What have we learned so far at the B Factories ?

Tom Browder (University of Hawaii)

Introduction/History

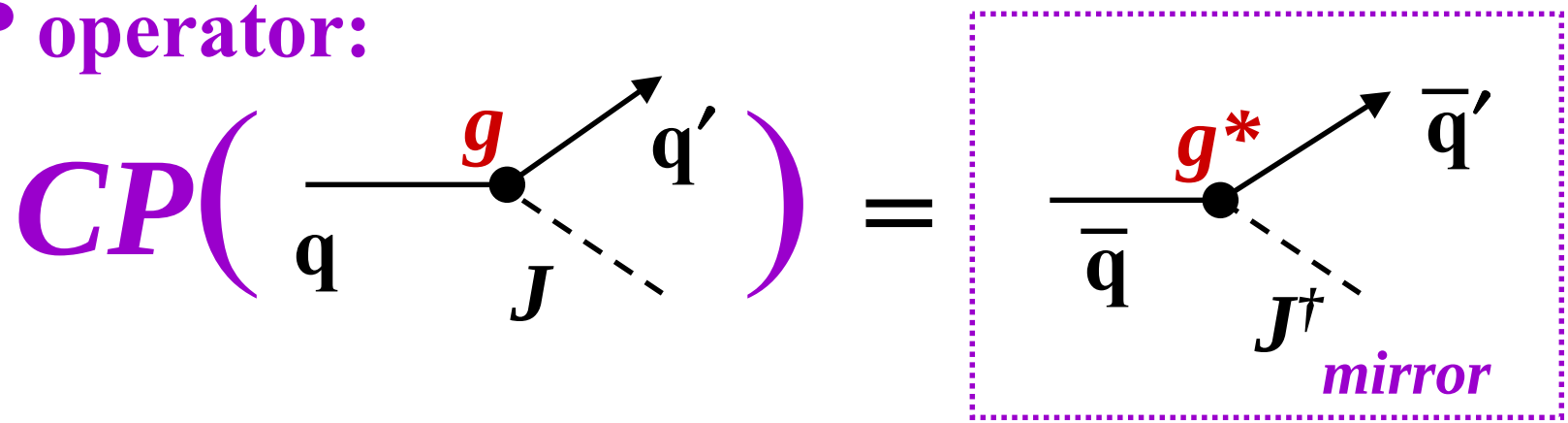
Observation of CPV outside of the kaon sector.

Controversies.

The Future.

Matter ⇔ antimatter ⇒ CP

CP operator:



if $g \neq g^*$ (*i.e.* g is complex):

CP symmetry is violated

CP violation was discovered in 1963 by Cronin, Fitch et al.

Only seen only as a ~0.2% effect in certain K_L decays (e.g. $K_L \rightarrow \pi\pi$)

(not in π or nuclear β-decays)

$\therefore$ need a complex coupling specific to strangeness-changing processes

A complex flavor-mixing matrix?

Why not incorporate CPV by making β complex?

$$\begin{pmatrix} \alpha & \beta \\ -\beta^* & \alpha \end{pmatrix}$$

not so simple:	**a 2x2 matrix has**	**8 parameters**
	unitarity:	**4 conditions**
	4 quark fields:	**3 free phases**

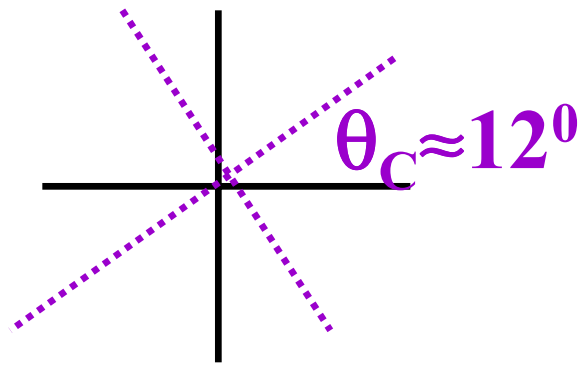
# of irreducible parameters: 1

2-generation flavor-mixing

$$\begin{pmatrix} \alpha & \beta \\ -\beta & \alpha \end{pmatrix} \rightarrow \begin{pmatrix} \cos\theta_C & \sin\theta_C \\ -\sin\theta_C & \cos\theta_C \end{pmatrix}$$

Only 1 free parameter: the Cabibbo angle

not enough degrees of freedom to incorporate a complex number



Enter Kobayashi Maskawa

Suppose there are 3 quark generations:

a 3x3 matrix has	**18 parameters**
unitarity:	**9 conditions**
6 quark fields:	**5 free phases**
# of irreducible parameters:	**4**

three are needed for 3-dim rotation (e.g. Euler angles)

one complex phase is possible!

KM (+others) circa 1973 (Kyoto)

Makoto Kobayashi

Toshihide Maskawa

Original KM paper

From: Prog. of Theor. Phys. Vol. 49 Feb. 2, 1973

Next we consider a 6-plet model, another interesting model of CP-violation. Suppose that 6-plet with charges $(Q, Q, Q, Q-1, Q-1, Q-1)$ is decomposed into $SU_{\text{weak}}(2)$ multiplets as $2+2+2$ and $1+1+1+1+1+1$ for left and right components, respectively. Just as the case of (A, C), we have a similar expression for the charged weak current with a 3×3 instead of 2×2 unitary matrix in Eq. (5). As was pointed out, in this case we cannot absorb all phases of matrix elements into the phase convention and can take, for example, the following expression:

$$\begin{pmatrix} \cos\theta_1 & -\sin\theta_2\cos\theta_3 & -\sin\theta_1\sin\theta_3 \\ \sin\theta_1\cos\theta_3 & \cos\theta_2\cos\theta_2\cos\theta_3-\sin\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\cos\theta_3\sin\theta_3+\sin\theta_2\cos\theta_3 e^{i\delta} \\ \sin\theta_1\sin\theta_3 & \cos\theta_1\sin\theta_2\cos\theta_3+\cos\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\sin\theta_2\sin\theta_3-\cos\theta_2\sin\theta_3 e^{i\delta} \end{pmatrix}.$$

3 Euler angles

CP-violating phase

KM ansatz: CPV is due to a complex phase in the quark mixing matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} Vud & Vus & Vub \\ Vcd & Vcs & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

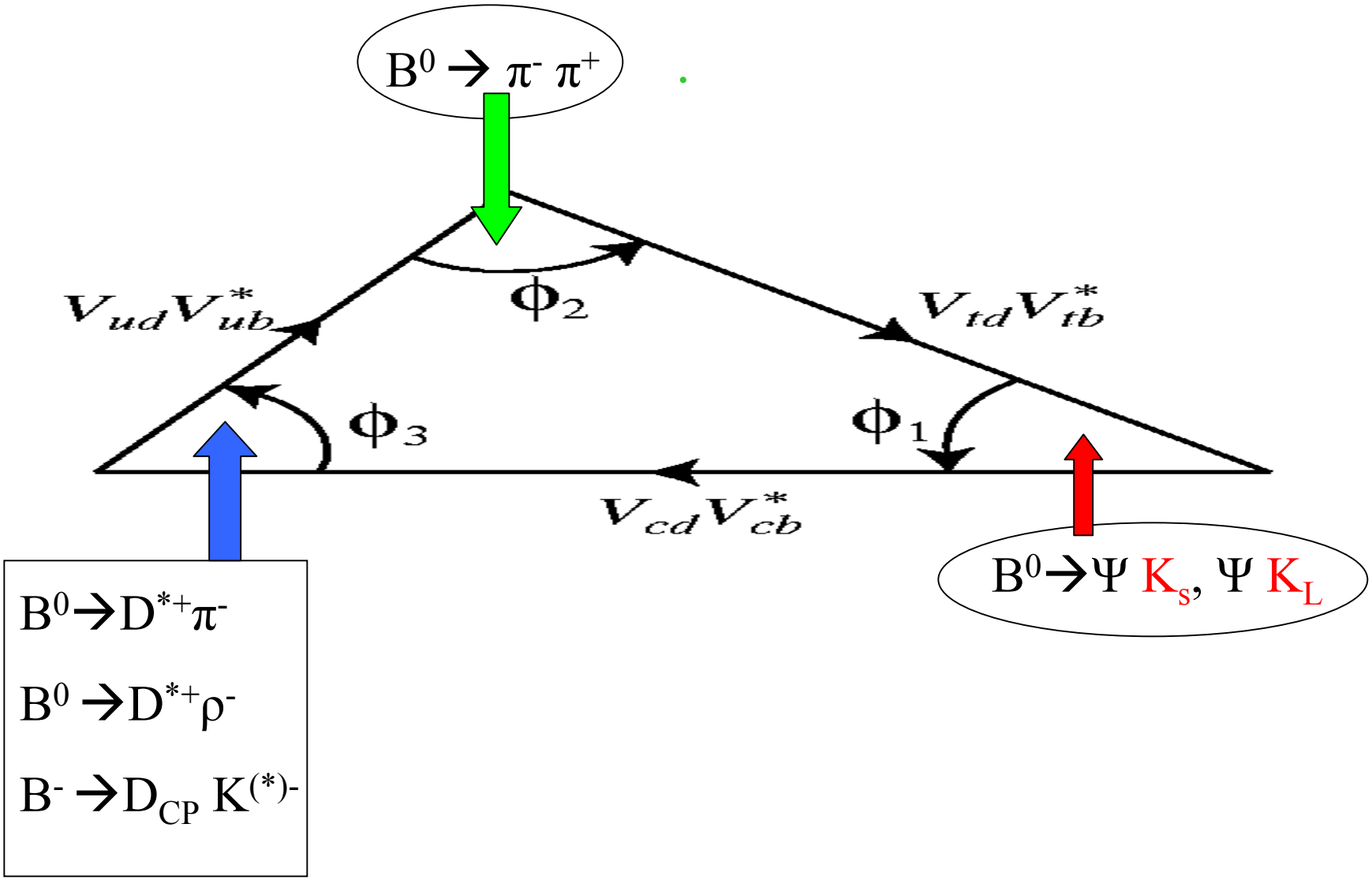
The B Physics Program

Quark couplings are complex and lead to CP violation. *Is CP violation a result of a single weak phase in the KM matrix ?*

Or is it a signal of new interactions beyond the Standard Model ?

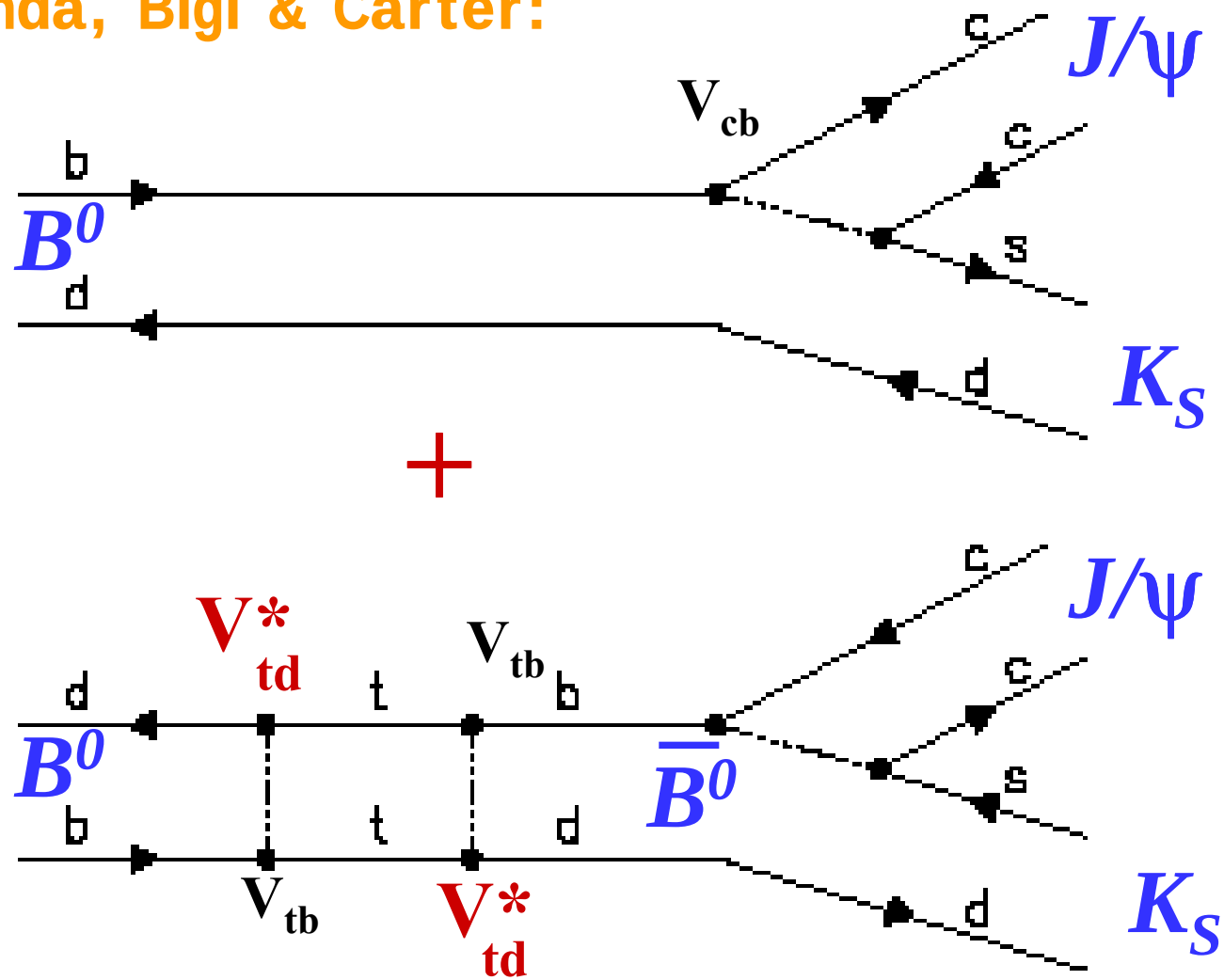
Is there new physics in loop decays ?

Three Angles: ($\varphi_1, \varphi_2, \varphi_3$) *or* ($\beta$, α, γ)



$\sin 2\phi_1$ from $B \to f_{CP}$ + $B \leftrightarrow \overline{B} \to f_{CP}$ interf.

Sanda, Bigi & Carter:



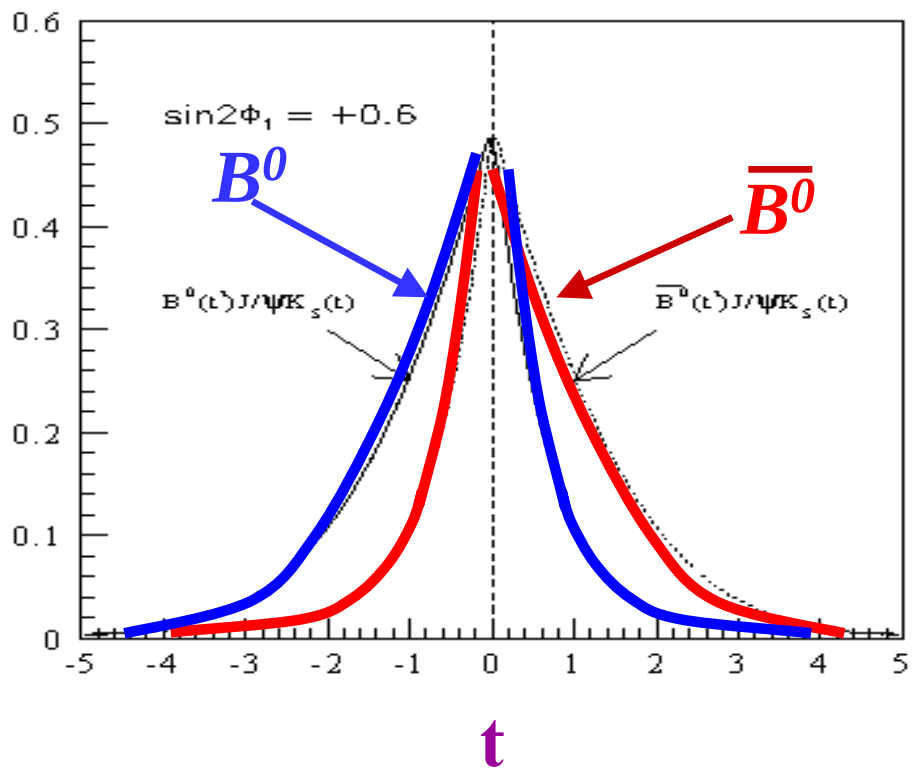
$\propto V^{*2}_{td}$

Mixing-induced CPV asymmetry

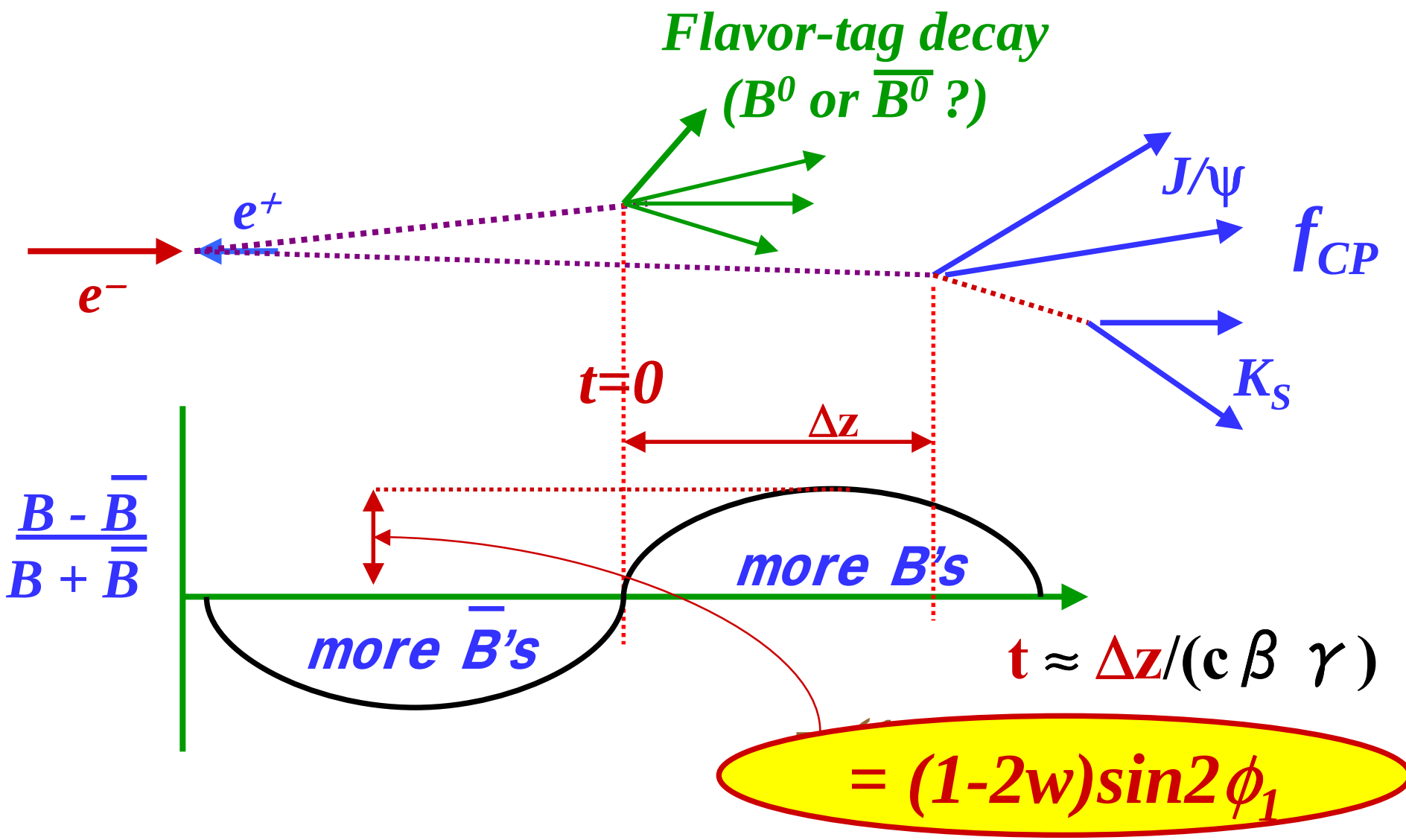
$\xi_f = \pm 1$ *for* $CP = \pm 1$

$$A(t) \equiv \frac{\Gamma(\overline{B}_d^0 \to f_{CP}) - \Gamma(B_d^0 \to f_{CP})}{\Gamma(\overline{B}_d^0 \to f_{CP}) + \Gamma(B_d^0 \to f_{CP})} = -\xi_f \sin 2\phi_1 \sin \Delta m t$$

a.k.a 2β



Principle of the Measurement



Requirements for CPV measmts.

- **Many B mesons** [Br (B$\rightarrow f_{CP}$) ~ O(10^{-3})]
  - KEKB ➔ 78 fb^{-1}, PEP-II➔ 81 fb^{-1}

- **Reconstruct+isolate CP eigenstate decays**
  - Kinematic variables for signal +(*cont. bkg suppr+PID*).

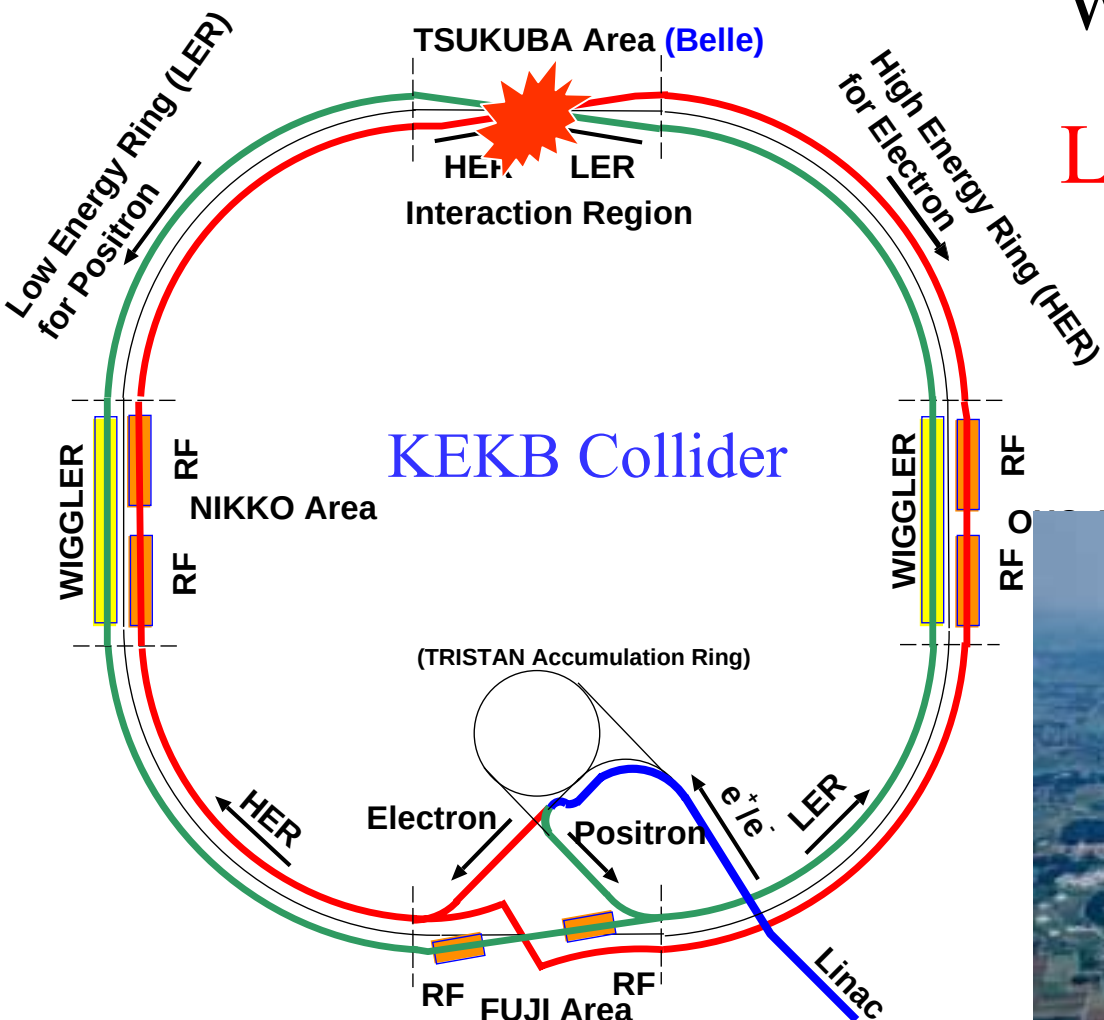
- **Tag flavor of the other B**
  - Likelihood (Belle) or hierachial NN (Babar) based flavor tagging
- **Measure decay-time difference**
  - Asymmetric beam energies, high precision vertexing(Δz)
  - Likelihood fit to the Δt distributions

The KEKB Collider (8 x 3.5 GeV, X angle)

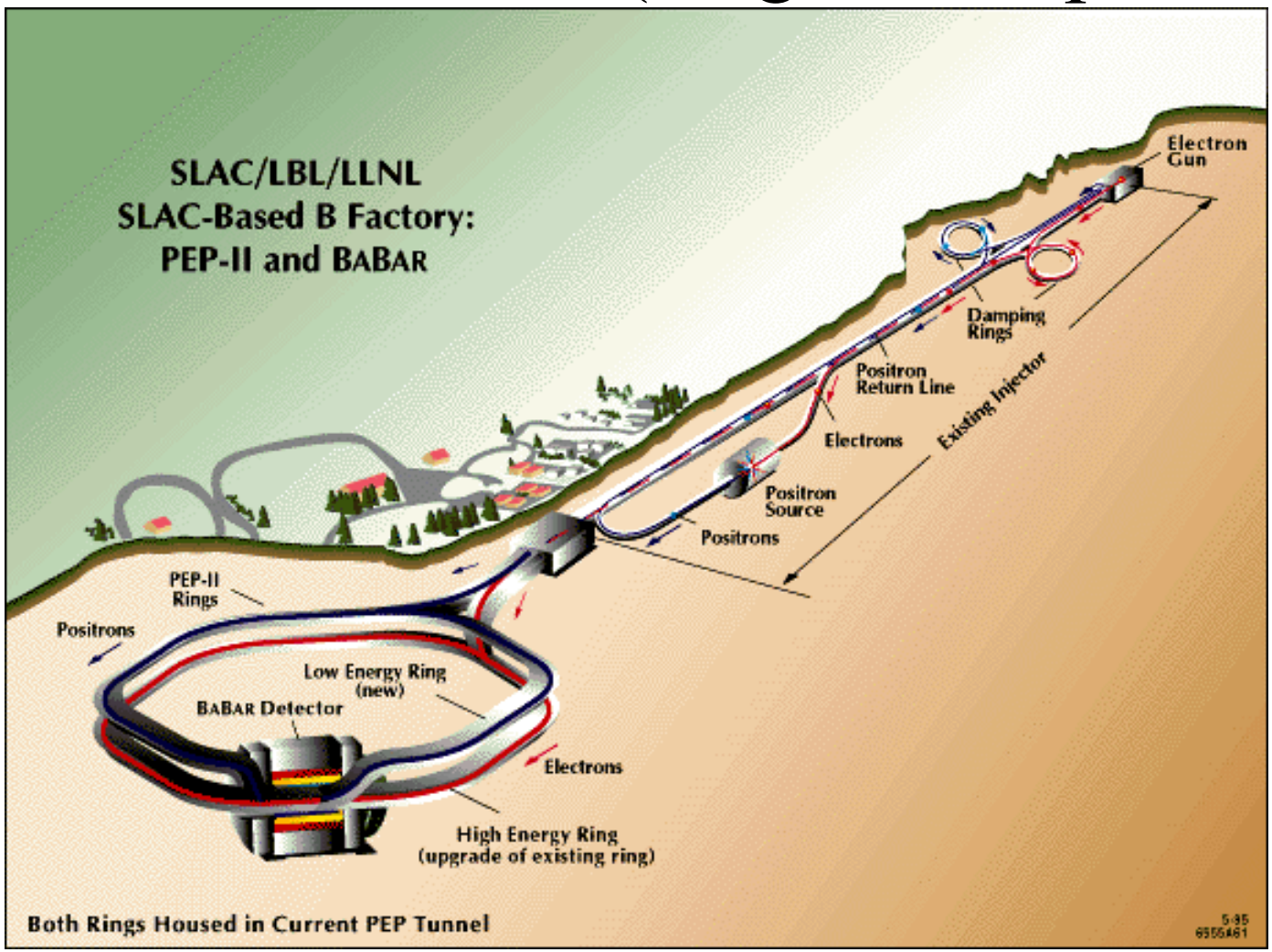
World record:

$L=(8.3x\ 10^{33})/cm^2/sec$

$Int(L\ dt)= 101\ fb^{-1}$

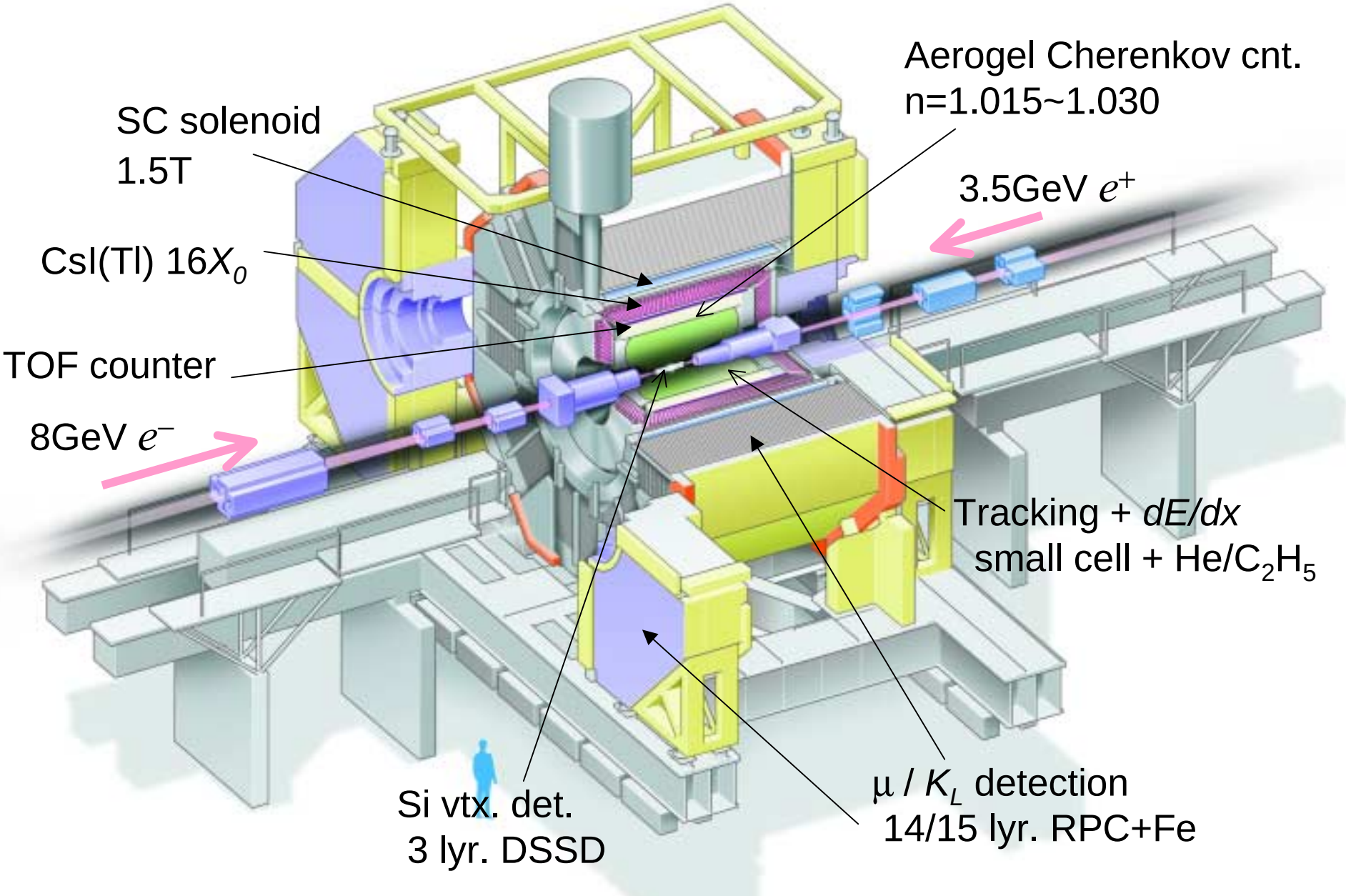


The PEPII Collider (magnetic separation)

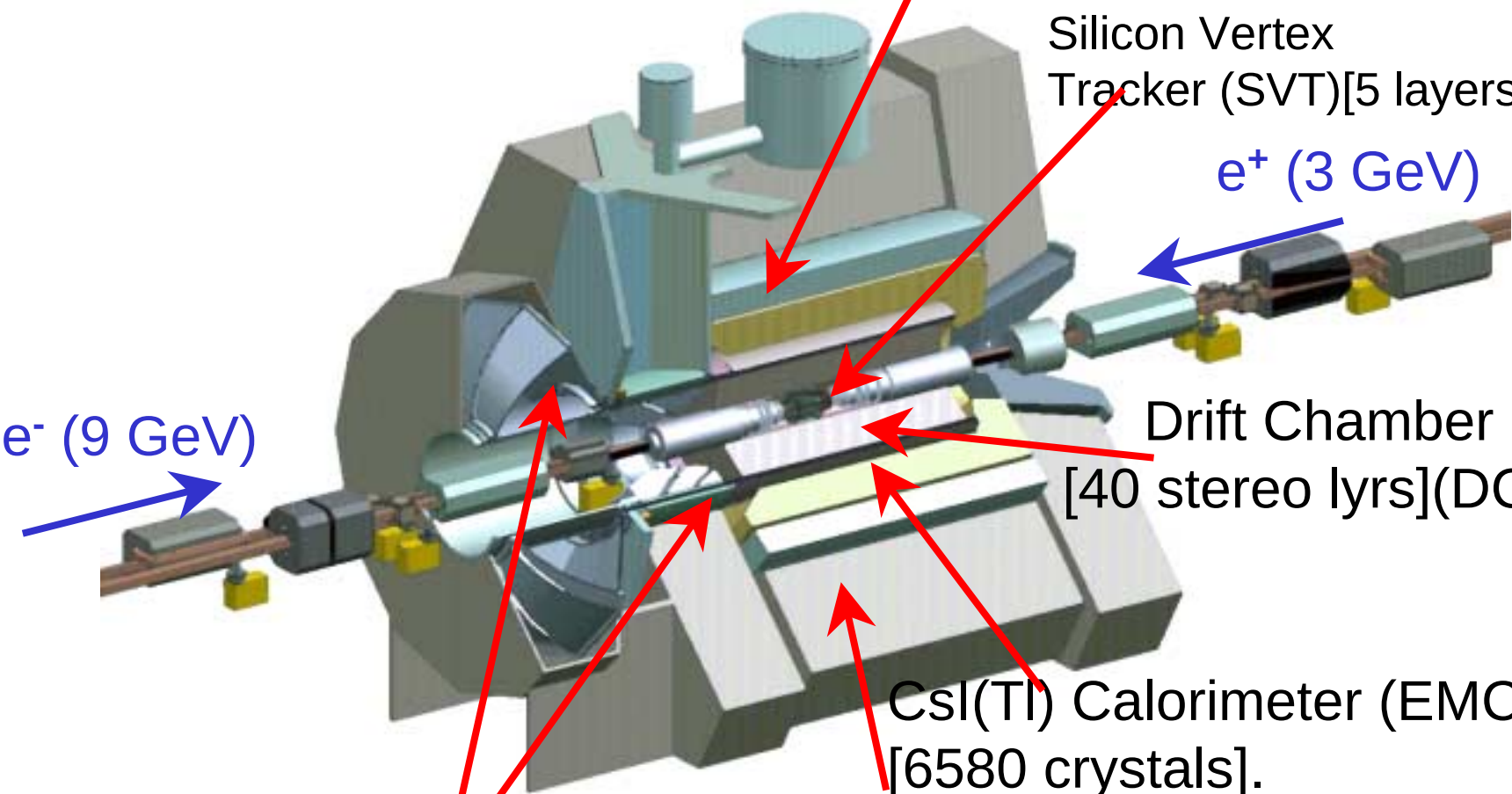


9x 3.0 GeV; L=(4.6 x 10^{33})/cm^2/sec

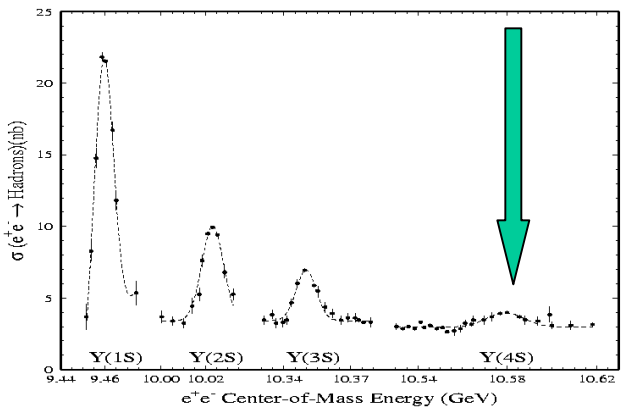
Belle Detector

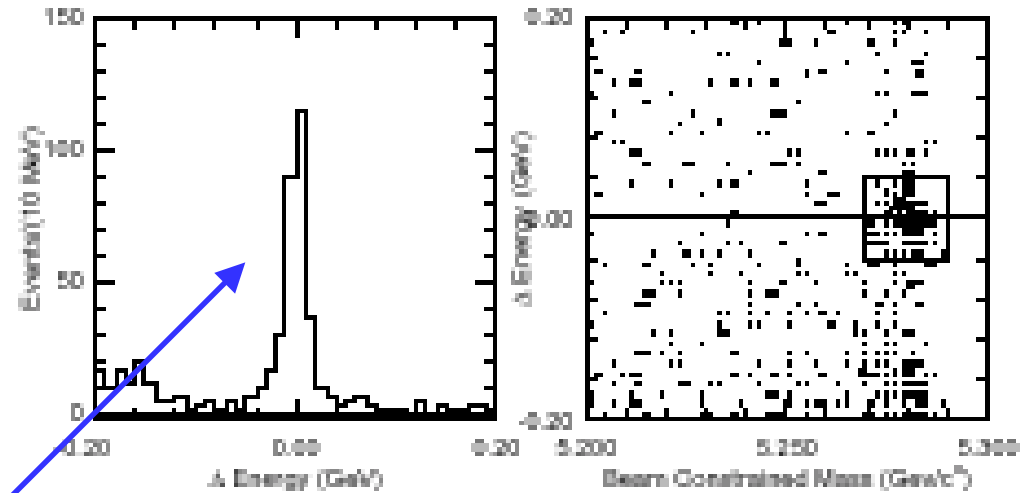


The BaBar Detector



Kinematic variables for the Y(4S)



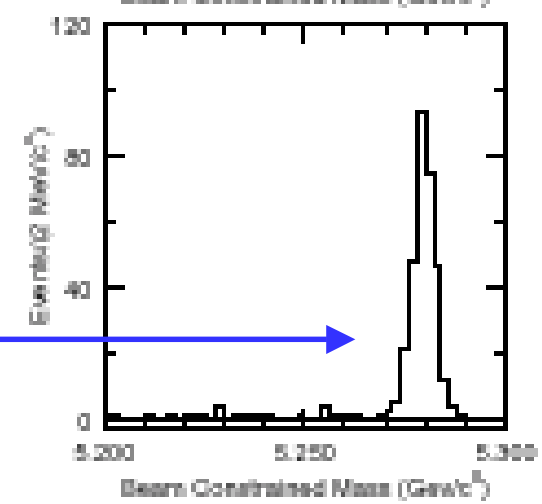


Energy difference:

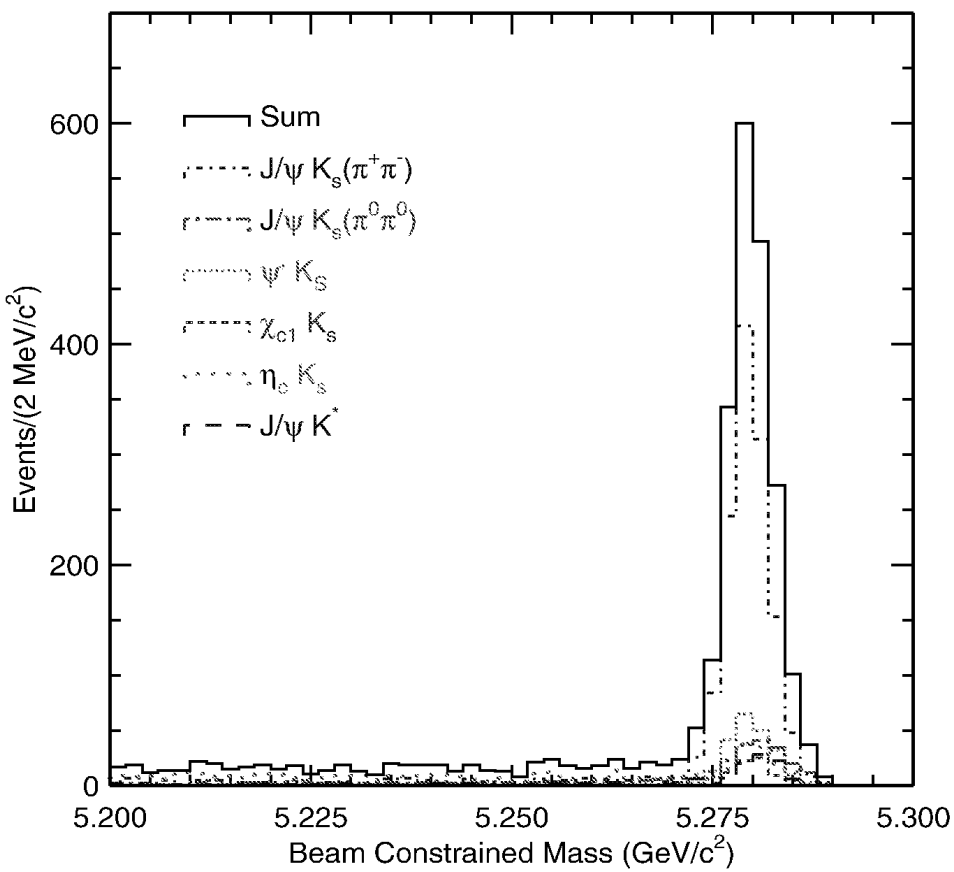
$$\Delta E \equiv E_{J/\psi} + E_{K_S} - E_{CM}/2$$

Beam-constrained mass:

$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{J/\psi} + \vec{p}_{K_S})^2}$$



Belle: CP eigenstates ($b \to c\bar{c}s$)



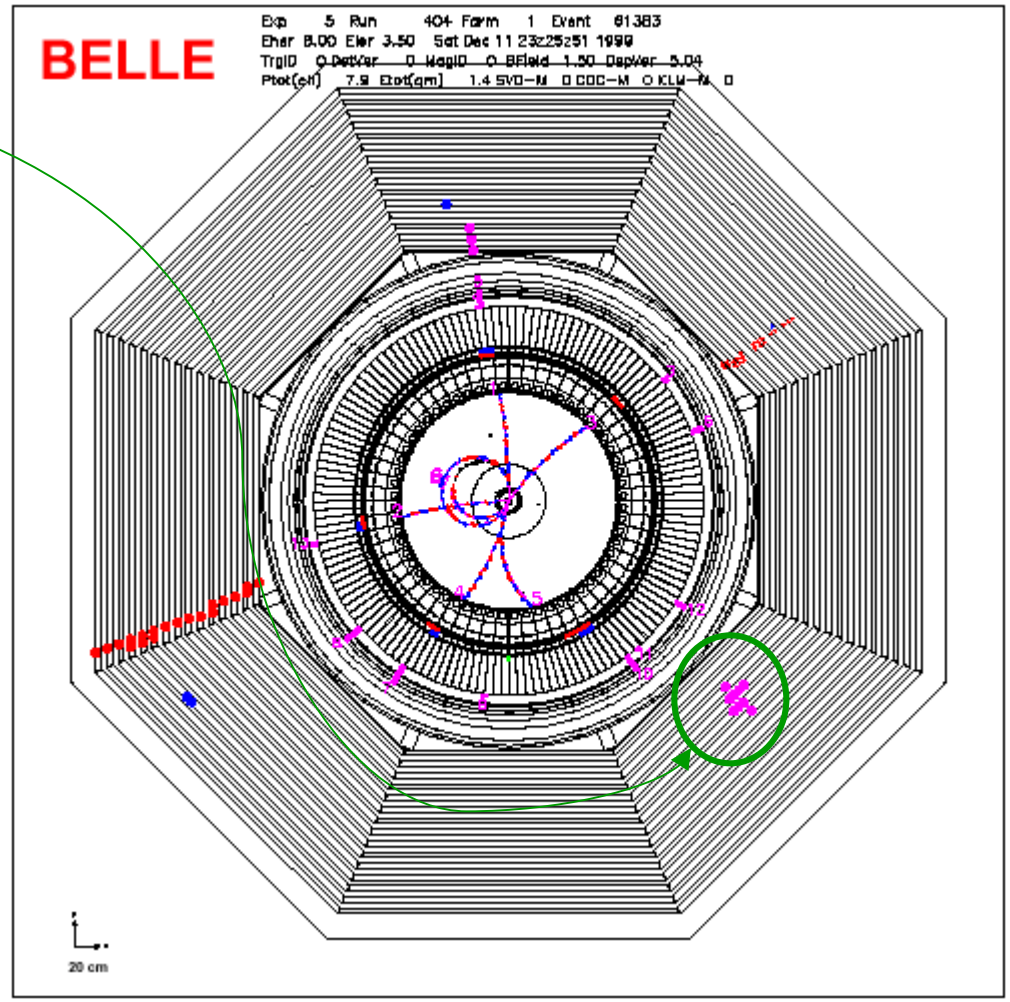
$B \to$	CP	# evts.	S/(S+N)
$J/\psi K_S$ ($K_S \to \pi^+\pi^-$)	odd	1285	0.98
$J/\psi K_S$ ($K_S \to \pi^0\pi^0$)	odd	188	0.82
$\psi(2S) K_S$ ($\psi(2S) \to l^+l^-$)	odd	91	0.96
$\psi(2S) K_S$ ($\psi(2S) \to \pi^+\pi^- J/\psi$)	odd	112	0.91
$\chi_{c1} K_S$ ($\chi_{c1} \to \gamma J/\psi$)	odd	77	0.96
$\eta_c K_S$ ($\eta_c \to K_S K^+\pi^-$)	odd	72	0.65
$\eta_c K_S$ ($\eta_c \to K^+K^-\pi^0$)	odd	49	0.73
$\eta_c K_S$ ($\eta_c \to \bar{p}p$)	odd	21	0.94
$J/\psi K^{*0}$ ($K^{*0} \to K_S \pi^0$)	81% even 19% odd	101	0.92
total		1996	0.94
$J/\psi K_L$	even	1330	0.63
total		3326	

2958 events are used in the fit.

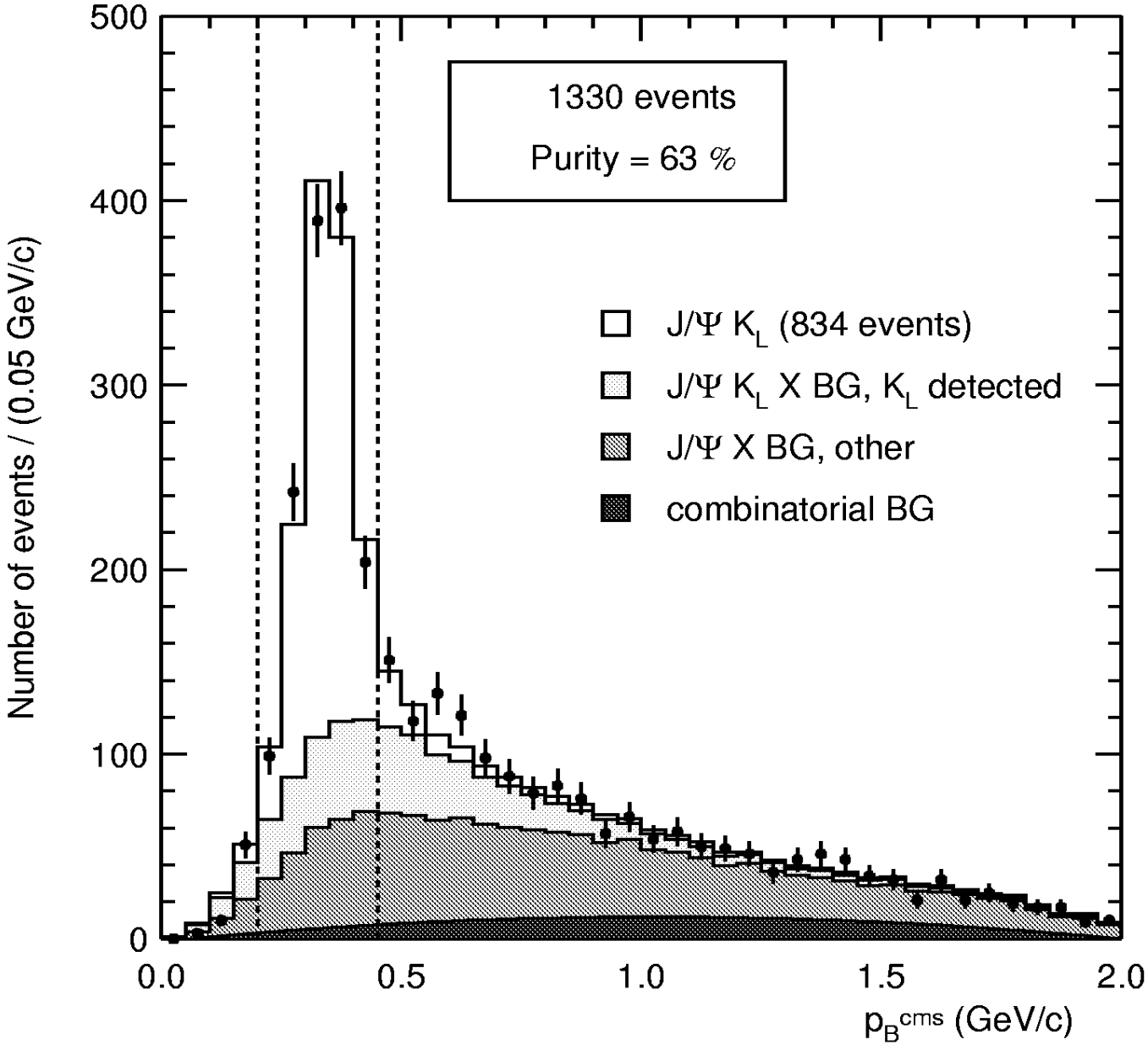
hep-ex/020825, PRD 66, 071102(2002)

Example of a $B^0 \rightarrow J/\psi\ K_L$ Decay

1) $J/\psi \rightarrow l^+l^- + K_L$
2) Assume $B \rightarrow J/\psi\ K_L$: compute $\vec{P}_{KL}$
3) Remove reconstructed $B \rightarrow J/\psi\ K$, $J/\psi\ K^*$, …
4) Cut on a likelihood based on kinematical and shape quantities
5) Plot $P^*_B = |\vec{P}_{J/\psi} + \vec{P}_{KL}|$



Belle: $B^0 \rightarrow \psi K_L$ signal



Flavor-tag the other B meson

Use *inclusive* flavor-specific properties:

- ***Inclusive Leptons:***
  - ***high-p*** l^- — $b \rightarrow c\, l^- \nu$
  - ***intermed-p*** l^+ — $\hookrightarrow s\, l^+ \nu$
- ***Inclusive Hadrons:***
  - ***high-p*** π^+ — $B^0 \rightarrow D^{(*)-} \pi^+$, $D^{(*)-} \rho^+$, etc.
  - ***intermed-p*** K^+ — $\rightarrow K^+ X$, $\hookrightarrow \pi^+ \pi^0$
  - ***low-p*** π^- — $\rightarrow \bar{D}^0 \pi^-$

➡ Also take into account correlations.

Flavor-tagging using NN (BaBar)

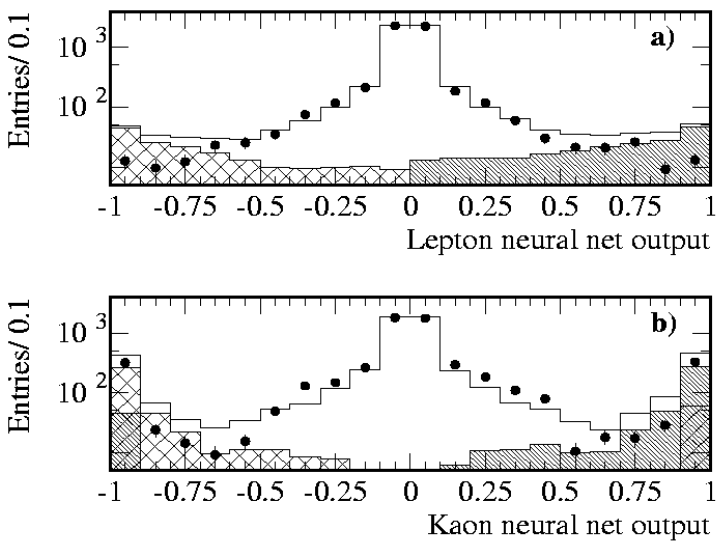


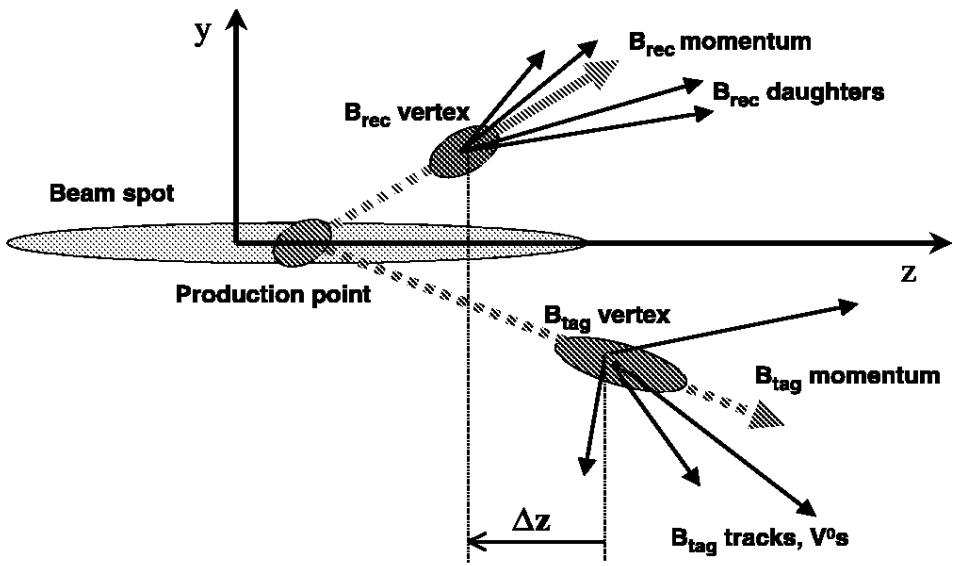
TABLE I: Efficiencies ϵ_i, average mistag fractions w_i, mistag fraction differences $\Delta w_i = w_i(B^0) - w_i(\overline{B}^0)$, and Q extracted for each tagging category i from the $B_{\rm flav}$ and B_{CP} samples.

Category	ε (%)	w (%)	Δw (%)	Q (%)
Lepton	9.1 ± 0.2	3.3 ± 0.6	-1.5 ± 1.1	7.9 ± 0.3
Kaon I	16.7 ± 0.2	10.0 ± 0.7	-1.3 ± 1.1	10.7 ± 0.4
Kaon II	19.8 ± 0.3	20.9 ± 0.8	-4.4 ± 1.2	6.7 ± 0.4
Inclusive	20.0 ± 0.3	31.5 ± 0.9	-2.4 ± 1.3	2.7 ± 0.3
All	65.6 ± 0.5			28.1 ± 0.7

Figure of merit(Q) =ε(1-2 w)^2
a.k.a effective tagging efficiency

c.f. Belle: Likelihood based approach, 28.8±0.6 %

Results for w are calibrated from data.



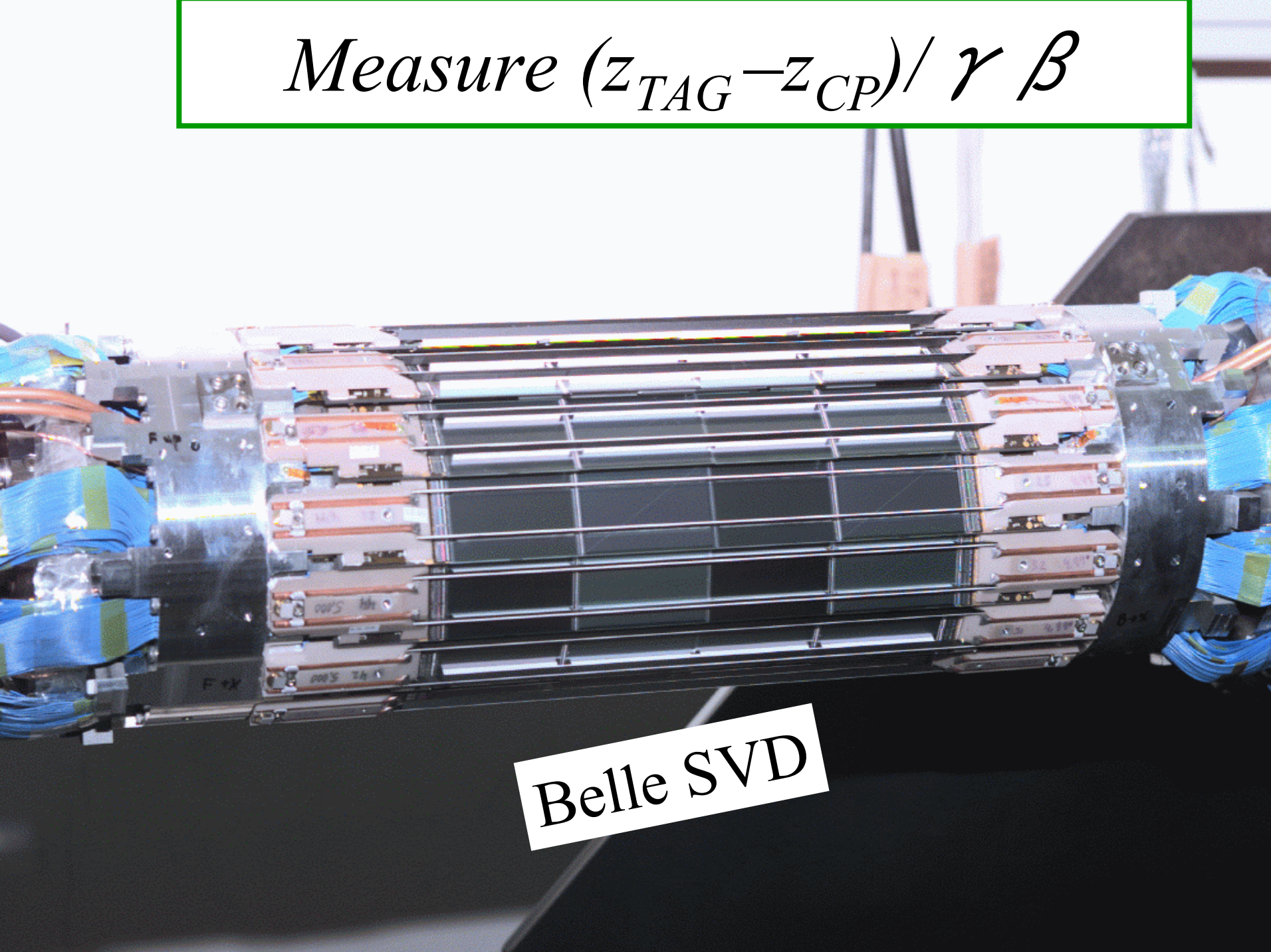
Beam spot: 110 μm x 5 μm x 0.35 cm

Both experiments use double-sided silicon strip detectors to measure Δz.

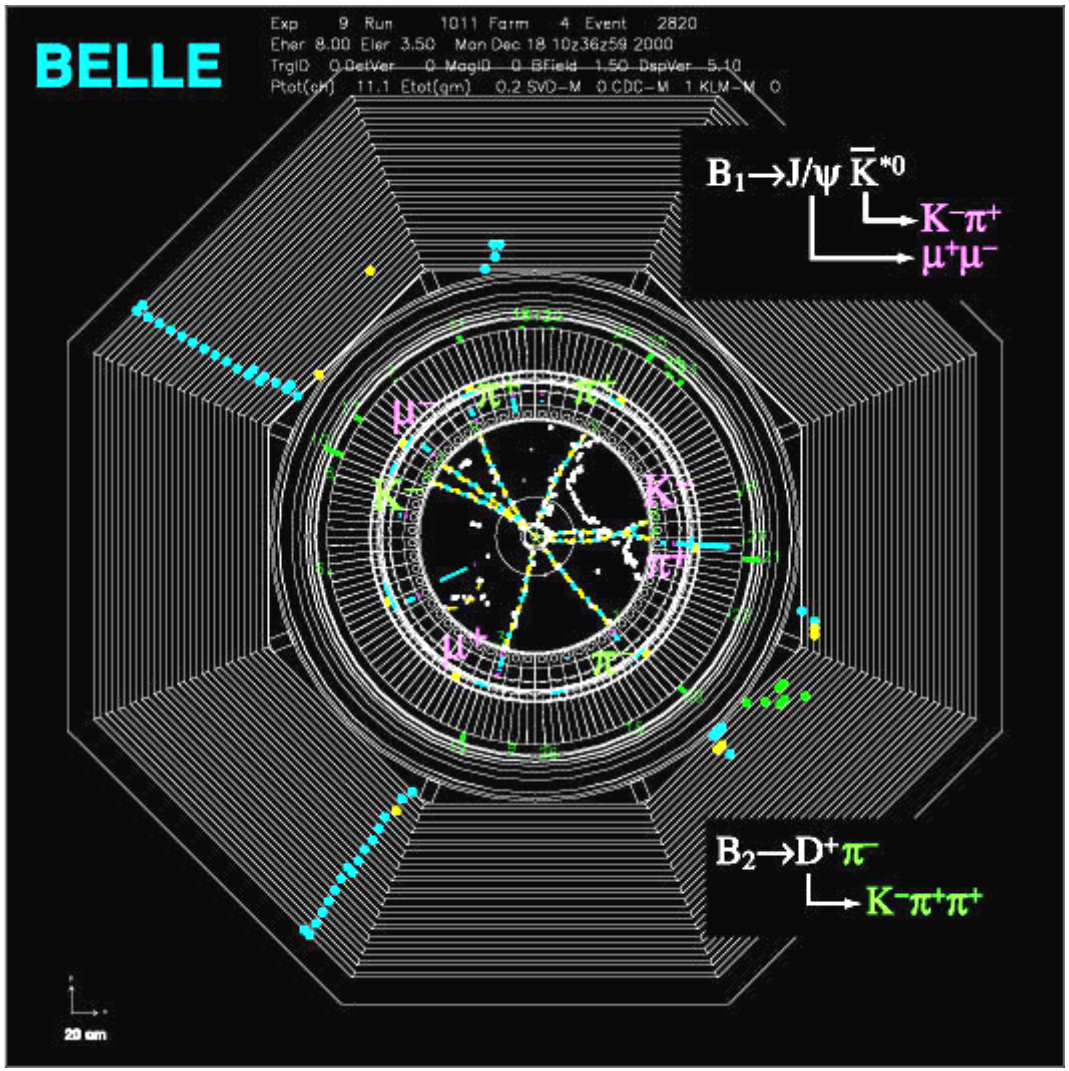
Belle: $\beta\gamma = 0.425$ BaBar: $\beta\gamma=0.56$

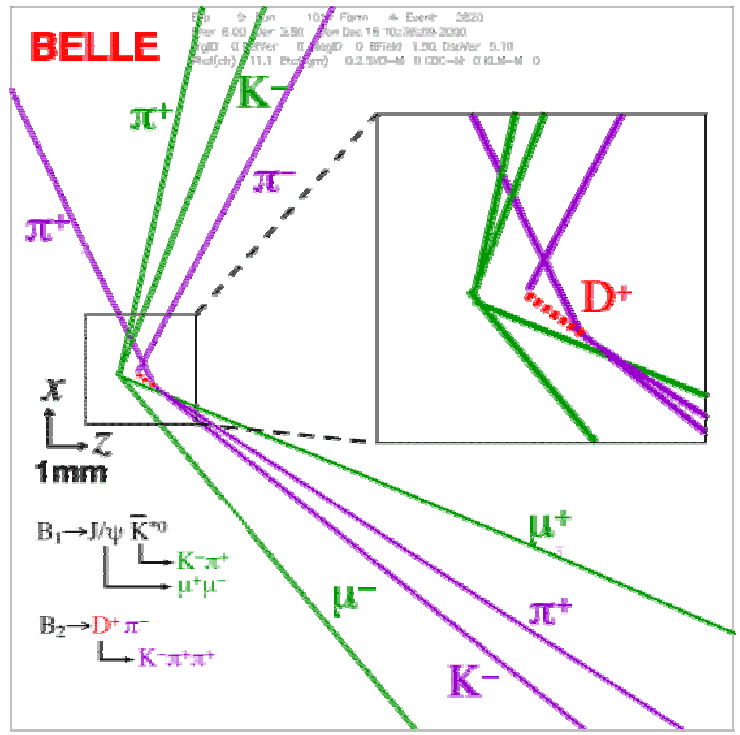
Vertex resolutions(Belle): ($\sigma(z_{cp}) = 75\mu m$; $\sigma(z_{tag}) = 140\mu m$)

Measure $(z_{TAG} - z_{CP}) / \gamma \beta$



Example of a Fully-reconstructed Event





Summer of 2001

VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of Large CP Violation in the Neutral B Meson System

Belle:

We present a measurement of the standard model CP violation parameter $\sin 2\phi_1$ based on a 29.1 fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. One neutral B meson is fully reconstructed as a $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$, $J/\psi K_L$, or $J/\psi K^{*0}$ decay and the flavor of the accompanying B meson is identified from its decay products. From the asymmetry in the distribution of the time intervals between the two B meson decay points, we determine $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$. We conclude that we have observed CP violation in the neutral B meson system.

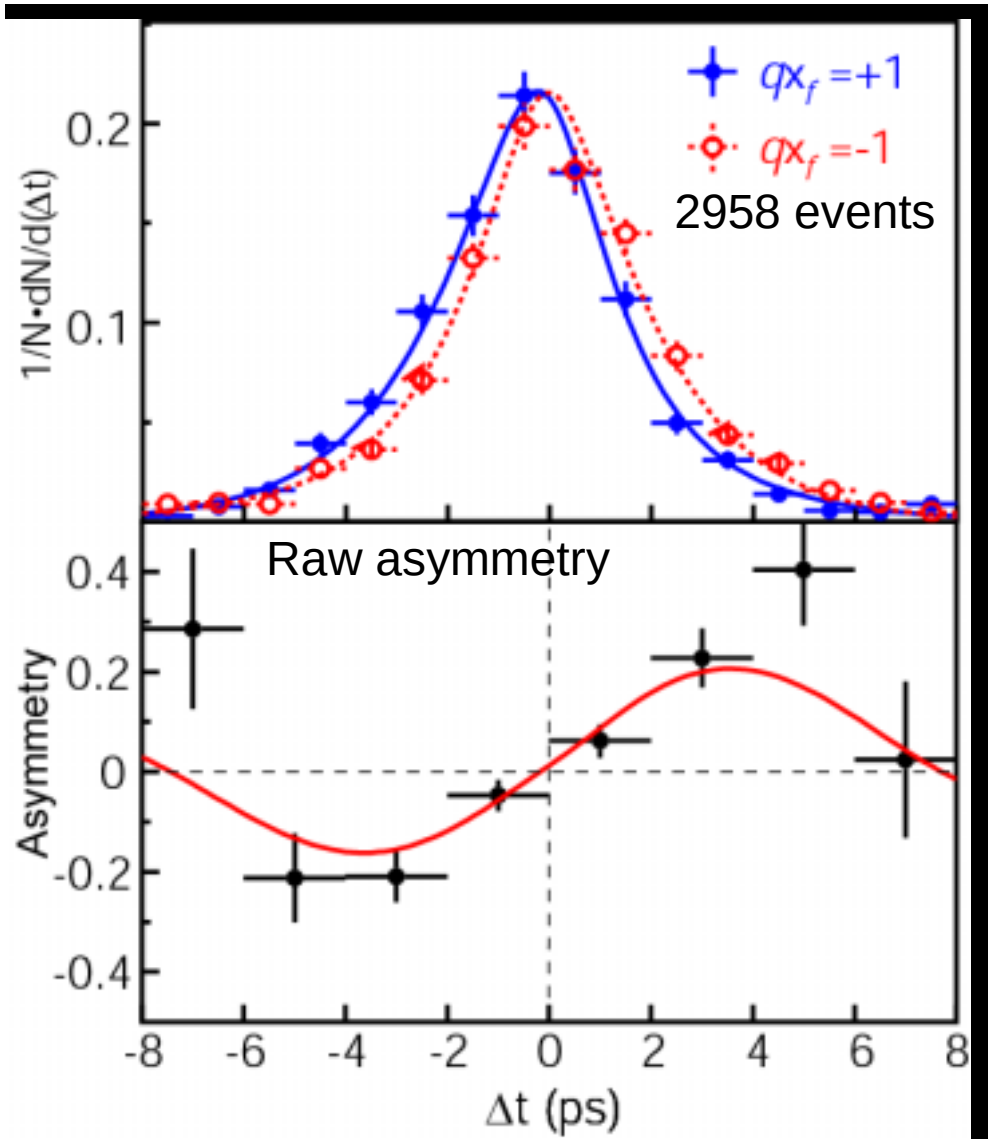
VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of CP Violation in the B^0 Meson System

BaBar:

We present an updated measurement of time-dependent CP-violating asymmetries in neutral B decays with the *BABAR* detector at the PEP-II asymmetric B Factory at SLAC. This result uses an additional sample of $\Upsilon(4S)$ decays collected in 2001, bringing the data available to 32×10^6 $B\overline{B}$ pairs. We select events in which one neutral B meson is fully reconstructed in a final state containing charmonium and the flavor of the other neutral B meson is determined from its decay products. The amplitude of the CP-violating asymmetry, which in the standard model is proportional to $\sin 2\beta$, is derived from the decay time distributions in such events. The result $\sin 2\beta = 0.59 \pm 0.14(\text{stat}) \pm 0.05(\text{syst})$ establishes CP violation in the B^0 meson system. We also determine $|\lambda| = 0.93 \pm 0.09(\text{stat}) \pm 0.03(\text{syst})$, consistent with no direct CP violation.

Precise measurement of $\sin 2\phi_1$ (Belle)



- 78 fb^{-1} (84M $B\bar{B}$)
- 6 $b \to c\bar{c}s$ decay modes ($B \to \Psi K_S, \Psi K_L, \eta_C K_S$..)
- $S_{ccs} = \sin 2\phi_1$

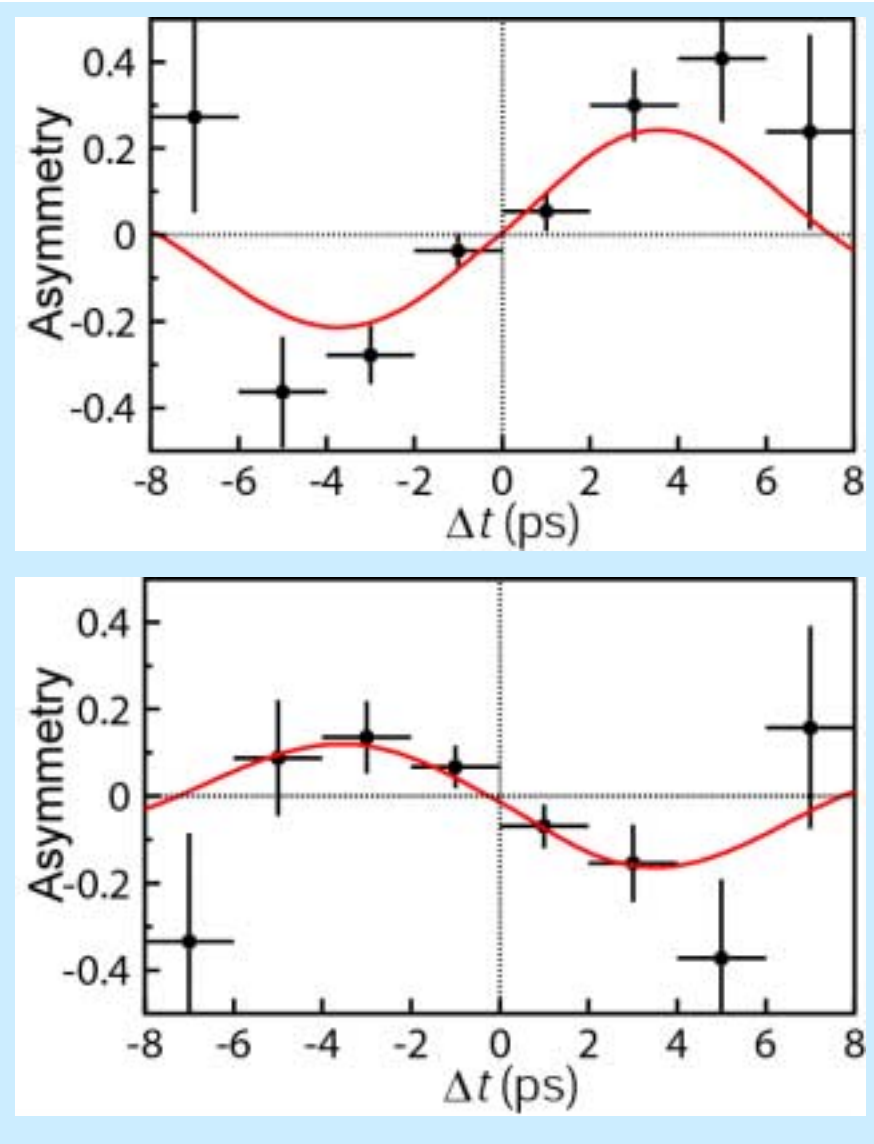
  $= 0.719 \pm 0.074 \pm 0.035$
- $|\lambda_{ccs}| = 0.950 \pm 0.049 \pm 0.026$

  i.e., consistent with no direct CPV.

hep-ex/020825, PRD 66, 071102 (2002)

Compare CP odd and CP even (Belle)

Raw asymmetry



CP = –1 sample

$\sin 2\phi_1$

= 0.716±0.083

CP = +1 sample

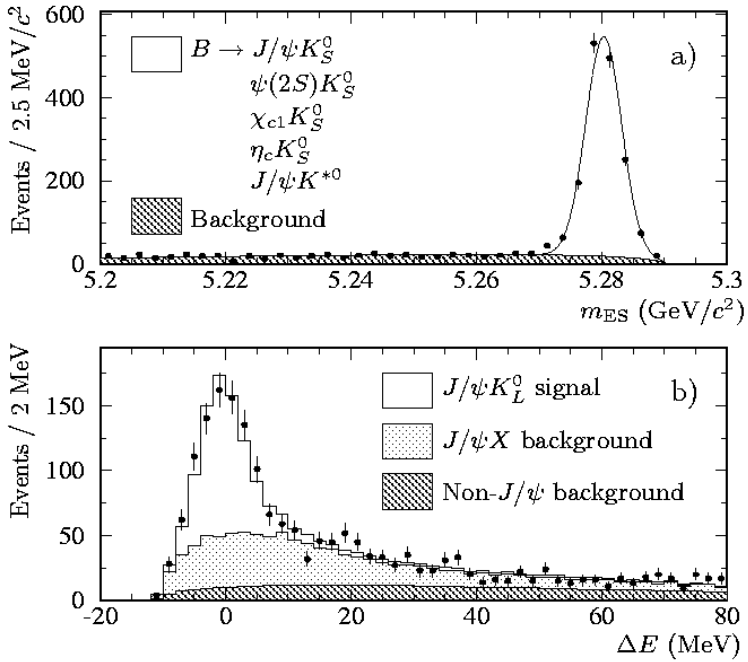
($B^0 \rightarrow J/\psi K_L$)

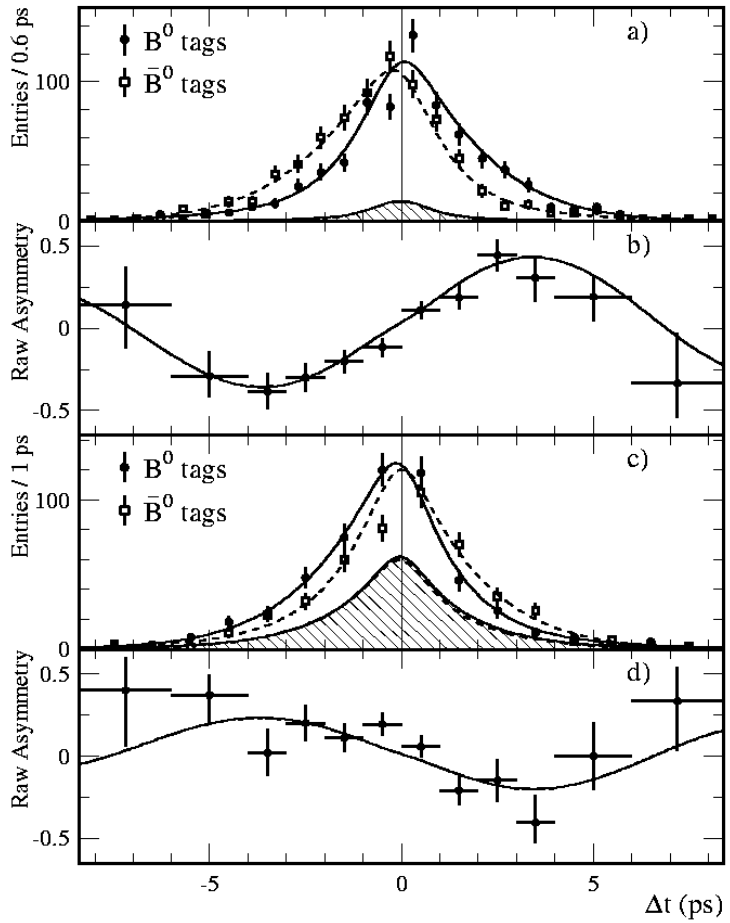
$\sin 2\phi_1$

= 0.78±0.17

hep-ex/020825, PRD 66,071102 (2002)

Precise measurement of $\sin 2\phi_1$ (Babar)





CP Eigenstate Sample

hep-ex/0207042, to appear in PRL

Status/history of results for $\sin(2\varphi_1)$

Belle 2001: $\sin(2\varphi_1) = 0.99 \pm 0.14 \pm 0.06$

Babar 2001: $\sin(2\varphi_1) = 0.59 \pm 0.14 \pm 0.05$

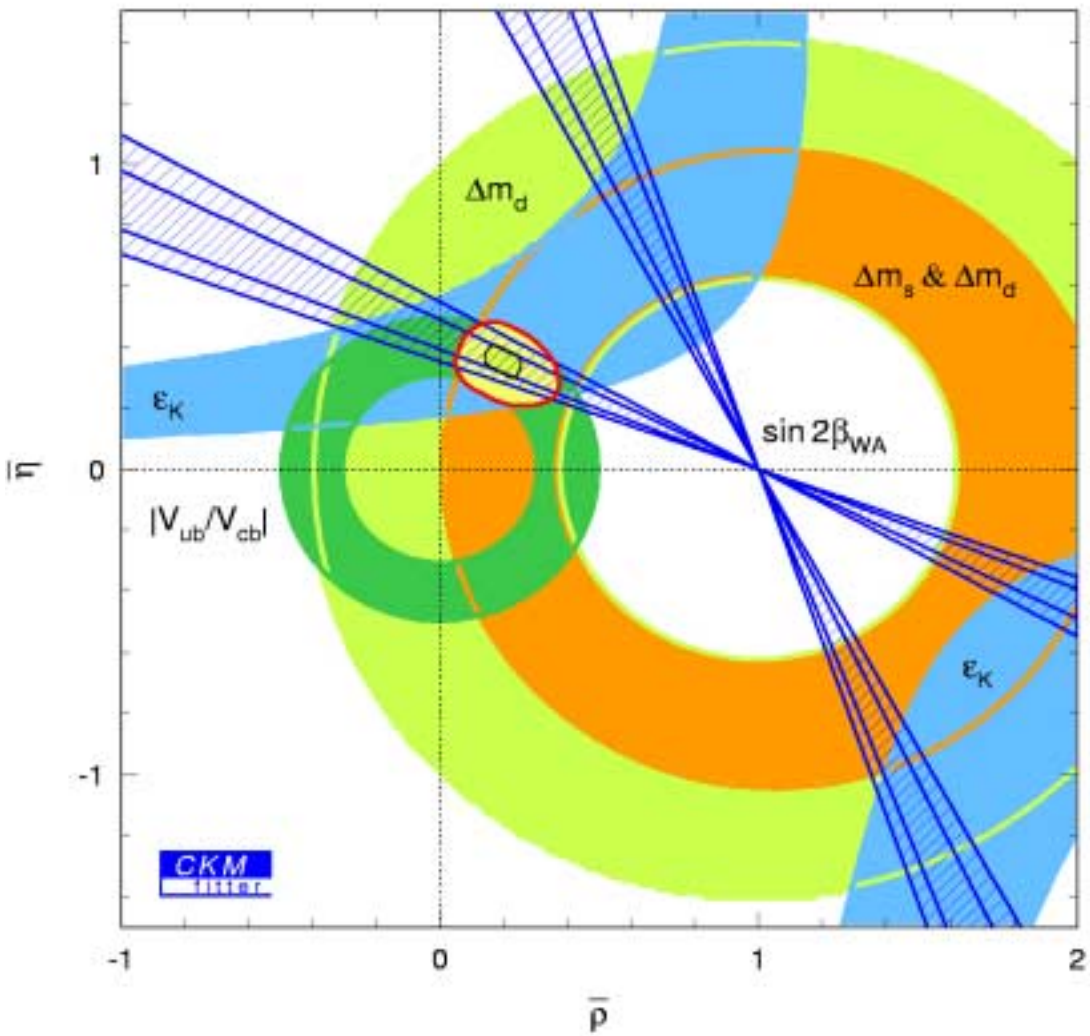
First signals for CPV outside of the kaon sector

Belle 78 fb^{-1} : $\sin(2\varphi_1) = 0.719 \pm 0.074 \pm 0.035$

Babar 81 fb^{-1}: $\sin(2\varphi) = 0.741 \pm 0.067 \pm 0.033$

Now becoming a precision measurement

Current Belle and BaBar Results for sin(2φ$_1$)



$\sin 2\phi_1$ (Belle)

=0.719±0.074±0.035

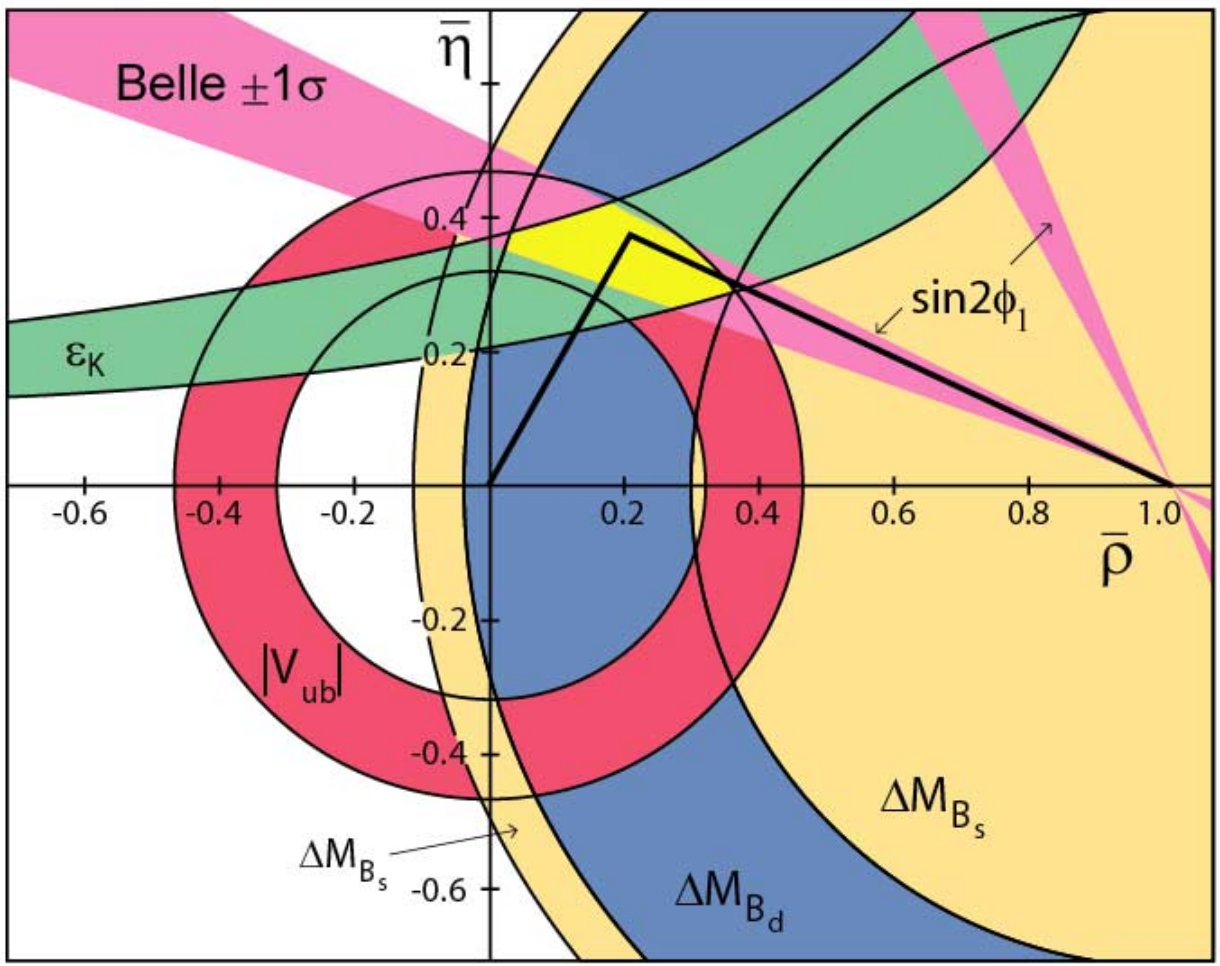
$\sin 2\phi_1$ (BaBar)

=0.741±0.067±0.033

$\sin 2\phi_1$ (World Av.)

=0.734±0.055

Belle's $\sin(2\varphi_1)$ measurement in the ρ-η plane



$\sin 2\phi_1$

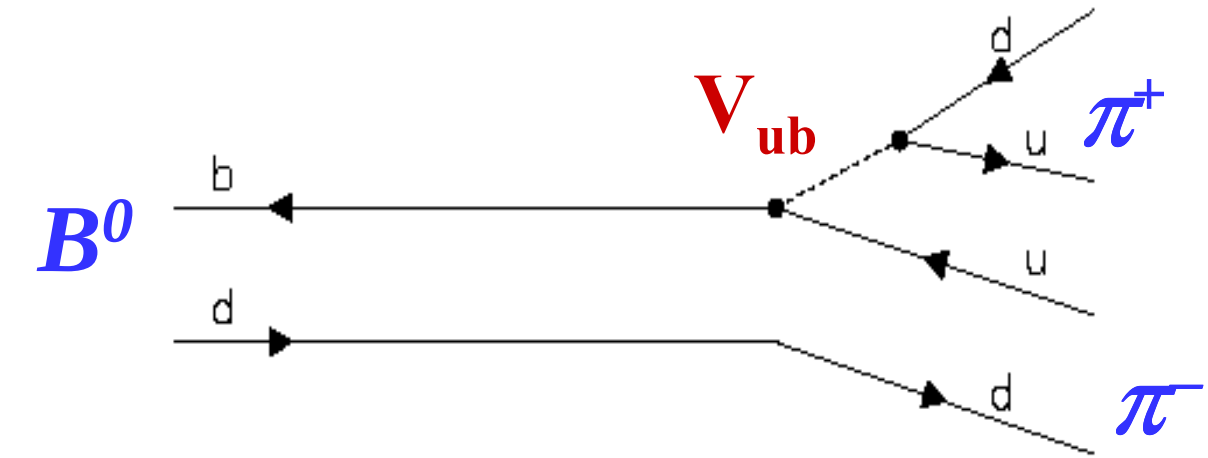
$=0.719 \pm 0.074 \pm 0.035$

Belle July, 2002

PDG2002
(http://pdg.lbl.gov/2002/kmmixrpp)

$B \rightarrow \pi^+ \pi^-$ CPV CONTROVERSY

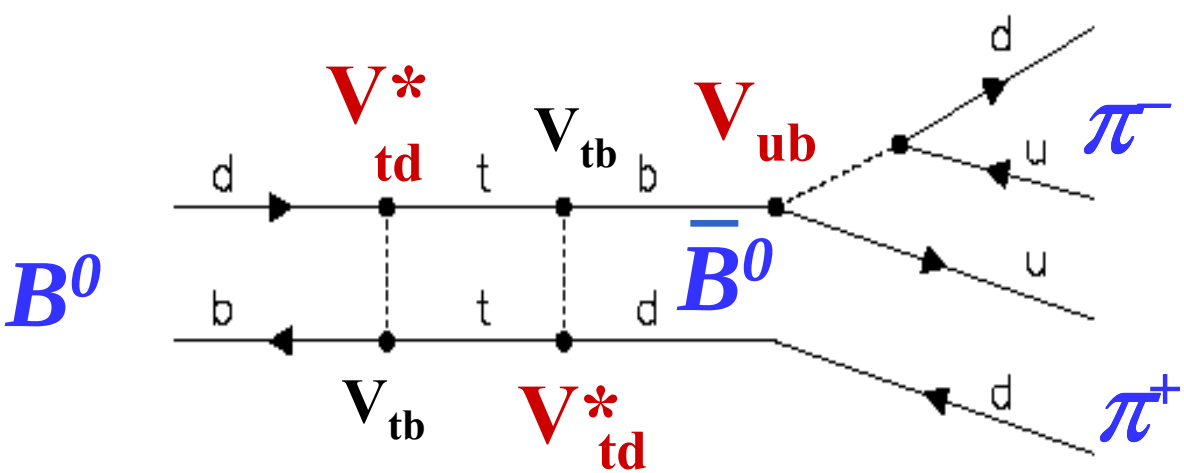
Next: $\phi_2(\alpha)$ from $B \to |f_{cp}\rangle = \pi^+\pi^-$



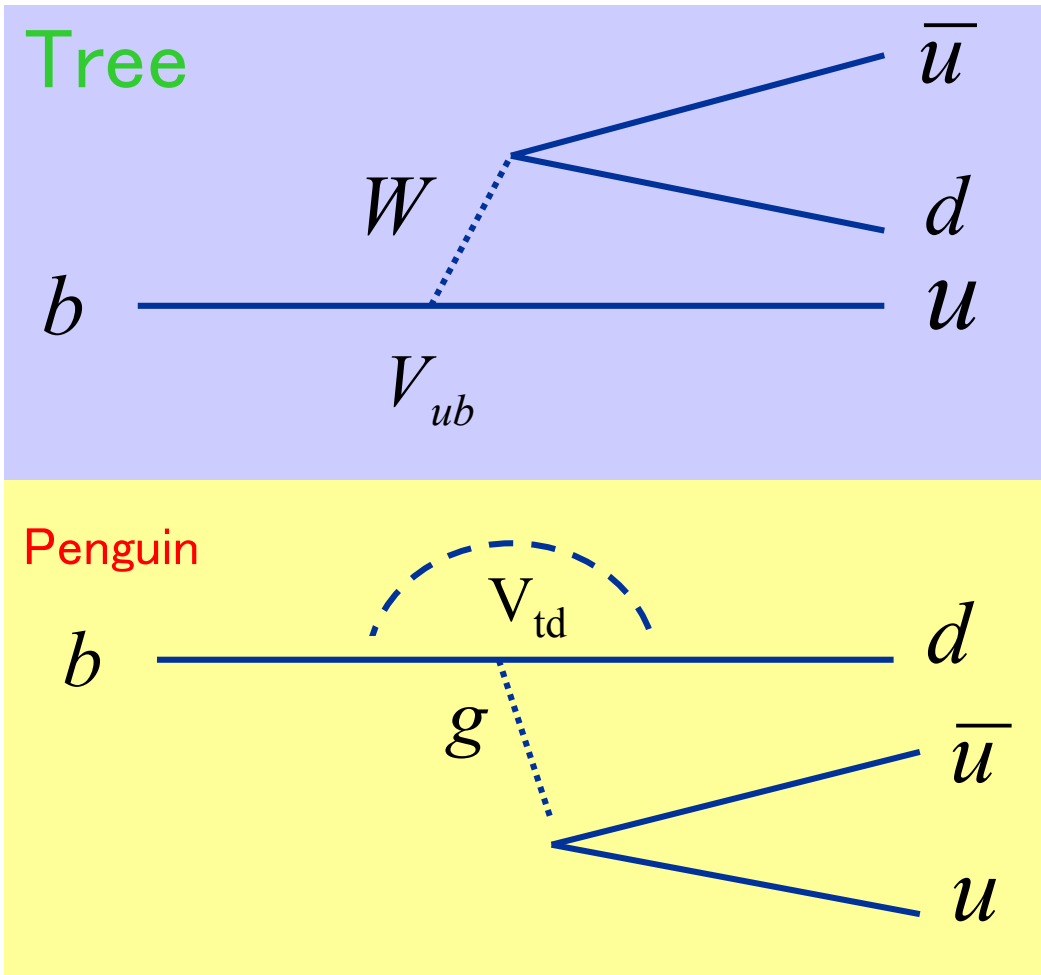
+

$\propto V_{td}^{*2}\, V_{ub}^{2} \propto \sin 2\phi_2$

(a.k.a sin 2α)



"*Penguin Pollution*" in $B \rightarrow \pi^+ \pi^-$



+ Mixing

Isospin analysis:

Isolate the penguin

Direct CPV asymmetry

- Asymmetry in B decay rates

$$A_{dir} \equiv \frac{\Gamma(\overline{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \bar{f}) + \Gamma(B \to f)}$$

$$= \frac{2r \sin\phi \sin\delta}{1 + r^2 + 2r\cos\phi\cos\delta}$$

$$r = |P|/|T|, \phi = weak\ \ phase\ diff$$

$$\delta = strong\ \ phase\ diff$$

- The direct CP asymmetry (A_{dir}) can be significant if the b→d penguin (P) and b→u tree(T) amplitudes are comparable.

Observables: $S_{\pi\pi}$ and $A_{\pi\pi}$

$$S_{\pi\pi} = \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2 + 1} = \sqrt{1 - A_{\pi\pi}{}^2}\,\boxed{\sin 2(\phi_2 + \theta)}$$

$$A_{\pi\pi} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1} = \frac{|\bar{A}_{+-}|^2 - |A_{+-}|^2}{|\bar{A}_{+-}|^2 + |A_{+-}|^2}$$

DCPV asymmetry

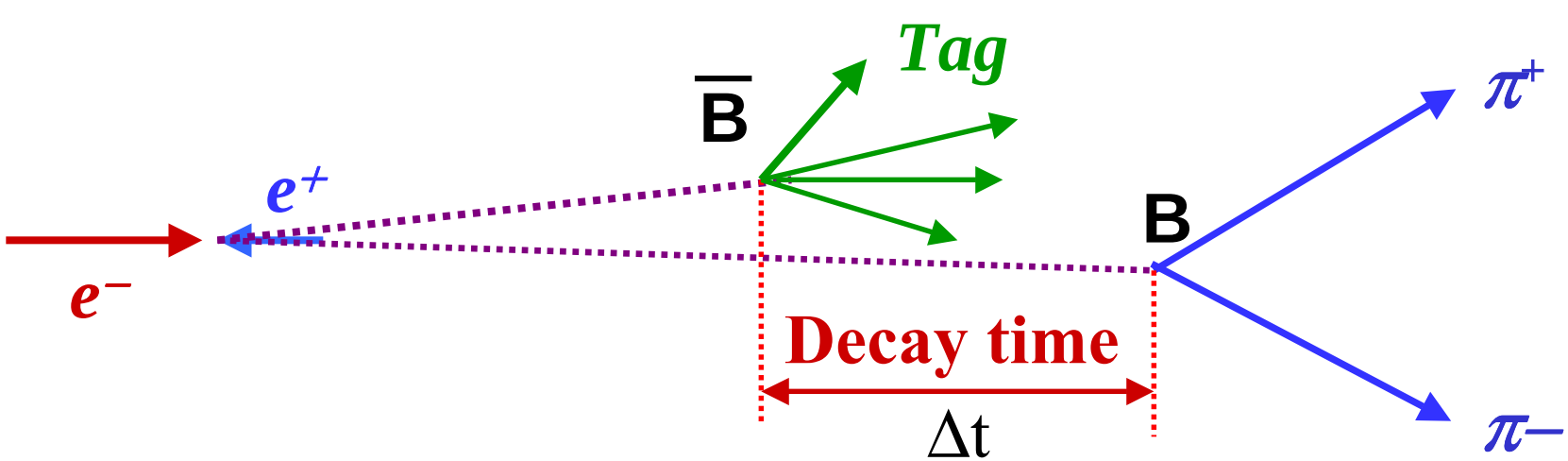
λ is a complex parameter: the product of p/q and the ratio of the amplitudes for B^0 and $\overline{B}^0$ decay to $\pi^+\pi^-$

N.B. Notational convention, $C_{\pi\pi} = -A_{\pi\pi}$

Measurement of CPV asymmetries

$$P_{\pi\pi}(B \to \pi^+\pi^-;\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_{\mathrm{B}}}[1 + q \cdot \{A_{\pi\pi}\cos(\Delta m \Delta t) + S_{\pi\pi}\sin(\Delta m \Delta t)\}]$$

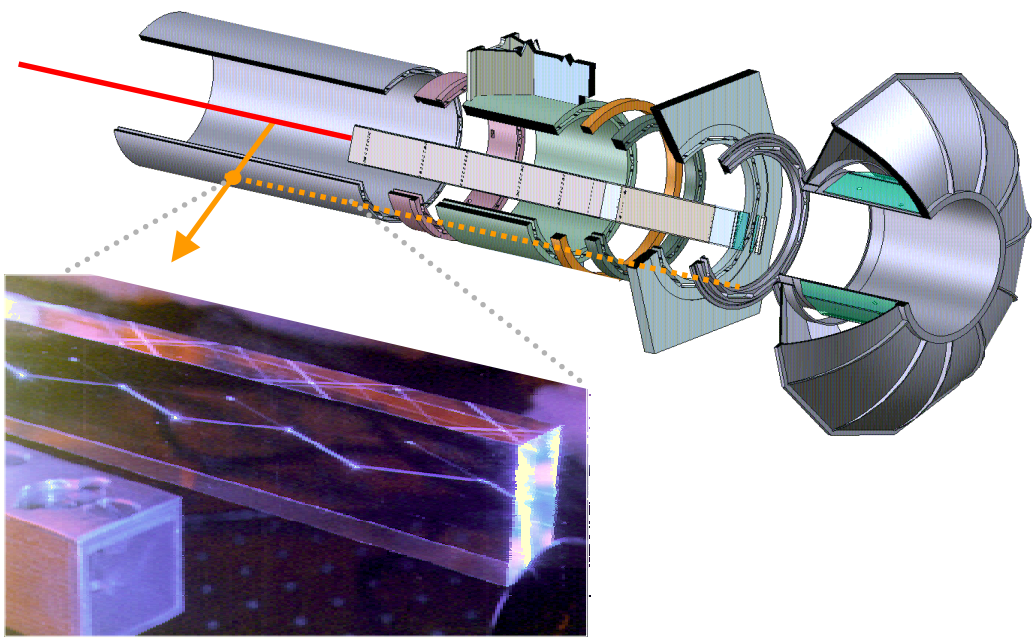
with q=±1



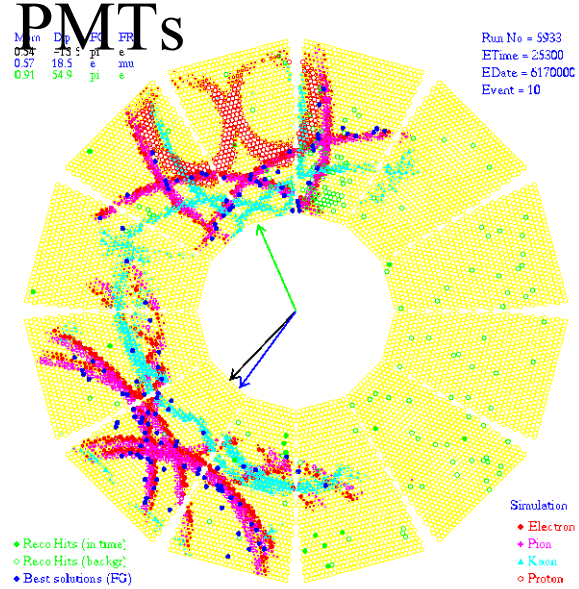
BaBar: Particle identification DIRC

Detector of Internally Reflected Cherenkov light (DIRC):

essential for this analysis to distinguish K from π

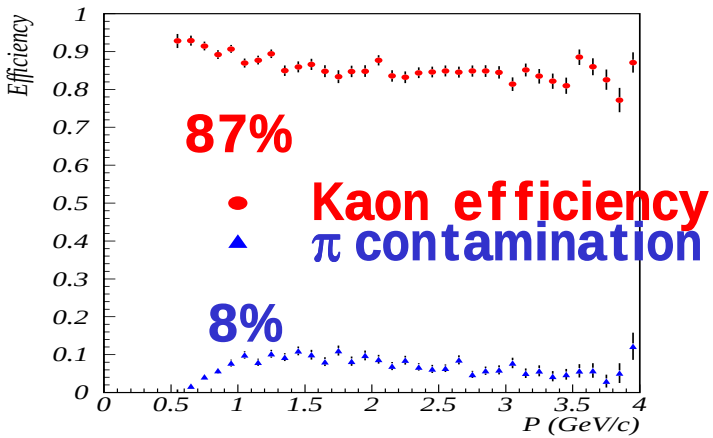


Reconstruct Cherenkov angle $\cos\theta_C = 1/n\beta$ from rings seen in PMTs

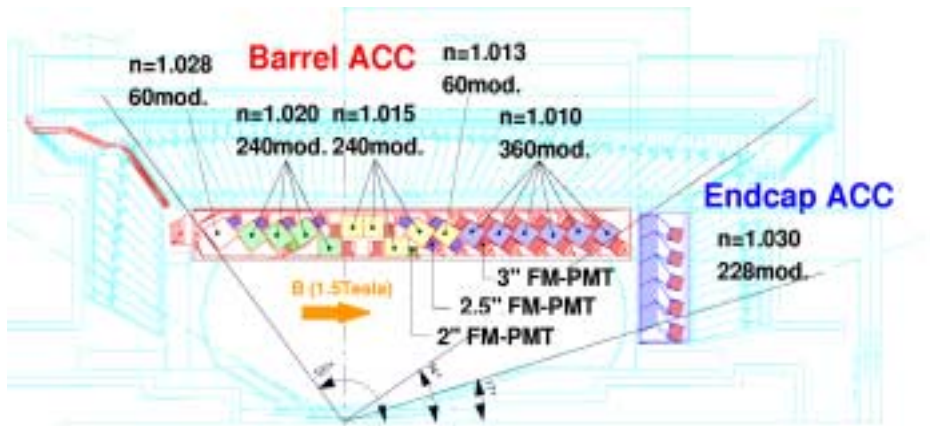


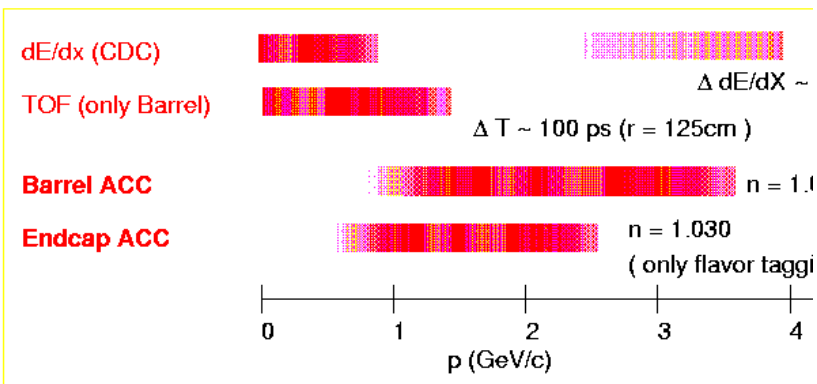
Cherenkov light transmitted down quartz bars by internal reflection

Particle Identification (Belle)

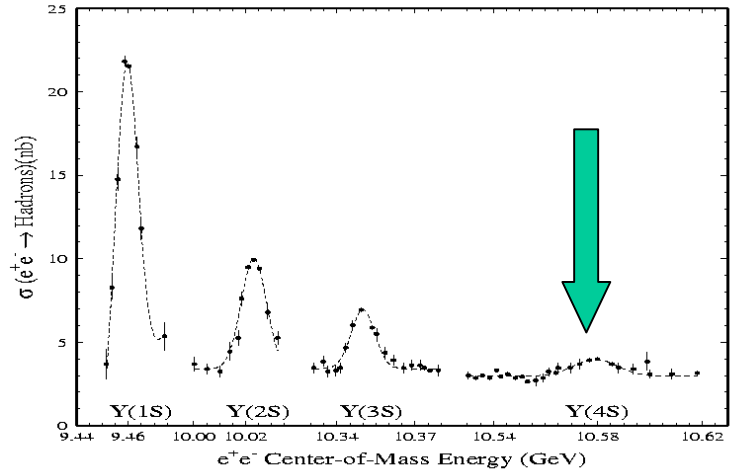


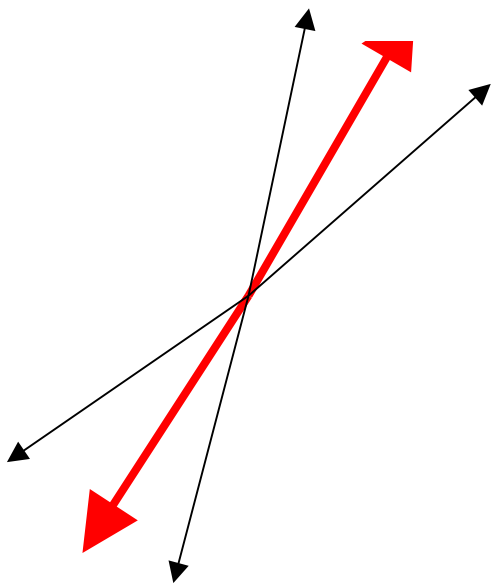
PID(K)>0.6

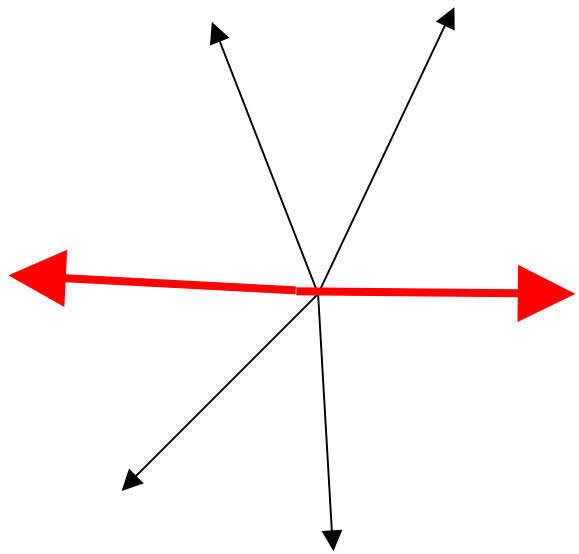




Continuum Background:



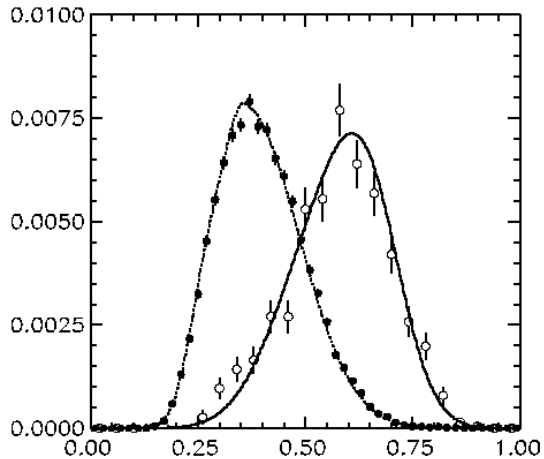




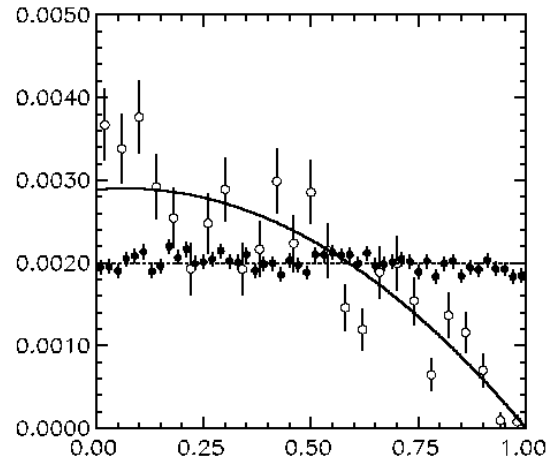
Jetty $(q\,\overline{q})$
Main Background

Spherical$(\overline{b}\,b)$

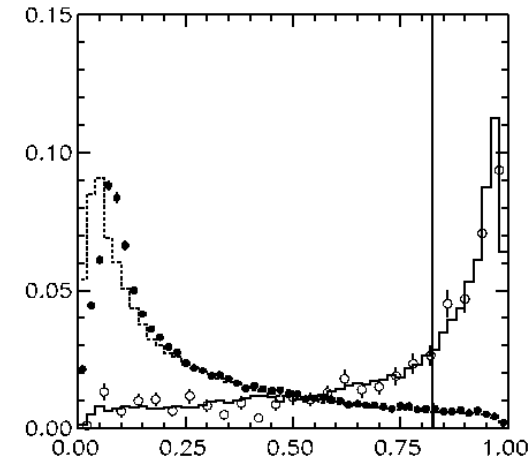
Belle



SFW

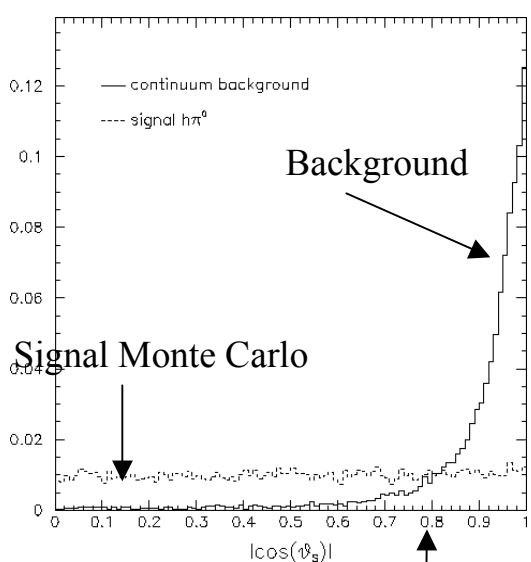


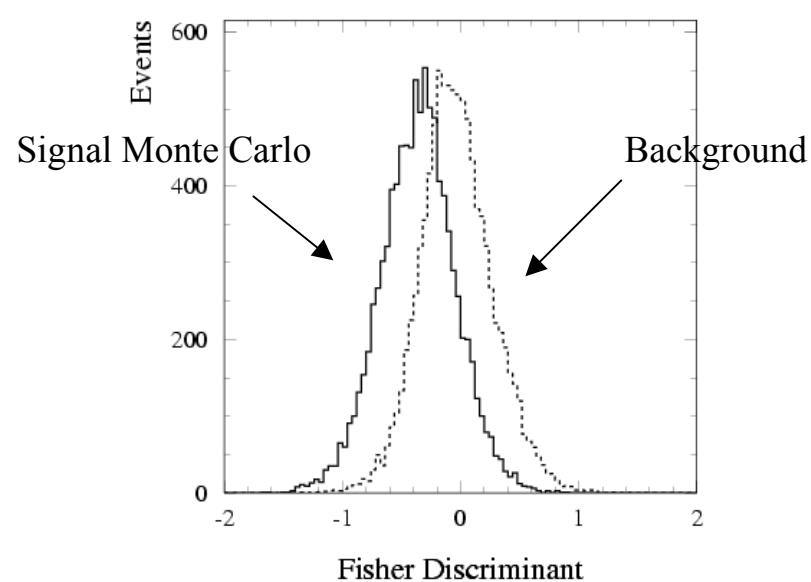
Cos θ_B



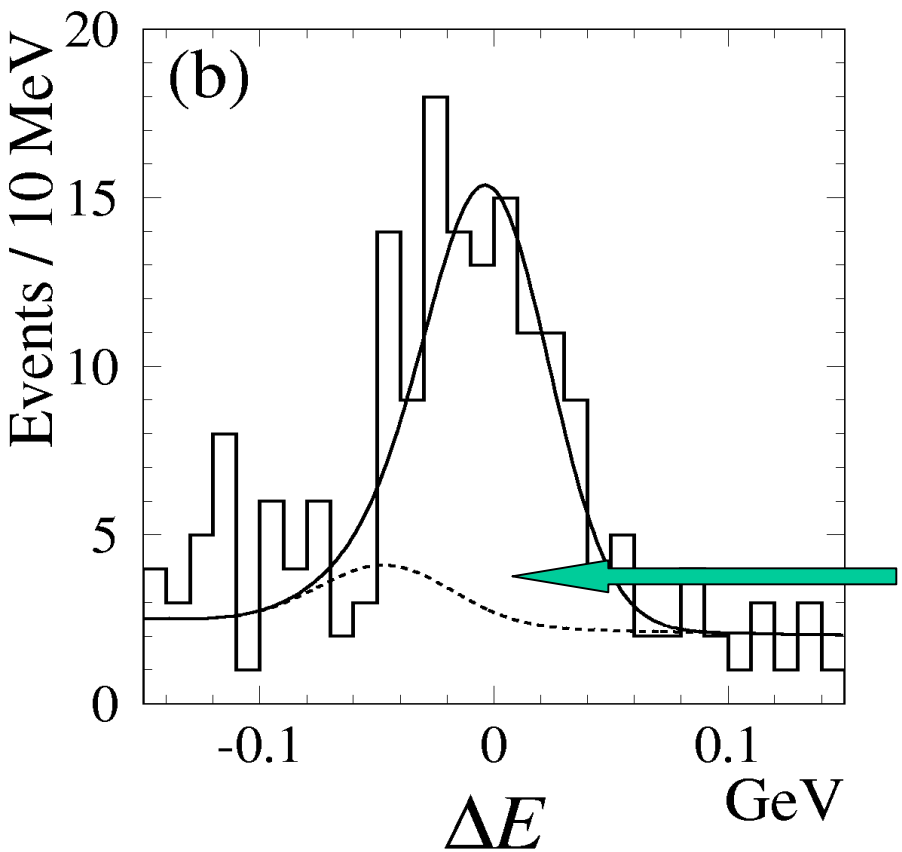
$L_S/(L_s + L_B)$

Babar





ΔE projection for $B \rightarrow \pi^+ \pi^-$ (BaBar)



$K^+\pi^-$ feed across

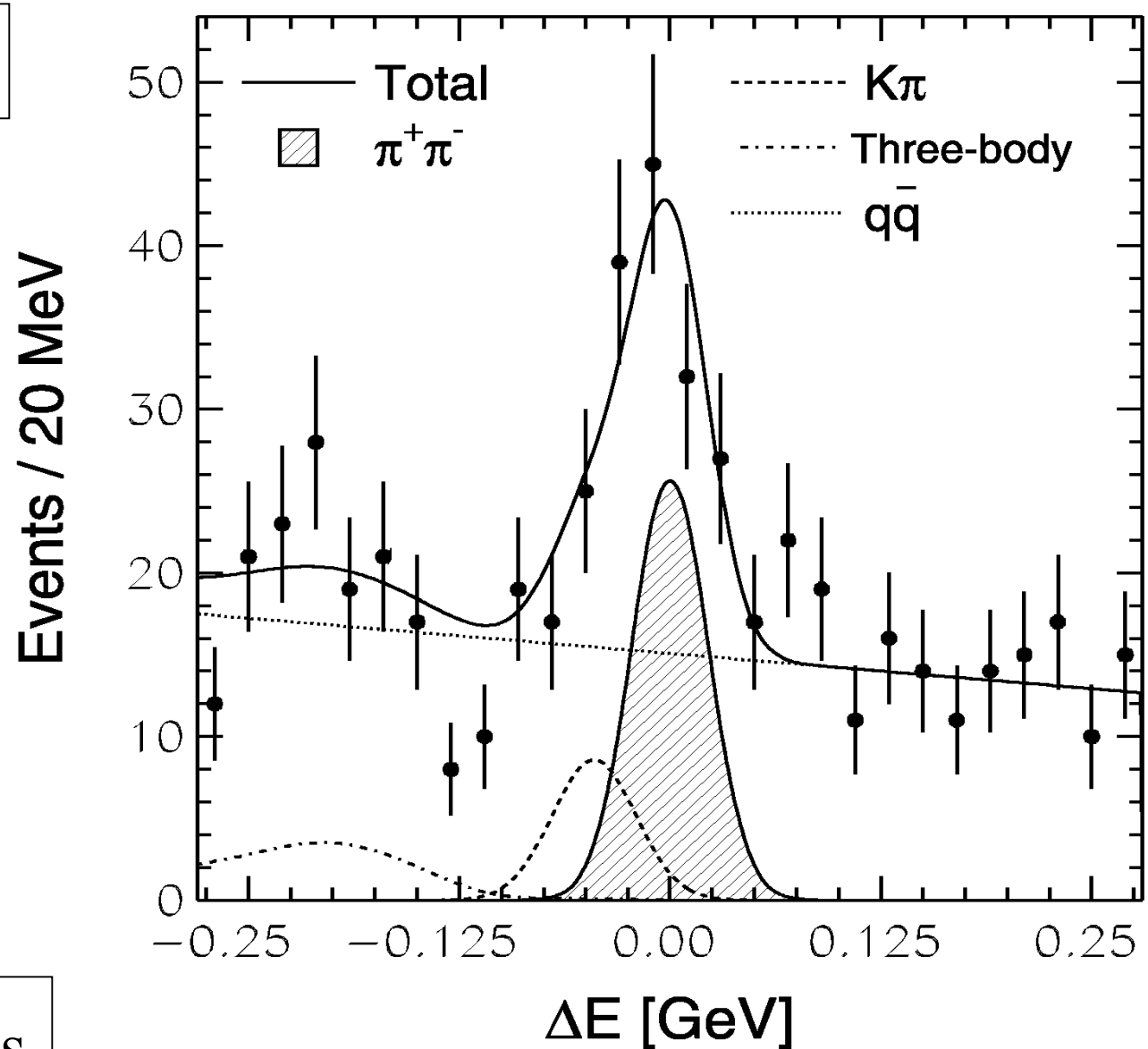
157±15±7 **ML fit yield**

Projection of a multidimensional fit (26070 candidates)

Belle ΔE spectrum for $B \rightarrow \pi^+ \pi^-$

$N(\pi\pi) = 73.5 \pm 13.8$

($N(K\pi) = 28.4 \pm 12.5$)



Signal region:

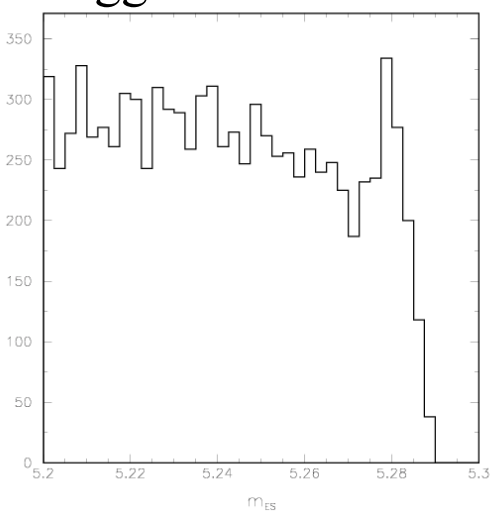
$5.271 < M_{bc} < 5.287$

$|\Delta E| < 0.067$ GeV

Fit to 162 candidates

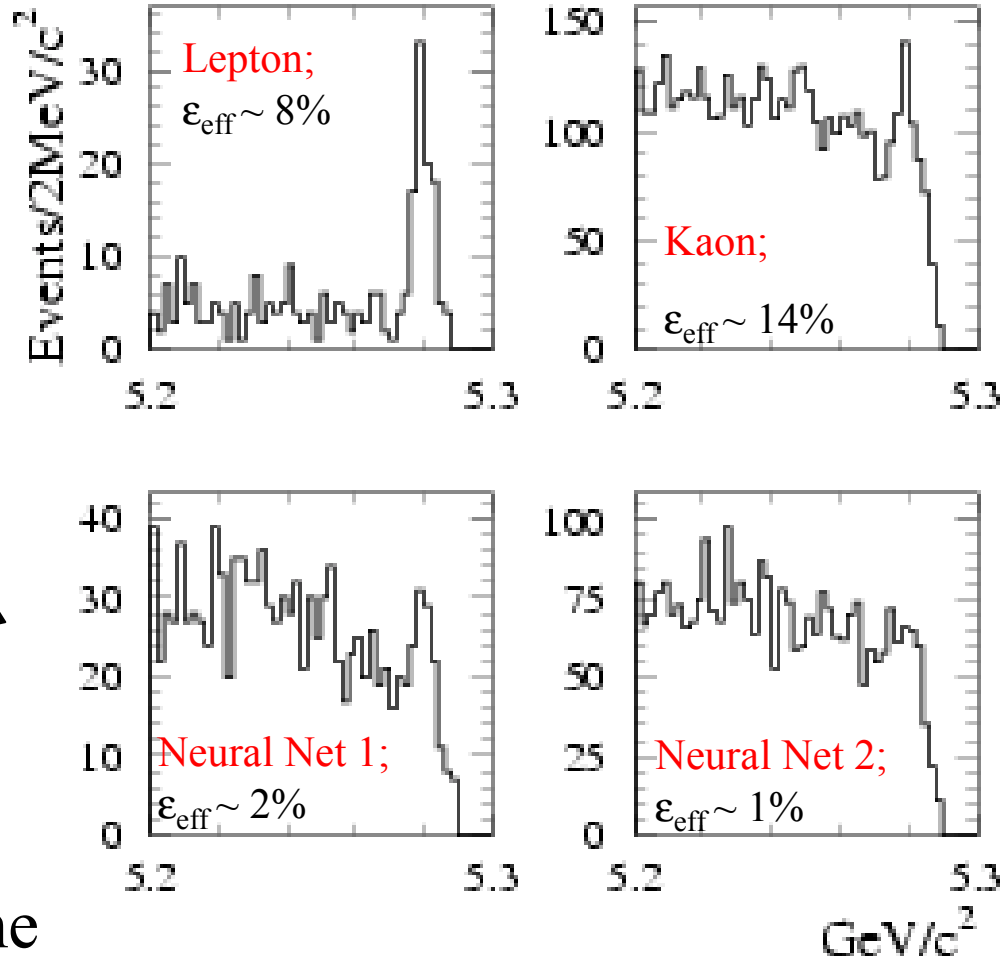
CP fitting: background issues (BABAR)

Fit sample: 9220 tagged candidates



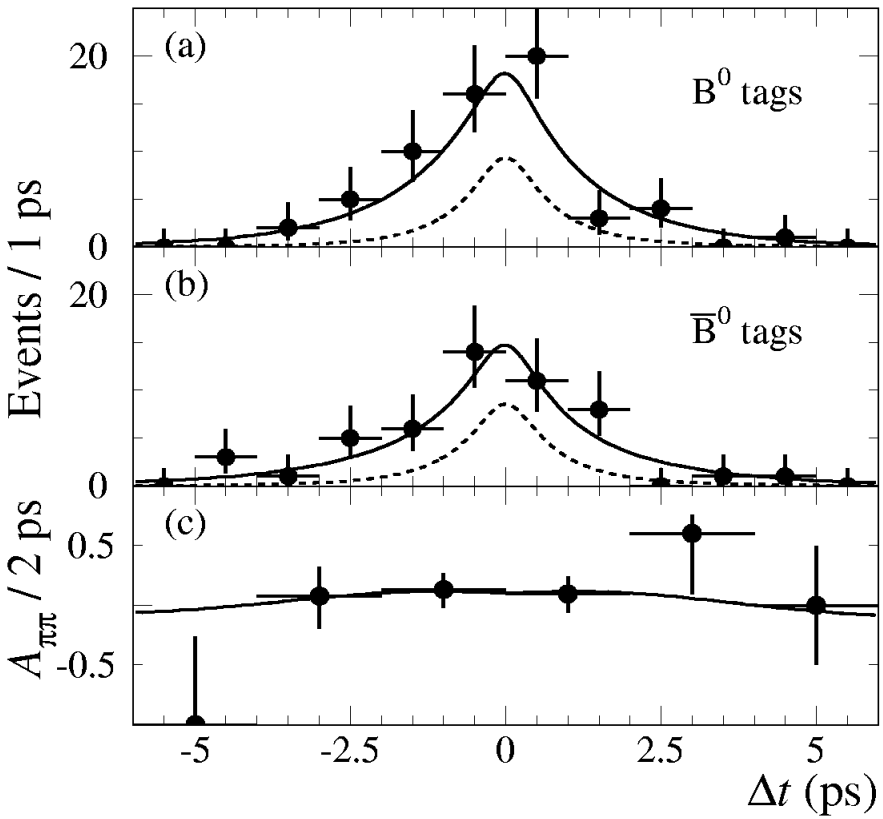
m_{ES} Gev/c²

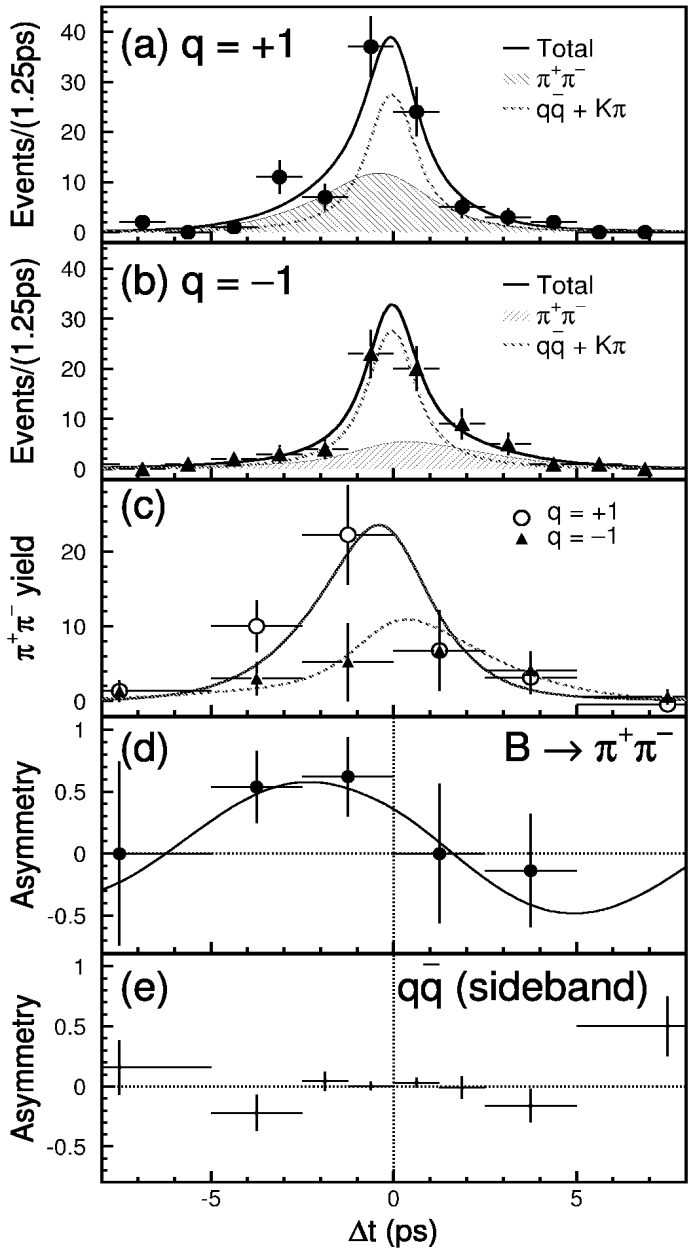
Separate into tag categories



Untagged events (~ 33%) retained in the fit to determine background shapes

Data: Babar (81 fb^{-1}) versus Belle (42 fb^{-1})





Time-dependent fit results (Babar)

Fit results:

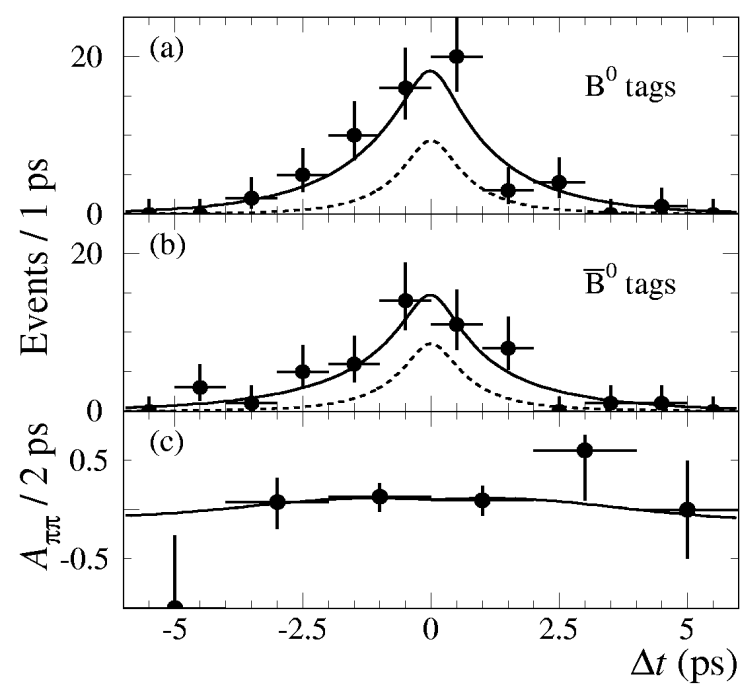
$$S_{\pi\pi} = 0.02 \pm 0.34 \pm 0.05$$

$$A_{\pi\pi} = 0.30 \pm 0.25 \pm 0.04$$

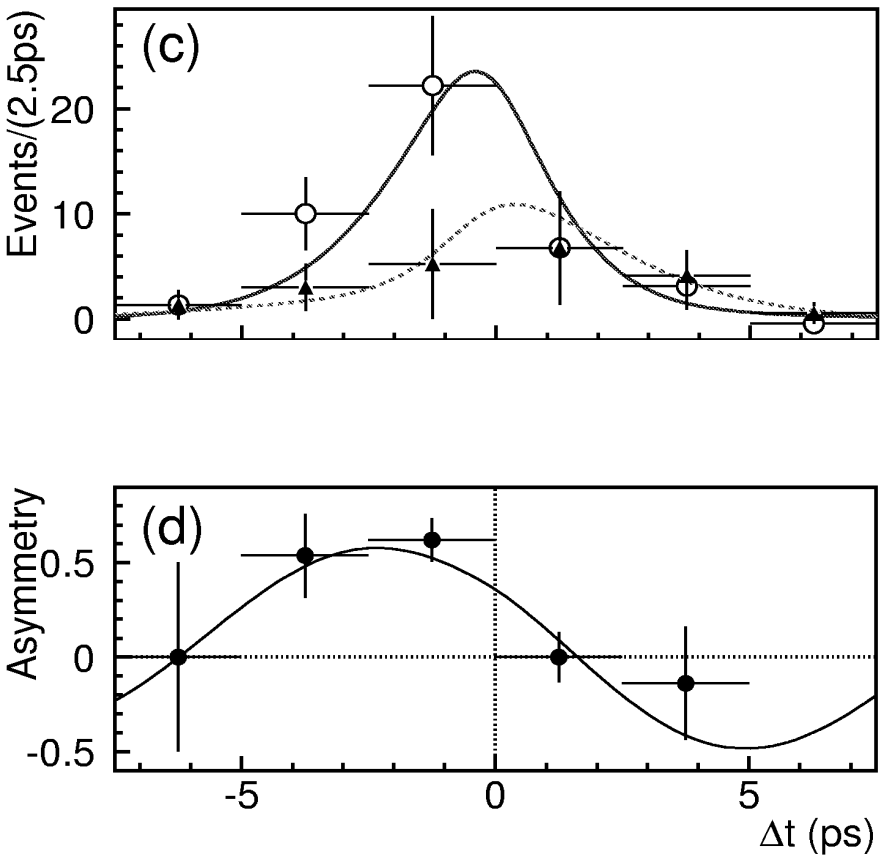
No indirect or direct CP violation in $B^0 \to \pi^+\pi^-$

- 90% C.L. $-0.54 < S_{\pi\pi} < 0.58$
- 90% C.L. $-0.12 < A_{\pi\pi} < 0.72$

Enhanced $B \to \pi\pi$ sample: Δt distributions and asymmetry between mixed and unmixed events.



Time-dependent fit results (Belle)



hep-ex/0204002, PRL 89 071801 (2002).

Each is 2.9σ from zero

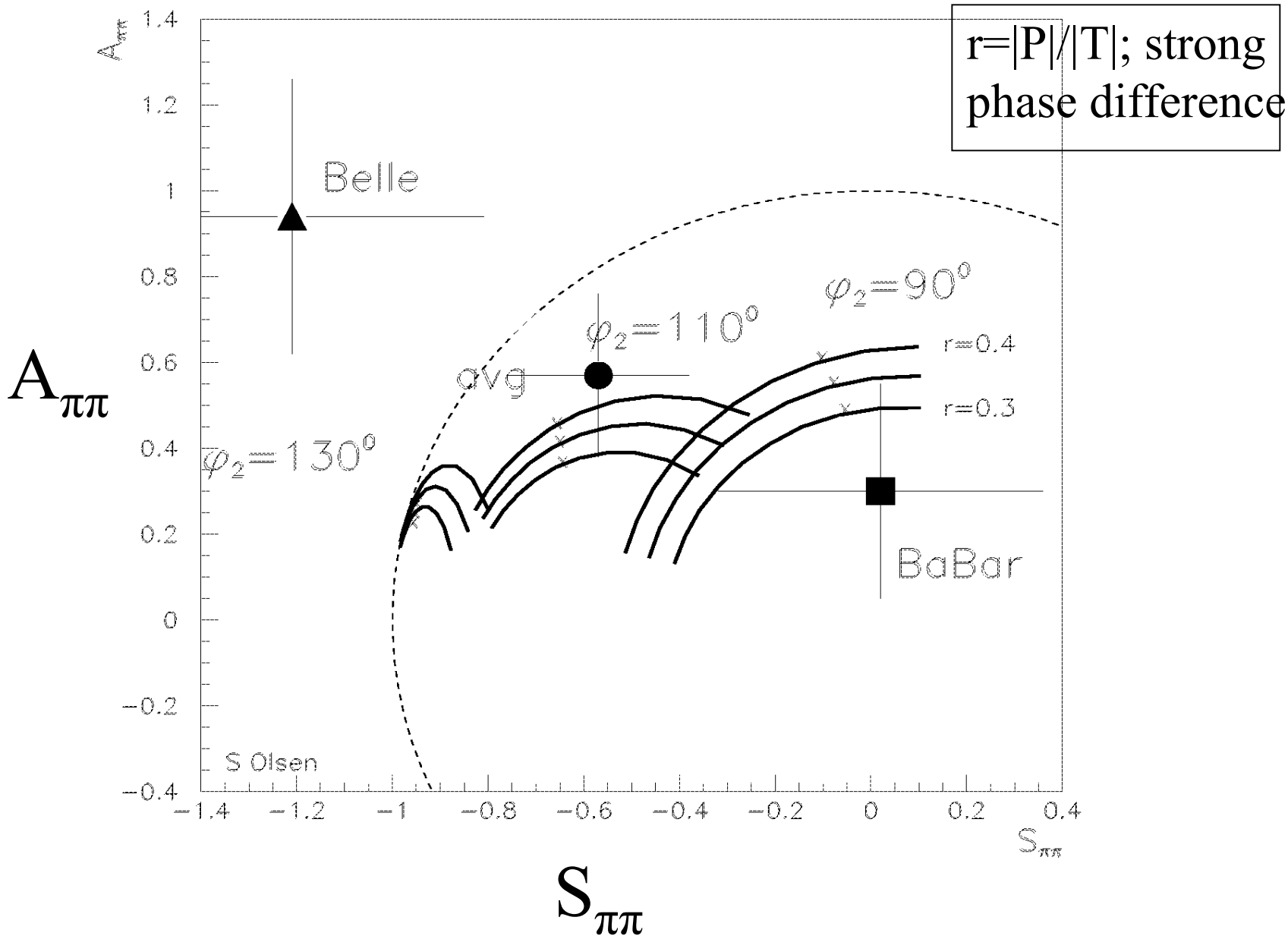
$$S_{\pi\pi} = -1.21 \begin{matrix} +0.38 \\ -0.27 \end{matrix} \begin{matrix} +0.16 \\ -0.13 \end{matrix}$$

$$A_{\pi\pi} = +0.94 \begin{matrix} +0.25 \\ -0.31 \end{matrix} \pm 0.09$$

(stat.) (syst.)

Indirect + Direct CPV asym.

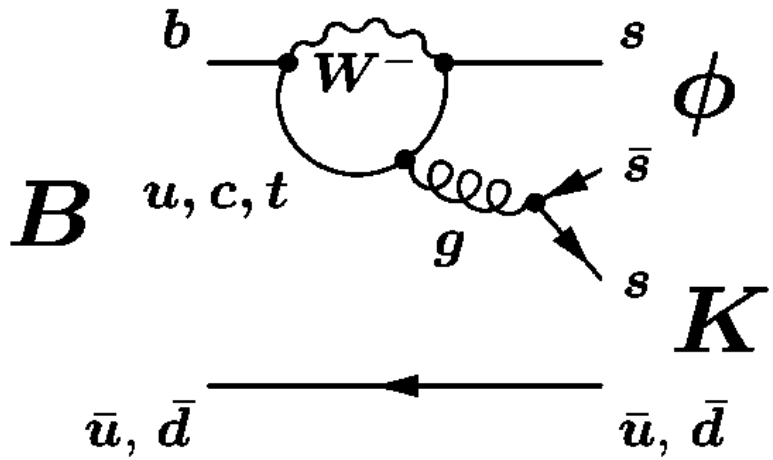
Comparison of ($S_{\pi\pi}$,$A_{\pi\pi}$) Results



Dreams of New Physics and Adventures with rare B decays.

Hunting for phases from new physics

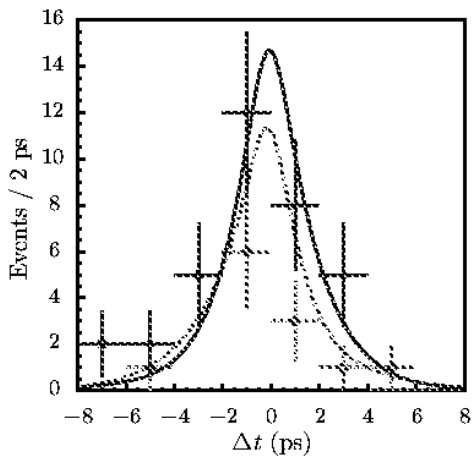
Example:

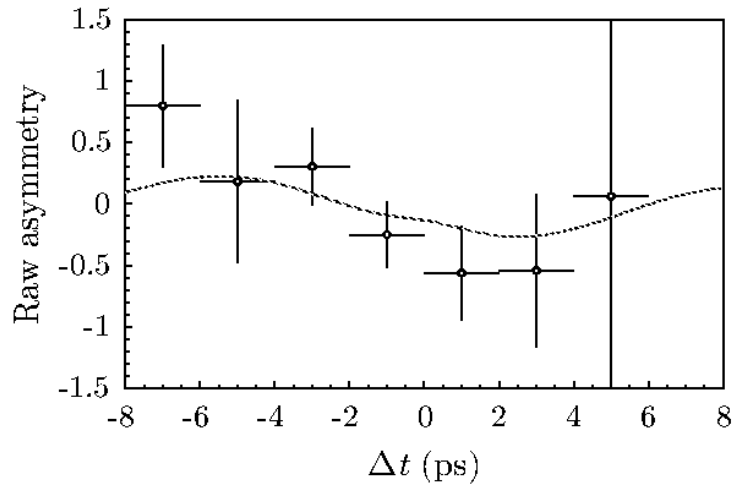


In the SM, $\sin(2\varphi_1)^{eff} = \sin(2\varphi_1)$ ($B \rightarrow \psi K_S$)

Hunting for new phases in b→s penguins

Belle





(hep-ph/0209290), J-P Lee, K. Y. Lee; (hep-ph/0208226) B. Dutta, C.S. Kim and S. Oh; (hep-ph/0208091), M. Raidal; (hep-ph/0208087), M. Ciuchini, L. Silvestrini; (hep-ph/0208016), A. Datta;(hep-ph/0208005), H. Murayama;(hep-ph/0207356), G. Hiller; (hep-ph/0207070), M-B. Causse; (hep-ph/0208080) Y. Nir .

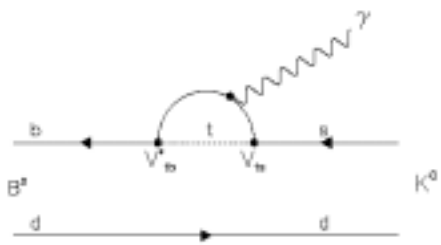
Belle: $\sin 2\varphi_{1\ \mathrm{eff}} = -0.73 \pm 0.64 \pm 0.20$

BABAR: $\sin 2\varphi_{1\mathrm{eff}} = -0.19 \pm 0.51 \pm 0.09$

2.7σ off

WA: $\sin 2\varphi_{1eff}(\varphi K_S) = -0.39 \pm 0.41$

The Hunt for the EW Penguin: $B \rightarrow X_s l^+ l^-$



Discovered by CLEO in 1994

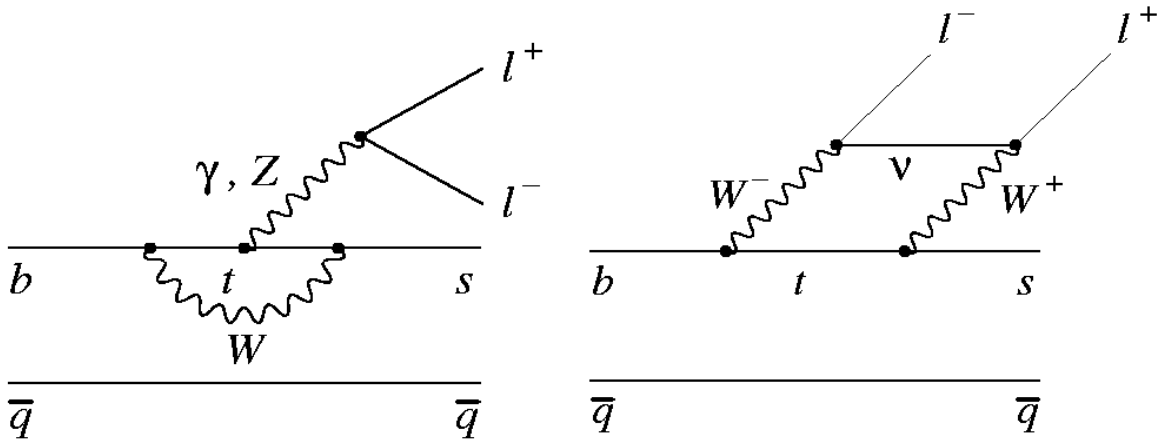
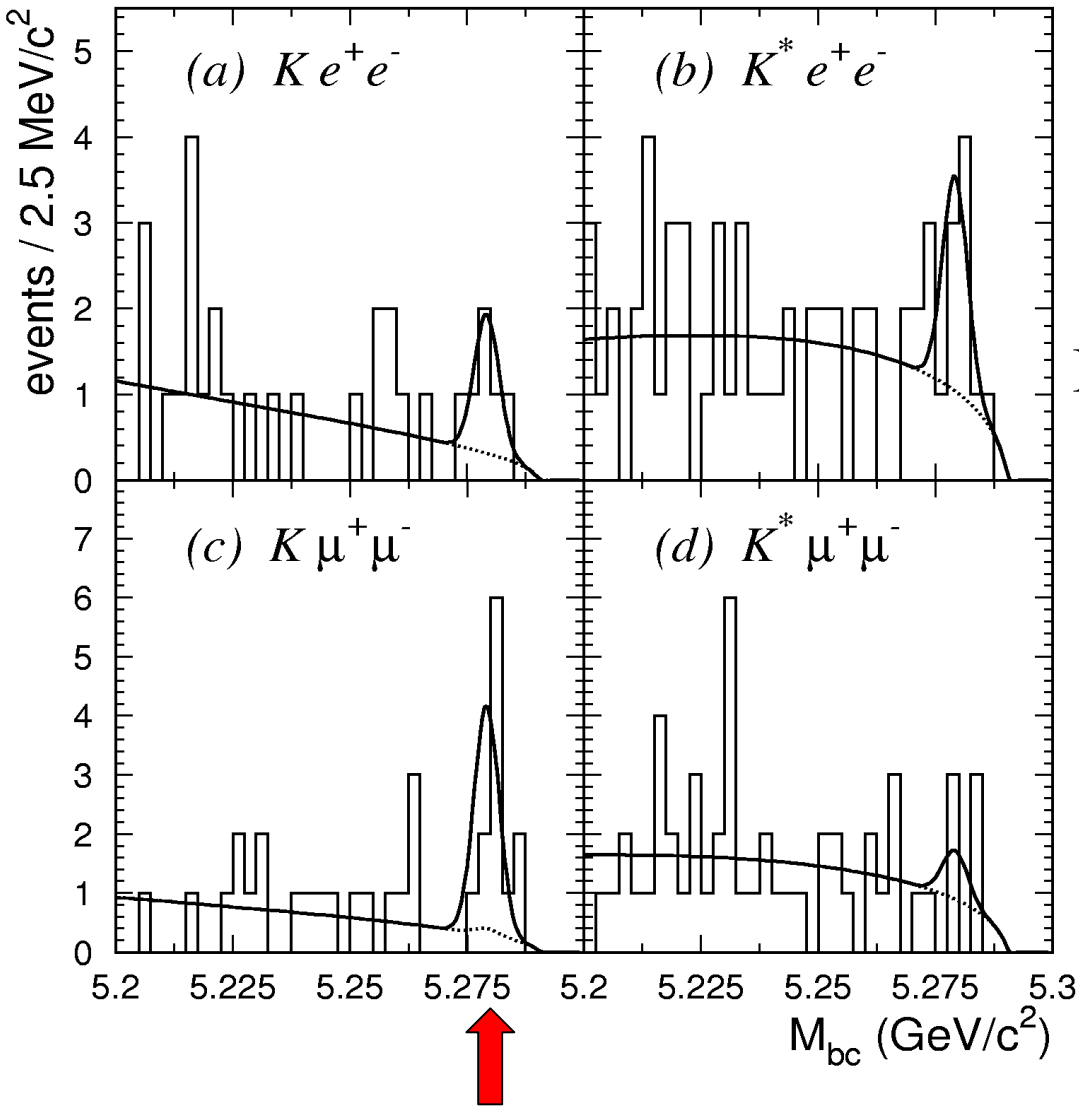


Figure 1: Standard Model diagrams for the decays $B \rightarrow K^{(*)}\ell^+\ell^-$.

As in $b \rightarrow s\,\gamma$, heavy particles in the loops can be replaced with NP particles (e.g. $W^+ \rightarrow H^+$)

Note contributions from virtual γ^*, W, Z^* and internal t quark.

Belle 2001: Observation of $B \rightarrow K l^+ l^-$



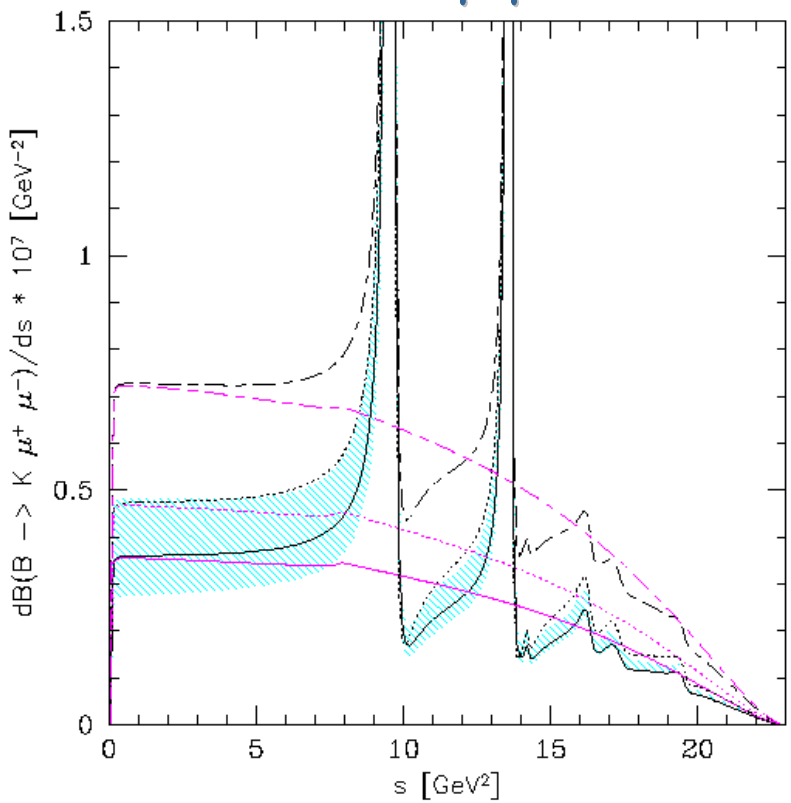
$$BF = (0.75^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6}$$

PRL 88, 052002 (2002)

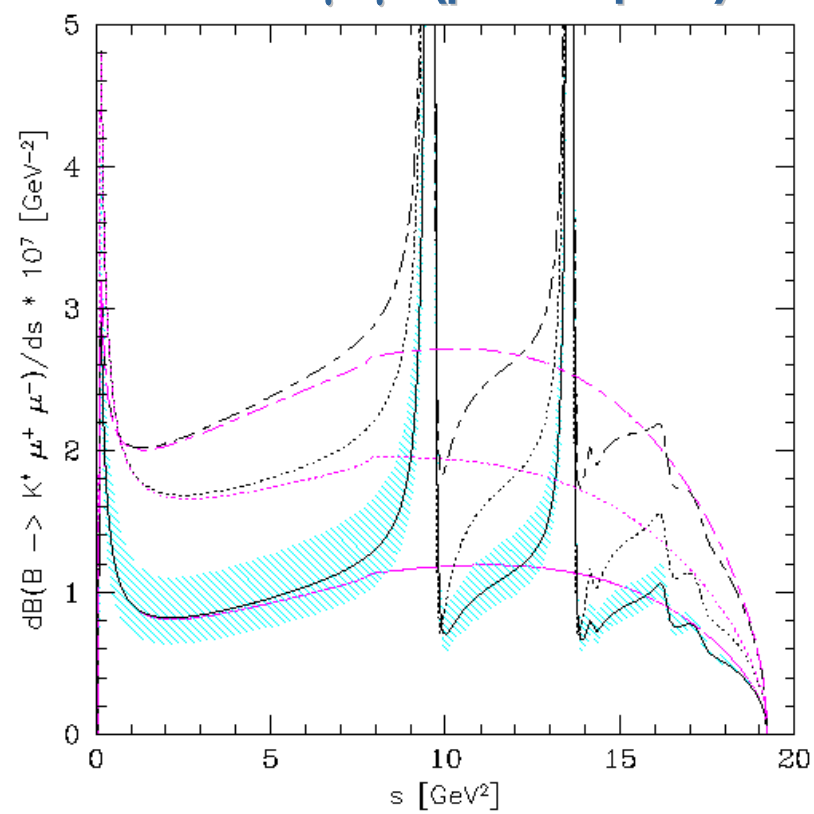
Recently confirmed by BaBar (preliminary)

Predicted distributions for $q^2 = M^2_{l+l-}$

***B* –> *K* $\mu^+\mu^-$:**



***B* –> *K**0 $\mu^+\mu^-$ (pole at $q^2 = 0$):**



- Solid line + blue bands: SM range ($\pm$ 35%); Ali et al. form factors
- Dotted line: SUGRA model (R_7 = -1.2, R_9 = 1.03, R_{10} = 1)
- Long-short dashed line: SUSY model (R_7 = -0.83, R_9 = 0.92, R_{10} = 1.61)

$m_{l^+l^-}$ distributions for $B \rightarrow K\, l^+\, l^-$

Belle 2002 (update)

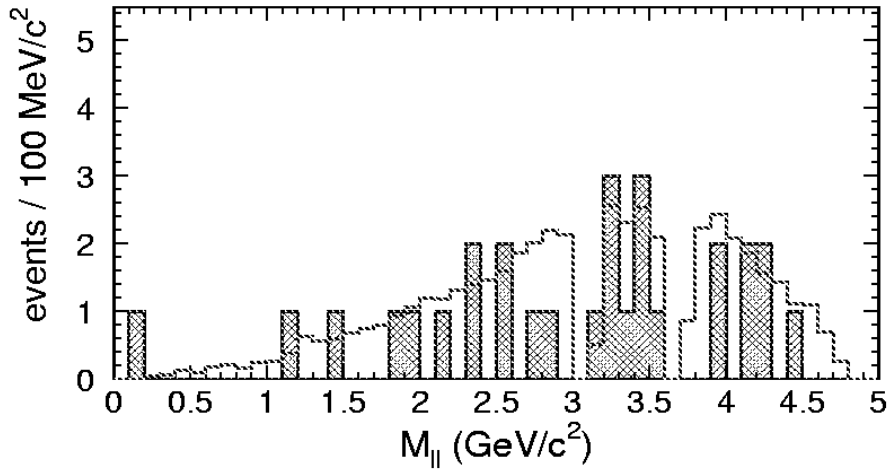


FIG. 5. The dilepton mass distributions for $B \rightarrow K\ell^+\ell^-$ candidates. The hatched histogram shows the data distribution while the open histogram shows the MC signal distribution.

Consistent with the SM. Statistics are low

Theoretical predictions: exclusive b→s $l^+ l^-$ modes

Authors	$\mathcal{B}(B\to Kl^+l^-)$ $/10^{-6}$	$\mathcal{B}(B\to K^*\mu^+\mu^-)$ $/10^{-6}$	$\mathcal{B}(B\to K^*e^+e^-)$ $/10^{-6}$
Ali *et al.* (2000)	$0.57^{+0.17}_{-0.10}$	$1.9^{+0.5}_{-0.4}$	$2.3^{+0.7}_{-0.5}$
Ali *et al.* (2001) [NNLO]	0.35 ± 0.12	1.19 ± 0.39	1.58 ± 0.49
Aliev *et al.* (1997)	0.31 ± 0.09	1.4	
Colangelo *et al.* (1996)	0.3	1.0	
Faessler *et al.* (2002)	0.55	0.81	
Geng and Kao (1996)	0.5	1.4	
Melikhov *et al.* (1998)	0.44	1.15	1.50
Zhong *et al.* (2002)	$0.69^{+0.28}_{-0.25}$	$1.98^{+0.66}_{-0.71}$	$2.01^{+0.65}_{-0.73}$

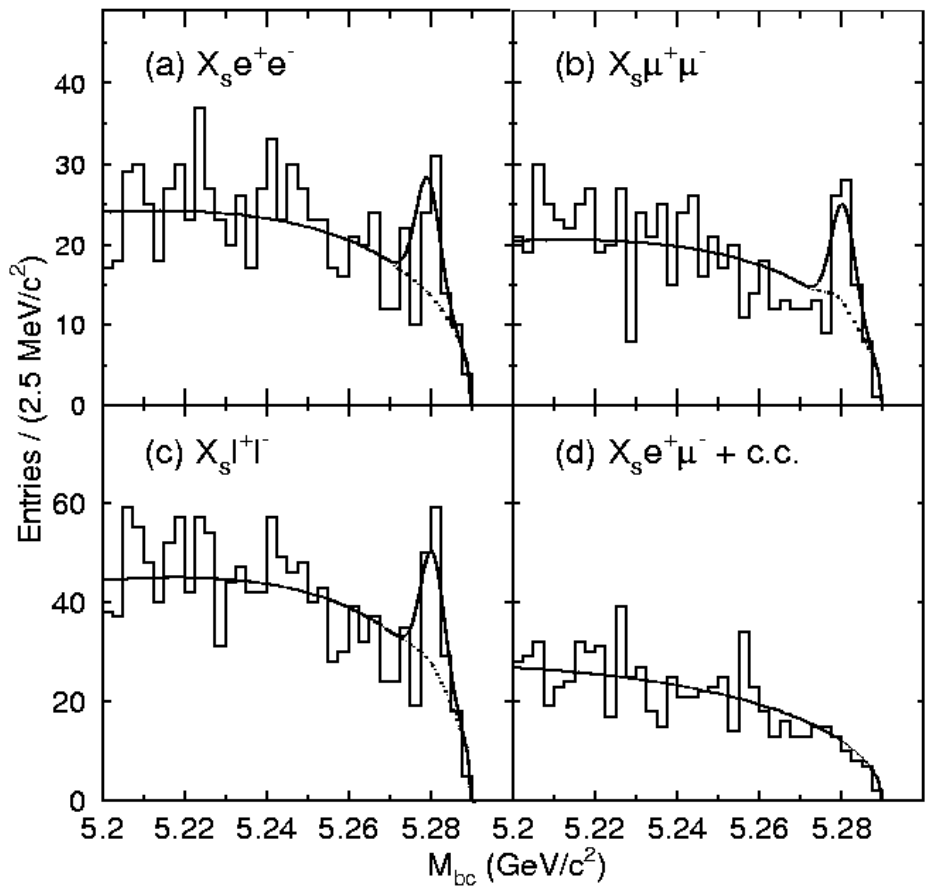
- $\mathcal{B}(B\to K\ell^+\ell^-) =$
  $(0.35 \pm 0.11(\text{form fac.}) \pm 0.04(\mu_b) \pm 0.02(m_{t,\text{pole}}) \pm 0.0005(m_c/m_b)) \times 10^{-6}$
  [Ali, Lunghi, Greub, Hiller, hep-ph/0112300, 2001]

dominant uncertainty: form factors

New calculations of QCD corrections predict too high a rate for B->K*γ; the necessary adjustment of T_1 form factor lowers the prediction for *B->K*l⁺l⁻*.

Belle 2002: Observation of *inclusive* $B \rightarrow X_s l^+ l^-$

25.5±11.2

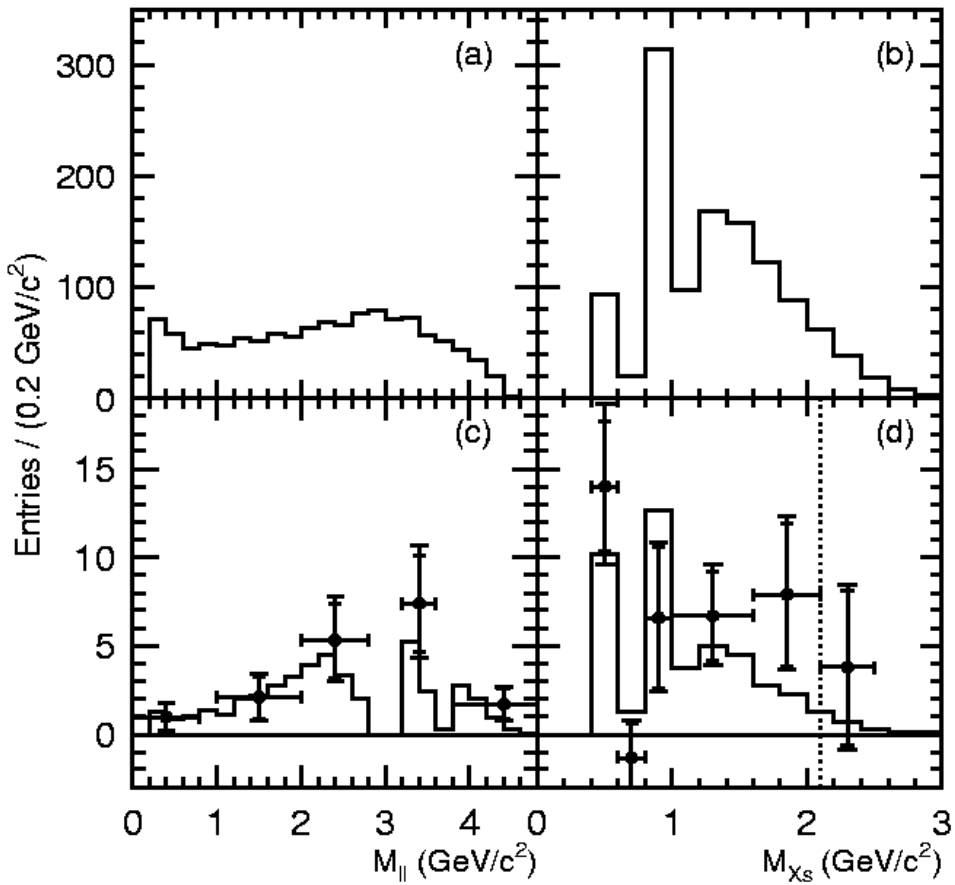


37.3±9.7

Control sample

$$BF(B \rightarrow X_s l^+ l^-) = (6.1 \pm 1.4^{+1.3}_{-1.1}) \times 10^{-6}$$

Belle 2002: M_{ll} and M_{Xs} distributions for $B \rightarrow X_s l^+ l^-$

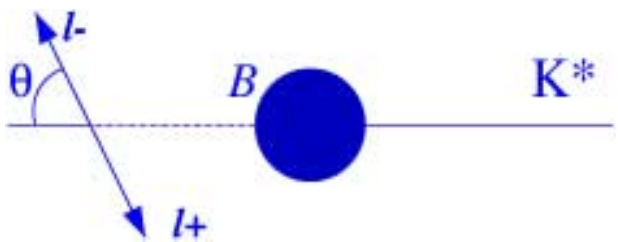


MC generator

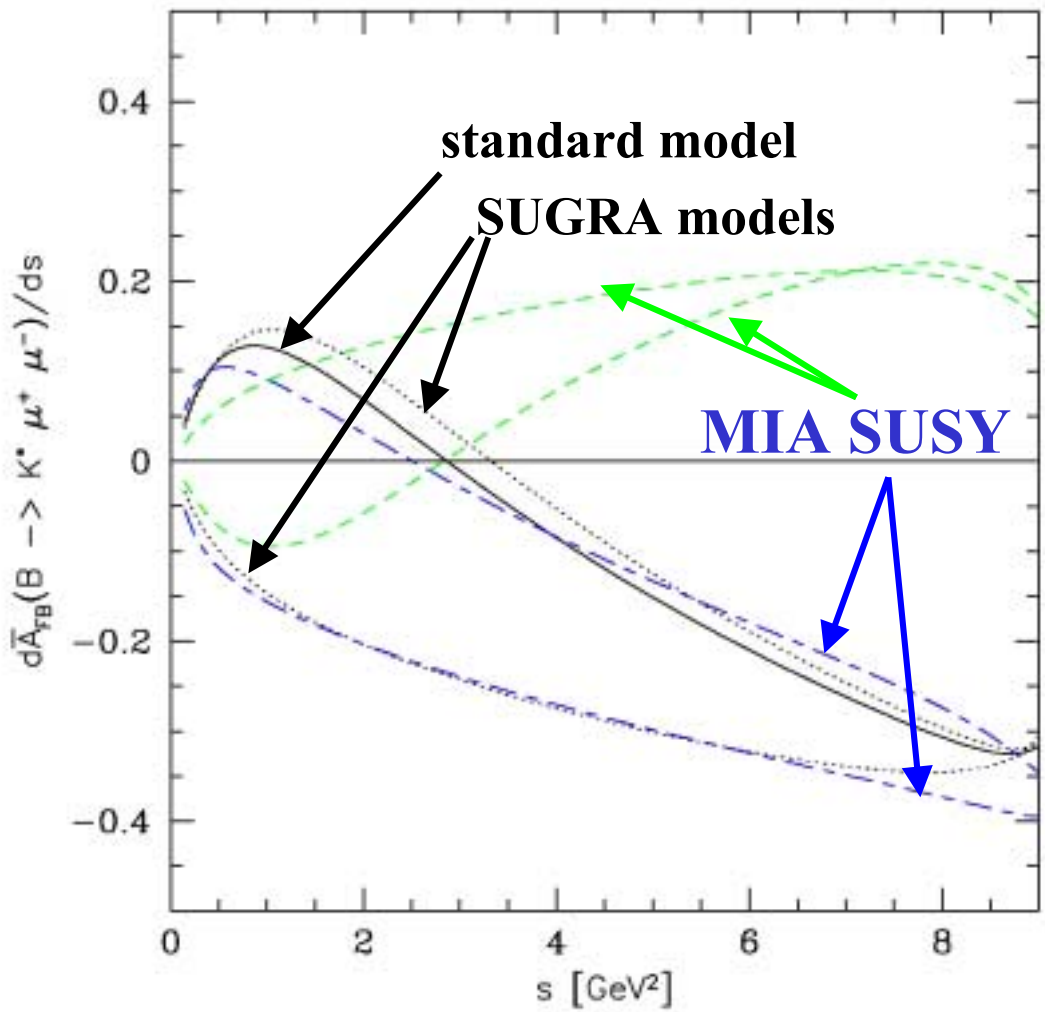
Data vs MC

hep-ex/0208029, submitted to PRL

Sensitivity to new physics in A_{FB} ($B \rightarrow K^* l^+ l^-$)



Polar angle of lepton in dilepton rest frame.



q^2(GeV^2)

A. Ali *et al.*, PRD 61, 074024 (2000).

Super KEKB, PEP-II, L=$10^{35\text{-}36}$/cm^2/sec;

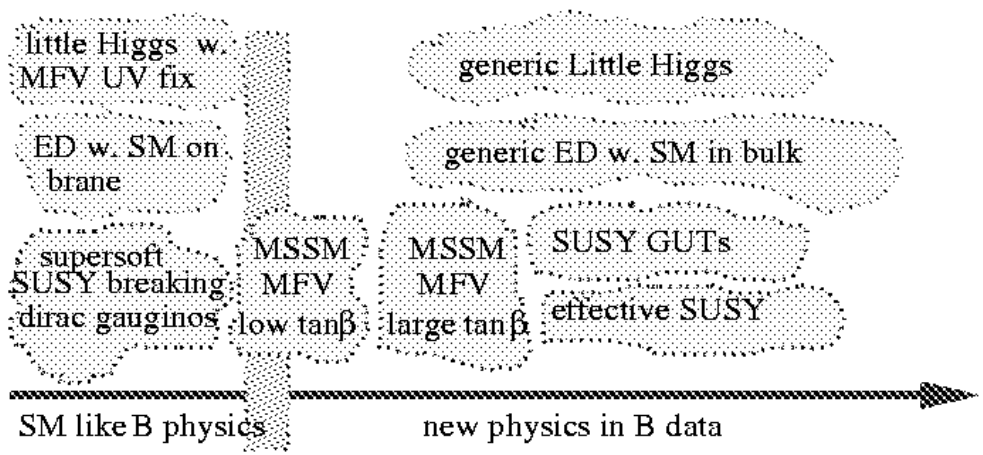


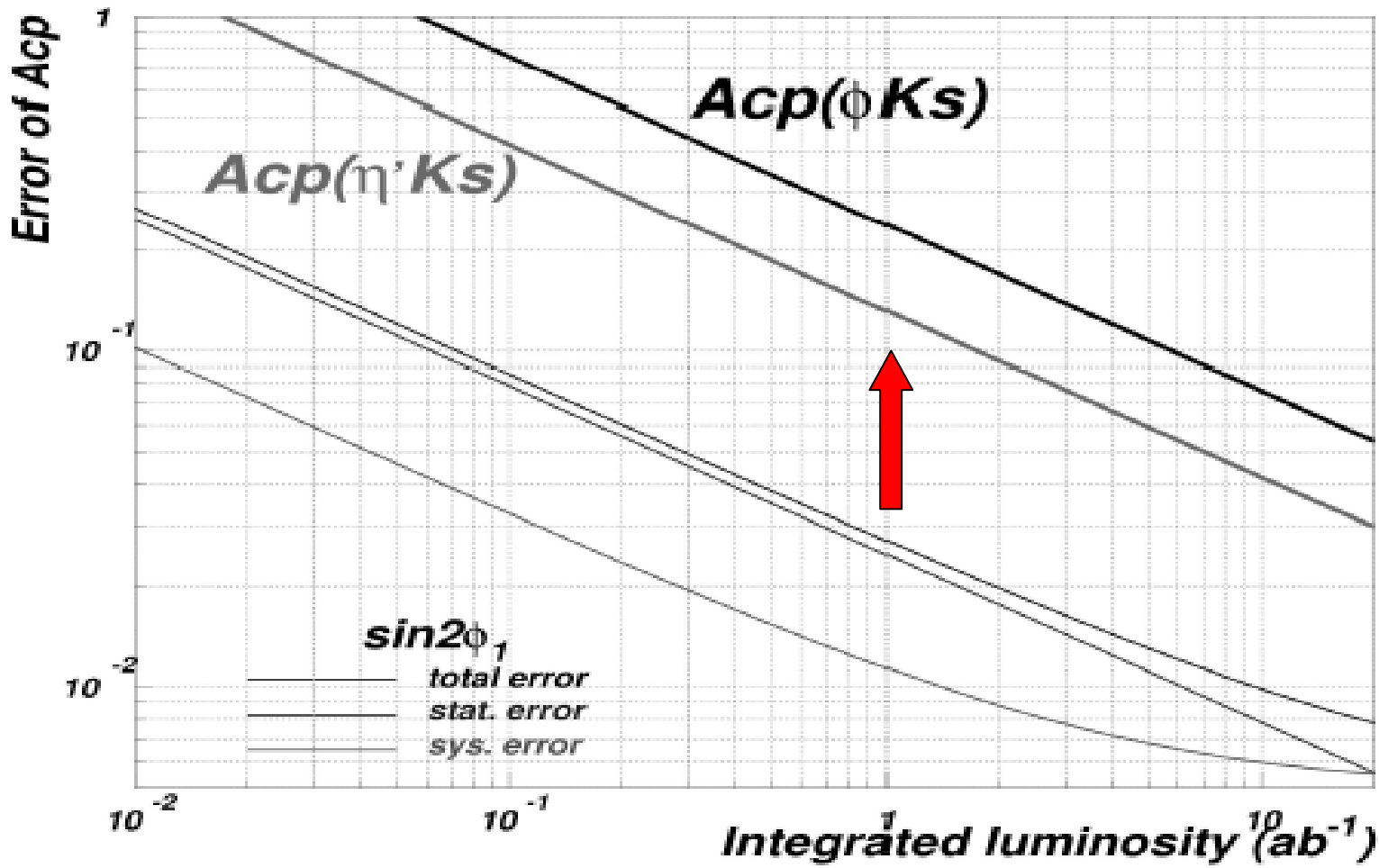
Figure 4. Flavor/CP yield of models of electroweak symmetry breaking.

G. Hiller

Scenarios for flavor physics beyond the SM.

Signatures in time-dependent CPV (φ K_S) , rare decays (e.g. $b \rightarrow s\, l^+ l^-$, $b \rightarrow s\, \gamma$)

Sensitivity to new physics phases



Super KEKB design parameters

Machine Parameters of the SuperKEKB

	LER	HER	
Horizontal Emittance	33	33	nm
Vertical Emittance	2.1	2.1	nm
x-y coupling	6.4	6.4	%
Beam current	9.4	4.1	A
Number of bunches	5018 (2% abort gap)		
Bunch current	1.87	0.817	mA
Bunch spacing	0.6		m
Half crossing angle	15		mrad
Luminosity reduction R_L	0.748		
$\tilde{\xi}_x$ reduction $R_{\tilde{\xi}x}$	0.691		
$\tilde{\xi}_y$ reduction $R_{\tilde{\xi}y}$	0.916		
Bunch length	3	3	mm
Radiation loss U_0	1.23	3.48	MeV/turn
Betatron tune ν_x / ν_y	45.515/43.57 ?	44.515/41.57 ?	
beta's at IP β_x^* / β_y^*	15/0.3	15/0.3	cm
beam-beam parameters ξ_x / ξ_y	0.068/0.05	0.068/0.05	
Beam lifetime	~150	~150	min.
Luminosity	1.0		$10^{35}/cm^2/sec$

KEKB Intermediate Upgrade

		Present KEKB		KEKB NS (Step 2)	
		LER	HER	LER	HER
Luminosity	$10^{33}/cm^2/sec$	8.3		15	
I beam	A	1.57	0.94	2.6	1.5
$\beta x/\beta y$	cm/mm	59/6.2	63/7	60/5	60/5
$\xi x/\xi y$		0.082/0.050	0.073/0.041	0.08/0.05	0.08/0.05
Bunch spacing	nm	8		4	
Bunch length	mm	7.5	7	5	5
Crab cavity		No	No	in operation	in operation
Abort gap	%	5	5	2.5	2.5

Updated History

- **1963 CP violation seen in K^0 system**
- **1973 KM 6-quark model proposed**
- **1974 charm (4th) quark discovered**
- **1978 beauty/bottom (5th) quark discovered**
- **1995 truth/top (6th) quark discovered**
- *2001 CPV in B-meson decays discovered*

Poetic Conclusion for FNAL

‘Beauty is truth, truth beauty’ - that is all

Ye know on earth, and all ye need to know

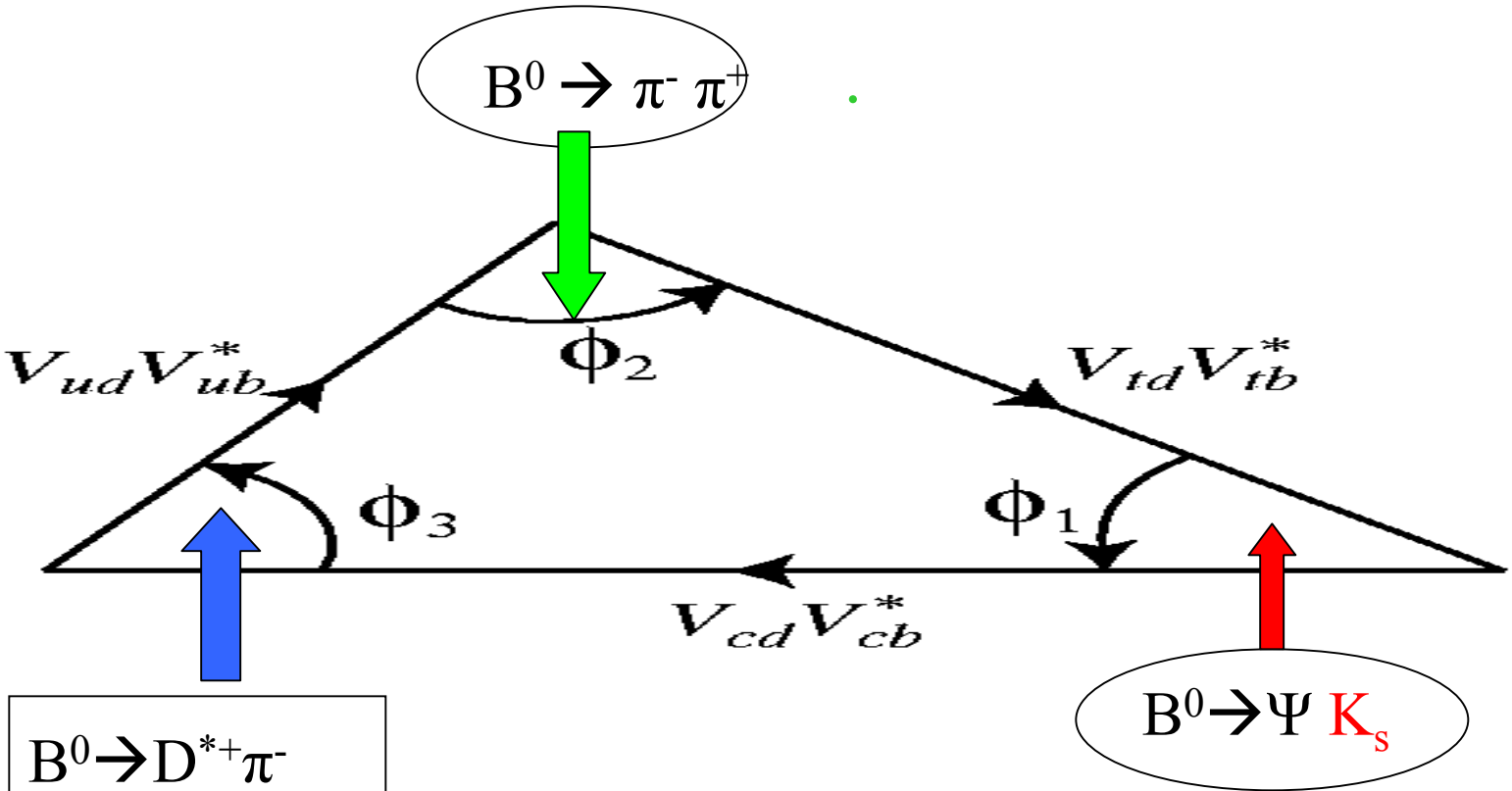
John Keats (1795-1821)

Backup Slides

The Wolfenstein parameterization of the CKM matrix

$$\begin{pmatrix} Vud & Vus & Vub \\ Vcd & Vcs & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Three Angles: ($\varphi_1,\varphi_2,\varphi_3$) or ($\beta,\alpha,\gamma$)

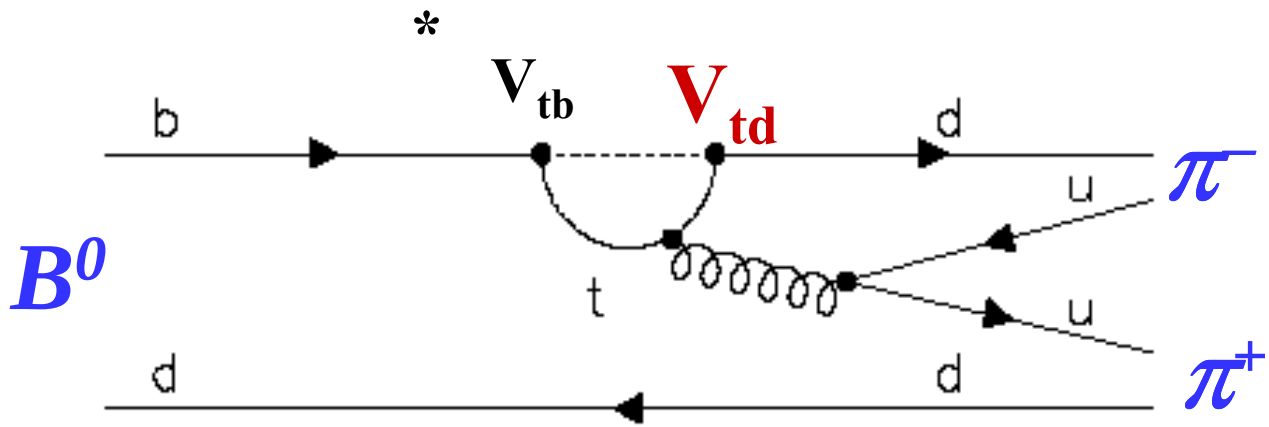


$B^0 \rightarrow D^{*+}\pi^-$

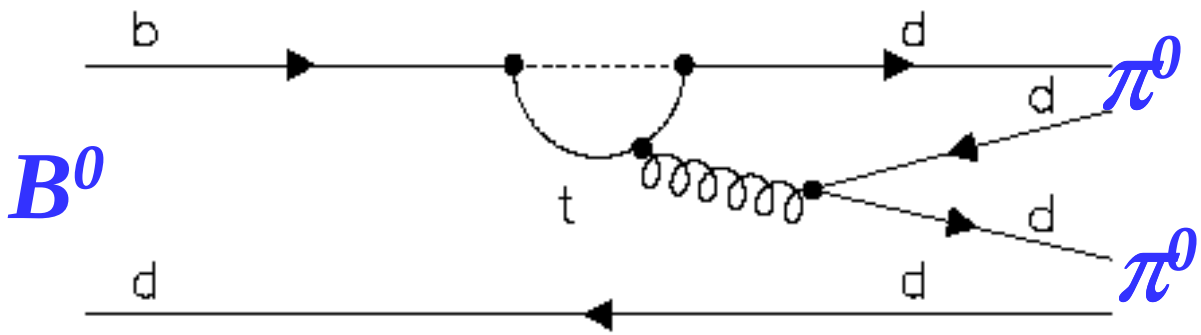
$B^0 \rightarrow D^{*+}\rho^-$

$B^- \rightarrow D_{CP} K^{(*)-}$

Must deal with "Penguin Pollution"



e.g. use $B \rightarrow \pi^0 \pi^0$ to determine size of penguin effects:



(SM:~10^{-6})

Branching Fractions for B→π π Modes

If all three B→π π modes are measured, an isospin analysis allows the additional strong phase δ to be determined. Can then extract $\sin(2\,\varphi_2)$.

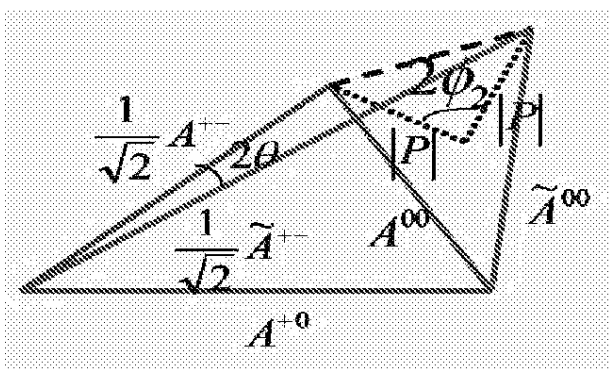


FIG. 10. The A and $\tilde{A}$ isospin triangles.

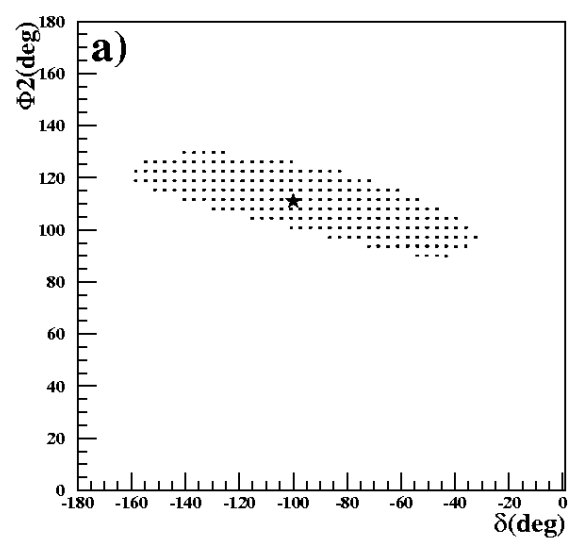
M. Gronau and D.London. PRL 65, 2381 (90)

Interpretations of $B \rightarrow \pi^+ \pi^-$ results

H. Sagawa (KEK), assume P/T=0.276±0.06

Average Belle+Babar results. Fit following Gronau and Rosner:

➔ $\varphi_2 = 111 \pm 16 \pm 4^0$ and $\delta = -110^{+62}_{-53} \pm 8^0$



Time-dependent fit checks (Babar)

Fit checked using toy MC studies:

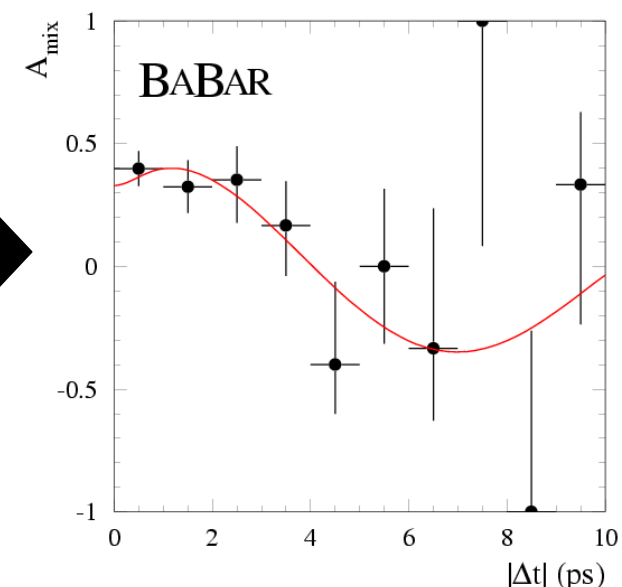
- All parameters unbiased
- All errors consistent with expectations
- Likelihood value (goodness of fit) consistent with expectations

Fit holds B lifetime and mixing constant: cross check by fitting

$\tau_B = 1.66 \pm 0.09$ ps

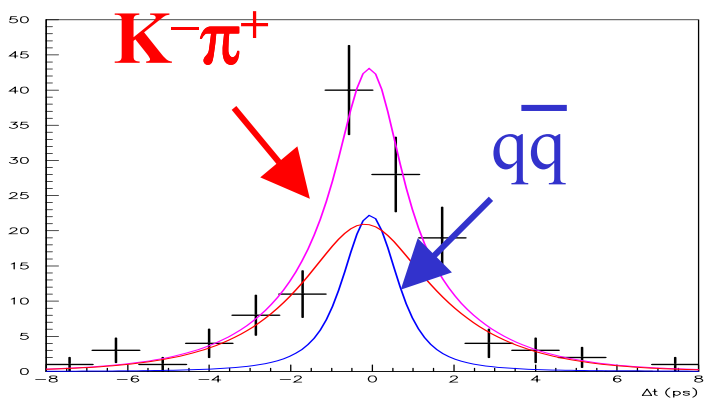
$\Delta m_d = 0.517 \pm 0.062$ ps^{-1}

Enhanced $B \rightarrow K\pi$ sample: asymmetry between unmixed and mixed events.



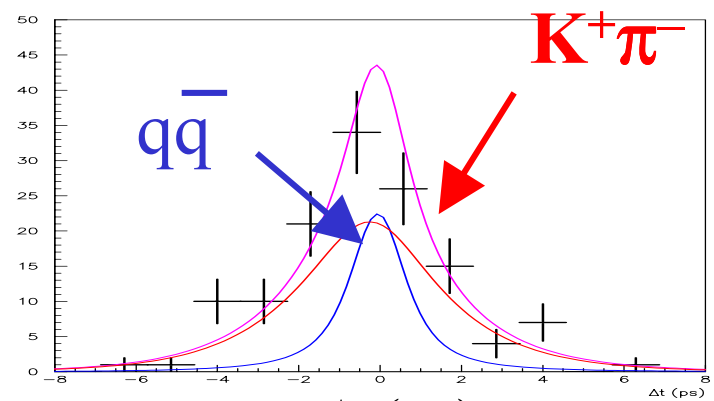
Asymmetry for $K^+\pi^-$ Control (Belle)

B^0 tagging



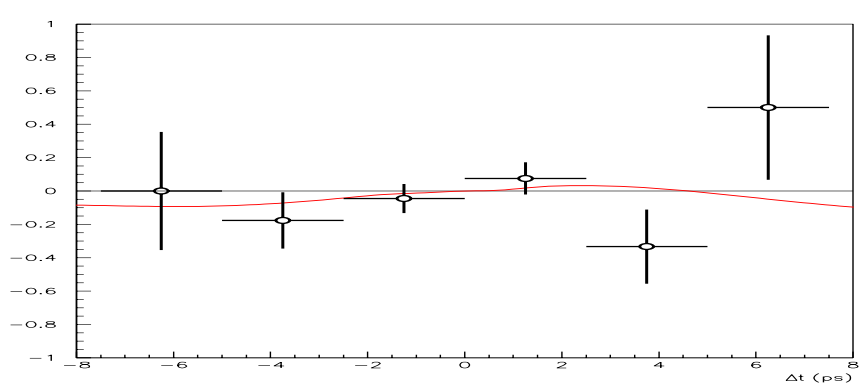
Δt(ps)

$\overline{B}^0$ tagging



Δt(ps)

A(Δt)



Δt(ps)

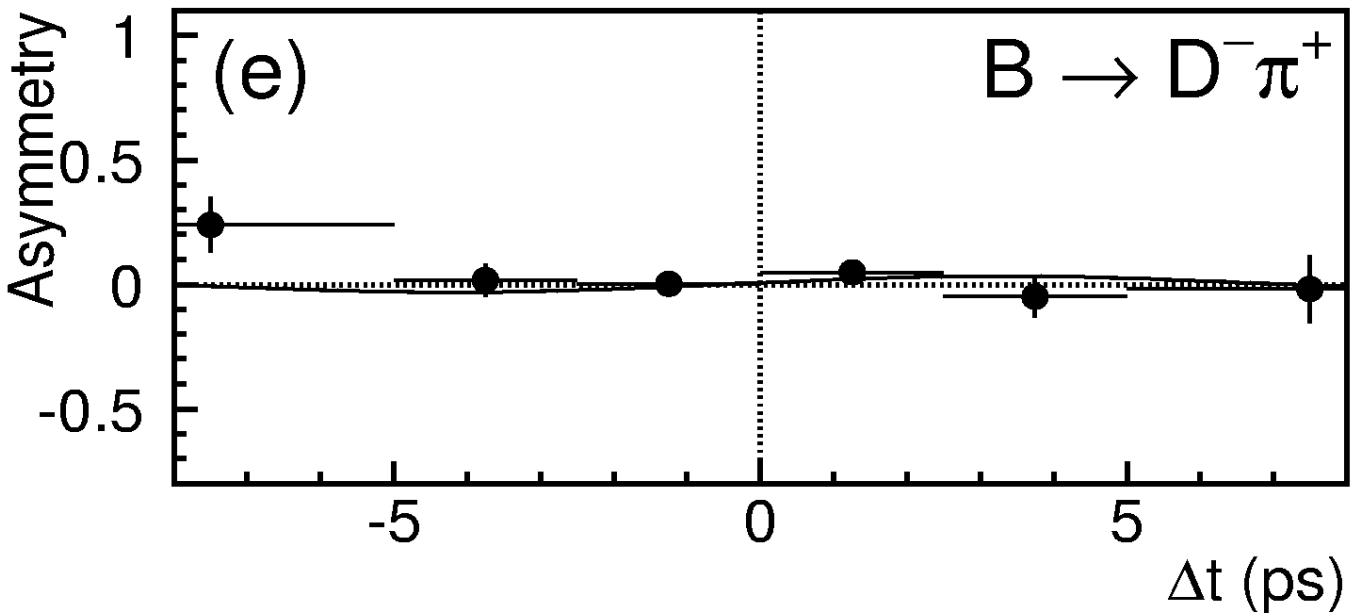
	$K^+\pi^-$
τ_B(ps)	1.73 ± 0.15
$\Delta m(ps^{-1})$	0.57 ± 0.08
S	0.15 ± 0.24
A	(0.07 ± 0.17)

$B^0 \rightarrow D^{(*)+} \pi$ control samples (Belle)

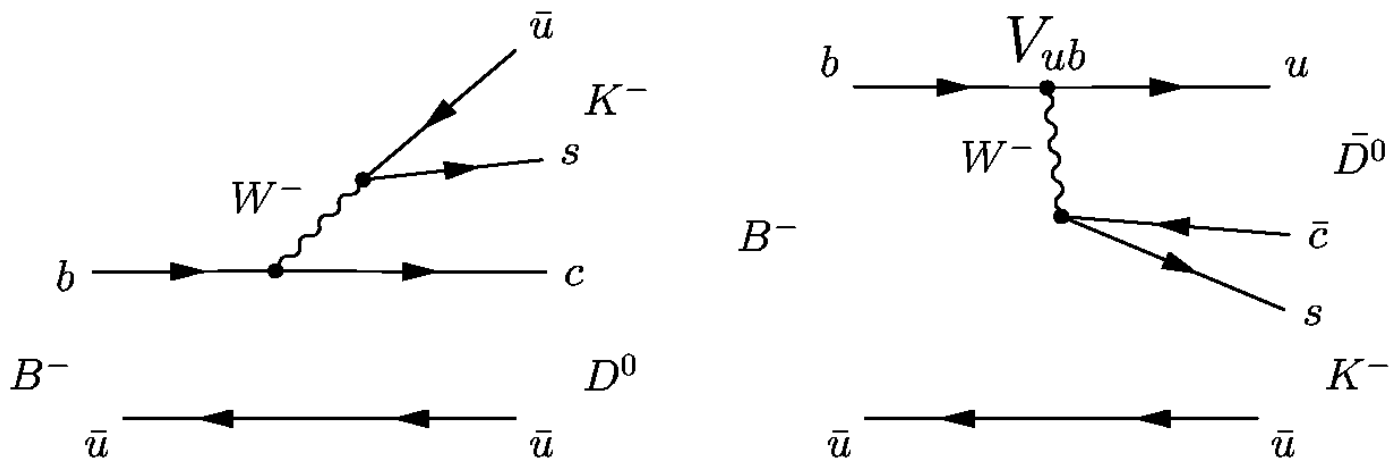
TABLE IX. CP fit results for control samples.

	$D^-\pi+$	$D^{*-}\pi^+$	$D^{*-}\rho^+$	Combined
# of fitted events	1978	1818	1752	
$\mathcal{A}_{\pi\pi}$	0.01 ± 0.06	-0.03 ± 0.06	-0.10 ± 0.07	
$\mathcal{S}_{\pi\pi}$	0.09 ± 0.09	0.13 ± 0.09	-0.04 ± 0.10	
Bkg. Enriched				
# of fitted events	4879	4795	4689	14363
$\mathcal{A}_{\pi\pi}$	0.04 ± 0.06	0.04 ± 0.06	-0.03 ± 0.07	0.03 ± 0.04
$\mathcal{S}_{\pi\pi}$	0.01 ± 0.09	0.12 ± 0.09	-0.03 ± 0.10	0.08 ± 0.06
Corr.Coef.	-0.050	-0.026	-0.022	0.029

Bkg enriched

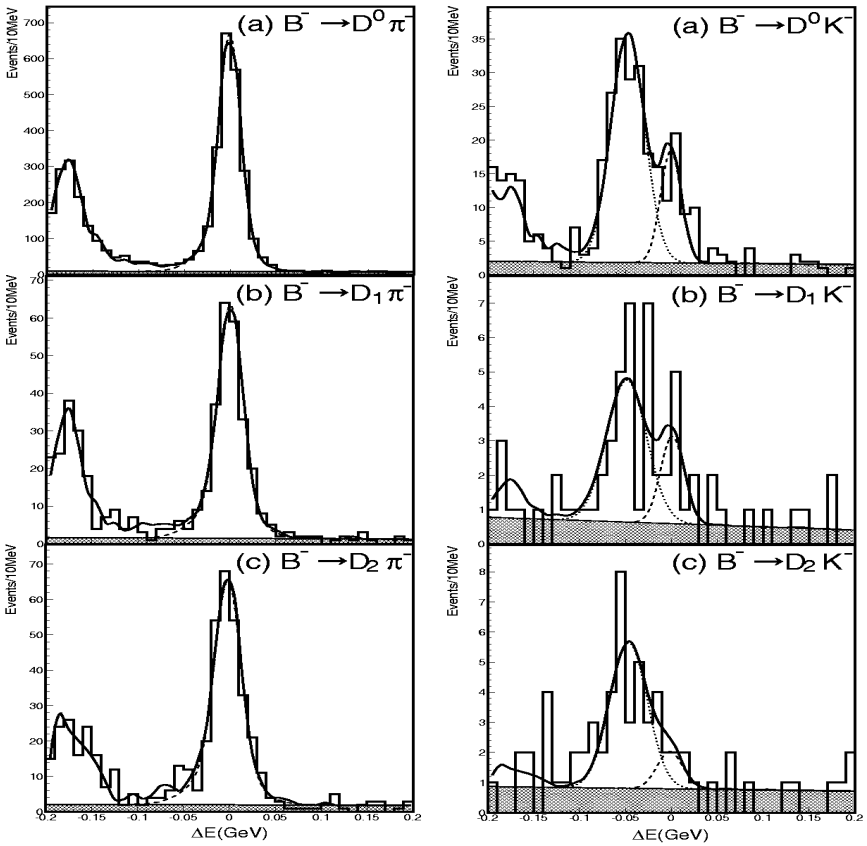


Measuring φ_3 (γ) in $D_{CP} K^-$ decays



When the D meson decays to a CP eigenstate, the two diagrams interfere. The interference depends on the phase of V_{ub} i.e. φ_3

BFs and Direct CPV in D_{CP} K^-



155.2+-13.6 D^0 ->K^- π^+

22.5+-5.7 CP=+1

24.7+-6.1 CP=-1

BELLE-CONF-0108,

hep-ex/nnnn

$\sin(2\varphi_1 + \varphi_3)$ from $B^0 \to D^{*+}\pi^-$

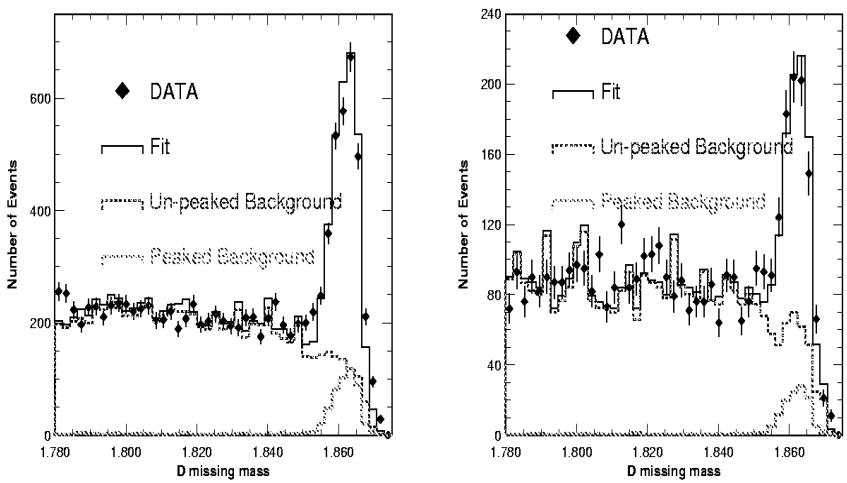
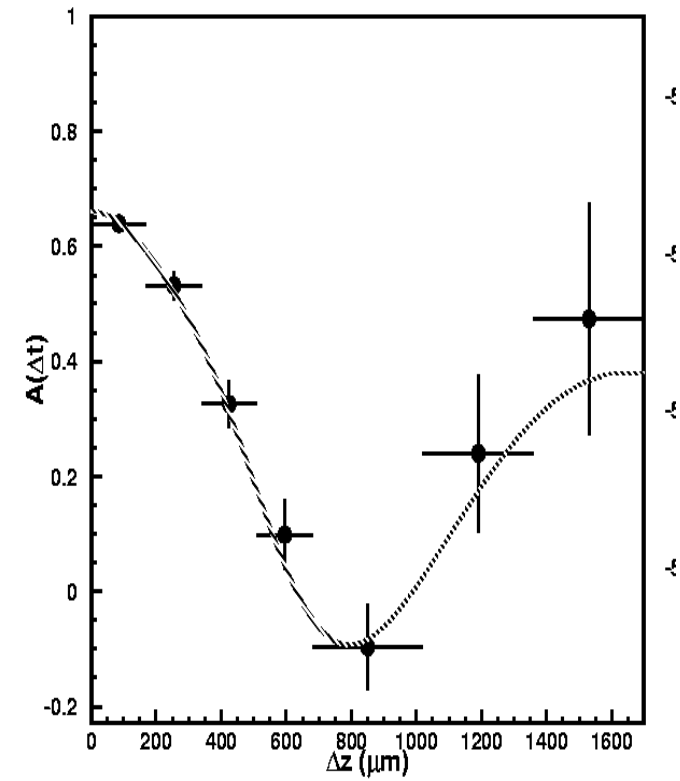


Figure 6: D^0 missing mass(GeV) distribution for $B^0 \to D^{*-}h^+$ opposite flavor final state(left plot) and same flavor final state(right plot)

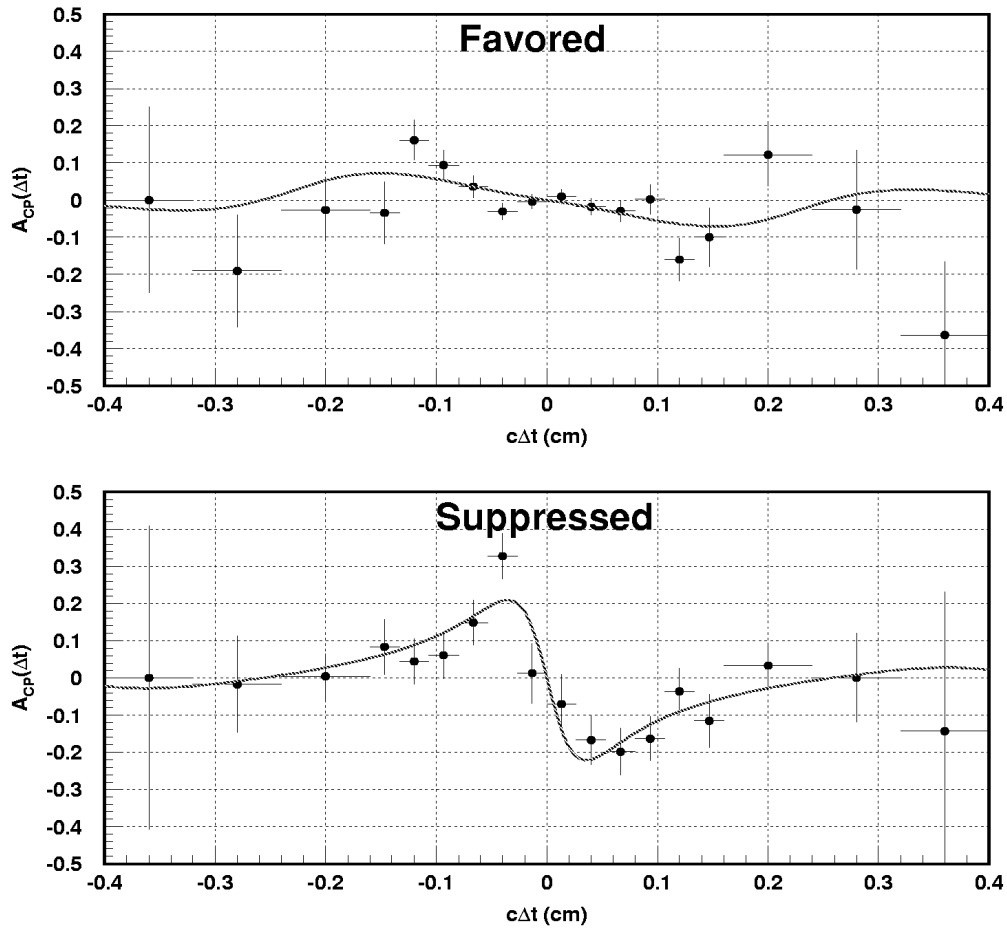


mixing freq Δm=0.517+-0.017(stat)+-0.019(sys)

PRD in preparation.

$\sin(2\varphi_1 + \varphi_3)$ from $B^0 \to D^{*+}\pi^-$

MC results



Sensitivity is +-0.34 with 200 fb^{-1}