Experimental Review on Weak Decays, CP Violation and CKM

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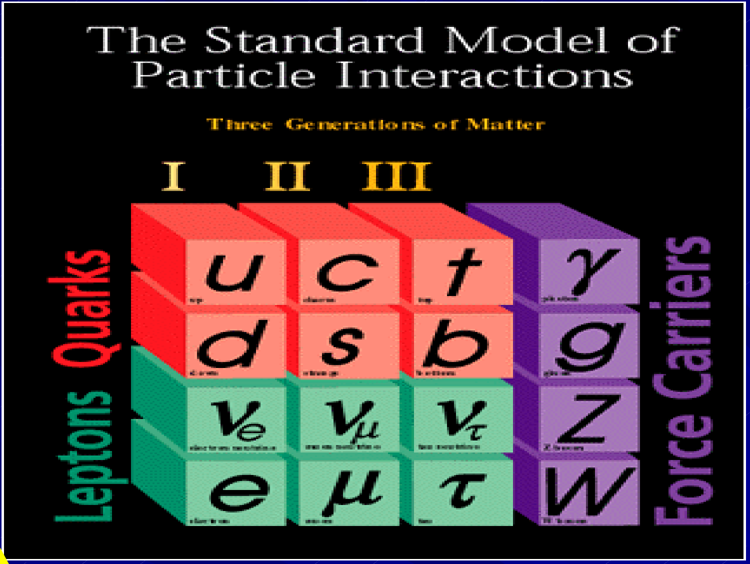
Quark Flavor Physics

- Players: K, D, B mesons and many baryon partners



- Physics targets:
  - CP violation
  - CKM
    precise test of SM
  - Rare processes
    FCNC
    LFV

  etc.

Detailed & Precise Survey of SM particles

→ Evidence of New Physics !

Experimental Activities

SO MANY and WIDE !

- High energy machines
  LEP, Tevatron, LHC
- Proton drivers
  AGS, KEK-PS, JPARC
- e+e- machines
  CESR, KEKB, PEPII, Super-B
  Frascati

L3
DELPHI
CDF D0 ALEPH
OPAL
FOCUS KTeV
SELLEX
NA48
E787 E949 KOPIO
E391a CKM
CLEO-c KLOE
CLEO LHCb
Belle
BaBar BTeV

My Apology in advance: I CANNOT cover all of these !

Brief History

Predictions and Discoveries after my birth (1964)!

Time = My age

1964 CPV in KL→$\pi^+\pi^-$

1973 Kobayashi – Maskawa

6 quarks - - - - - - - - - 1974 Charm

Direct CPV

1977 Bottom

1981 Carter – Sanda

Large CPV in B system

1994 Top

1999 Direct CPV in K system

Next slide

2001 Large CPV in B system

All major predictions of KM now confirmed.

⇨ What comes next ?

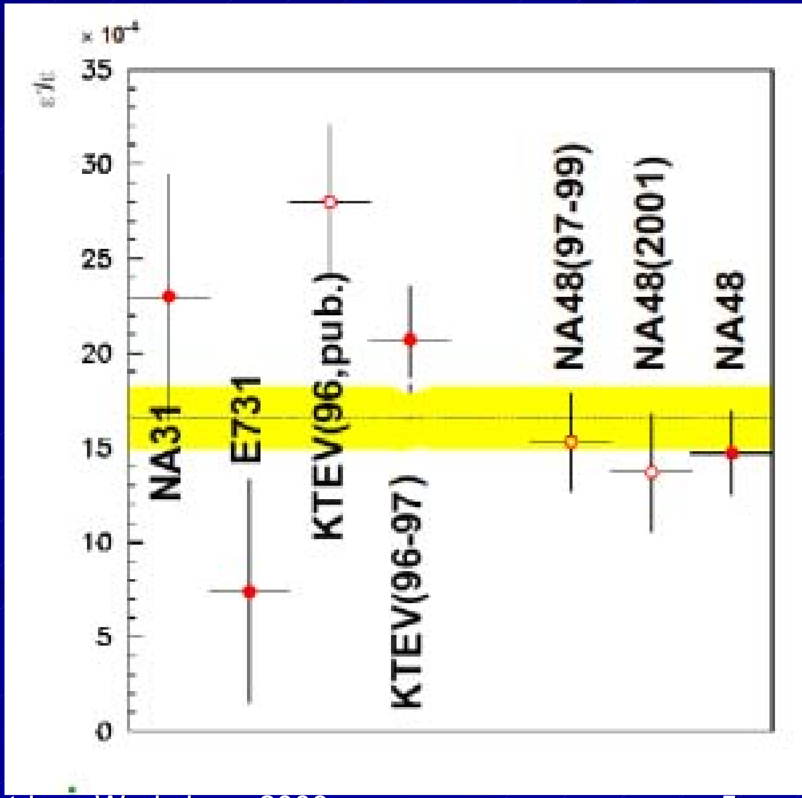
Direct CPV in K

- NA48 (CERN) and KTEV (FNAL)
- Double ratio

$$\frac{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)} = 1 + 6\,\mathrm{Re}\frac{\epsilon'}{\epsilon}$$

- Simultaneous logging of all the 4 modes
- The most updated result

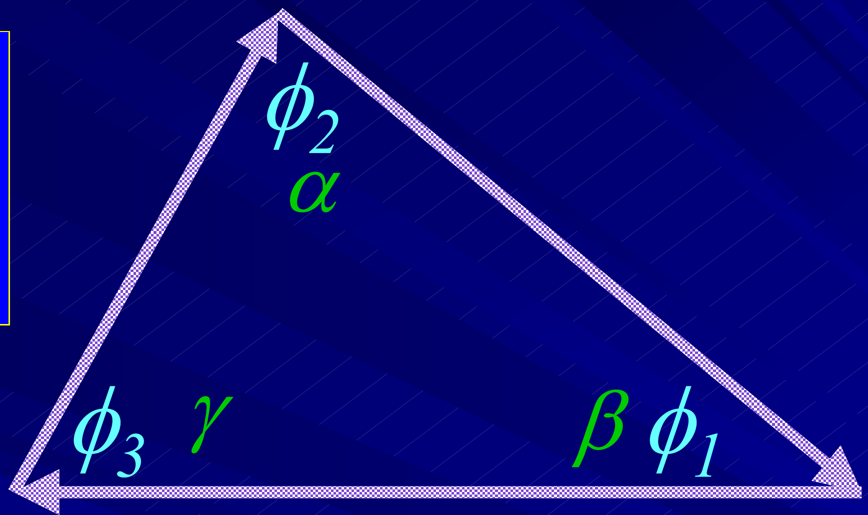
$$\mathrm{Re}\frac{\epsilon'}{\epsilon} = \begin{cases} (14.7 \pm 2.2) \times 10^{-4} \\ \qquad (NA48\text{: full data, } PL\text{,2002}) \\ (20.7 \pm 2.8) \times 10^{-4} \\ \qquad (E832\text{: partial data, } PRD\text{,2003}) \end{cases}$$

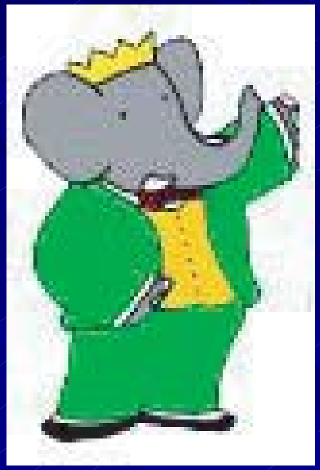


- No meaningful CKM contraint because of hadronic uncertainty

Note

BELLE





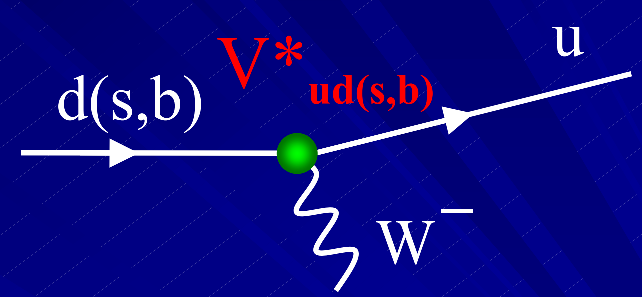
$$(\phi_1, \phi_2, \phi_3) \equiv (\beta, \alpha, \gamma)$$

$$A_f = -C_f$$

CP Violation in SM

Weak eigenstate — Mass eigenstate

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



Wolfenstein

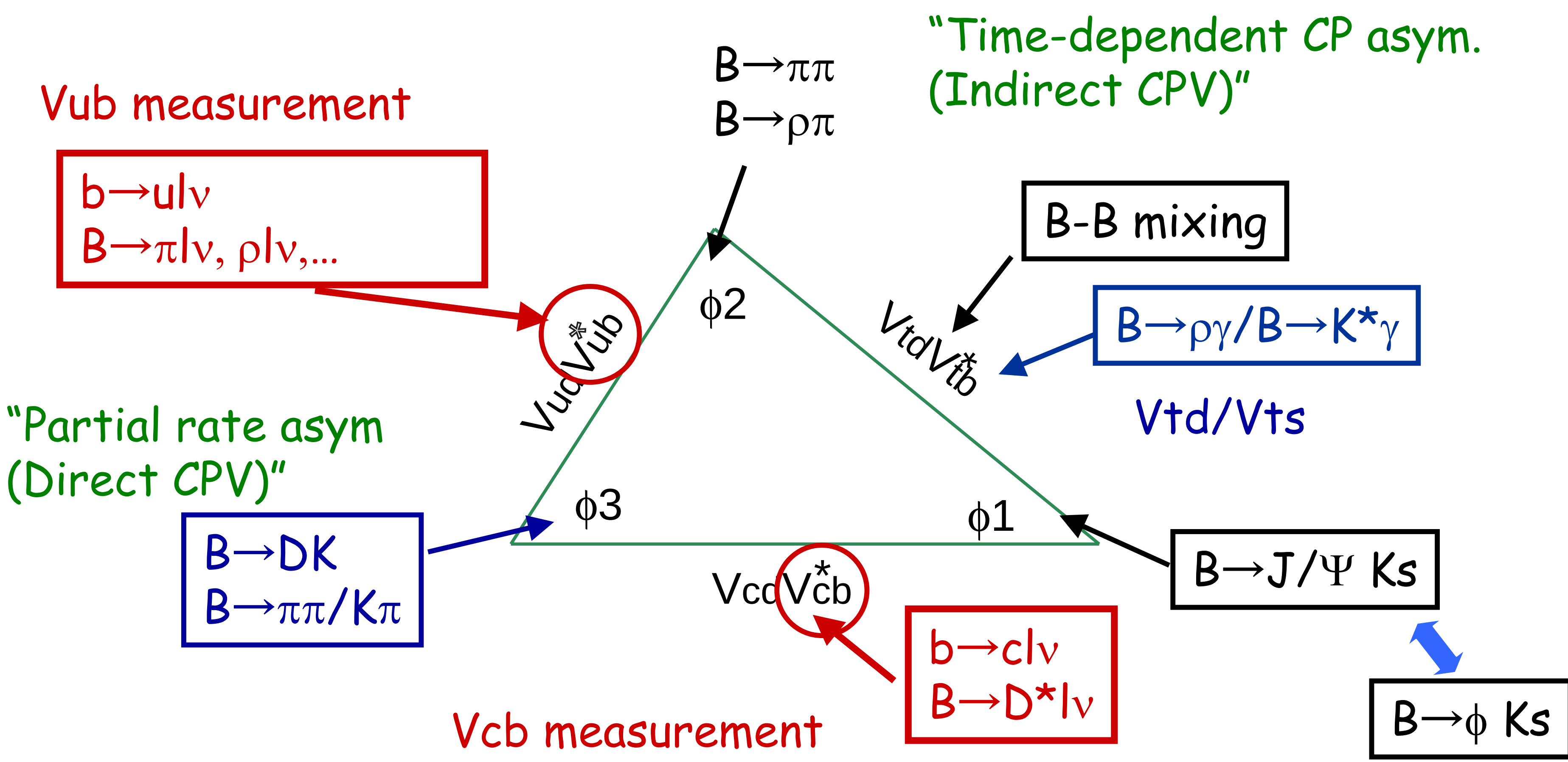
$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$\lambda \sim 0.2,\ A \sim \rho \sim \eta \sim O(1)$

SM: CPV is a consequence of the single complex phase.

The Unitarity Triangle & B Decays

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

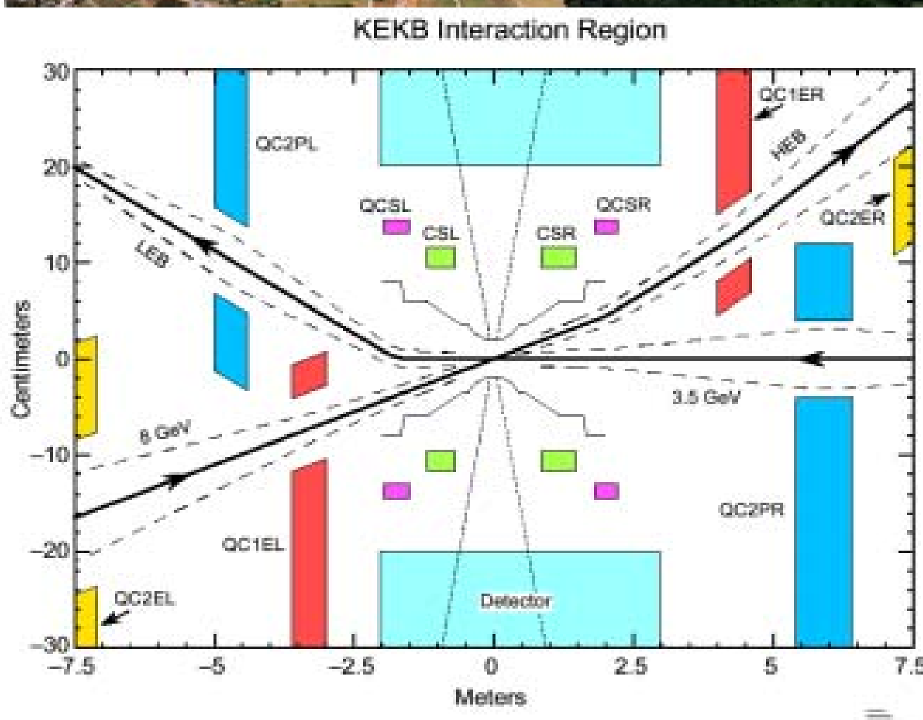


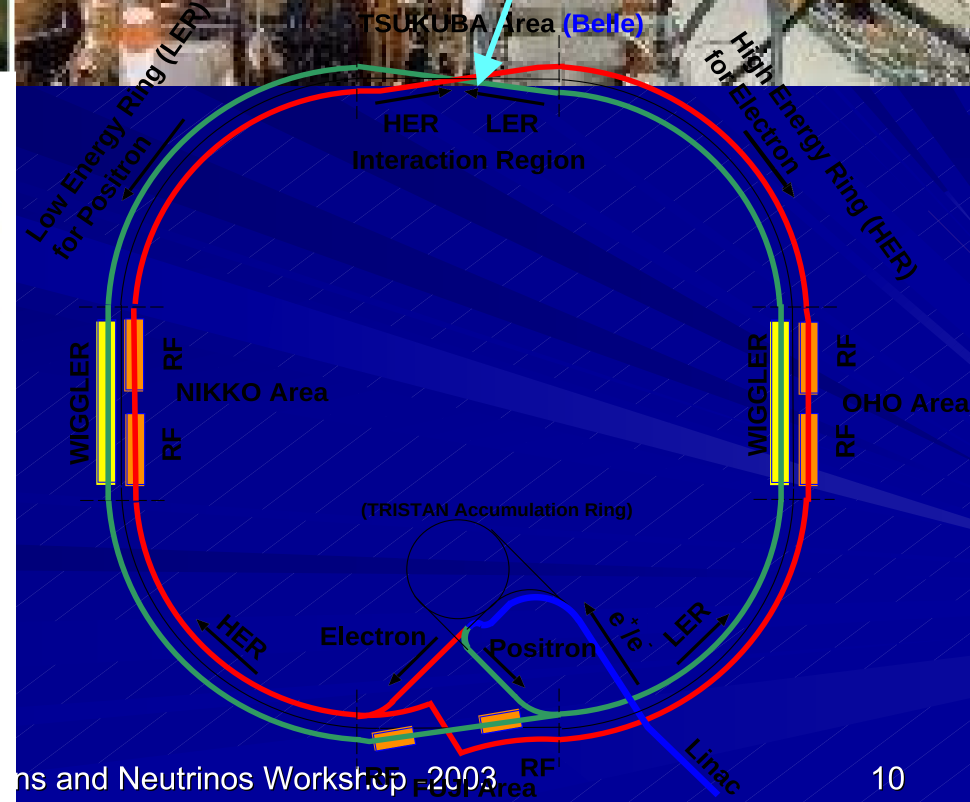
Accelerator Challenge

- History of luminosity improvement

KEKB Accelerator

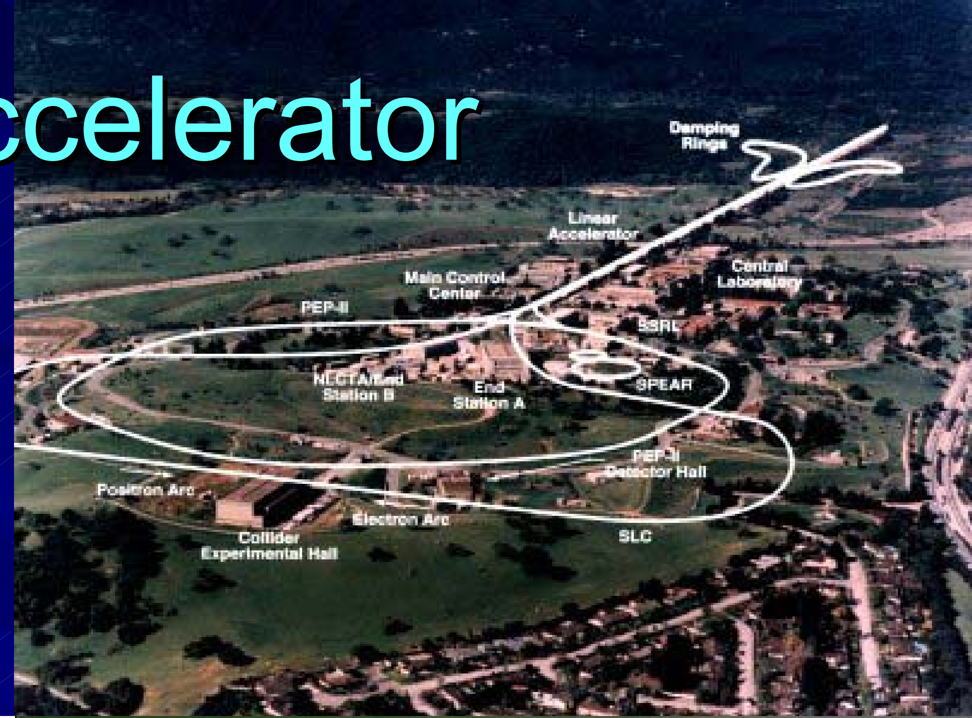
- e^- (HER: 8.0GeV) + e^+ (LER: 3.5GeV)
  - $\Rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
  - $\Rightarrow$ Lorentz boost: $\beta\gamma = 0.425$
- Finite crossing angle: 11mrad ×2

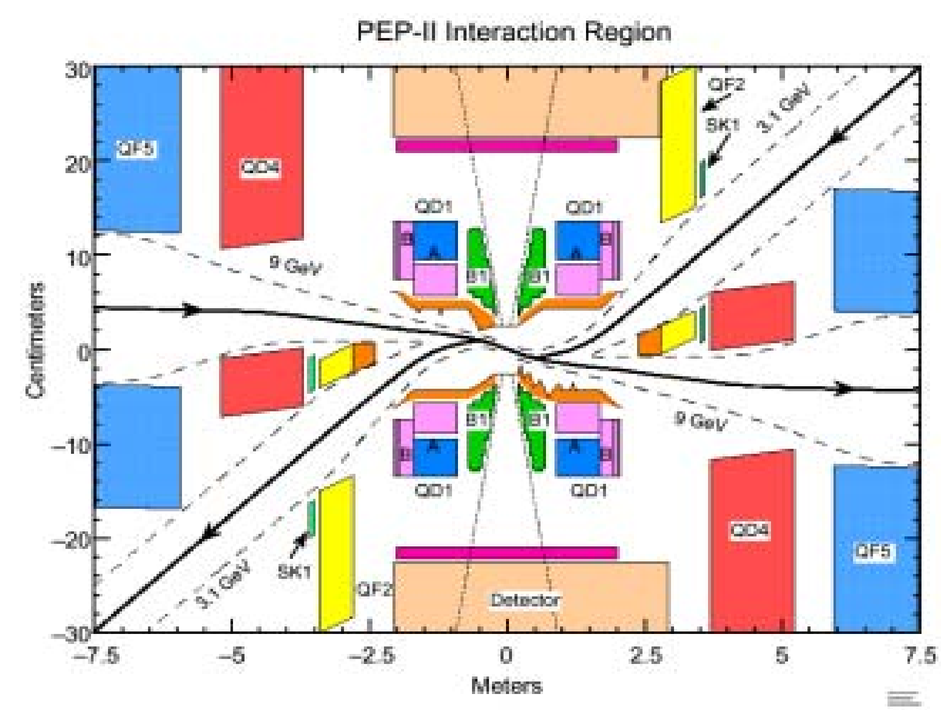


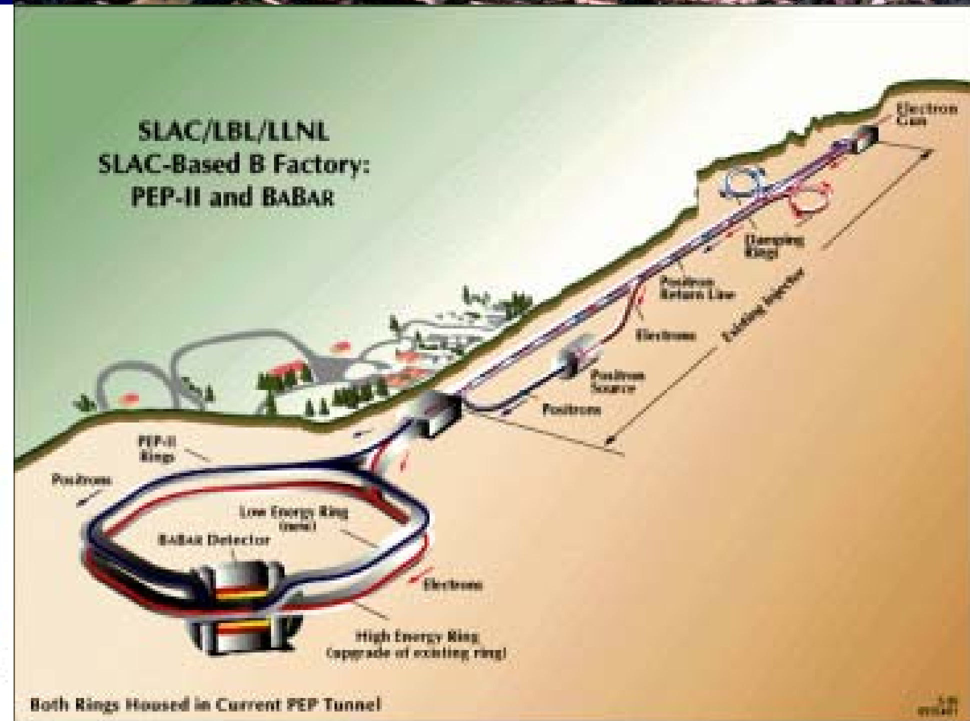


PEPII Accelerator

- e^- (9.0GeV) + e^+ (3.0GeV)
  $\Rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
  $\Rightarrow$Lorentz boost: $\beta\gamma$ =0.56
- Head-on collision



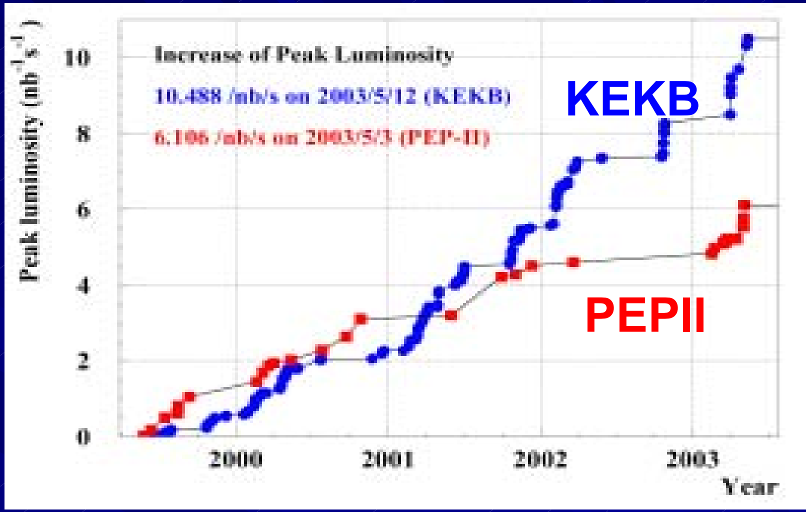




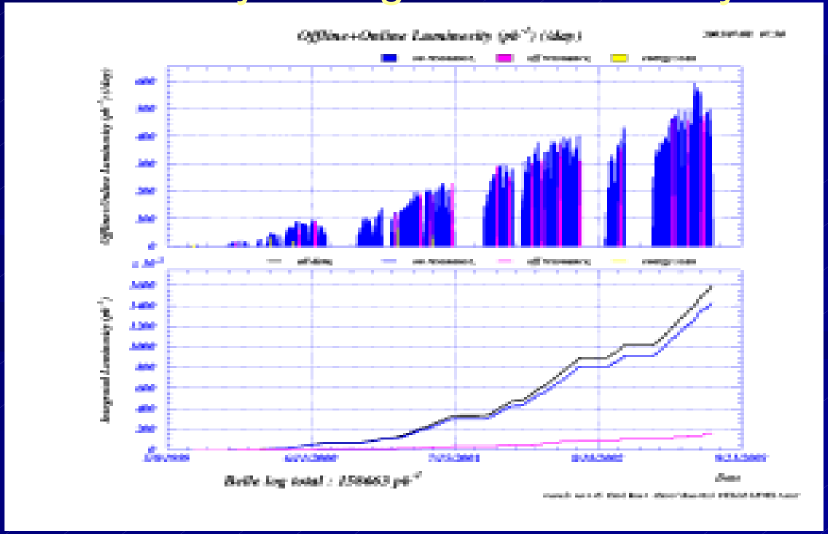
Luminosity Now !

- Peak luminosity
  - KEKB: **10.567** $cm^{-2}s^{-1}$
  - PEPII: 6.582 $cm^{-2}s^{-1}$
- Integrated luminosity (on $\Upsilon(4S)$)
  - KEKB/Belle: 158 (140) fb^{-1}
  - PEPII/BaBar: 131 (113) fb^{-1}

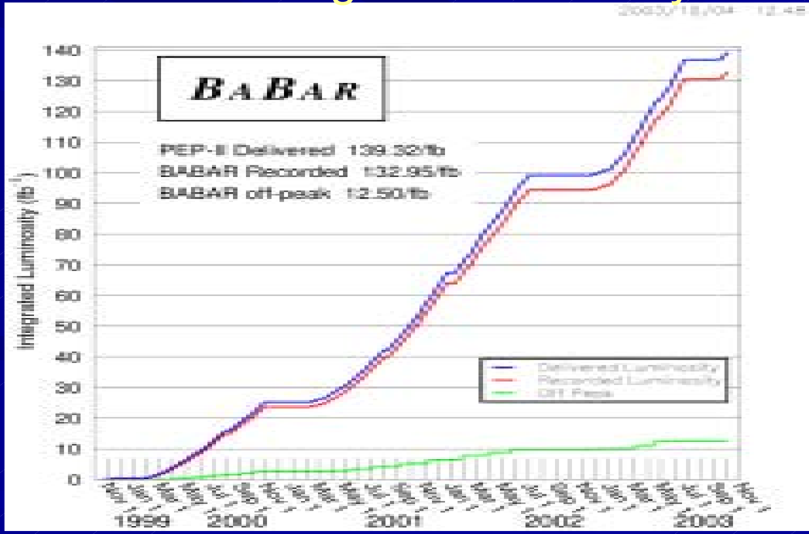
Peak Lumi



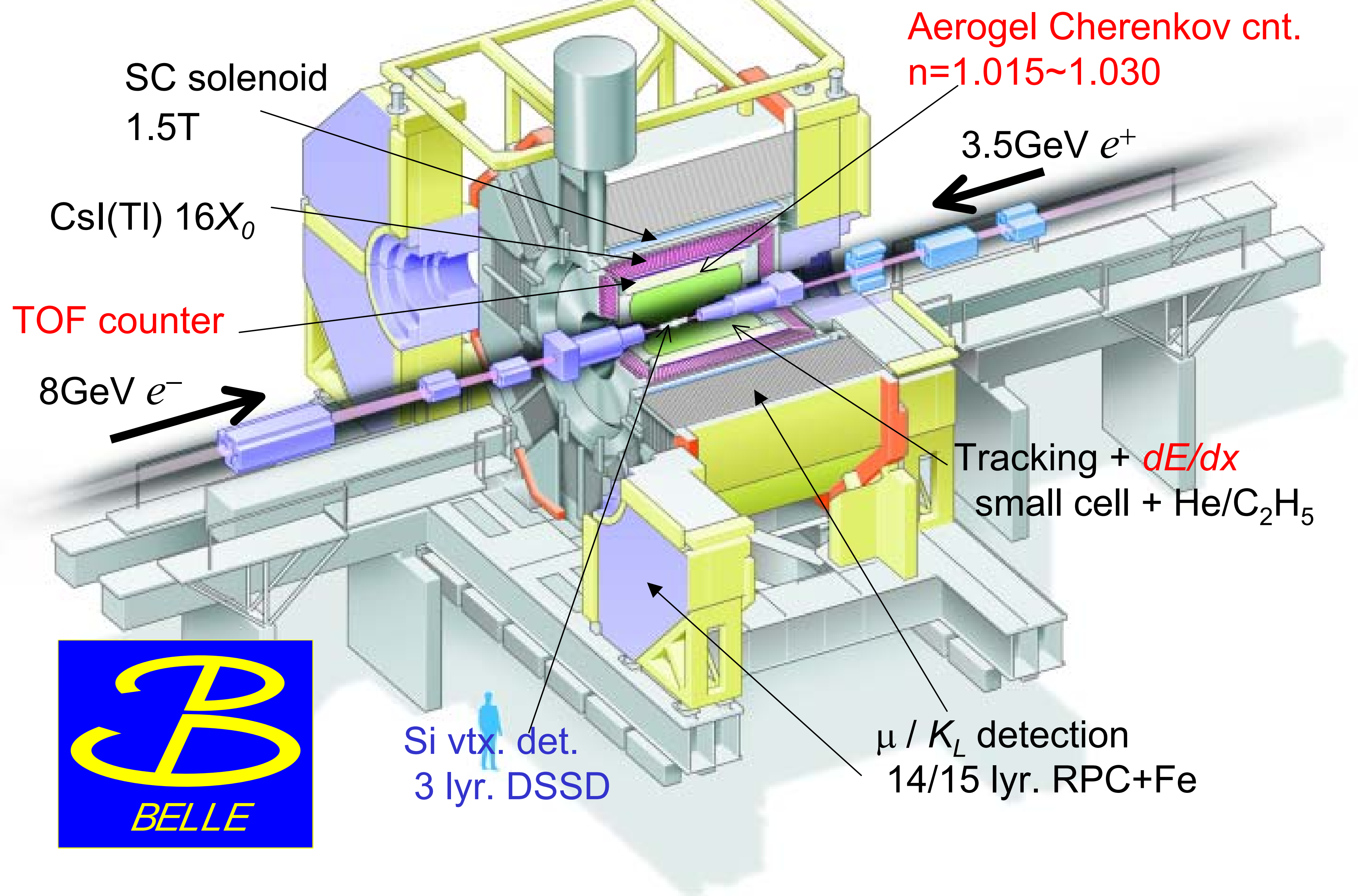
Belle daily / Integrated luminosity



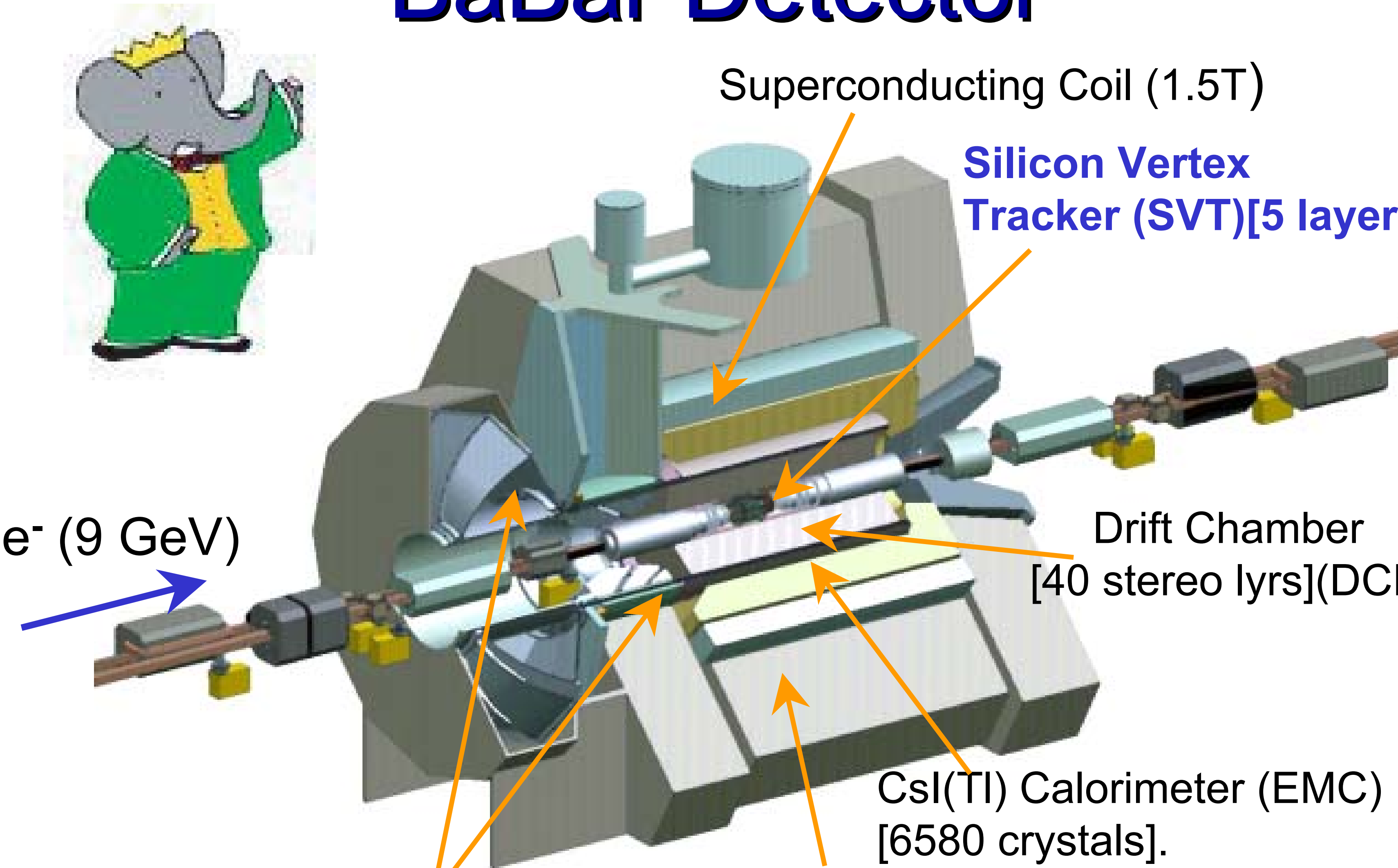
BaBar Integrated luminosity



Belle Detector

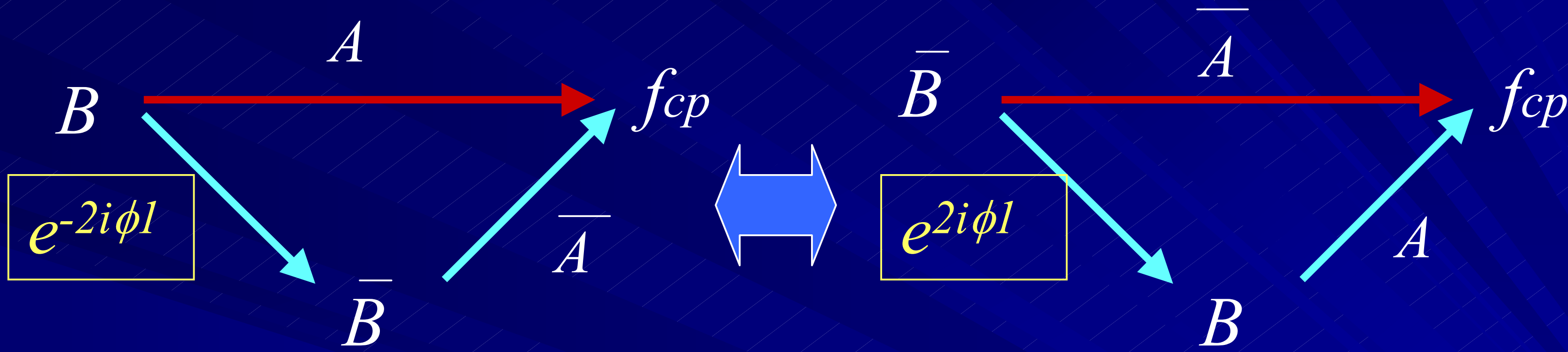


BaBar Detector

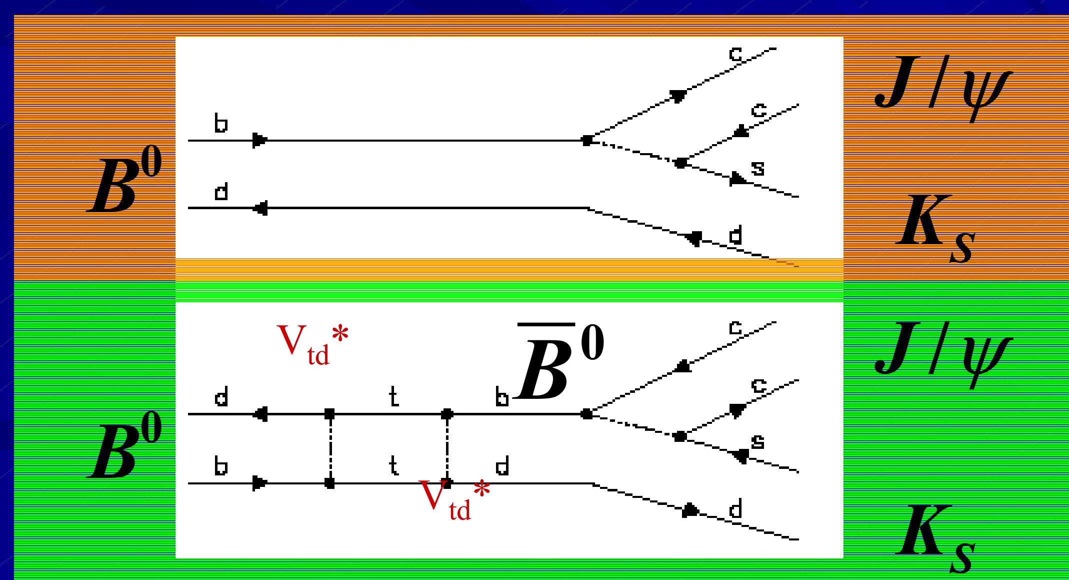


CP Violation through Mixing

- CP violation in B^0 decays into a CP eigenstate (f_{CP}).



  – Mixing: $e^{-2i\phi 1}$



Cont'd

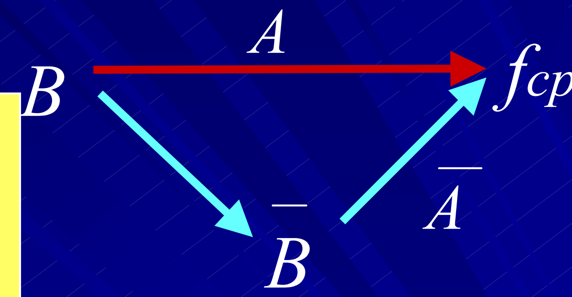
- If only one single decay amplitude

⇨ $\bar{A} = A, |\lambda| = 1$ ex) $B \rightarrow J/\psi K^0$

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

@ t=0

CP eigen value

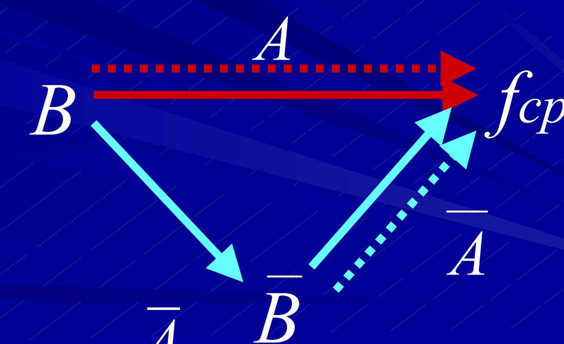


- If more than one amplitide and additional weak phases

⇨ Asymmetry in decay amplitude $\lambda \neq 1$

$$A_{CP}(t) = \frac{2\,\mathrm{Im}\lambda}{1+|\lambda|^2}\sin(\Delta m_d t) - \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m_d t)$$

$$= S_f \sin(\Delta m_d t) + A_f \cos(\Delta m_d t)$$



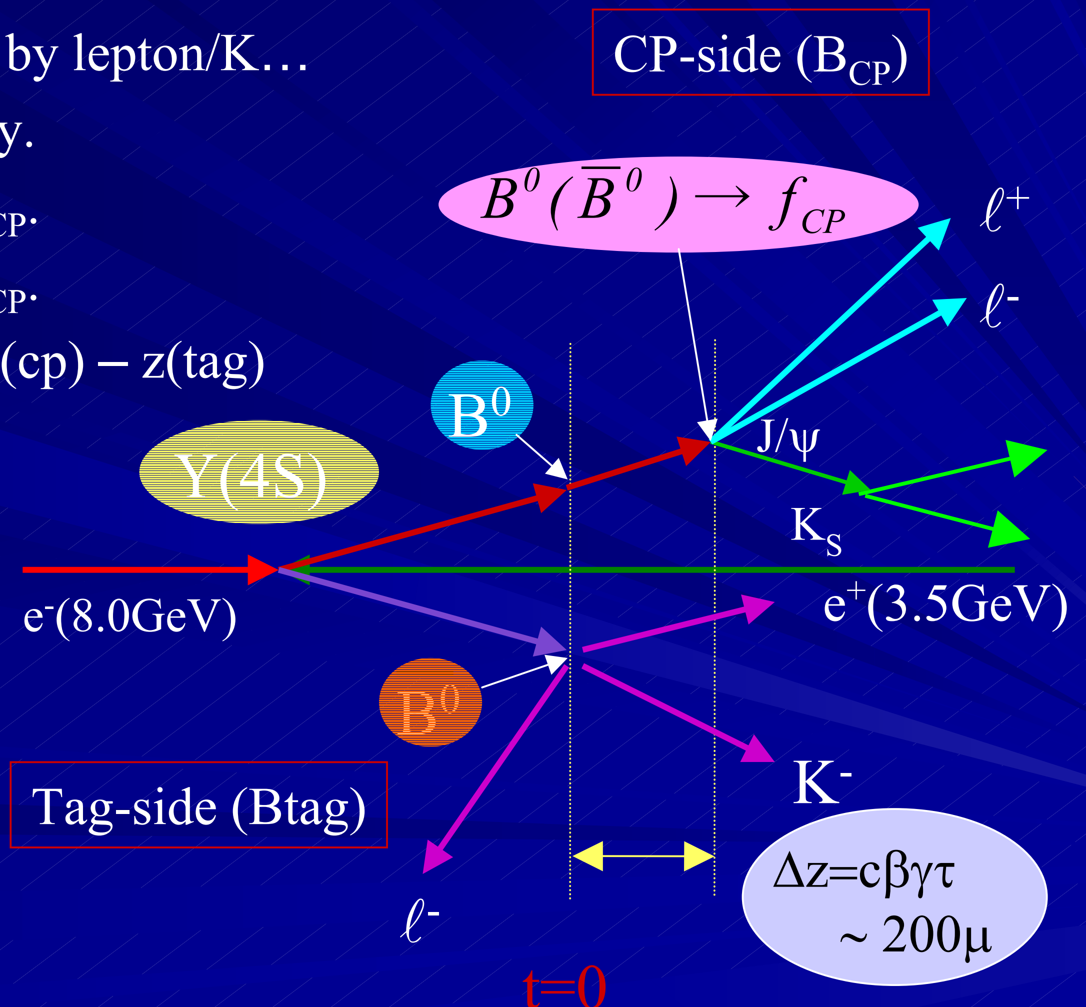
$A_f \neq 0$ ⟶ Direct CP violation

$$\lambda = e^{-2i\phi_1}\frac{\bar{A}}{A}$$

A_f (Belle) = $-C_f$ (BaBar)

CP Measurement

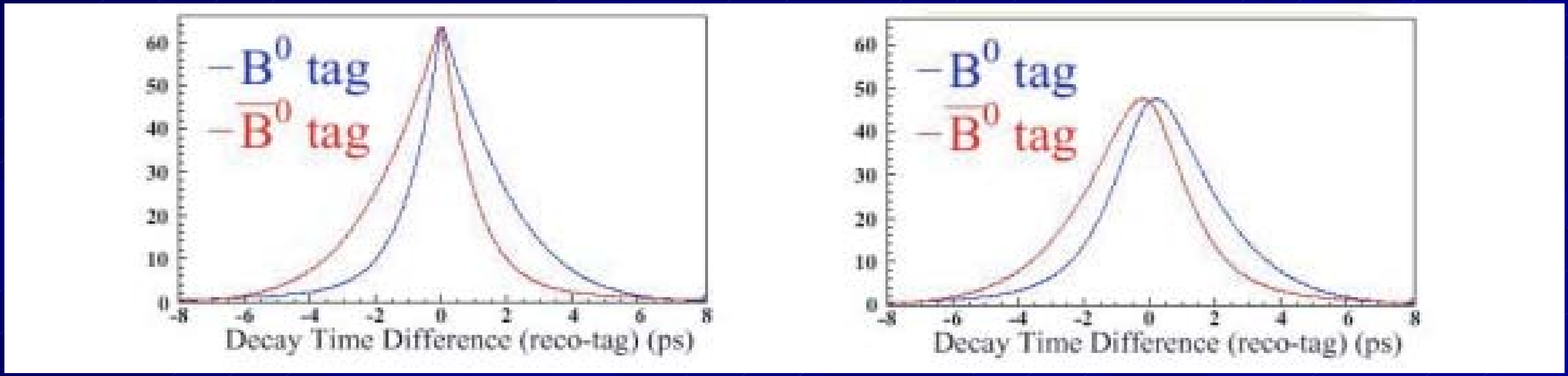
- Asymmetric e^+e^- collision $\Rightarrow \Upsilon(4S) \Rightarrow$ boosted B-$\overline{B}$ pair
- One B decays into f_{CP}.
- Flavor of the other B is tagged by lepton/K…
  - t=0: time of the Btag decay.
  - If Btag=$B^0 \Rightarrow \overline{B}^0(t=0) \to f_{CP}$.
    If Btag=$\overline{B}^0 \Rightarrow B^0(t=0) \to f_{CP}$.
- Precise measurement of $\Delta z = z(cp) - z(tag)$
  $\Rightarrow$ decay time difference (Δt)
- Measure *Acp(t)* by fitting



CP Analysis

- Expected time distribution

Perfect tagging & Δt resolution | Realistic mis-tagging & Finite Δt resolution



$$f_\pm(\Delta t) = \left\{ \frac{e^{-|\Delta t|/\tau_{B_d}}}{2\tau_{B_d}} \times (1 \mp \xi_f (1-2w)\sin 2\phi_1 \sin(\Delta m_d \Delta t)) \right\} \otimes R$$

+: B^0 tag,
-: $\overline{B}^0$ tag

w: wrong tag fraction

R: Δt resolution function

$\sigma_z(CP) \simeq 75\mu m$

$\sigma_z(tag) \simeq 140\mu m$

Flavor Tagging

Use *inclusive* flavor-specific properties

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

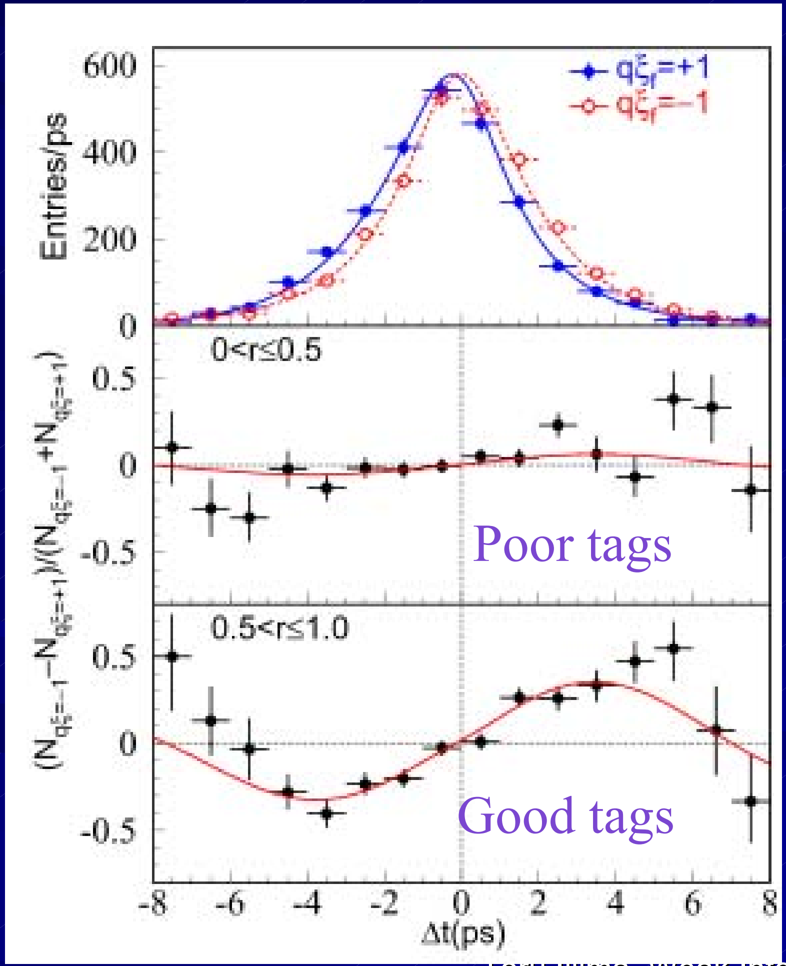
- Belle: Multi-dimensional likelihood ⇒ $\varepsilon_{eff} = 28.7 \pm 0.5\%$
- BaBar: Neural Net ⇒ $\varepsilon_{eff} = 28.1 \pm 0.7\%$

- Wrong tag fraction is calibrated by time-dependent mixining analysis of self-tagging B decays: $B^0 \to D^{*-} \ell^+ \nu$

Measurement of $\sin 2\phi_1$ (Belle2003)

BELLE-CONF-0353

- $140 fb^{-1}$, Updated at LP03
- Include both CP-odd and CP-even



$\sin 2\phi_1$ (Belle2003)
= <u>0.733±0.057±0.028</u>

$|\lambda_{ccs}|$ =1.007±0.041(stat)

i.e., consistent with no direct CPV.

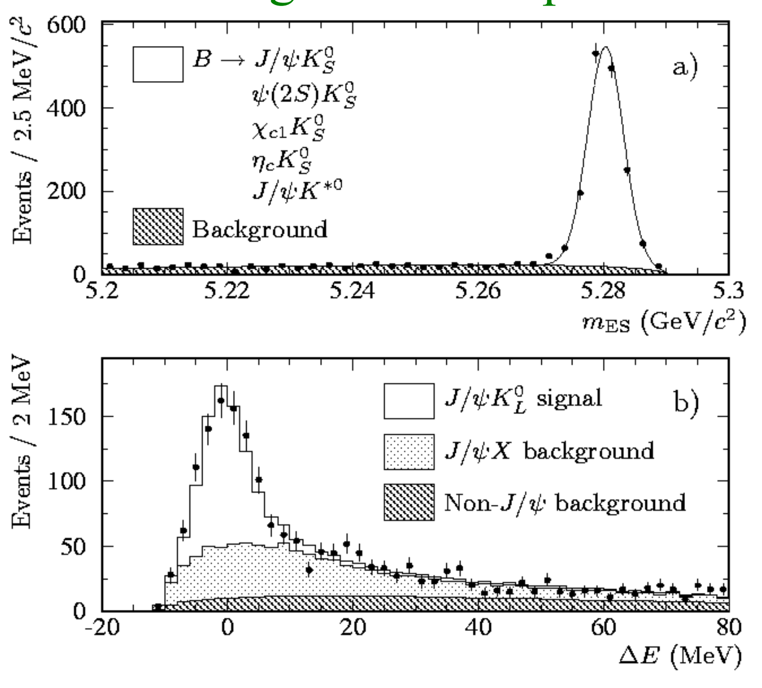
Measurement of sin2ϕ_1 (BaBar2002)

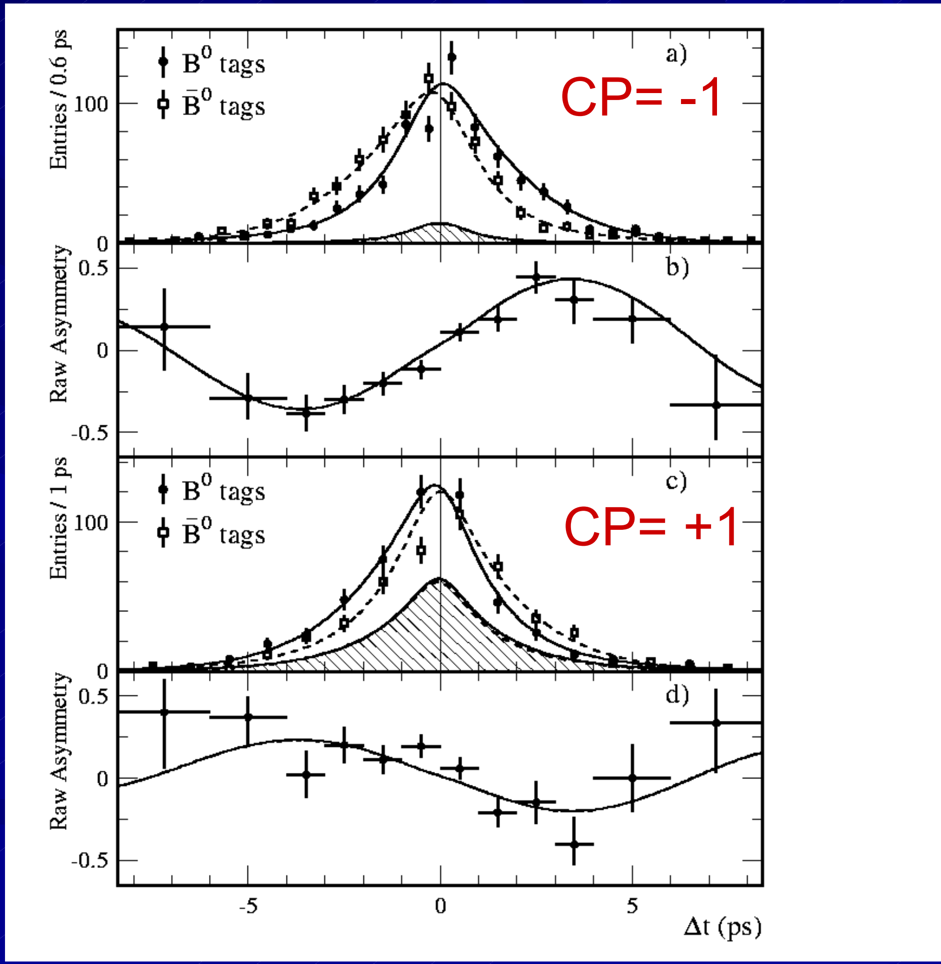
- $81fb^{-1}$

hep-ex/0207042, PRL 89, 201802 (2002)

sin2ϕ_1 (BaBar2002)
= 0.741±0.067±0.034

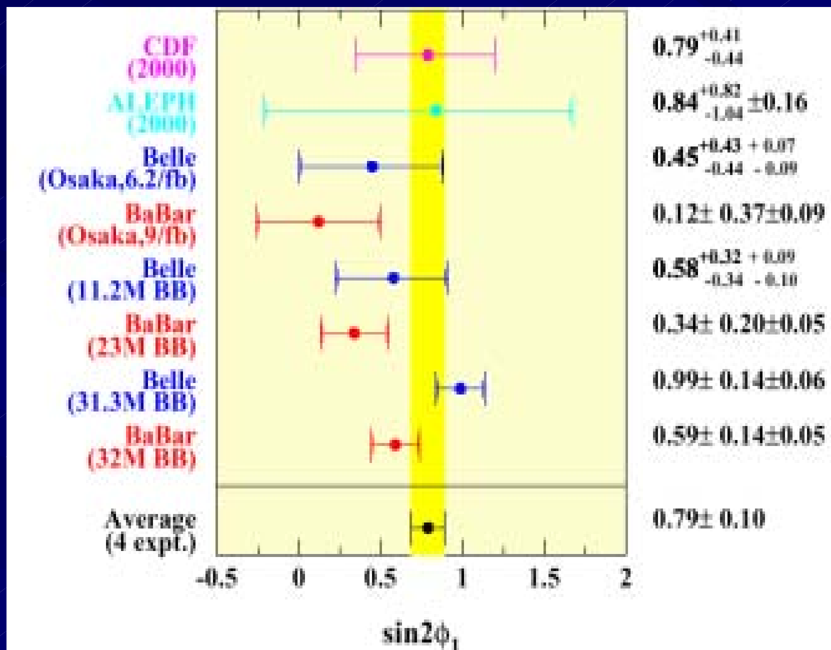
CP eigenstate sample



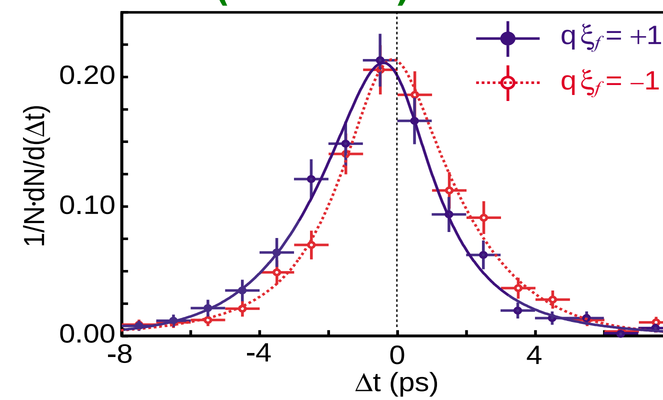


$\sin 2\phi_1$ Measurement History

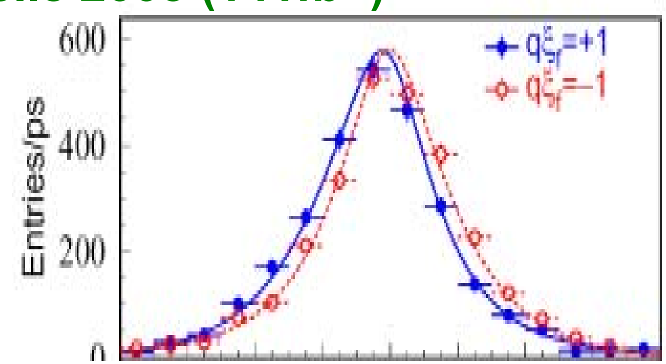
- 2001 First observation of CPV outside K.



Belle 2001 ($29.1fb^{-1}$)



Belle 2003 ($141fb^{-1}$)



- 2002 Belle: $0.719 \pm 0.074 \pm 0.035$

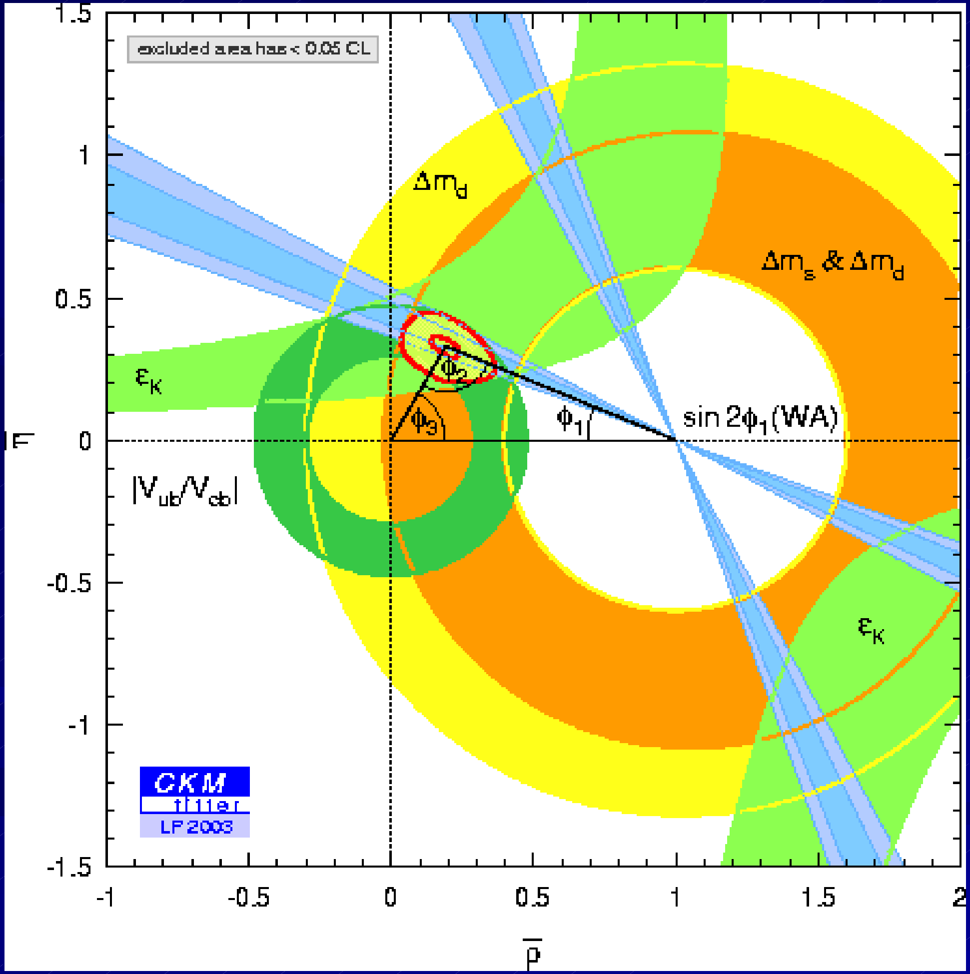
  BaBar: $0.741 \pm 0.067 \pm 0.034$
- 2003 Belle: $0.733 \pm 0.057 \pm 0.028$

$\sin 2\phi 1$(W.A.) = 0.736 ± 0.049

Now it is a precision measurement !

$\sin 2\phi_1$ Measurement Status

- CKM fitter group (A.Hoecker)



$\sin 2\phi_1$ (Belle 2003,140 fb^{-1})
$=0.733\pm0.057\pm0.028$

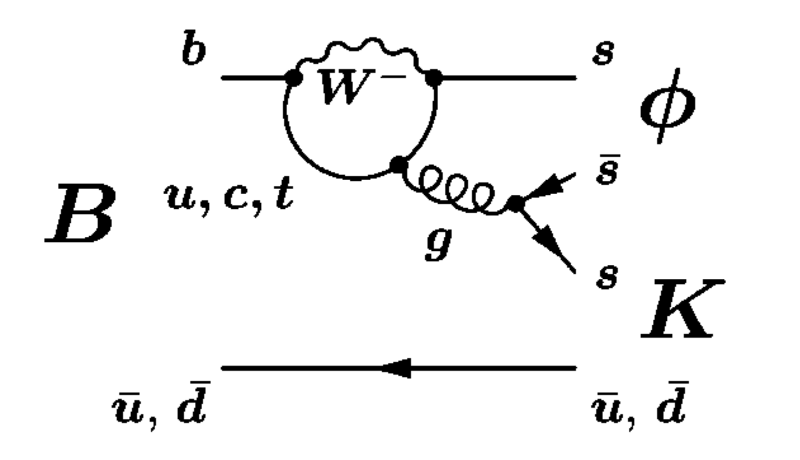
$\sin 2\beta$ (BaBar 2002, 81 fb^{-1})
$=0.741\pm0.067\pm0.033$

$\sin 2\phi_1$ (New 2003 World Av.)

$=0.736\pm0.049$

$\sin 2\phi_1$ in Penguin Dominated Decays

- In the Standard Model
  - $S_{sss} = \sin 2\phi_1$ ($b \to c\bar{c}s$)
  - $A_{sss} \sim 0$



- If a New Particle exists in the Penguin loop and introduce additional phase,

$$A_{CP}(t) = -\xi_{CP} \sin 2(\phi_1 + \phi_{NP}) \times \sin(\Delta m_d t)$$

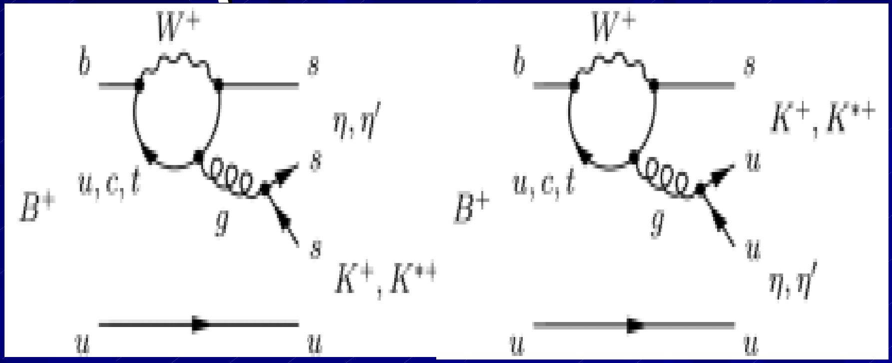
$$\sin 2\phi_1^{eff} \neq \sin 2\phi_1 (B \to J/\psi K_S)$$

- $\sin 2\phi_1(B \to J/\psi Ks)$ is already precise enough for comparison.

CPV in B→η' Ks

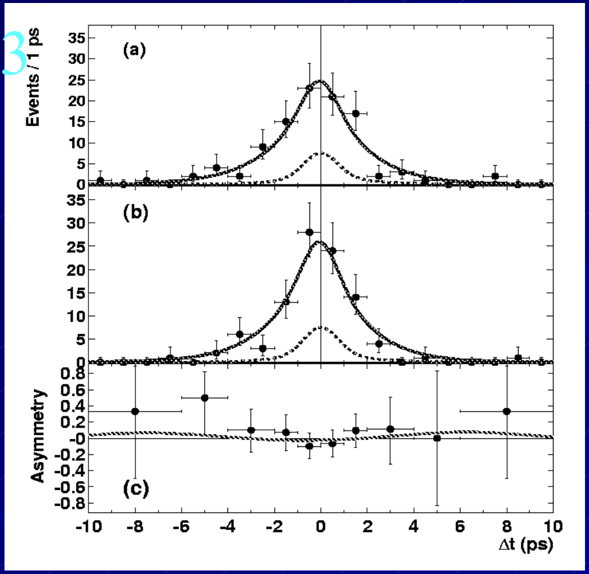
- B→sss, suu, sdd
- Tree expected be small.
- Unexpectedly large rate.

Br(B^0→η'Ks)=5.8×10^{-5}



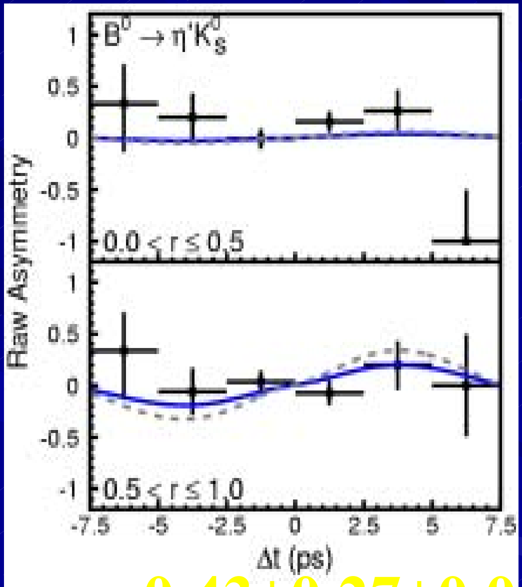
BaBar 2003

[81 fb^{-1}]



Belle 2003

[140 fb^{-1}]



Babar: $S_{\eta' Ks}$ = 0.02±0.34±0.03

(A=-0.10±0.22±0.03)

Belle: $S_{\eta' Ks}$ = 0.43±0.27±0.05

(A=-0.01±0.16±0.04)

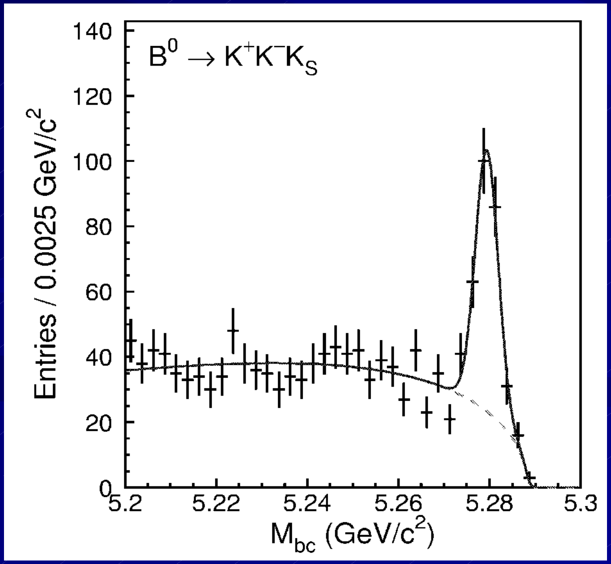
Current WA: $\sin 2\phi_1^{eff}$ (B→η'Ks)=0.27±0.21

CPV in $B \to K^+K^-K_S$ Decays

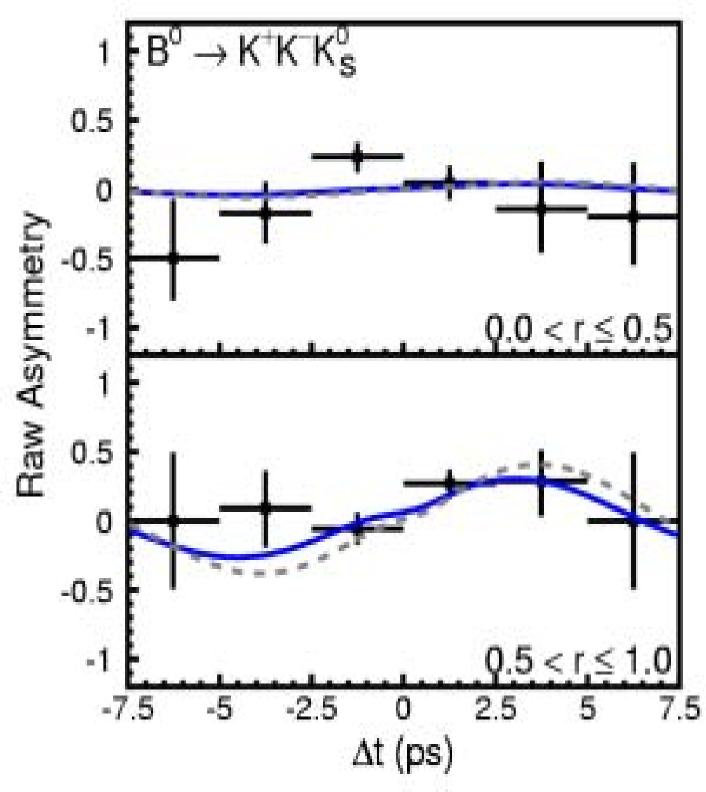
- $B \to \phi K_S$ events are excluded.
- CP-even component is dominant, with a fraction of 1.03±0.15±0.05 (angular analysis)

$$S_{KKKs} = 0.51 \pm 0.26 \pm 0.05 \begin{matrix} +0.18 \\ -0.00 \end{matrix}$$

$$(A=-0.17 \pm 0.16 \pm 0.04)$$



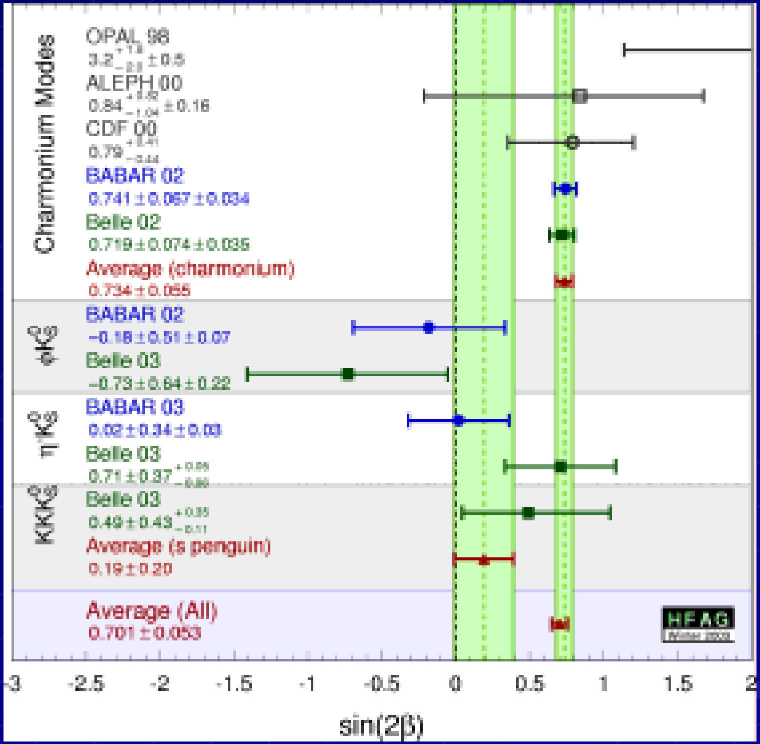
Belle 2003:[140 fb^{-1}]



CPV in $B \rightarrow \phi K_S$

- Pure b→sss Penguin process.
  - ⇨ Theoretically the cleanest channel.

- Status before LP03

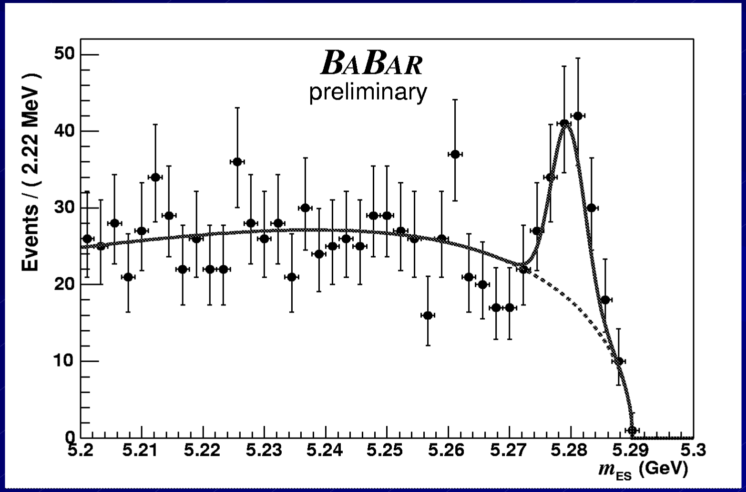


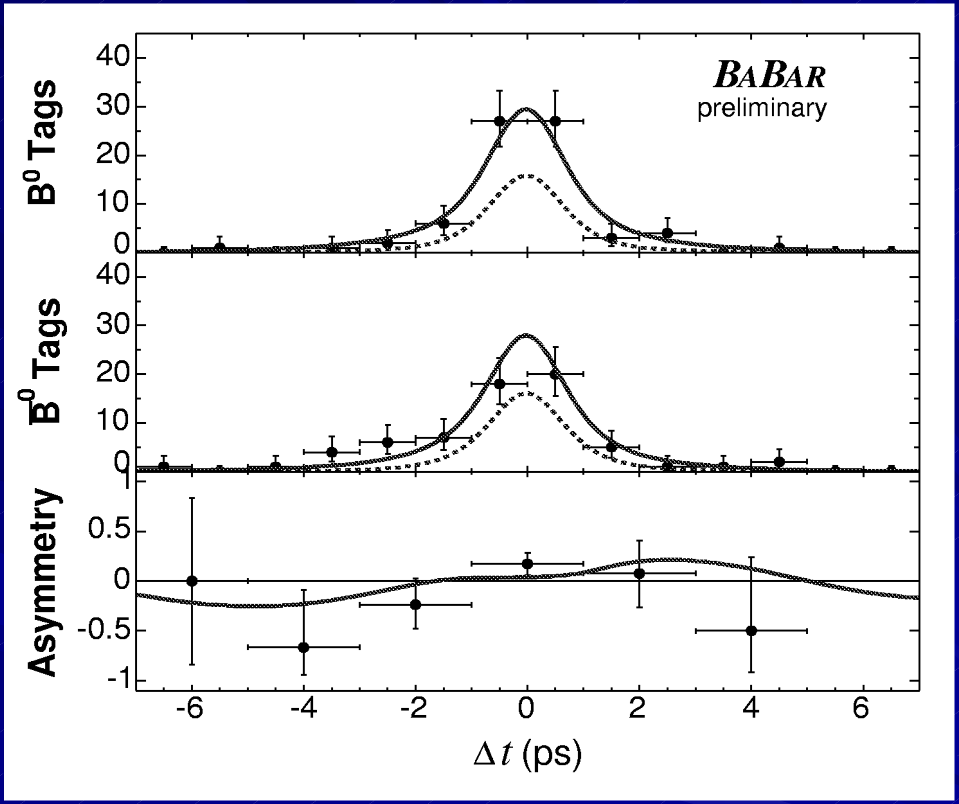
- Both BaBar and Belle updated the results at LP03 with 110fb-1 and 140fb-1 data, respectively.

CPV in B→φK_S (BaBar 2003)

BaBar 2003: 110 fb^{-1}

70±9 events





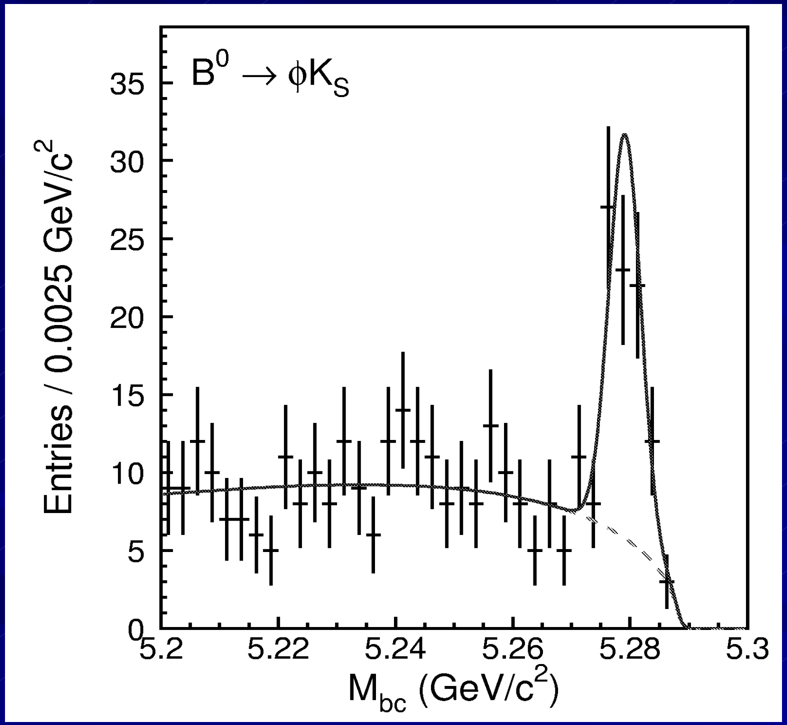
BaBar 2003: $\sin2\phi_1^{\mathrm{eff}}(\phi K_S) = +0.45 \pm 0.43 \pm 0.07$

(A=0.38±0.37±0.12)

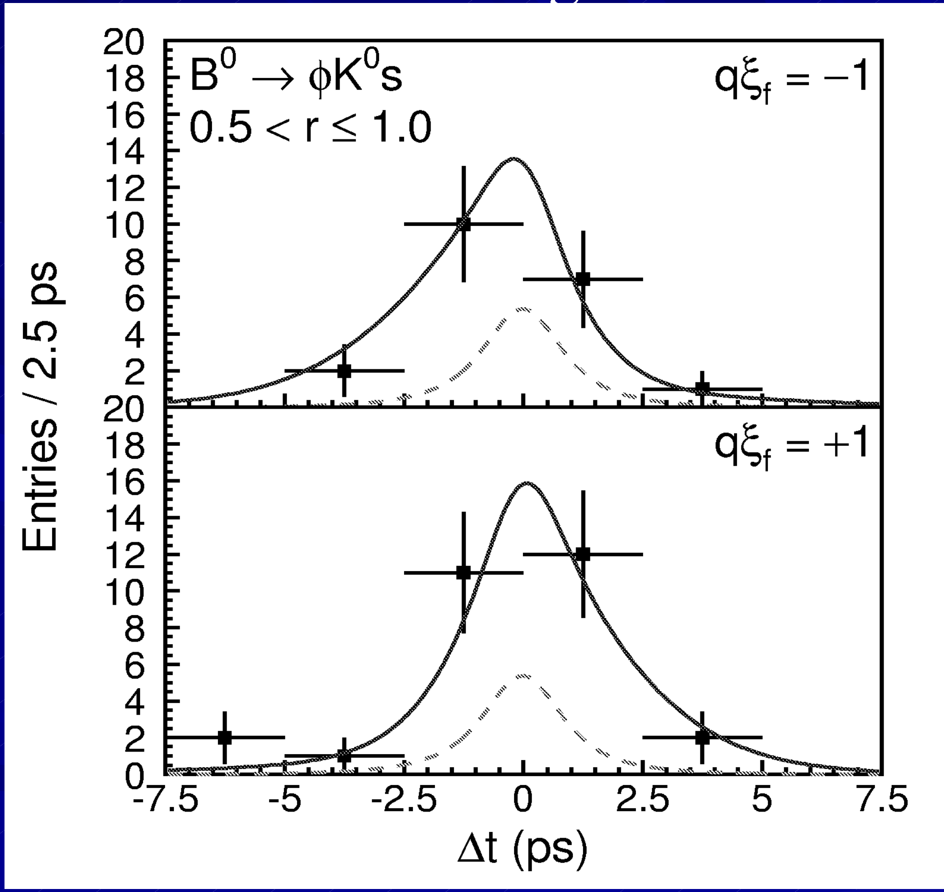
CPV in $B \rightarrow \phi K_S$ (Belle 2003)

BaBar 2003: 140 fb^{-1}

68±11 events

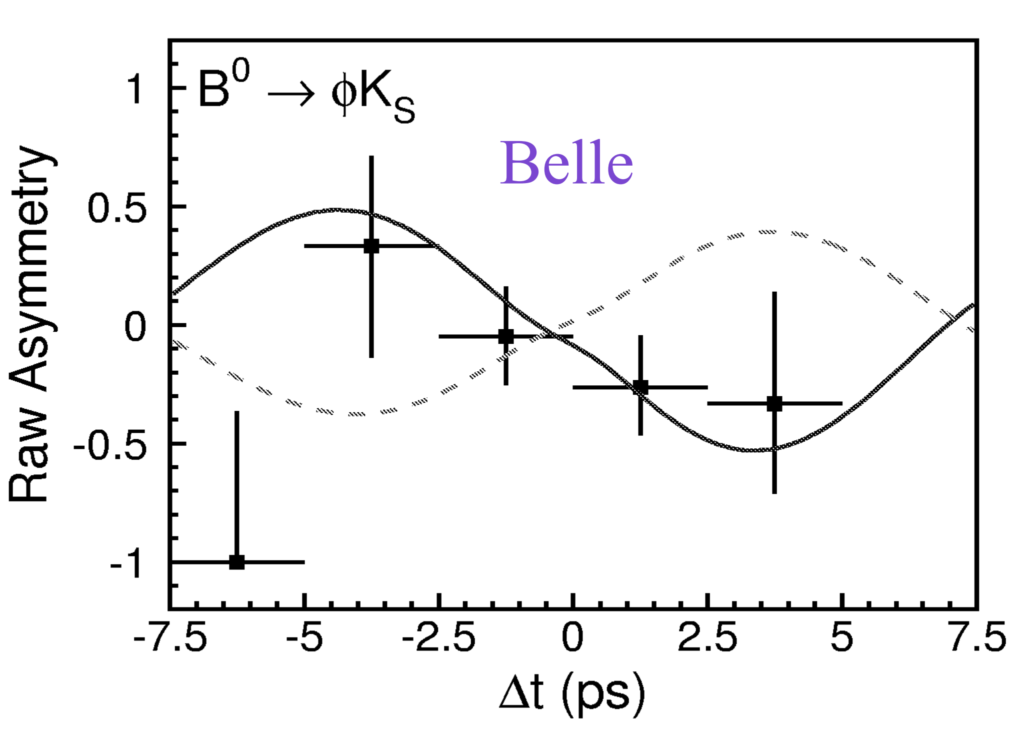


Good tags



CPV in $B \rightarrow \phi K_S$ Results (Belle 2003)

140 fb^{-1}



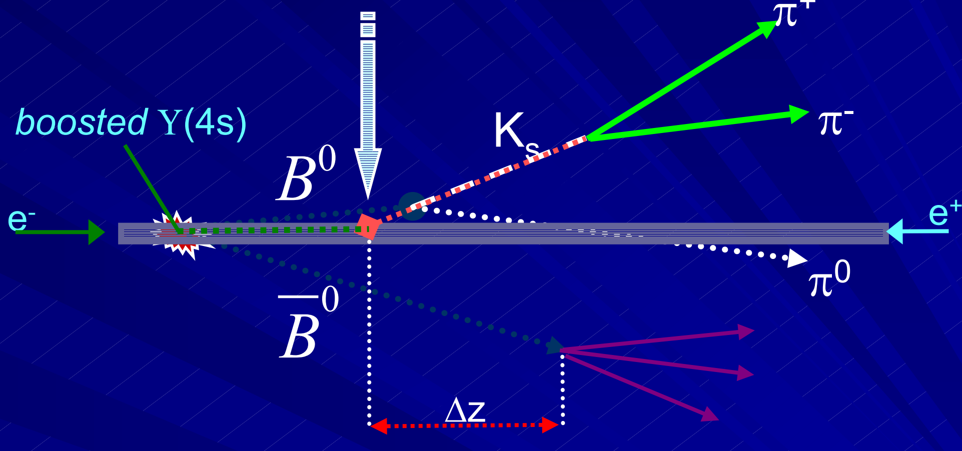
Belle 2003: $\sin 2\phi_1^{eff}(\phi K_S) = -0.96 \pm 0.50\ ^{+0.09}_{-0.11}$

($A = -0.15 \pm 0.29 \pm 0.07$)

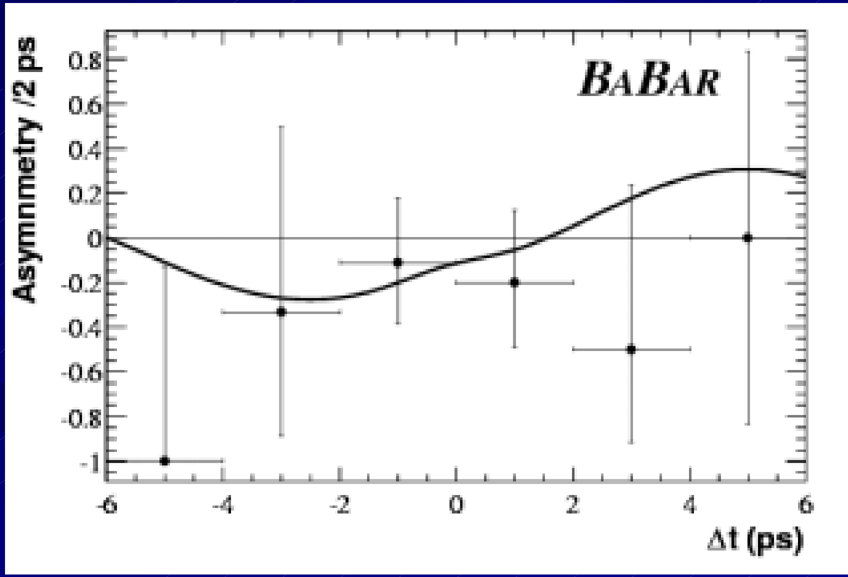
3.5 σ deviation from $\sin 2\phi_1 (J/\psi K_S) = 0.731 \pm 0.056$!!

CPV in $B \to K_S \pi^0$ (BaBar 2003)

- Reconstruct $B \to K_S \pi^0$ decay vertex by using Ks trajectory and boost trajectory.



Challenging Measurement !



$$N = 123 \pm 16$$

$$C = 0.40^{+0.27}_{-0.28} \pm 0.10$$

$$S = 0.48^{+0.38}_{-0.47} \pm 0.11$$

$$S(C=0) = 0.41^{+0.41}_{-0.48} \pm 0.11$$

Summary of $\sin 2\phi_1$ (Summer 2003)

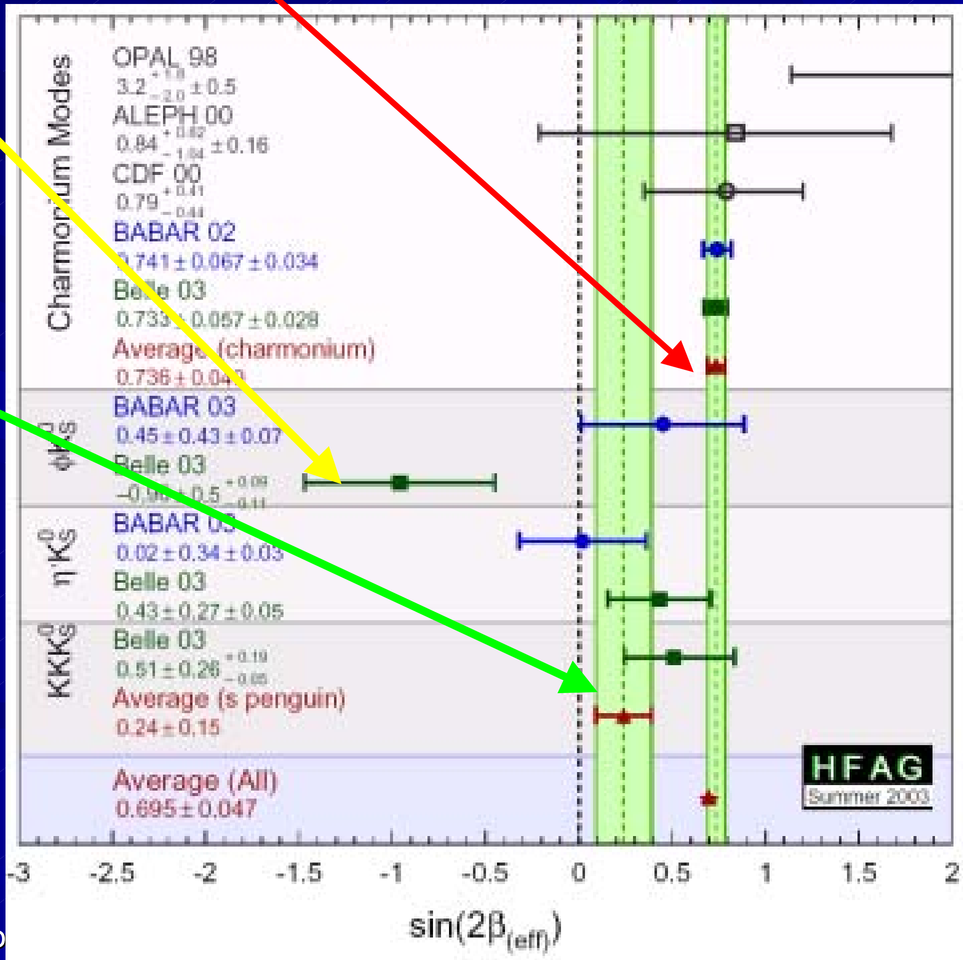
- J/ψ Ks precision already < 5%
- Belle φKs gives a 3.5σ away from WA of sin2φ1(J/ψ Ks)

  φKs WA gives a 2.7σ deviation

  $$-0.14 \pm 0.33$$

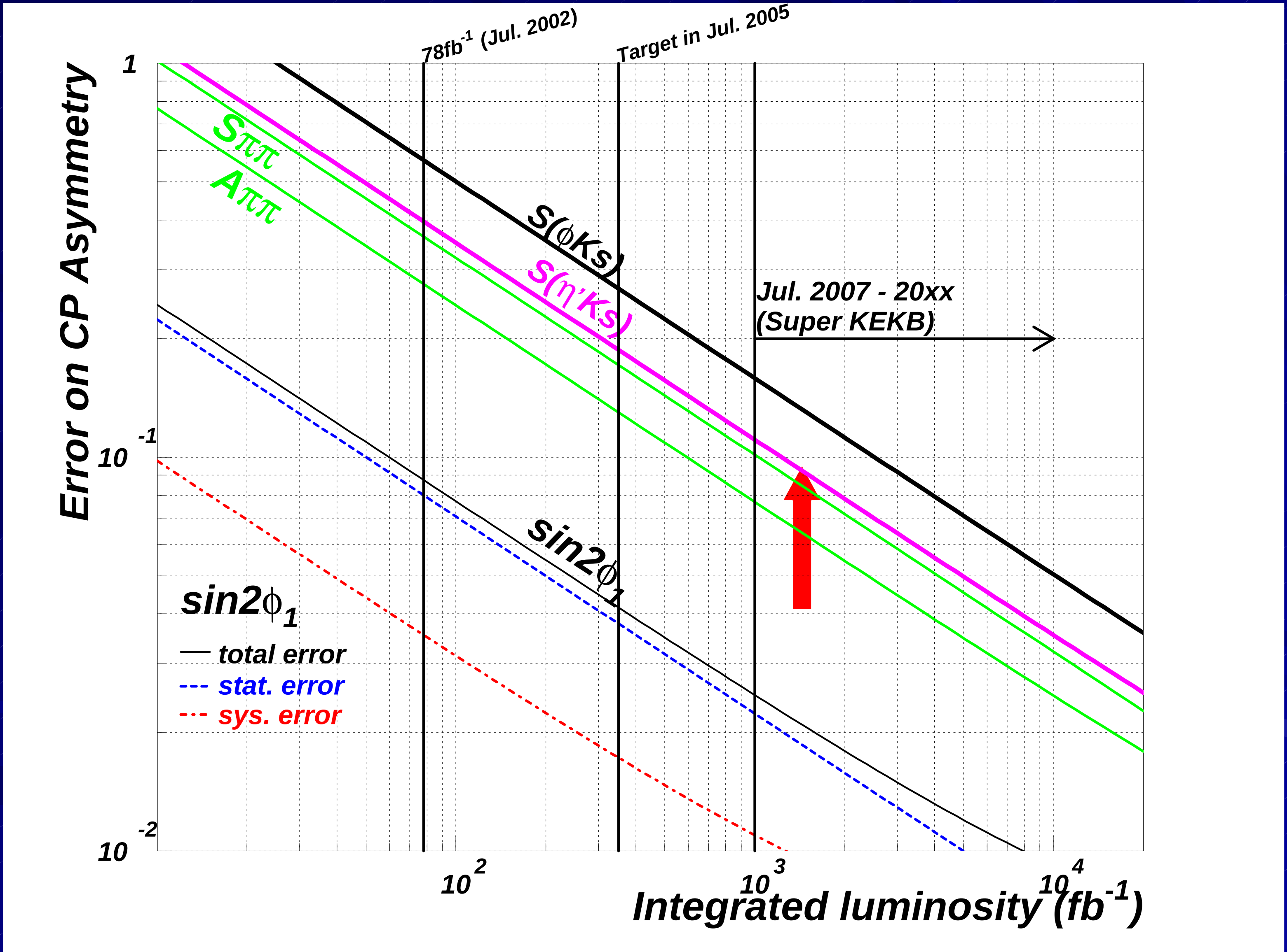
- b→s Penguin WA still gives a 3.1σ deviation

CPV in b→ccd modes: ⇒ K.F.Cheng



It is of great importance to confirm the ϕK_S anomaly

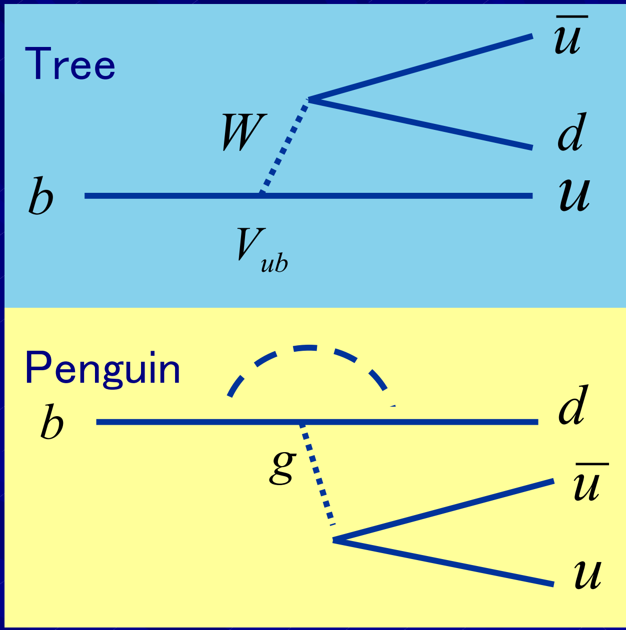
Precision in Future



CPV in B→π⁺π⁻

- Time-dependent CP asymmetry

$$A_{CP}(t) = A_{\pi\pi}\cos\Delta m t + S_{\pi\pi}\sin\Delta m t$$



- If b→u tree(T) was dominant,

⇒

$$\lambda = e^{2i\phi_2}$$
$$A_{\pi\pi} = 0$$
$$S_{\pi\pi} = \sin 2\phi_2$$

- Both tree(T) and Penguin(P) diagrams contributes with different weak phases.

⇒

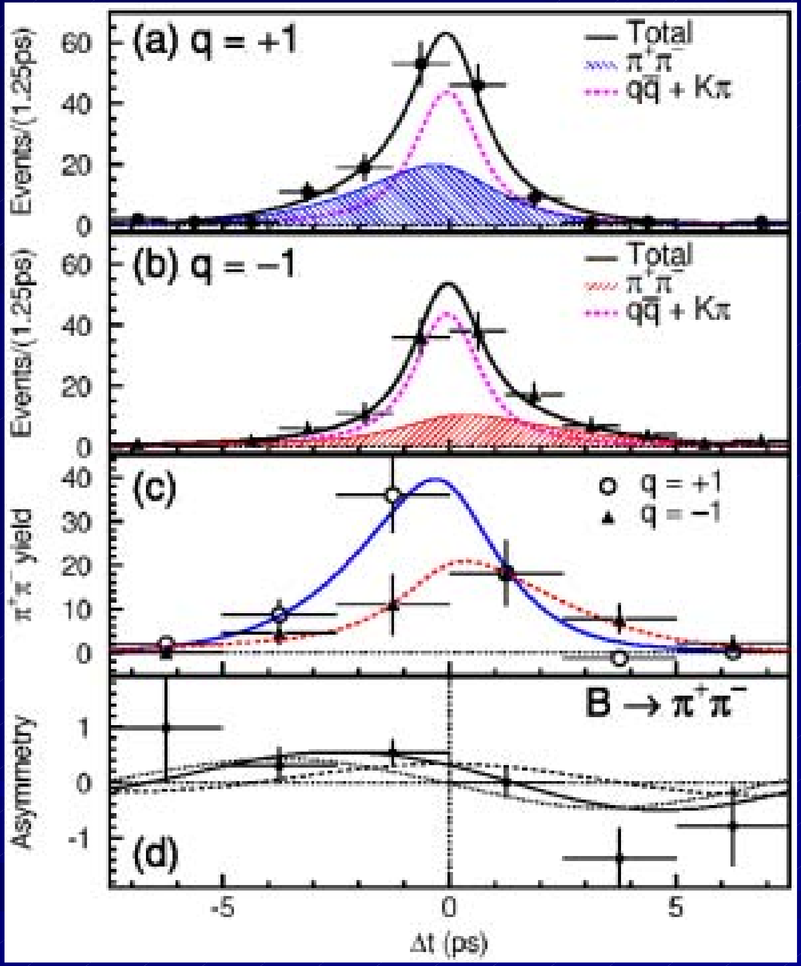
$$\lambda = e^{2i\phi_2}\frac{1+|P/T|e^{i\delta}e^{i\phi_3}}{1+|P/T|e^{i\delta}e^{-i\phi_3}}$$
$$A_{\pi\pi} \propto \sin\delta$$
$$S_{\pi\pi} = \sqrt{1-A_{\pi\pi}^{2}}\,\sin 2\phi_2^{eff}$$

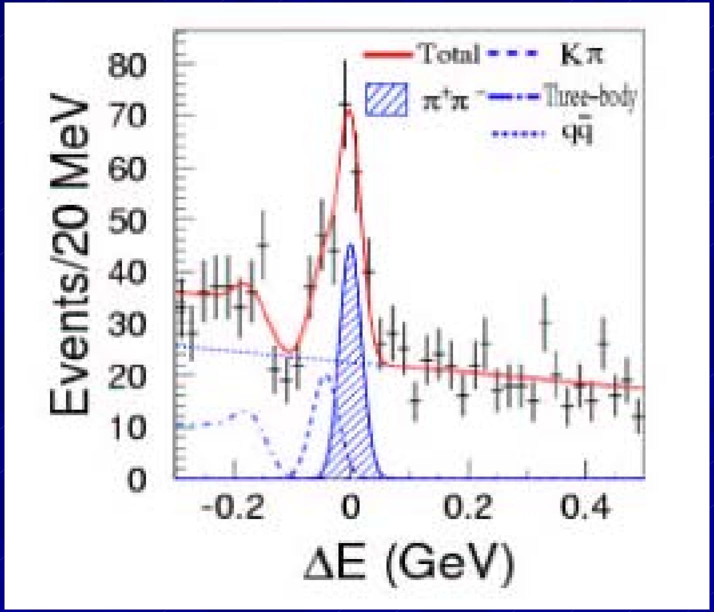
"Penguin Pollution"

CPV in B→$\pi^+\pi^-$ (Belle)

- Belle [78fb^{-1}]

$N_{\pi\pi} = 163 \pm 18$





$$S_{\pi\pi} = -1.23 \pm 0.41^{+0.08}_{-0.07}$$

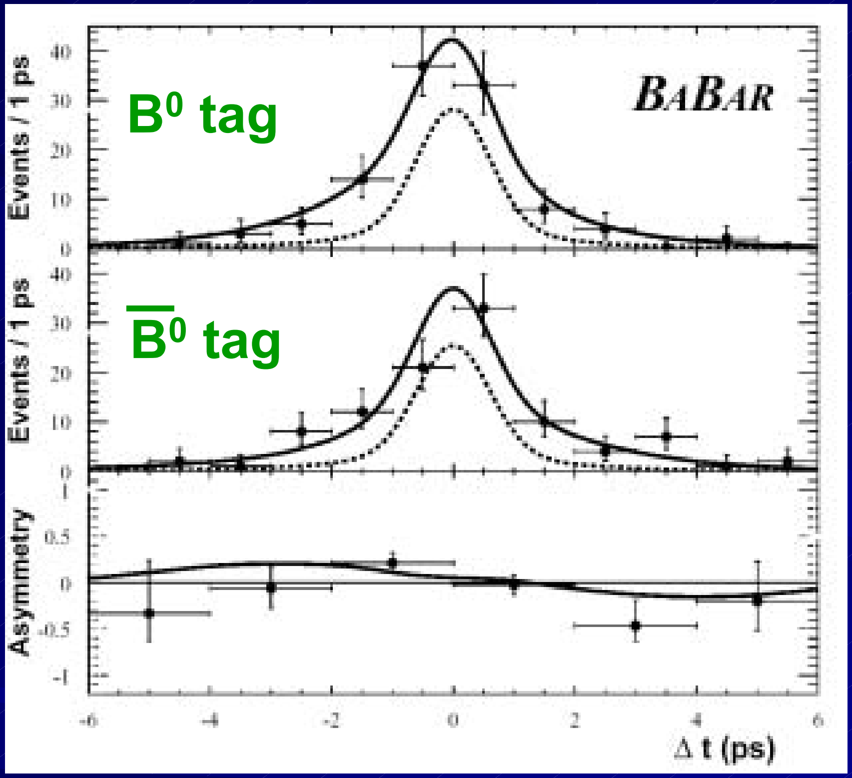
$$A_{\pi\pi} = +0.77 \pm 0.27 \pm 0.08 \; (-C_{\pi\pi})$$

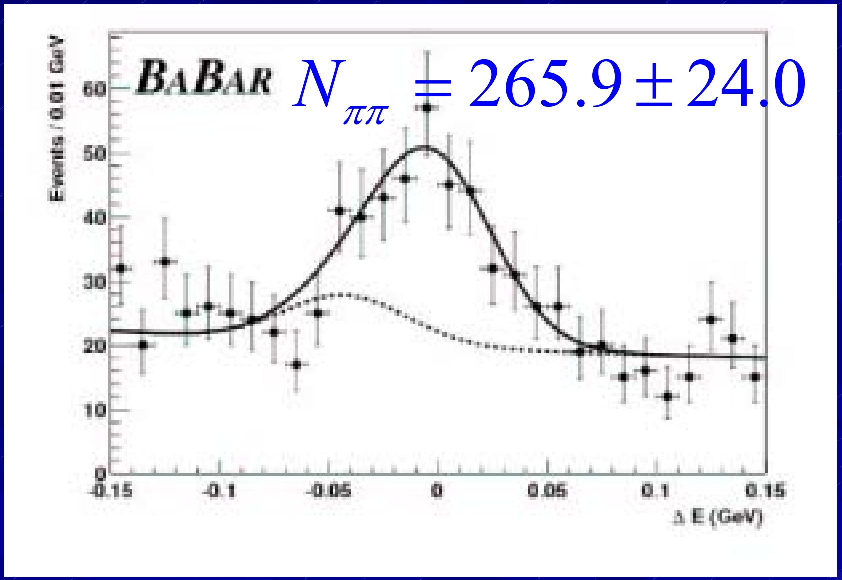
CP conservation (S=A=0) ruled out at 99.93% (3.4σ)

Belle updated result is coming…

CPV in B→$\pi^+\pi^-$ (BaBar)

- BaBar's result updated with 113fb^{-1} (LP03).





$$S_{\pi\pi} = -0.40 \pm 0.22 \pm 0.03$$

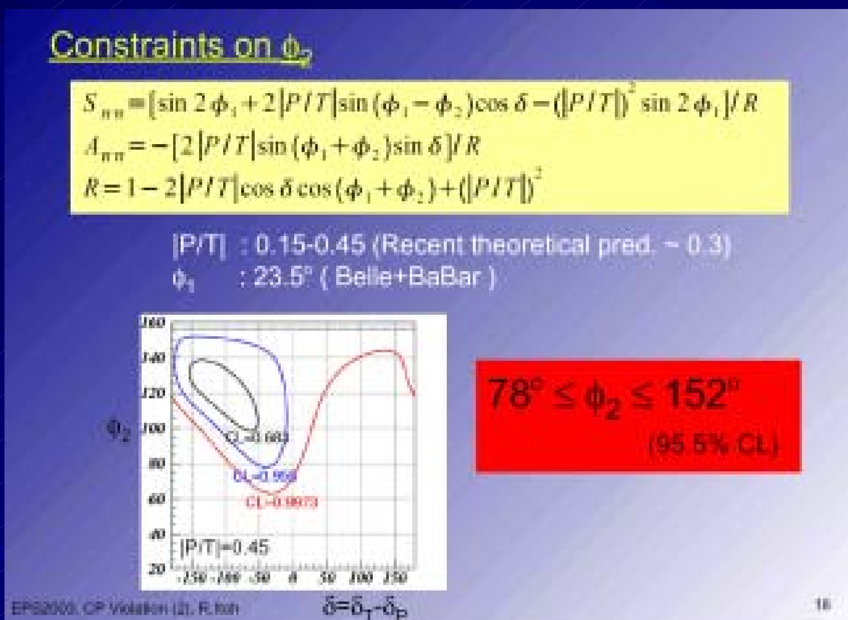
$$A_{\pi\pi} = +0.19 \pm 0.19 \pm 0.05 \; (-C_{\pi\pi})$$

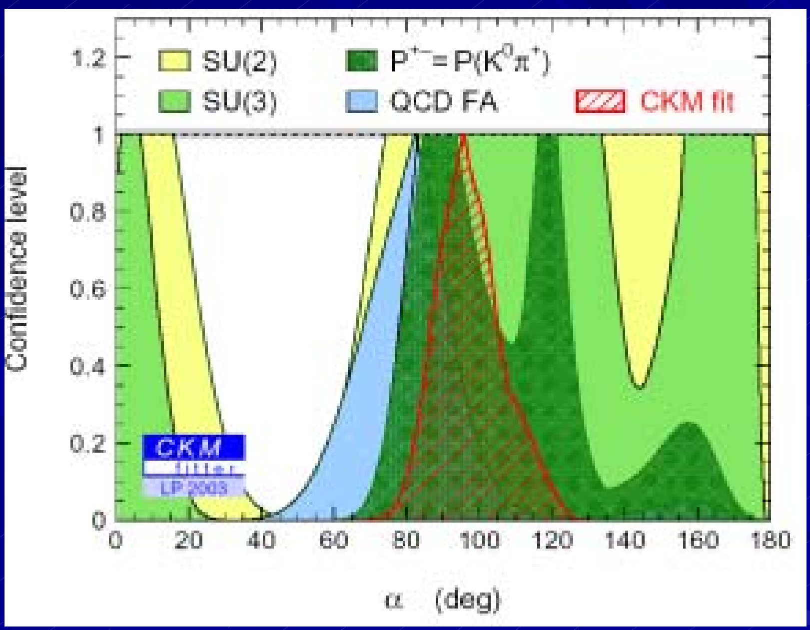
$$(A_{K\pi} = -0.107 \pm 0.041 \pm 0.013)$$

Current WA: $S_{\pi\pi} = -0.58 \pm 0.20, \quad A_{\pi\pi} = +0.38 \pm 0.16 (-C_{\pi\pi})$

Extraction of ϕ_2 (model-dep.)

- Estimation of |P/T| with
  Data: $B \to K^0\pi^+, B \to \pi\ell\nu, B \to \pi^0\pi^+$
  Assumption: SU(3), factorization



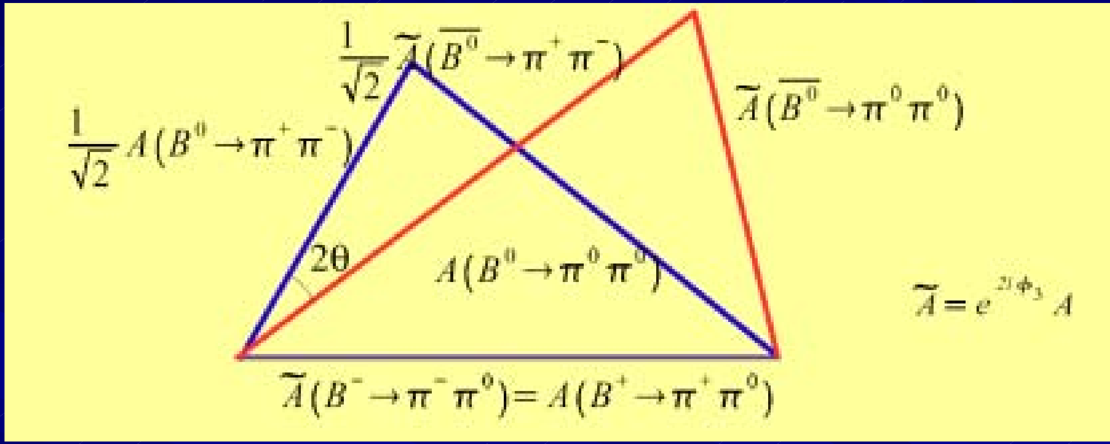


Constraint (even with model/assumption) is weak yet.
Data consistent with SM (CKM fit) in all scenario.

Extraction of ϕ_2 (model-indep.)

- Isospin analysis (ultimate goal).
  Theoretically the cleanest, but require $B^0 \to \pi^0\pi^0$ and $\bar{B} \to \pi^0\pi^0$ data.

$$\theta = |\phi_2 - \phi_2^{eff}|$$



- Grossman-Quinn ('98) bound and its extensions.
  - Charles ('99)
  - Gronau/London/Sinha/Sinha

$$\cos 2\theta \geq \frac{\left(\frac{1}{2}B^{+-} + B^{+0} - B^{00}\right)^2 - B^{+-}B^{+0}}{B^{+-}B^{+0}\sqrt{1 - A_{\pi\pi}^{\ 2}}}$$

These bound gives good constraint if $B \to \pi^0\pi^0$ is very small.

$B \rightarrow \pi^0\pi^0$

- BaBar [113fb^{-1}]

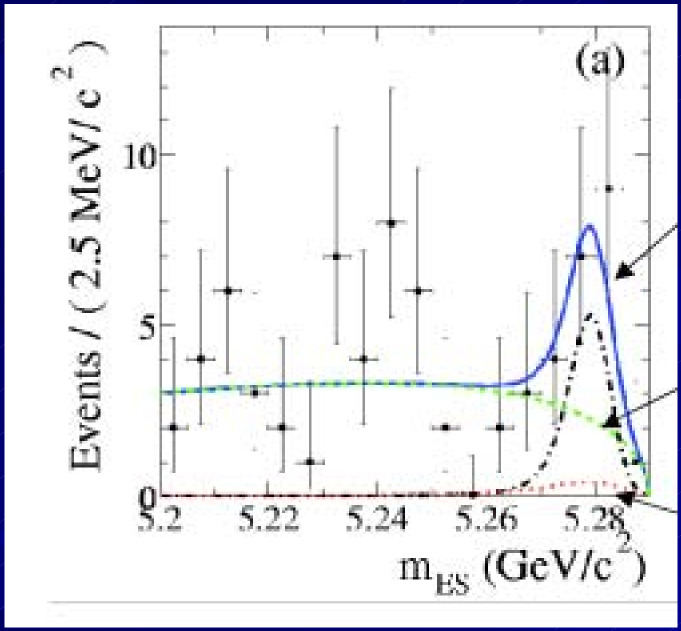
$$N(\pi^0\pi^0) = 46^{+14+2}_{-13-3}, \quad 4.2\sigma$$

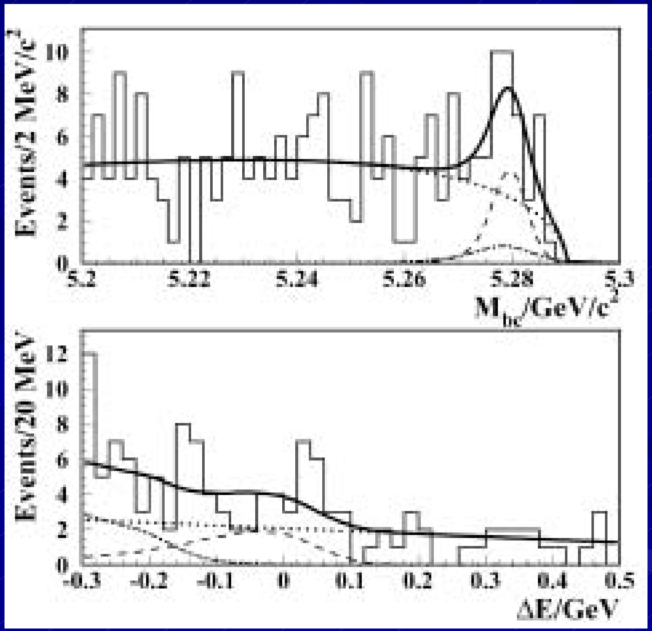
$$B(B^0 \rightarrow \pi^0\pi^0) = (2.1 \pm 0.6 \pm 0.3) \times 10^{-6}$$

- Belle [140fb^{-1}]

$$N(\pi^0\pi^0) = 25.6^{+9.3}_{-8.4}, \quad 3.4\sigma$$

$$B(B^0 \rightarrow \pi^0\pi^0) = (1.7 \pm 0.6 \pm 0.3) \times 10^{-6}$$





Current WA: $B(B^0 \rightarrow \pi^0\pi^0) = (1.90 \pm 0.47) \times 10^{-6}$

ϕ_2 Measurement Status

- CPV in B→$\pi^+\pi^-$ is being measured.

$$S_{\pi\pi} = -0.58 \pm 0.20$$
$$A_{\pi\pi} = +0.38 \pm 0.16 (-C_{\pi\pi})$$

Stay tuned for the next Belle result.

- Pieces of the isospin analysis being measured.

$$Br(B^0 \to \pi^+\pi^-) = (4.55 \pm 0.44) \times 10^{-6}$$
$$Br(B^0 \to \pi^0\pi^0) = (1.90 \pm 0.47) \times 10^{-6}$$
$$Br(B^0 \to \pi^+\pi^0) = (5.27 \pm 0.79) \times 10^{-6}$$

- B→$\pi^0\pi^0$ is too large to give useful G-Q type bound.

$$\theta = \left| \phi_2 - \phi_2^{eff} \right| < 35^\circ$$

- Need measure Acp($\pi^0\pi^0$).

Require a lot of luminosity !

- Another channel: B→$\rho\pi$

A_{cp} in Charmless B Decays

- Direct CPV through Tree and Penguin interference.

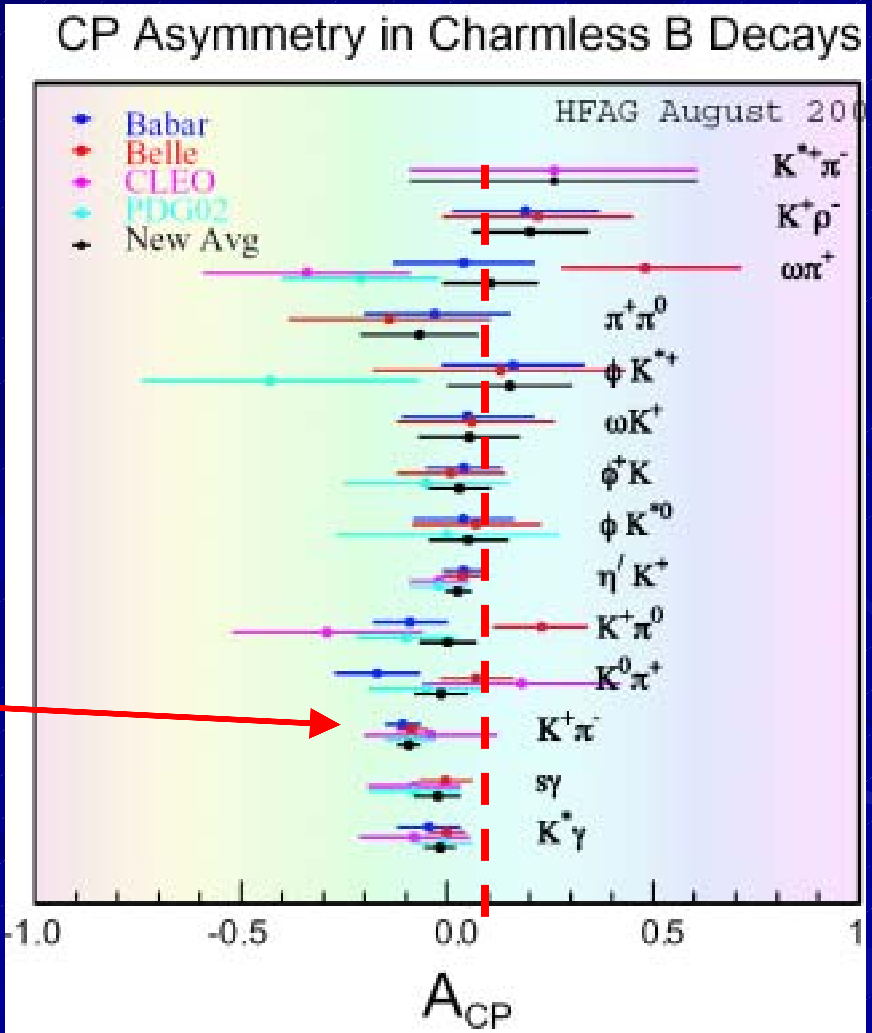
$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\bar{B} \to \bar{f}) + \Gamma(B \to f)}$$

$$\propto \sin\phi_3 \bullet \sin(\delta_P - \delta_T)$$

- Acp(Kπ) evidence?
  - Belle: $-0.086 \pm 0.035 \pm 0.014$
  - BaBar: $-0.107 \pm 0.041 \pm 0.012$
  - CLEO: $-0.04 \pm 0.16 \pm 0.02$

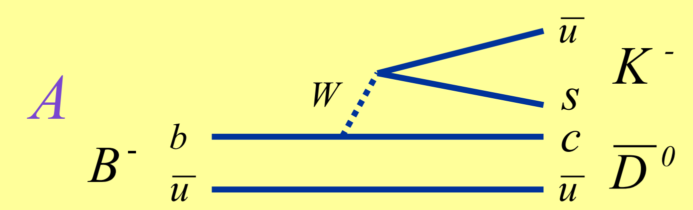
  WA: -0.09 ± 0.03

- Thoretical effort necessary to pin-down φ3.

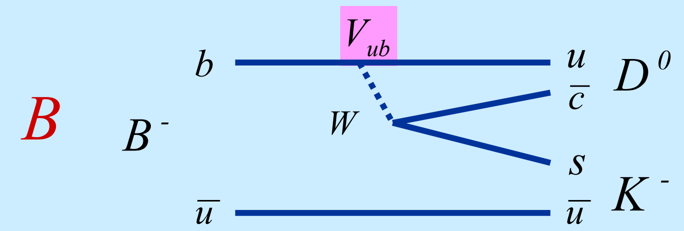


$\phi 3$ Measurement with DK$^{(*)}$

- Gronau, Wyler ('91)

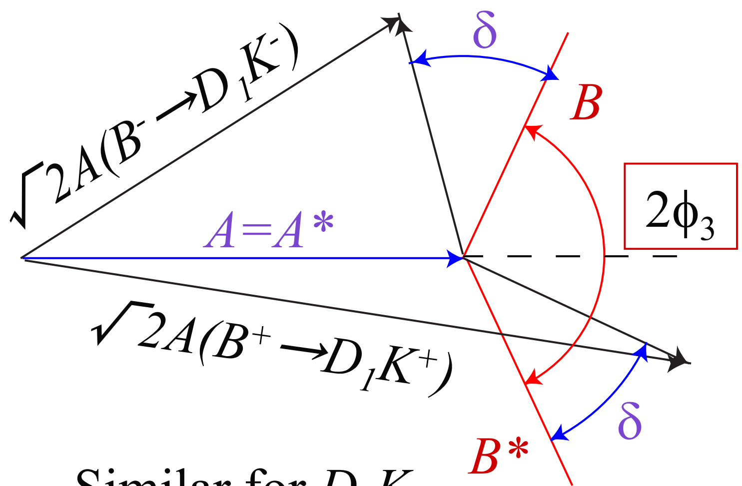


b→c tree (Cabibbo suppressed)



b→u tree (color suppressed)

$\Rightarrow$ *Interference in* $B \rightarrow D_1 K$ ($D_1 \rightarrow K^+K^-$, $\pi^+\pi^-$, ...)



Similar for D_2K

$$r = |A(B^+ \rightarrow D^0 K^+) / A(B^+ \rightarrow \bar{D}^0 K^+)|$$

$$\sim |V_{ub}^* V_{cs}| / |V_{cb}^* V_{us}| \times [color\ \ suppression]$$

$$\sim 0.4 \times 0.25 = 0.1$$

$\Rightarrow$Interference w/ DCS mode may be a problem.

Many extensions of this method
- Gronau, London ('91), Dunietz('91)
- Atwood, Dunietz, Soni ('97)
- etc.

$B \rightarrow D_{cp}K$ (Belle)

- Belle [$78 fb^{-1}$]

  D_1: K^-K^+, $\pi^-\pi^+$

  D_2: $K_S\pi^0$, $K_S\omega(\pi^+\pi^-\pi^0)$, $K_S\phi(K^+K^-)$, $K_S\eta(\gamma\gamma)$, $K_S\eta'(\eta\pi^+\pi^-)$

$$R_1 = +1.21 \pm 0.25 \pm 0.14$$

$$R_2 = +1.41 \pm 0.27 \pm 0.15$$

$$A_1 = +0.06 \pm 0.19 \pm 0.04$$

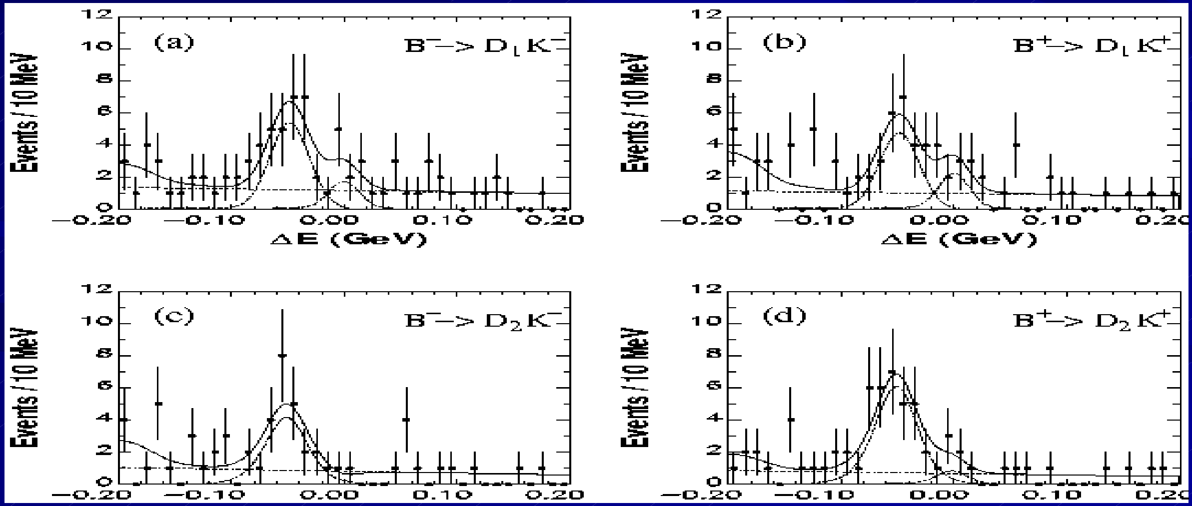
$$A_2 = -0.18 \pm 0.17 \pm 0.05$$

Measure the 4 ratios (3 indep.) and obtain 3 unknowns

$$R_{1(2)} = \frac{Br(D_{1(2)}K)/Br(D_{1(2)}\pi)}{Br(D^0K)/Br(D^0\pi)} = 1 + r^2 + 2r \bullet \cos\delta \bullet \cos\phi_3$$

$$Acp = \frac{2r \bullet \sin\delta \bullet \sin\phi_3}{1 + r^2 + 2r \bullet \cos\delta \bullet \cos\phi_3}$$

$$\delta \rightarrow \delta + \pi \quad \text{for } D_2$$



$\delta A_{1(2)}, \delta R_{1(2)}$ $\sim 10\%@300fb^{-1}$

$B \to D(K_S\pi^+\pi^-)$ Dalitz Analysis

BELLE-CONF-0343, hep-ex/0308043

- Belle [140fb-1]

$$B^{\mp} \to D_{CP} K^{\mp}$$

$$D^0 \to \bar{K}^0 \pi^+ \pi^- \searrow$$
$$\bar{D}^0 \to K^0 \pi^+ \pi^- \nearrow \quad D^0 \to K_S \pi^+ \pi^-$$

⇨ Interference !

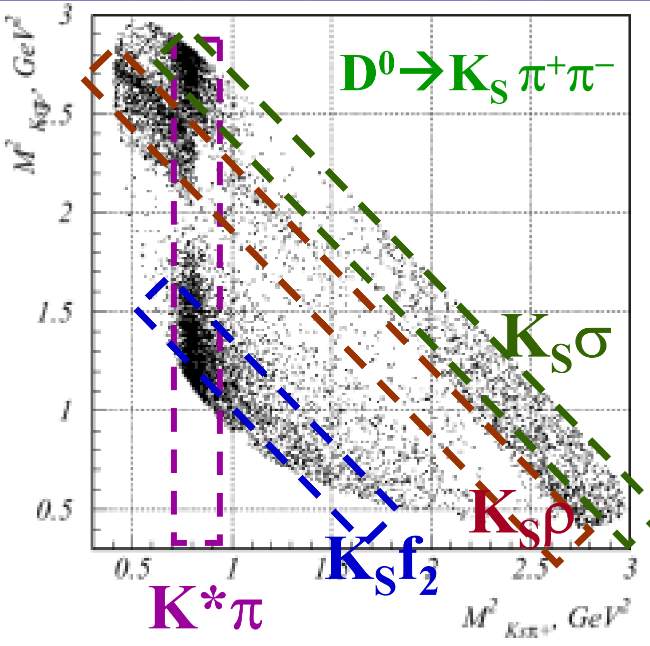
$$A(B^+ \to DK^+) = f(m_+^2, m_-^2) + r \cdot e^{i(\phi_3+\delta)} f(m_-^2, m_+^2)$$
$$A(B^- \to DK^-) = f(m_+^2, m_-^2) + r \cdot e^{i(-\phi_3+\delta)} f(m_-^2, m_+^2)$$

Complex amplitude of $D^0 \to Ks\pi^+\pi^-$ decay

$$f(m_+^2, m_-^2) = \sum_k a_k \cdot e^{i\alpha} A_k(m_+^2, m_-^2) + b \cdot e^{i\beta}$$

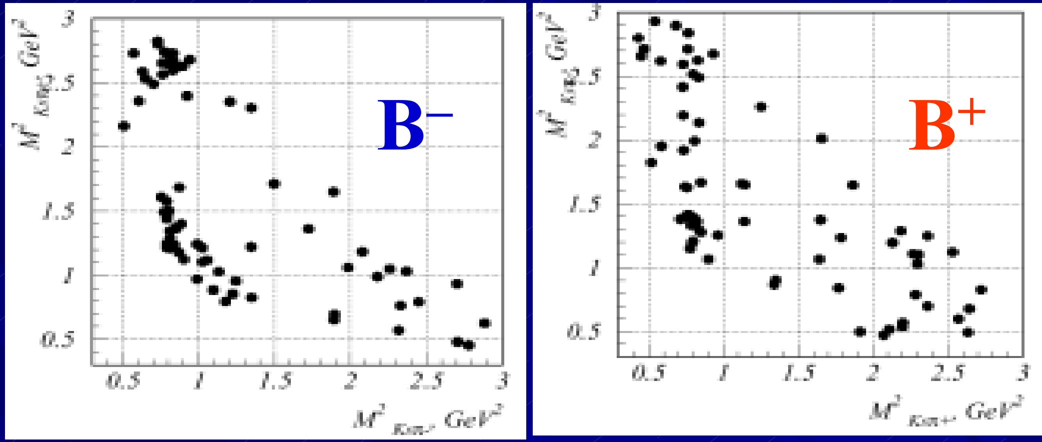
12 two-body resonance decays — Non-resonant

$D^0 \to Ks\pi^+\pi^-$ decay modeled with 13 amplitudes



$B \to D(K_S\pi^+\pi^-)$ Dalitz Analysis

- Event selection $B^\pm \to K^\pm D^0(\to K_S\pi^+\pi^-)$ $N = 107 \pm 12$
- Form Dalitz plots for B^+ and B^-

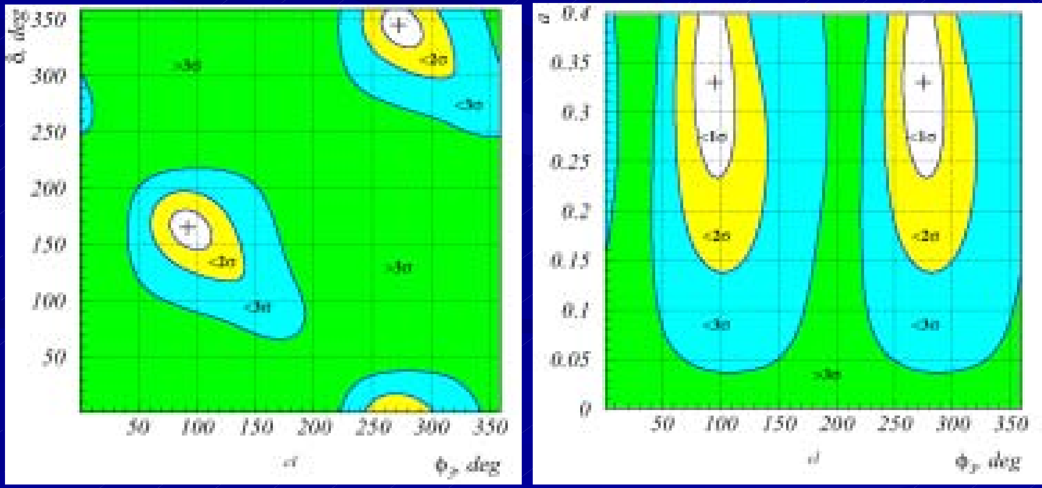


- Fit Dalitz plot for B+,B- simultaneously with *r*, *φ3*, *δ* as free parameters.

$$\phi_3 = 95^\circ \pm 25^\circ \pm 13^\circ \pm 10^\circ$$
$$\delta = 162^\circ \pm 25^\circ \pm 12^\circ \pm 24^\circ$$
$$r = 0.33 \pm 0.10$$

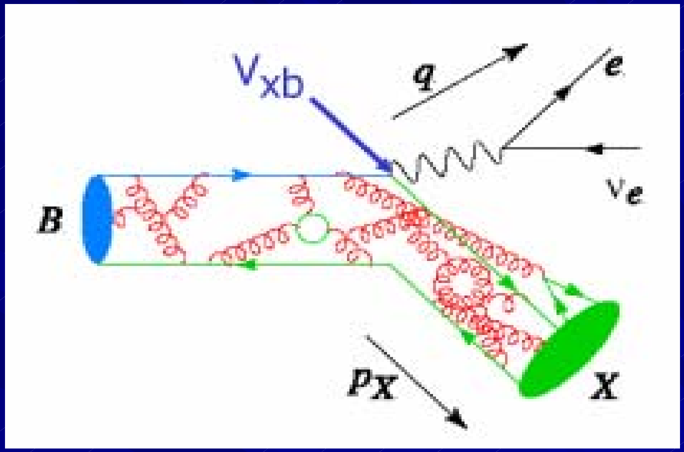
Model dep.

$$\Rightarrow 61^\circ < \phi_3 < 142^\circ (90\% CL)$$



Measurements of $|V_{cb}|$, $|V_{ub}|$

- Semileptonic decays are the most common utilities to determine $|V_{cb}|$ and $|V_{ub}|$



$|V_{cb}|$: b→c

$|V_{ub}|$: b→u

  - Theoretically easy since the QCD effects are much simplified due to the two leptons in the final state
  - Experimentally easy to access (in principle)

- Both exclusive and inclusive decays can be used.
  - Exclusive decays ← Form factor
  - Inclusive decays ← OPE, HQE parameters

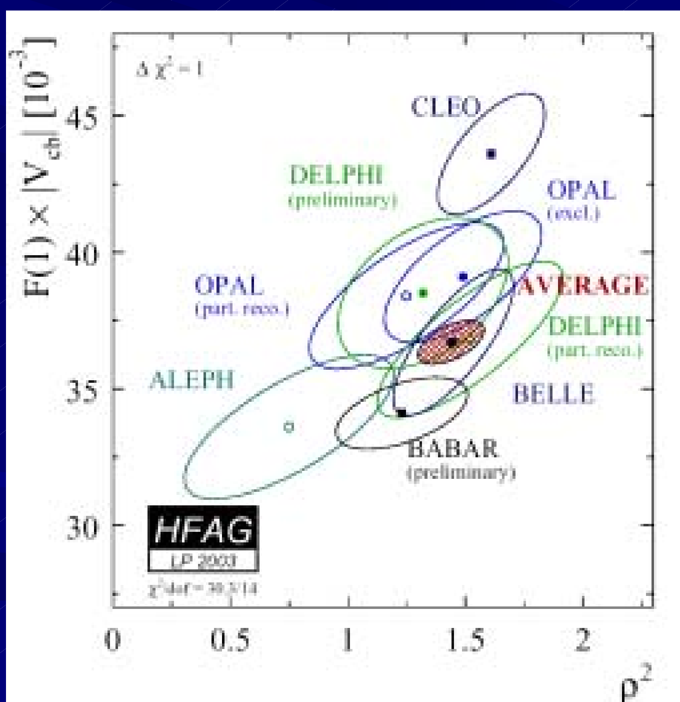
$|V_{cb}|$ Status

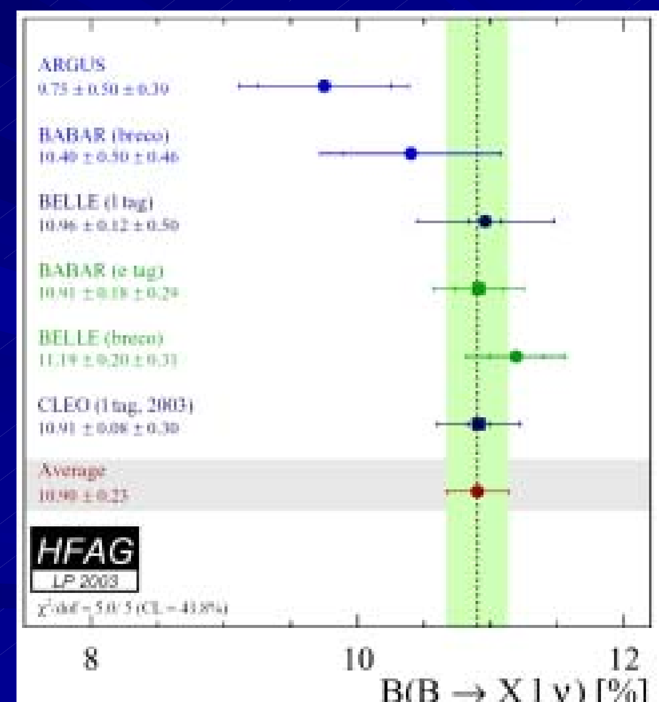
- Exclusive B→D*lν
  - Form factor known to ~3-4% at zero recoil.
  - BaBar's new measurement at LP03.
- Inclusive B→Xlν
  - HQE parameter determination (CLEO, LEP, BaBar)

$$|V_{cb}|_{excl} \cdot F(1) = 0.0367 \pm 0.0013$$

$$|V_{cb}|_{excl} = 0.0402 \pm 0.0020$$

$$|V_{cb}|_{incl} = 0.0421 \pm 0.0013$$



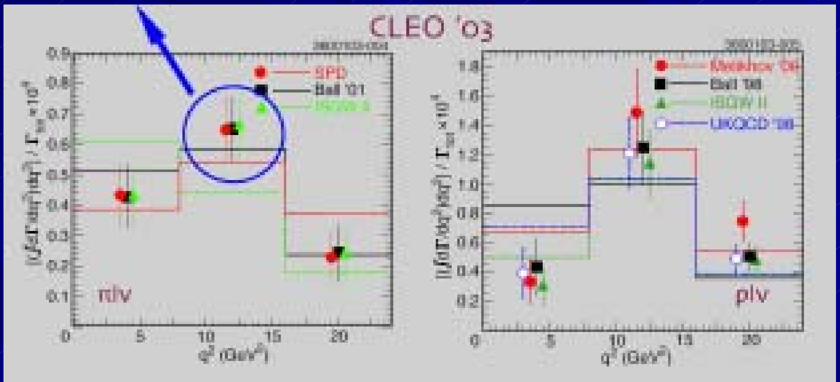


Now Δexcl <5% Δincl~3%

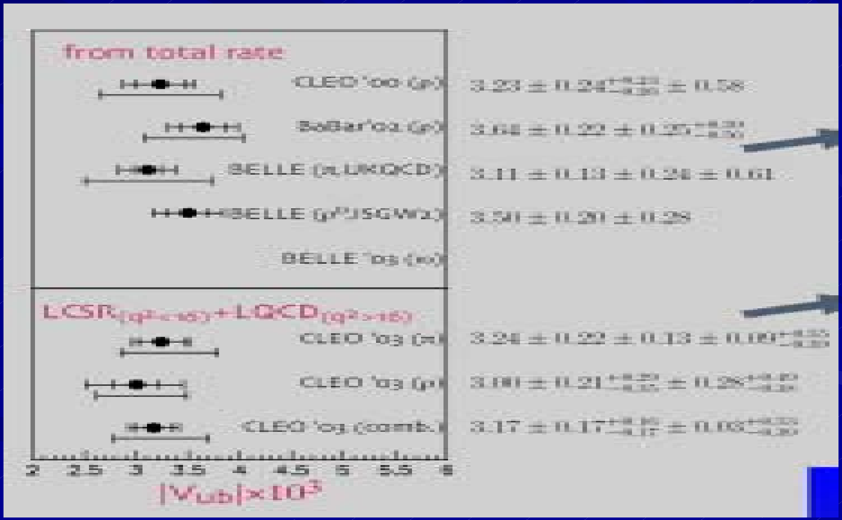
Exclusive $|V_{ub}|$ Status

- B→ π l ν, ρ l ν
  heavy→light transition
  - HQET does not work
  - Large&Uncontrollable theory error.

  ΔLQCD ~20% + quenching error



- q^2 measurements by CLEO 2003 (Belle 2002 prelim. also)
  - Test of theory model ?



Want unquenched LQCD F.F calculation !

Inclusive $|V_{ub}|$ Measurements

- Require cuts to eliminate the large b→c background

1) Lepton energy (End-point)

$$E_\ell > \frac{m_B^2 - m_D^2}{2m_B}$$

~10%

2) Lepton invariant mass

$$q^2 > (m_B - m_D)^2$$

~20%

3) Hadron invariant mass

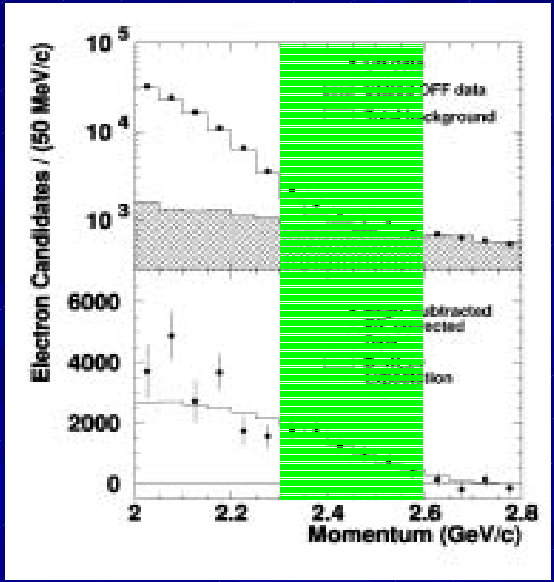
$$M_X < M_D$$

~80%

Acceptance for b→u l ν signals

(larger the better)

- Belle end-point spectrum [27.1fb^{-1}]



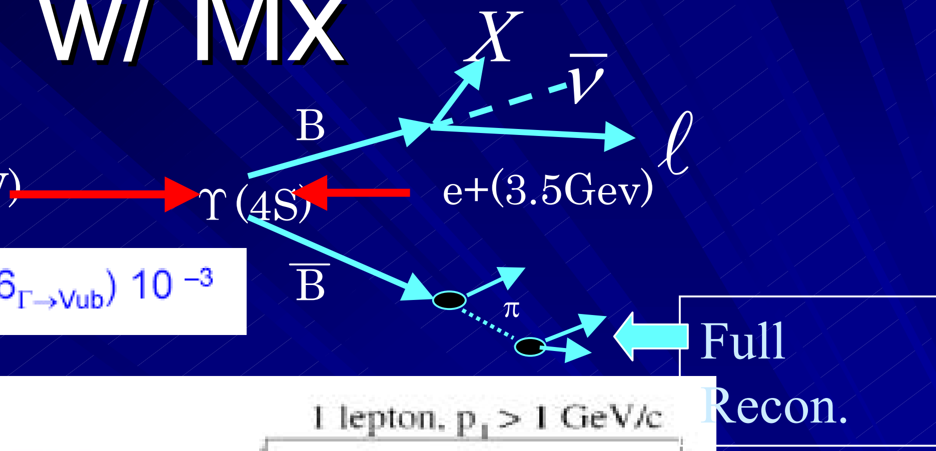
$$Br = \Delta Br / f_u$$
$$= (1.66 \pm 0.14 \pm 0.13 \pm 0.37 \pm 0.28) \times 10^{-4}$$

- Large extrapolation error due to small accpetance

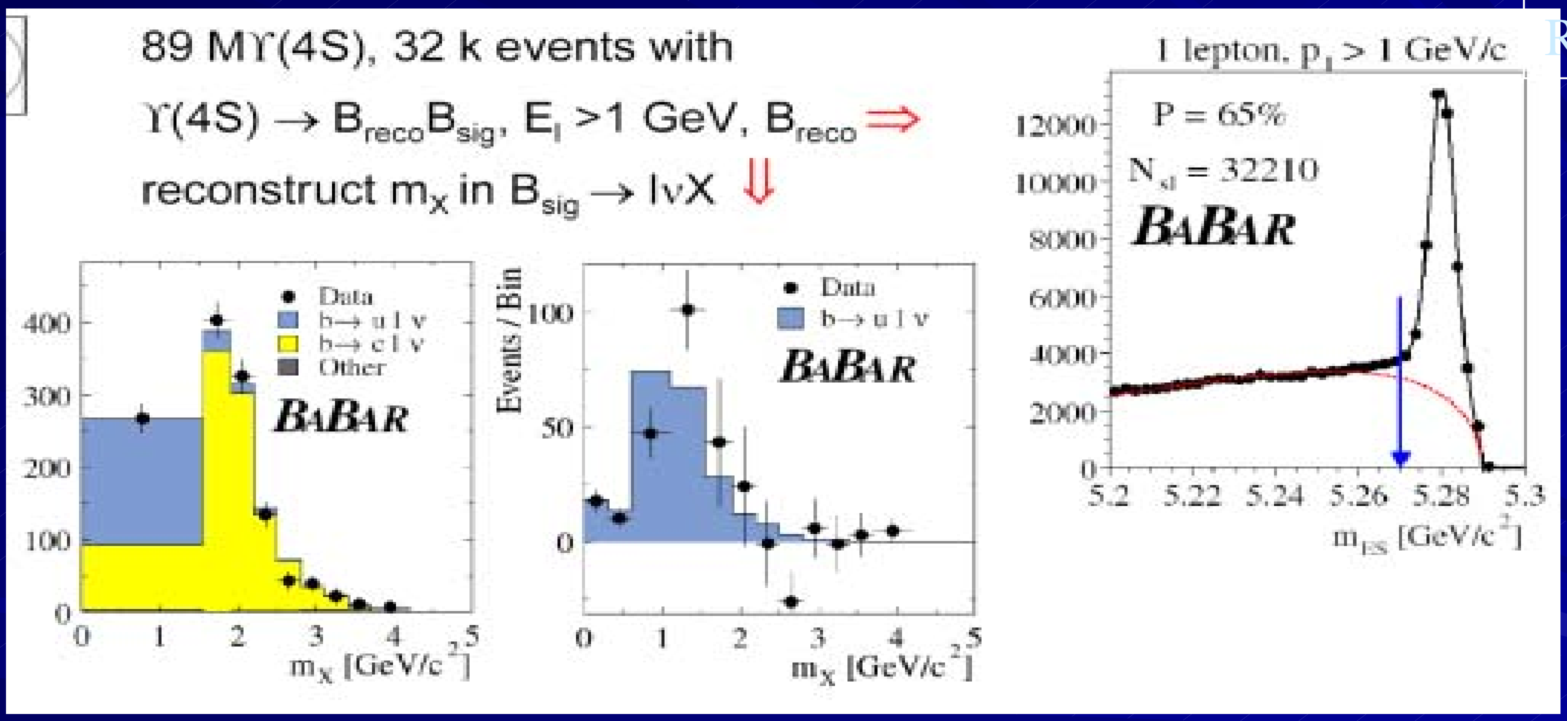
⇒ Mx measurement

Inclusive $|V_{ub}|$ w/ Mx

- BaBar w/ full recon tag.



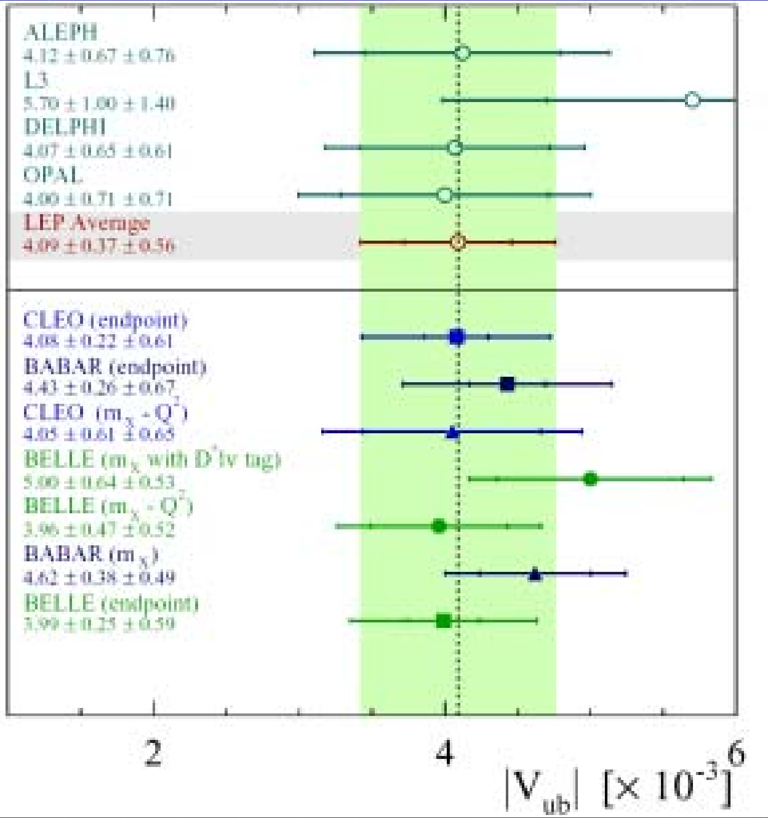
$|V_{ub}| = (4.62 \pm 0.28_{stat} \pm 0.27_{sys} \pm 0.40_{shf} \pm 0.26_{\Gamma\to Vub})\ 10^{-3}$



- Belle w/ semileptonic tag + ‘advanced’ ν recon.
- CLEO ν recon.

Inclusive $|V_{ub}|$ Status

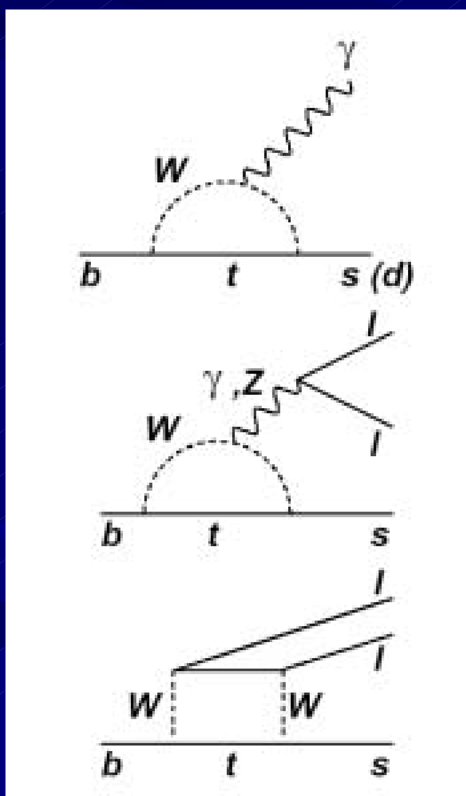
- Each measurement has (15-20)% error.
  The BaBar's Mx measurement: Δ=13% (best).
- Good prospect for (Mx,q2) method.
  (not discussed here)
  ⇨ 10%
- Semileptonic decay moment analyses are important to determine theory parameters.
  mb ⇨ 5%?

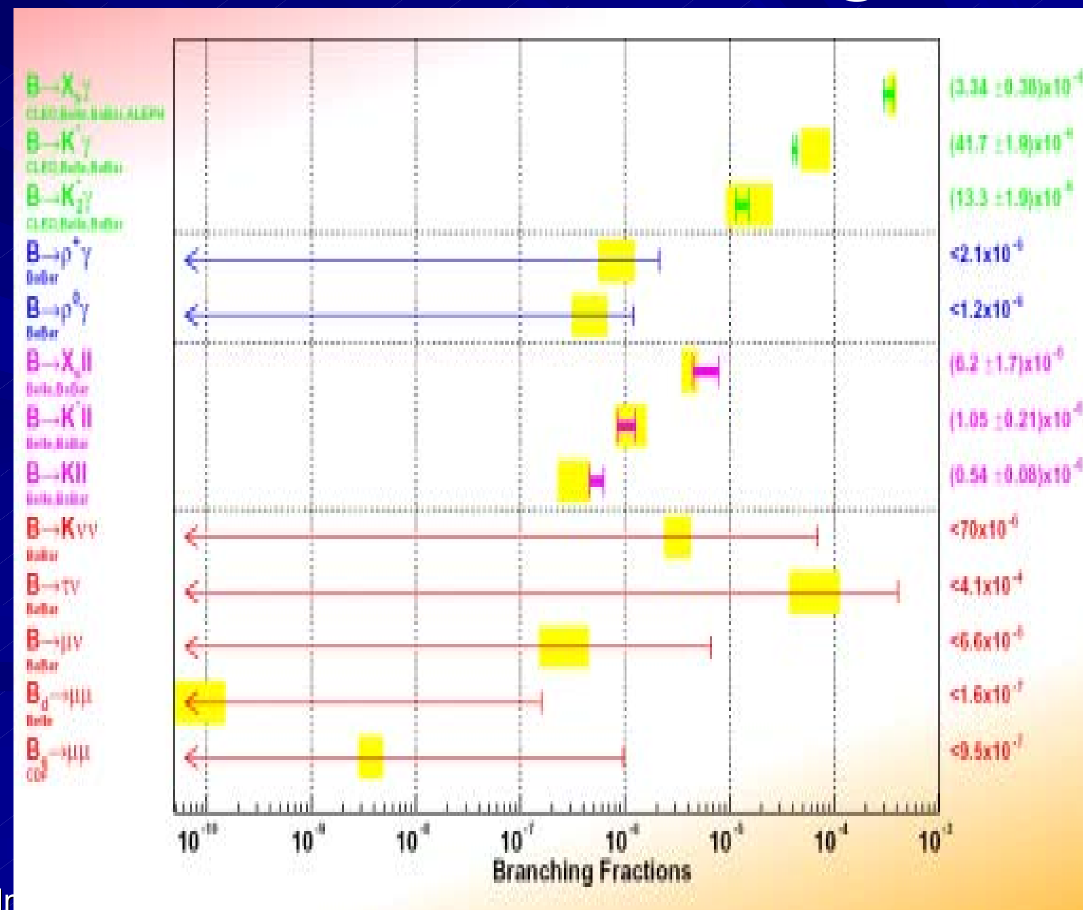


Rare B Decays (Radiative/EW)

- The B factory luminosity extends the search down to $O(10^{-7})$.
- If the ϕK_S anomaly is true, radiative/electroweak B decays are sensitive to new physics.

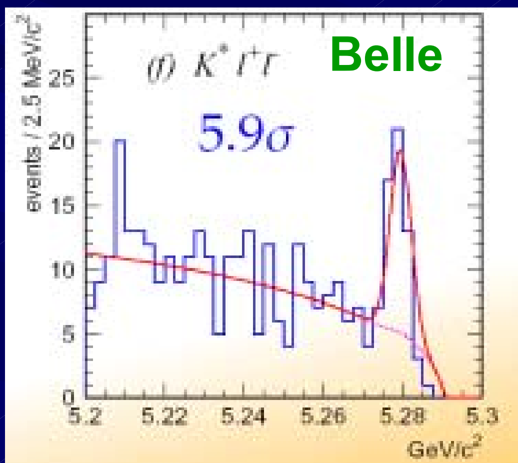
M.Nakao @ LP03

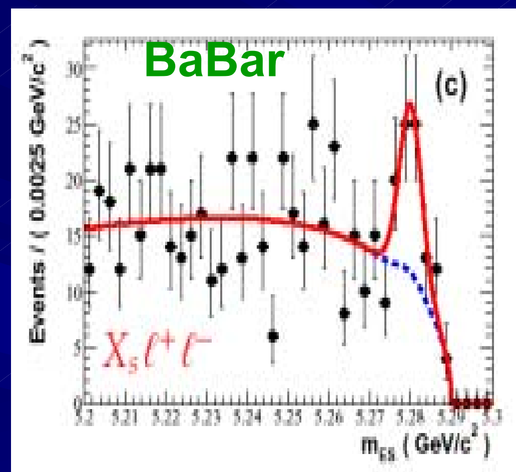


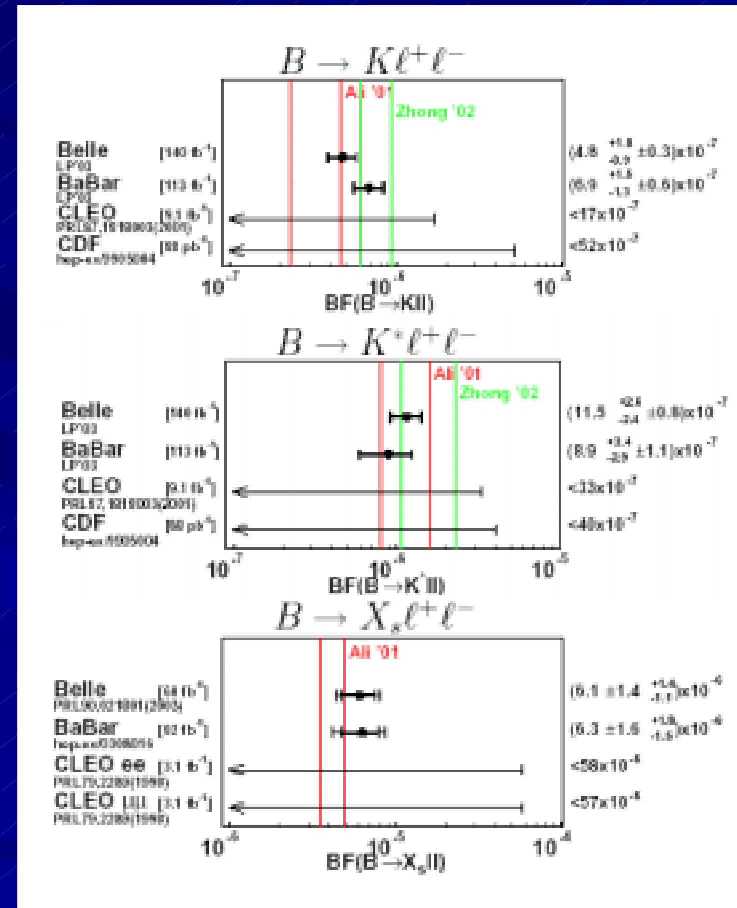


$B \to K^{(*)}ll$, $X_s ll$

- Both Belle and BaBar updated the results at LP03 with 140 and 113 fb^{-1} data.







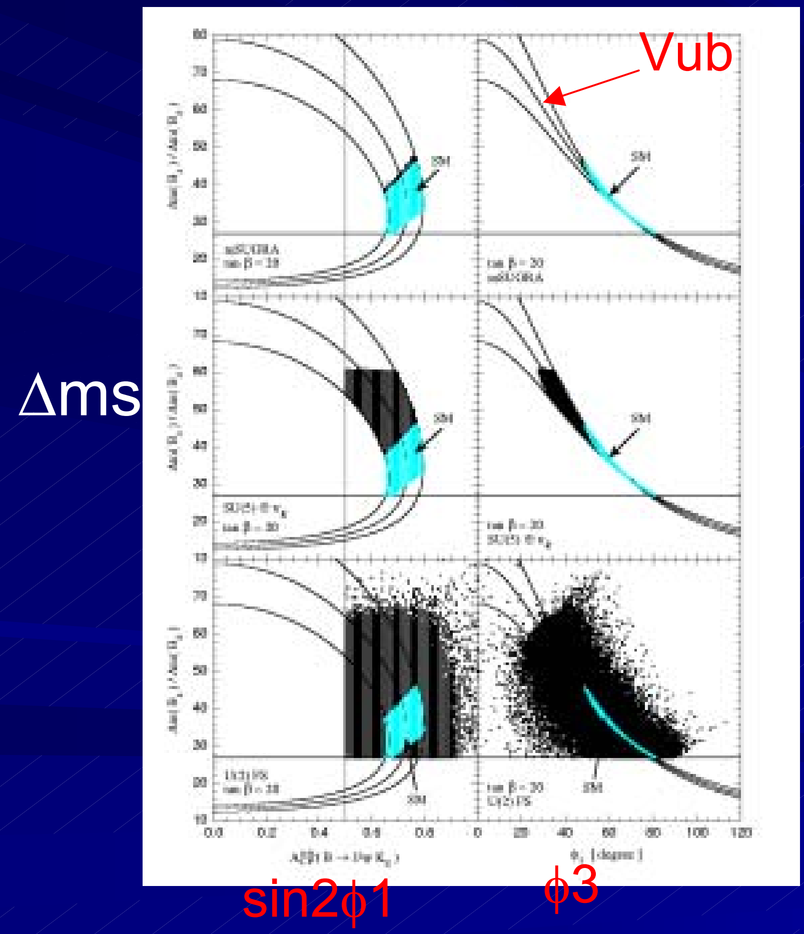
All K(*)ll and Xsll signals are found !

➡ ***Next Target: Precise distribution; m_{ll}, A_{FB} !***

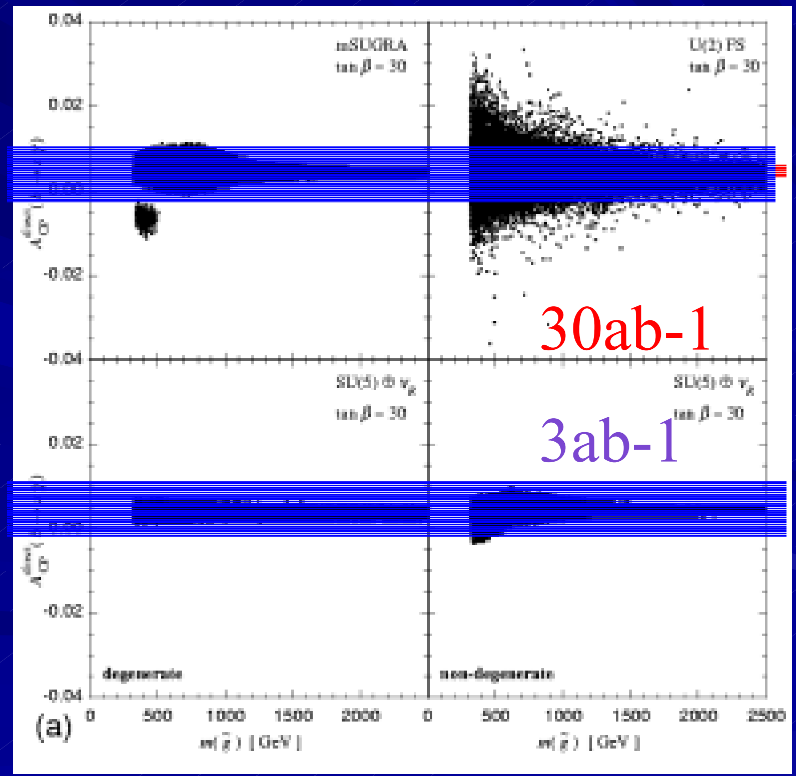
SUSY Scenario vs B Decays

Goto, Okada, Shimizu, Shindou, Tanaka,
PRD66, 035009 (2003)
hep-ph/0306093

UT test



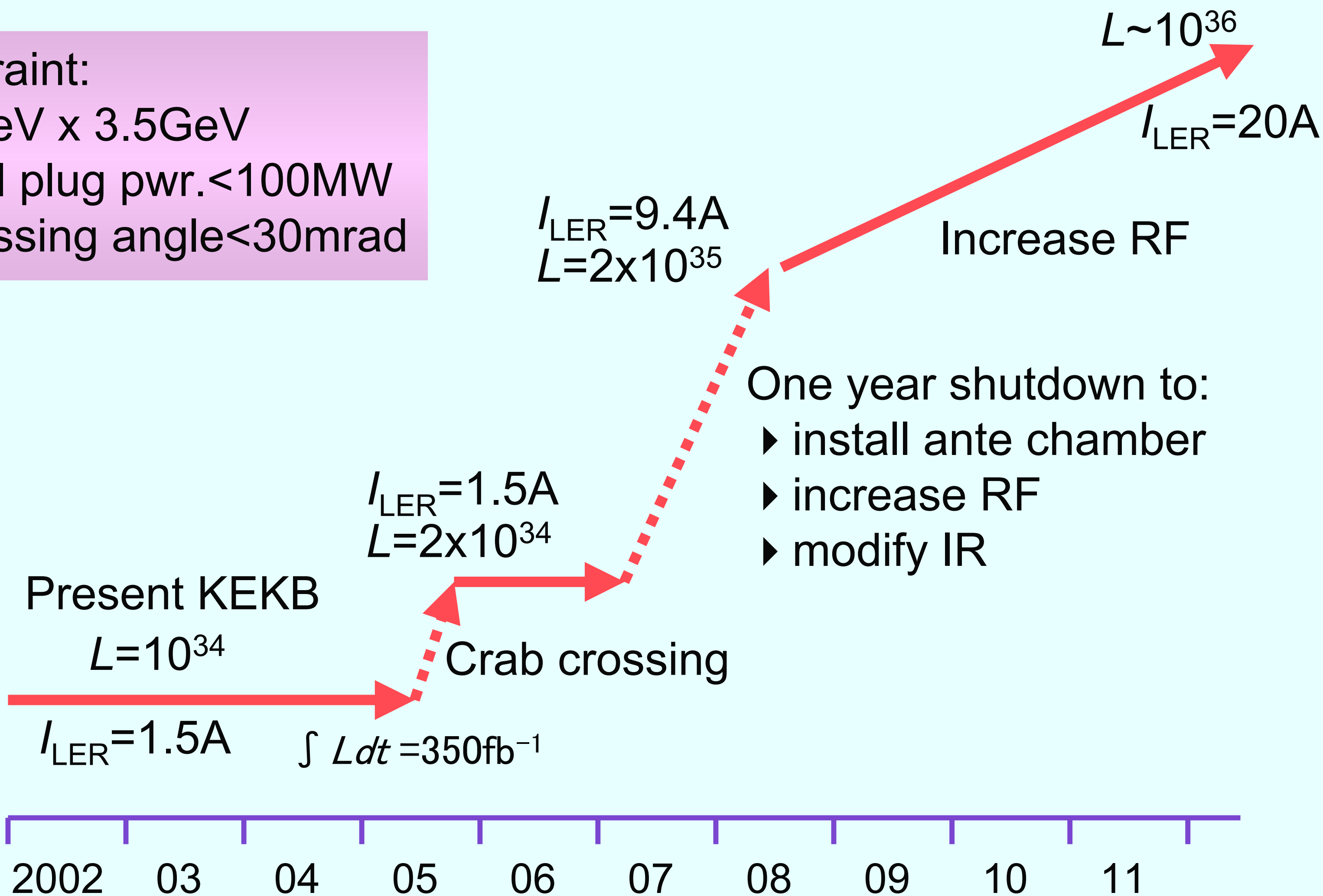
Direct CPV in b → sγ



KEKB Strategy

Scenario under discussion

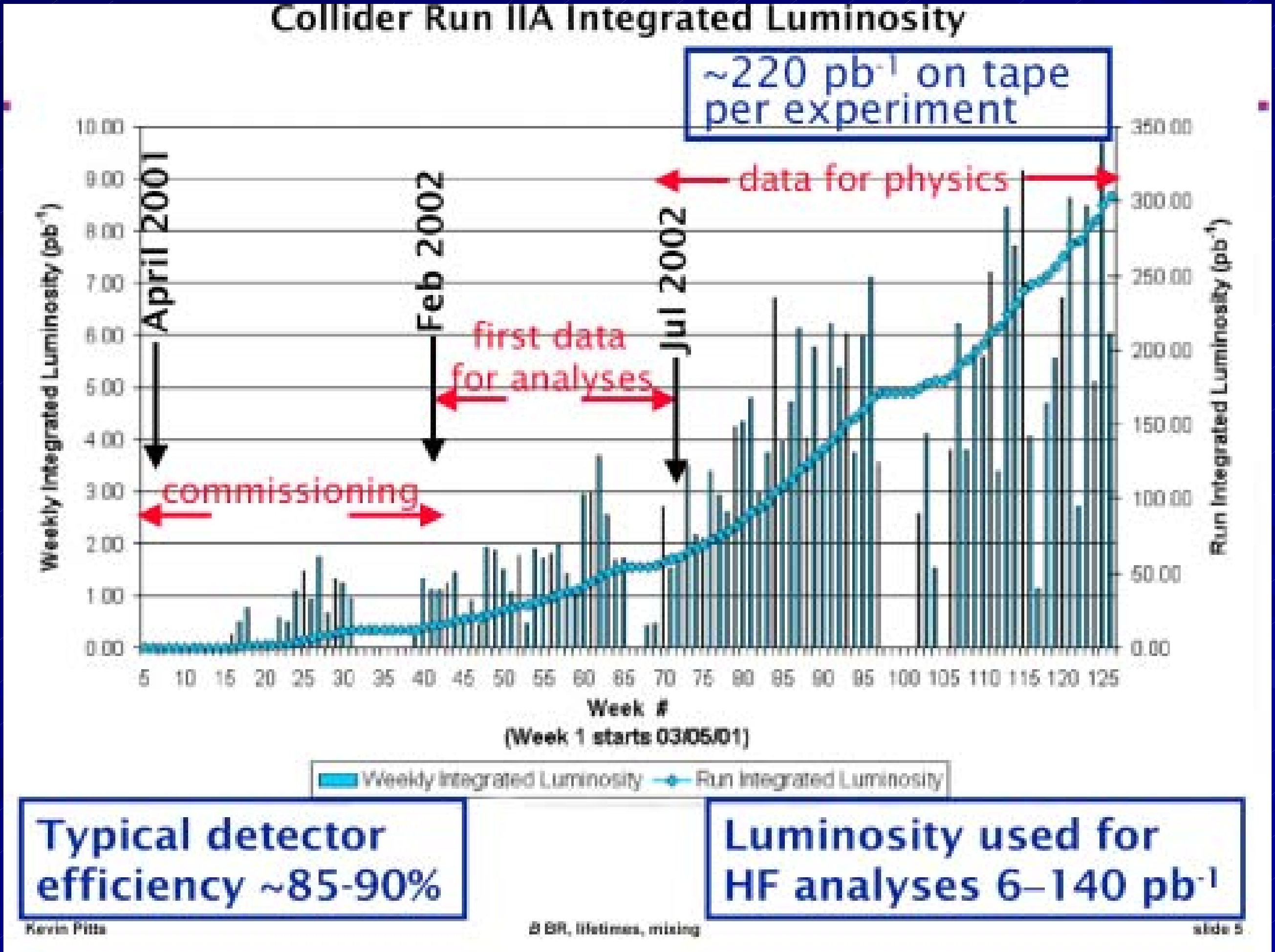
Constraint:
- 8GeV x 3.5GeV
- wall plug pwr.<100MW
- crossing angle<30mrad



Tevatron Run IIA

New pieces of information coming from CDF/D0

Kevin Pitts @ LP03



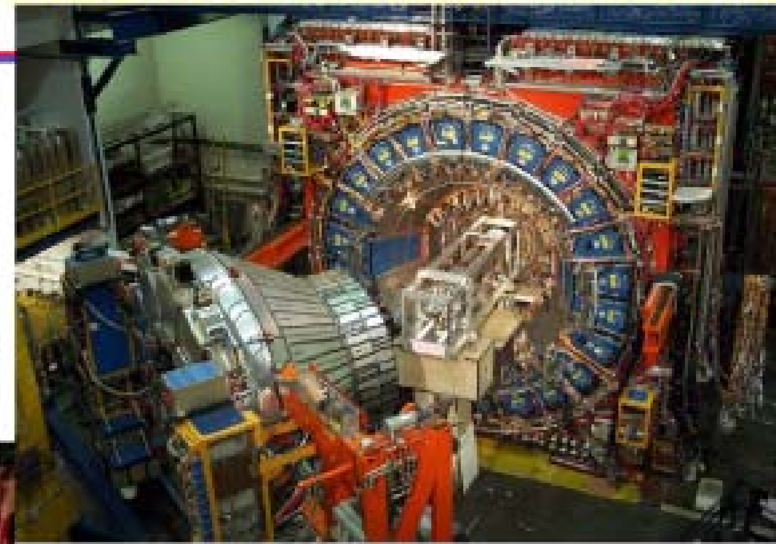
CDF/D0

Kevin Pitts @ LP03

Detectors

- Both detectors
  - silicon microvertex detectors
  - axial solenoid
  - central tracking
  - high rate trigger/DAQ system
  - calorimeter & muon systems

CDF silicon detector installation



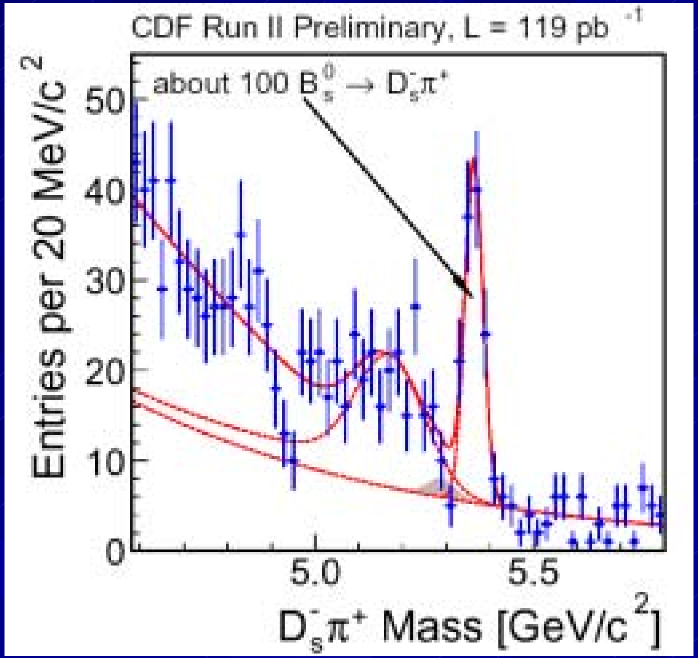
DØ fiber tracker installation

- DØ
  - Excellent electron & muon ID
  - Excellent tracking acceptance
- CDF
  - Silicon vertex trigger
  - Particle ID (TOF and dE/dx)
  - Excellent mass resolution

Kevin Pitts B BR, lifetimes, mixing slide 4

Toward B_S Mixing

- New measurement of $B_S \rightarrow D_S^+ \pi^-$ (CDF, $119 pb^{-1}$) w/ $D_s \rightarrow \phi\pi^+$ and $\phi \rightarrow K^+K^-$



$$Br(B_S \rightarrow D_S \pi^{\pm})$$
$$= (4.8 \pm 1.2 \pm 1.8 \pm 0.8 \pm 0.6) \times 10^{-3}$$

BR　sys　f_S / f_d

➡ 1600ev / fb^{-1}, S / N ~ 2

- Tagging efficiency $\varepsilon D^2 = 4\%$
- Proper time resolution $\sigma_t \sim 67\, fs$

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If $\varepsilon D^2 \rightarrow 4\%$, $\sigma_t \rightarrow 50\, fs$ ⟶

2σ sensitivity for Δm_S = 15/ps w/ $0.5 fb^{-1}$ data.

5σ sensitivity for Δm_S = 18/ps w/ $1.7 fb^{-1}$ data.

$B_s \to KK$

- Charmless two-body B decays at Tevatron
  - ⇒ Combination of $B \to \pi^+\pi^-/K^+\pi^-$, $B_S \to K^+K^-/\pi^+K^-$
- Extract each component by fitting kinematics and PID(dE/dx).

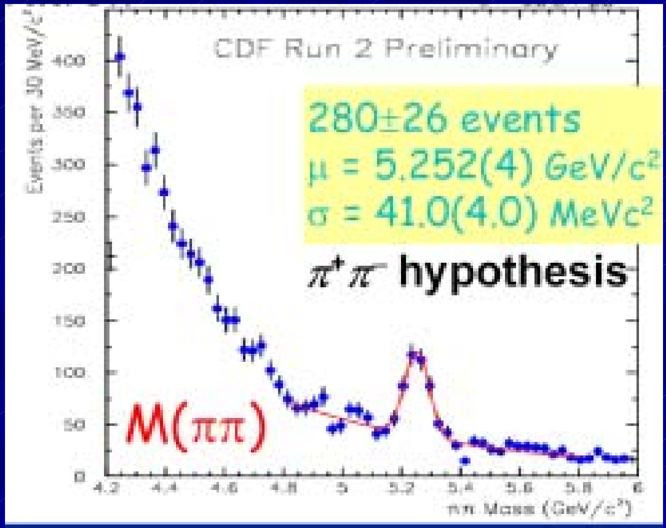
⇒

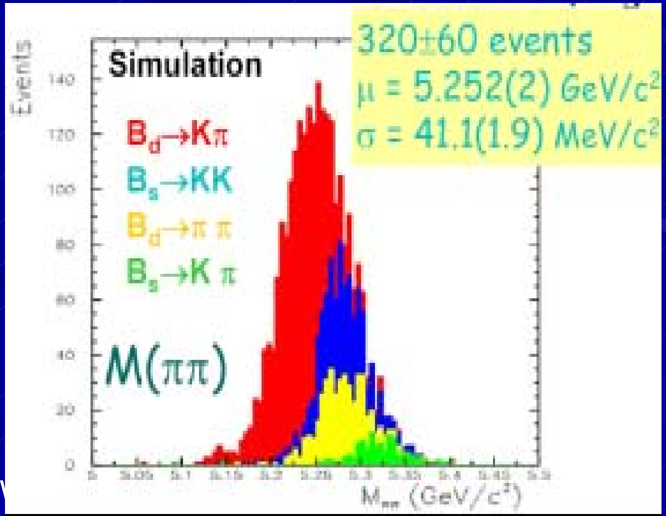
$B^0 \to K\pi$	$148 \pm 17 \pm 17$
$B^0 \to \pi\pi$	$39 \pm 14 \pm 17$
$B_S \to KK$	$90 \pm 17 \pm 17$
$B_S \to K\pi$	$3 \pm 11 \pm 17$

$$\frac{Br(B_S \to K^{\pm}K^{\mp})}{Br(B_d \to K^{\pm}\pi^{\mp})} = 2.71 \pm 1.15$$

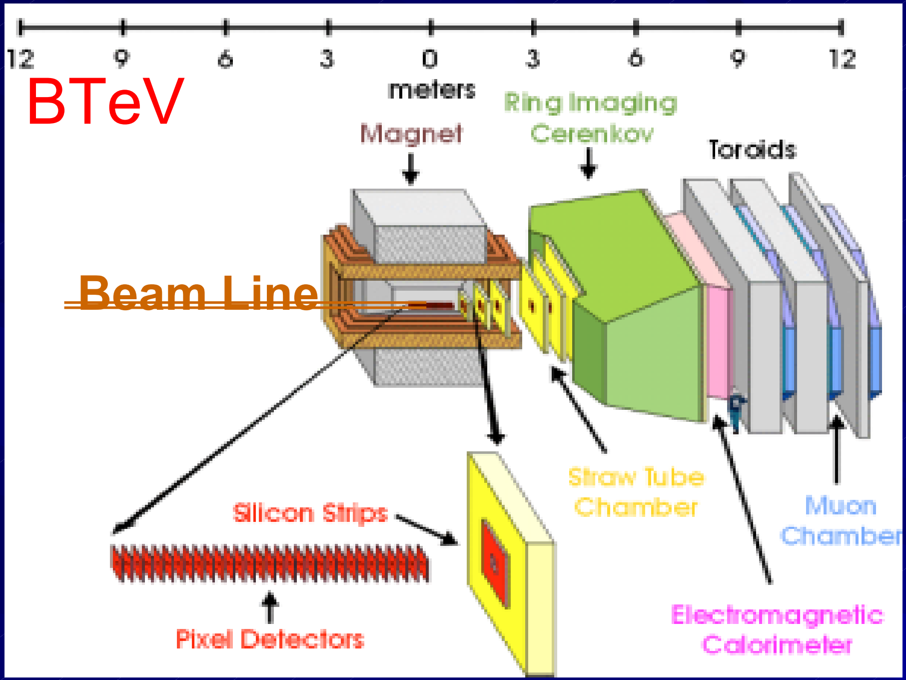
First observation !

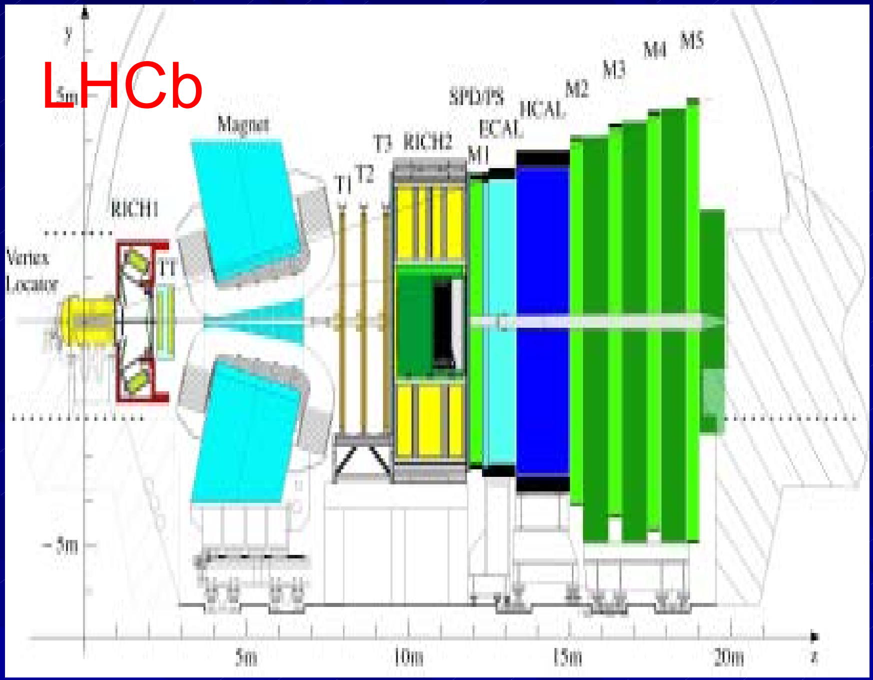
⇒ *$\phi 3$ extraction for longer term*





Future Hadron Machine Exp.





	LHCb		BTeV	
$\sigma_{b\bar{b}}$	$500\mu b$		$100\mu b$	
$\# b\bar{b}$	10^{12}		1.5×10^{11}	
$B_d \to J/\Psi K_S$	$119K$	$\sigma_\beta \sim 0.6^\circ$	$168K$	$\sigma_{\sin 2\beta} \sim 0.017$
$B_d \to \rho^0 \pi^0$			$0.78K$	$\sigma_\alpha \sim 4^\circ$
$B_d \to \pi^+ \pi^-$	$27K$	$\sigma_\alpha^* \sim 5\text{-}10^\circ$	$14.6K$	$\sigma_A \sim 0.03$
$B_s \to K^+ K^-$	$35K$		$18.9K$	$\sigma_A \sim 0.02$
$B_s \to D_s K$	$8K$	$\sigma_\gamma \sim 10^\circ$	$7.5K$	$\sigma_{\gamma - 2\chi} \sim 8^\circ$
$B_s \to J/\Psi \phi$	$128K$	$\sigma_{2\delta\gamma} \sim 2^\circ$		
$B_s \to J/\Psi \eta / \eta'$			$12.6K$	$\sigma_{\sin 2\chi} \sim 0.024$

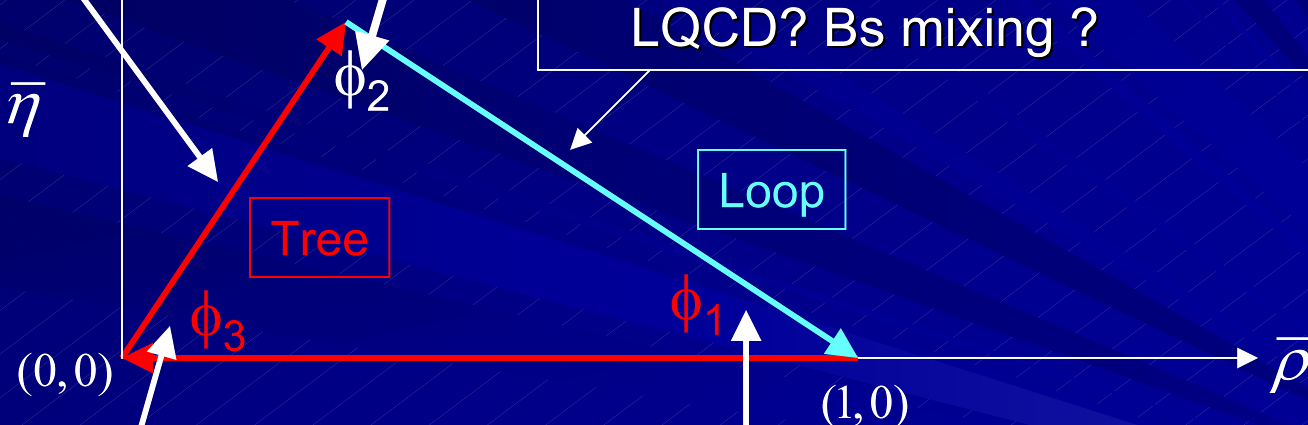
* Requires SU(3) modeling.

Summary/Remarks-1

- $|V_{ub}|$ → 10% with (M_x,q^2) method (full reco tag.)
  → 5% by improving HQE parameters (m_b) ?

- ϕ_2 require isospin analysis.
  Need $A_{cp}(\pi^0\pi^0)$ Tough!

- Error totally dominated by fb,Bd
  Crucial to test SM
  LQCD? Bs mixing ?

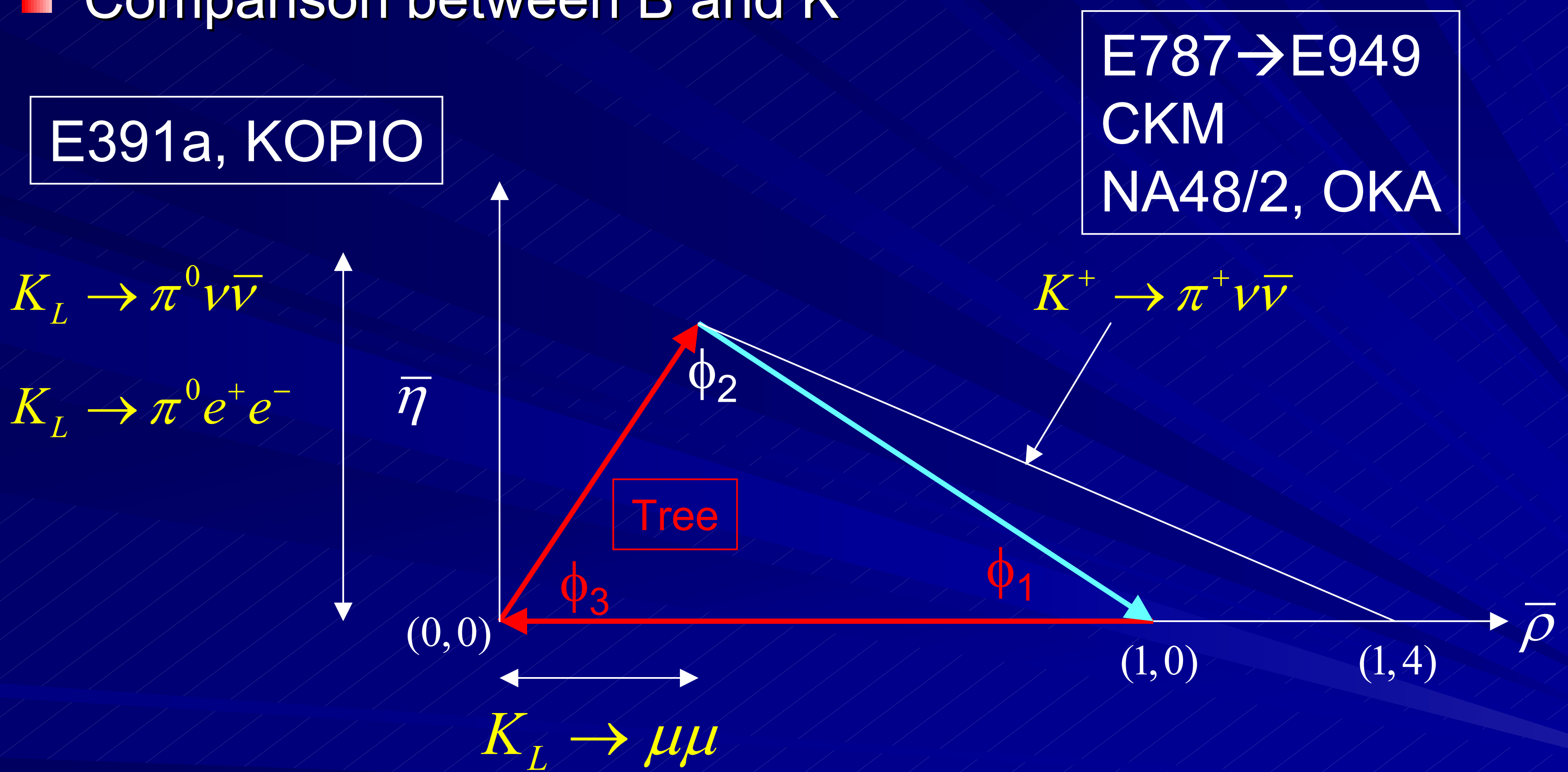


- ϕ_3 by DK improves with L
  The Dalitz analysis is a promising approach.
  Δ~10° (stat) by L~x5

- Sin2ϕ1(J/ψ Ks) already < 5%
  The error still dominated by sys.

Summary/Remarks-2

- Comparison between B and K



How NP comes into B and K decays?

b→s loop ⟺ s→d loop

Summary/Remark-3

- It is of great importance to confirm the Belle's ϕK_s anomaly.

- In future, more interesting to see (esp. if the anomaly is true)
  Acp in many Penguin decays

  Many intersting CPV phenomena may come out !

  $K^{(*)}ll$, Xsll distributions $\quad M_{ll}, \quad A_{FB}$

  Acp in radiative decays $\quad B \to K^* \gamma, b \to s\gamma, b \to d\gamma$

  $B \to D\tau\nu$

  $\tau \to \mu\gamma$

  etc.

  Future Projects: BTeV, LHCb ⇔ Super-B

  Now the time to discuss the sensitivity for NP!

KEKB Strategy

Scenario under discussion

Constraint:
- 8GeV x 3.5GeV
- wall plug pwr.<100MW
- crossing angle<30mrad