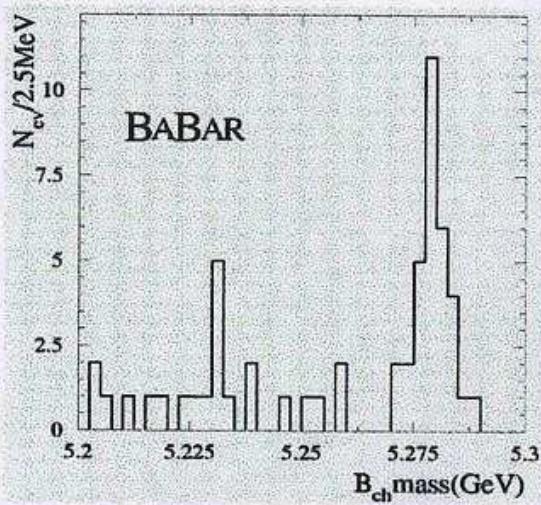


Control sample

- 125 $B^+ \rightarrow J/\psi K^+$ / fb^{-1} are produced
- Self tagging B decay

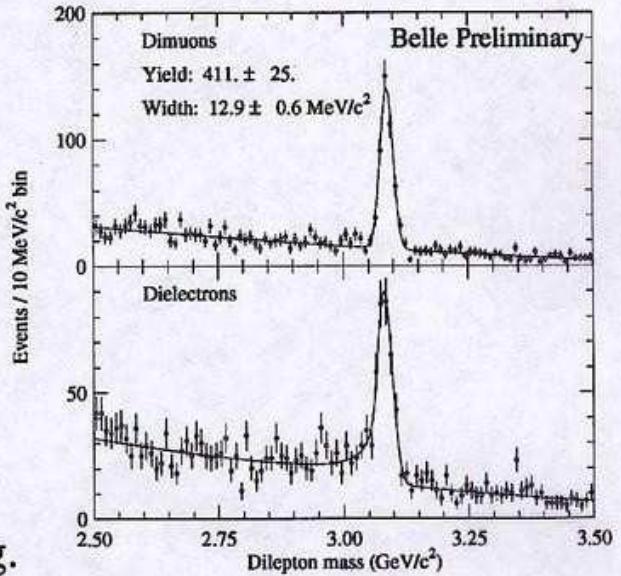


- Luminosity 620 pb^{-1}
- 32 signal events observed in the signal box
- 4.9 bg events



J/ψ Reconstruction

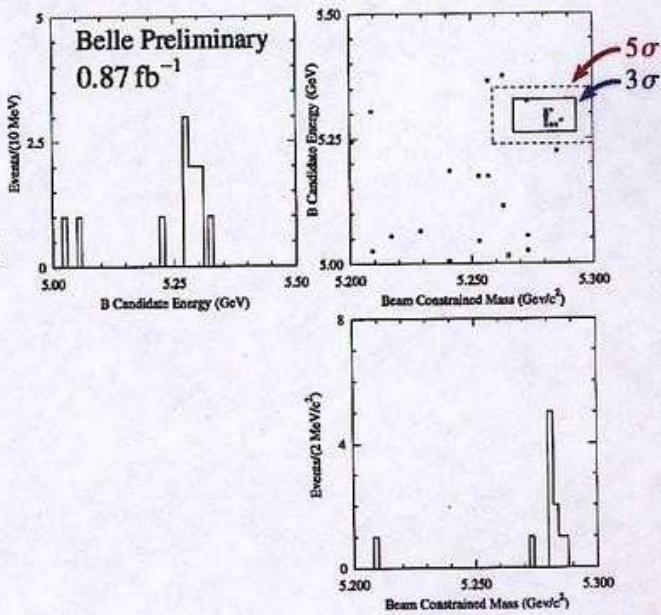
- Use dileptons:
 - Large branching fraction
 - Little background
- Dimuons:
 - Gaussian fit ignores small radiative tail.
- Dielectrons:
 - Crystal Ball function to account for final state radiation and Bremsstrallung.



Golden Mode: B to $J/\psi K_S$

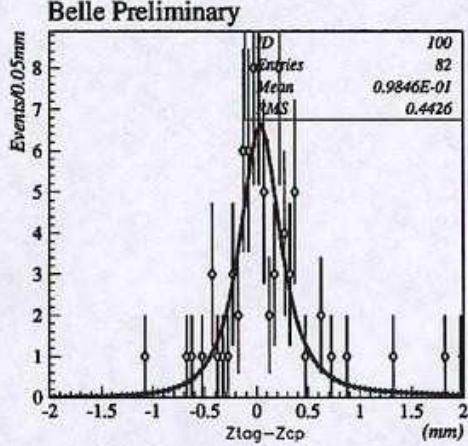
- Combine J/ψ candidate with K_S candidate.
- Two kinematic variables:
 - Energy: $E_{J/\psi} + E_{K_S}$
 - Beam Constrained Mass:

$$M = \sqrt{E_{beam}^2 - (\sum \vec{P})^2}$$

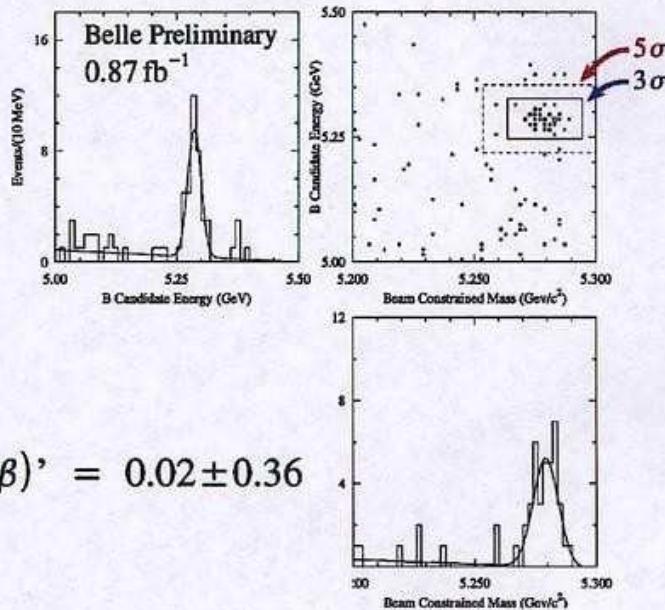


B to J/ψ $K^{+/-}$

- Calibration mode for Golden mode
 - Test fitting for $\sin(2\beta)$



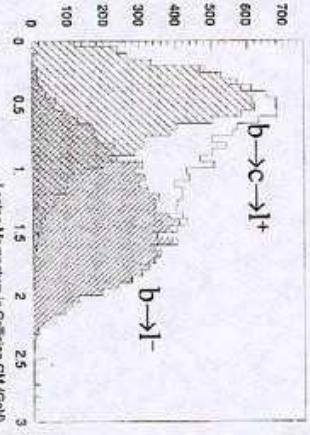
$$\text{'sin}(2\beta)\text{' = }0.02 \pm 0.36$$



Stephen Schenck: Seminar February 2000

Flavor Tagging

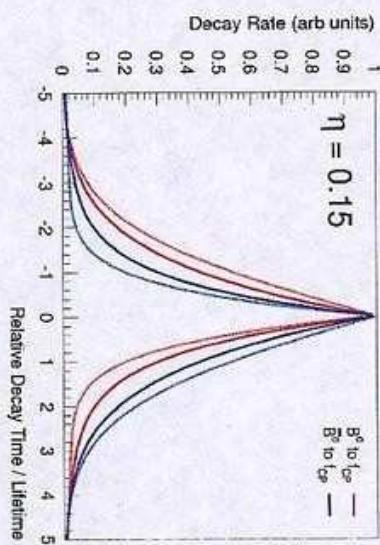
Tagging exploits correlations between the flavor of a B and the charge of its decay products (e, μ, K^\pm), e.g:



Tagging methods generally have some inefficiency ϵ (not all events contain an identified e, μ, K^\pm), and false rate η (due to reconstruction errors or physics effects).

The measured CP asymmetry is diluted by incorrectly tagged decays. Mistagging limits the statistical precision of a $\sin 2\beta$ measurement:

$$1/\sigma_{\text{stat}}^2 \approx \epsilon(1-2\eta)^2 N_{\text{rec}}/3$$



How do we know the value of the mistag rate η ?

Mixing as a Calibration Signal

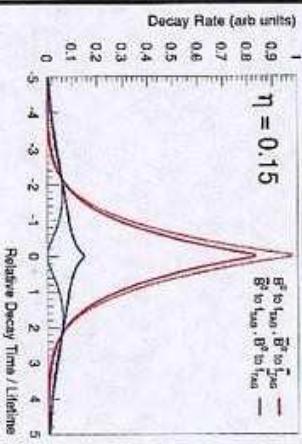
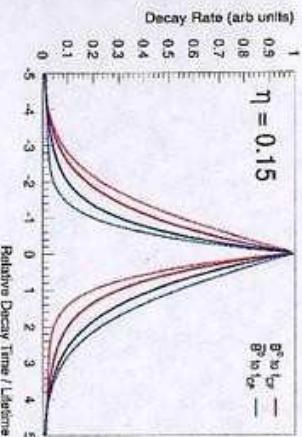
B mixing provides a calibration signal for developing a $\sin 2\beta$ analysis and measuring the tagging dilution from data:

CP asymmetry

- fully reconstruct f_{CP}
- use remaining tracks to tag flavor of f_{CP} parent
- measure $B^0 \rightarrow f_{CP}$ and $B_s^0 \rightarrow f_{CP}$ rates vs Δt

Mixing asymmetry

- fully reconstruct f_{TAG} or \bar{f}_{TAG}
- use remaining tracks to tag flavor of f_{TAG} or \bar{f}_{TAG} parent
- measure $B^0 \rightarrow f_{TAG} + \bar{B}^0 \rightarrow f_{TAG}$ and $B_s^0 \rightarrow f_{CP} + B^0 \rightarrow f_{CP}$ rates vs Δt



assume $\eta_{CP} \approx \eta_{MIX}$

- fit asymmetry to:
 $(1 - 2\eta_{CP}) \sin 2\beta \sin(\Delta m \Delta t)$
- fit asymmetry to:
 $(1 - 2\eta_{MIX}) \cos(\Delta m \Delta t)$

B^0 Lifetime and Mixing: cont.

- Time Dependence:

$$P_{os}(t) = \frac{1}{2\tau} e^{-\frac{1}{\tau}} (1 + \cos(\Delta mt))$$

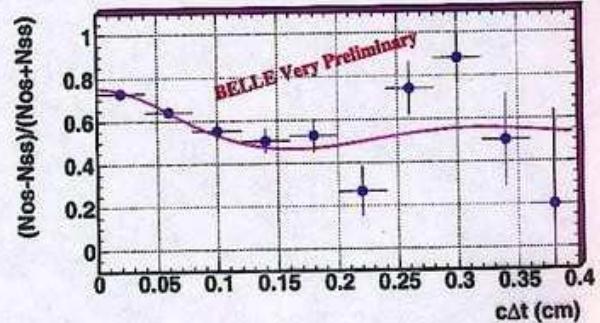
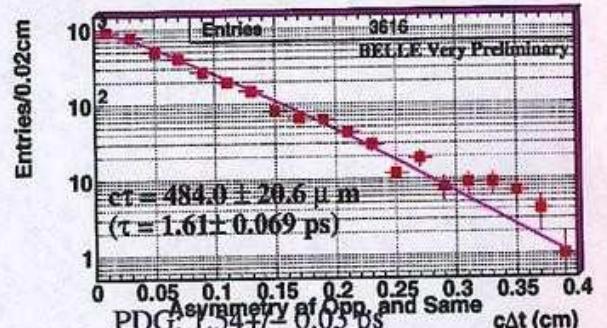
$$P_{ss}(t) = \frac{1}{2\tau} e^{-\frac{1}{\tau}} (1 - \cos(\Delta mt))$$

$$A(t) = \frac{N_{os}(t) - N_{ss}(t)}{N_{os}(t) + N_{ss}(t)} \propto \cos(\Delta mt)$$

Fixed parameters in lifetime fit:

$$\beta\gamma = 0.425$$

$$x_d = 0.723$$



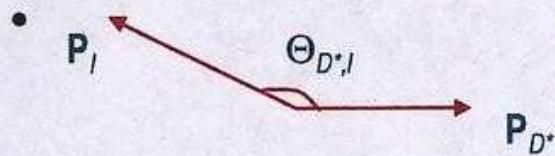
Stephen Schreier: Seminar February 2000

$B^0 \rightarrow D^{*-} e^+ \nu_e$ Analysis

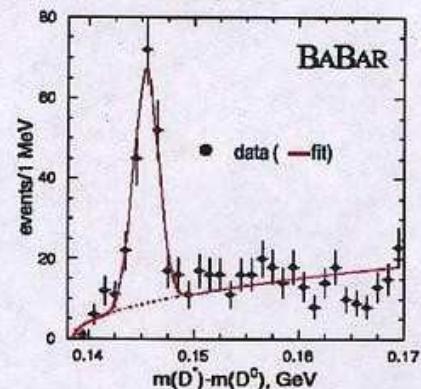
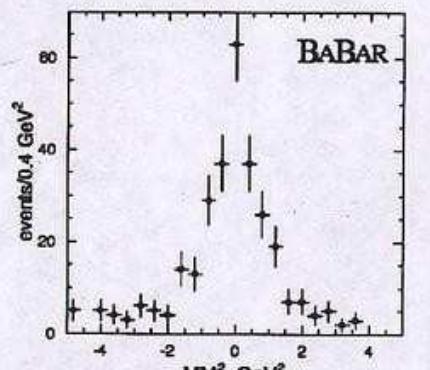
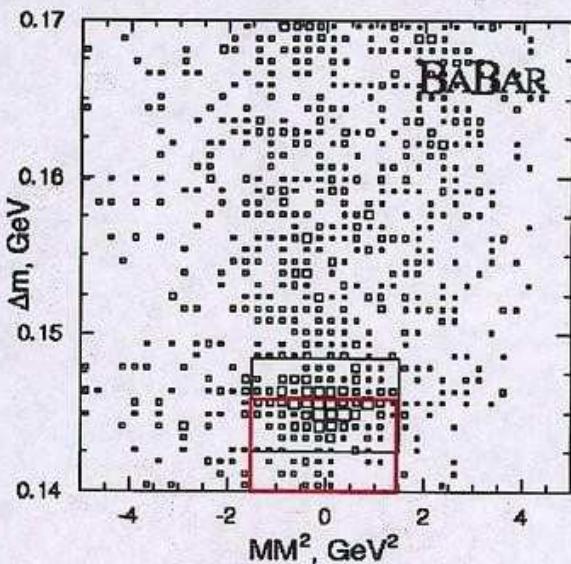
- Basic ideas:
 - Select electrons with $p_{CM} > 1 \text{ GeV}/c$
 - Use decay chain $D^{*-} \rightarrow \bar{D}^0 \pi^-$, $\bar{D}^0 \rightarrow K^+ \pi^-$
 - Require kinematic consistency with missing neutrino and known $P_B^{CM} \sim 330 \text{ MeV}/c$
- Missing mass² in this analysis is defined as:

$$m_{miss}^2 \equiv (P_B - P_{D^*,l})^2 \approx M_B^2 + M_{D^*l}^2 - 2E_B E_{D^*l}$$

► $P_B^{CM} \sim 330 \text{ MeV}/c$ is ignored.

-  $\Theta_{D^*,l}$ ⇒ D^* and lepton tend to be in opposite hemispheres in the B rest frame for signal; we require $\cos\Theta(D^*, l) < 0$.

$B^0 \rightarrow D^{*-} e^+ \nu_e$ Signal

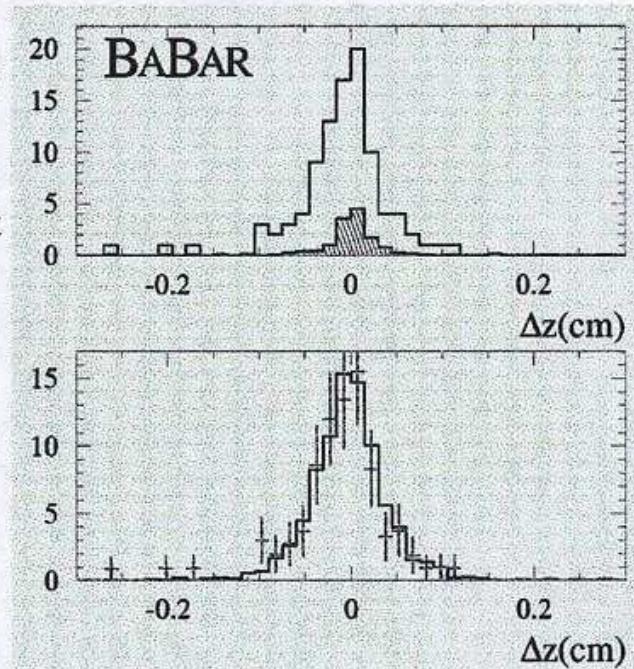


~120 events in 390 pb^{-1} (mostly $D^* e \bar{\nu}$, with small contribution from $D^{**} e \bar{\nu}$) with statistical significance $\sim 6 \sigma$

Reconstruction of Δz

- Vertexing Tools to reconstruct the decay vertices have been developed
- CP Vertex - easiest
- B-tag vertex - more difficult because the tagging B is not fully reconstructed

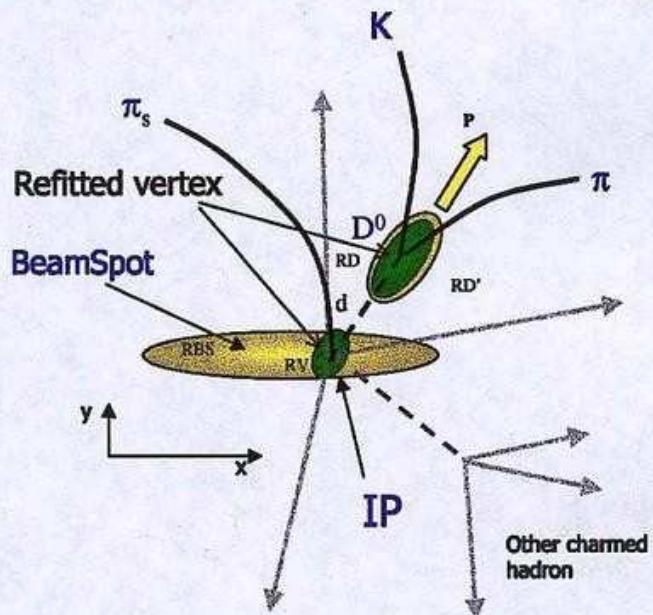
- 96+12 events
- $B^+ \rightarrow J/\Psi K^+$ and
- $B^0 \rightarrow J/\Psi K^{*0} (K^+\pi^-)$
- Luminosity $\sim 1 \text{ fb}^{-1}$
- Background subtracted
- data agree with MC



D⁰ lifetime analysis

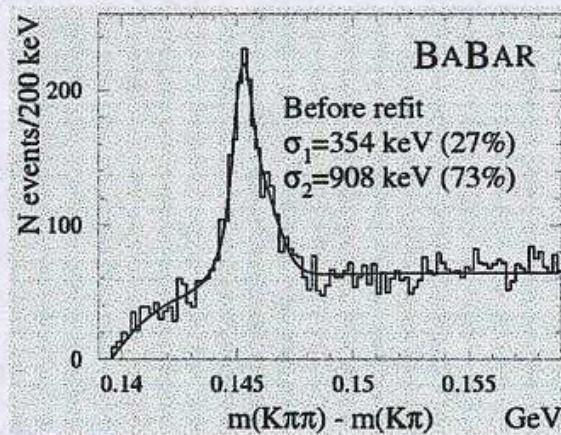
$$e^+e^- \rightarrow D^{*+}c\bar{X} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+$$

- Measurement of Beam Spot
- Reconstruction of D⁰ decay vertex
- The D⁰ decay position, IP and the flight length are obtained from a minimum χ^2 fit to the 3 parameters
- Refit the slow pion to improve the M_{D*} - M_{D0} resolution

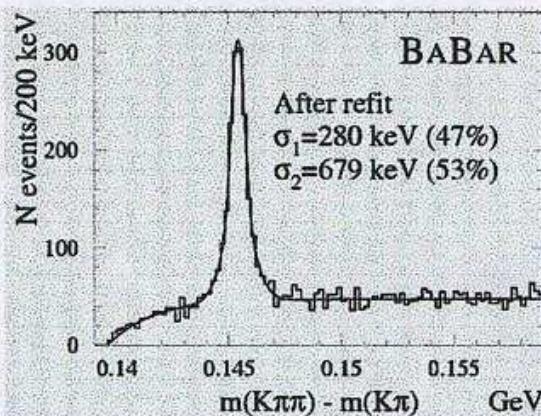


Soft pion refit

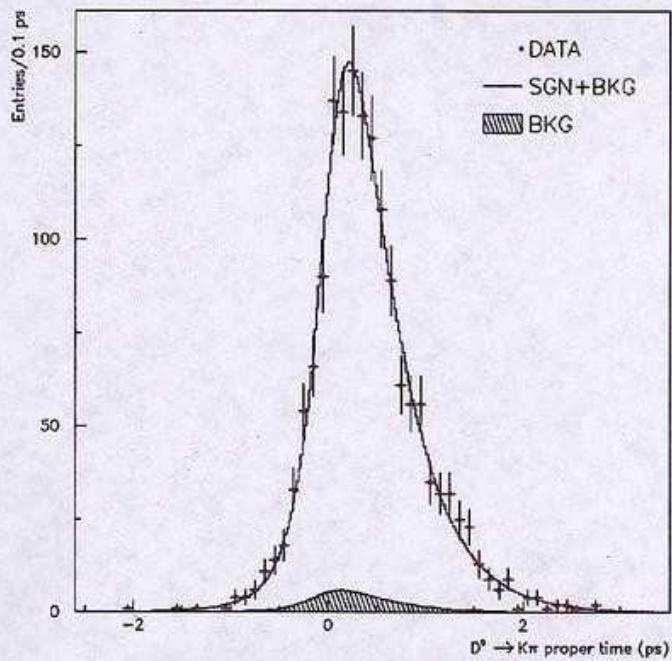
- Very low momentum => Multiple Scattering in the Beam Pipe
- The track is refitted to a point insided the Beam Spot
- Angular resolution is improved =>better invariant mass resolution



$$\sigma(\Delta m) = 280 \text{ Kev}$$
$$\sigma(m D^0) = 8 \text{ Mev}$$



D⁰ lifetime observation



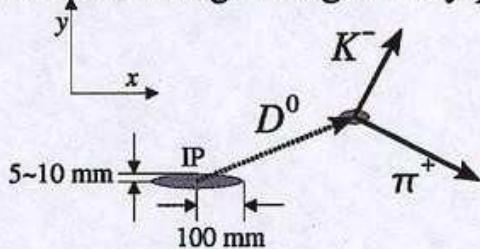
Benchmark for Vertexing capability

Decay Resolution 120 μ m
(core 85 μ m) on the average decay length

Statistical error 0.013 ps
First look at systematic errors:
Beam Spot 0.005 ps
Background 0.005 ps
Luminosity $\sim 800 \text{ pb}^{-1}$

D Lifetimes: Fit

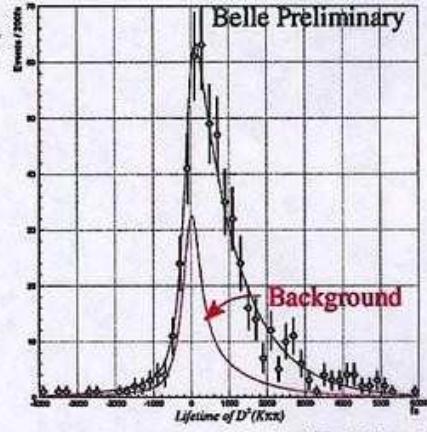
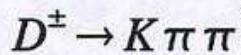
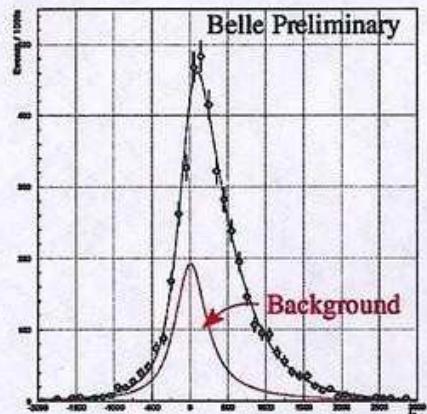
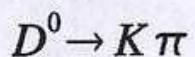
Lifetime from *D* flight length in xy plane.



D momentum required to be
 $> 2.5 \text{ GeV}/c$ in the center of
 mass to avoid *D*'s from *B*'s.

$$\tau(D^0) = 405.2^{+10.2}_{-10.1} \text{ fs (stat.)} \\ (= 415 \pm 4 \text{ fs PDG98})$$

$$\tau(D^+) = 0.97 \pm 0.08 \text{ ps (stat.)} \\ (= 1.057 \pm 0.015 \text{ ps PDG98})$$



Detector related factors in $\sin(2\beta)$ meas.

The estimated error on $\sin(2\beta)$ with **10 fb⁻¹** is **0.2-0.3** depending from the value of $\sin(2\beta)$.

Tagging is the main contribution

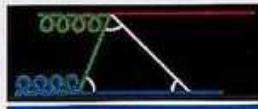
$$d_{\text{tag}} = \sqrt{\frac{1}{(1-2w)}} \sim 0.48-0.54 \quad \varepsilon = \text{tag. eff.} \quad w = \text{mistag fraction}$$

- will be determined from data studying the time dependent mixing to minimize systematic effect

$$d_{\text{vtx}} \sim \exp(-(\sigma_z/\Delta z)/2) \sim 0.85$$

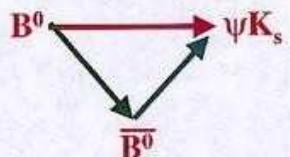
- $\sigma_z \sim 140 \mu\text{m}$; from a 2 gaussian vertex resolution:
narrow 100 μm (80%), wide 320 μm
- $\Delta z \sim 250 \mu\text{m}$ average B vertices separation

$$d_{\text{bg}} = \sqrt{\frac{N_s}{N_s + N_b}} \sim 0.93$$



Measurement of $\sin 2\beta$

$$A_{CP}(t) = \frac{N_{\overline{B}^0 \rightarrow J/\psi K_S^0}(t) - N_{B^0 \rightarrow J/\psi K_S^0}(t)}{N_{\overline{B}^0 \rightarrow J/\psi K_S^0}(t) + N_{B^0 \rightarrow J/\psi K_S^0}(t)} = \sin 2\beta \sin(\Delta m_d t)$$



- Requires:
 - Reconstruction of the signal $B^0/\overline{B}^0 \rightarrow J/\psi K_S^0$
 - Measurement of the proper time t
 - Flavor tagging to determine if we had a B^0 or a \overline{B}^0 at the time of production
- The effectiveness of flavor tagging algorithms is quantified by:

$$\epsilon = \frac{N_{tag}}{N_{total}} \quad D = \frac{N_R - N_W}{N_R + N_W}$$

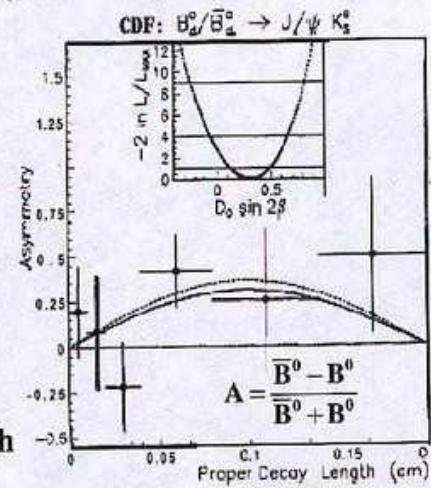
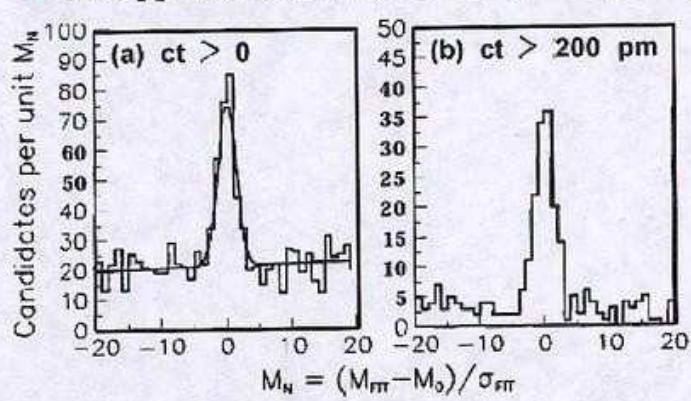
- Measured A_{CP} is reduced by D , while ϵD^2 effects δA and $\delta(\sin 2\beta)$

$$A_{CP}^{Measured}(t) = D \sin 2\beta \sin(\Delta m_d t) \quad \delta \sin(2\beta) = \sqrt{\frac{1}{\epsilon D^2 N}} \sqrt{\frac{N + B}{B}}$$

Measurement of $\sin 2\beta$



- CDF $p\bar{p} \rightarrow b\bar{b}$ Abe et al. PRL. 81, 5513 (1998) (June 1998)



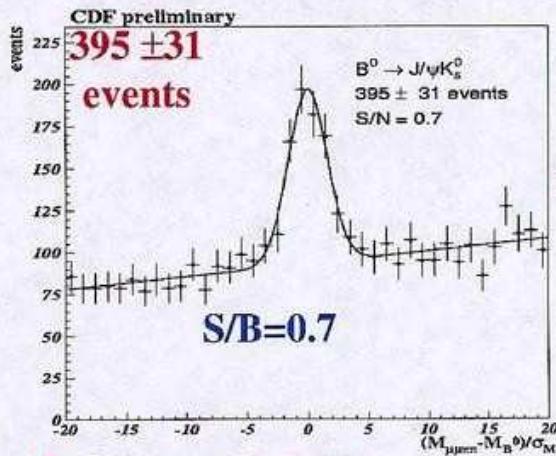
- 198 ± 17 $B^0/\bar{B}^0 \rightarrow J/\psi K_S^0$ candidates with both muons in the SVX (S/B ≈ 1.2). Measure asymmetry with Same side tagging
- $D\sin 2\beta = 0.31 \pm 1.1 \pm 0.3$.
- Using $D = 0.166 \pm 0.018$ (data) ± 0.013 (MC) from mixing measurement + MC

$$\sin 2\beta = 1.8 \pm 1.1 \pm 0.3$$



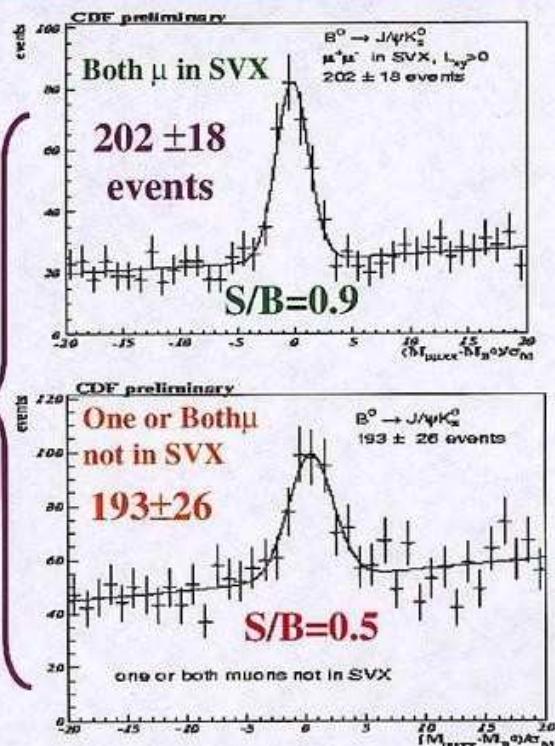
J/ ψ K $_S^0$ Signal sample

- CDF run1, $L=110 \text{ pb}^{-1}$
 - 202 events with both muons in SVX $\Rightarrow \sigma(\text{ct}) \approx 60 \mu\text{m}$.
 - 193 with one or both muons NOT in SVX $\Rightarrow \sigma(\text{ct}) \approx 300\text{-}900 \mu\text{m}$



- Plot normalized mass

$$M_{\mu\mu\pi\pi} - M_B / \text{error on } M$$





Improved measurement

- Accepted for publication in PRD, T. Affolder et. Al., FERMILAB-Pub-99/225-E, hep-ex/9909003
- Improve statistical significance
 - Add candidate events not fully reconstructed in the SVX
 - Double the signal to 400 events but additional signal has larger $\sigma(ct)$
 - Use two additional flavor tag methods to establish b flavor at production (Increase εD^2)
 - soft lepton and jet charge (both opposite side tagging methods used for the mixing analysis)
 - calibrated using $B^- \rightarrow J/\psi K^-$
- Use a maximum likelihood method to combine the tags. Include terms in the likelihood for
 - Account for detector biases
 - Prompt background
 - Long lived background



Flavor tagging methods

- We must determine if we had a B^0 or a \bar{B}^0 at the time of production.
- Opposite-side flavor tagging (OST) $\Rightarrow b\bar{b}$ produced by QCD \Rightarrow Identify the flavor of the other b in the event to infer the flavor of the $B^0/\bar{B}^0 \rightarrow J/\psi K^0_S$. At CDF $\approx 60\%$ loss in efficiency due the acceptance of the other B^0 .

- Lepton tagging :

- $\bar{b} \rightarrow \ell^+ X \Rightarrow b$
- $b \rightarrow \ell^- X \Rightarrow \bar{b}$

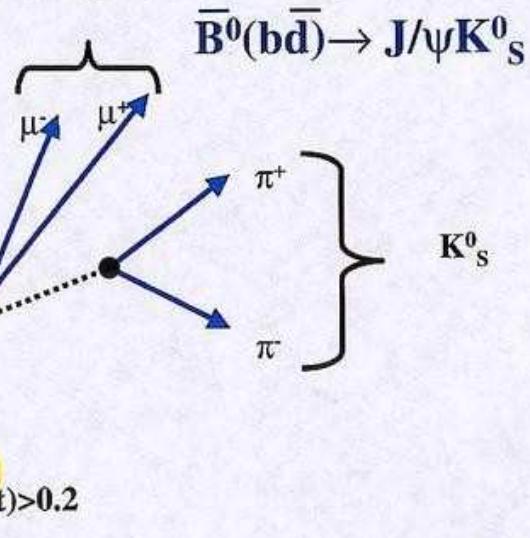
- Jet charge tag :

- $Q(\bar{b}\text{-jet}) > 0.2 \Rightarrow b$
- $Q(b\text{-jet}) < -0.2 \Rightarrow \bar{b}$

Opposite side

\bar{b}

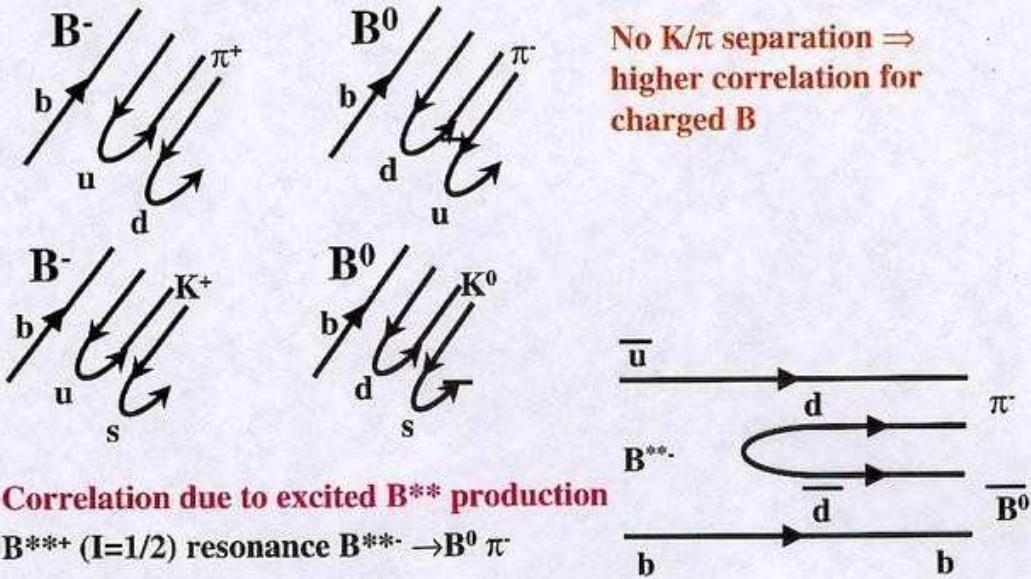
$Q(\bar{b}\text{-jet}) > 0.2$





Same side tagging

- Same side flavor tagging (SST). Exploits the correlation between the charge of nearby π and the b quark charge due to fragmentation or B^{**} production (Gronau,Nippe,Rosner)





Flavor Tagging Summary

- Soft lepton e: $p_T(e) > 1 \text{ GeV}/c$; $\mu : pT(\mu) > 2 \text{ GeV}/c$
 $\epsilon = (5.6 \pm 1.8)\%$ $D = (62.5 \pm 14.6)\%$ $\epsilon D^2 = (2.2 \pm 1.0)\%$
- Jet charge
If there is a soft lepton do not use jet charge
 $\epsilon = (40.2 \pm 3.9)\%$ $D = (23.5 \pm 6.9)\%$ $\epsilon D^2 = (2.2 \pm 1.3)\%$
- Same side pion tagging
 $\epsilon = (35.5 \pm 3.7)\%$ $D = (16.6 \pm 2.2)\%$ in SVX $\epsilon D^2 = (2.1 \pm 0.5)\%$
 $\epsilon = (38.1 \pm 3.9)\%$ $D = (17.4 \pm 3.6)\%$ not in SVX
- Combined flavor tagging power including correlations and multiple tags
$$\boxed{\epsilon D^2 = (6.3 \pm 1.7)\%}$$
- A sample of 400 events has the statistical power of 25 perfectly tagged events
- About 80% of the events have a tag



Measurement of $\sin 2\beta$

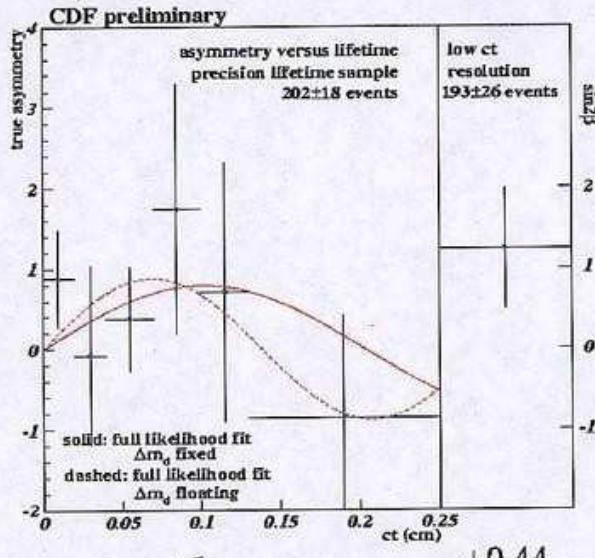
- The minimization of the likelihood function yields:

$$\sin 2\beta = 0.79 \pm 0.39 (\text{stat}) \pm 0.16 (\text{syst})$$

Statistical error > systematics.

$$\sin 2\beta = 0.79^{+0.41}_{-0.44} \quad (\text{stat.+sys.})$$

- Time integrated measurement
 $\sin 2\beta = 0.71 \pm 0.63$ (stat+syst)
- Using Feldman and Cousins frequentist approach
 $0 < \sin 2\beta < 1$ @ 93% C.L.
- New world average (Taipei)
 includes this measurement and a new Aleph results
 $\sin 2\beta = 0.82 \pm 0.38$

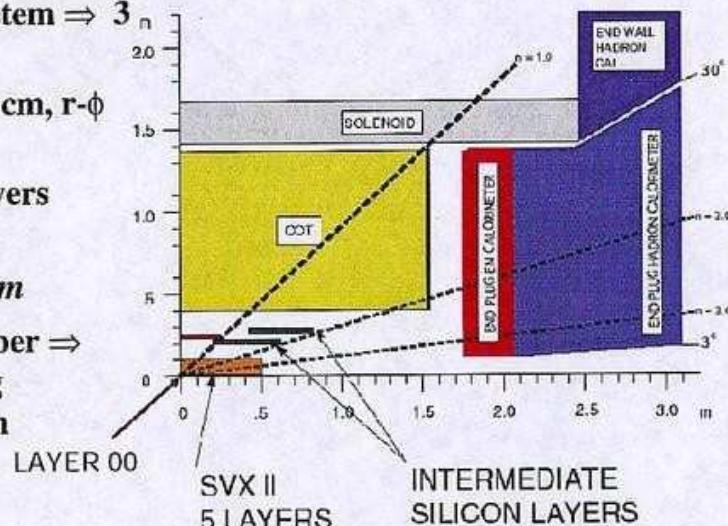


$$\left. \begin{array}{l} \text{Float} \\ \Delta m_d \end{array} \right\} \begin{array}{c} \sin 2\beta = 0.88^{+0.44}_{-0.41} \\ \Delta m_d = 0.68 \pm 0.17 \text{ ps}^{-1} \end{array}$$

Run II upgrade



- New silicon tracking system \Rightarrow 3 D information
 - SVX II: 5 layers, 96 cm, r- ϕ and r-z readout
 - ISL: 2 additional layers
 - L00 at $r=1.4$ cm
 - $\sigma_{d_0} = 5.5 + 17 / p_T \mu m$
- New central drift chamber \Rightarrow maintain run 1 tracking efficiency and resolution
- New trigger:
 - L1 tracking trigger
 - L2 trigger on displaced tracks \Rightarrow trigger on hadronic B decays



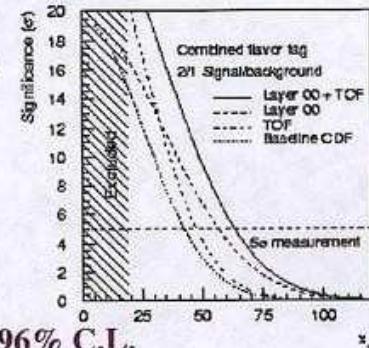
- Time off flight $\Rightarrow 2\sigma K/\pi$ separation for $p < 1.6$ GeV/c
- $> 2 \text{ fb}^{-1}$ of data



Run II expectations

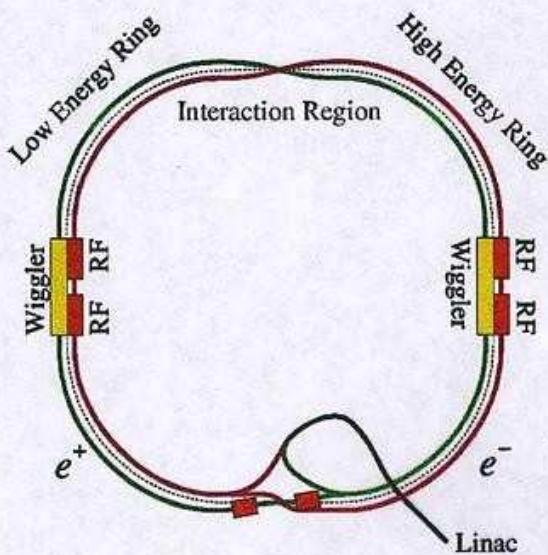
- $\sin 2 \beta$ from $B^0/\bar{B}^0 \rightarrow J/\psi K^0_S$
 - for 10K events, $\varepsilon D^2 = 6.7\% (+2.4\% \text{ TOF}) \Rightarrow \delta(\sin 2 \beta) \approx 0.084$
- $B \rightarrow \pi\pi$ expect 8400-15200 events if $\text{BR} = 1 \times 10^{-5}$
 - for 5K events, $\varepsilon D^2 = 9.1\% \Rightarrow \delta A(\pi\pi) \approx 0.1 - 0.15$
- Modes to study γ
 - $B_s^0 / \bar{B}_s^0 \rightarrow D_s^\pm K^\mp \quad 700 \text{ events}$
- Expect 6000 $B_s \rightarrow J/\psi \phi$ where asymmetry would be sign of new Physics
- B_s oscillations
 - Expected signal 20,000 $B_s \rightarrow D_s^- \pi^+, D_s^- \pi^+ \pi^- \pi^+$ with $D_s^- \rightarrow \phi\pi, K^* K$
 - Proper time resolution with L00
 $\sigma_t = 0.045 \text{ ps} \oplus t \cdot \sigma_{p_T} / p_T$
 - Flavor tagging effectiveness
 - $\varepsilon D^2 = 11.3\%$ with TOF (5.7% with old baseline)

Sensitive to $x_s < 63$ if S/N=2/1 $20 < x_s < 30.8$ @ 96% C.L.
Sensitive to $x_s < 56$ if S/N=1/2



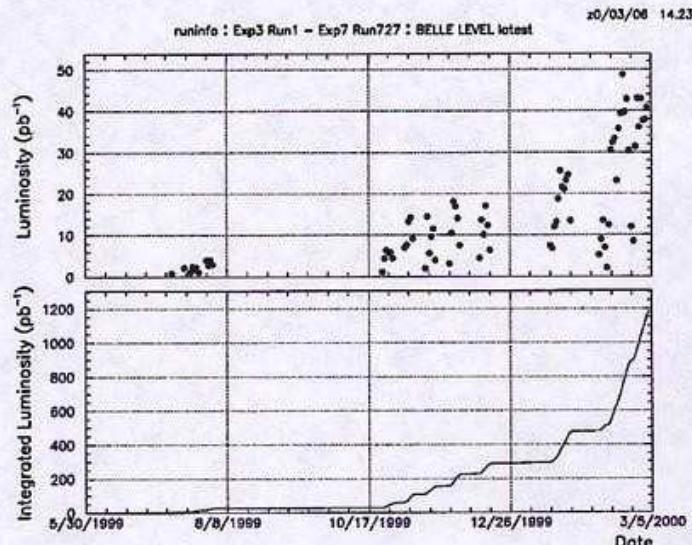
KEK– B Accelerator

Integrated Luminosity:	$100 fb^{-1}$ per year
Peak Luminosity:	$10^{34} cm^{-2} s^{-1}$
Circumference:	3016 m
Number of Bunches:	5000
Current: of Positrons:	2.6 A
Current of Electrons	1.1 A
Energy of Positrons:	3.5 GeV
Energy of Electrons:	8.0 GeV
$\beta\gamma$ for B Meson:	0.425
Crossing Angle:	2×11 mrad

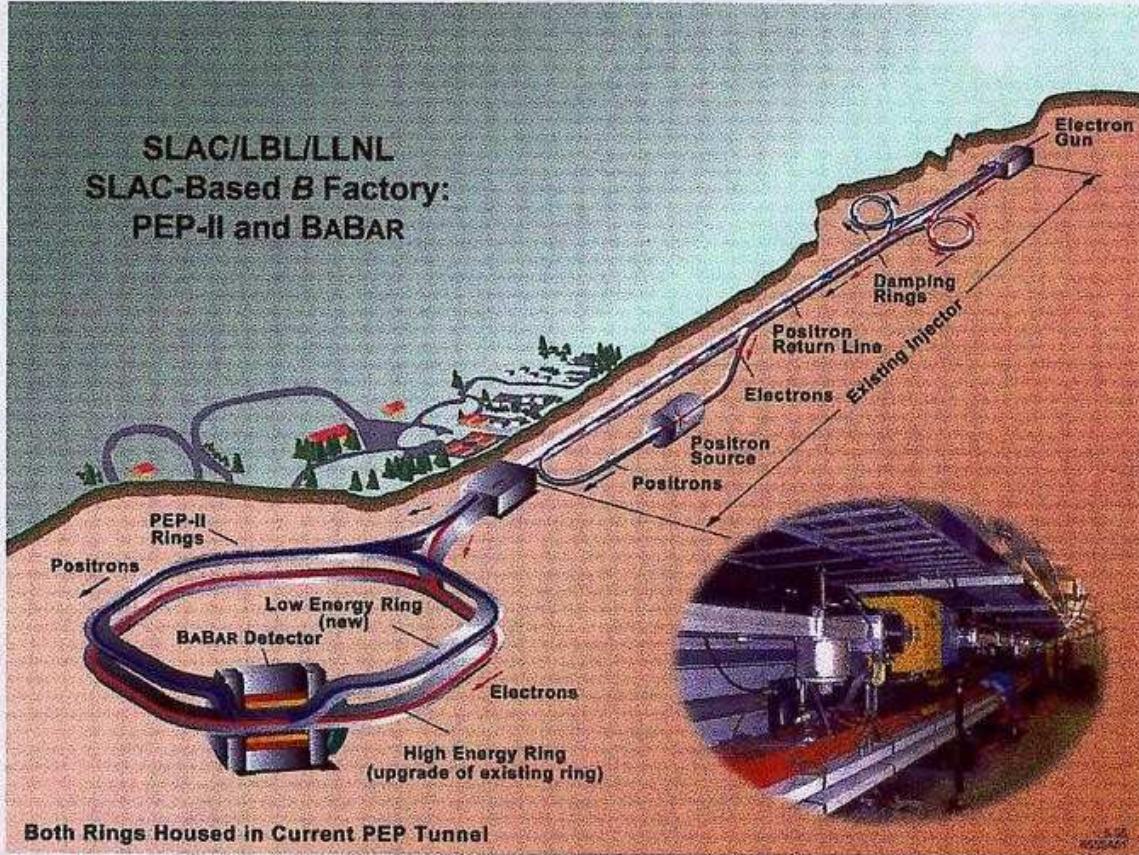


Peak and Integrated Luminosity

- Peak luminosity:
 - ~~$1.09 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$~~
 1.19
- Peak daily luminosity:
 - 48.5 pb^{-1}
- Integrated luminosity:
 - ~~1.2 fb^{-1}~~
 1.4
- Plan:
 - Accumulate $4\text{--}8 \text{ fb}^{-1}$ by summer.



Most results used first 440 pb^{-1} .

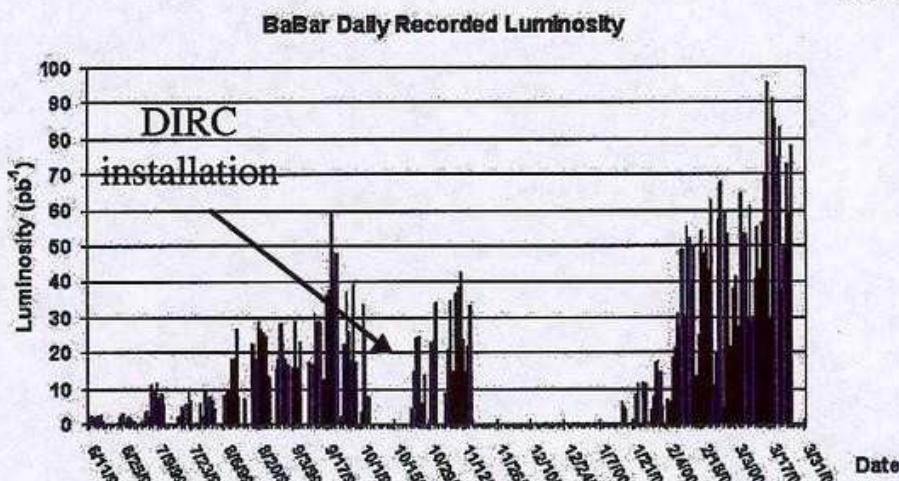


XXXV Rencontres de Moriond, March 2000

Massimo Carpinelli University of Pisa & I.N.F.N

BaBar/Pep-II running

Luminosity record
 $1.8 \cdot 10^{33}$



Monday, March 27, 2000

I. Adam & L. Lanceri

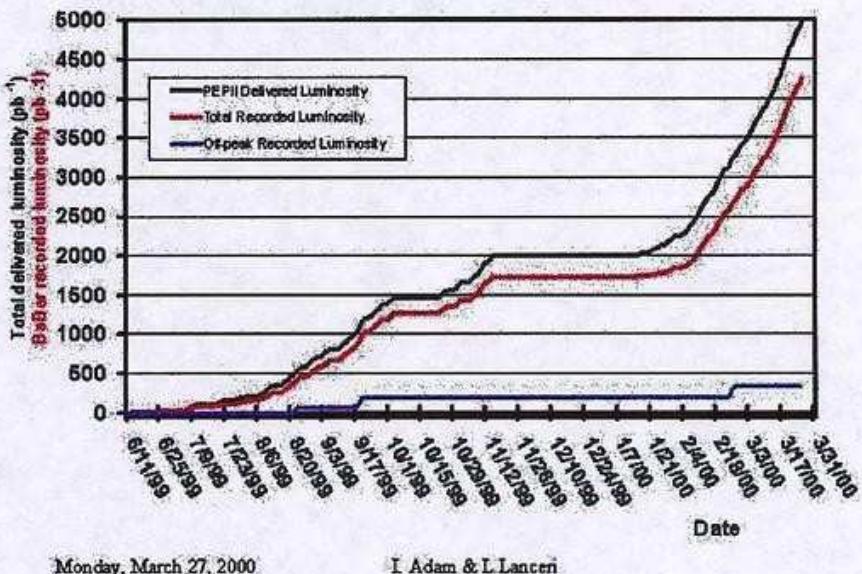
Gruppo 1 Roma March 29 2000

Massimo Carpinelli University of Pisa & I.N.F.N

Recorded Event

- ~ 5.0 fb⁻¹ delivered
- ~ 4.5 fb⁻¹ recorded

BaBar Recorded luminosity - 1999 + 2000



Monday, March 27, 2000

I. Adam & L. Lanceri

Gruppo 1 Roma March 29 2000

Massimo Carpinelli University of Pisa & I.N.F.N

PEP-II Luminosity Performance: Best Achieved

<u>Parameter</u>	<u>Units</u>	<u>Design</u>	<u>Achieved</u>
Luminosity	$\text{cm}^{-2} \text{ sec}^{-1}$	3×10^{33}	1.56×10^{33}
Specific Luminosity	$\text{cm}^{-2} \text{ sec}^{-1} \text{ mA}^{-2} / \text{bunch}$	3.1×10^{30}	2.7×10^{30}
Horizontal Spot Size	μm	220	200
Vertical Spot Size	μm	6.6	6.3

PEP-II delivered 3.3 fb^{-1} from June 99 through Feb 2000

Updated 3/02/2000

PEP-II HER Performance Results

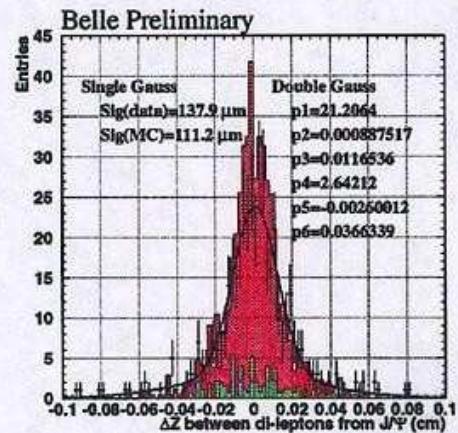
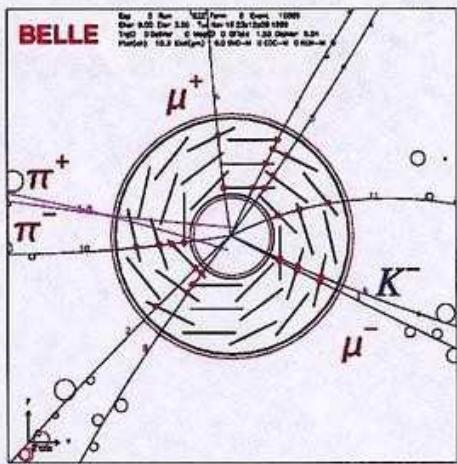
<u>Parameter</u>	<u>Units</u>	<u>Design</u>	<u>Best achieved</u>	<u>Running with BABAR, "typical"</u>
Energy	GeV	9.0	9.0, ramp to 9.1 & back	9.0, ramp 8.84-9.04
Single bunch current	mA	0.6	12	0.75
Number of bunches		1658	1658	829
Total beam current	A	0.75 (1.0)	0.92	0.65
Beam Lifetime		4 hrs @ 1A	11 hrs @ 0.9 A	9 hrs @ 0.65 A
Max. Injection Rate	mA/sec	2.1 @ 60Hz	4.0 @ 15Hz	2.5 @ 15 Hz

PEP-II LER Performance Results

<u>Parameter</u>	<u>Units</u>	<u>Design</u>	<u>Best achieved</u>	<u>Running with BABAR , "typical"</u>
Energy	GeV	3.1	3.1	3.1
Single bunch current	mA	1.3	7.0	1.2
Number of bunches		1658	1658	829
Total beam current	A	2.1	1.7	1.0
Beam Lifetime		4 hrs @ 2A	3.5 h@ 1 A	3 hrs @ 1 A
Max. Injection Rate	mA/sec	5.9 @ 60 Hz	9.0 @ 30 Hz	4.0 @ 15 Hz

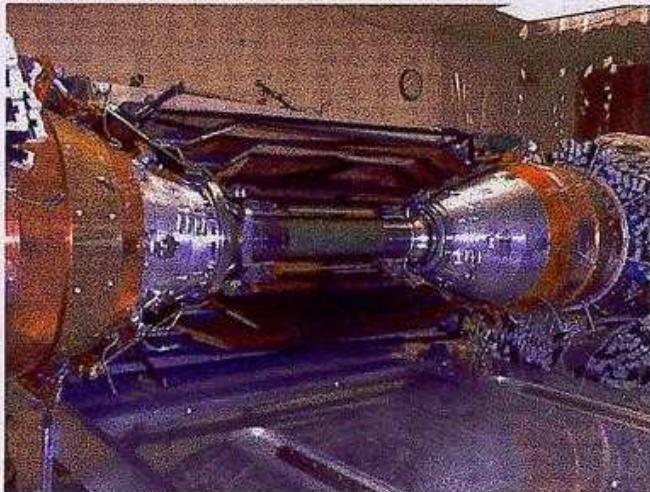
Vertexing: Silicon Vertex Detector

- 3 Layers of Double Sided Silicon.
 - Matching efficiency: Bhabhas: 97%, Hadrons: 96.7%

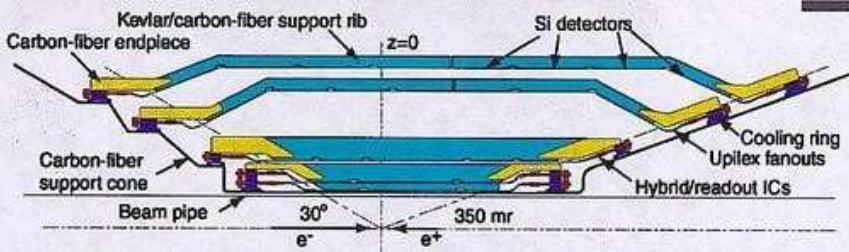


Δz resolution from $J/\psi \rightarrow l^+ l^-$: $138 \mu\text{m}$

SVT:Silicon Vertex Tracker

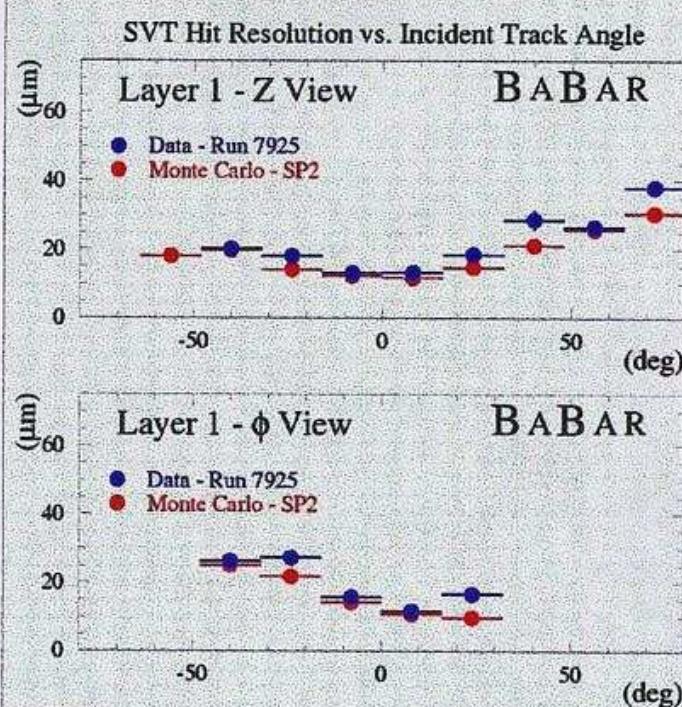
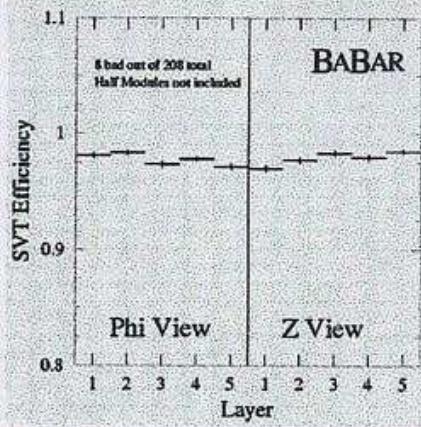


<u>Layer</u>	<u>Radius</u>
1	3.3 cm
2	4.0 cm
3	5.9 cm
4	9.1 to 12.7 cm
5	11.4 to 14.6 cm



Beam Pipe
1.0% radiation
length

SVT performances

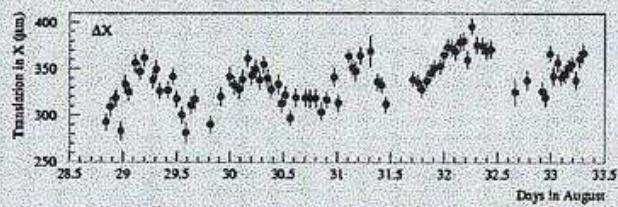


- Drift chamber svt association;
eff. of hardware + reconstruction software

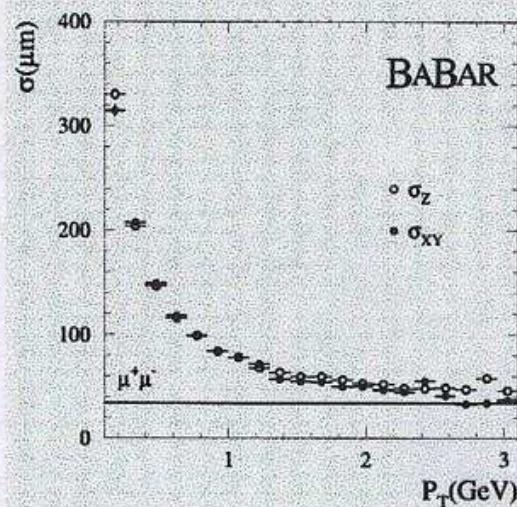
- design resolution 15 μm at 90 deg.

Tracking resolution

SVT/DCH Global Alignment (Example of diurnal effect)

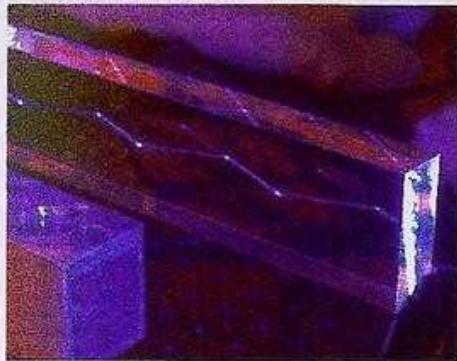


- SVT-DCH relative movement of $\sim 100 \mu\text{m}$ on a daily base
- Relative alignment done run by run in the prompt reconstruction
- Impact parameter resolution at high momentum less than $40 \mu\text{m}$.
- D^0 mass resolution 8 Mev



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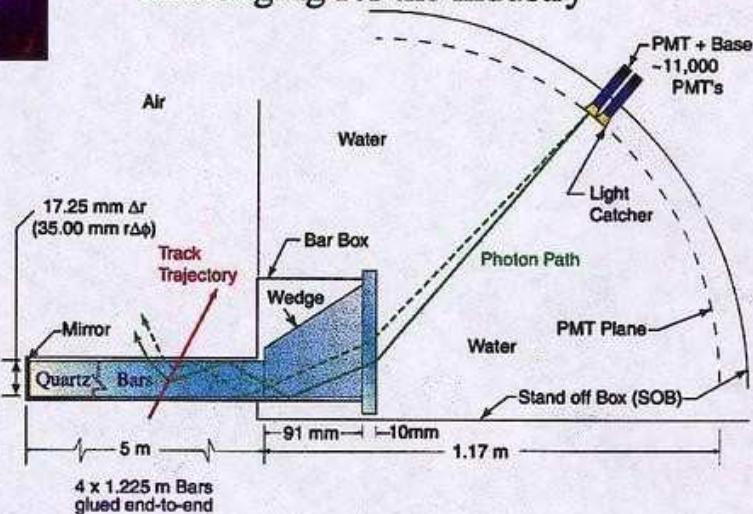
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DIRC

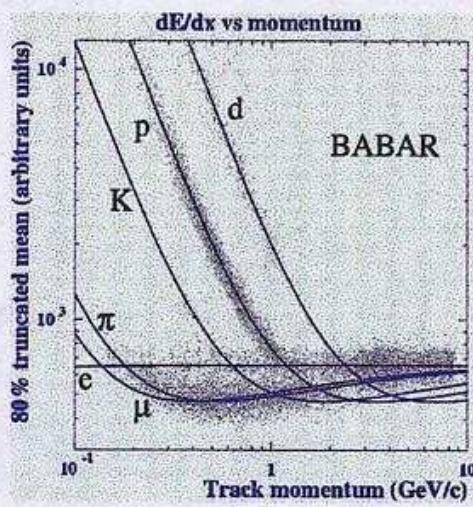
- 144 bars of synthetic fused silica
- Surface polish 0.5 nm (RMS)
- Parallel sharp edge
- Building adequate bar in such a large scale has been very challenging for the industry

- Average DIRC refraction index 1.47 (water 1.33)
- Cherenkov light trapped by total reflection

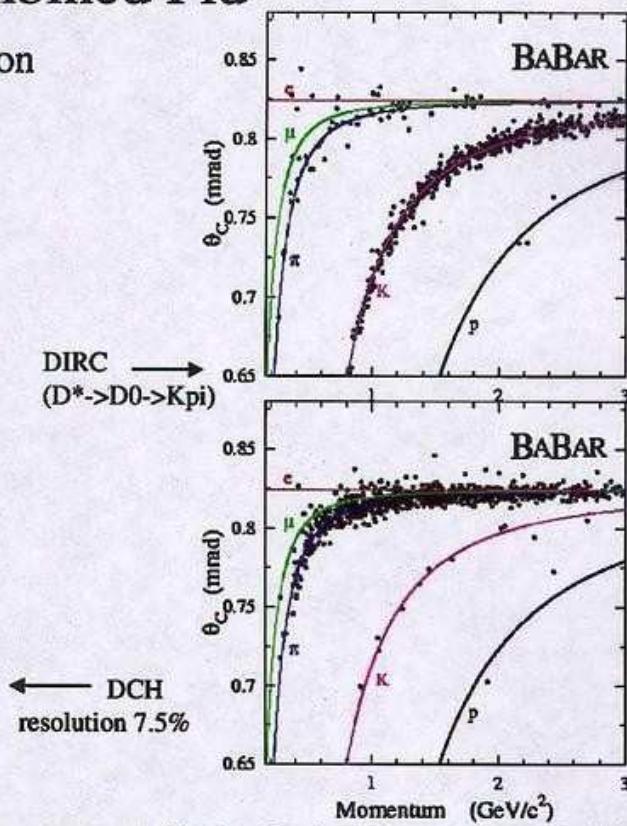


Combined Pid

>3sigma pi/K separation
DCH up to 0.5 GeV
DIRC from 0.5 GeV

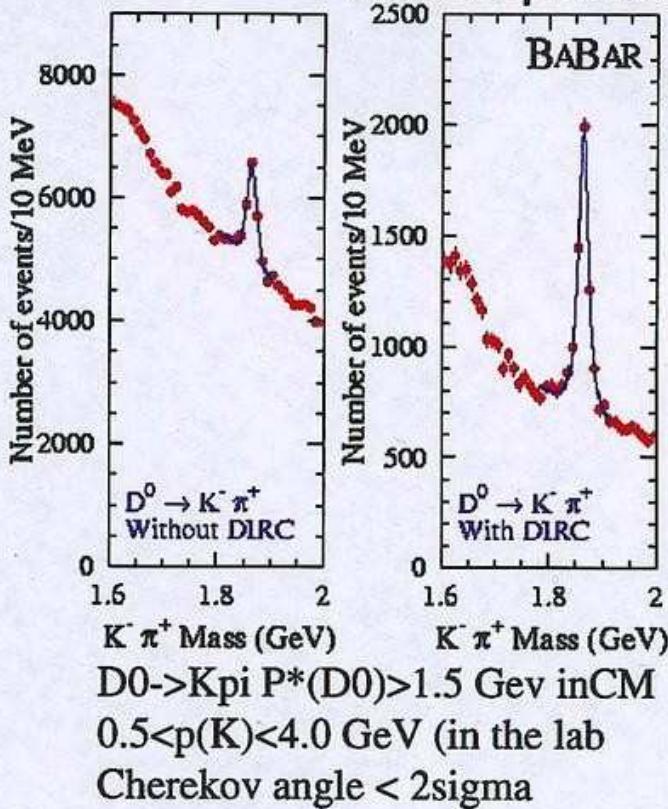


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DIRC performance



K eff 80% within acceptance
Bg reduction by > 6 times



Conclusion

- PEP-II is running extremely well
- BaBar performance at the design level
- Detailed study of the detector is going on
- A set of validation analysis is almost complete
- We expect **10 fb⁻¹** by the end of this run,
allowing a measurement of $\sin(2\beta)$ with an
error of $\sim \mathbf{0.2-0.3}$