CKM results from the B-Factories

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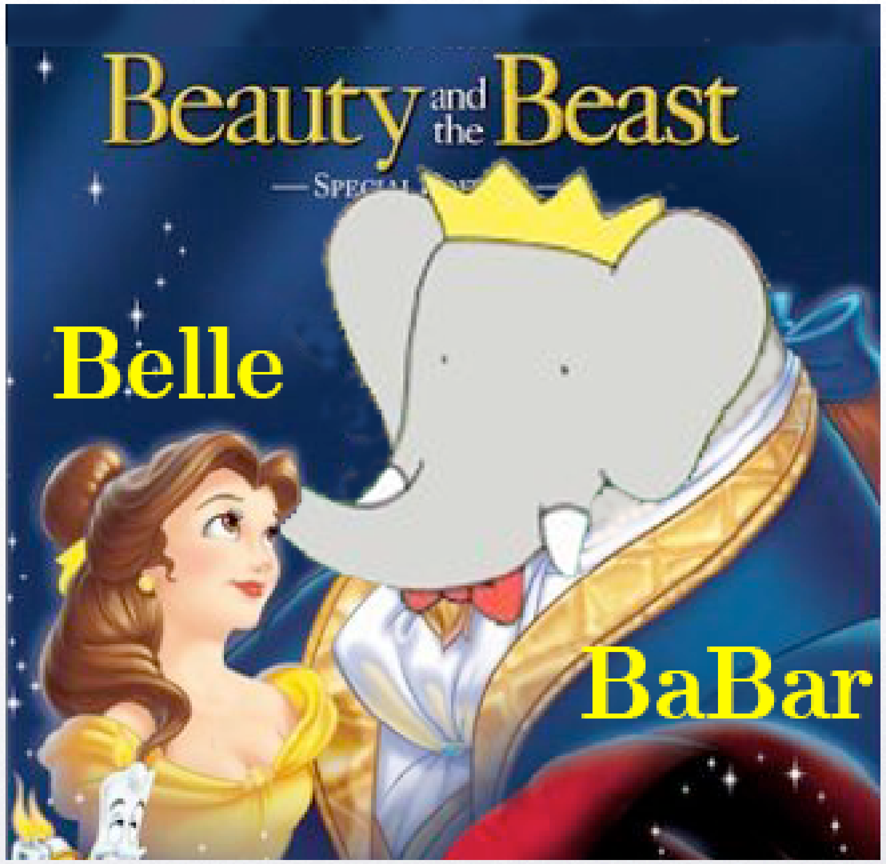
Yonsei Univ. (on behalf of the Belle collab.)

The 6th KEK Topical Conference
“Frontiers in Particle Physics & Cosmology”

Overview

- Intro. (for non-experts)
- Experimental Results
  - The angles
  - The sides
- Summary & Outlook



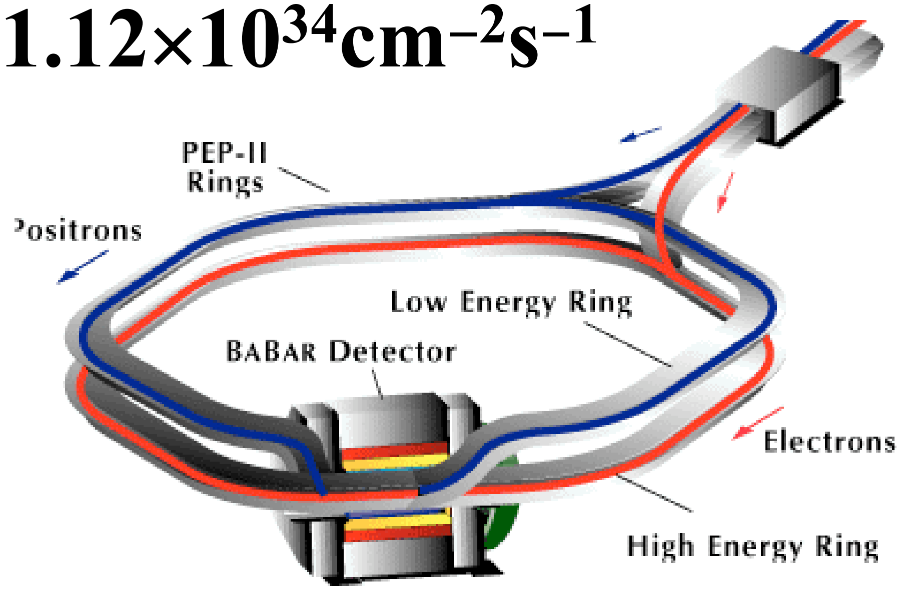
Two asymmetric-energy B factories

PEP-II at SLAC

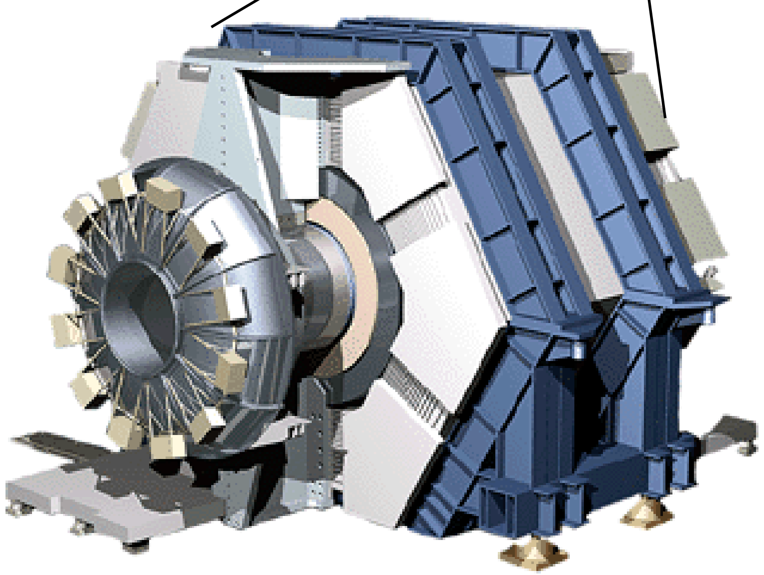
9GeV (e^-) × 3.1GeV (e^+)

peak luminosity:

$1.12\times10^{34}cm^{-2}s^{-1}$

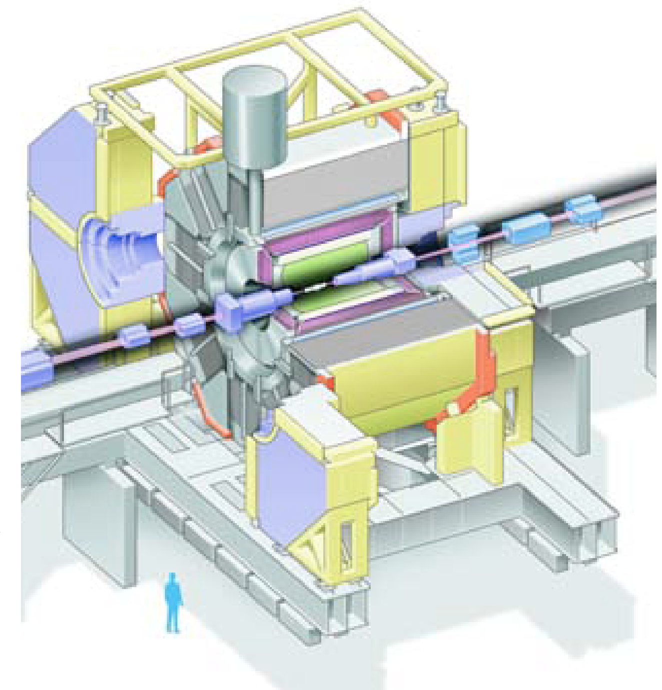


BaBar

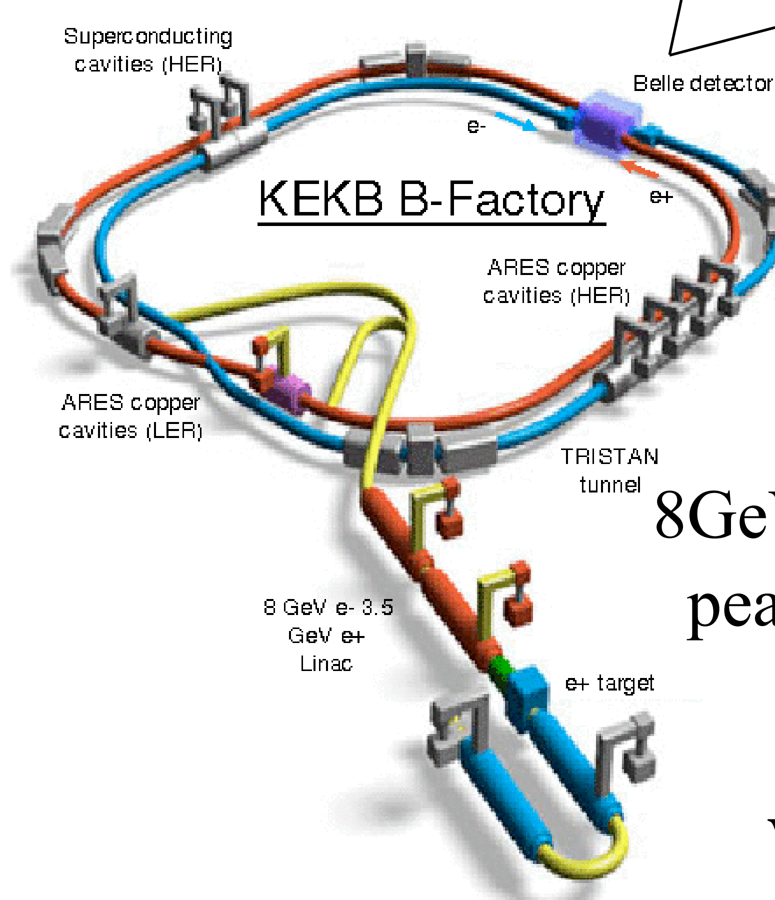


11 nations,
80 institutes,
623 persons

13 countries,
57 institutes,
~400 collaborators



Belle



KEKB at KEK

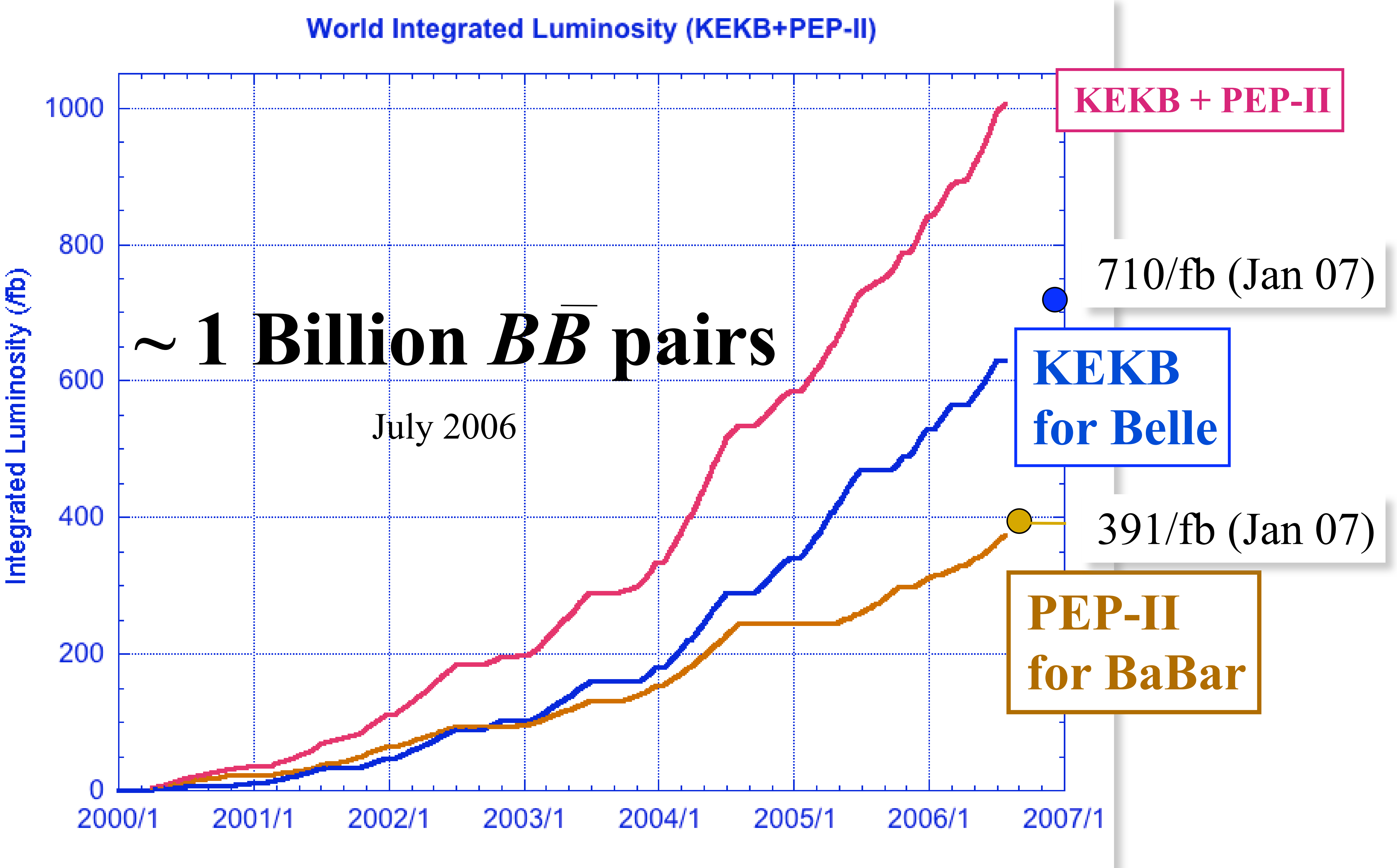
8GeV (e^-) × 3.5GeV (e^+)

peak luminosity:

$1.71\times10^{34}cm^{-2}s^{-1}$

world record

Integrated Luminosity



Motivations

- Big bang cosmology suggests a balanced production of matter & antimatter, but our current universe is dominated by matter -- at least, the visible part.
- A. Sakharov's 3 conditions for matter dominance
  - baryon number non-conservation
  - C and CP violation
  - not in thermal equilibrium
- Lorenz-invariant quantum field theory demands invariance under CPT, but nothing more.
- In the Standard Model, we actually have a mechanism for CP violation:

  ⇨ the KM mechanism.

Kobayashi-Maskawa (KM) ansatz


"CPV is due to an irreducible phase in the quark mixing matrix in 3 generations"

of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

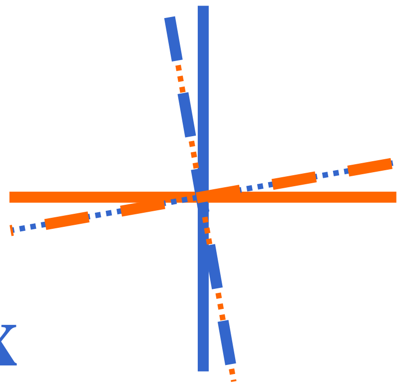
In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system, we have some limitations on the hadron model. It is well known that there exists, in the case of the triplet model, a difficulty of the strangeness changing neutral current and that the quartet model is free from this difficulty. Fur-

First 3rd-gen. particle (τ) seen in 1975

Flavor mixing and CKM matrix

- For quarks,
  - weak interaction eigenstates ≠ mass eigenstates
  - mixing of quark flavors through a **unitary matrix**



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \left(V_{\text{CKM}} \right) \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

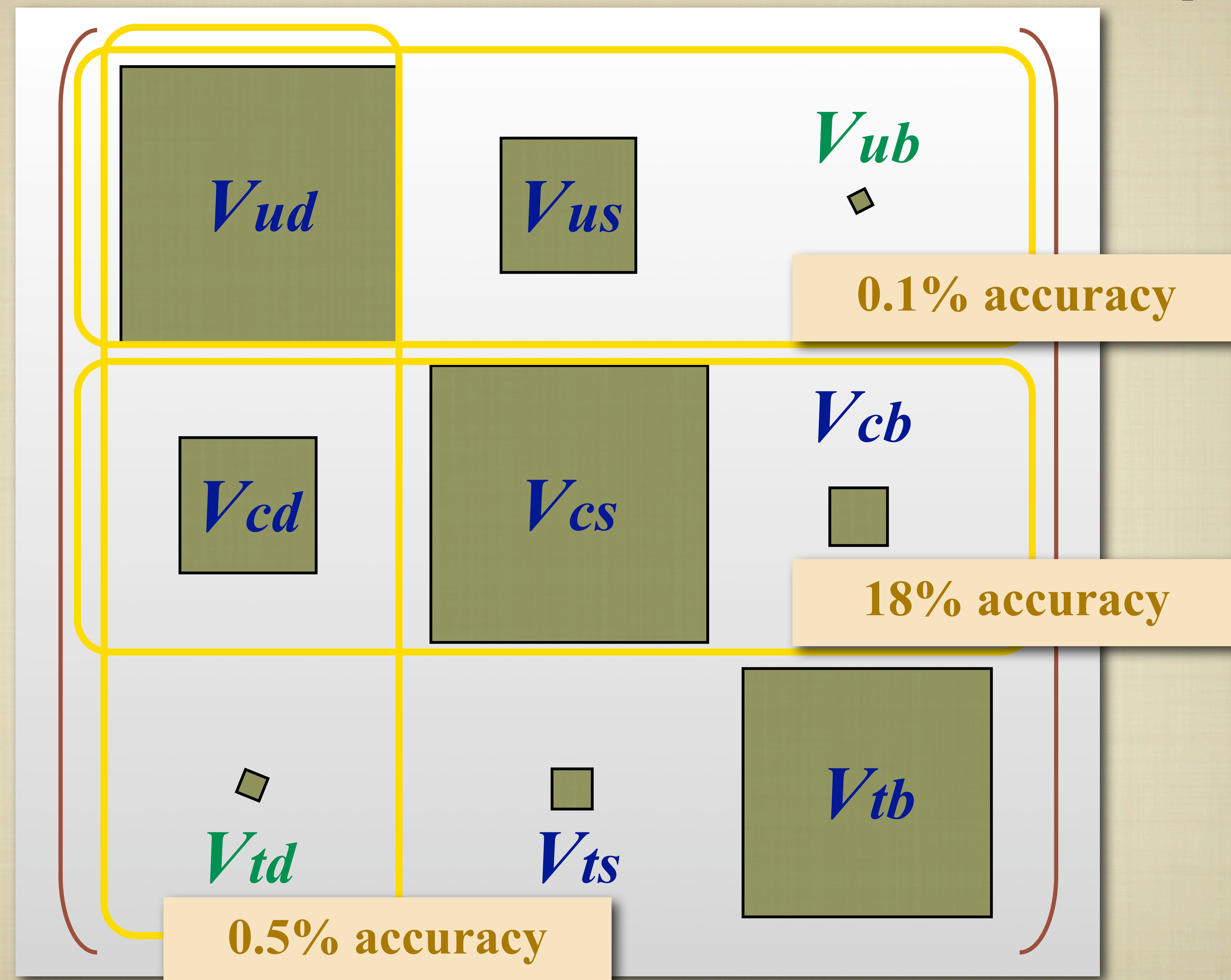
Wolfenstein parametrization

$$V_{\text{CKM}} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & \underline{A\lambda^3(\rho - i\eta)} \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ \underline{A\lambda^3(1-\rho-i\eta)} & -A\lambda^2 & 1 \end{pmatrix}$$

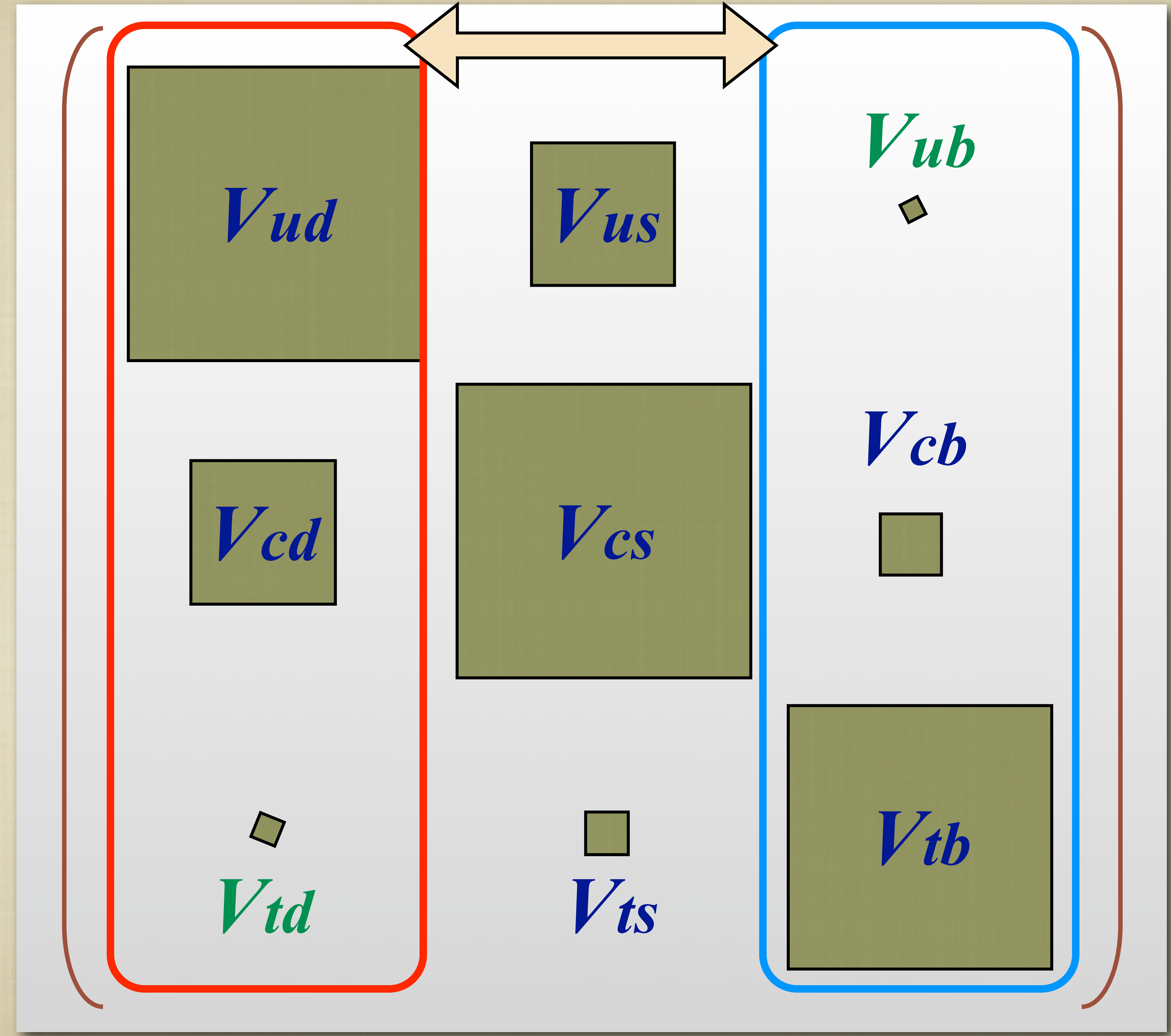
$|\lambda| \approx O(0.1)$

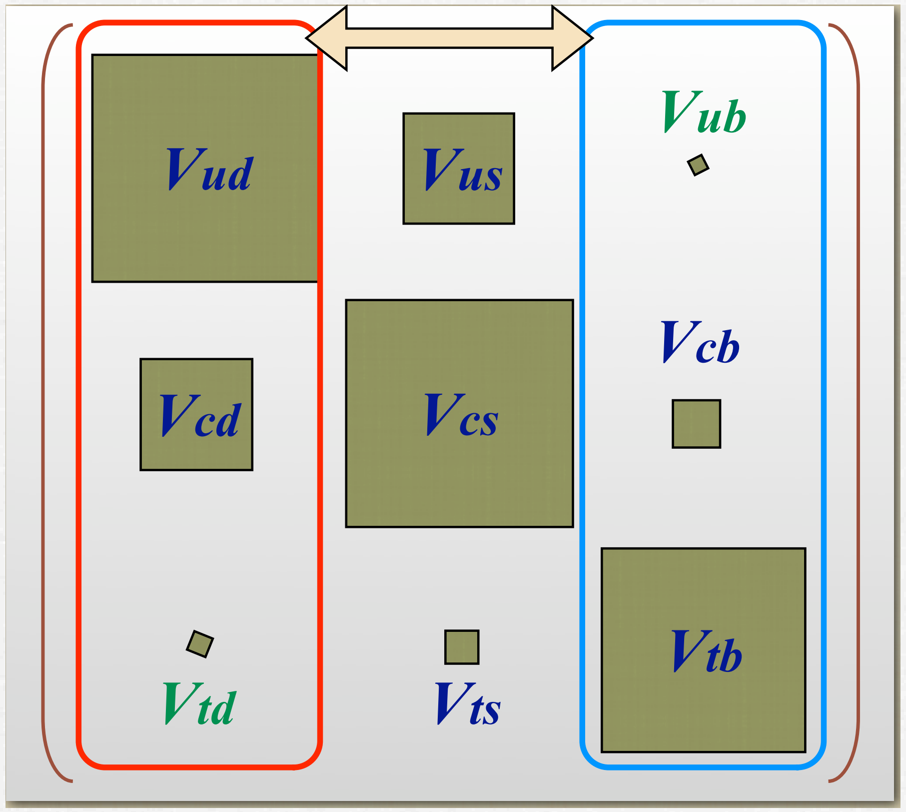
3 real parameters (λ, A, ρ) and 1 phase (η)

Test of Unitarity



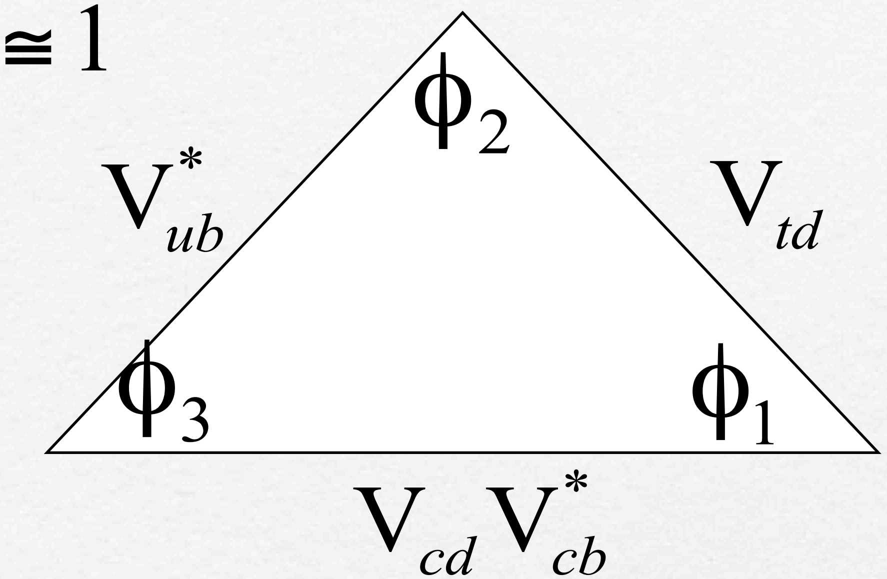
Test of Unitarity





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

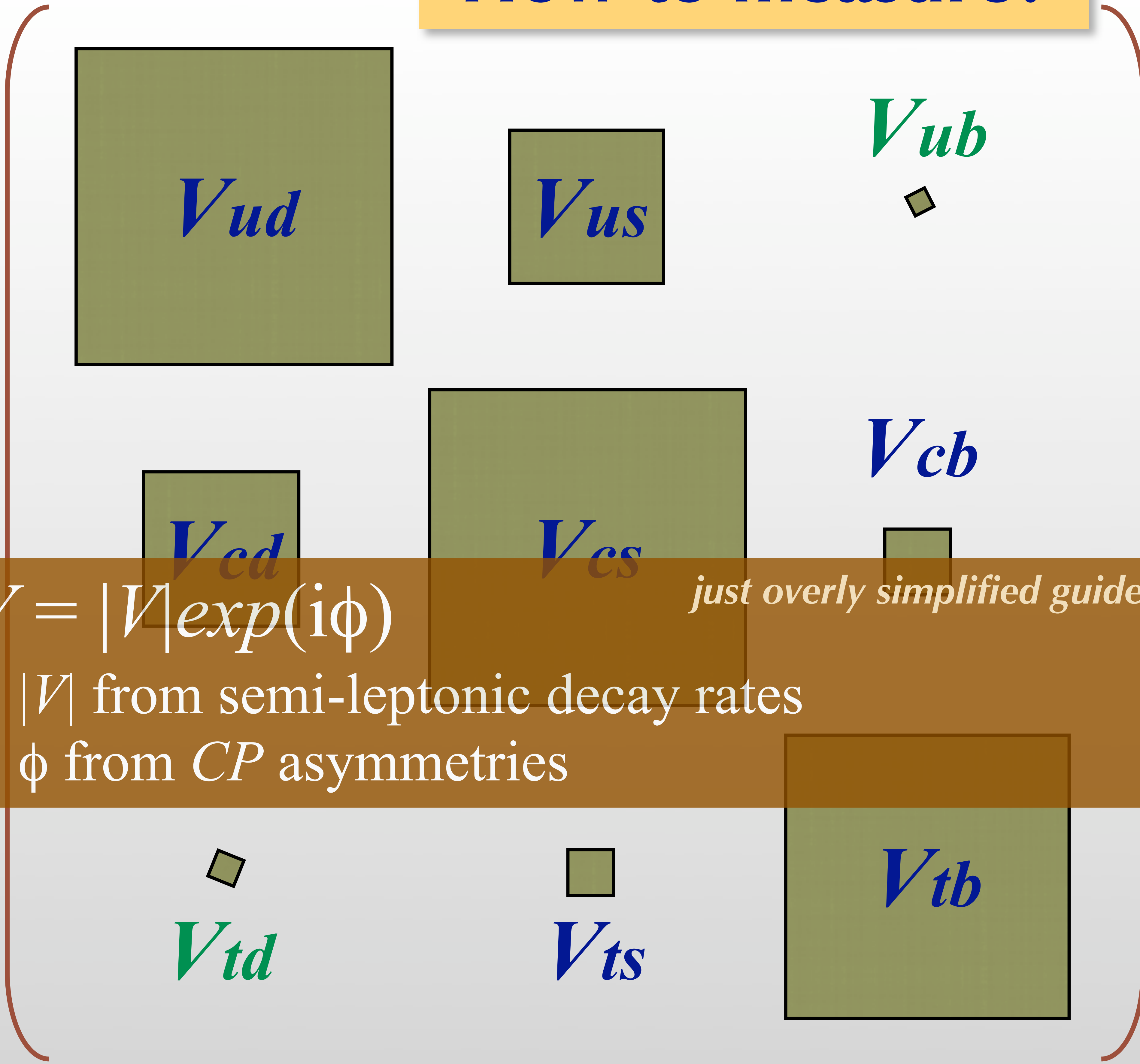
$$V_{ud} \cong V_{tb} \cong 1$$



Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
This talk:	易	難	魔

Z. Ligeti, ICHEP 2004

How to measure?



just overly simplified guidelines

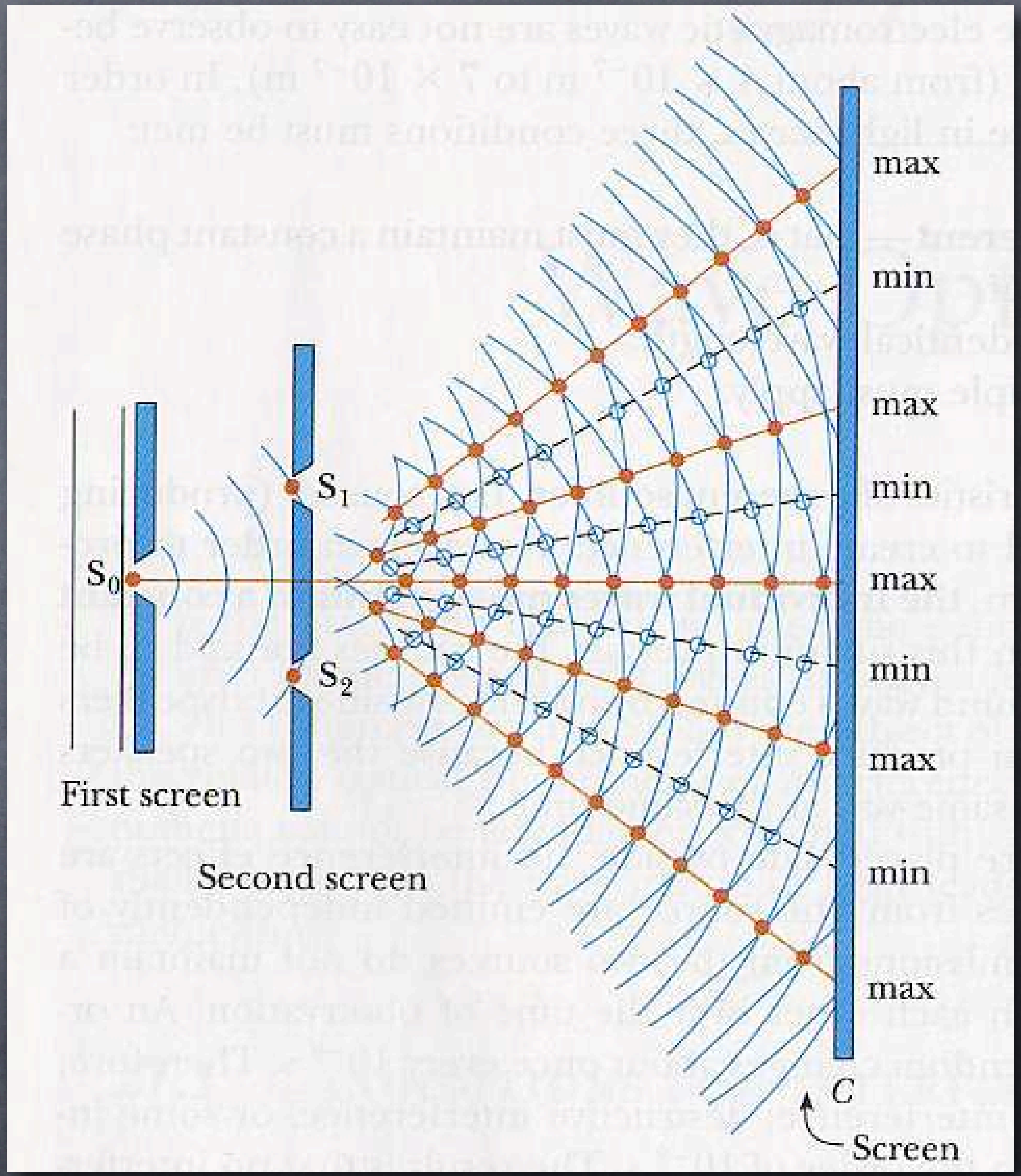
- $V = |V| exp(i\phi)$
  - $|V|$ from semi-leptonic decay rates
  - ϕ from *CP* asymmetries

CP violation in the SM

- Interference of 2 amplitudes

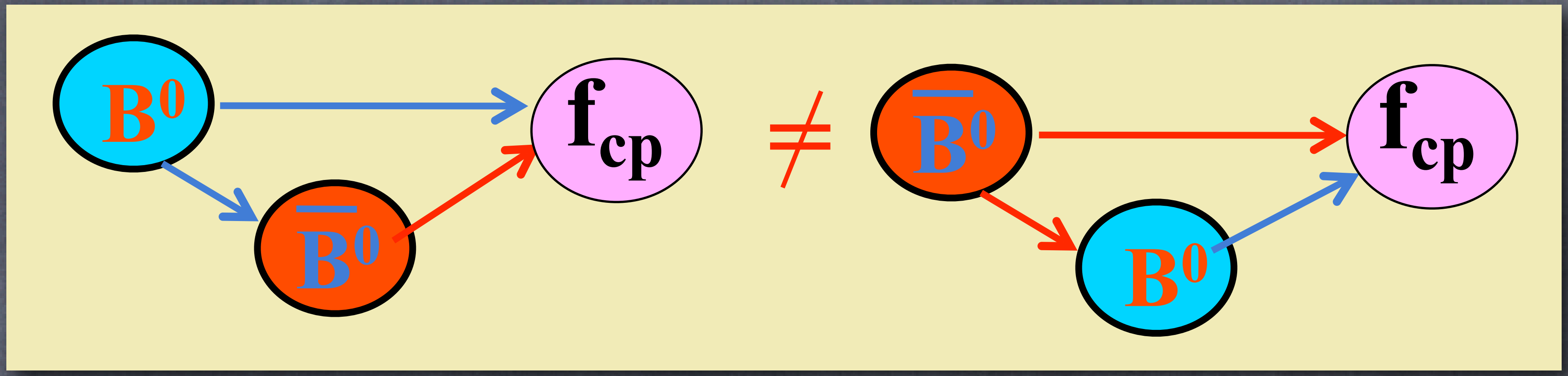
  case (1) : mixing-induced

  case (2) : b/w tree & penguin

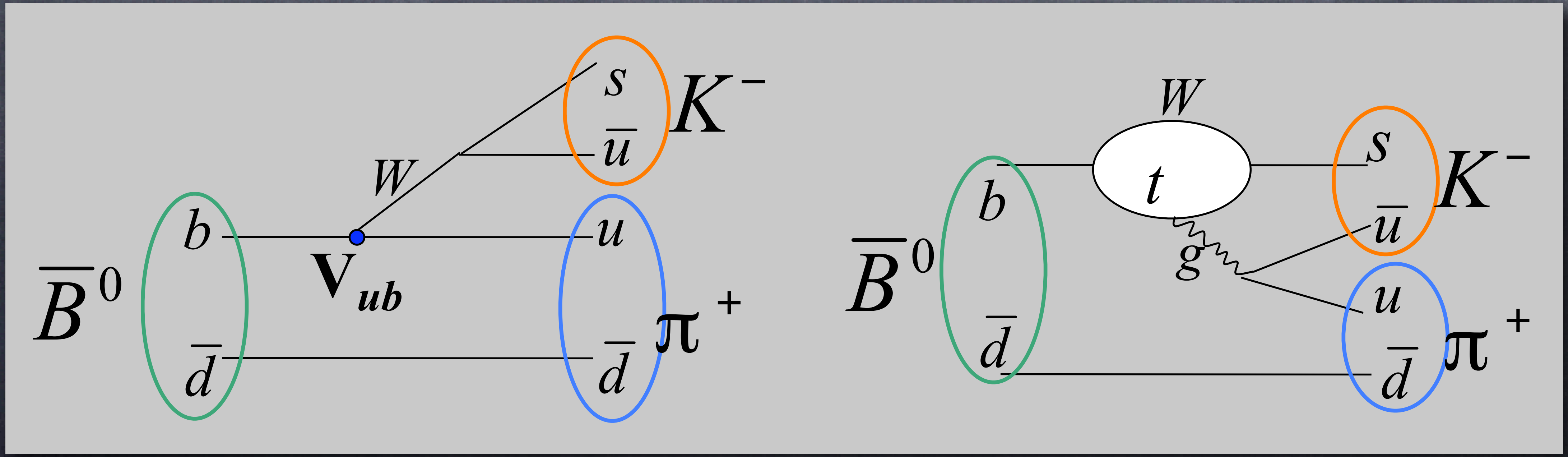


CP violation in the SM

- mixing-induced



- interference of different decay amplitudes

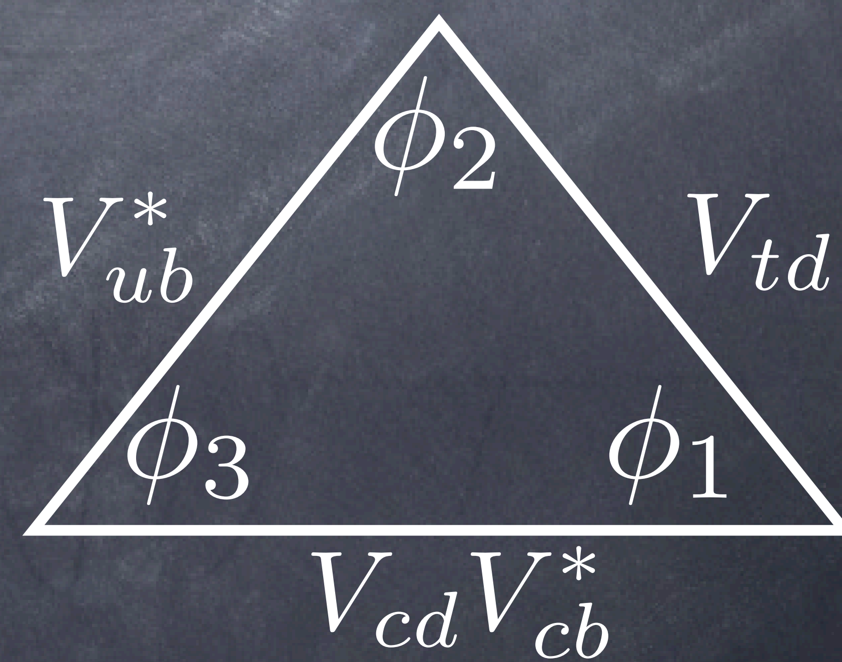


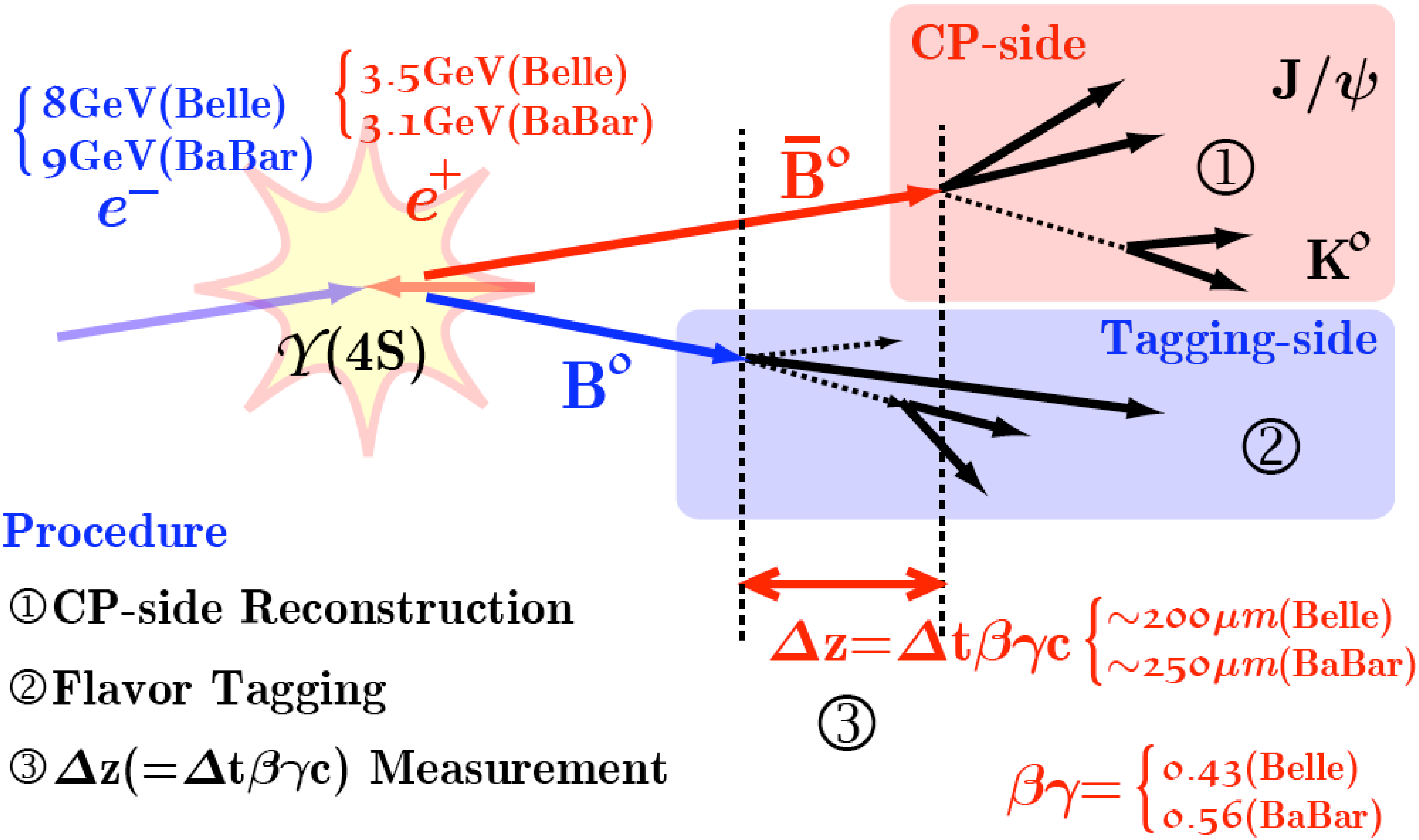
Experimental Results

CKM U.T. Angles

- Extract the three angles ϕ_1, ϕ_2, ϕ_3 through time-dependent A$_{CP}$ meas'mt.
- State-of-the-art expt'l technology
  - asymmetric beam energy
  - good vertexing $\Delta I \sim 55\mu\text{m}$
  - Flavor tagging
- Most importantly,

--> need lots of luminosity !





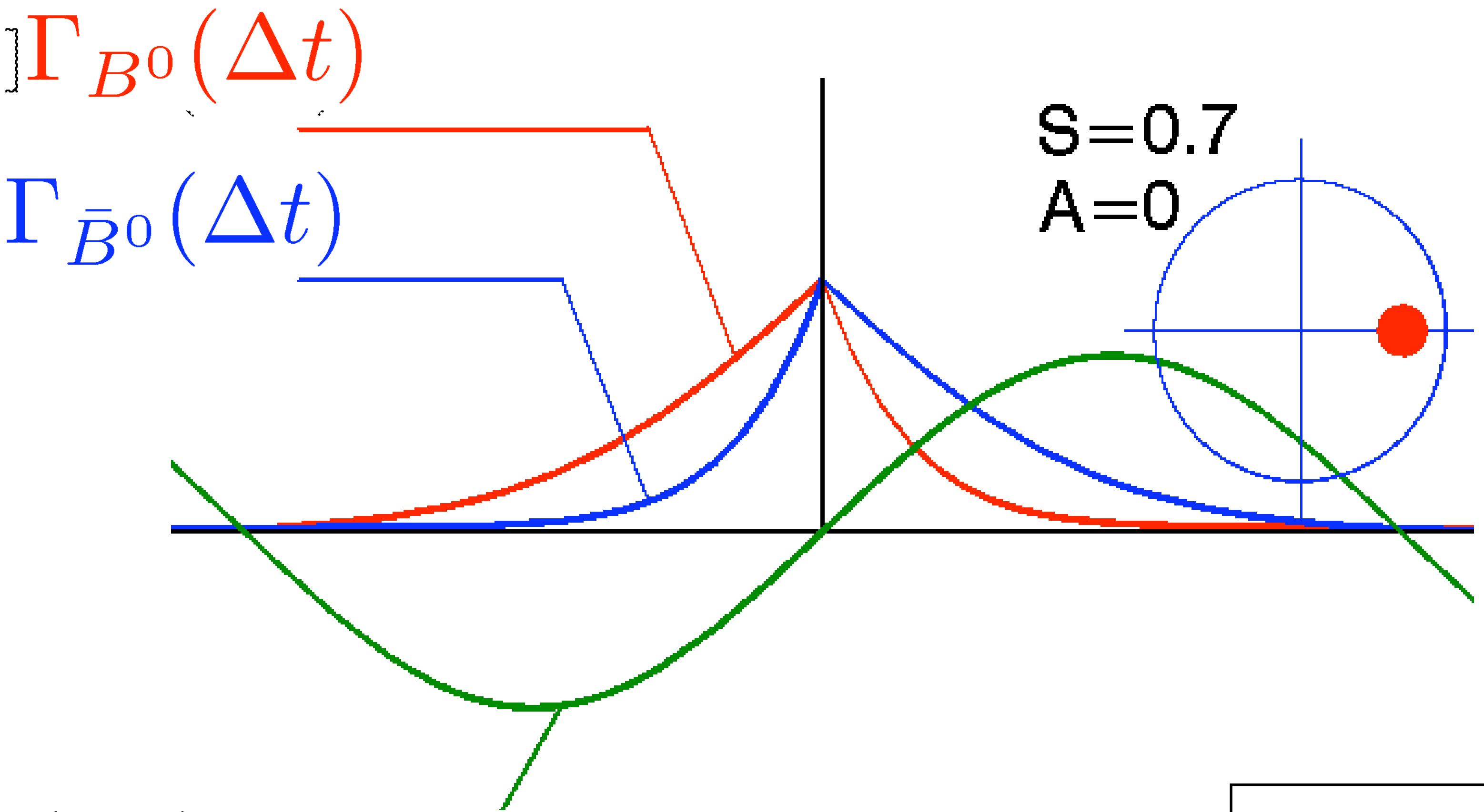
Procedure

①**CP-side Reconstruction**

②**Flavor Tagging**

③**$\Delta z(=\Delta t \beta\gamma c)$ Measurement**

T-dep't CPV in B^0 decays



$$A_{CP}(\Delta t) \equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)} = \mathcal{S} \sin \Delta m \Delta t + \mathcal{A} \cos \Delta m \Delta t$$

Mixing-induced CPV

Direct CPV

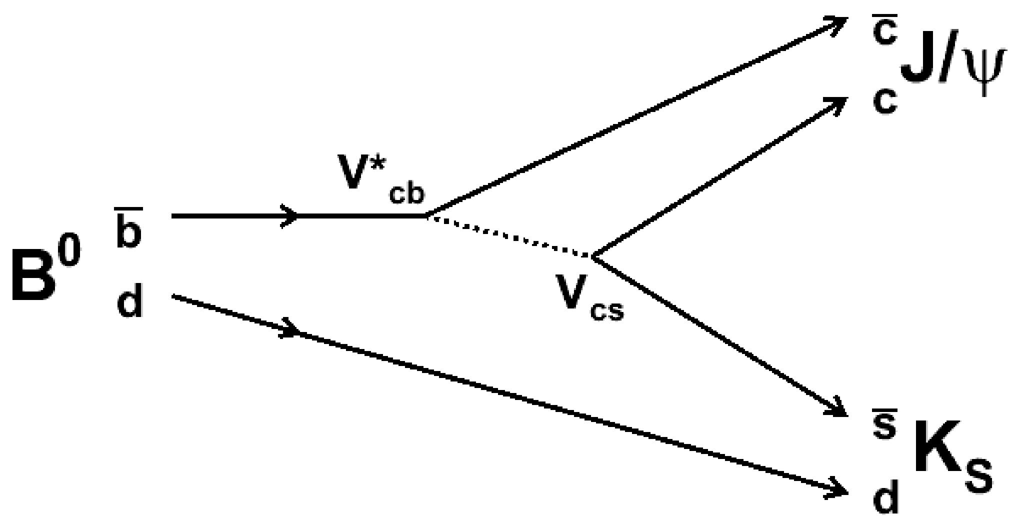
e.g. for J/ψ *Ks*
$\mathcal{S} = -\xi_{CP} \sin 2\phi_1 = +\sin 2\phi_1$
$\mathcal{A} = 0$
to a good approximation
(ξ_{CP} : CP eigenvalue)

($\mathcal{A} = -C$ a la BaBar)

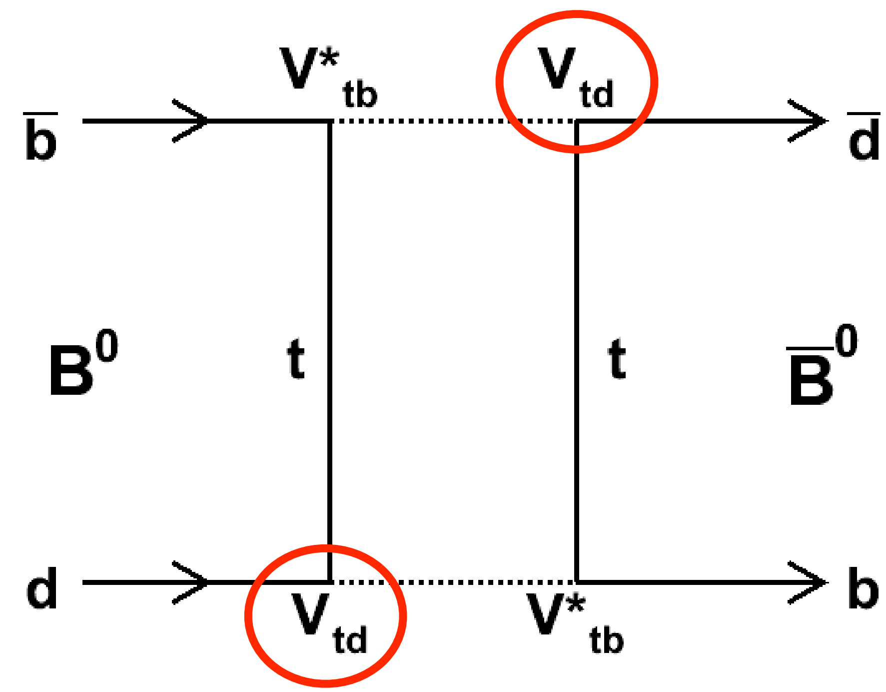
The Golden mode for ϕ_1

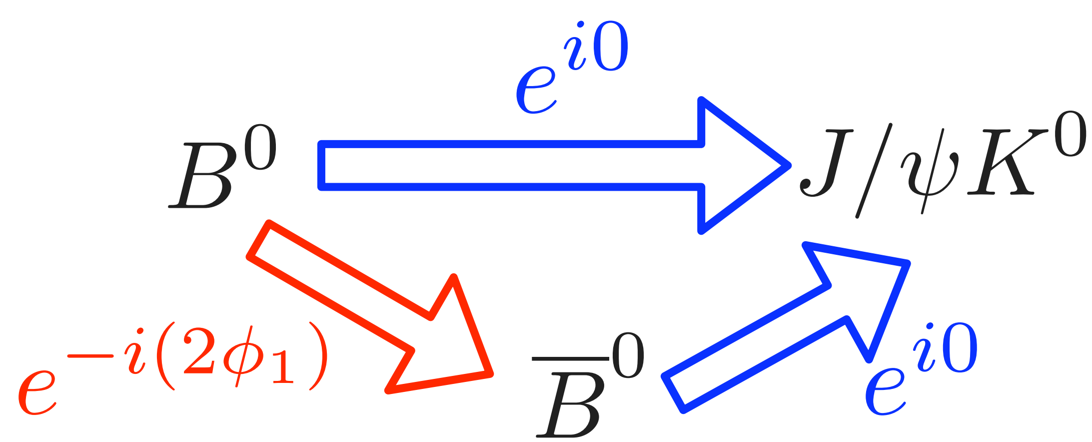
$B^0 \to J/\psi\ K^0$; high rate, theoretically clean

No CKM phase e^{i0}



Two V_{td} vertices $e^{-i(2\phi_1)}$



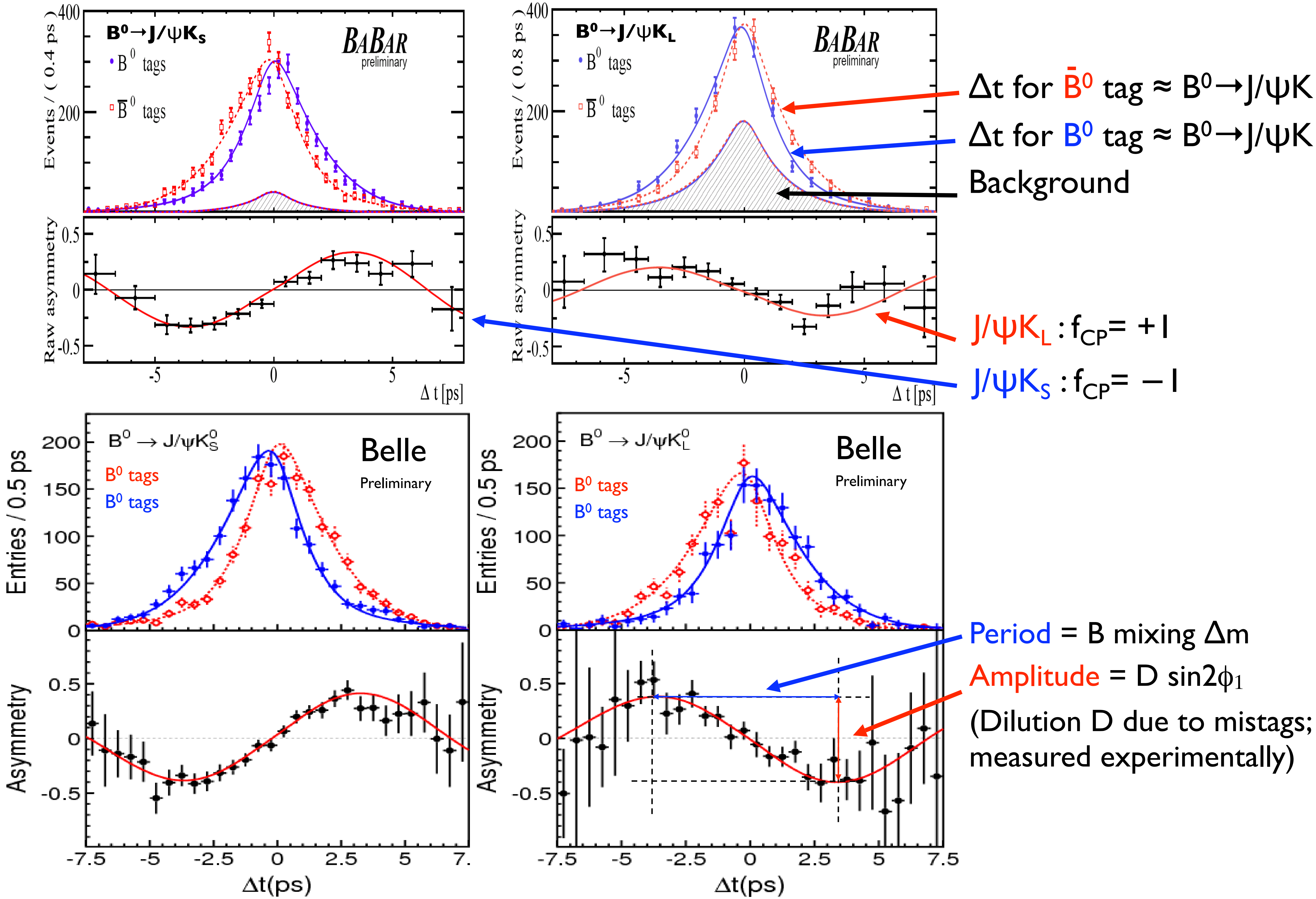


Note: true for any B^0 decay with no phase from decay amplitude

$A_{CP}(\Delta t)$ time-dependence

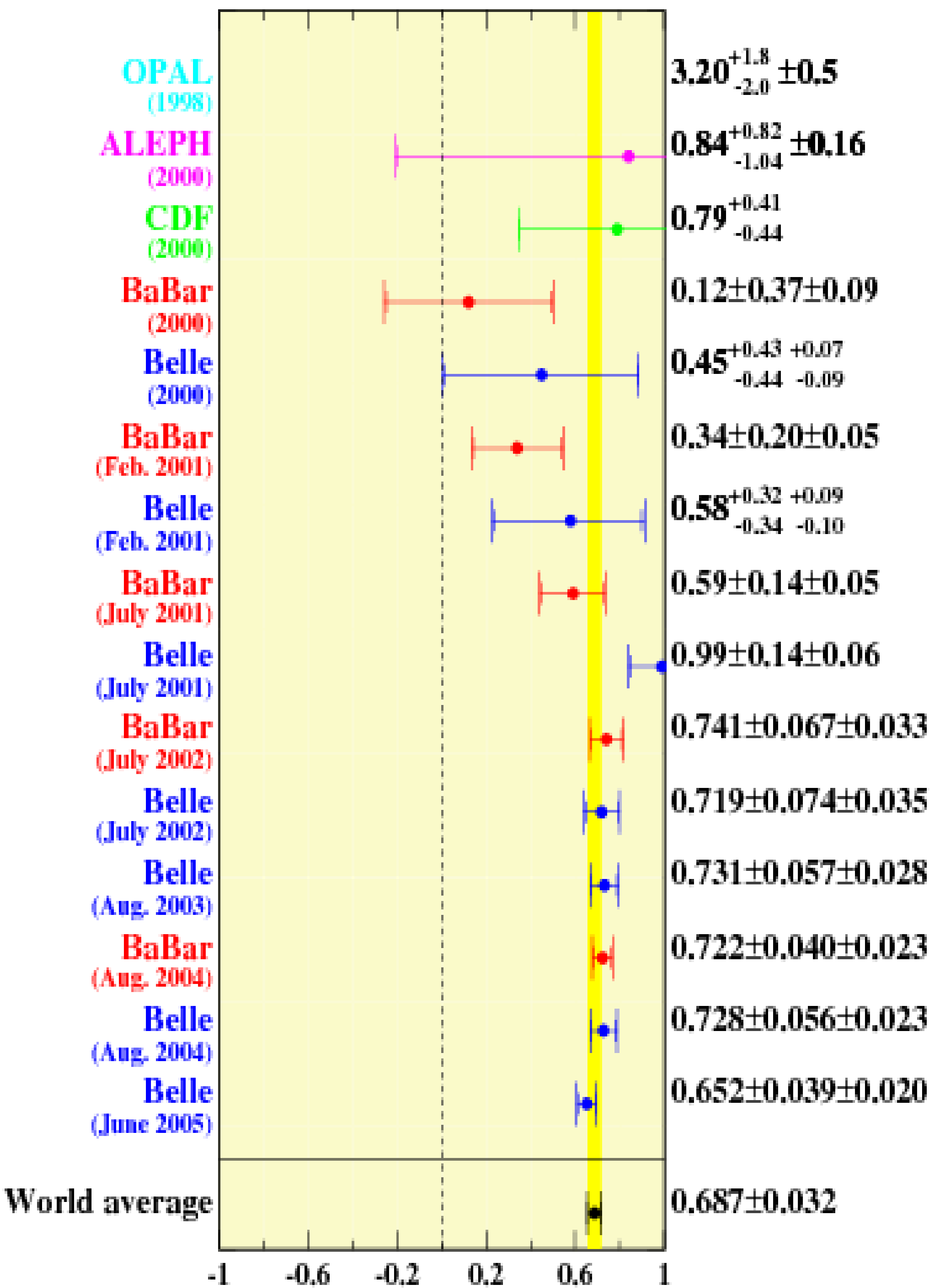
BaBar preliminary, hep-ex/0607107

Belle preliminary, hep-ex/0608039



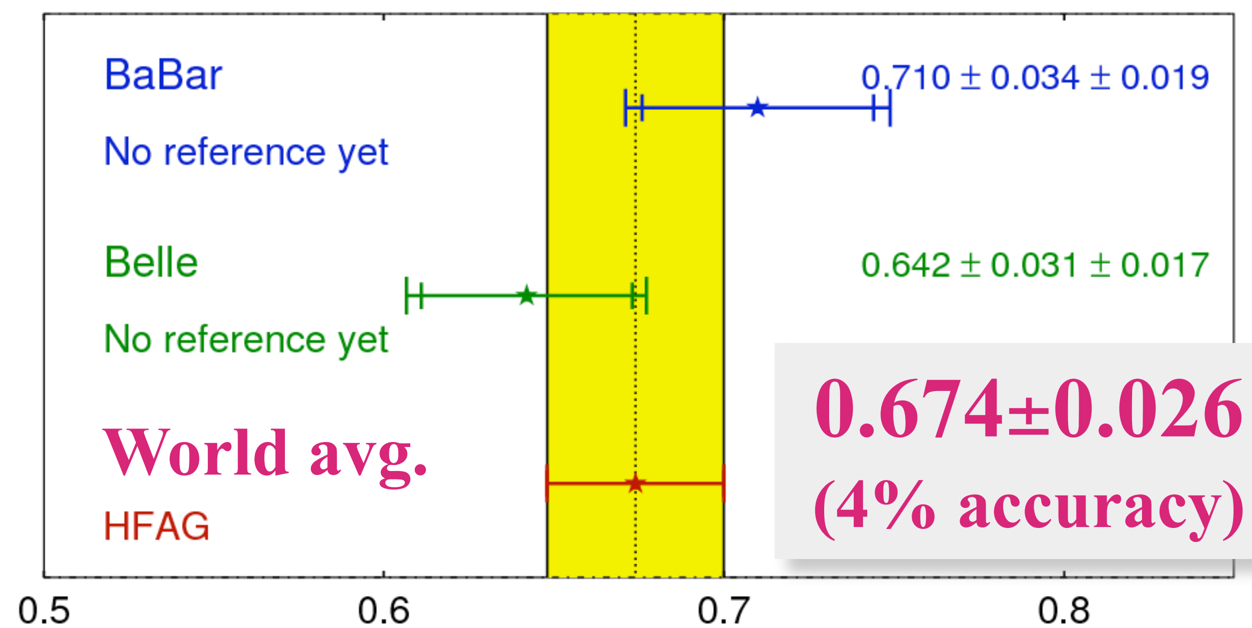
2006 BaBar + Belle

sin2β history (1998-2005)



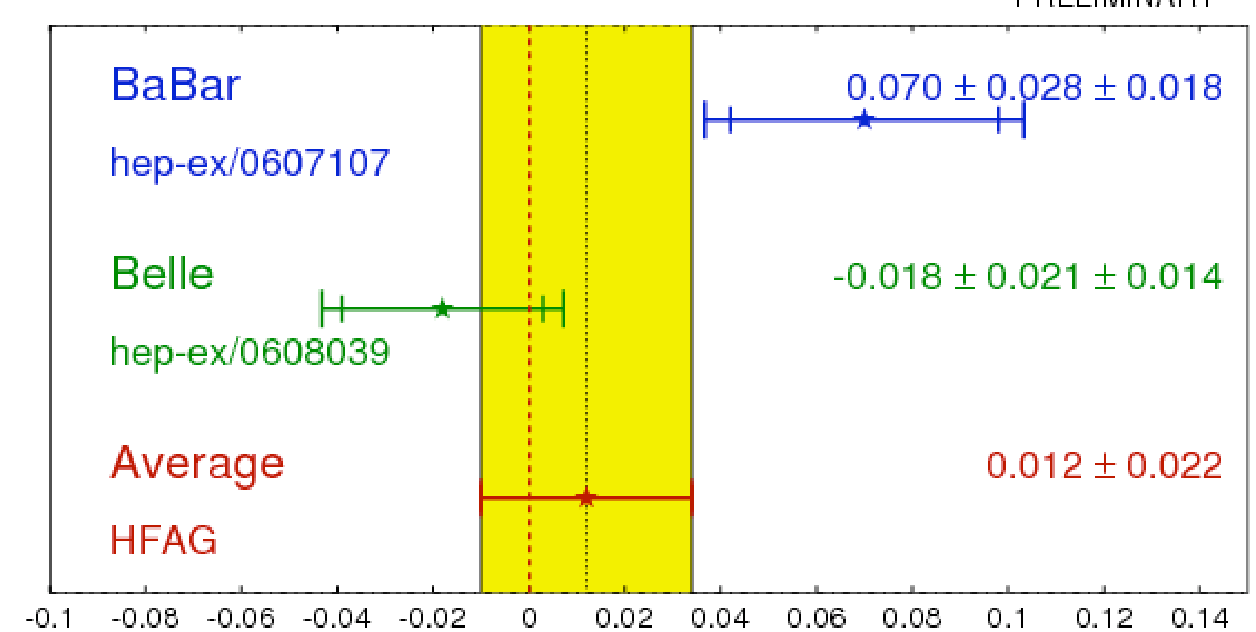
$S_{CP} = \sin(2\beta) \equiv \sin(2\phi_1)$

HFAG ICHEP 2006 PRELIMINARY

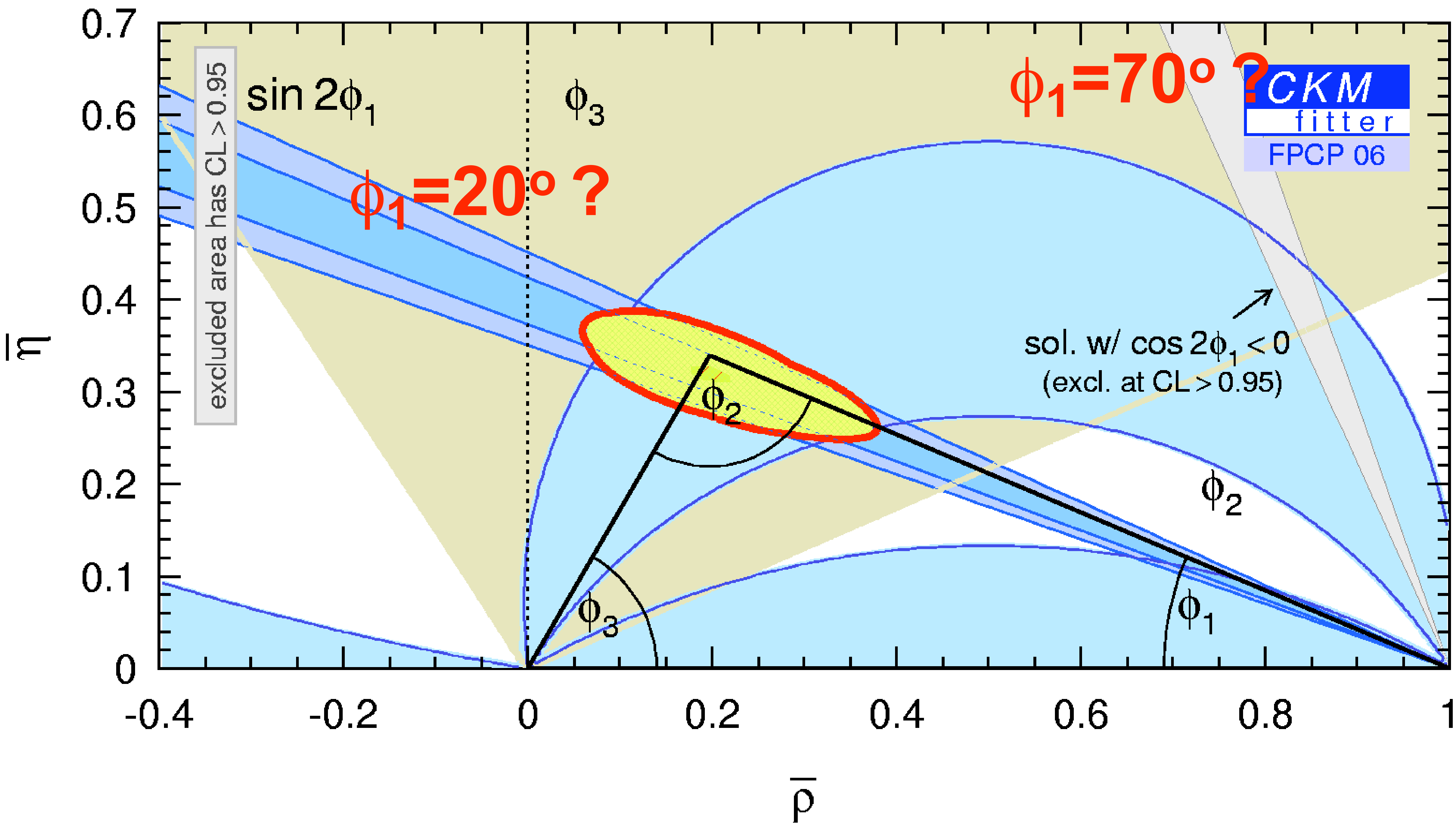


$b \to ccs\ C_{CP}$

HFAG ICHEP 2006 PRELIMINARY



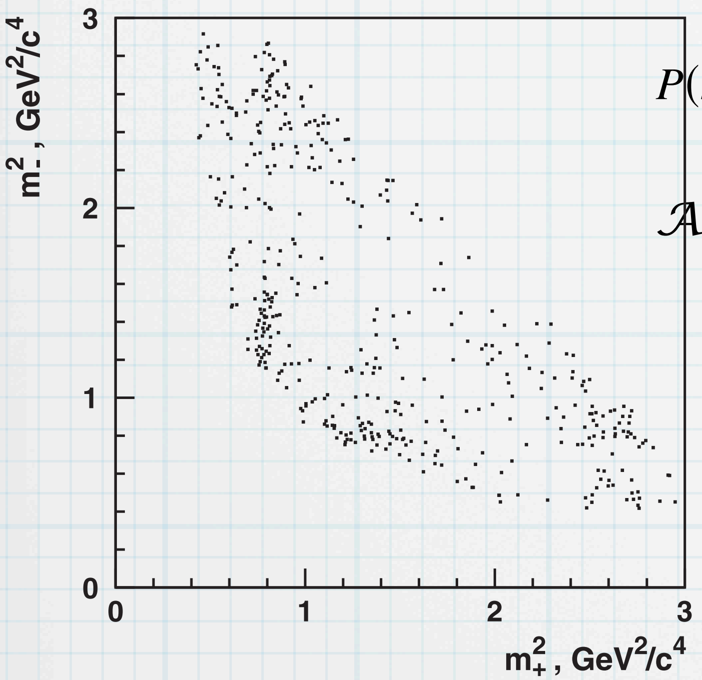
Intrinsic ambiguity still remains … $2\phi_1 \leftrightarrow \pi - 2\phi_1$



PRL **97,** 081801 (2006) PHYSICAL REVIEW LETTERS week ending 25 AUGUST 2006

Measurement of the Quark Mixing Parameter $\cos 2\phi_1$ Using Time-Dependent Dalitz Analysis of $\bar{B}^0 \to D[K^0_S \pi^+ \pi^-]h^0$

P. Krokovny,[5] K. Abe,[5] K. Abe,[36] I. Adachi,[5] H. Aihara,[38] D. Anipko,[1] K. Arinstein,[1] Y. Asano,[41] V. Aulchenko,[1] T. Aushev,[8] S. Bahinipati,[3] A. M. Bakich,[33] V. Balagura,[8] E. Barberio,[15] A. Bay,[13] U. Bitenc,[9] I. Bizjak,[9] A. Bondar,[1] A. Bozek,[21] M. Bračko,[5,14,9] T. E. Browder,[4] Y. Chao,[20] A. Chen,[18] W. T. Chen,[18] Y. Choi,[32] A. Chuvikov,[28] S. Cole,[33]



$$P(m^2_+, m^2_-, \Delta t, q_B) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{8\tau_{B^0}} \frac{F(m^2_+, m^2_-)}{2N}(1 + q_B \times \{\mathcal{A}(m^2_-, m^2_+)\cos(\Delta m \Delta t) + \mathcal{S}(m^2_-, m^2_+)\sin(\Delta m \Delta t)\}),$$

$$\mathcal{A} = (|f(m^2_-, m^2_+)|^2 - |f(m^2_+, m^2_-)|^2)/F(m^2_+, m^2_-), \qquad \mathcal{S} = \frac{-2\xi_{h^0}(-1)^l \mathrm{Im}\{f(m^2_-, m^2_+)f^*(m^2_+, m^2_-)e^{2i\phi_1}\}}{F(m^2_+, m^2_-)},$$

Process	N_{tot}	Efficiency (%)	N_{sig}	Purity
$D\pi^0$	265	8.7	157 ± 24	59%
$D\omega$	88	4.1	67 ± 10	76%
$D\eta$	101	3.9	58 ± 13	57%
$D^*\pi^0$, $D^*\eta$	67		43 ± 12	64%
Sum	521		325 ± 31	62%

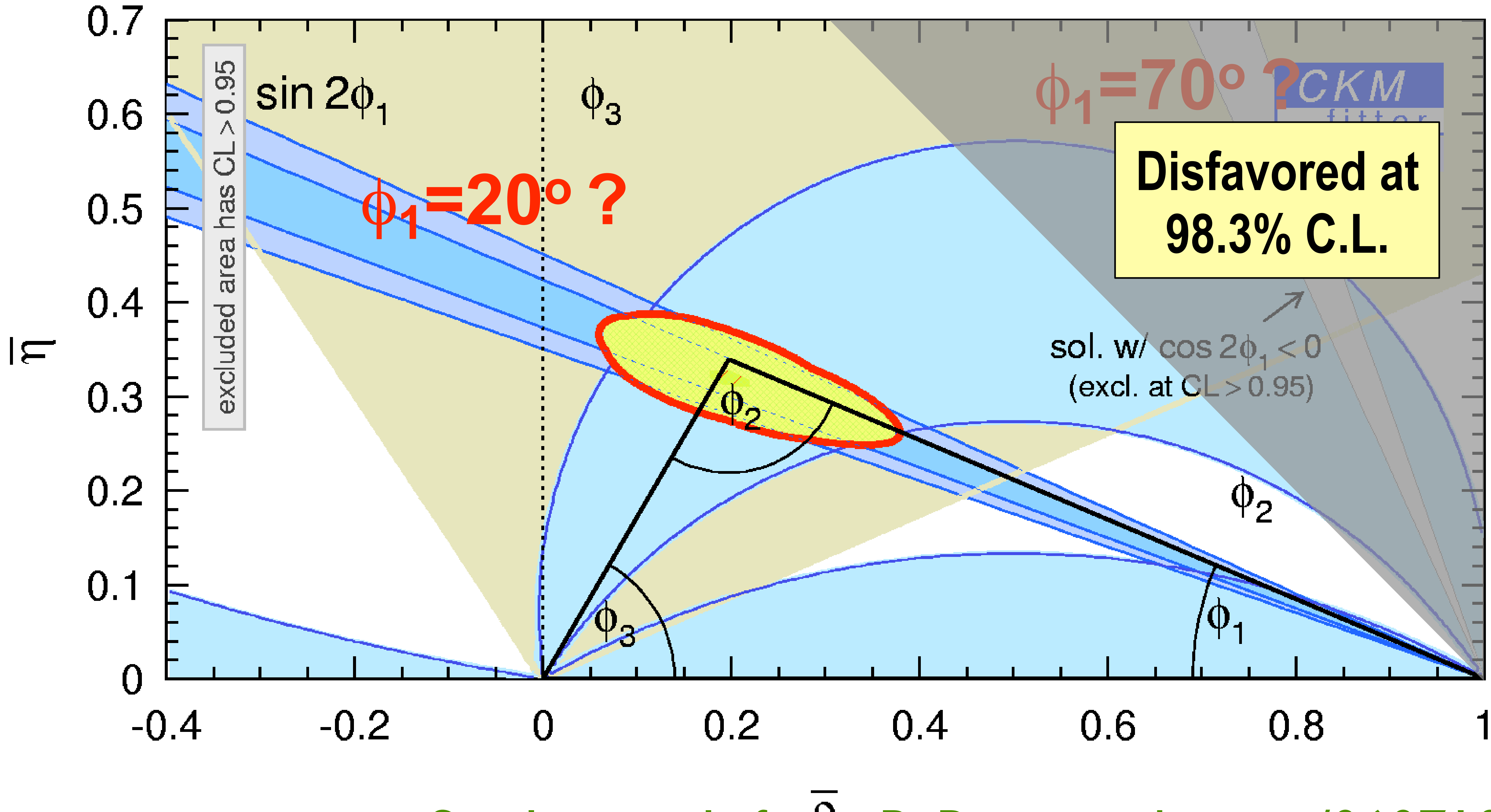
TABLE II. Fit results for the data. Errors are statistical only.

Final state	$\sin 2\phi_1$	$\cos 2\phi_1$
$D\pi^0$, $D\eta[\gamma\gamma]$	$0.80^{+0.54}_{-0.60}$	$2.07^{+0.78}_{-0.91}$
$D\omega$, $D\eta[3\pi]$	0.43 ± 0.90	$1.53^{+0.67}_{-0.93}$
$D^*\pi^0$, $D^*\eta$	1.07 ± 1.14	$3.46^{+1.80}_{-2.01}$
Simultaneous fit	0.78 ± 0.44	$1.87^{+0.40}_{-0.53}$

In summary, we have presented a new method to measure the unitarity triangle angle ϕ_1 using a time-dependent amplitude analysis of the $D \to K^0_S \pi^+ \pi^-$ decay produced in the processes $\bar{B}^0 \to D^{(*)}h^0$. We find $\sin 2\phi_1 = 0.78 \pm 0.44 \pm 0.22$ and $\cos 2\phi_1 = 1.87^{+0.40+0.22}_{-0.53-0.32}$. The sign of $\cos 2\phi_1$ is determined to be positive at 98.3% C.L., favoring the $\phi_1 = 23°$ solution.

Intrinsic ambiguity: resolved at C.L. > 95%

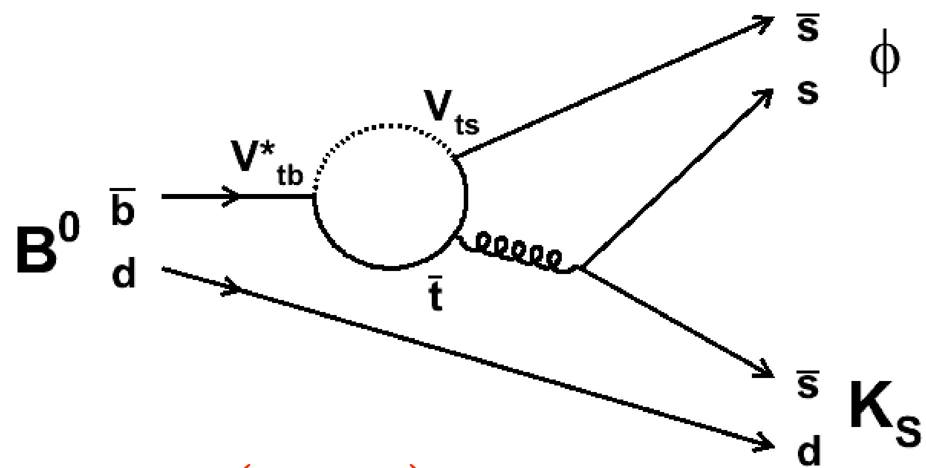
Time-dependent Dalitz analysis of $\bar{B}^0 \to D[K_S\pi^+\pi^-]h^0$
PRL97, 081801 (2006)

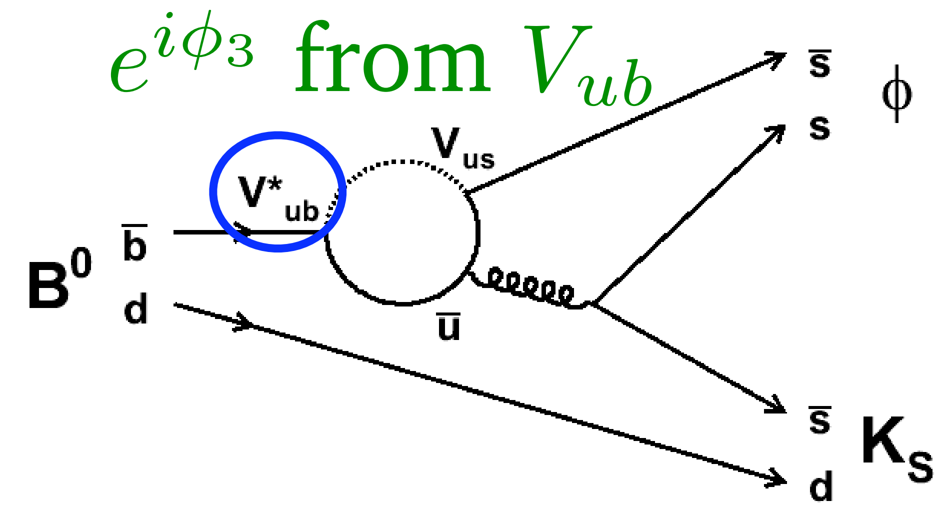


Similar result from BaBar, too. hep-ex/0607105

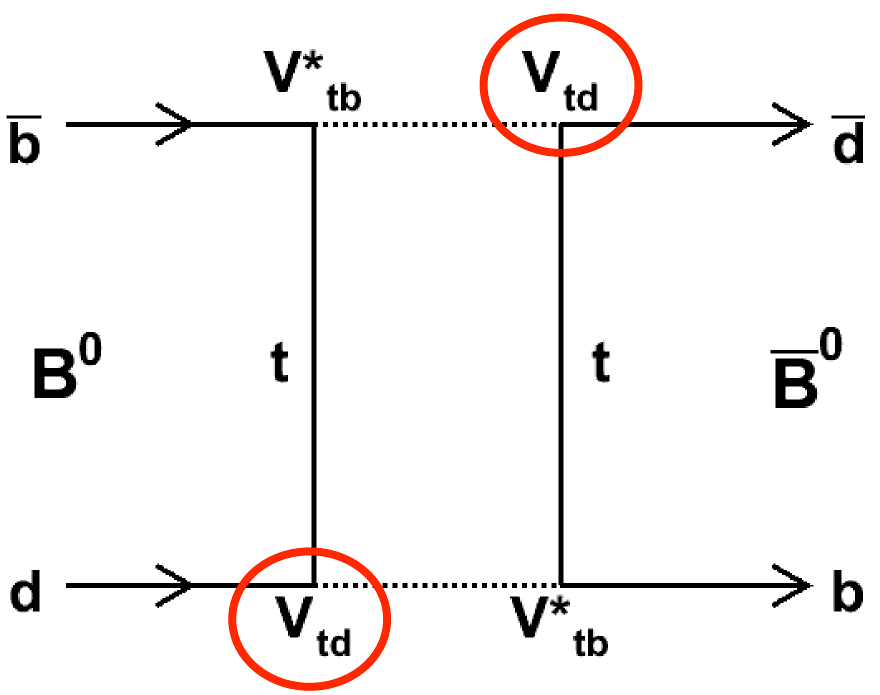
ϕ_1 from $b \to s\bar{s}s$

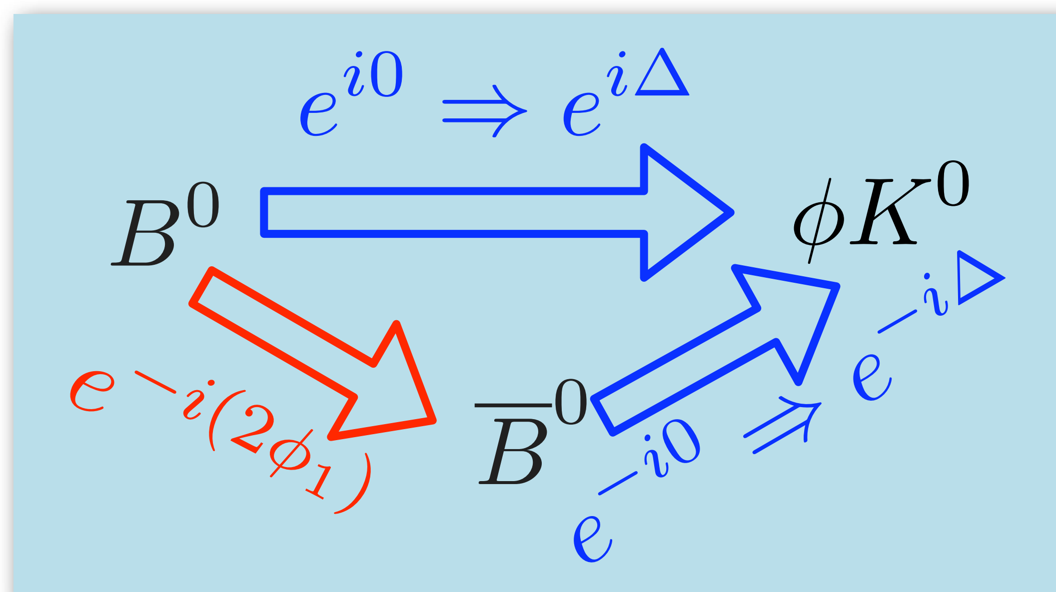
e.g. $B^0 \to \phi K_S$





Two V_{td} vertices $e^{-i(2\phi_1)}$

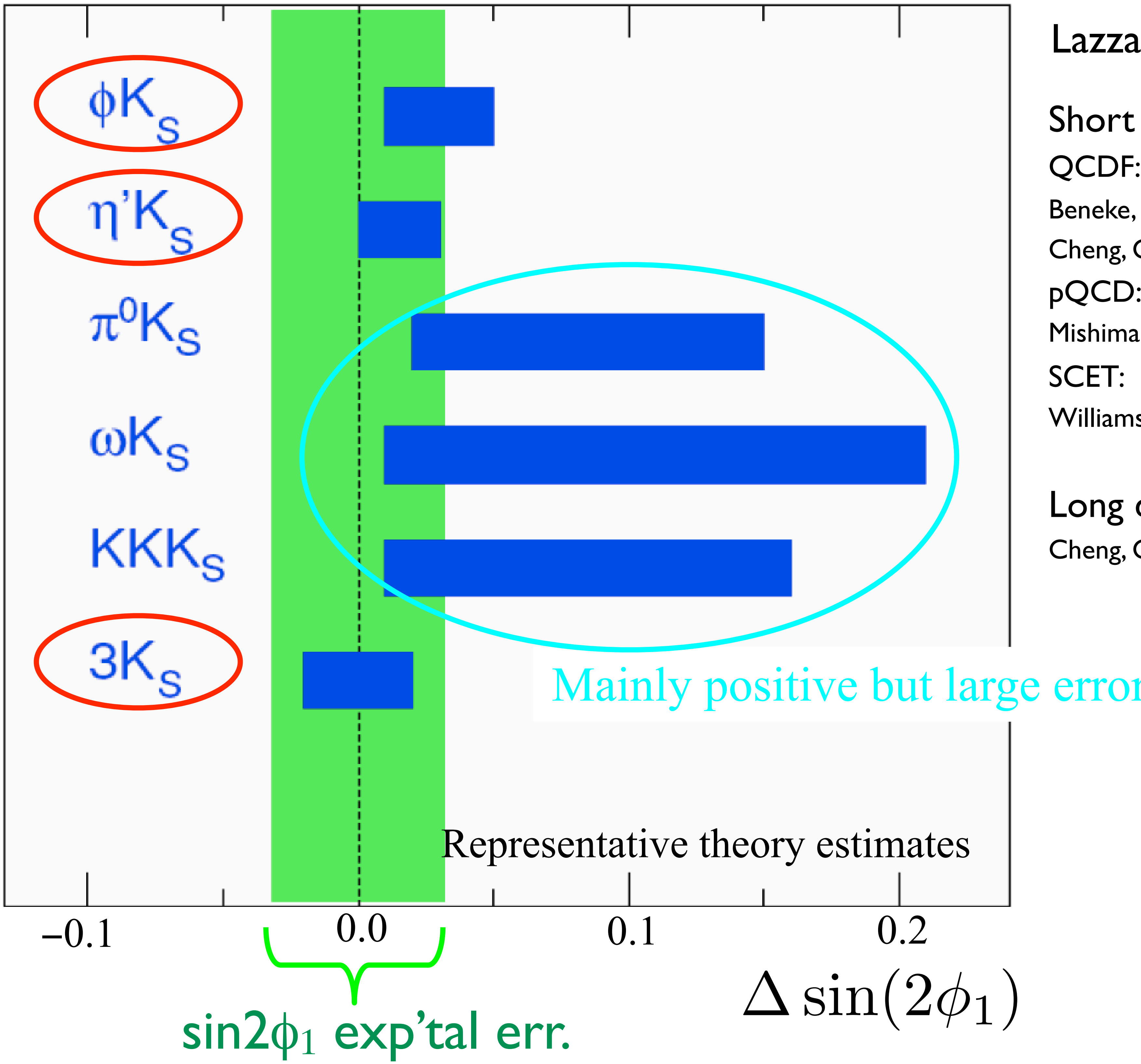




Relative phase = $e^{i2(\phi_1+\Delta)} \neq e^{i2\phi_1}$

$\sin(2\phi_{1\mathrm{eff}}) \neq \sin(2\phi_1)$

Theoretical estimates of SM offsets



Lazzaro, ICHEP06

Short distance effect:

QCDF:

Beneke, PLB 620, 143 (2005)

Cheng, Chua, Yang, PRD 73, 014017 (2006)

pQCD:

Mishima, Sanda, PRD 72, 114005 (2005)

SCET:

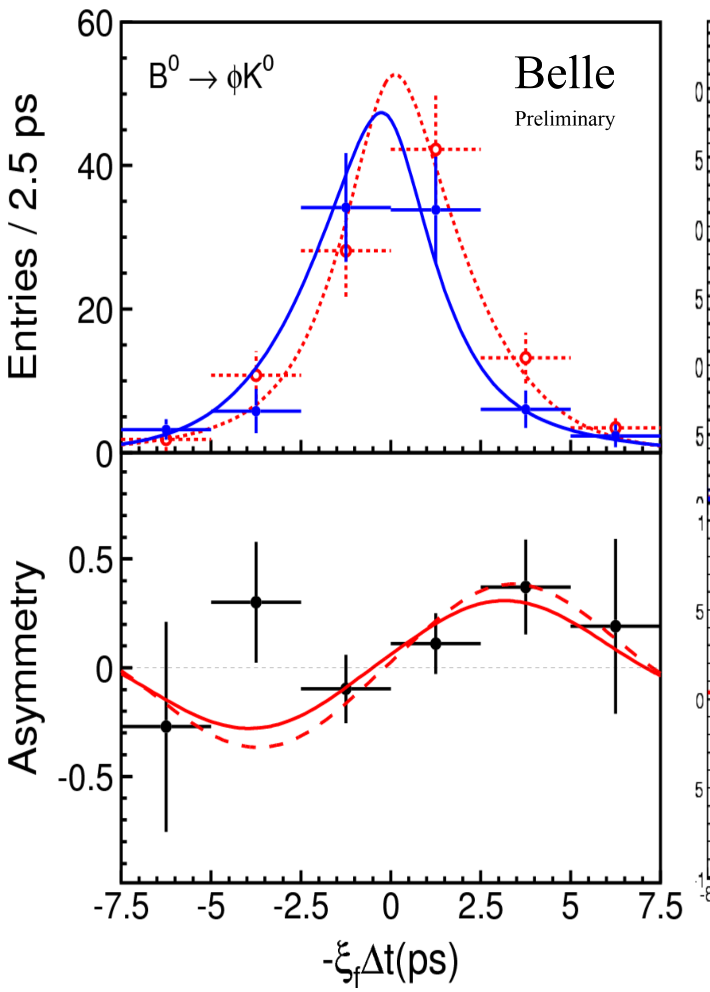
Williamson, Zupan, PRD 74, 014003 (2006)

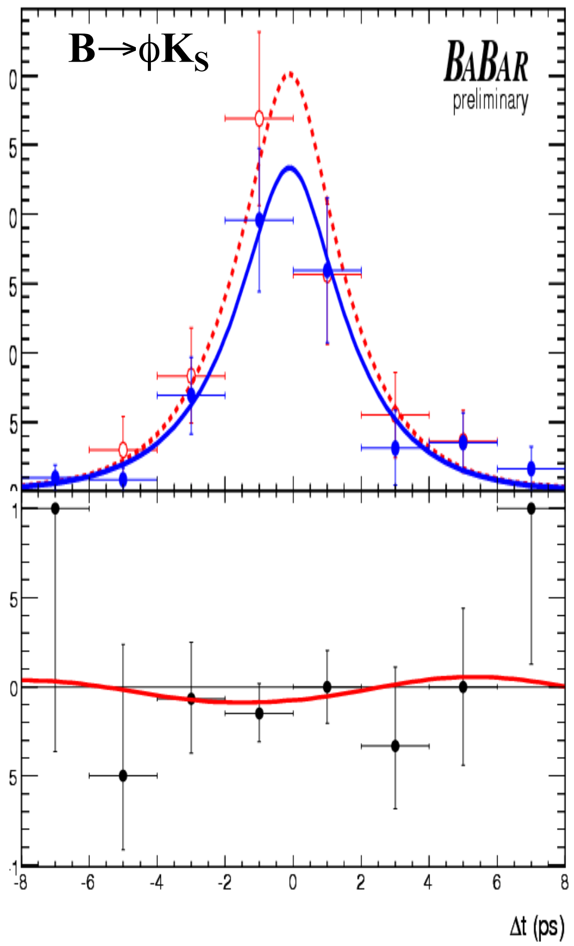
Long distance effect:

Cheng, Chua, Soni, PRD 72, 014006 (2005)

$B \to \phi K_S$ and $B \to \eta' K_S$

$B \to \phi K_S$: B.F. = $(4.3 \pm 0.6) \times 10^{-6}$

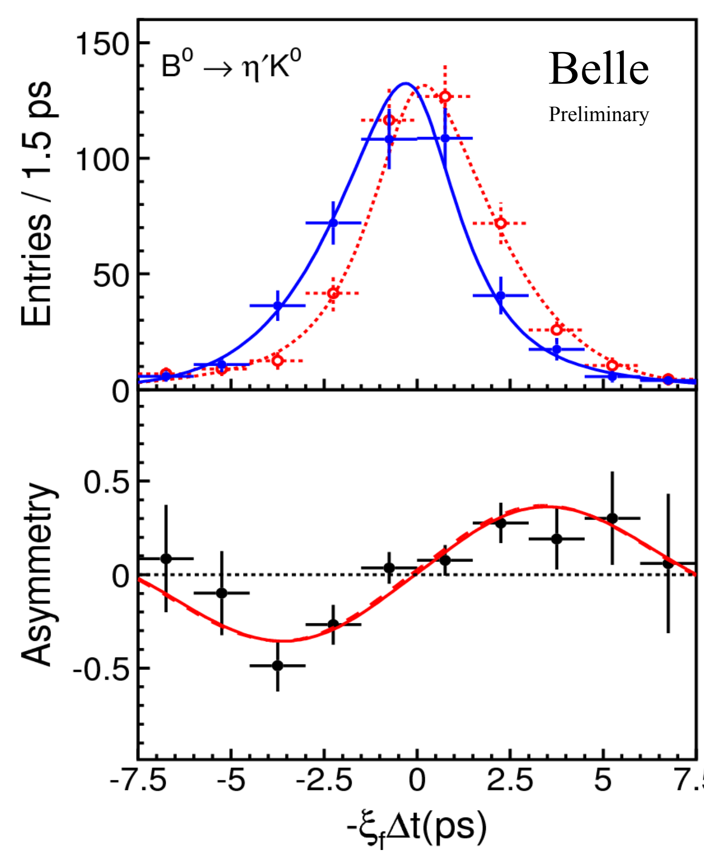


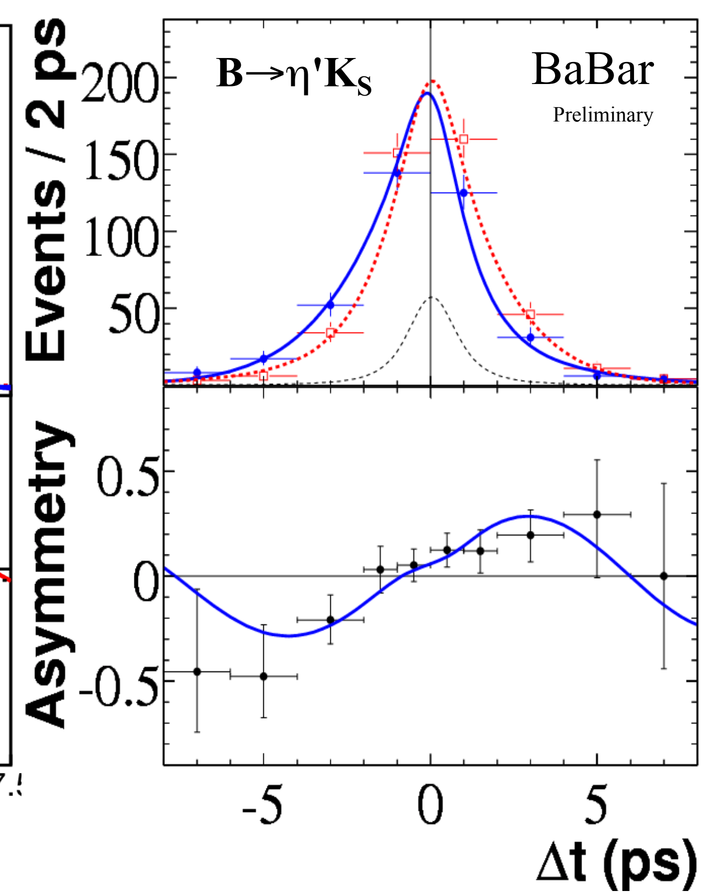


Even with small rates,

clear CP violation observed in penguin decays

$B \to \eta' K_S$: B.F. = $(3.4 \pm 0.2) \times 10^{-5}$

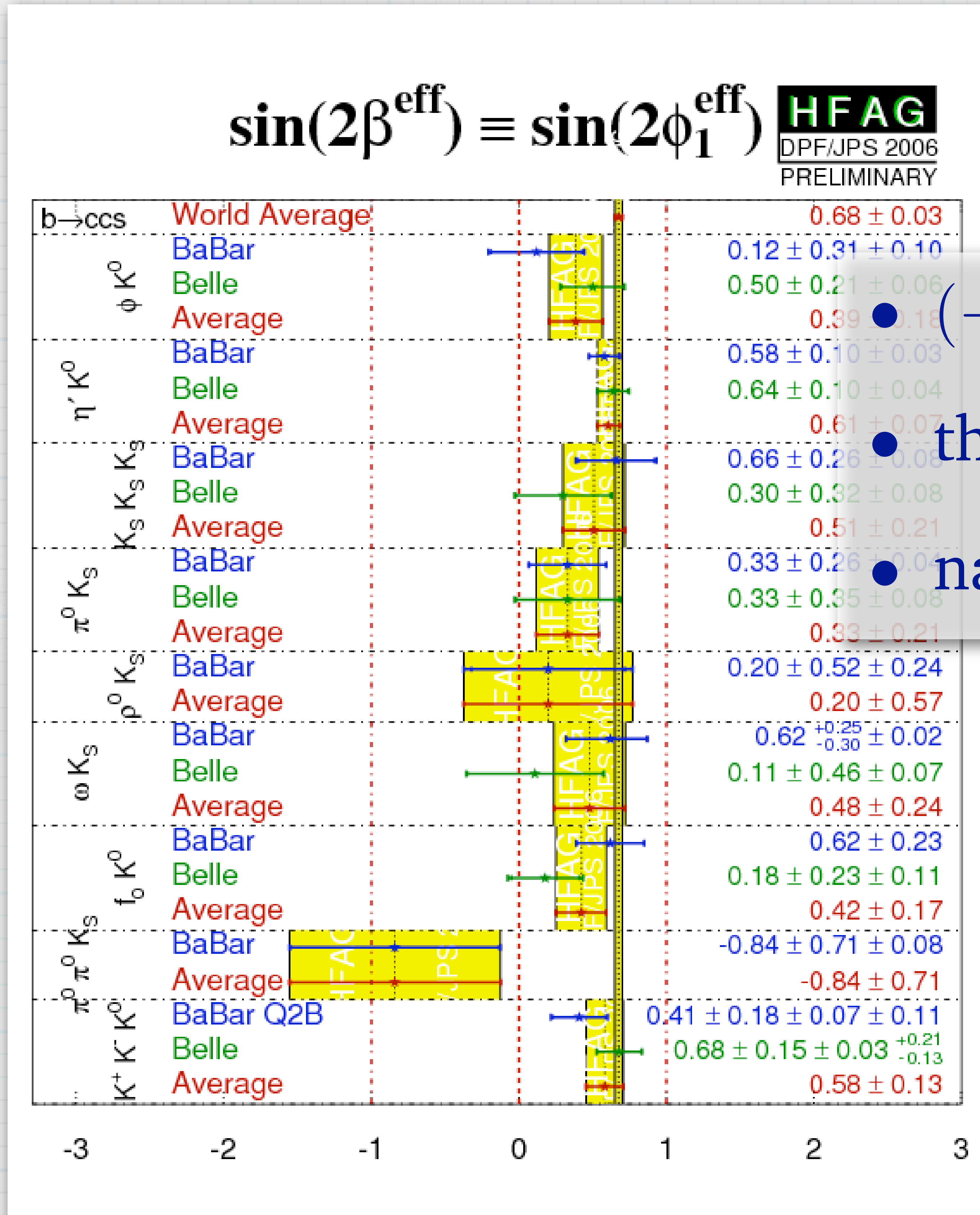




Belle preliminary, hep-ex/0608039

BaBar preliminary, hep-ex/0607112

BaBar preliminary, hep-ex/0609052



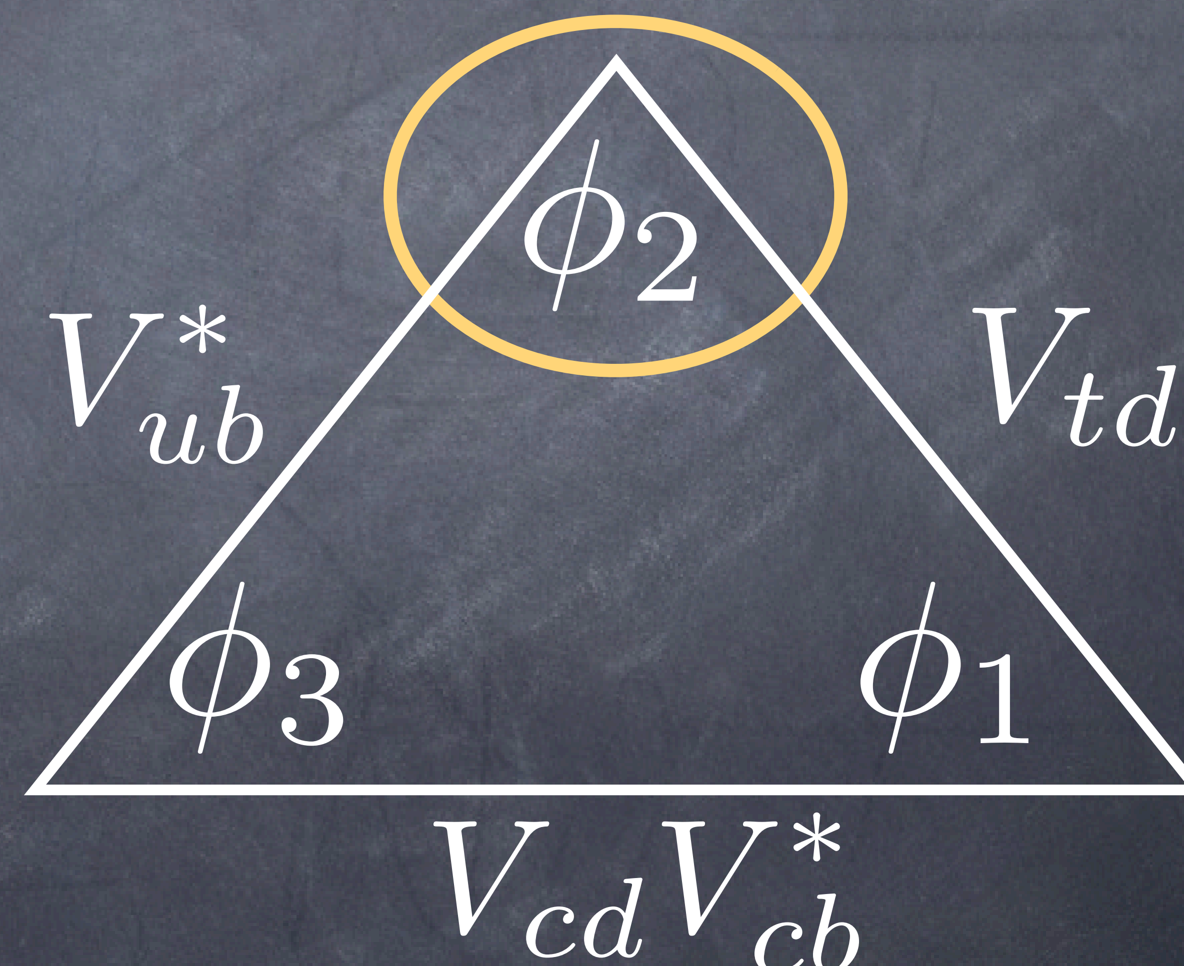
- $(-)$ in all 9 modes
- theory tends to predict $(+)$ shifts
- naive avg. $\sin 2\phi_1^{\rm eff} = 0.52 \pm 0.05$

$\Rightarrow$ 2.6 σ difference

More stat. is crucial for mode-by-mode comparison!

Other angles?

Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
	易	難	魔



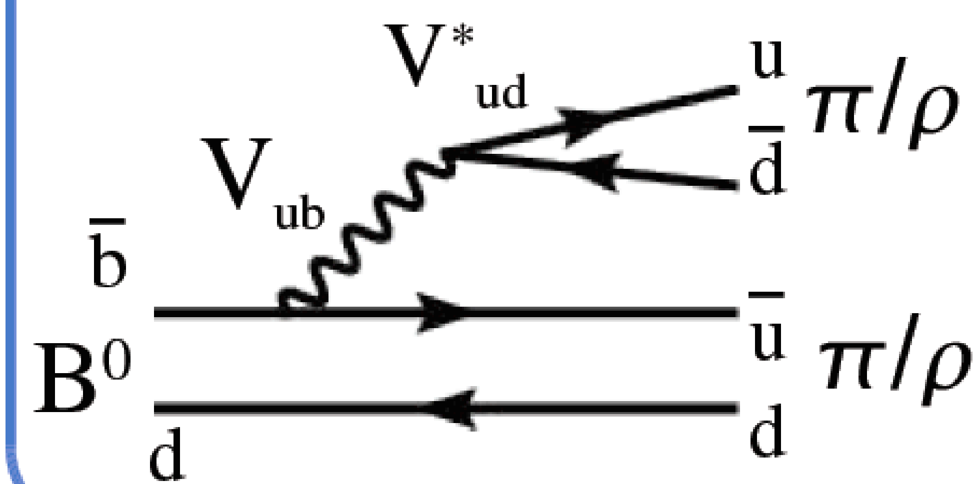
penguin's shaking a tree...

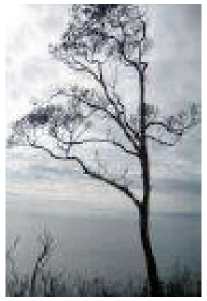
$B^0 \to \rho^+\rho^-$

$B^0 \to \rho^\pm\pi^\mp$

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

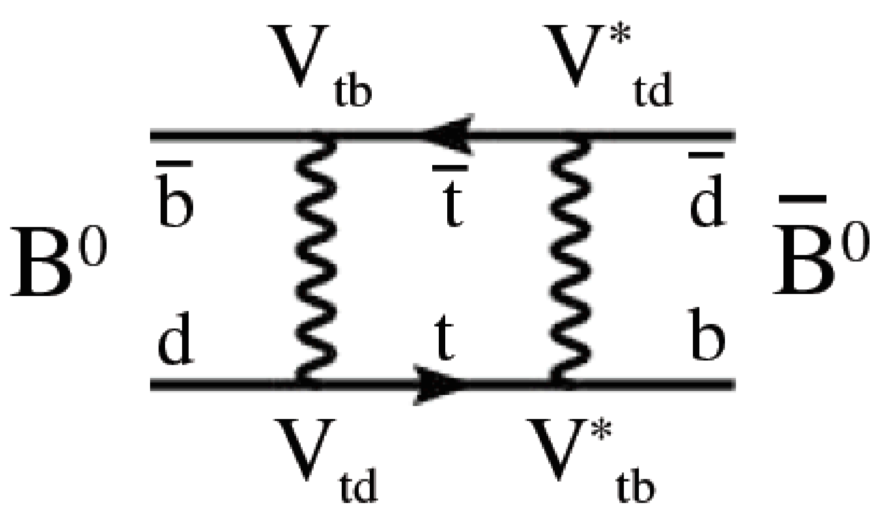
Tree diagram



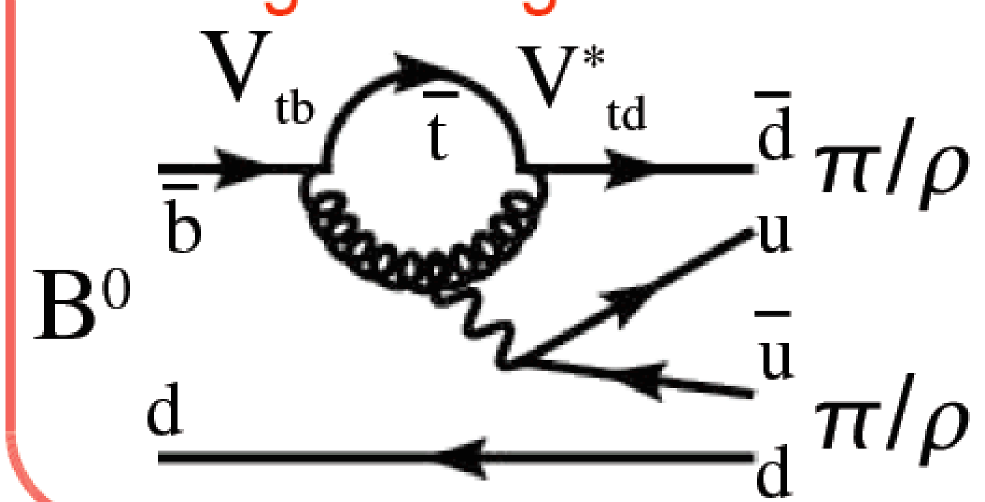


ϕ_2

Mixing



Penguin diagram



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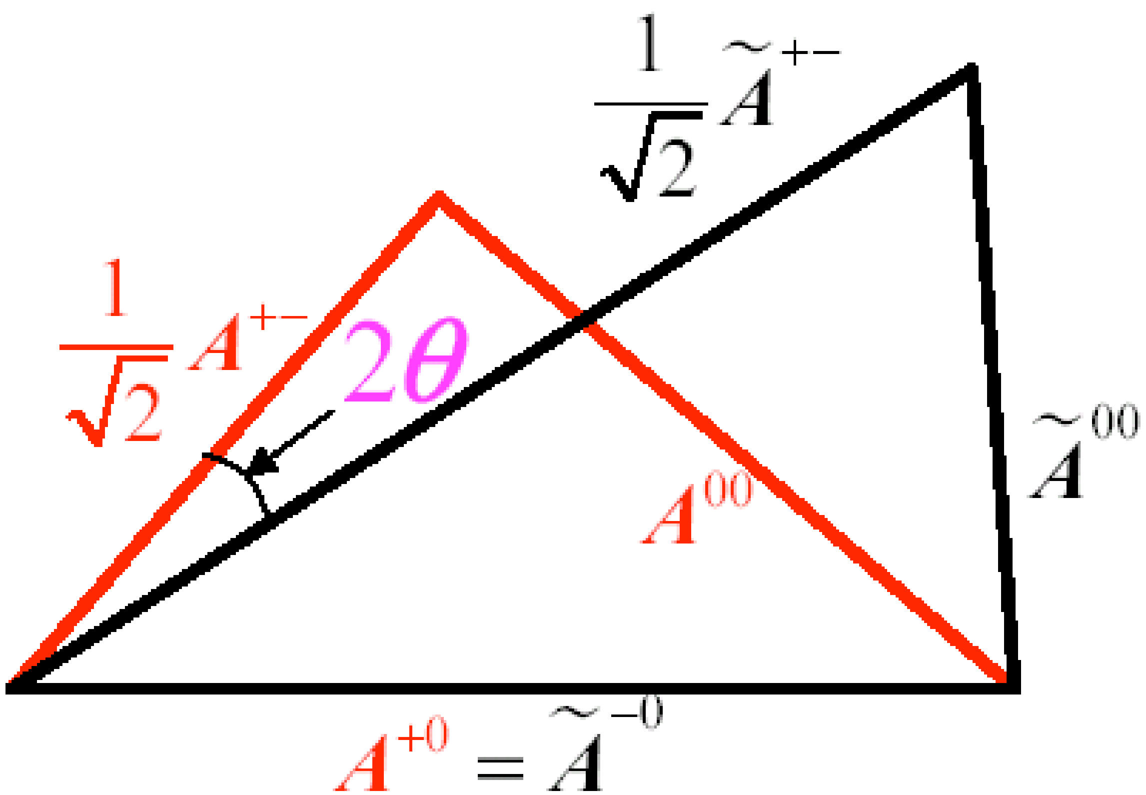
Isospin analysis: flavor SU(2)

Gronau-London (1990)



	Amplitude for
$A^{+-}(\bar{A}^{+-})$	$B^0(\bar{B}^0) \to \pi^+\pi^-$
$A^{00}(\bar{A}^{00})$	$B^0(\bar{B}^0) \to \pi^0\pi^0$
$A^{+0}(\bar{A}^{-0})$	$B^+(B^-) \to \pi^+\pi^0(\pi^-\pi^0)$

$$\tilde{A}^{ij} = e^{2\phi_3}\bar{A}^{ij}$$

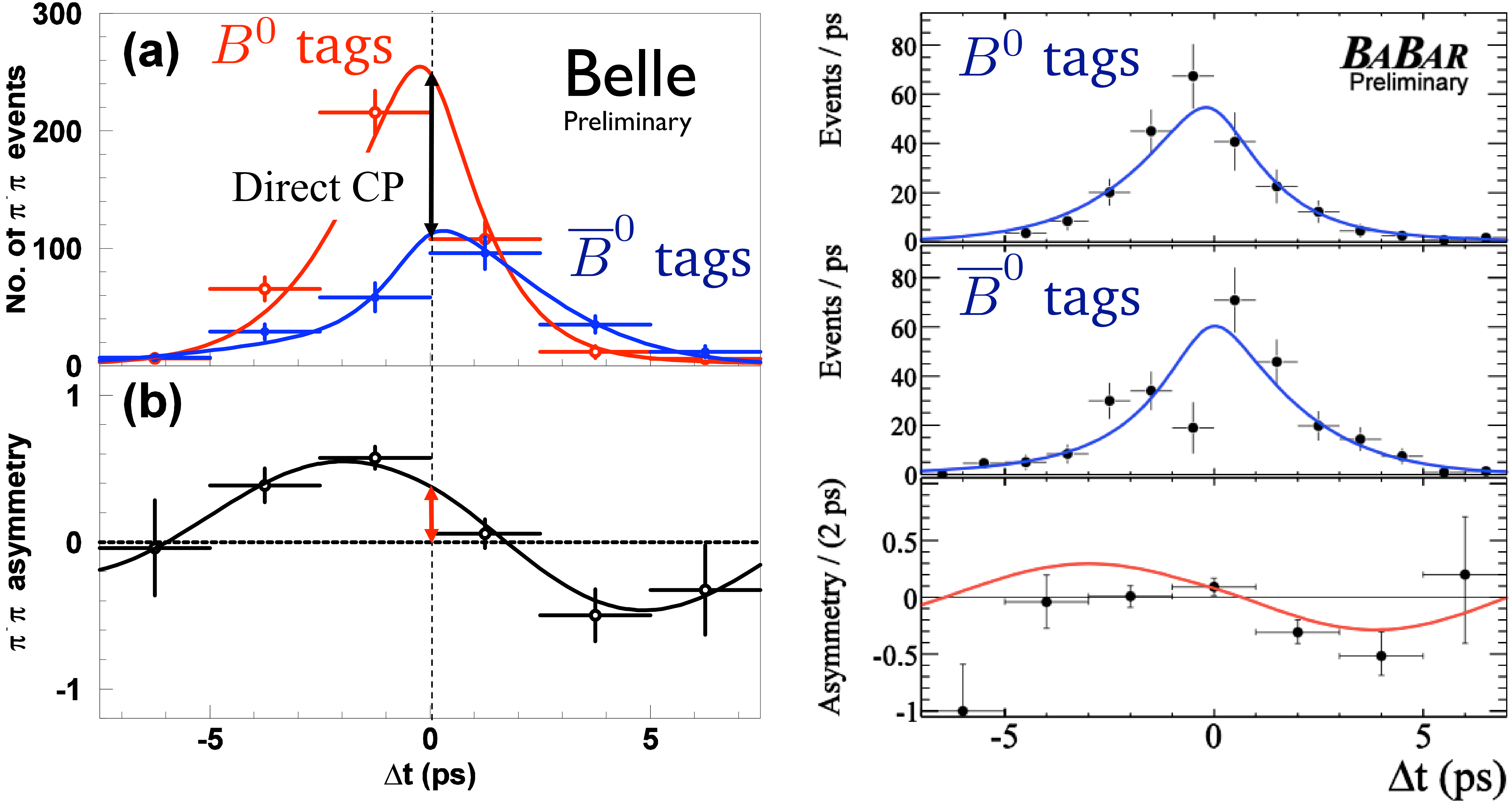
- Model-independent (symmetry-dependent) method
- SU(2) breaking effect well below present statistical errors

"Penguin pollution" can be removed

$B^0 \rightarrow \pi^+\pi^-$

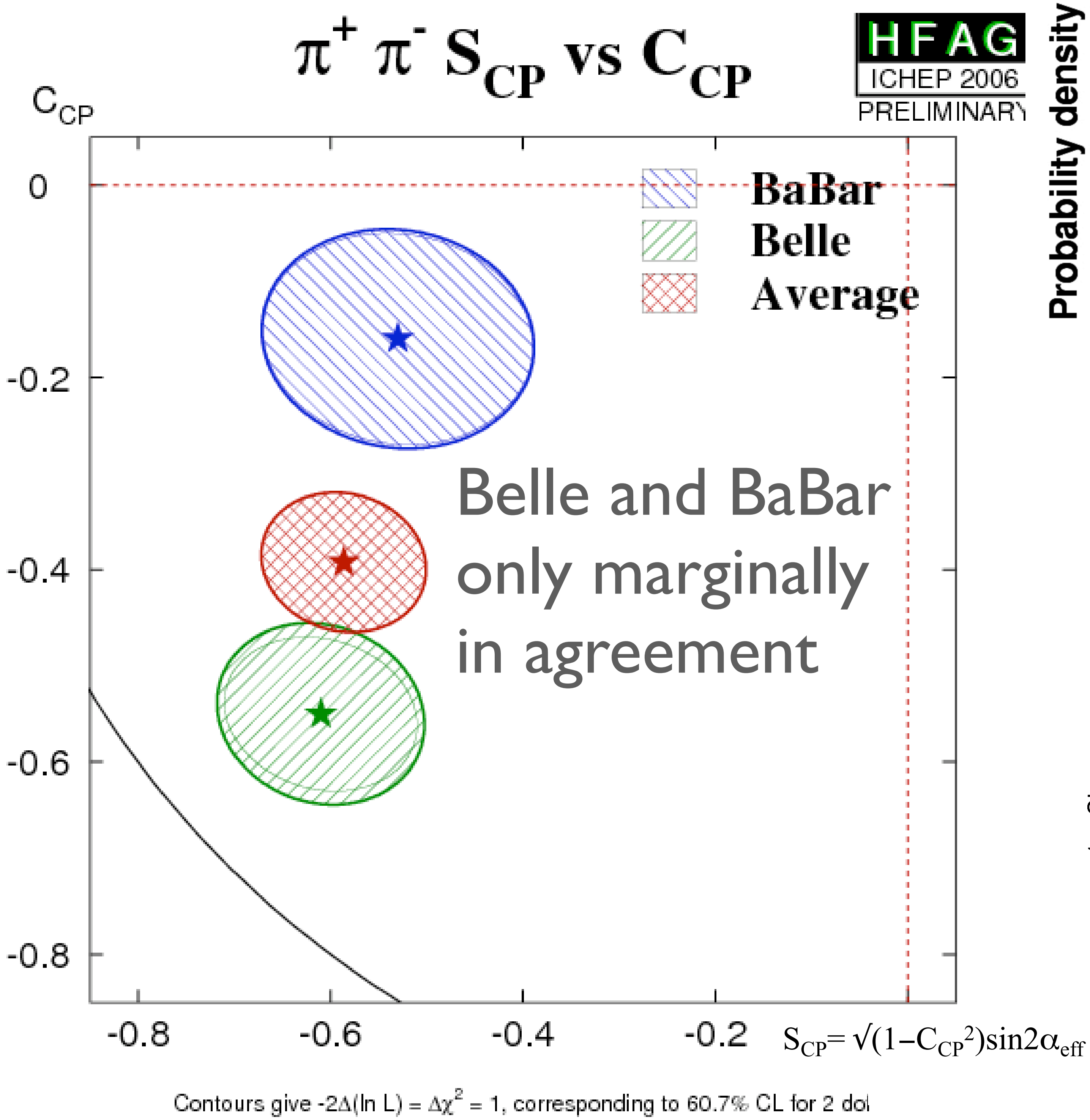
Belle preliminary; hep-ex/0608035

BaBar preliminary; hep-ex/0607106



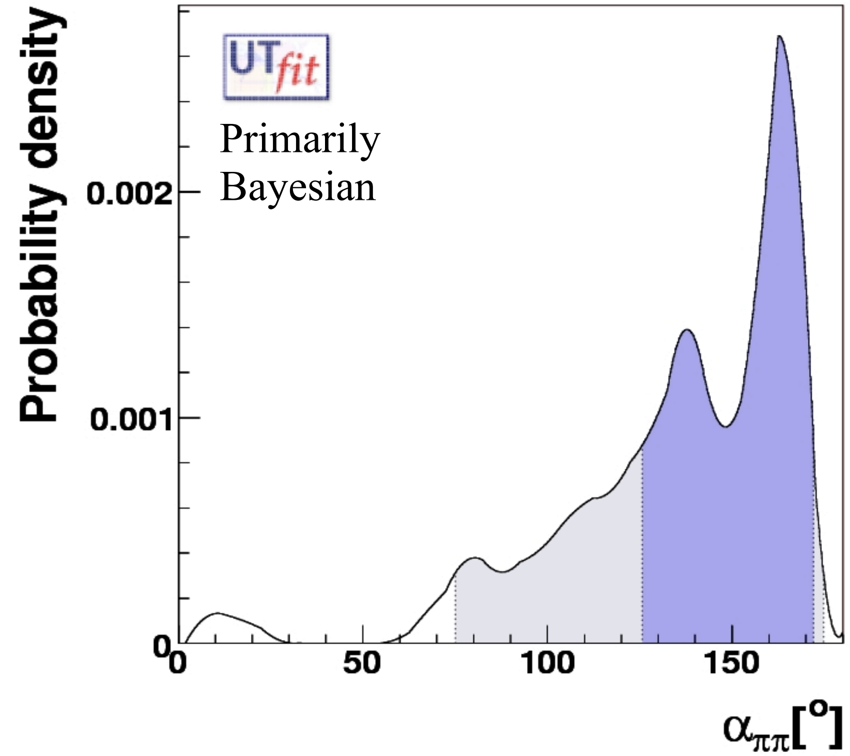
$C_{CP} \neq 0 \rightarrow S_{CP} = \sqrt{(1-C_{CP}^2)}\sin 2\alpha_{eff}$

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

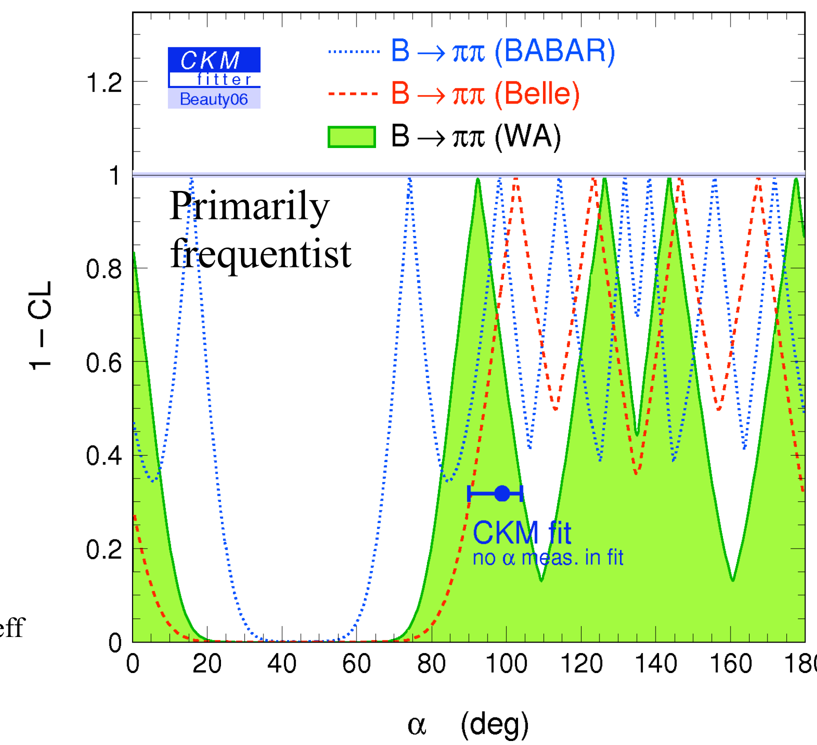


Belle and BaBar only marginally in agreement

Including $\pi^+\pi^0$, $\pi^0\pi^0$ isospin analysis



UTFit, M.Bona et al., hep-ph/0606167



CKMFitter, J.Charles et al., Eur.Phys.J.C41, 1 (2005)

Bayesian and frequentist interpretations give quantitively different conclusions

ϕ_2 from $B^0 \to \rho^+\rho^-$

BaBar hep-ex/0612021
subm'd to PRL

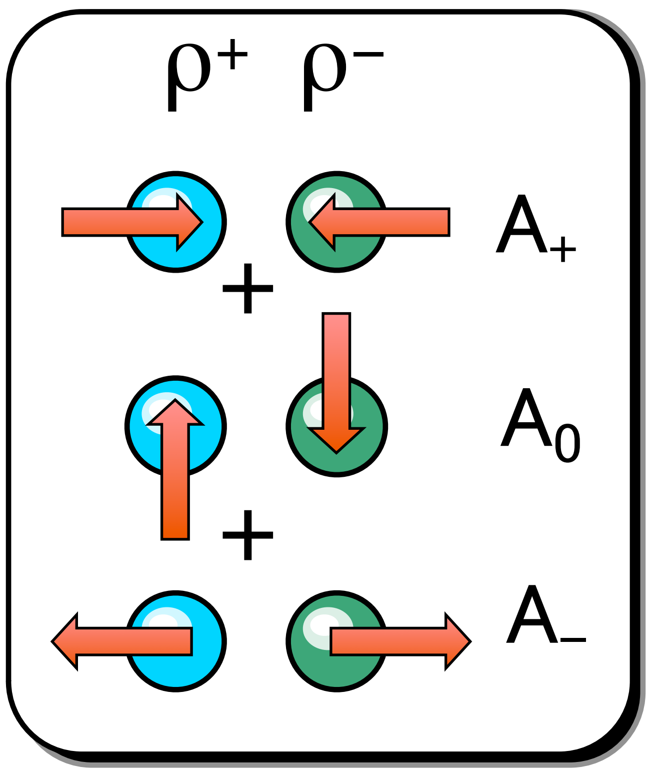
Advantages of $\rho^+\rho^-$:

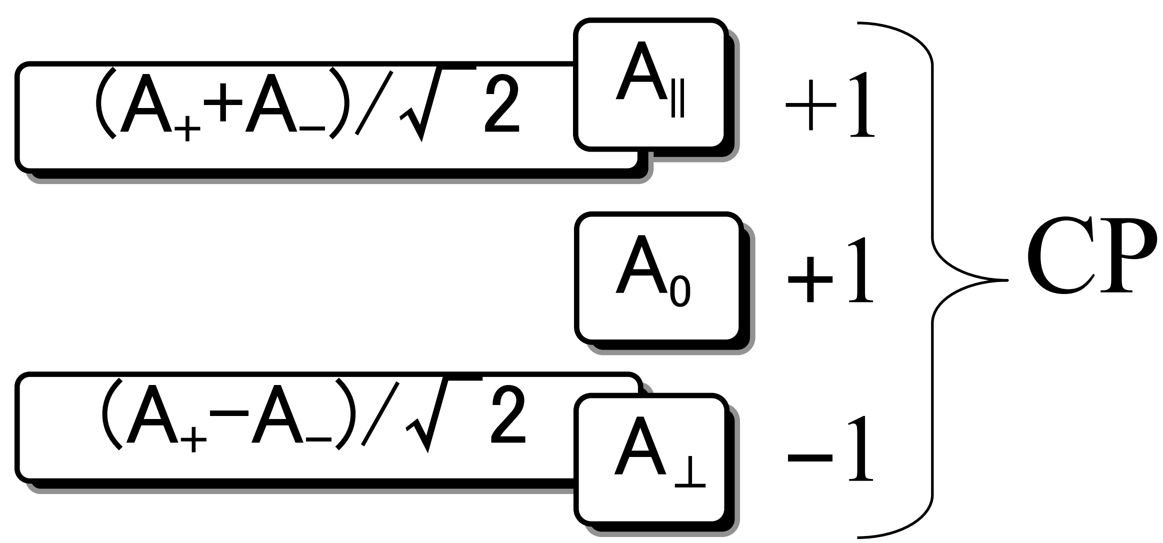
- **small penguin contribution due to relatively small**

$$\mathrm{BF}(B^0 \to \rho^0\rho^0) = (1.07 \pm 0.33 \pm 0.19) \times 10^{-6}$$

- **relatively large measured branching fraction** $\dfrac{\mathrm{Br}(B^0 \to \rho^+\rho^-)}{\mathrm{Br}(B^0 \to \pi^+\pi^-)} \sim 4.4$

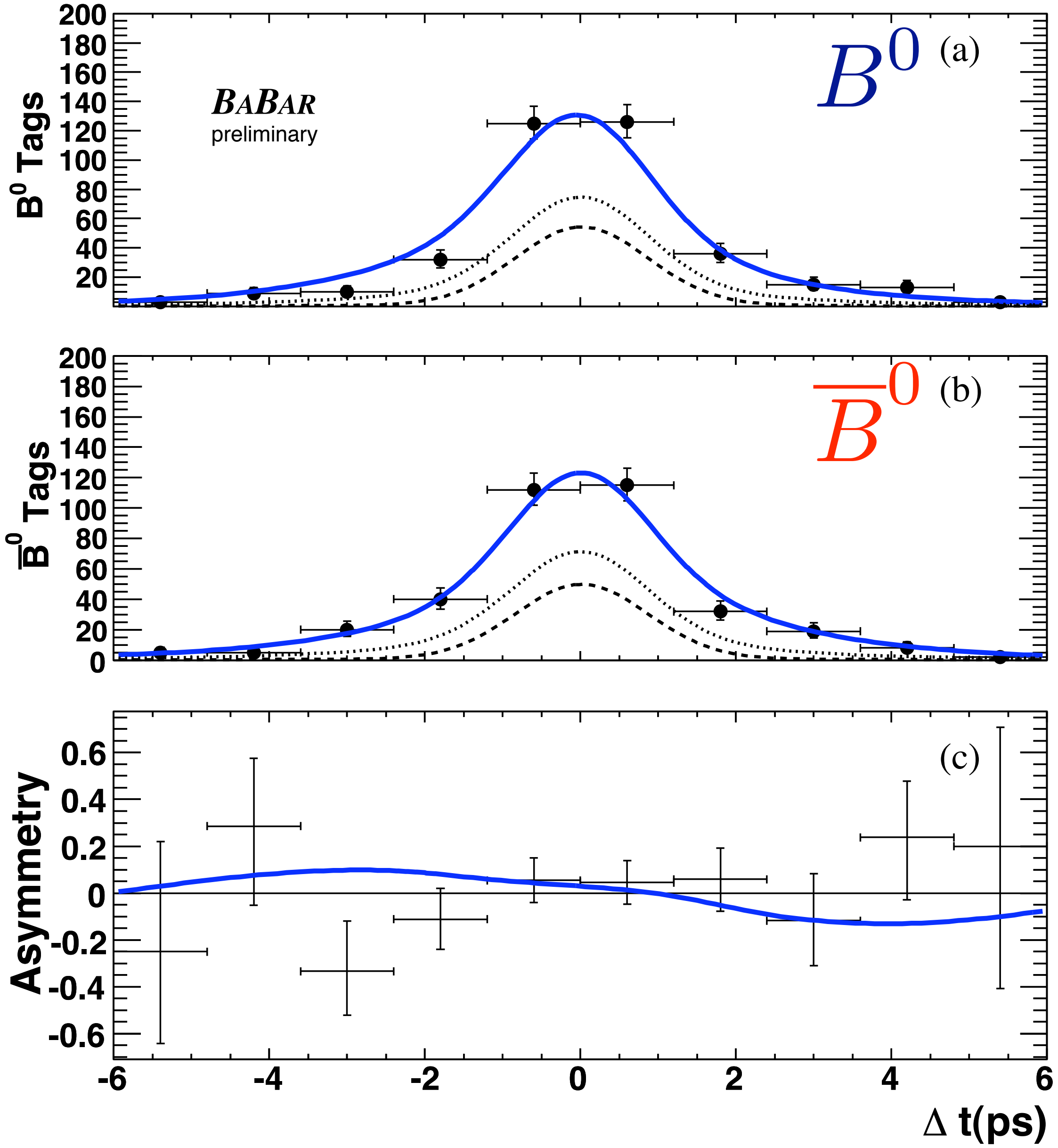
Fortunately, longitudinal polarization dominates





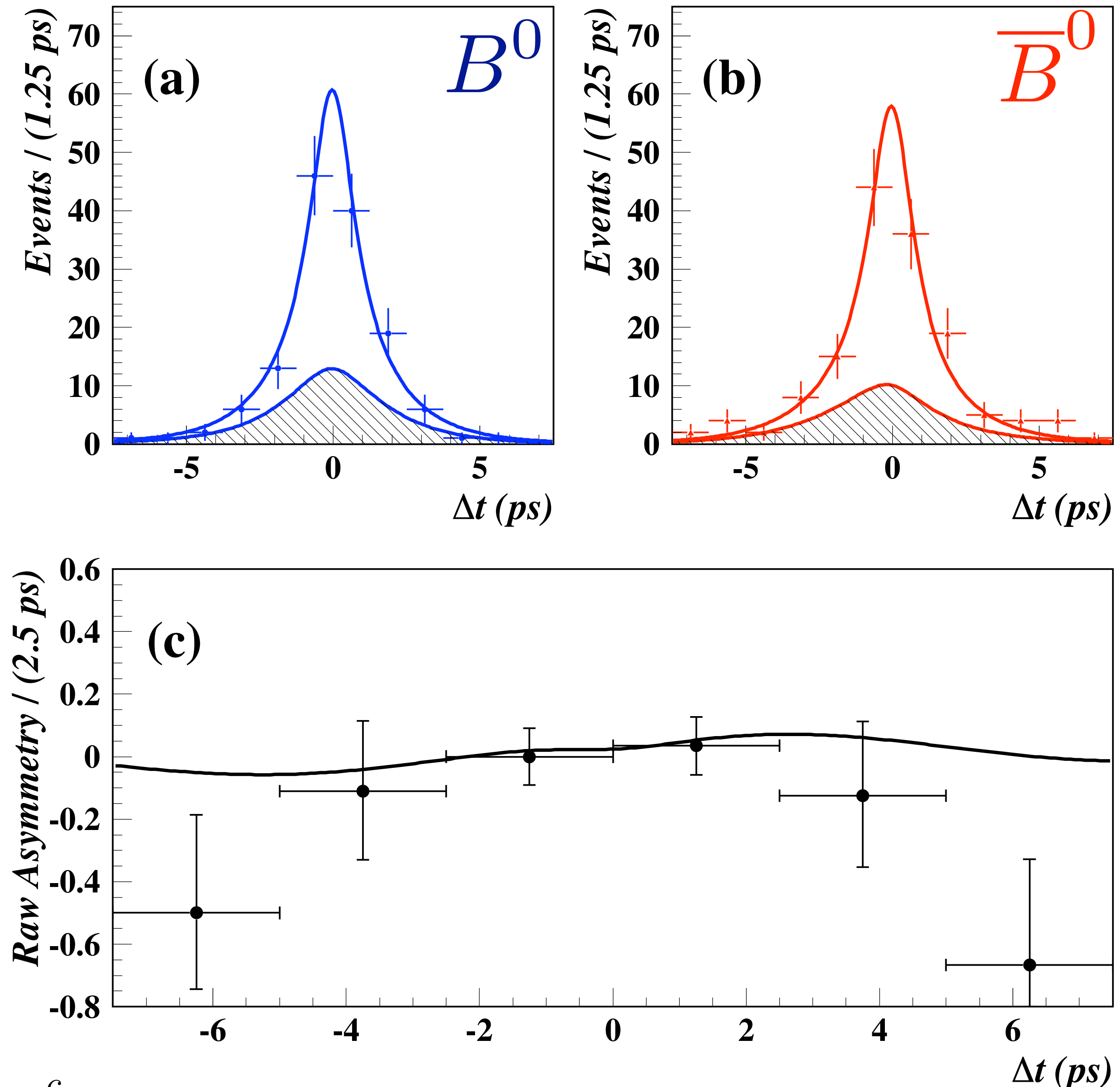
ϕ_2 from $B^0 \to \rho^+\rho^-$

BaBar preliminary; hep-ex/0607098



$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (23.5 \pm 2.2(\text{stat}) \pm 4.1(\text{syst}))\times 10^{-6},$$
$$f_L = 0.977 \pm 0.024(\text{stat})^{+0.015}_{-0.013}(\text{syst}),$$
$$S_{\text{long}} = -0.19 \pm 0.21(\text{stat})^{+0.05}_{-0.07}(\text{syst}),$$
$$C_{\text{long}} = -0.07 \pm 0.15(\text{stat}) \pm 0.06(\text{syst}).$$

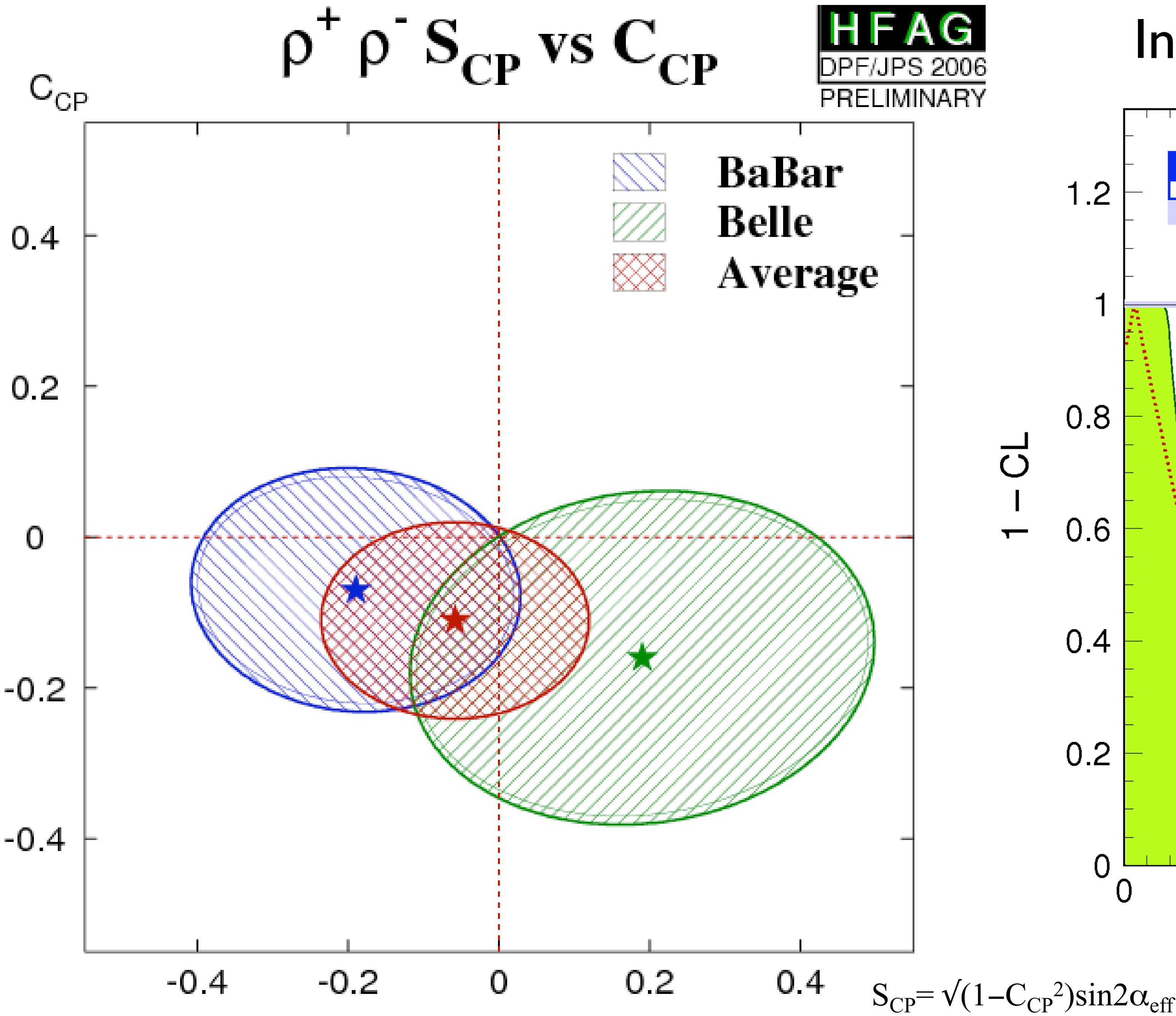
Belle, preliminary; hep-ex/0702009



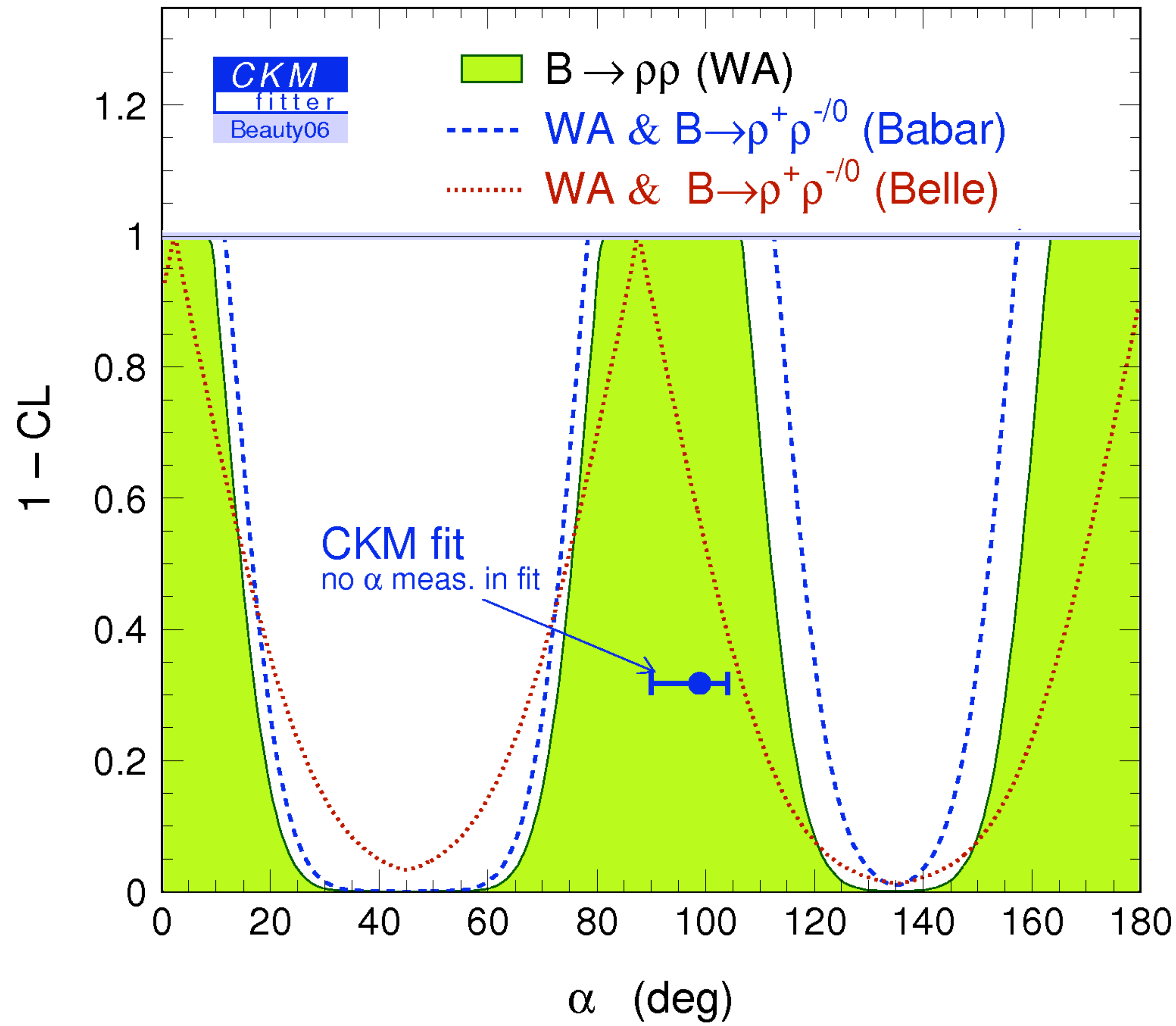
$$\mathcal{A}_L = 0.16 \pm 0.21\,(\text{stat}) \pm 0.07\,(\text{syst})$$
$$\mathcal{S}_L = 0.19 \pm 0.30\,(\text{stat}) \pm 0.07\,(\text{syst})$$

A, S : both consistent with 0

ϕ_2 from $B^0 \to \rho^+\rho^-$

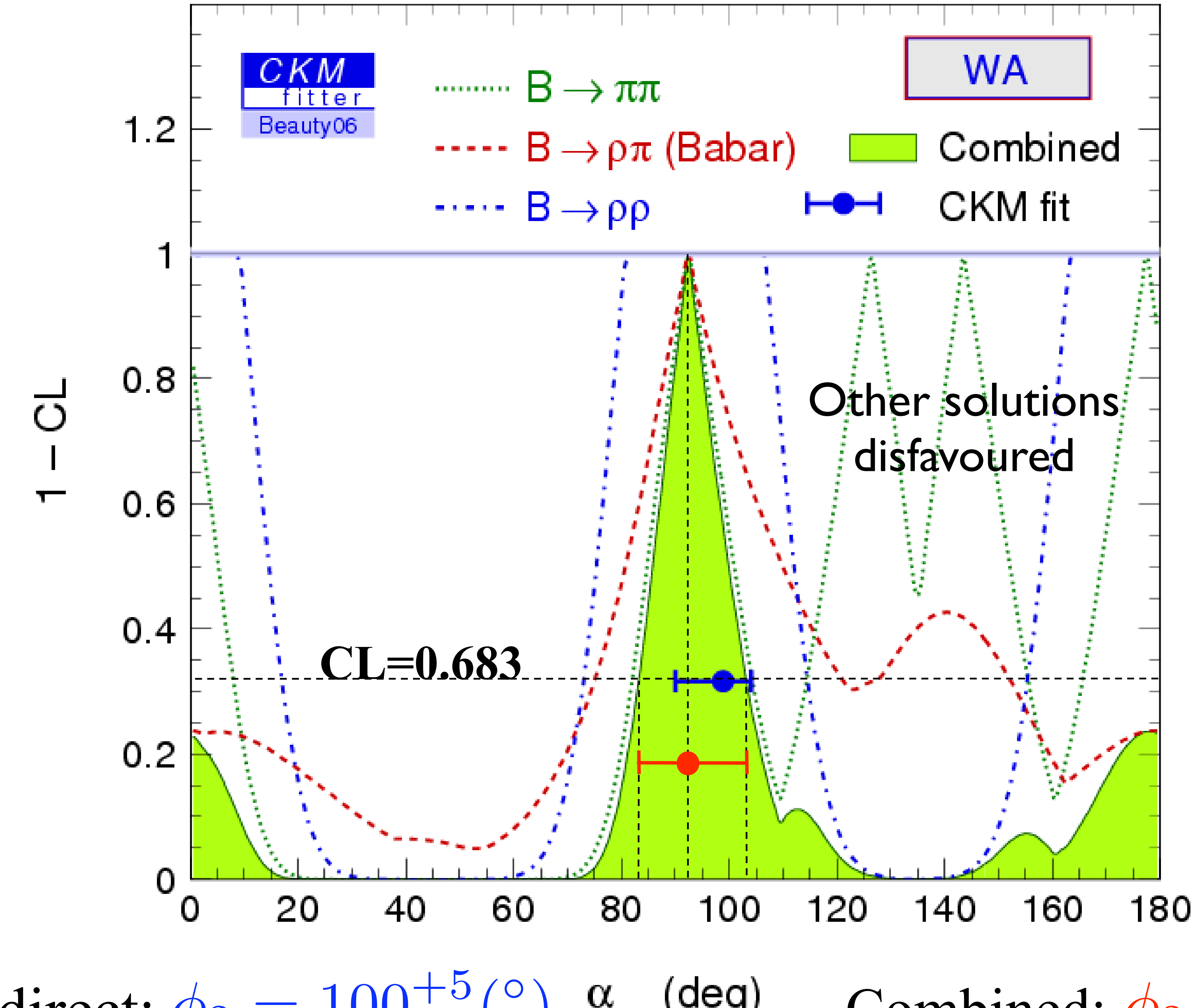


Including $\rho^+\rho^0$, $\rho^0\rho^0$ isospin analysis



Small CP violation: α_{eff} ~ 90° or 0/180°

ϕ_2 combined (including $\rho\pi$)

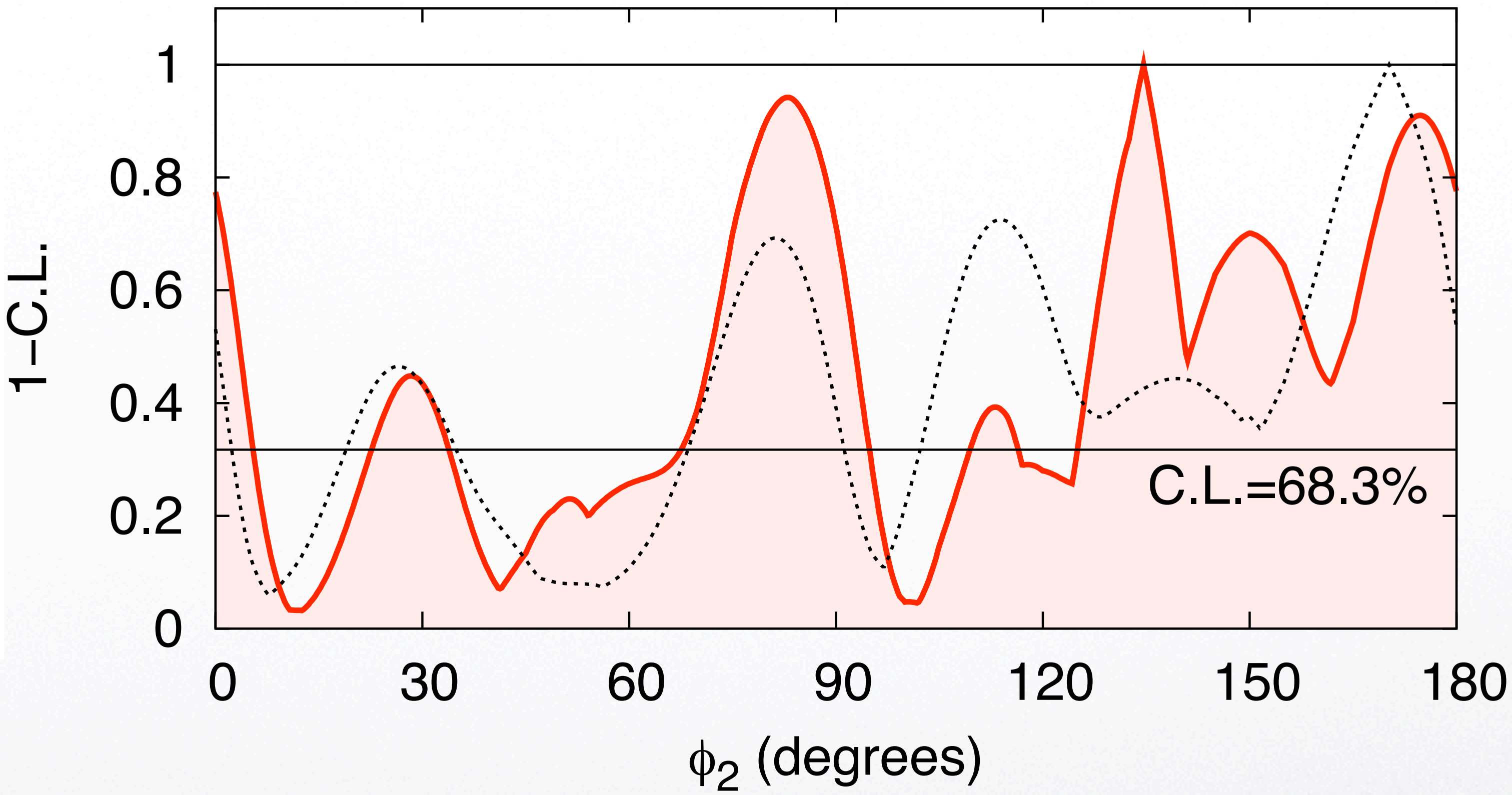


Indirect: $\phi_2 = 100^{+5}_{-7}(^\circ)$ Combined: $\phi_2 = 93^{+11}_{-9}(^\circ)$

$B^0 \to (\rho\pi)^0$ from Belle

New!
hep-ex/0701015

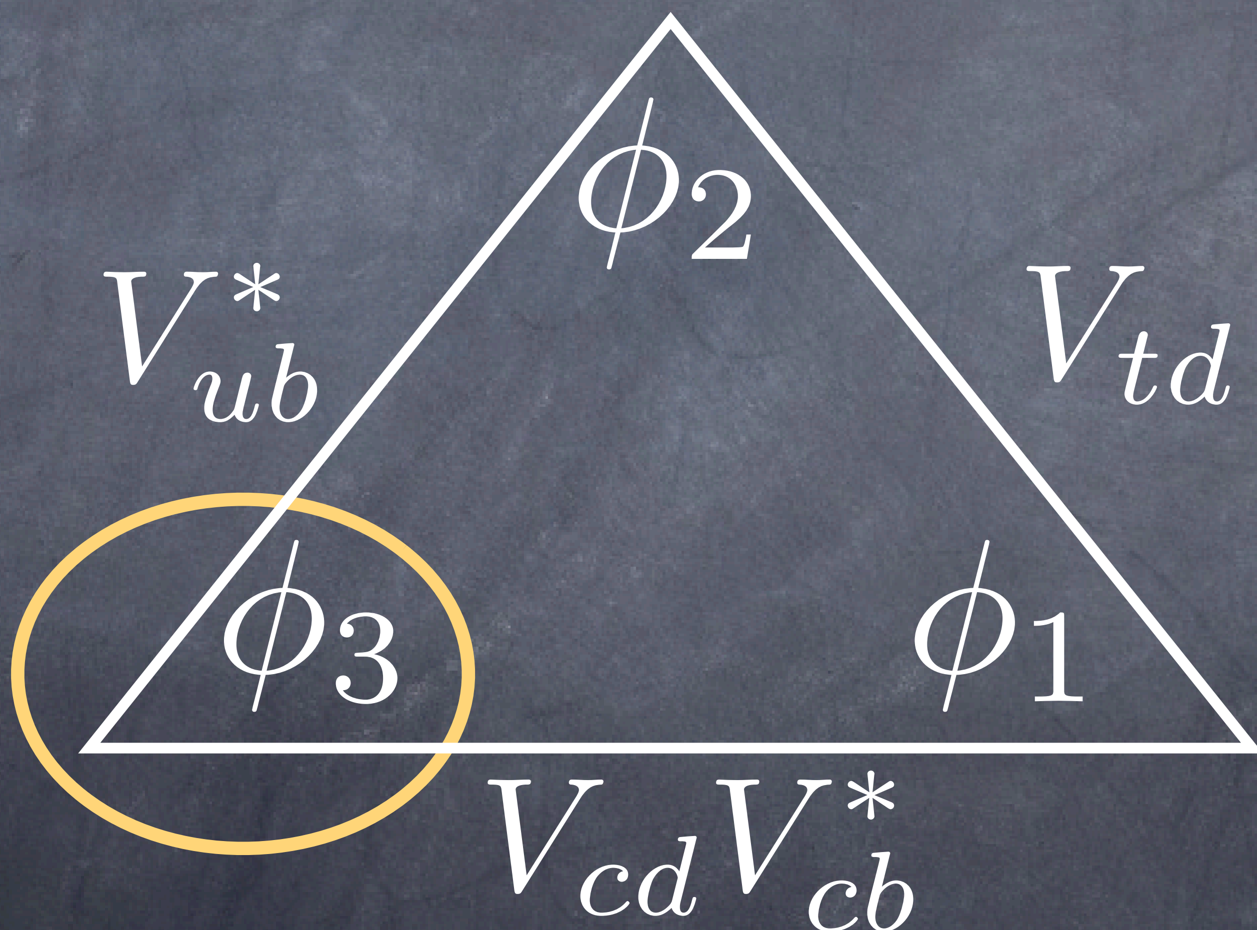
$$|\rho^+\pi^0\rangle = \sqrt{\tfrac{1}{2}}\,|2,1\rangle + \sqrt{\tfrac{1}{2}}\,|1,1\rangle\,,$$
$$|\rho^0\pi^+\rangle = \sqrt{\tfrac{1}{2}}\,|2,1\rangle - \sqrt{\tfrac{1}{2}}\,|1,1\rangle\,,$$
$$|\rho^+\pi^-\rangle = \sqrt{\tfrac{1}{6}}\,|2,0\rangle + \sqrt{\tfrac{1}{2}}\,|1,0\rangle + \sqrt{\tfrac{1}{3}}\,|0,0\rangle\,,$$
$$|\rho^-\pi^+\rangle = \sqrt{\tfrac{1}{6}}\,|2,0\rangle - \sqrt{\tfrac{1}{2}}\,|1,0\rangle + \sqrt{\tfrac{1}{3}}\,|0,0\rangle\,,$$
$$|\rho^0\pi^0\rangle = \sqrt{\tfrac{2}{3}}\,|2,0\rangle - \sqrt{\tfrac{1}{3}}\,|0,0\rangle\,.$$



- Time-dependent Dalitz + isospin pentagon (1st time!)
- subm'ed to PRL & to be included in the world average

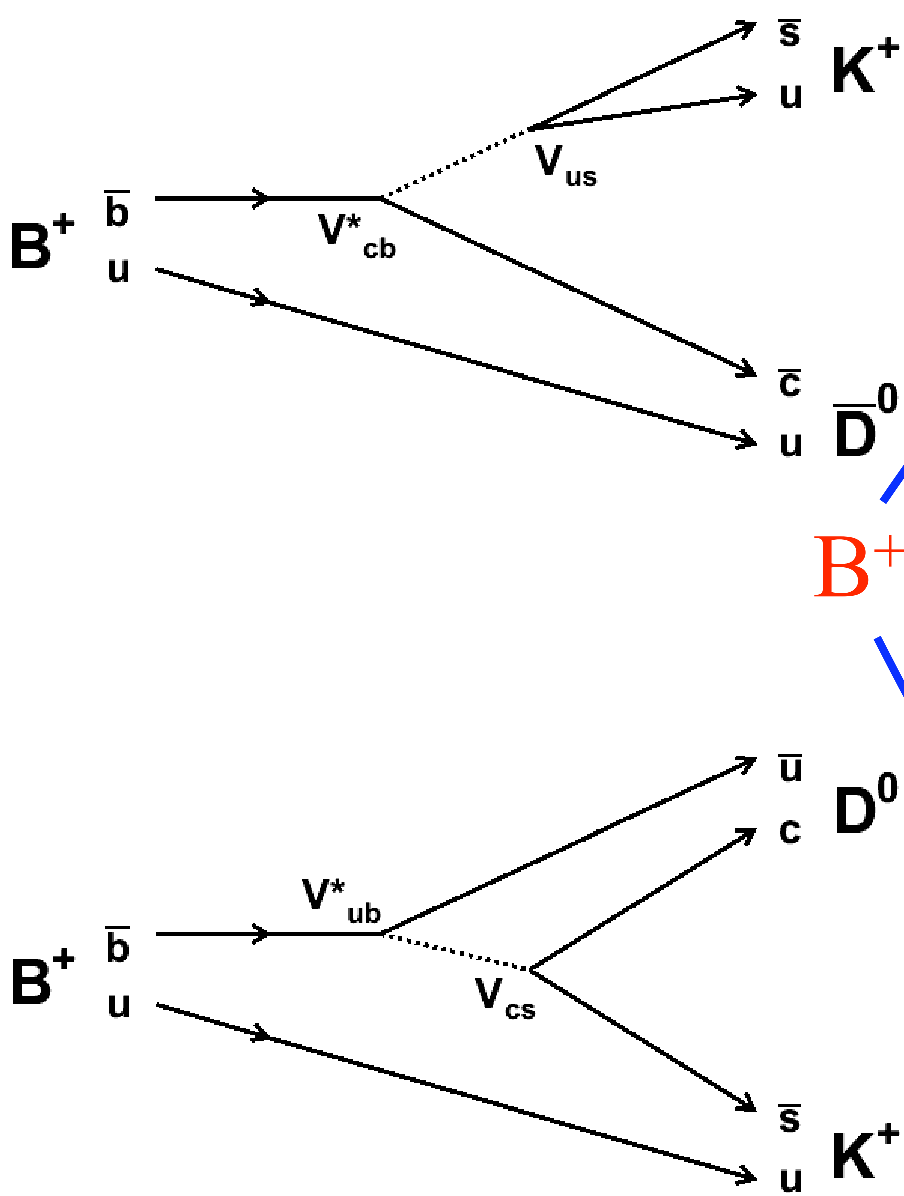
Other angles?

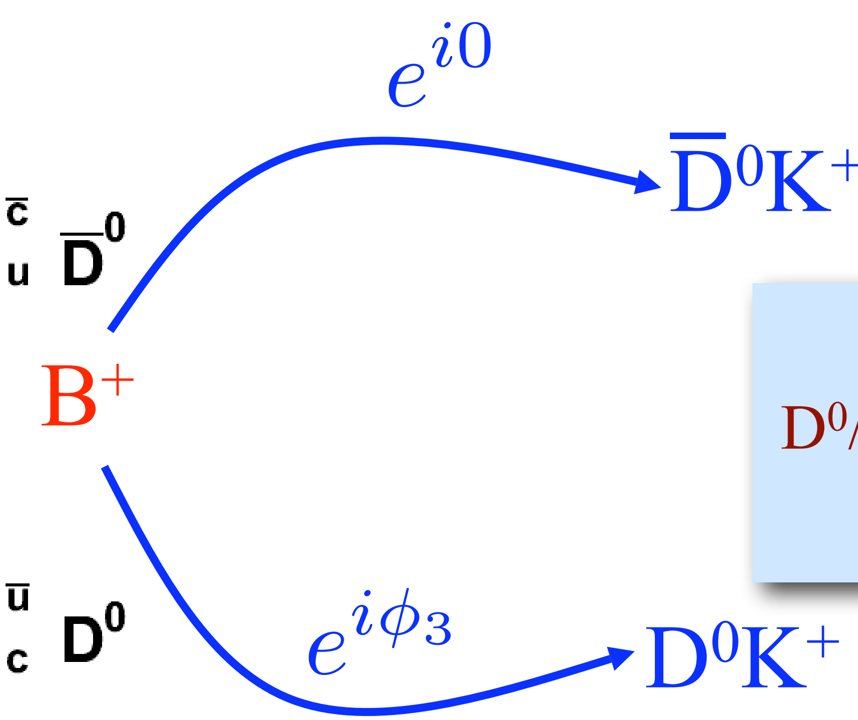
Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
	易	難	魔



ϕ_3 from CPV in DK modes

e.g. $B^+ \to D^0/\overline{D}^0 K^+$





GLW: Gronau, London, Wyler (2001)
ADS: Atwood, Dunietz, Soni (1997)
GGSZ: Giri, Grossman, Soffer, Zupan (2003)

$D^0/\overline{D}^0$
- → CP state (GLW)
- → $K^-\pi^+/K^+\pi^-$, CA/DCS (ADS)
- → $K_S\pi^+\pi^-$, Dalitz (GGSZ)

Relative phase = $e^{-i\phi_3}$

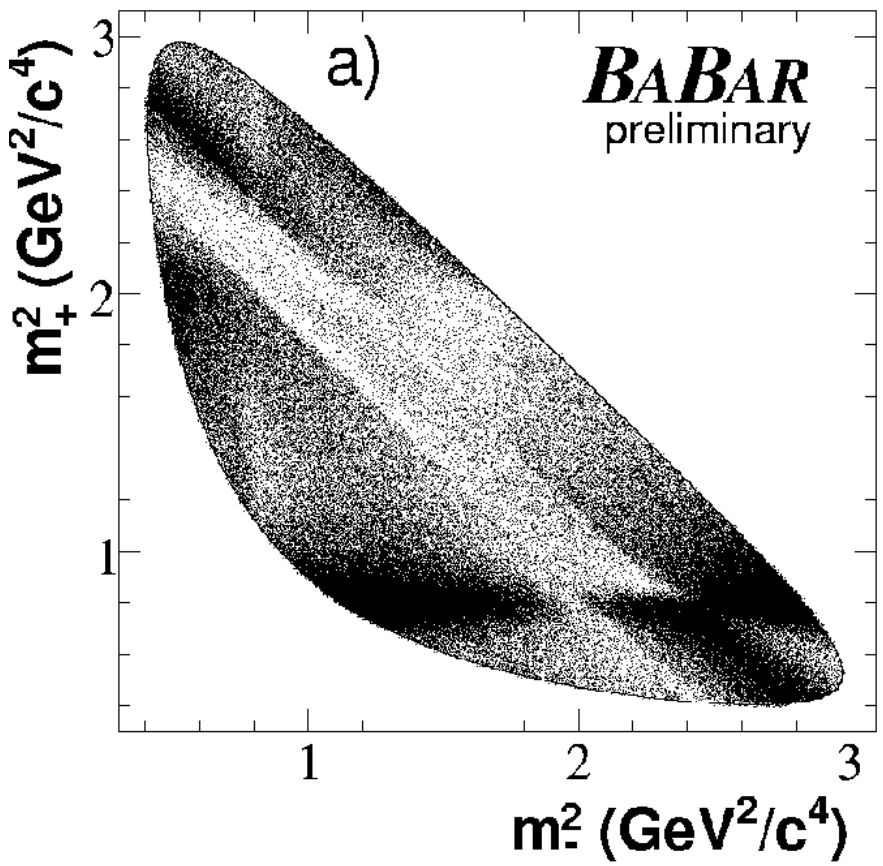
D decays do not involve V_{ub} or V_{td}
→ no contribution to phase

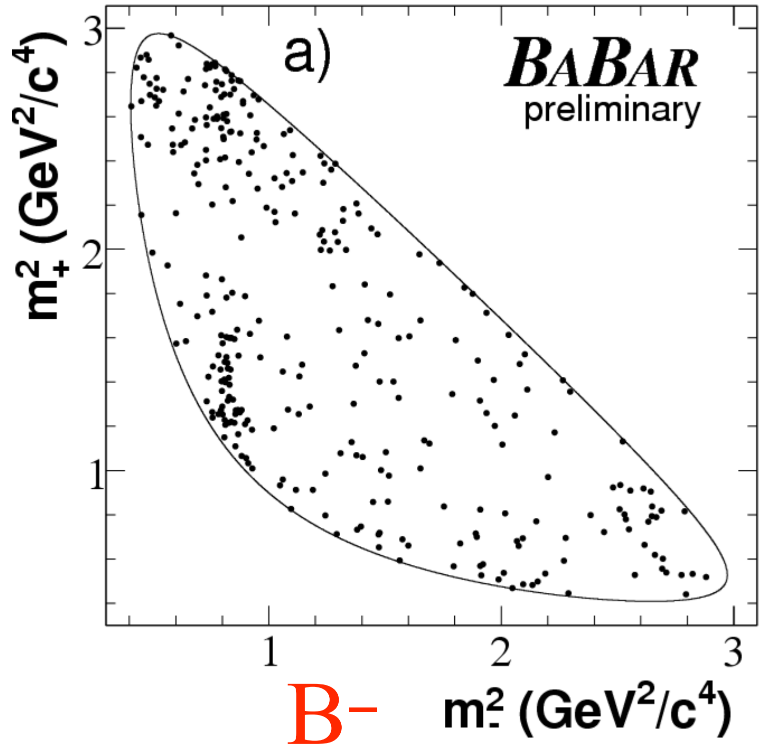
$B^\pm$ → no mixing, no *t*-dependence

The GGSZ method

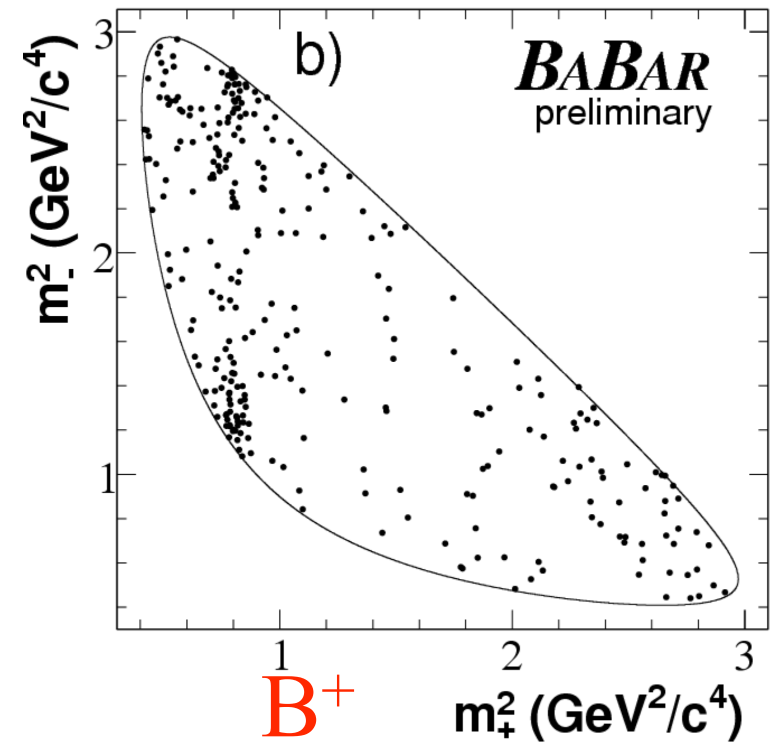
Look for deviations in $B^{\pm} \rightarrow D^0 K^{\pm}$ plots

Map out Dalitz plot from all D^0 decays

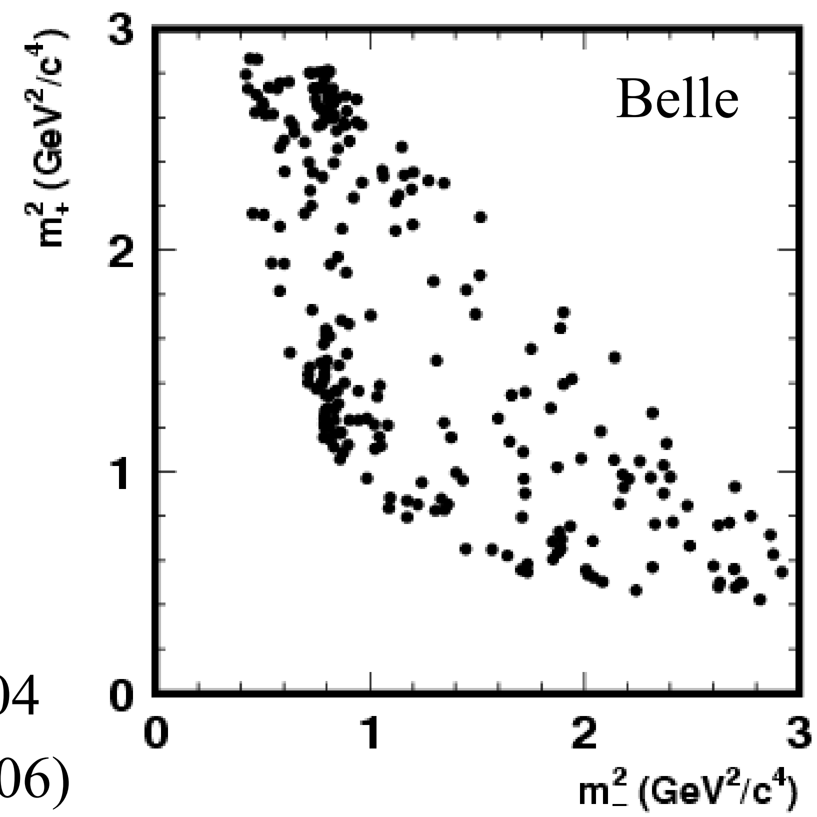


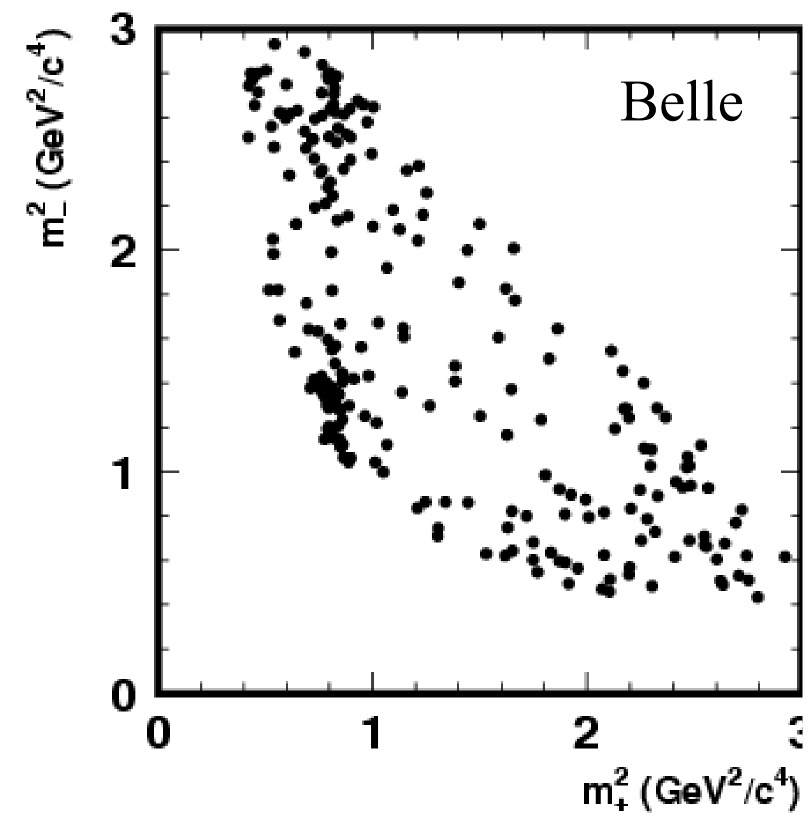


B^-



B^+





BaBar preliminary; hep-ex/0607104

Belle; Phys.Rev.D 73, 172009 (2006)

Results from GGSZ method

Express in terms of measurables from $B^\pm$

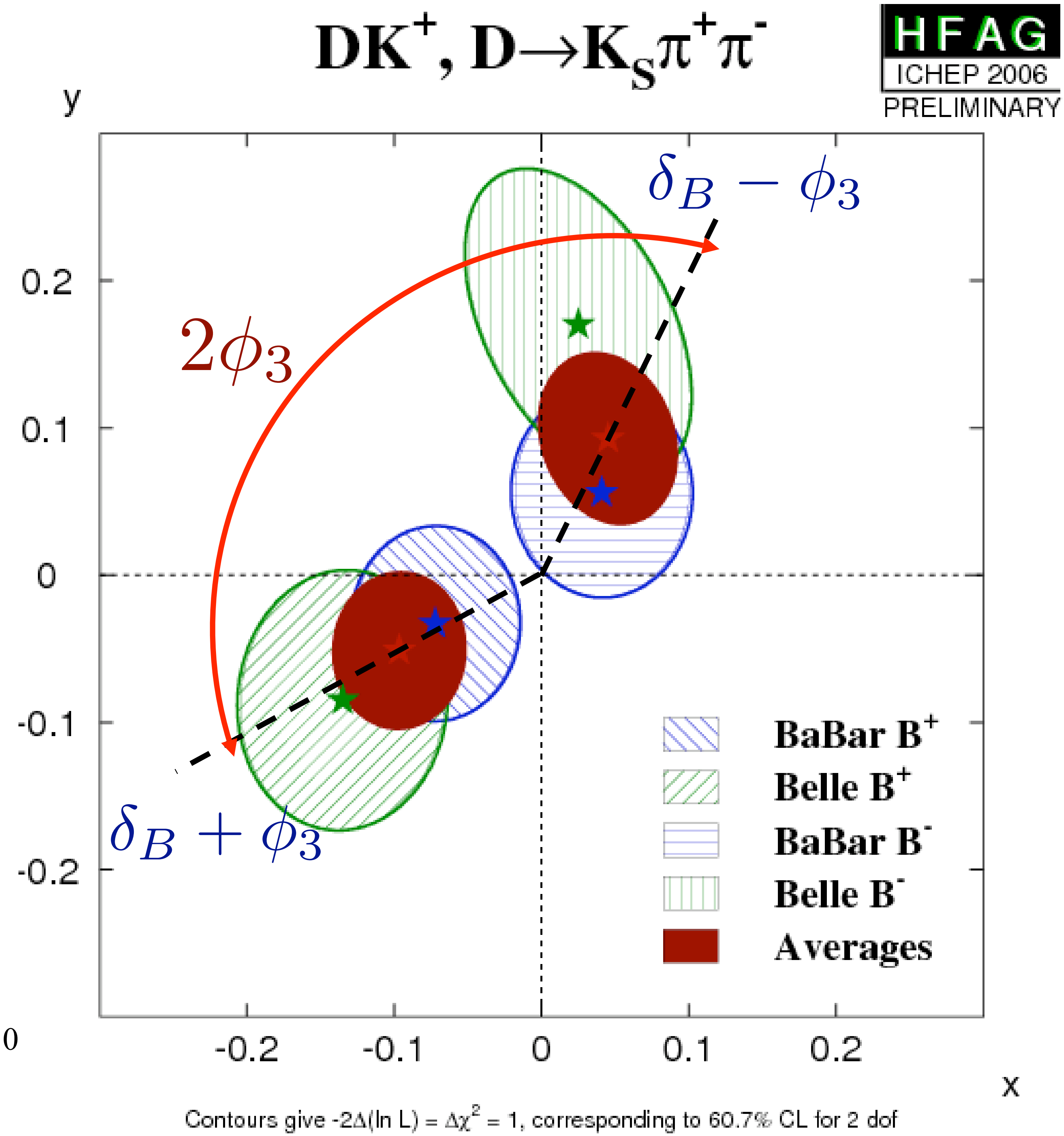
$$x_\pm = r_B \cos(\delta_B \pm \phi_3)$$

$$y_\pm = r_B \sin(\delta_B \pm \phi_3)$$

r_B : ratio of $D/\bar{D}$ ampl. $=0.16\pm0.07$

δ_B : $D/\bar{D}$ relative phase

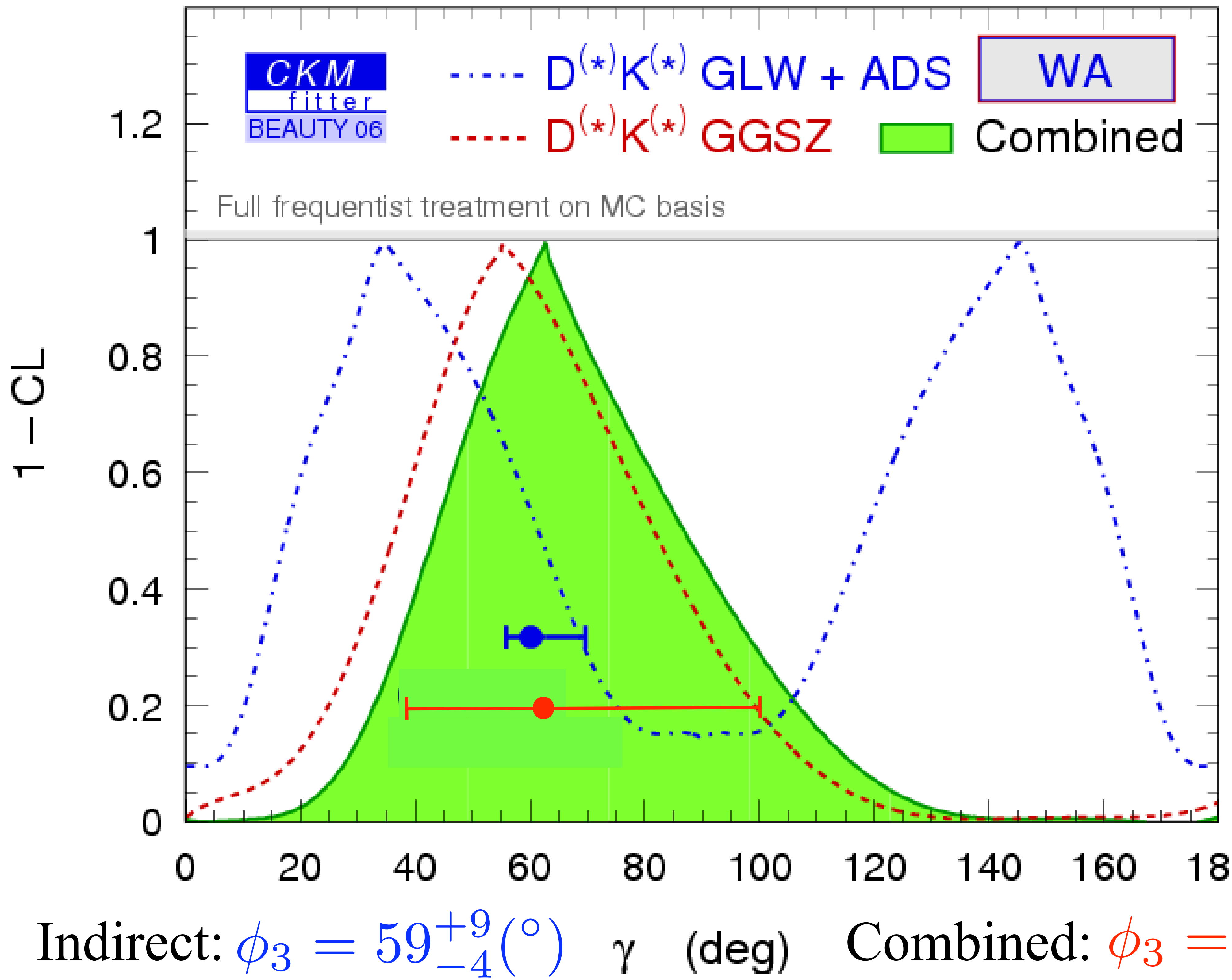
Different r_B, δ_B for each mode $D^{(*)}K^{(*)}$



BaBar preliminary; hep-ex/060710

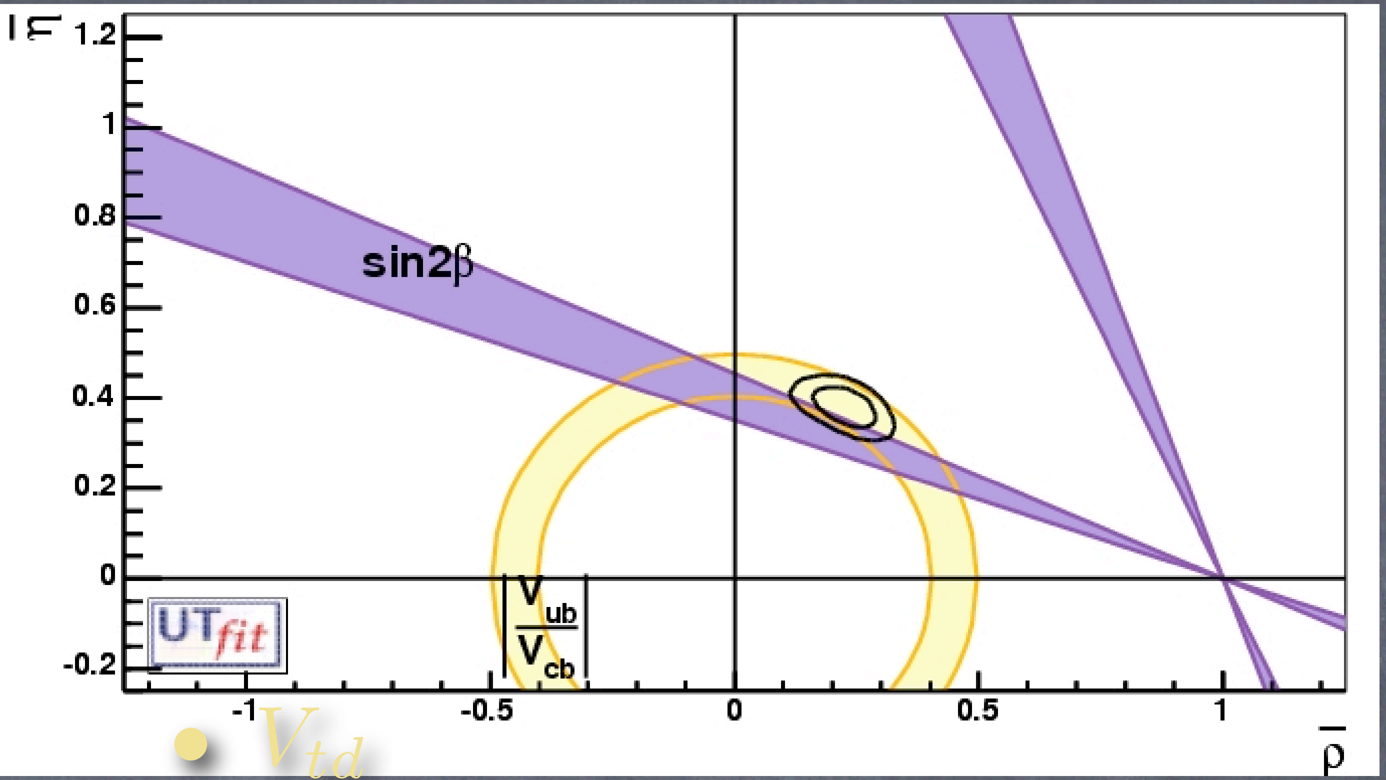
Belle; PRD 73, 112009 (2006)

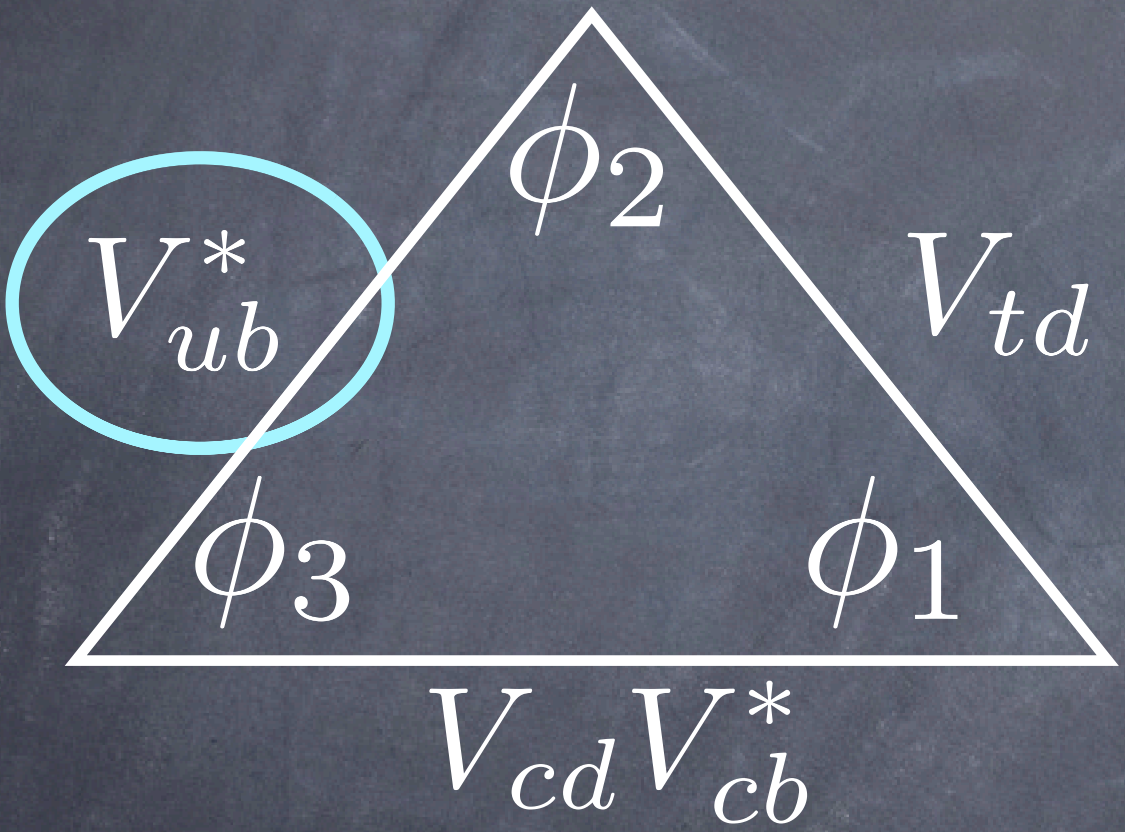
Overall result



Indirect: $\phi_3 = 59^{+9}_{-4}(^\circ)$ Combined: $\phi_3 = 62^{+38}_{-24}(^\circ)$

The Sides



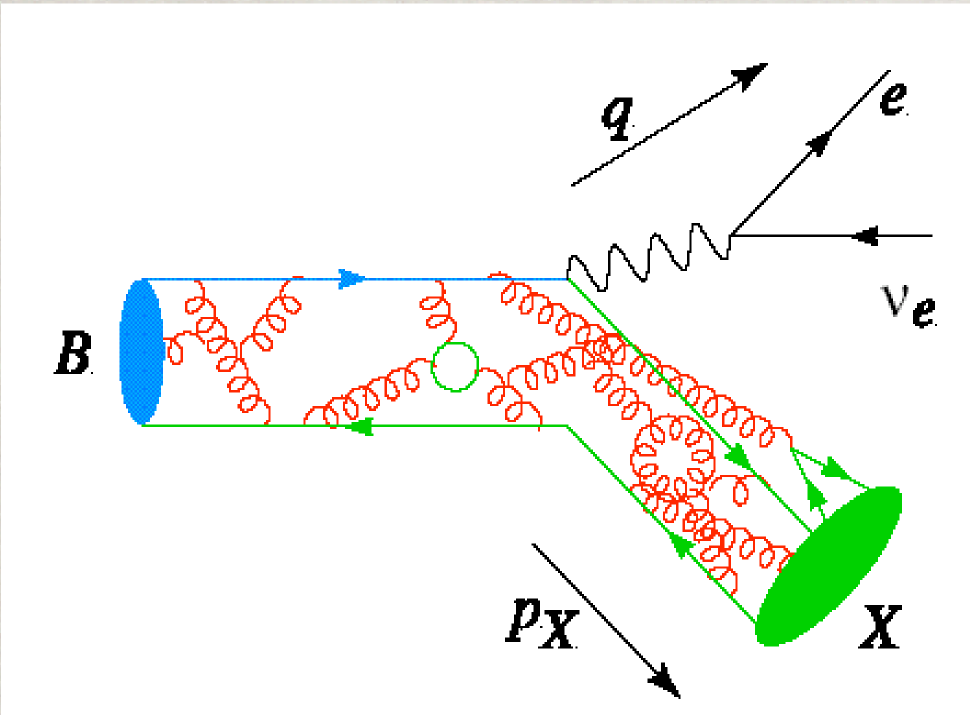


- V_{td}
  - $B \to X_d\gamma$ (A. Bevan)
  - B_s mixing (K. Pitts)
- V_{cb}
  - $\mathcal{O}(1\%)$ precision

just overly simplified guidelines

- $V = |V| exp(\mathrm{i}\phi)$
  - $|V|$ from semi-leptonic decay rates $\quad \Gamma_{X\ell\nu} \propto |V_{ij}|^2$
  - ϕ from *CP* asymmetries

Semileptonic B Decays



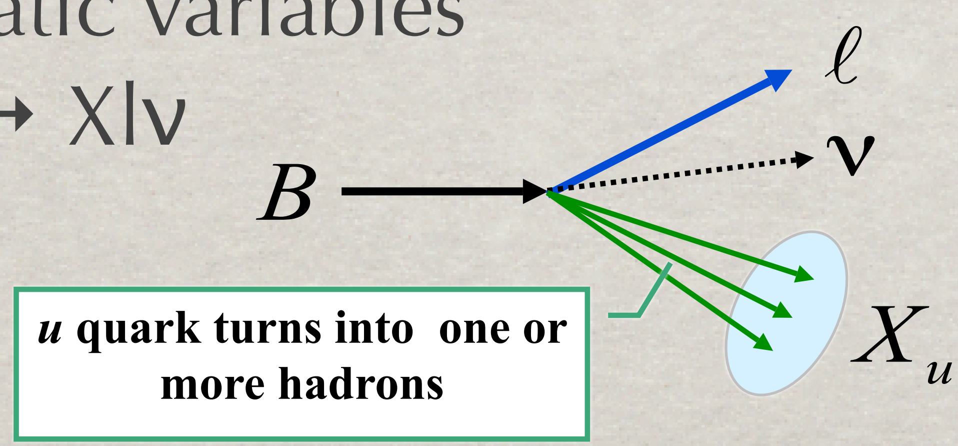
* Semileptonic B decays allow measurement of $|V_{cb}|$ and $|V_{ub}|$ from tree level processes.

* Presence of a single hadronic current allows control of theoretical uncertainties.

$$|V_{cb}| \gg |V_{ub}|$$

$$\frac{\Gamma\left(b \to u\ell^- \bar{\nu}\right)}{\Gamma\left(b \to c\ell^- \bar{\nu}\right)} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

kinematic variables for B → Xlν

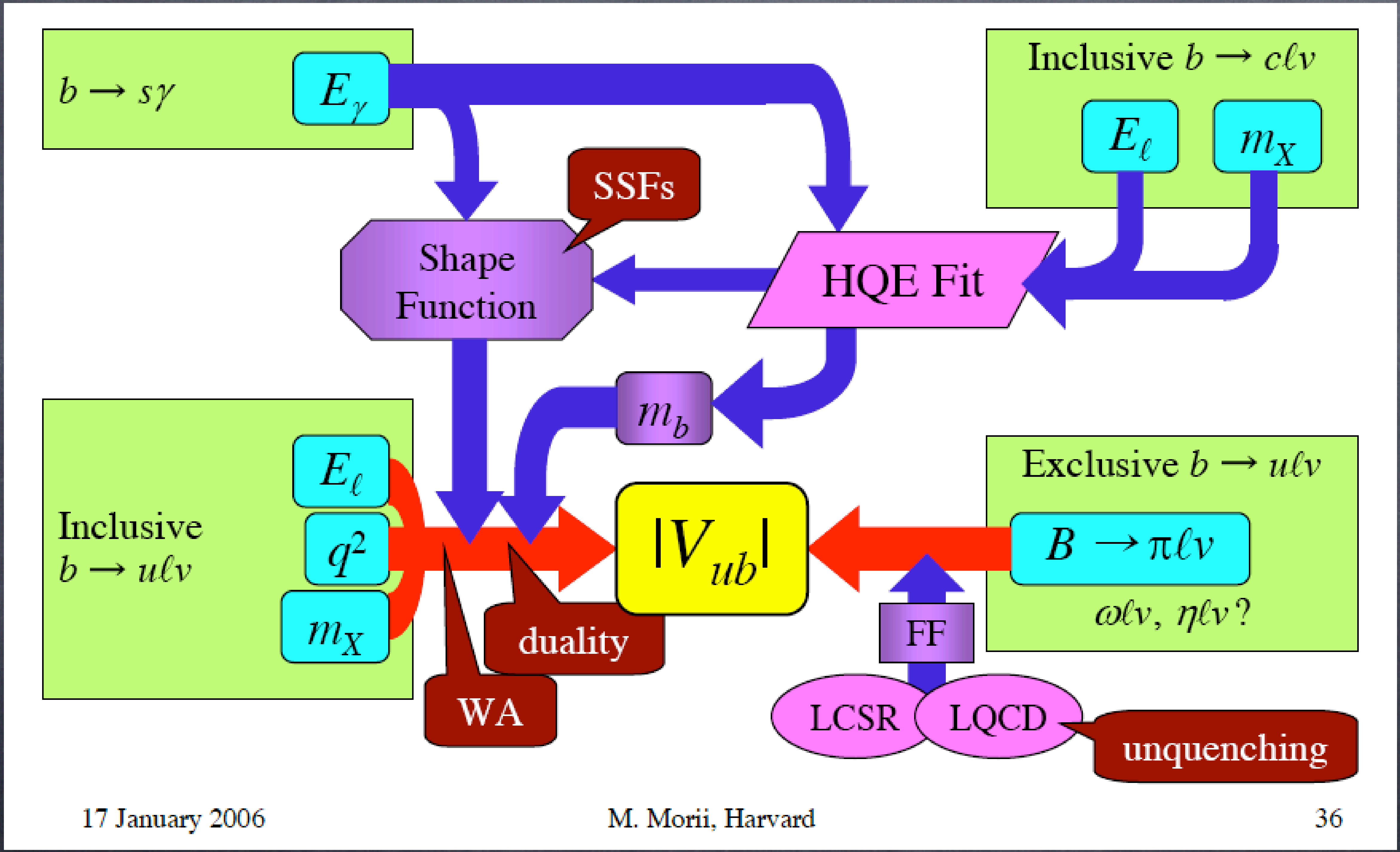


$E_\ell =$ lepton energy

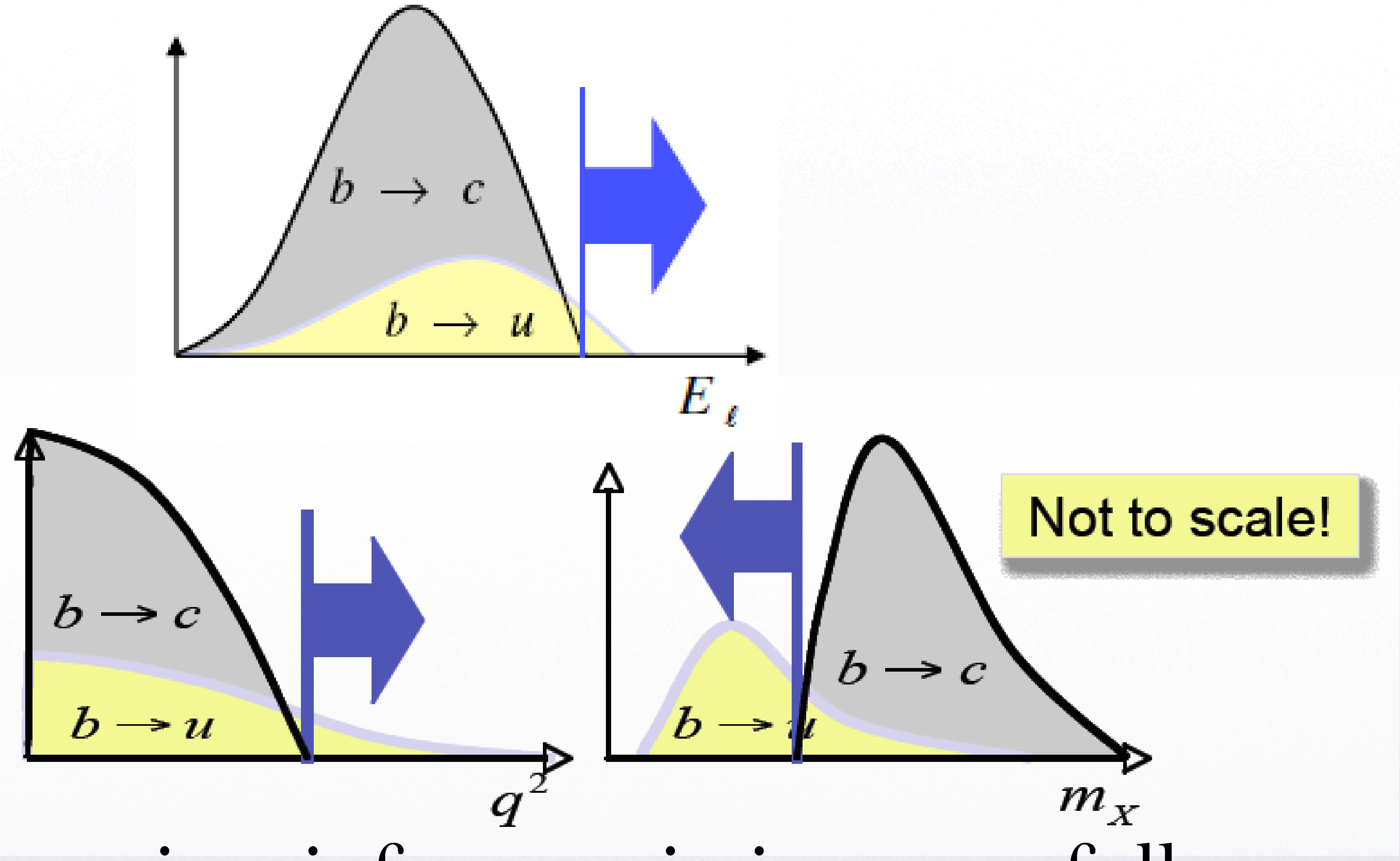
$q^2 = (p_\ell + p_\nu)^2$

$m_X =$ mass of the hadronic part

Morii's chart for V_{ub}



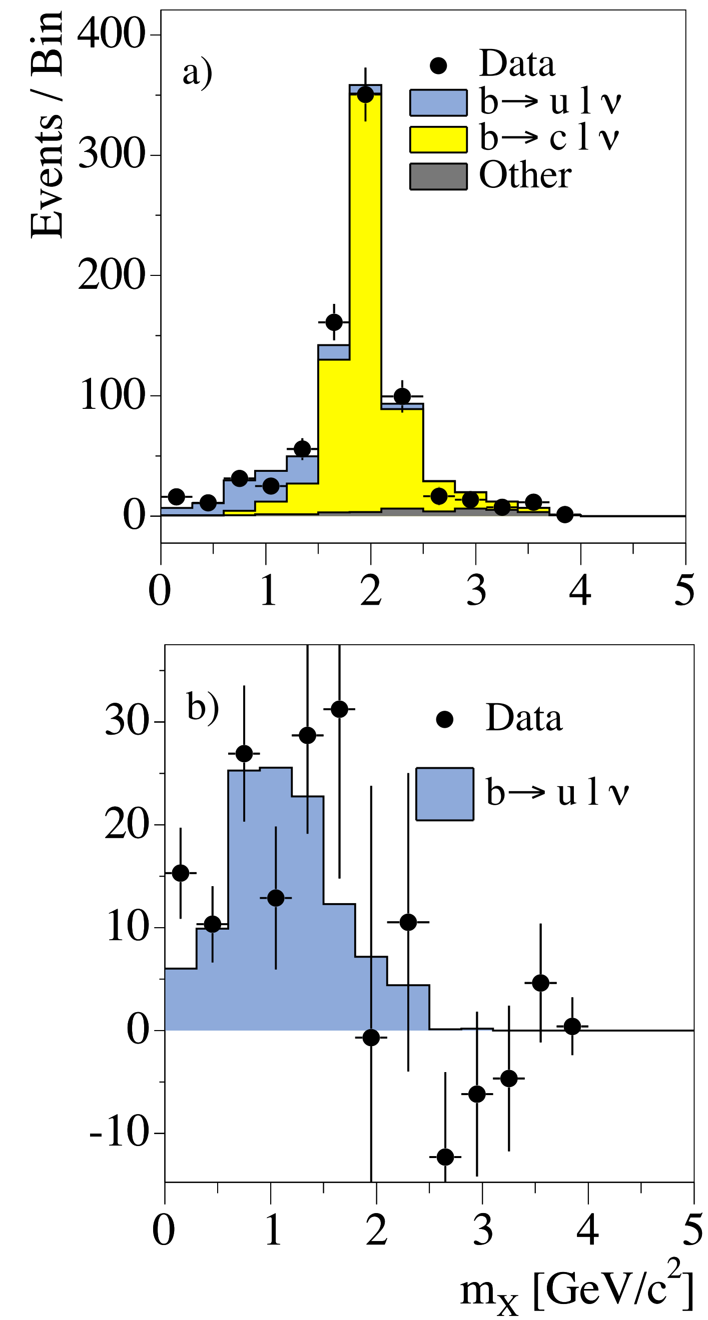
Inclusive $B \to X_u \ell \nu$



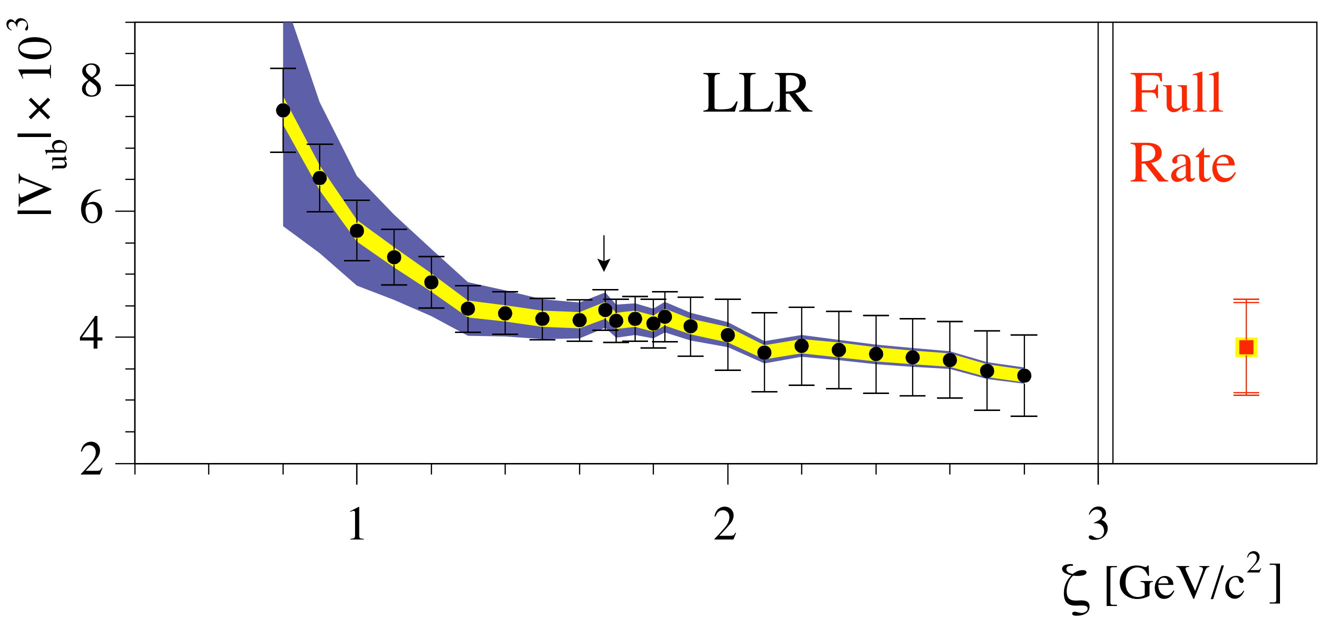
q^2 and M_x requires info. on missing ν --> full-recon.

$$\Gamma(B \to X_u \ell\nu) = \frac{|V_{ub}|^2}{|V_{ts}|^2} \int W(E_\gamma) \frac{d\Gamma(B \to X_s\gamma)}{dE_\gamma} dE_\gamma$$

V_{ub} (LLR method)



- m_{X_u} $(B \to X_u\ell\nu)$ and E_γ $(B \to X_s\gamma)$
- two methods
  - ⋆ $m_{X_u} < \zeta(< 1.67\ \mathrm{GeV})$ (LLR)
  - ⋆ m_{X_u} in full range (U, HLM)



m_X acceptance

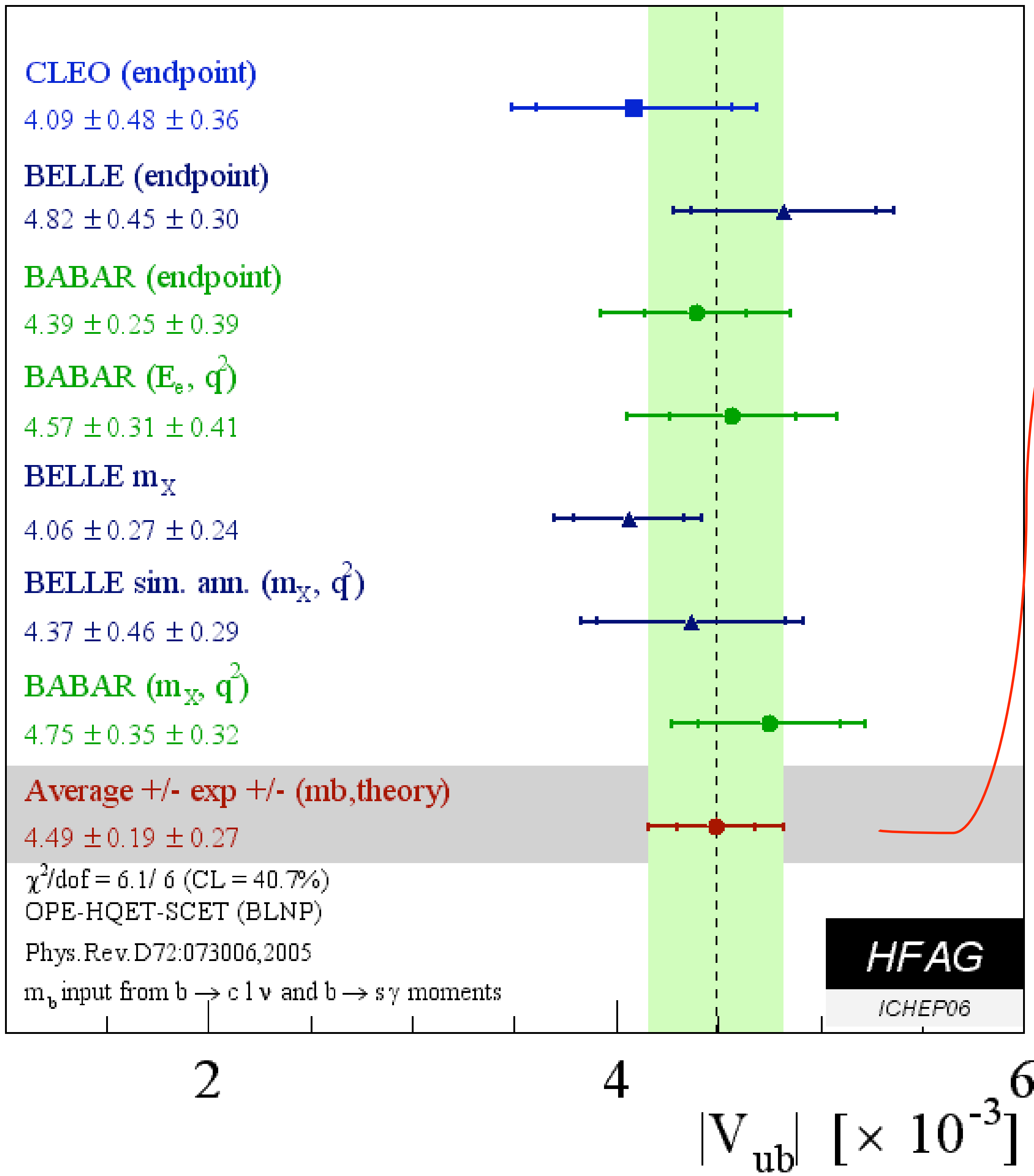
LLR : M_X < 1.67 GeV: $|V_{ub}| = (4.43 \pm 0.38_{stat} \pm 0.25_{syst} \pm 0.29_{theo})\ 10^{-3}$ 12% 72%

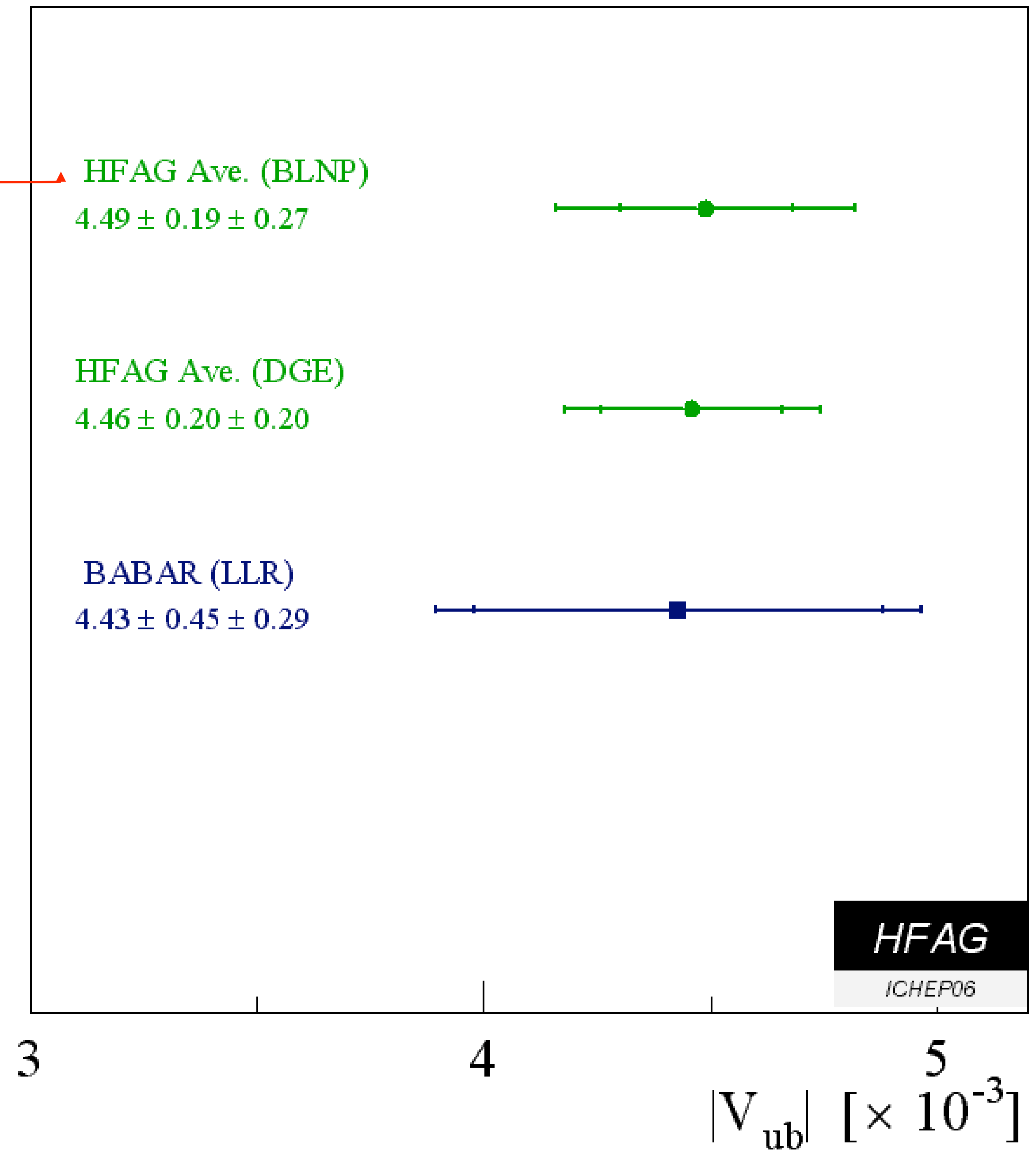
OPE: M_X < 2.50 GeV: $|V_{ub}| = (3.84 \pm 0.70_{stat} \pm 0.30_{syst} \pm 0.10_{theo})\ 10^{-3}$ 20% 98%

V_{ub} inclusive summary

BLNP: Bosch, Lange, Neubert, Paz (2005)
DGE: Anderson, Gardi (2006)
LLR: Leibovich, Low, Rothstein (2006)

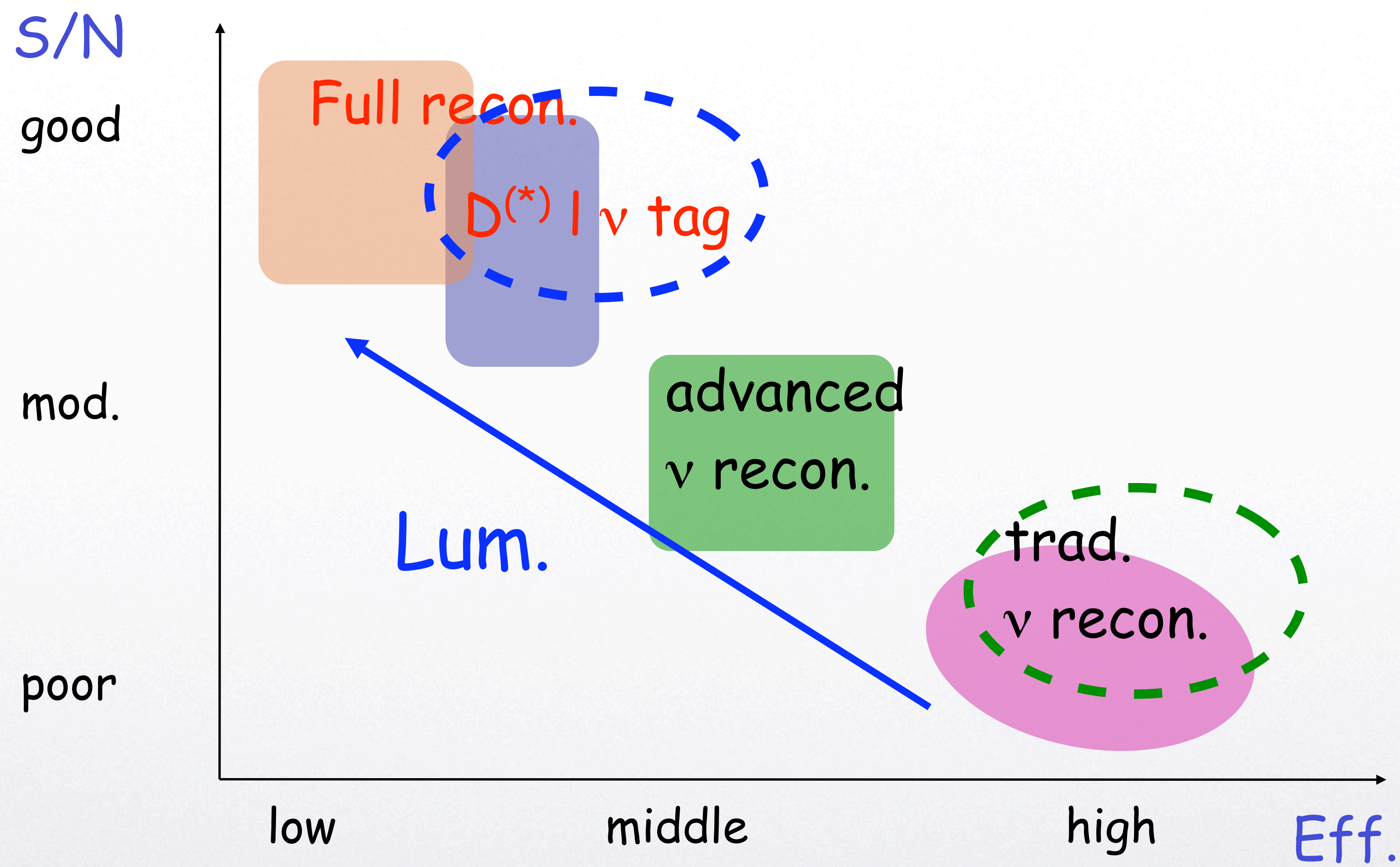
Representative theory example (BLNP)





Room for some experimental statistical improvement

Exclusive $B \to X_u \ell \nu$



How well can we measure the q^2 dist. for $B \to X_u l \nu$?

V_{ub} by $D^*\ell\nu$ tagging

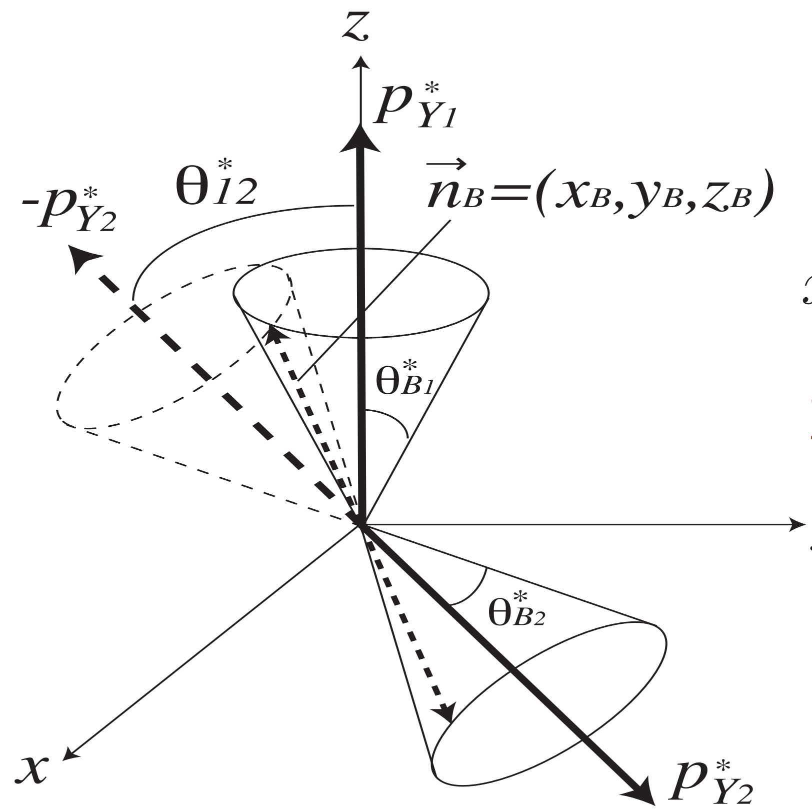
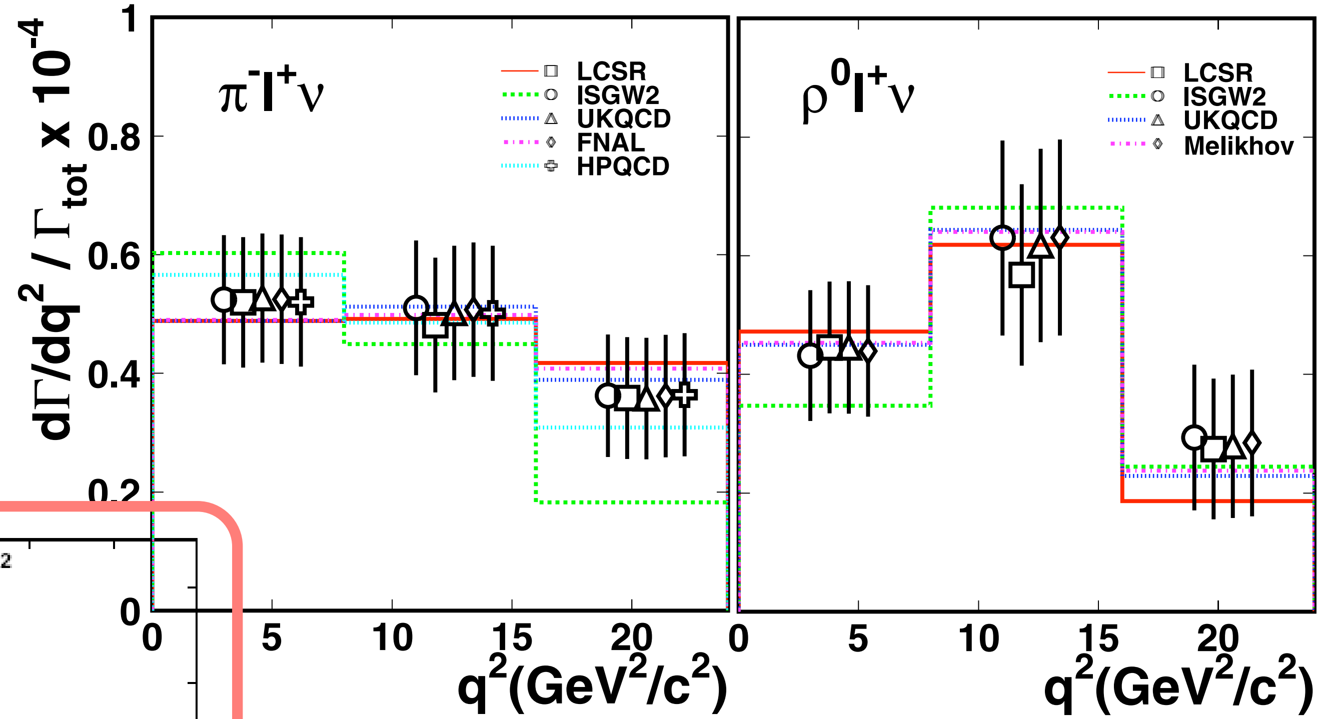
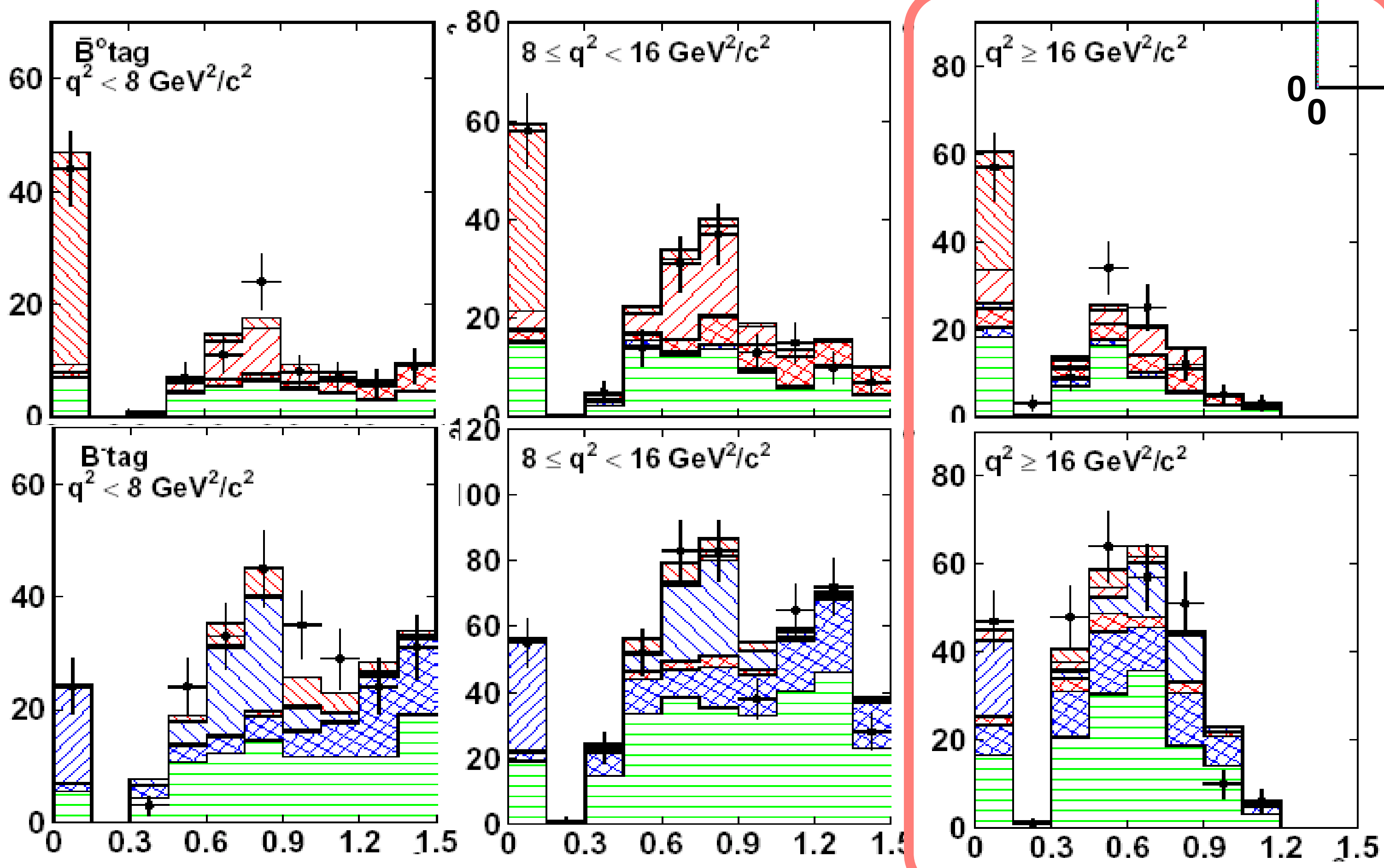


Fig. 1. Kinematics of the double semileptonic decay.

$$x_B{}^2 = 1 - \frac{1}{\sin^2\theta^*_{12}}(\cos^2\theta^*_{B_1} + \cos^2\theta^*_{B_2} - 2\cos\theta^*_{B_1}\cos\theta^*_{B_2}\cos\theta^*_{12})$$

for true signal, $0 < x_B^2 < 1$

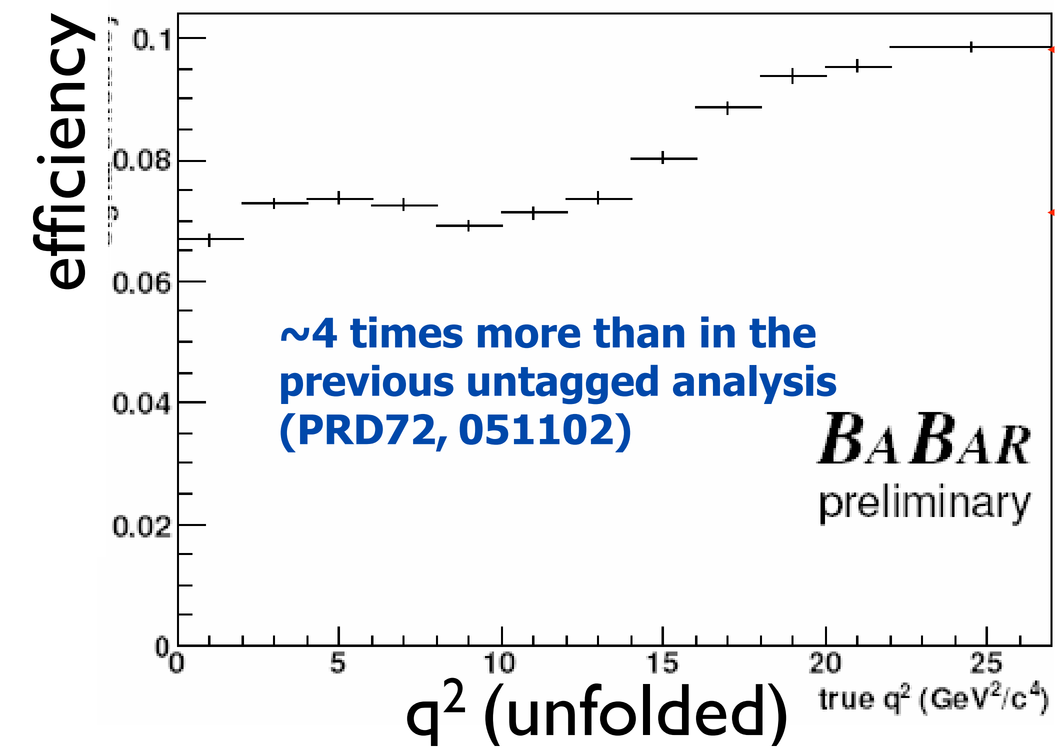




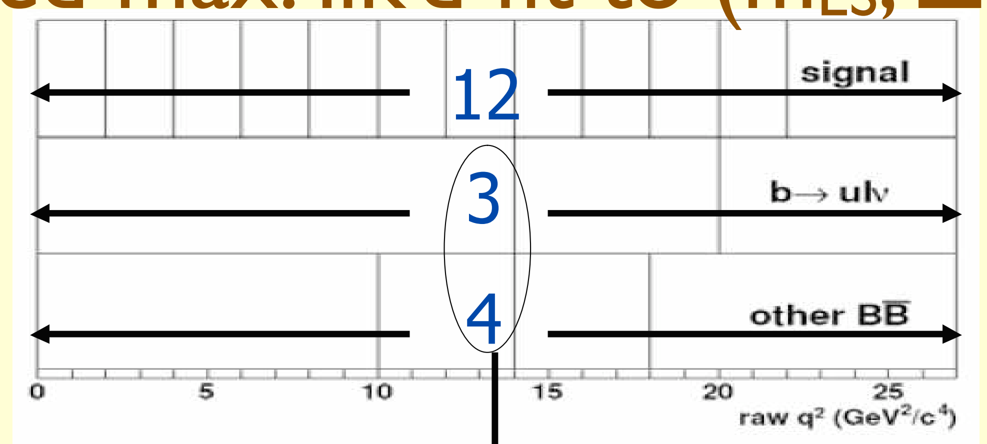
Mode	$\lvert V_{ub}\rvert(\times 10^{-3})$
$\pi^-\ell^+\nu$	$3.59 \pm 0.51 \pm 0.$ **FNAL**
$\pi^0\ell^+\nu$	$3.63 \pm 0.70 \pm 0.20^{+0.63}_{-0.41}$
$\pi^-\ell^+\nu + \pi^0\ell^+\nu$	$3.60 \pm 0.41 \pm 0.20^{+0.62}_{-0.41}$
$\pi^-\ell^+\nu$	$4.02 \pm 0.57 \pm$ **HPQCD**
$\pi^0\ell^+\nu$	$4.06 \pm 0.78 \pm 0.22^{+0.60}_{-0.41}$
$\pi^-\ell^+\nu + \pi^0\ell^+\nu$	$4.03 \pm 0.46 \pm 0.22^{+0.59}_{-0.41}$

Measurement of the $B^0 \to \pi^- \ell^+ \nu$ Form-Factor Shape and Branching Fraction, and Determination of $|V_{ub}|$ with a Loose Neutrino Reconstruction Technique

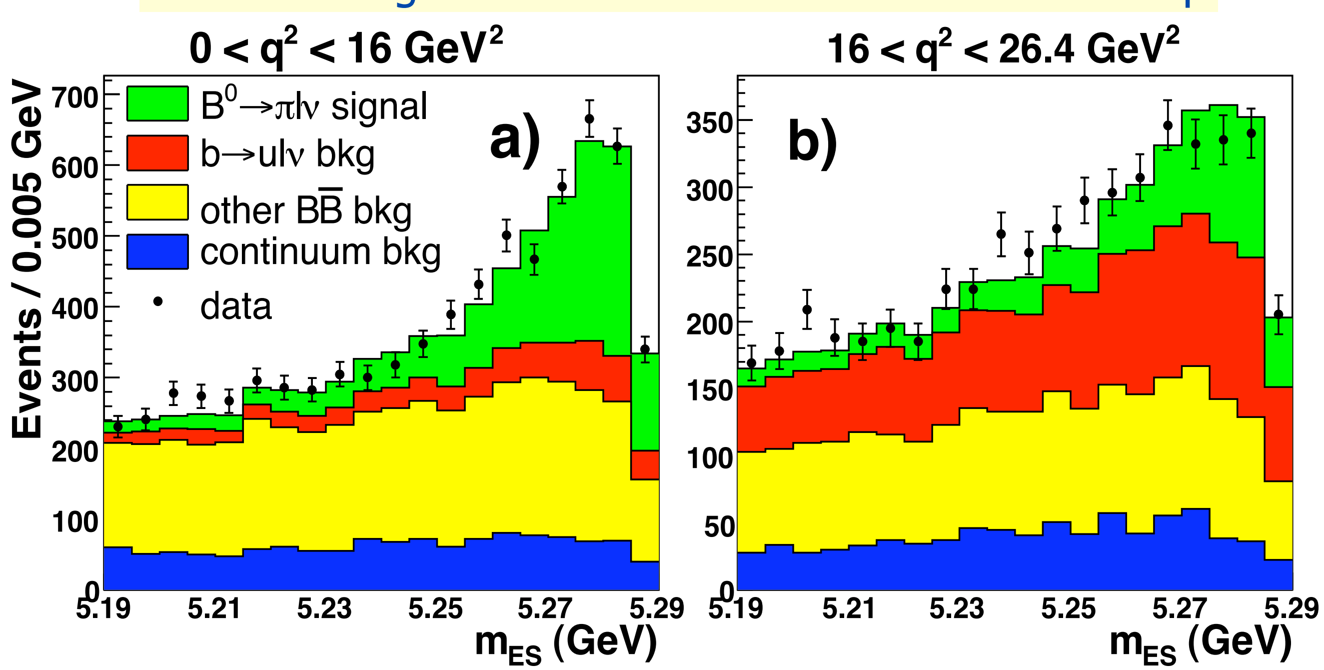
- loose requirement on $\pi^- \ell^+$
- cuts optimized as a ftn. of q^2
- eff. up by ~4 times

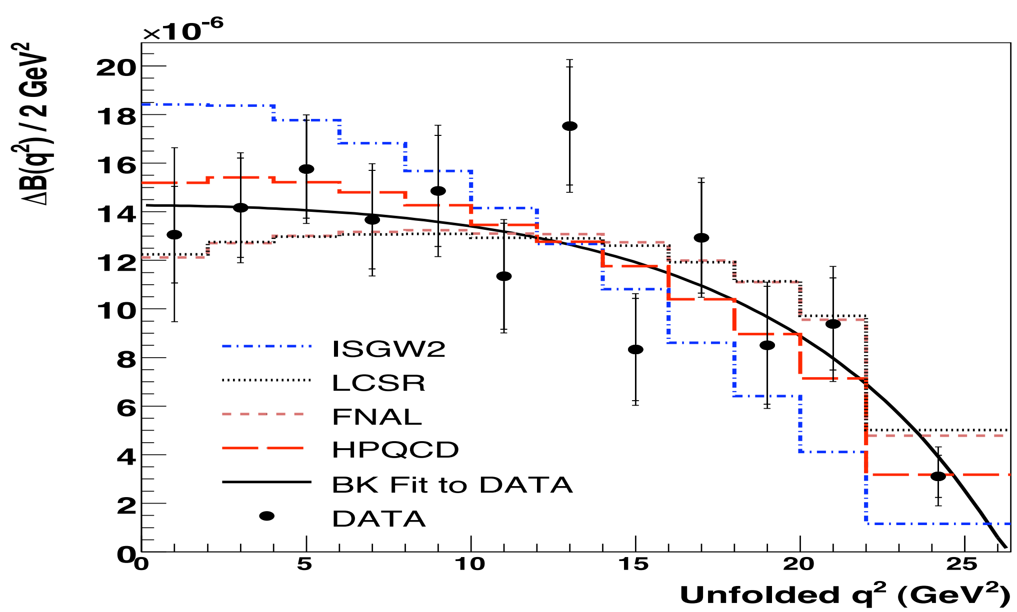


binned max. lik'd fit to $(m_{ES}, \Delta E, q^2)$



Fit the background normalization as a function of q^2



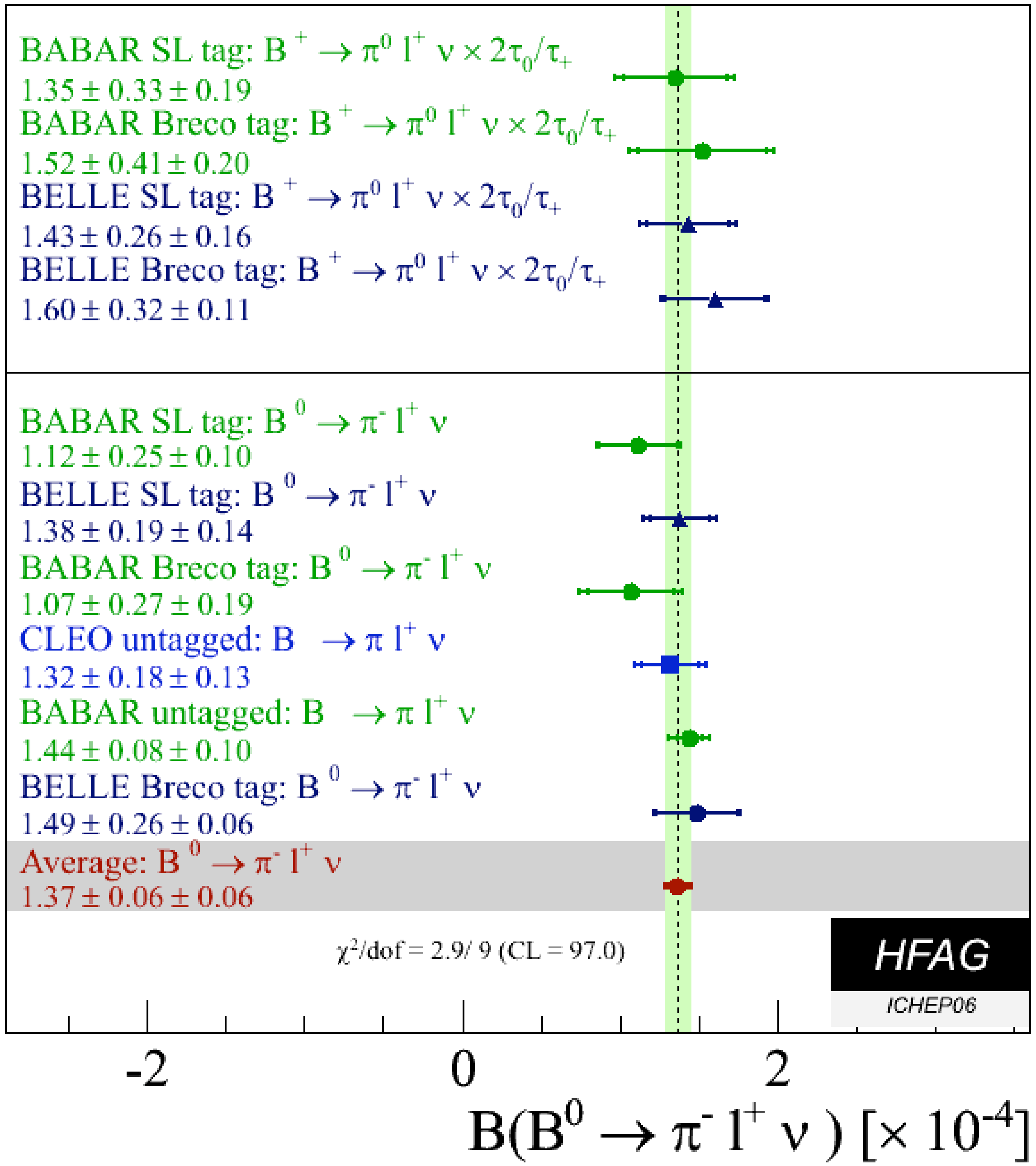


$$|V_{ub}| = \left(4.1 \pm 0.2 \pm 0.2^{+0.6}_{-0.4}\right) \times 10^{-3}$$

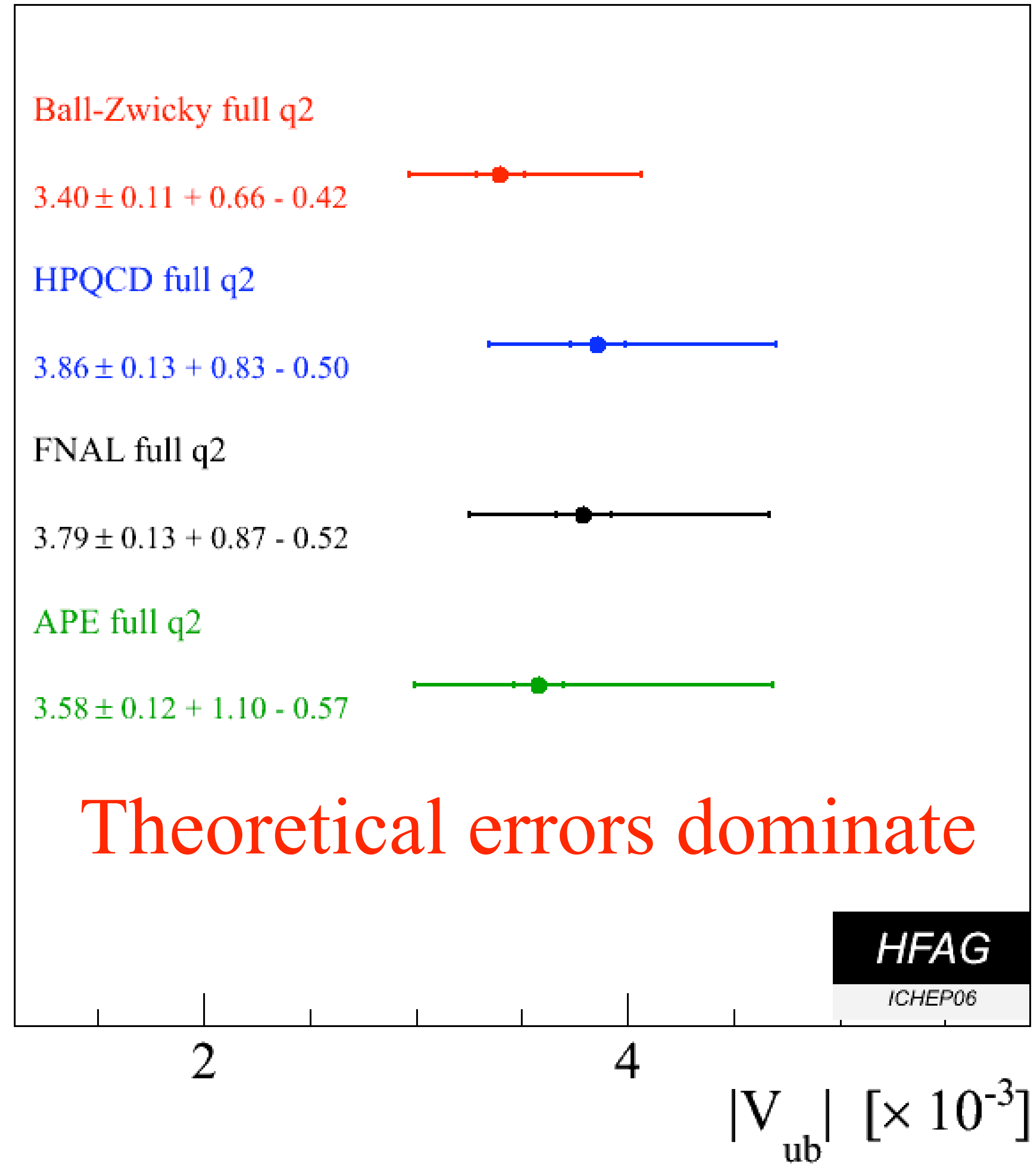
on $q^2 > 16$; by HPQCD

V_{ub} exclusive summary

Measured branching fractions (all 2006)

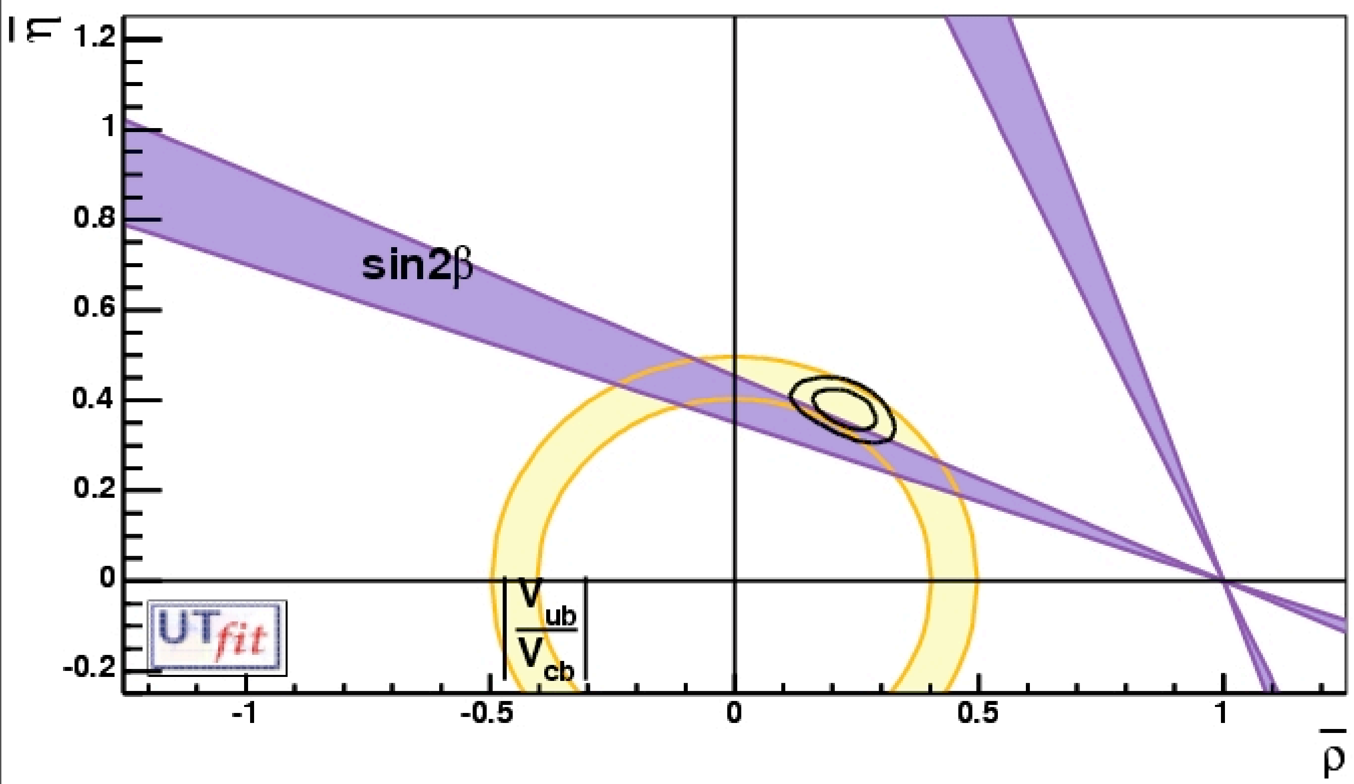


Using theoretical form factors



Experiments starting to measure form factor shape from data; allows elimination of some theory models

V_{ub} vs. $\sin 2\phi_1$

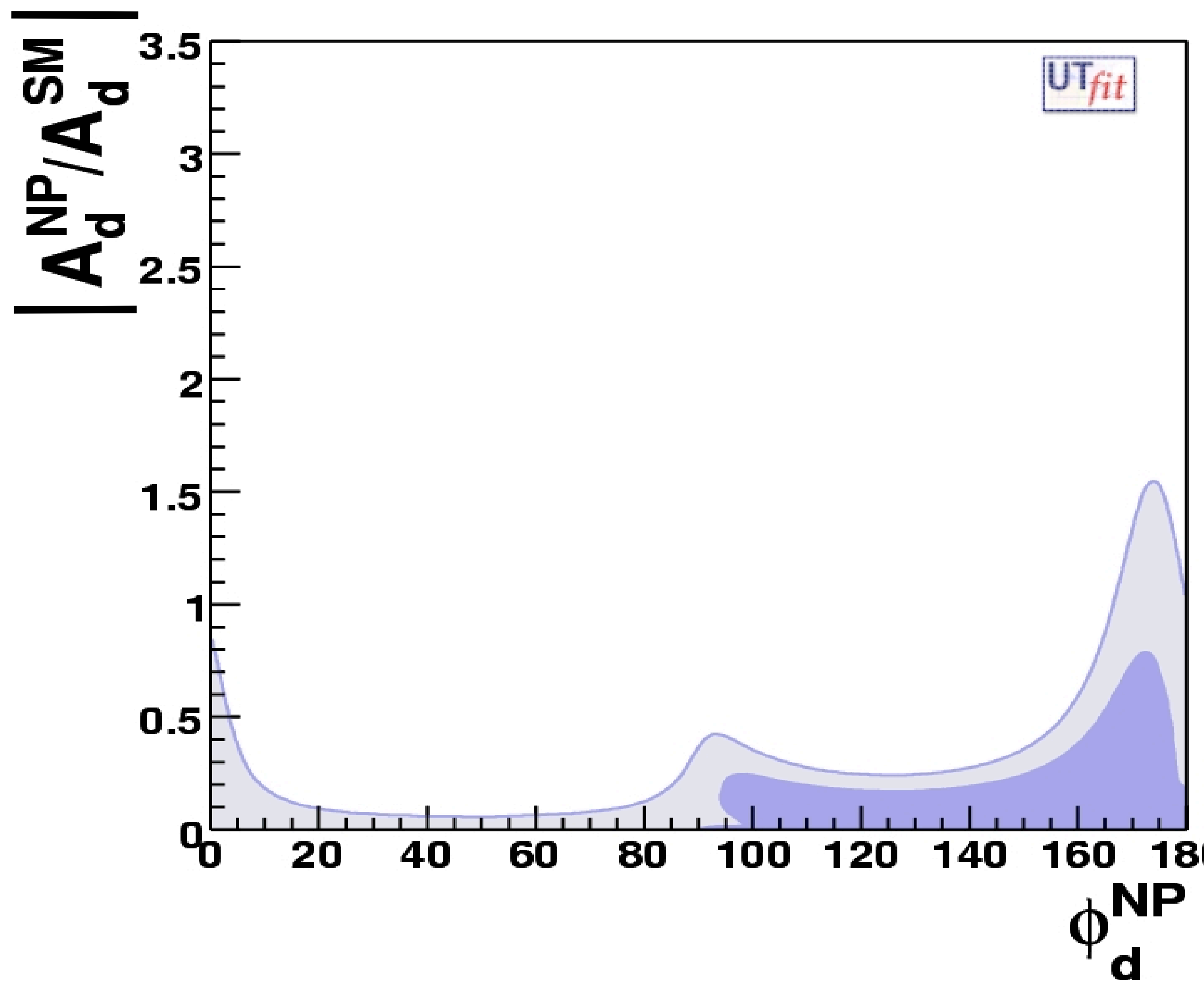


Direct: $\sin 2\phi_1 = 0.67 \pm 0.03$

Indirect: $\sin 2\phi_1 = 0.76 \pm 0.04$

Difference: $= 0.09 \pm 0.05$

Not statistically significant, but…



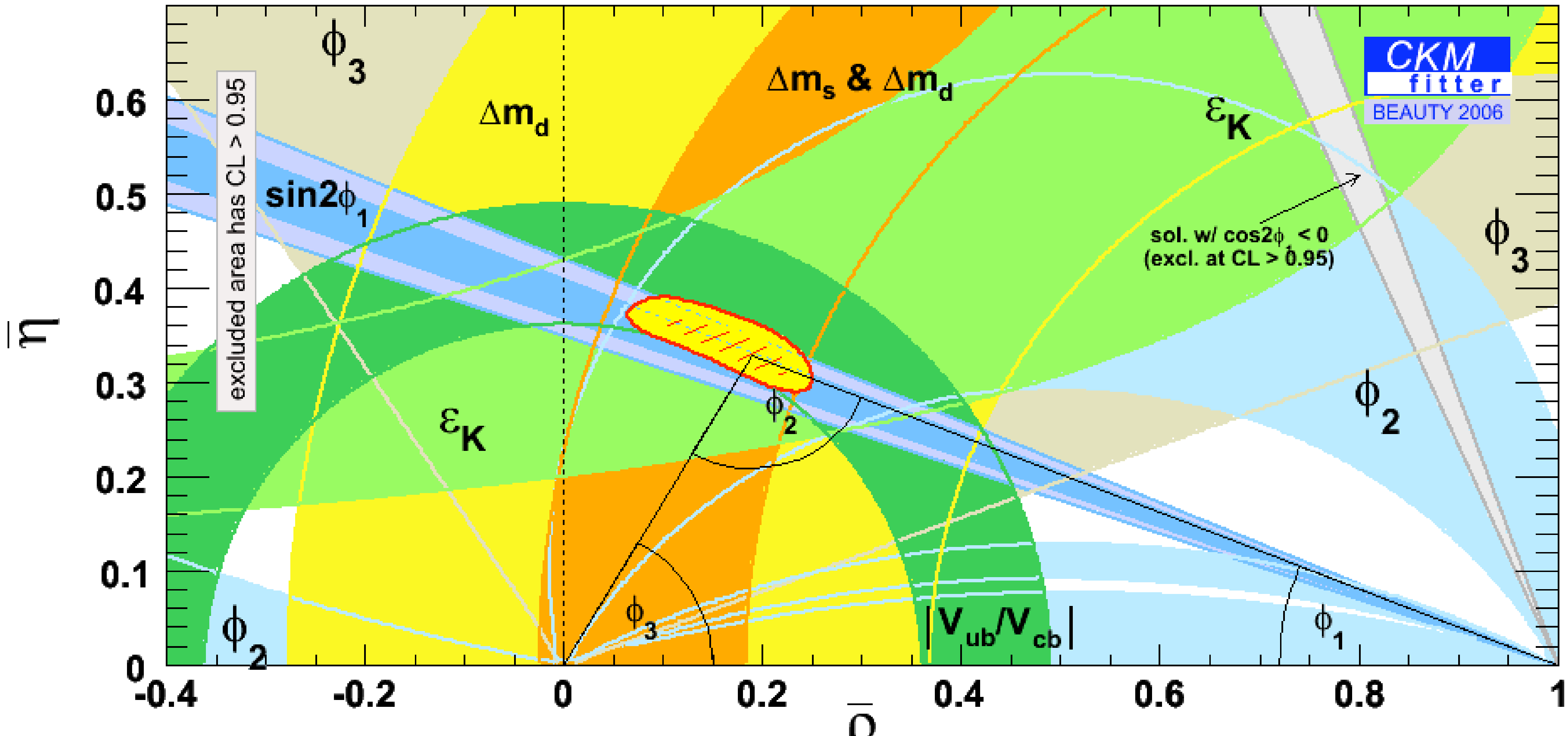
Model independent NP in B mixing

Add new amplitude to SM

$$A_d = A_d^{SM}\left[1 + \left|A_d^{NP}/A_d^{SM}\right| e^{i2\phi_d^{NP}}\right]$$

$\rightarrow$ modifies ϕ_1 to $\phi_1 + \phi_d^{NP}$

Summary



Good overall agreement. O(1) new physics unlikely.

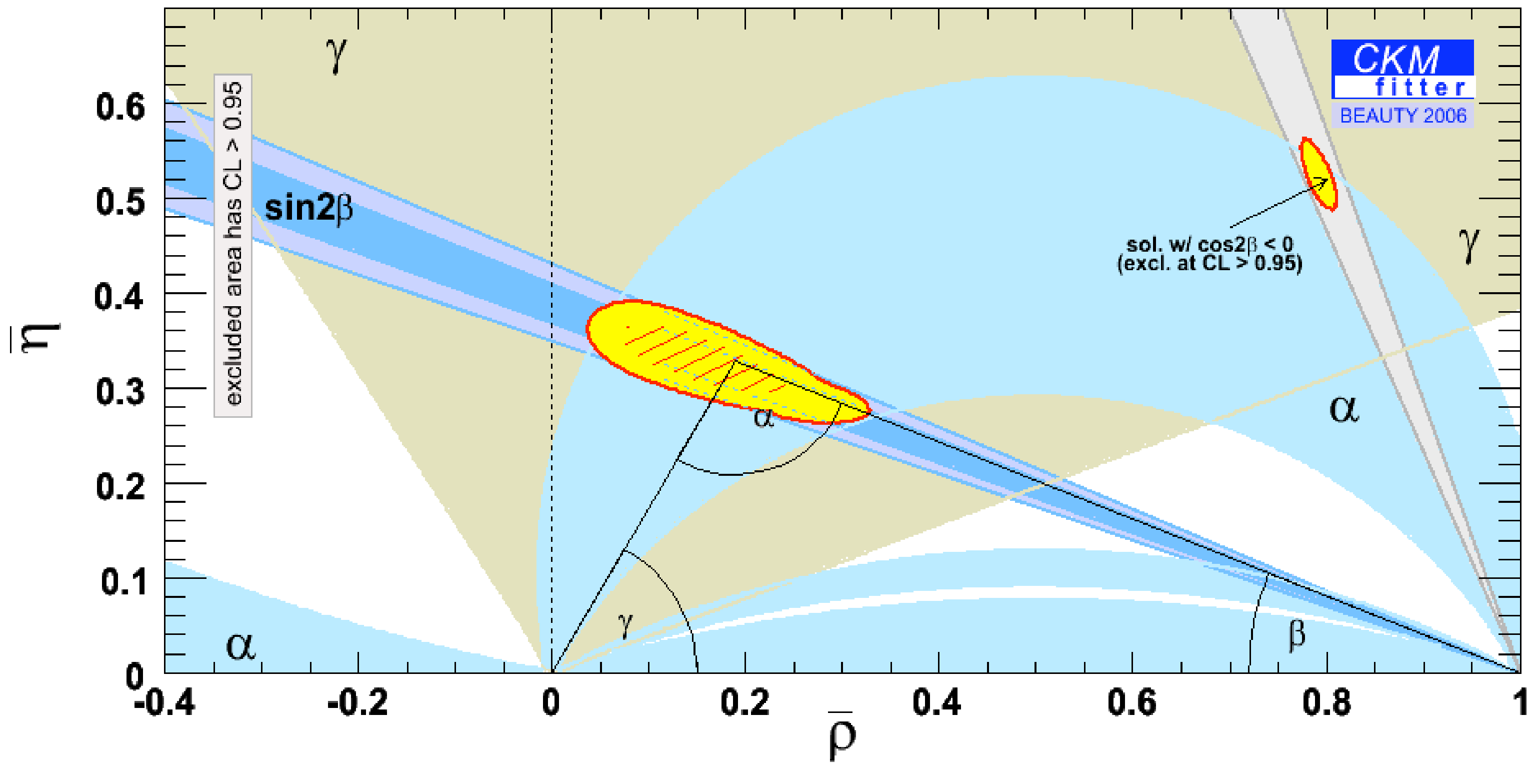
If $\exists$ (new physics @ TeV), deviation might be ~$[(M_{top}/M_{NP})^2, (M_{top}/M_{NP})]$,

Prospects

- e^+e^- B-factories are only half-way
  - each aiming at $\sim 1\mathrm{ab}^{-1}$
- Many measurements are statistics-limited
  - $\sin 2\phi_1$: $b \to c\bar{c}s$ vs. $b \to s\bar{s}s$
  - CKM test: all-angles vs. all-sides
- V_{ub} is largely theory-limited; *but*
  - HQE parameters can be better determined experimentally by measuring moments of $B \to X_c \ell \nu$, $B \to X_s \gamma$
- More data also brings new decay modes & improved analysis
  - resulting in better than $1/\sqrt{N}$
- LHC, Super-B, ...

All-angles vs. All-sides

Angles



Sides