B Factories: Status and Prospects

CKM: Cabibbo-Kobayashi-Maskawa
CPV: CP Violation

Masashi Hazumi
(KEK)

March 28, 2007
Flavor in the era of the LHC
CERN

It seems all the important results from B factories have already been shown and discussed at this workshop in the last two days. What should I talk about ?

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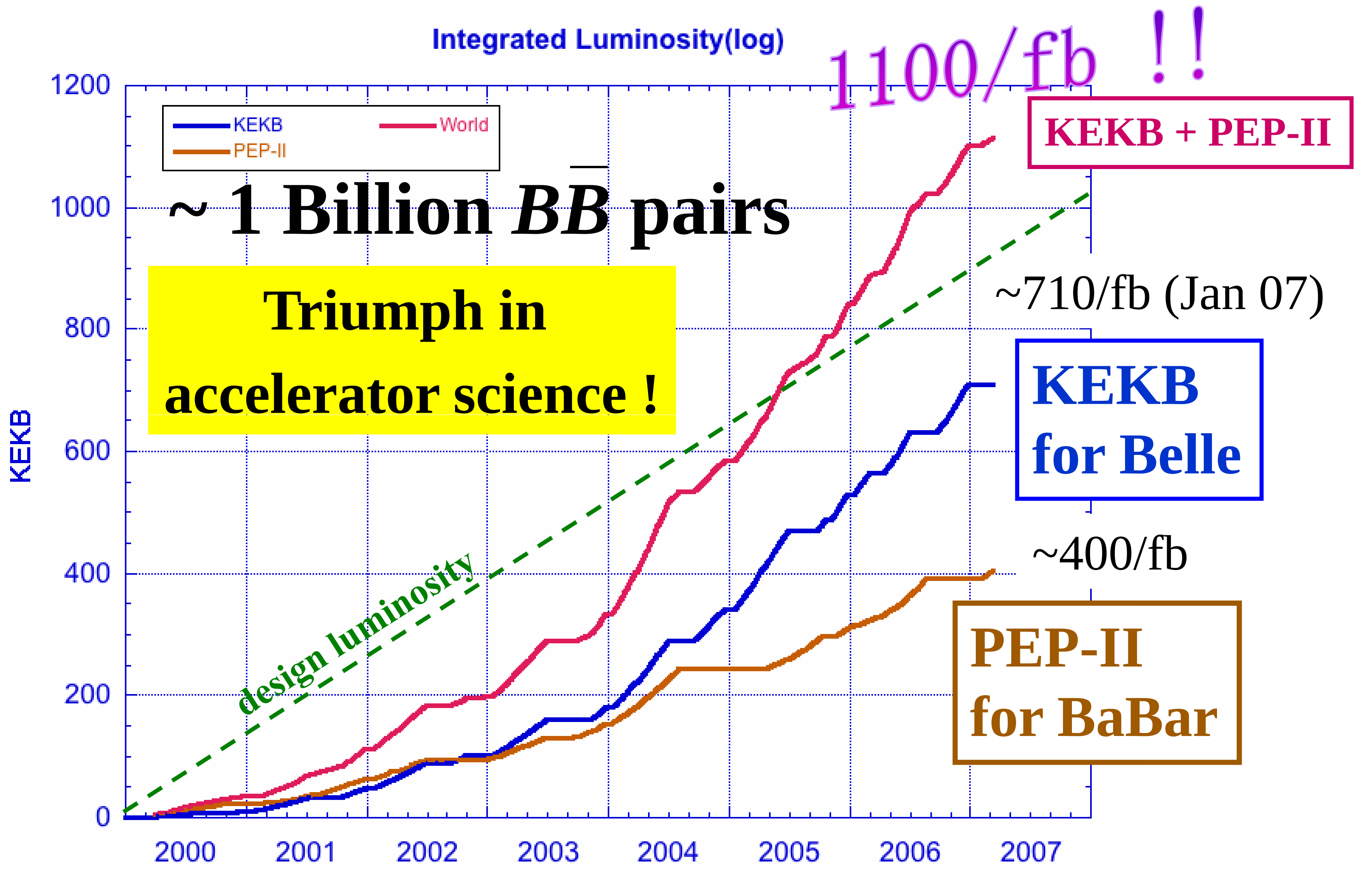
Outline

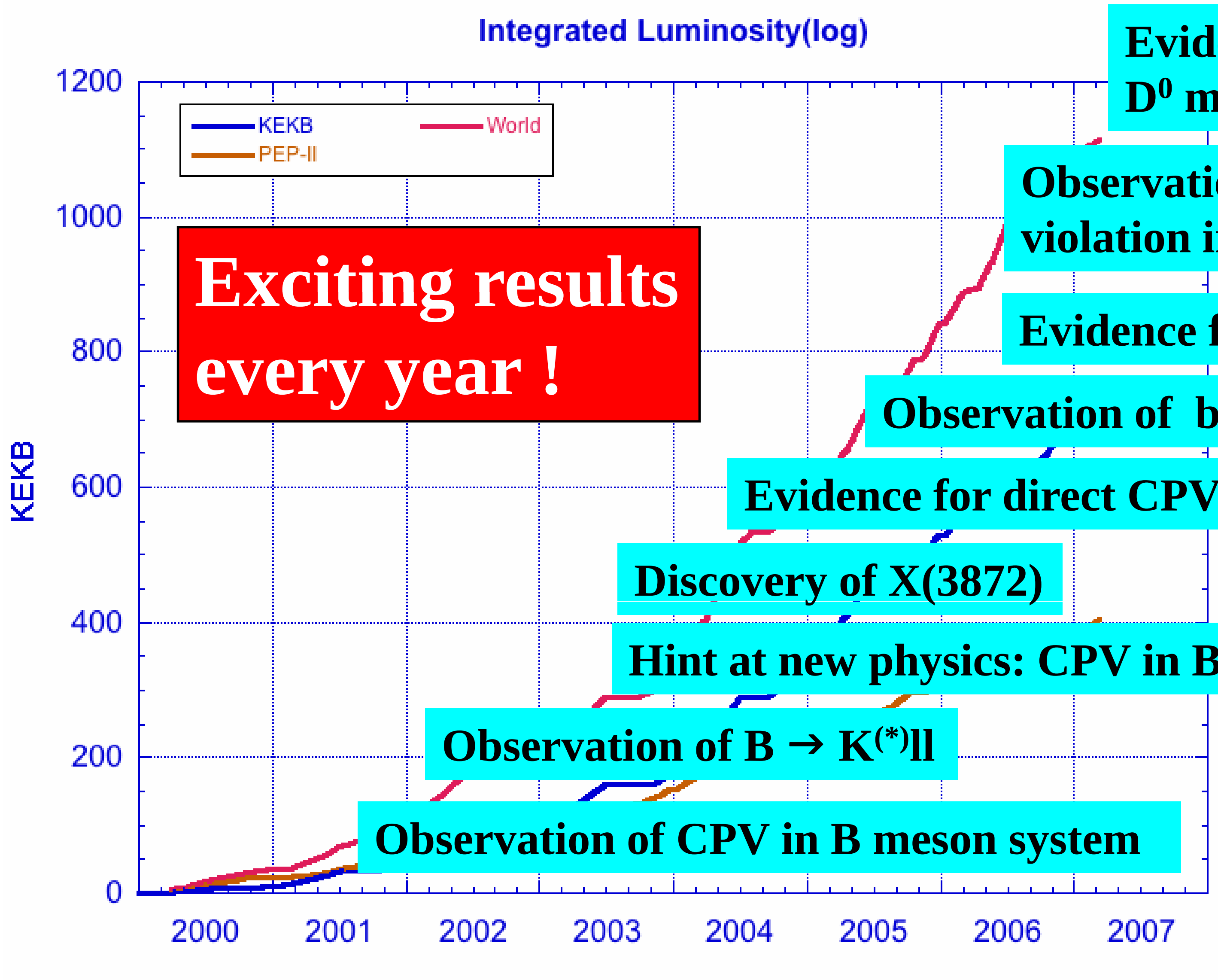
- **Introduction**
- **CPV and CKM**
- **New physics searches**
- **Future prospects**

All introductory slides are put in the backup part.

Integrated luminosity



Achievements at B factories

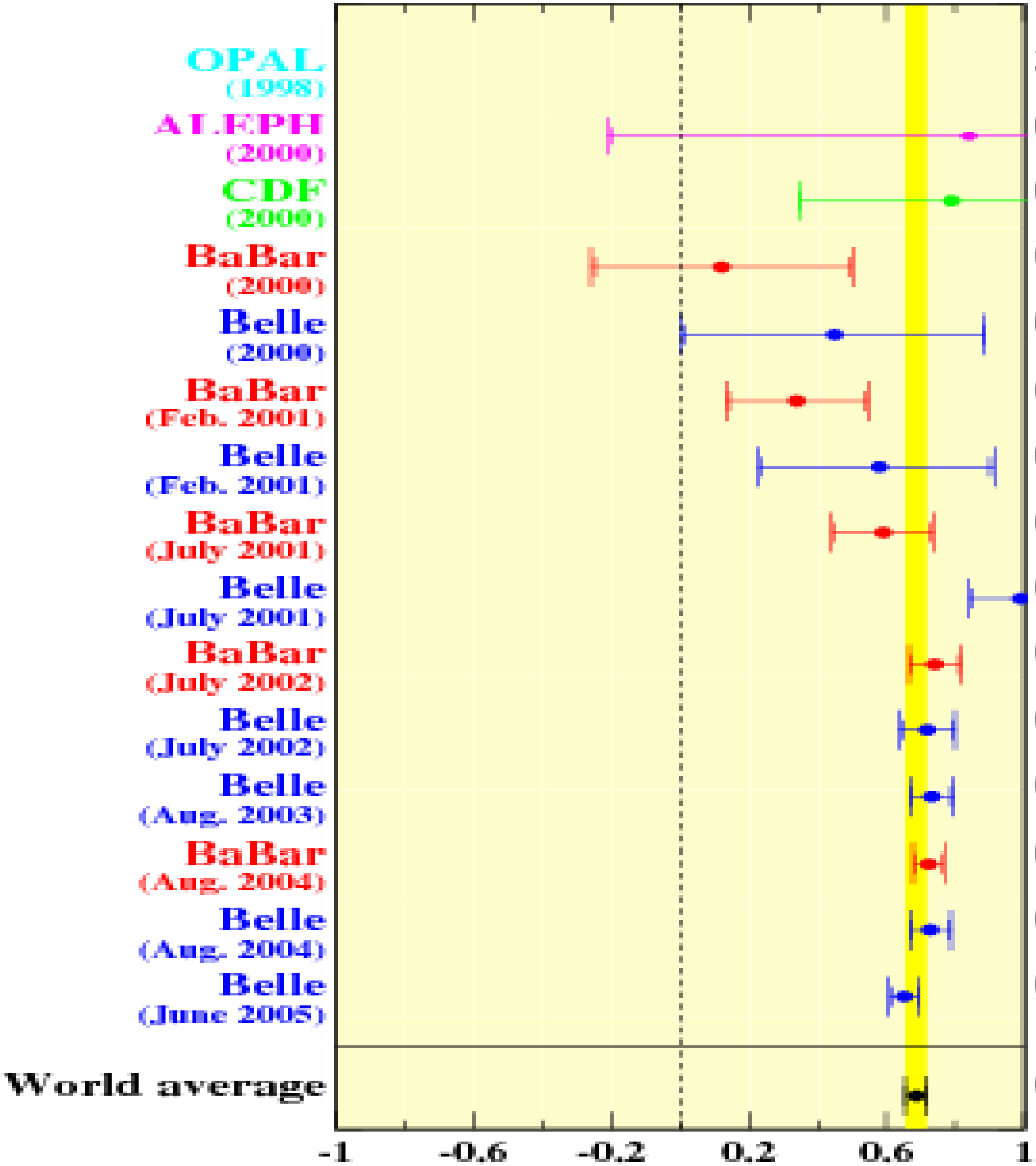


Exciting results every year !

- Evidence for D^0 mixing
- Observation of direct CP violation in $B \to \pi^+\pi^-$
- Evidence for $B \to \tau\nu$
- Observation of $b \to d\gamma$
- Evidence for direct CPV in $B \to K^+\pi^-$
- Discovery of X(3872)
- Hint at new physics: CPV in $B \to \phi K_s$
- Observation of $B \to K^{(*)}ll$
- Observation of CPV in B meson system

CPV and CKM

sin2β history (1998-2005)



OPAL (1998)	$3.20^{+1.8}_{-2.0} \pm 0.5$
ALEPH (2000)	$0.84^{+0.82}_{-1.04} \pm 0.16$
CDF (2000)	$0.79^{+0.41}_{-0.44}$
BaBar (2000)	$0.12 \pm 0.37 \pm 0.09$
Belle (2000)	$0.45^{+0.43}_{-0.44}{}^{+0.07}_{-0.09}$
BaBar (Feb. 2001)	$0.34 \pm 0.20 \pm 0.05$
Belle (Feb. 2001)	$0.58^{+0.32}_{-0.34}{}^{+0.09}_{-0.10}$
BaBar (July 2001)	$0.59 \pm 0.14 \pm 0.05$
Belle (July 2001)	$0.99 \pm 0.14 \pm 0.06$
BaBar (July 2002)	$0.741 \pm 0.067 \pm 0.033$
Belle (July 2002)	$0.719 \pm 0.074 \pm 0.035$
Belle (Aug. 2003)	$0.731 \pm 0.057 \pm 0.028$
BaBar (Aug. 2004)	$0.722 \pm 0.040 \pm 0.023$
Belle (Aug. 2004)	$0.728 \pm 0.056 \pm 0.023$
Belle (June 2005)	$0.652 \pm 0.039 \pm 0.020$
World average	0.687 ± 0.032

Discovery of CPV in the B meson system (2001) by BaBar and Belle

Mar. 2007

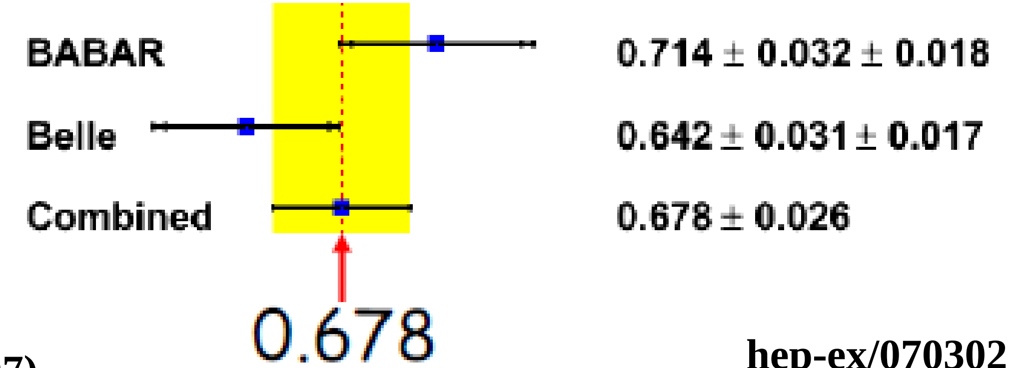
$\sin 2\phi_1 = 0.678 \pm 0.025$ (4% accuracy)

World avg.

(i.e. with OPAL, ALEPH,CDF)

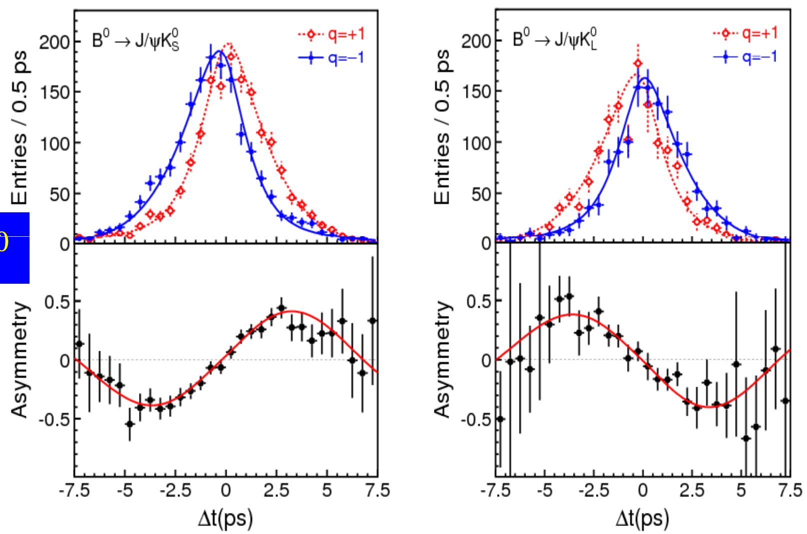
($\phi_1 = 21.3 \pm 1.0$ deg.)

Average with B factories only

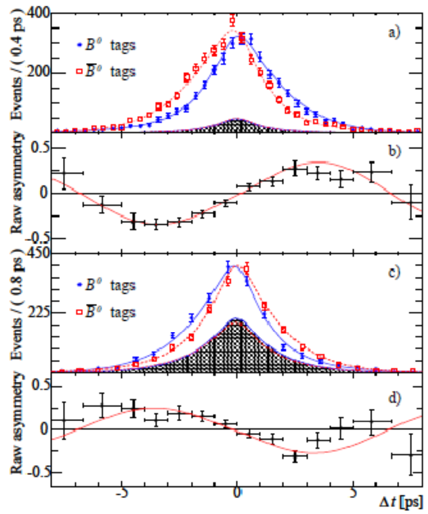


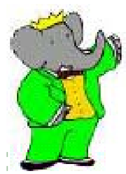
PRL 98, 031802 (2007)

$B^0 \to J/\psi K^0$



hep-ex/0703021



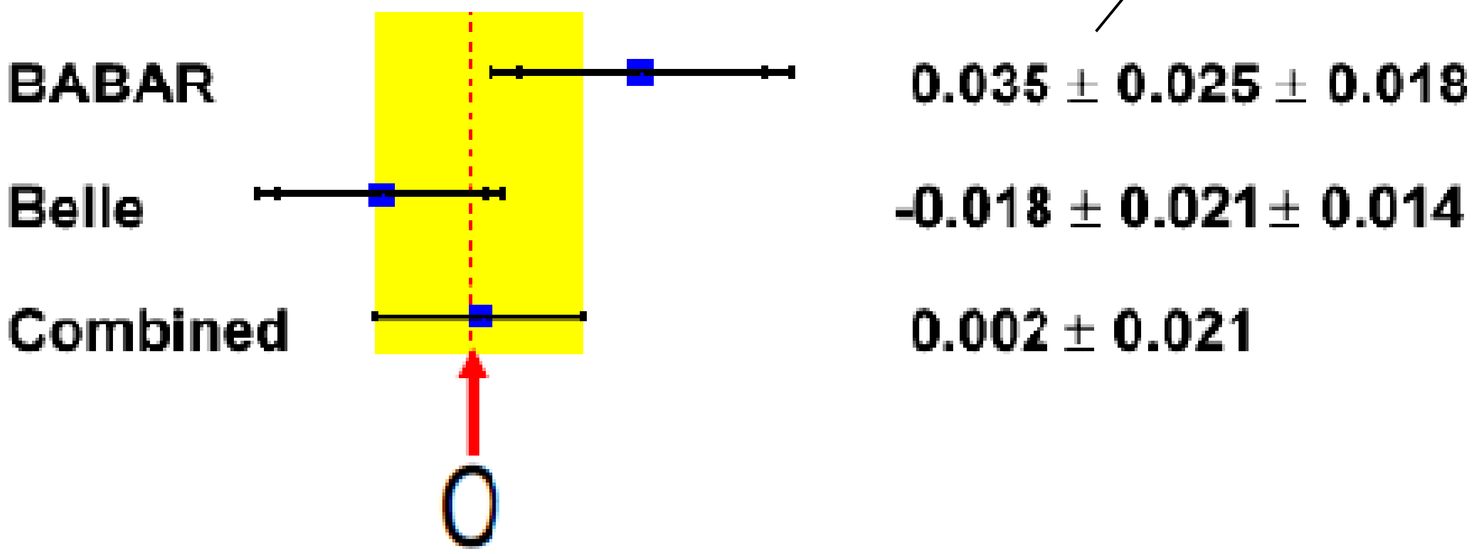


$B^0 \to J/\psi K^0$,
$\psi(2S) K_S$,
$\eta_c K_S$,
$\chi_{c1} K_S$,
$J/\psi K^{*0}$

Direct CPV in $B^0 \to J/\psi K^0$

$C = 0.049 \pm 0.022 \pm 0.017$ with all charmonium modes combined

$C(J/\psi K^0)$



Systematic uncertainties

	$\mathrm{Sin}2\phi_1$	$\mathcal{A}$
Vertexing	**0.012**	**0.009**
Flavor tagging	**0.004**	**0.003**
Δt Resolution	**0.006**	**0.001**
Physics parameters.	**0.001**	**0.001**
Possible fit bias	**0.007**	**0.004**
BG fractions ($J/\psi K_S$)	**0.003**	**0.001**
BG fractions ($J/\psi K_L$)	**0.005**	**0.002**
BG Δt	**0.001**	**0.001**
Tag-Side interference	**0.001**	**0.009**
total	0.017	0.014

Source/sample	Full	
Beamspot	0.005	sin2β
	0.002	C
Mistag differences	0.009	
	0.002	
Δt resolution	0.008	
	0.002	
$J/\psi K^0_L$ background	0.007	
	0.004	
Backgrounds	0.007	
	0.006	
m_{ES} parameterization	0.002	
	0.001	
$\Delta m_d, \tau_B, \Delta\Gamma_d/\Gamma_d$	0.003	
	0.001	
Tag-side interference	0.001	
	0.015	
Fit bias (MC statistics)	0.004	
	0.002	
Total systematic error	0.018	
	0.017	

Uncertainties from vertex reconstruction ~ 0.01
OK for present B factories, key for more precise measurements at Super B

b → s tCPV: One of the best new physics probes

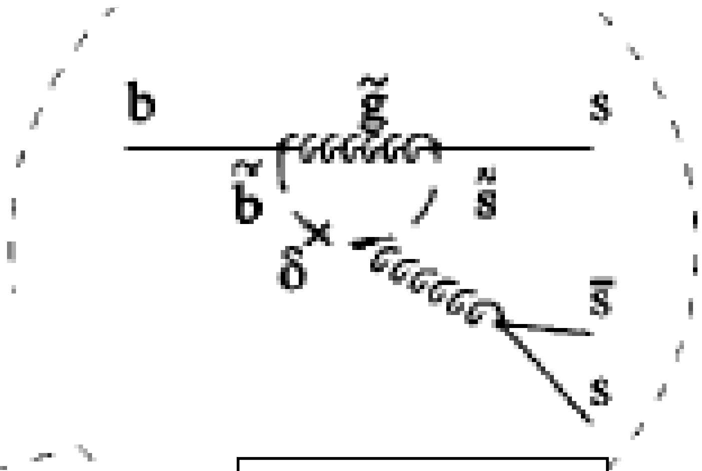
<u>Method</u>: Compare

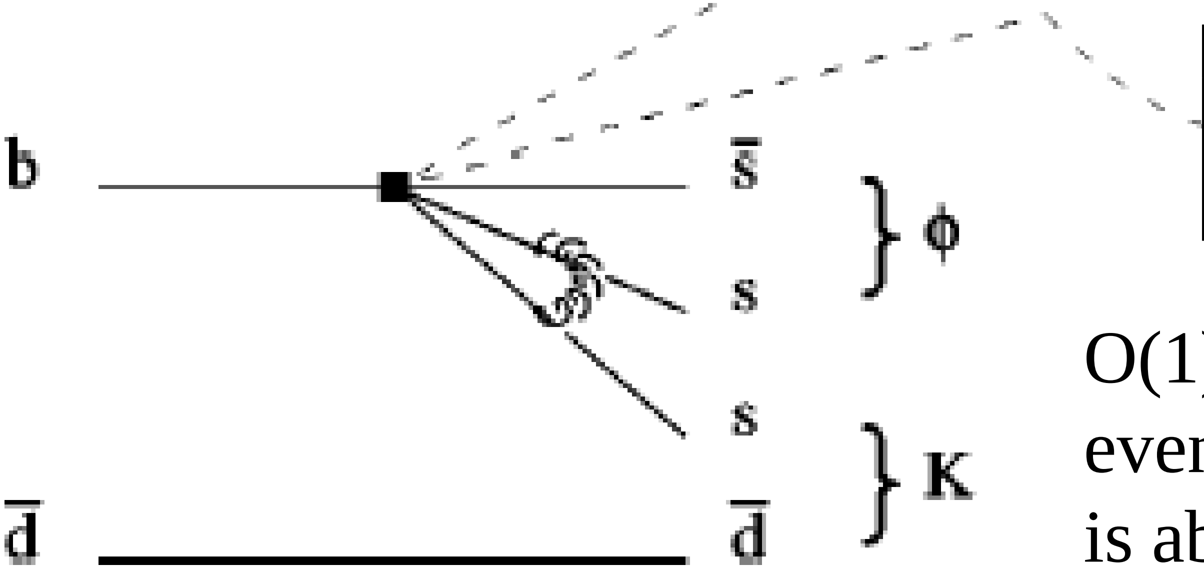
$S(\phi K^0)$ with $S(J/\psi K^0)$

SM prediction:

$$\Delta S \equiv S(\phi K^0) - S(J/\psi K^0) \cong 0$$

SUSY as an example

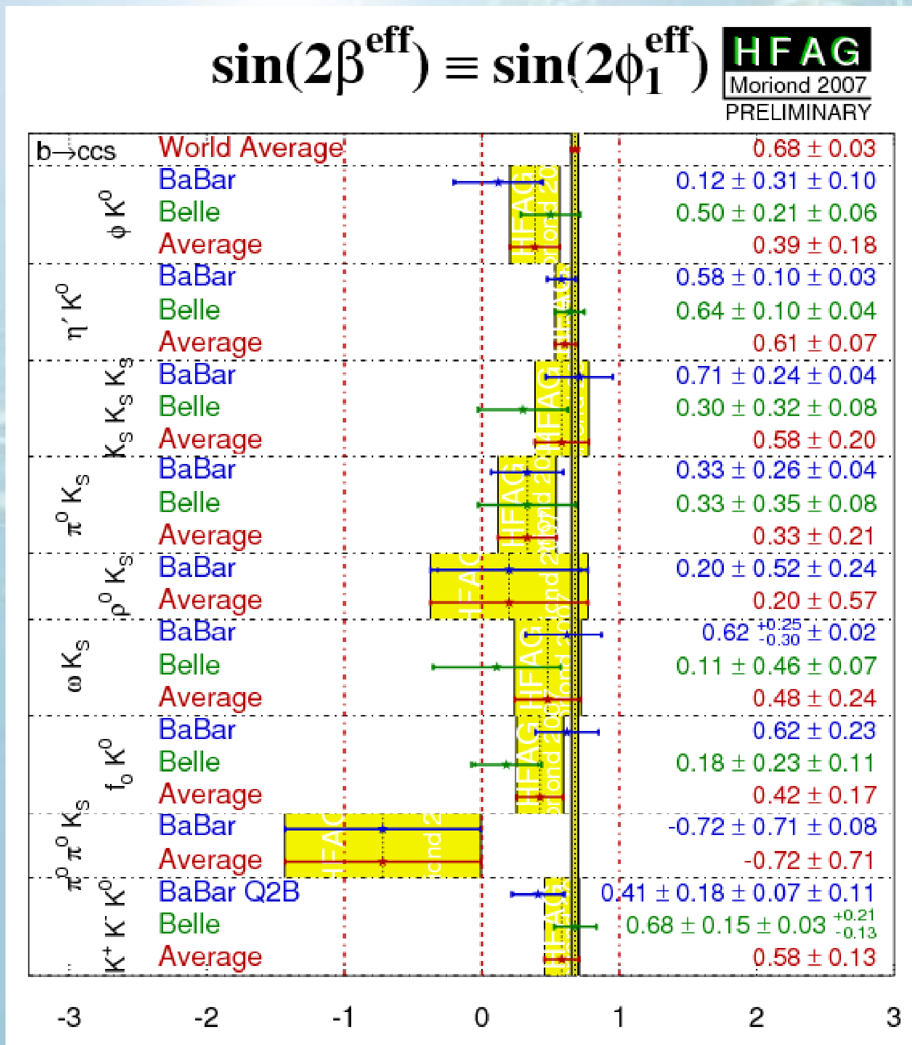




New
CP-violating
phase can enter

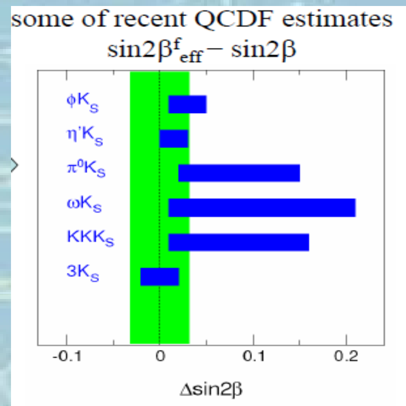
O(1) effect allowed even if SUSY scale is above 2TeV.

Mar. 2007: ϕ_1 with $b \to s$ Penguins



Smaller than b→c$\bar{c}$s in all of 9 modes

Theory tends to predict positive shifts (originating from phase in Vts)



Naïve average of all b → s modes

$\sin 2\beta^{eff} = 0.53 \pm 0.05$

2.6 σ deviation between penguin and tree

(b → s) (b → c)

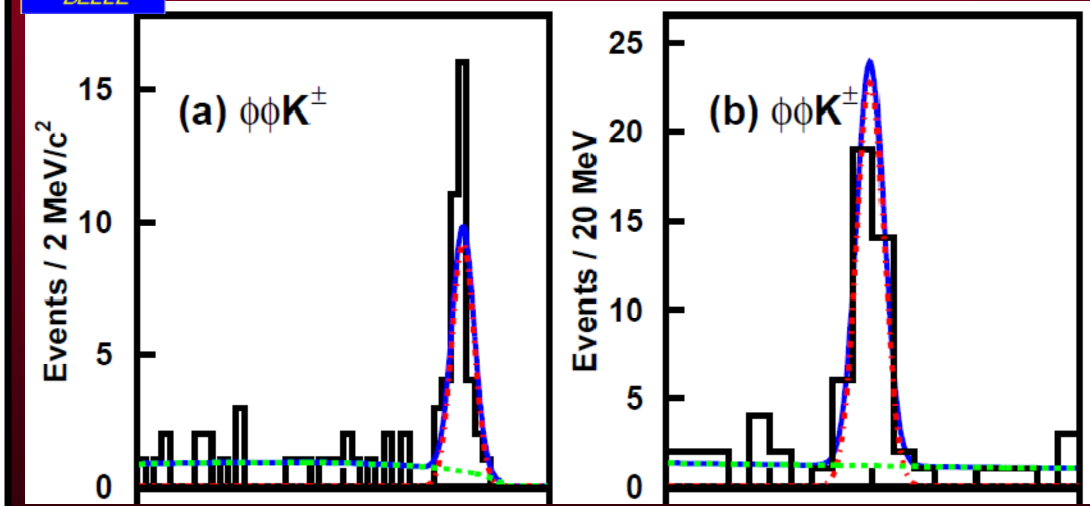
More statistics crucial for mode-by-mode studies

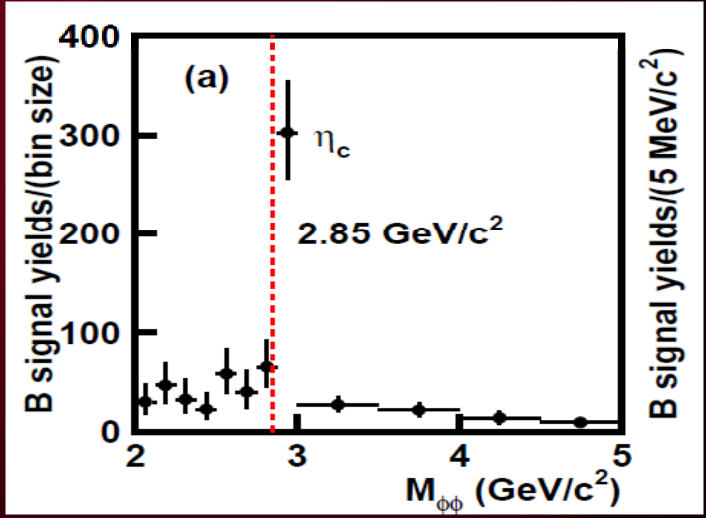
$B^{\pm} \to \phi\phi K^{\pm}$: ultra-clean mode

M. Hazumi, PLB583, 285 (2004)

- Interference between B → η_c(→ φφ)K and 3-body b → s process
- *CP* violation in the SM ~0, can be ~0.4 if new physics enters b → s
- Ultra-clean mode to reconstruct, almost no background

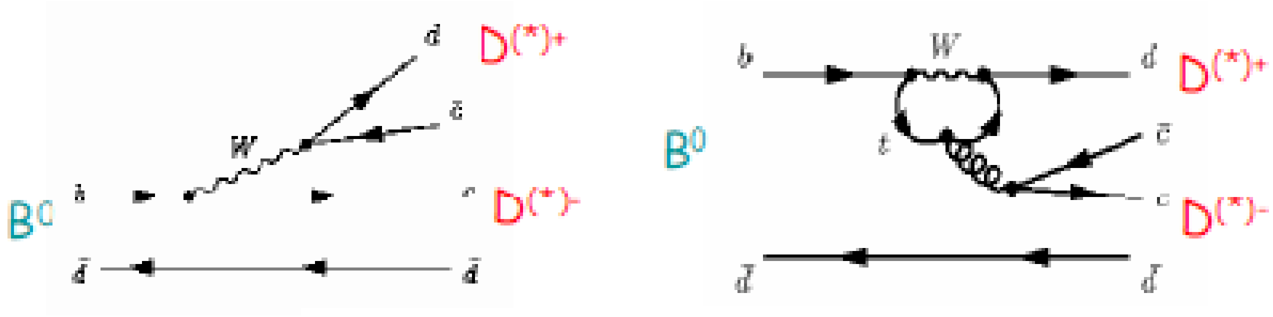
Belle observation (hep-ex/0609016)





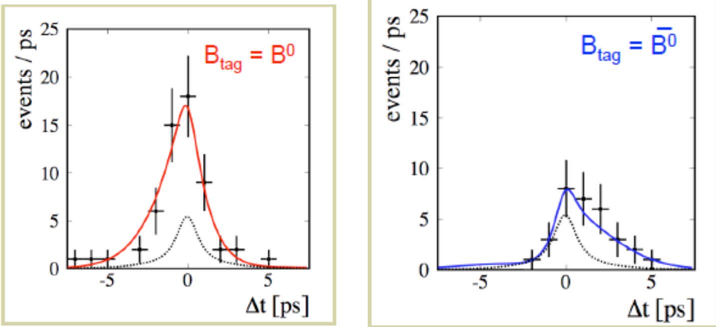
CP asymmetry in η_c region: $0.15^{+0.16}_{-0.17} \pm 0.02$

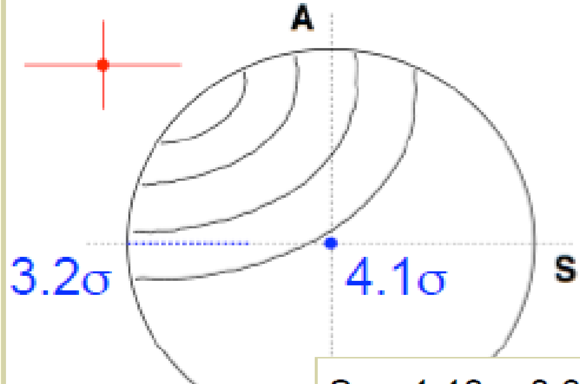
$b \rightarrow c\bar{c}d$



another place to study ϕ_1

hep-ex/0702031 **$B^0 \rightarrow D^+D^-$**

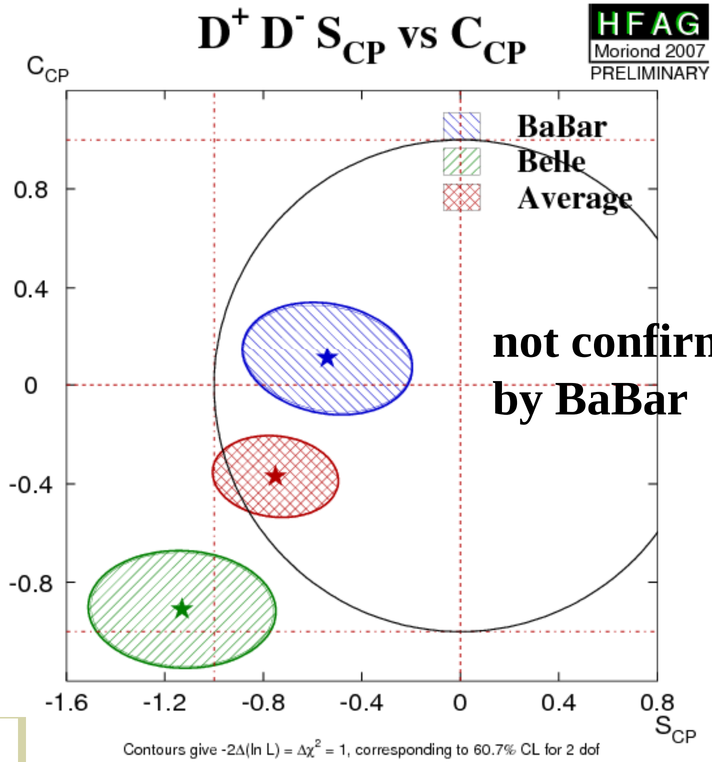




Evidence for large CPV from Belle

S = -1.13 ± 0.37 (stat) ± 0.09 (syst)

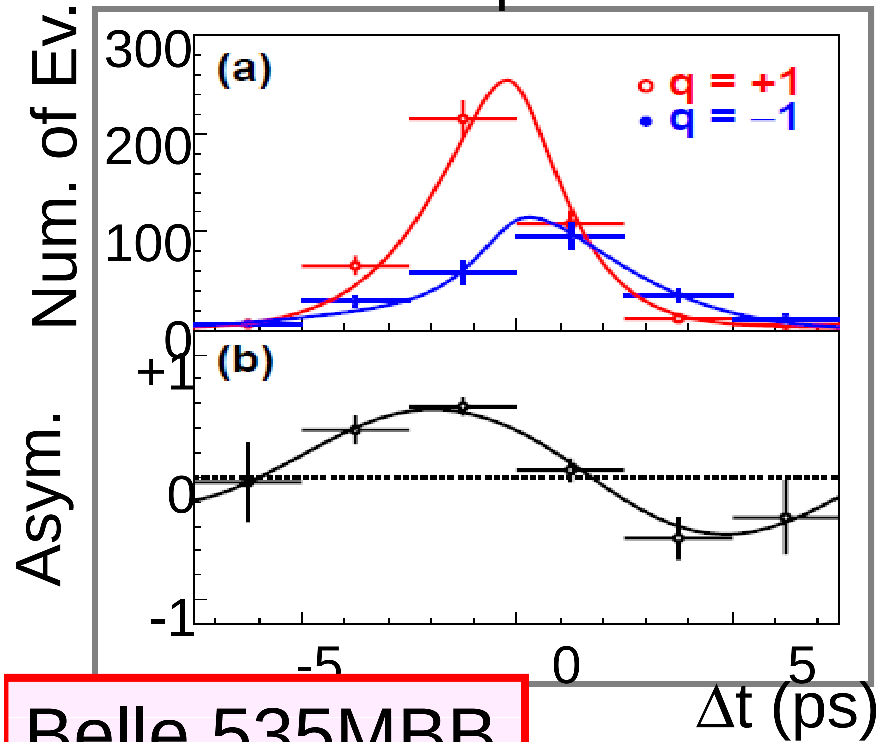
A = 0.91 ± 0.23 (stat) ± 0.06 (syst)

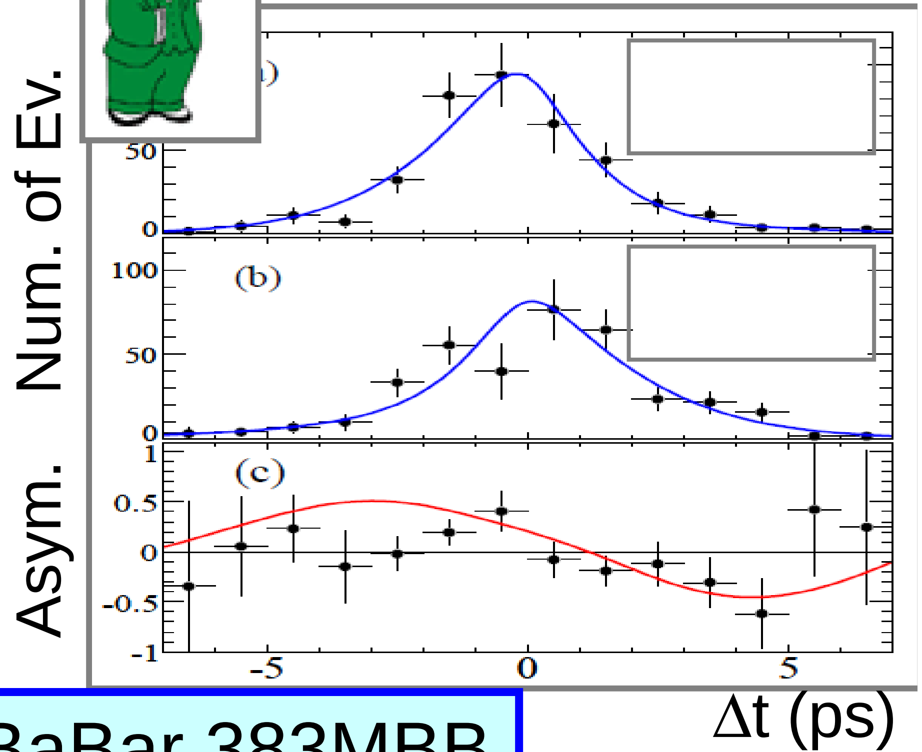


not confirmed by BaBar

→ Need more data

ϕ_2 (α): $B^0 \rightarrow \pi^+\pi^-$





Belle 535MBB

$\mathcal{A}_{\pi\pi} = +0.55 \pm 0.08 \pm 0.05$

$\mathcal{S}_{\pi\pi} = -0.61 \pm 0.10 \pm 0.04$

Direct CPV @ 5.5σ

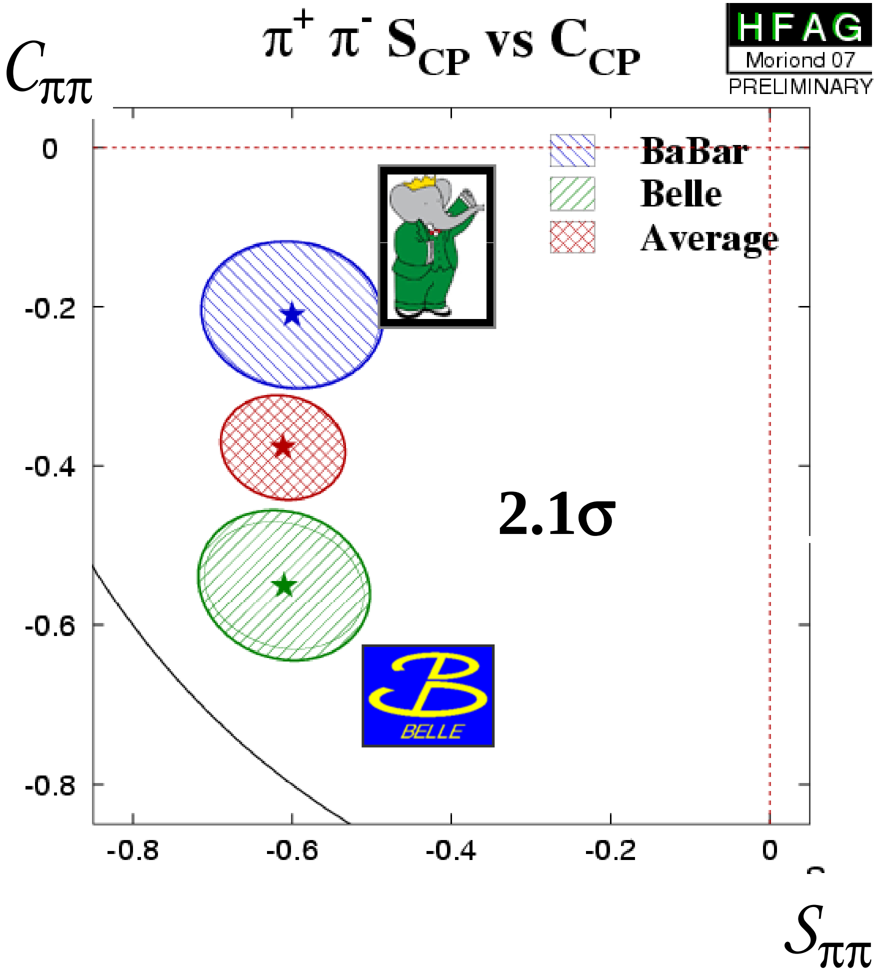
BaBar 383MBB

$\mathcal{C}_{\pi\pi} (-\mathcal{A}_{\pi\pi}) = -0.21 \pm 0.09 \pm 0.02$

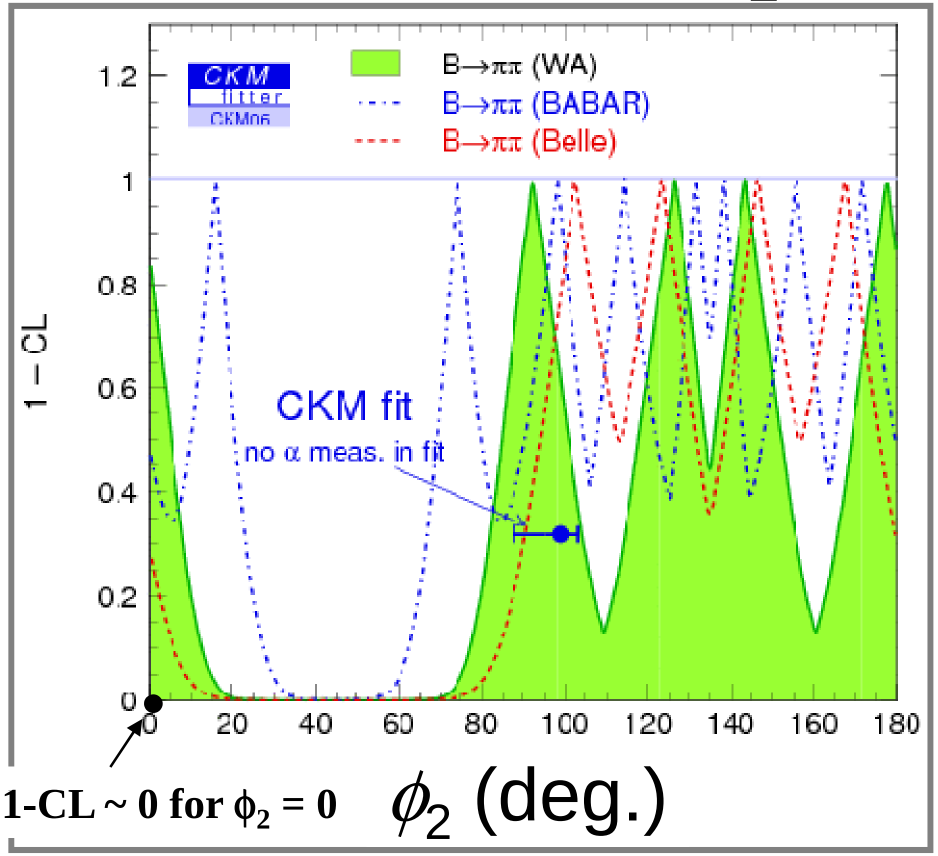
$\mathcal{S}_{\pi\pi} = -0.60 \pm 0.11 \pm 0.03$

CPV @ 5.5σ

ϕ_2 (α): $B^0 \rightarrow \pi\pi$



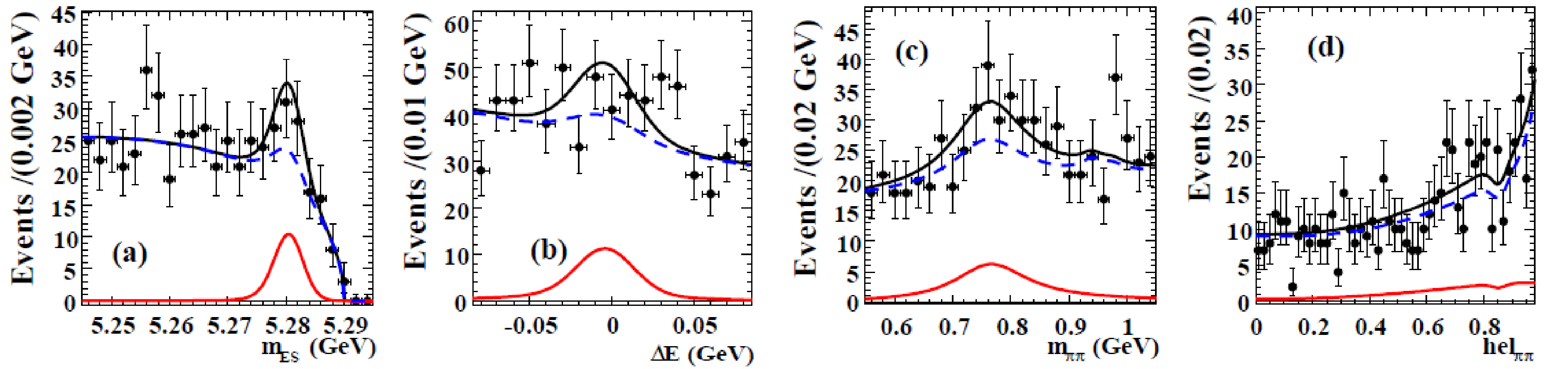
Constraint on ϕ_2



* 1-CL ~ 0 for $\phi_2 = 0$

$$\phi_2 = 92^{+12}_{-10}$$

$\phi_2\,(\alpha)$: $B^0 \rightarrow \rho^0 \rho^0$



BaBar 384MBB

hep-ex/0612021

$$\mathcal{B} = (1.07 \pm 0.33 \pm 0.19) \times 10^{-6}$$

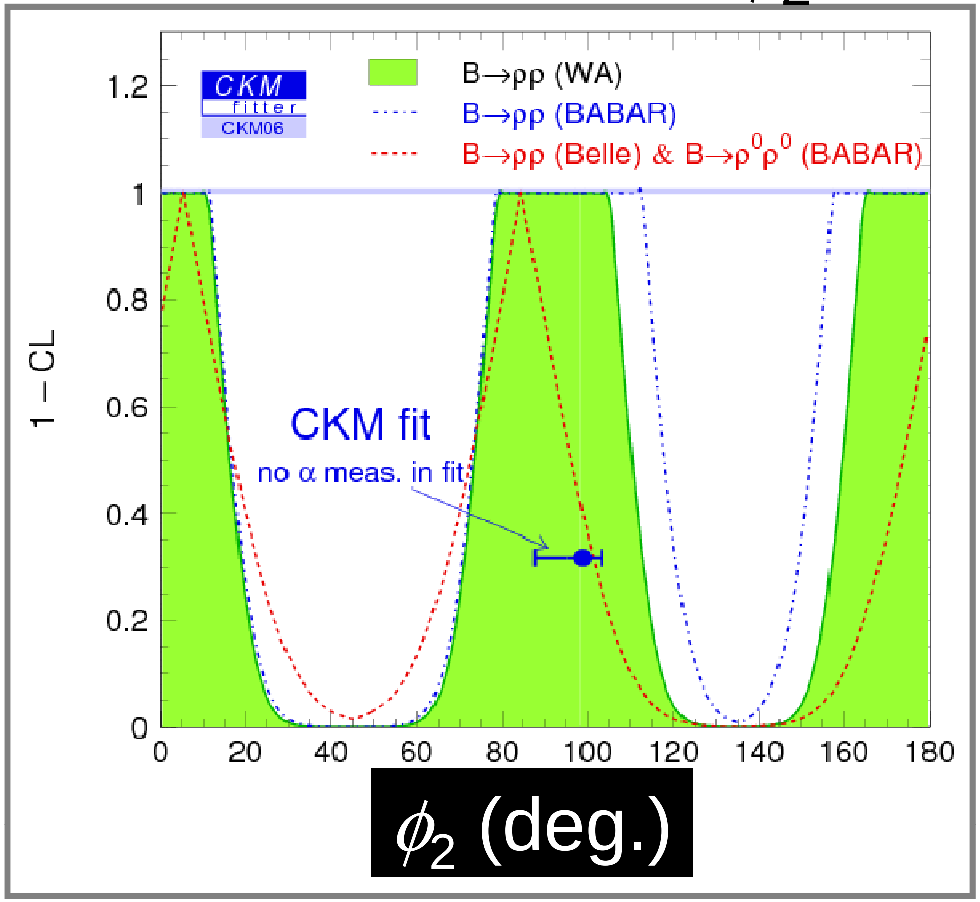
3.5σ

$$f_L = 0.87 \pm 0.13 \pm 0.04$$

ϕ_2 (α): $B^0 \rightarrow \rho\rho$

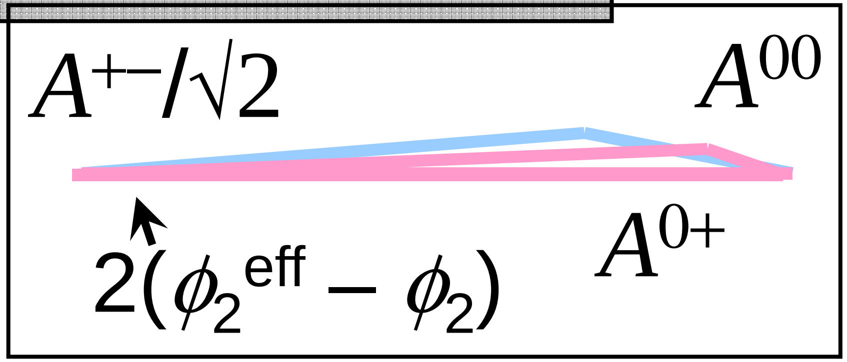
$B \rightarrow \rho\rho$ is
not the best mode anymore

Constraint on ϕ_2



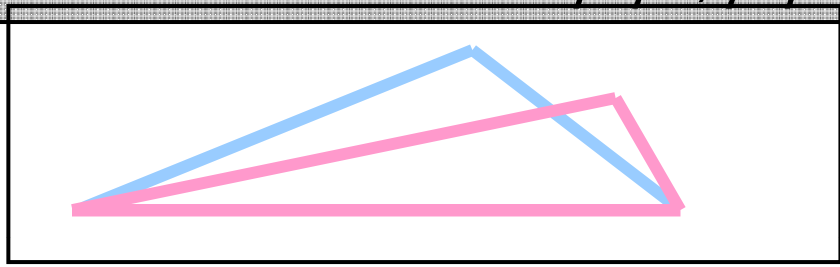
$\phi_2 = 92 \pm 21$ deg.

Before 2006 Summer



Triangles were squashed

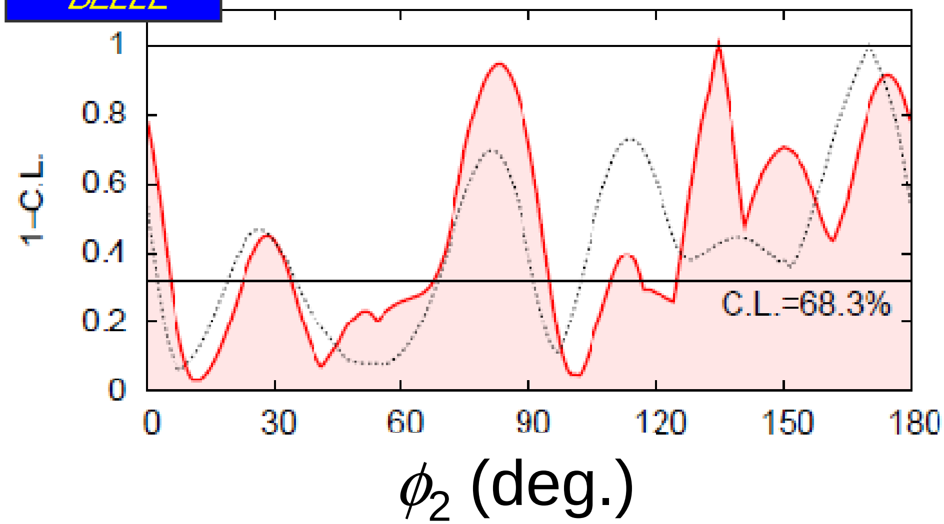
With New B.F. of $B \rightarrow \rho^0\rho^0$, $\rho^+\rho^0$



For further improvement,
we need A_{CP} of $B^0 \rightarrow \rho^0\rho^0$.

ϕ_2 (α): $B^0 \rightarrow (\rho\pi)^0$ Dalitz Analysis

hep-ex/0701015

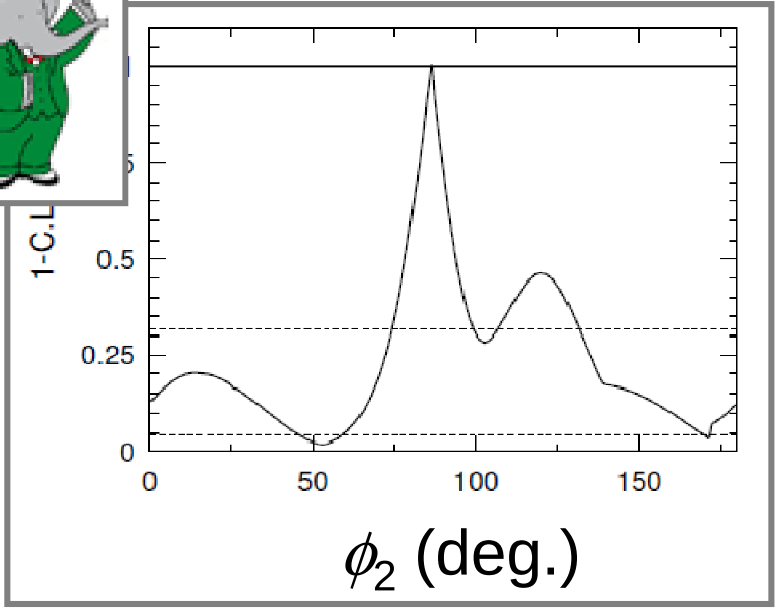


Dalitz + Pentagon Analysis

Belle 449MBB

$68° < \phi_2 < 95°$
with other
allowed regions

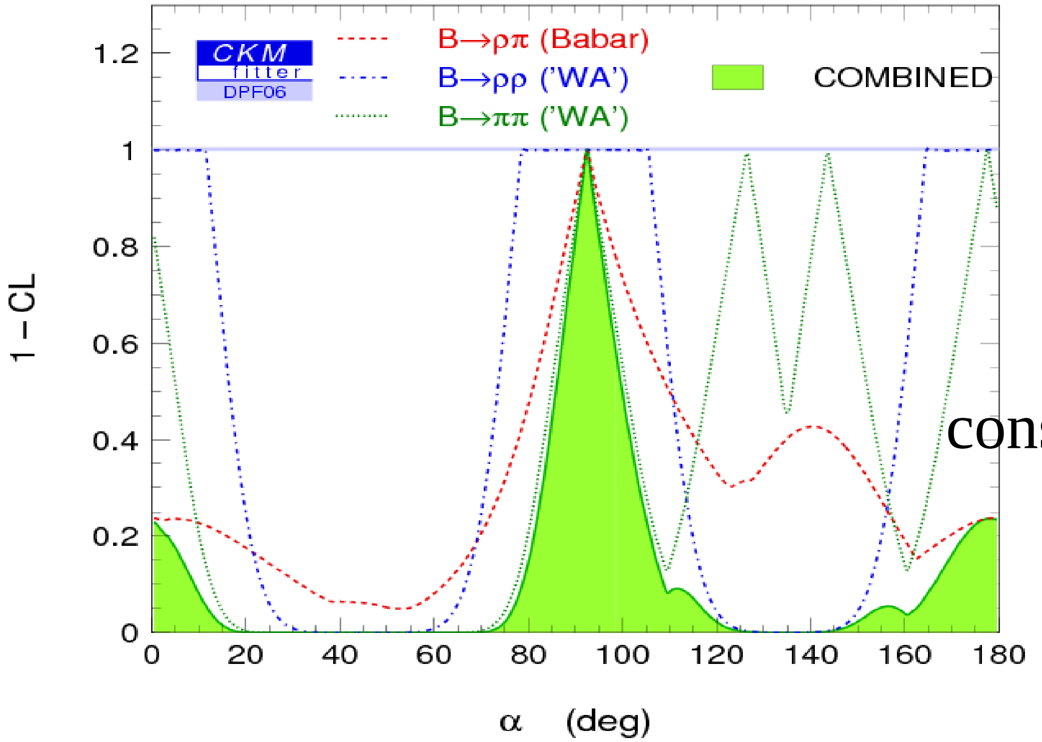
hep-ex/0703008



BaBar 375MBB

$$\phi_2 = (87\ ^{+45}_{-13})^\circ$$

DPF/JPS2006: BaBar(ππ/ρπ/ρρ) + Belle(ππ/ρρ)



$$\alpha/\phi_2 = [93^{+11}_{-9}]^\circ$$

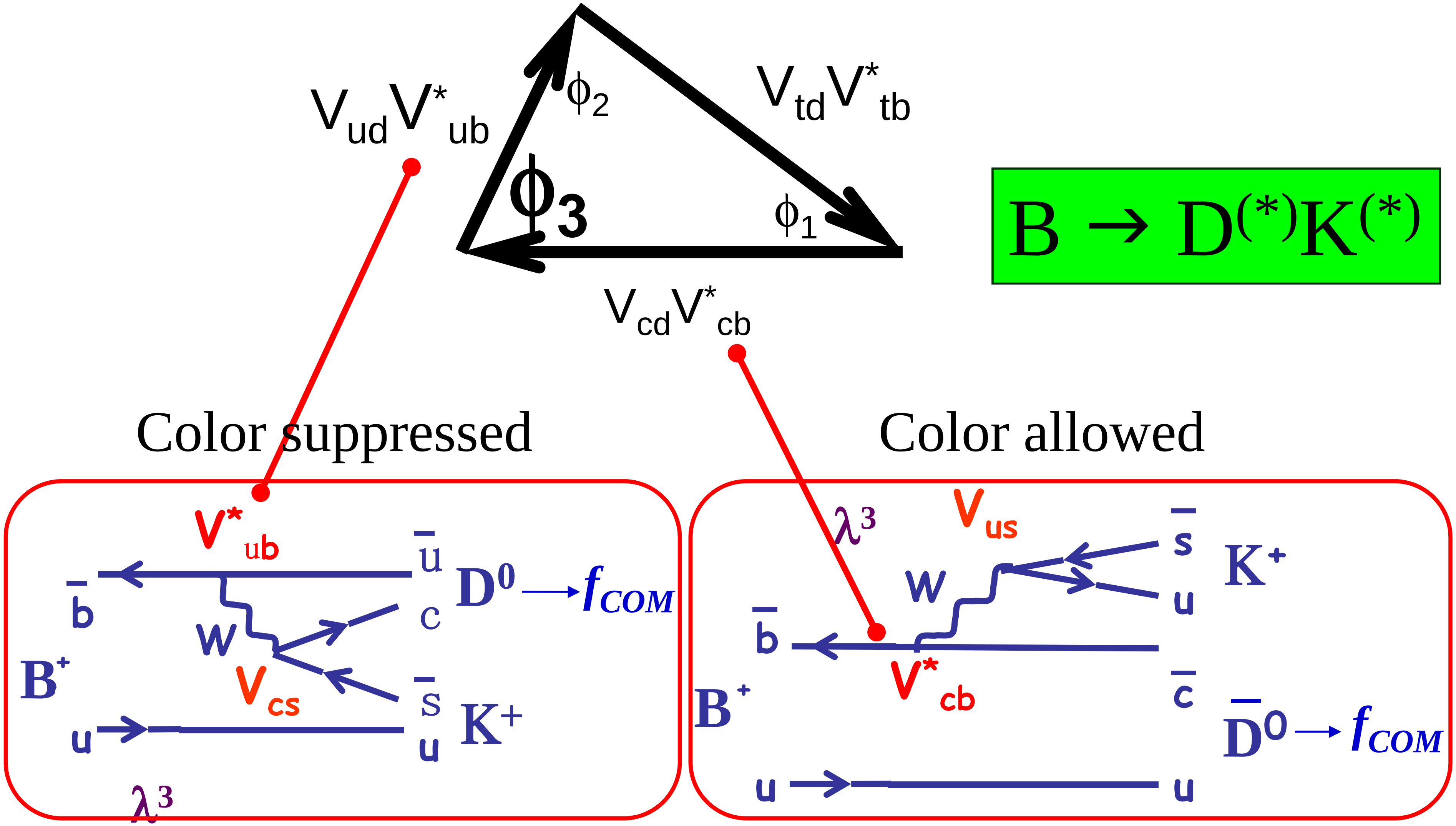
consistent with a global fit w/o α/ϕ_2

$\alpha_{\text{Global Fit}} = [\,98\,^{+5}_{-19}]^\circ$

B→ρπ to be included

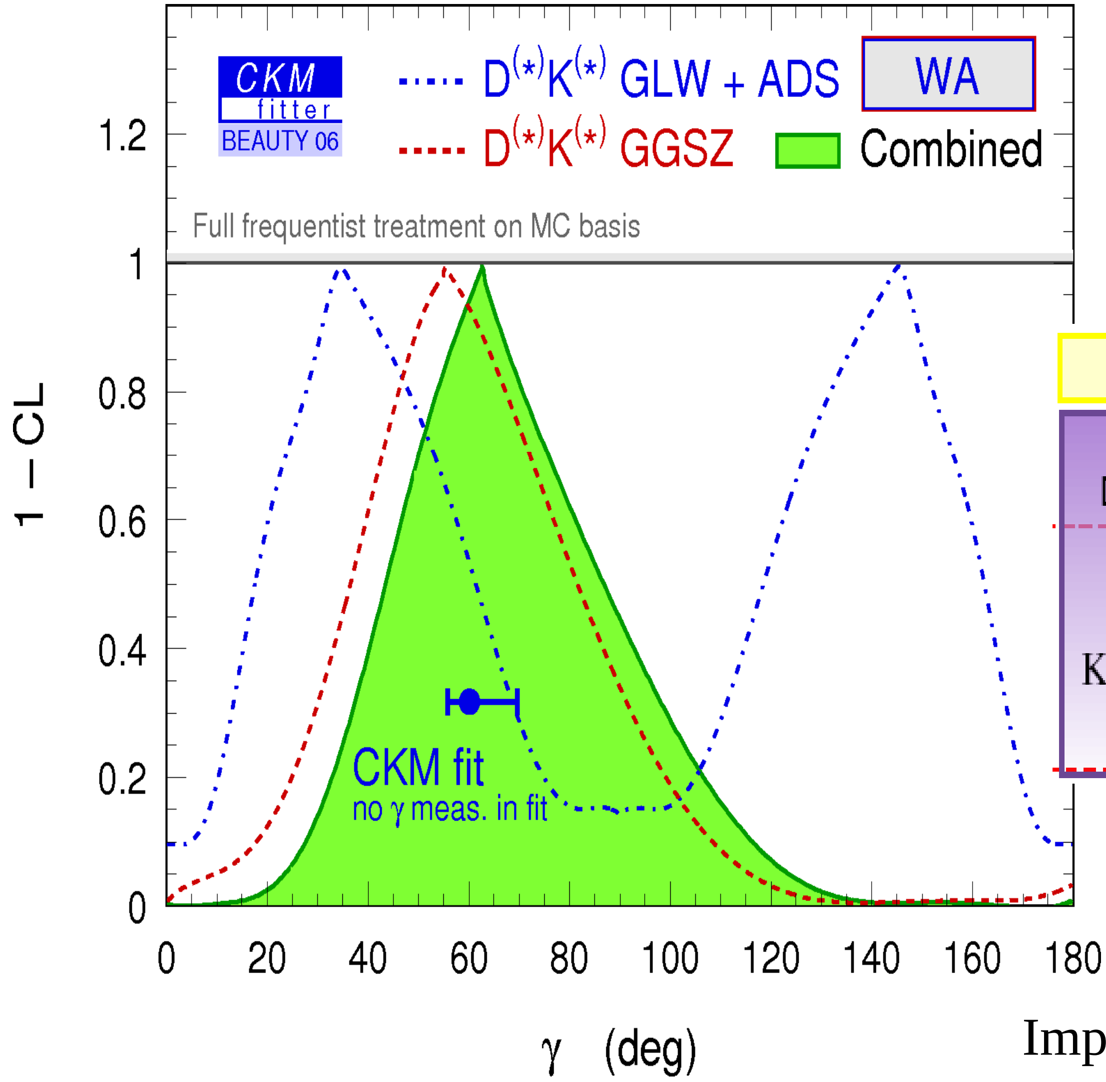
- **Solution around 0/180deg. is eliminated if Br(Bs → K⁺K⁻) + SU(3) is used for ππ. (see talk by M.Ciuchini)**

Direct CP violation and ϕ_3 (γ)

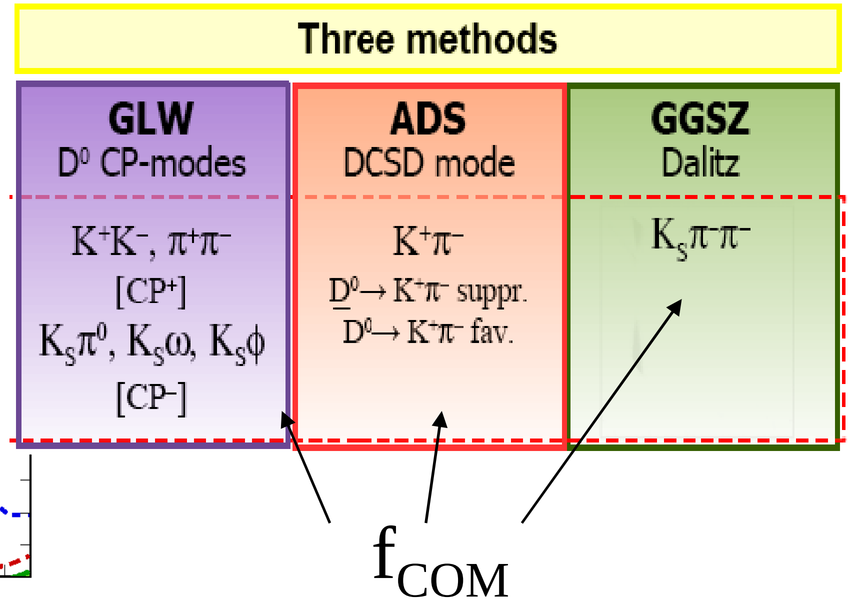


Choice of f_{COM} very important !

ϕ_3 Summary



$$\gamma/\phi_3 = [62^{+38}_{-24}]^\circ$$



Improvements with more statistics expected in the near future

Vcb

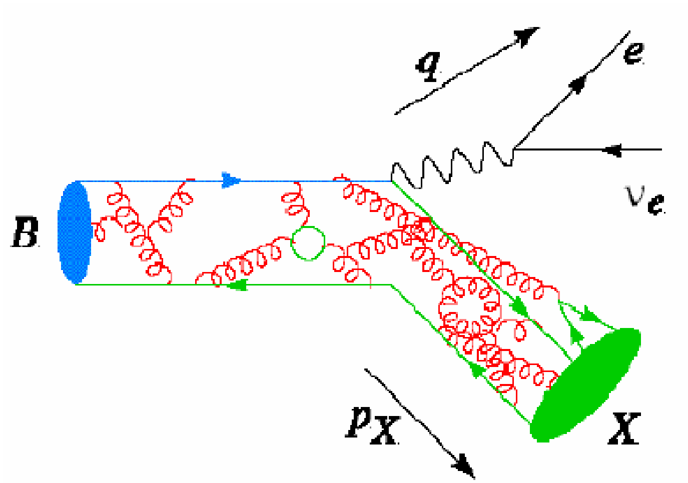
HQE (Heavy Quark Expansion)

Decay rate with expansion in series of $1/m_b$, non-perturbative parameters extracted from shape information

THEORY

METHOD

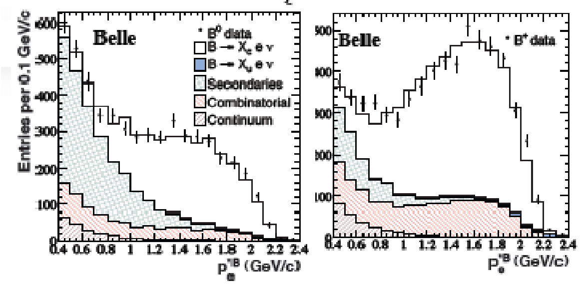
Inclusive semileptonic B decays: $B \rightarrow X_c l\nu$



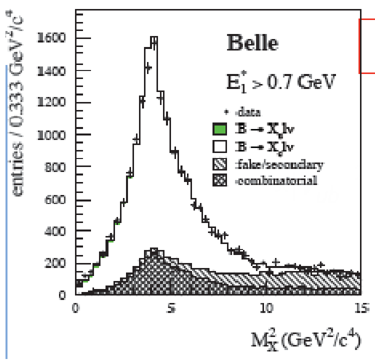
3 independent parameters

- E_l: lepton energy
- q^2: lepton-neutrino mass squared
- M_x: hadronic mass

Inclusive E_ℓ spectrum



Inclusive M_x spectrum



rate → $|V_{cb}|$

shape → $m_b, m_c, \mu^2_G, \mu^2_\pi$ ← shape

m_b → $|V_{ub}|$

EXPERIMENT

$$|V_{cb}| = (41.69 \pm 0.33_{fit} \pm 0.20_{T}) \times 10^{-3}$$

$$m_b^{1s} = 4.718 \pm 0.030 \text{ GeV}$$

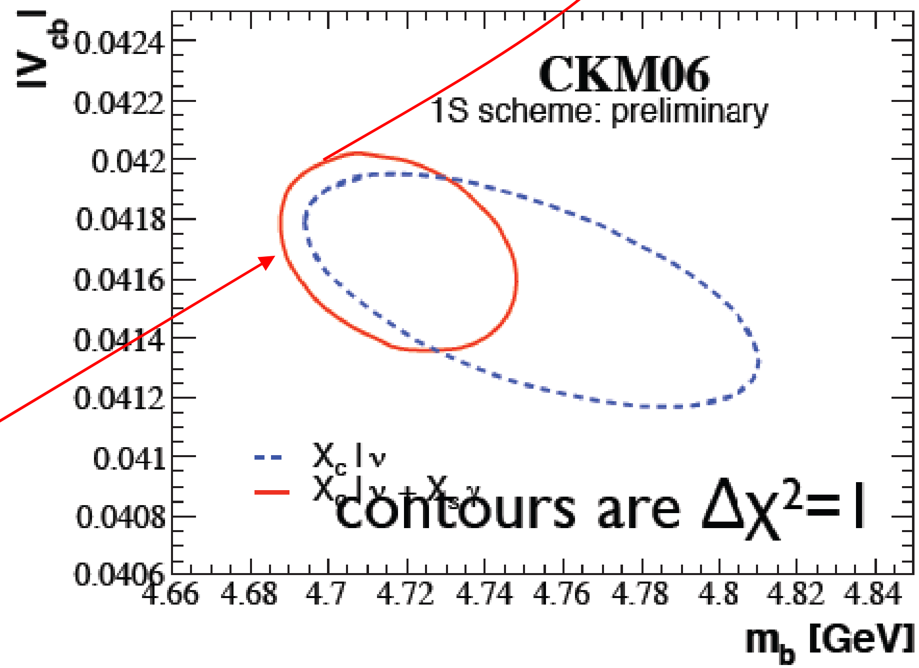
$$\lambda_1 = -0.30 \pm 0.03 \text{ GeV}^2$$

1% accuracy**

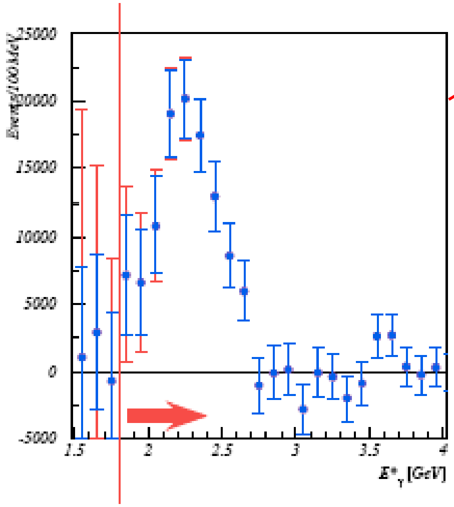
RESULTS

Inclusive semileptonic B decays: $B \rightarrow X_c l\nu$

Inputs:
decay rates and moments (shape) from BaBar, Belle, CDF, CLEO, DELPHI

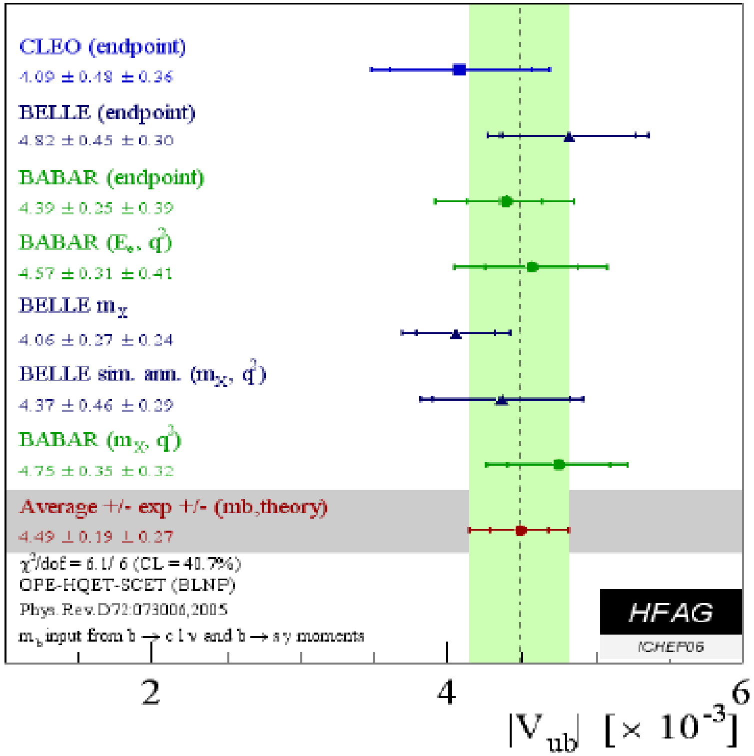


$B \rightarrow X_s\gamma$
$E\gamma$ spectrum also used as an input



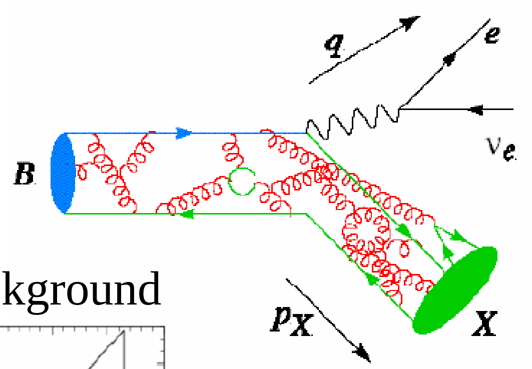
** $B \rightarrow D^{(*)}l\nu$ (exclusive) with LQCD → ~4% accuracy

|Vub| = (4.49±0.19±0.27)x10^{-3}
~7% accuracy**

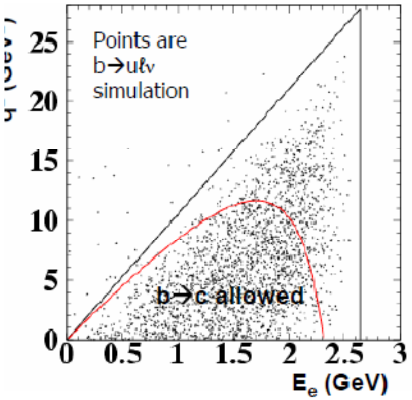


Method

Inclusive semileptonic B decays: B → X$_u$lν



large b→c background



EXPERIMENT

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}}{\tau_B}\frac{1}{R}}$$

theory uncertainties (shape function)
→ several different schemes

Tagging:

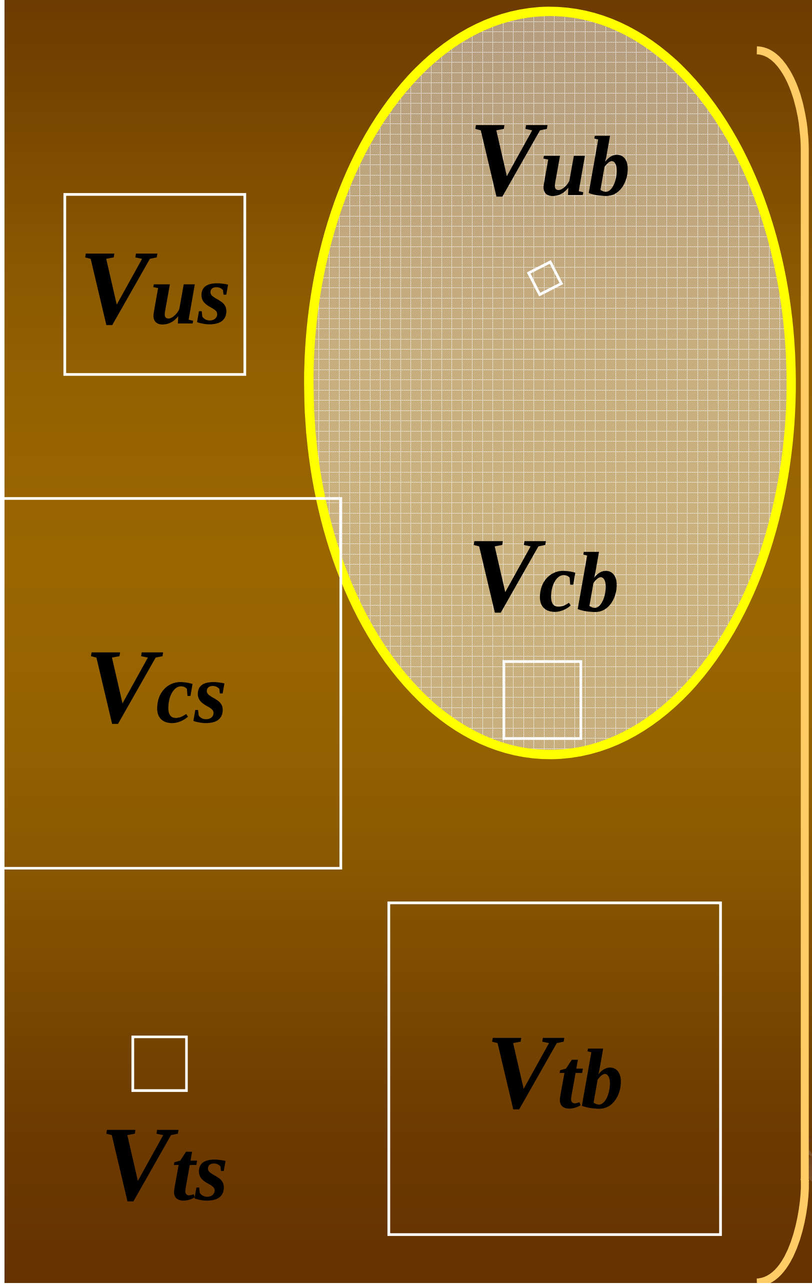
- untagged
- semileptonic tag
- hadronic tag

low purity, high statistics

high purity, low statistics

** B → πlν (exclusive) with LQCD → ~12% accuracy

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



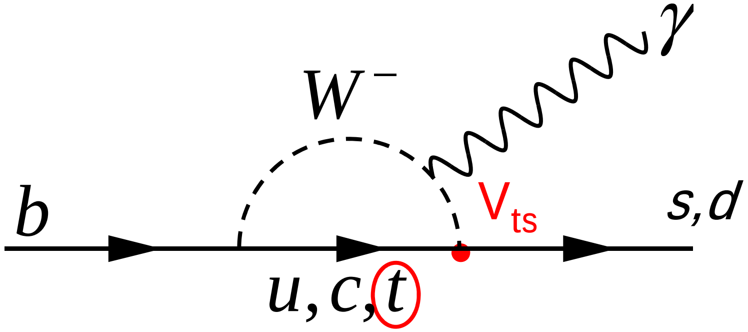
	$\lvert V_{cb}\rvert(10^{-3})$	$\lvert V_{ub}\rvert(10^{-3})$
Exclusive	39.4±1.6	3.97±0.55
Inclusive	41.7±0.4*	4.49±0.33

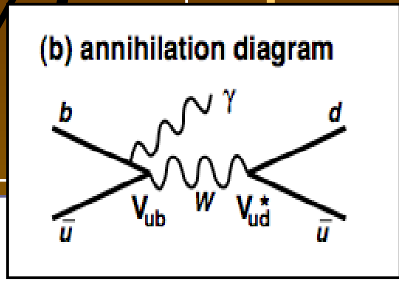
*P. Urquijo, CKM2006
other numbers from C. Schwanda, Lathuile2007

Vtd **Vts**

Cannot be measured from top semileptonic decays ...

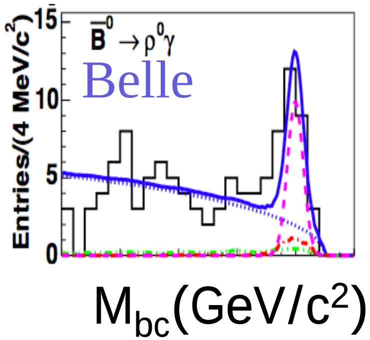
METHOD1 Loop diagrams





$$\frac{BF(B\to(\rho/\omega)\gamma)}{BF(B\to K^{*}\gamma)}=\left|\frac{V_{td}}{V_{ts}}\right|^{2}\left(\frac{m_B^2-m_\rho^2}{m_B^2-m_{K^*}^2}\right)^{3}\zeta^{2}(1+\Delta R)$$

Light Cone Sum Rules



BaBar+Belle(10^{-6})

$1.22^{+0.23}_{-0.21}\pm0.05$

Inclusive BF($B\to X_s\gamma$)
for E_γ>1.6GeV
→ |Vts| with ~7% accuracy

Caveat: This assumes the unitarity.

B→ργ

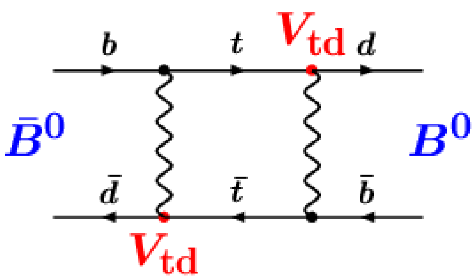
$$\left|\frac{V_{td}}{V_{ts}}\right|_{\rho\gamma}=0.197^{+0.019}_{-0.018}(\mathrm{exp})\pm0.015(\mathrm{th})$$

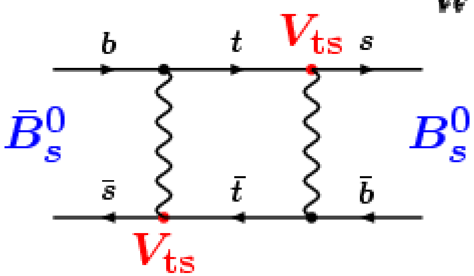
Vtd *Vts* *Vtb*

METHOD2

$$\Delta m_q = \frac{G_f^2}{6\pi^2} m_{B_q} M_W^2 f\left(\frac{m_t^2}{M_W^2}\right) \eta_{\rm QCD} B_{B_q} f_{B_q}^2 |V_{tb}^* V_{tq}|^2 \quad q = d, s$$

<u>Box diagrams</u>



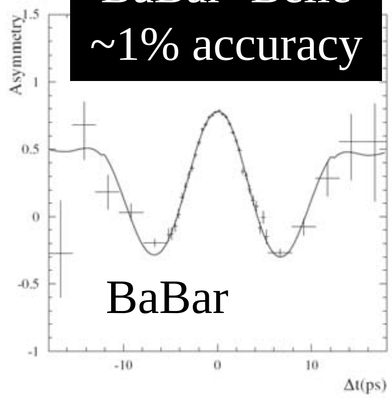


LQCD

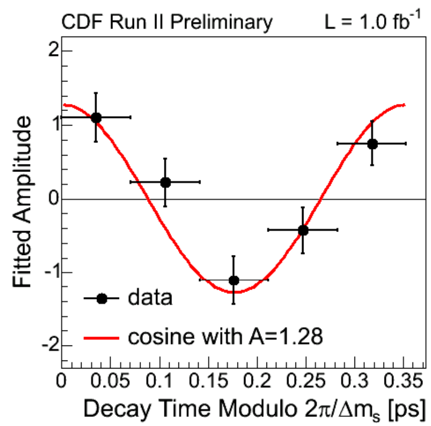
$$\sqrt{B_{B_d}} f_{B_d} = 244 \pm 26 \text{ MeV}$$

(Okamoto, hep-lat/0510113)

BaBar+Belle
~1% accuracy



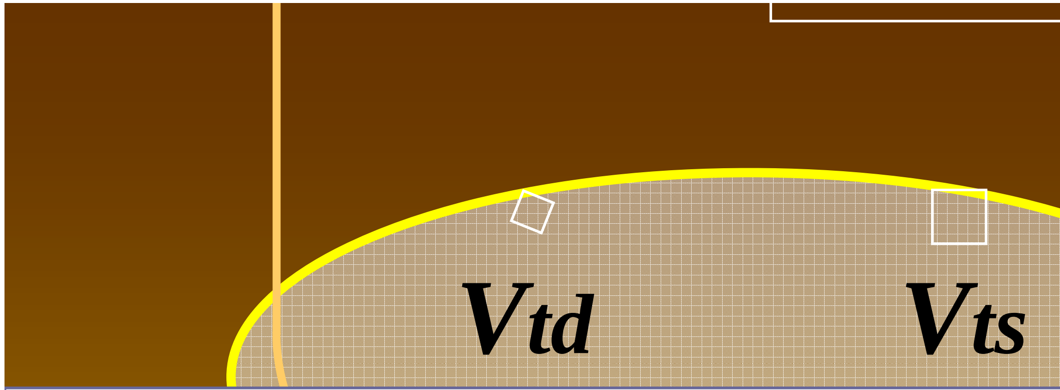
CDF
~0.7% accuracy



Limits precision on
$|V_{td}|$, $|V_{ts}|$ to ~ 10%

$$|V_{td}| = (7.4 \pm 0.8) \times 10^{-3}$$

(PDG2006)

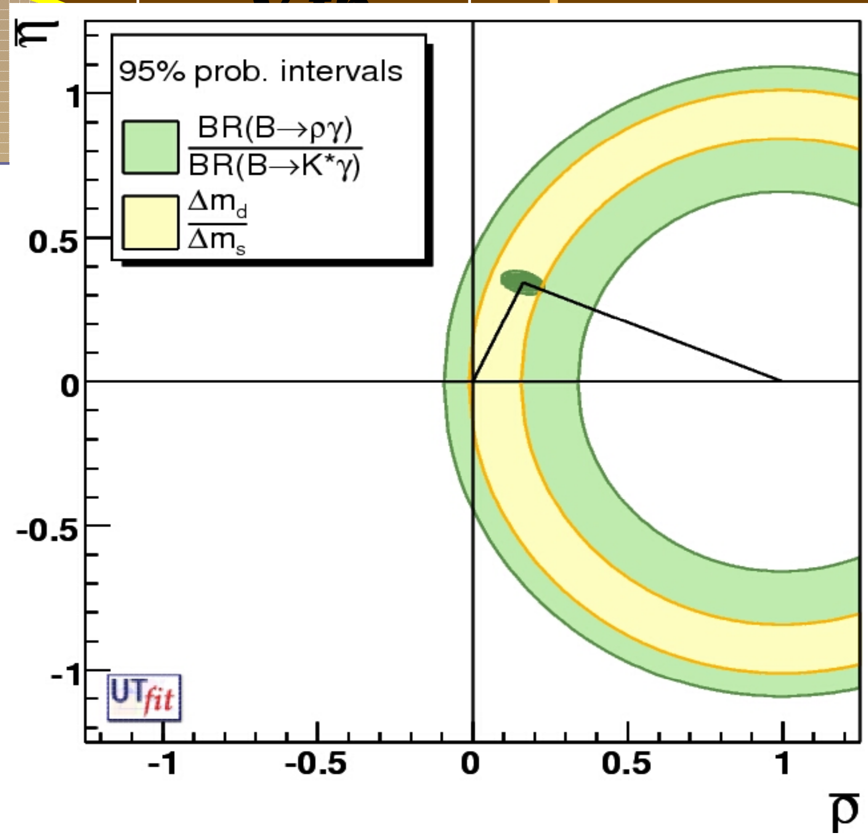


METHOD2 Box diagrams

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

$$\xi = \frac{B_{B_s}\sqrt{f_{B_s}}}{B_{B_d}\sqrt{f_{B_d}}} = 1.210^{+0.047}_{-0.035}$$

(~4% accuracy)

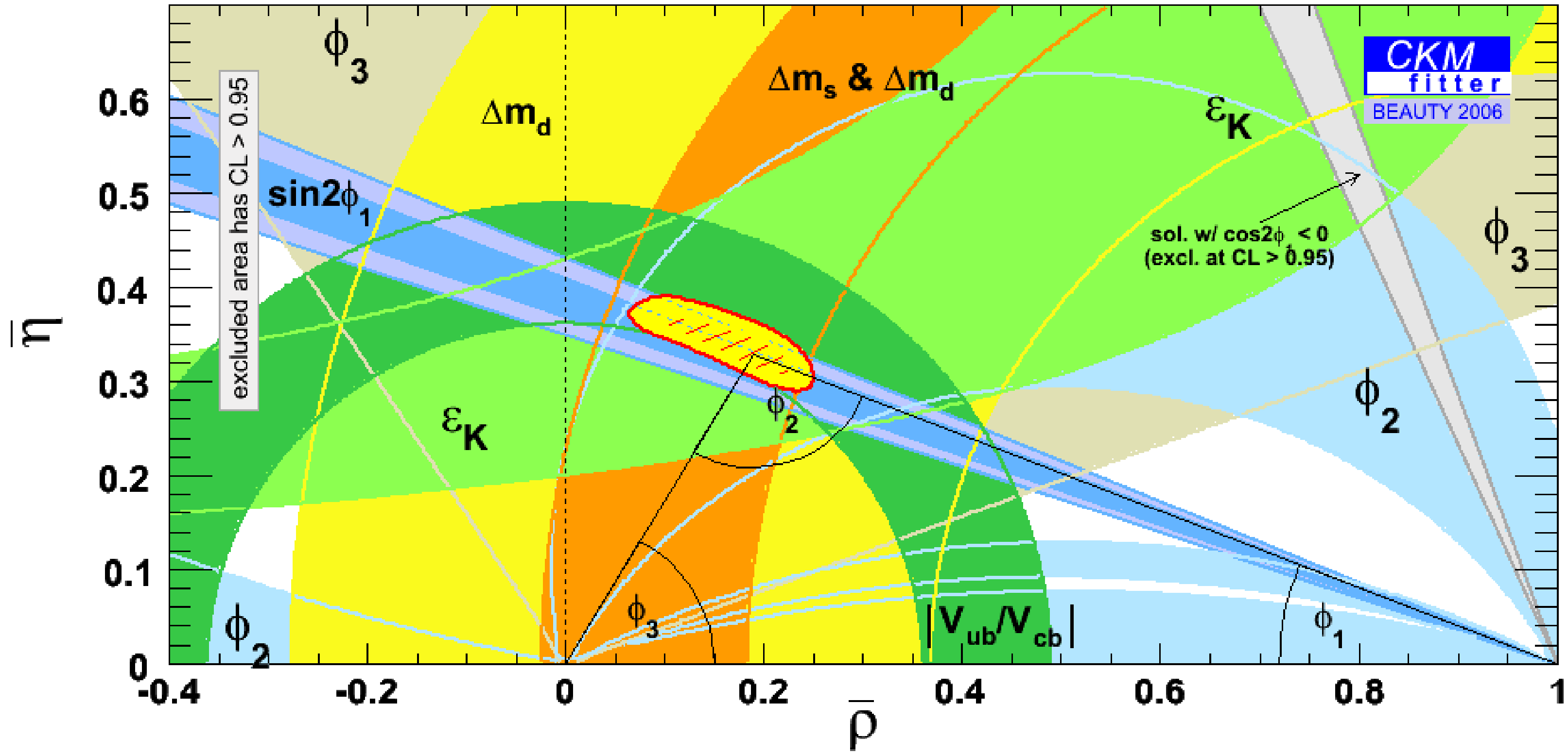


$$\Delta m_d = 0.507 \pm 0.005 (1\%) \ \ (\text{PDG 2006})$$

$$\Delta m_s = 17.77 \pm 0.10\,(\text{stat.}) \pm 0.07\,(\text{syst.})\ \text{ps}^{-1}$$ CDF (2006)

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2060 \pm 0.0007\,(\text{exp.})^{+0.0081}_{-0.0060}\,(\text{theo.})$$

CKM Global Fit



Good overall agreement. O(1) new physics unlikely.
Need to be able to detect O(0.1) effects as the next step.

Kobayashi-Maskawa model of CP violation has been firmly established, just like Newtonian mechanics was established.

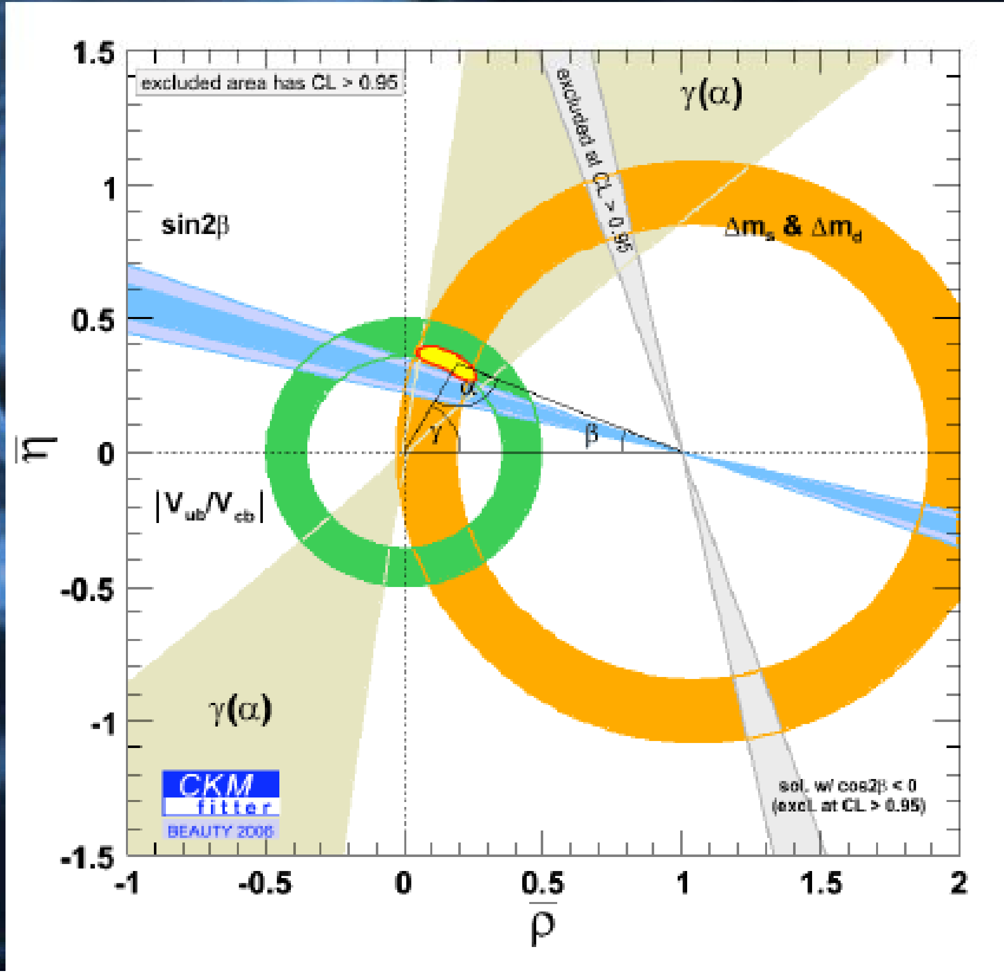
Comment on $|V_{ub}|$ tension (1)

M. Neubert

Moriond EW 2007

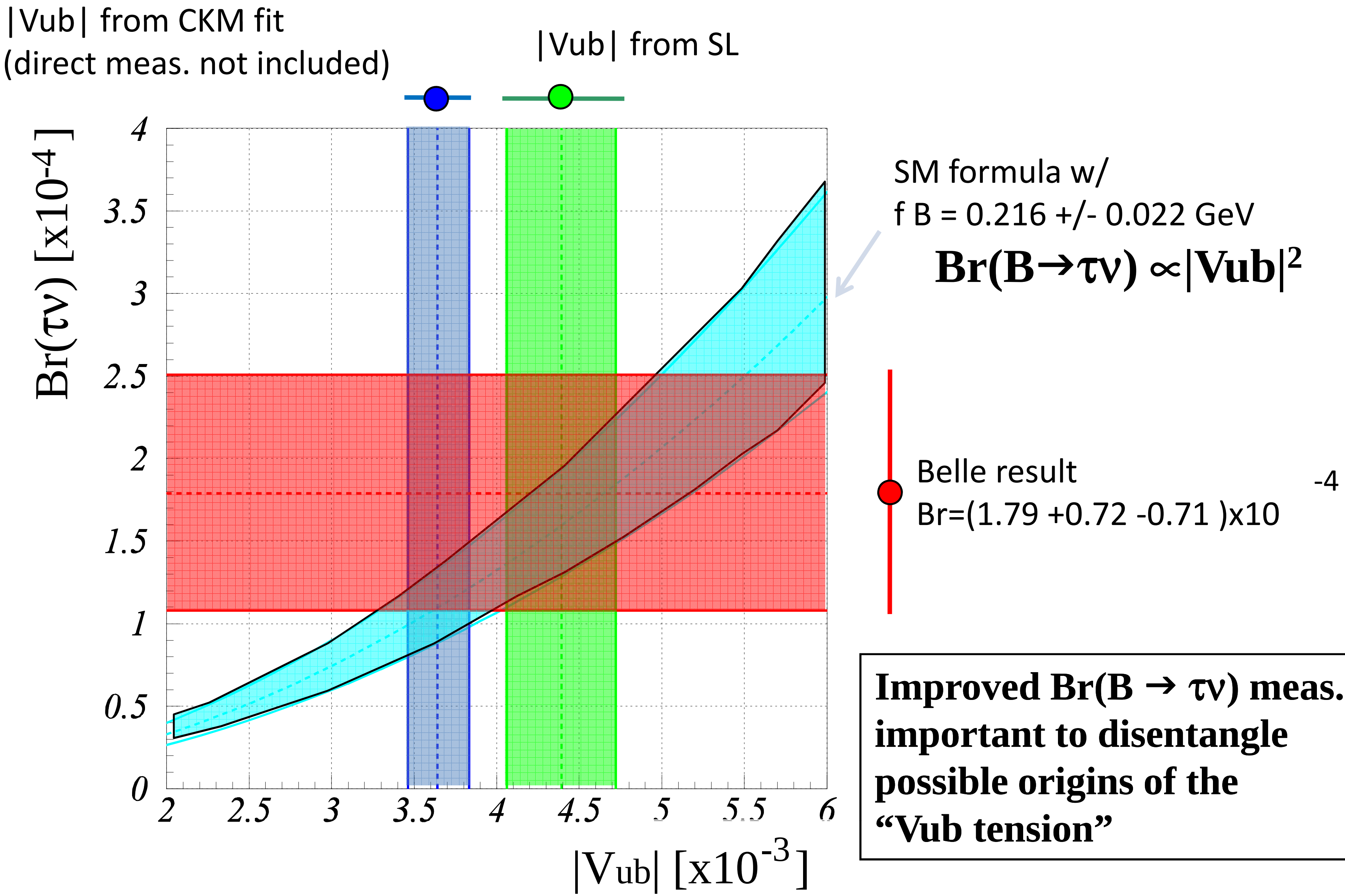
Impact of precise $|V_{ub}|$

- Combined average $\sin 2\beta = 0.647 \pm 0.024$ below “tree” value $\sin 2\beta = 0.794 \pm 0.045$ deduced from $|V_{ub}|$ and $|V_{td}|$
- Deviation 2.9σ (!)
- Increased precision in $|V_{ub}|$ and recent measurement of B_s-$\overline{B}_s$ mixing (D0, CDF) crucial



Comment on $|V_{ub}|$ tension (2)

T. Iijima



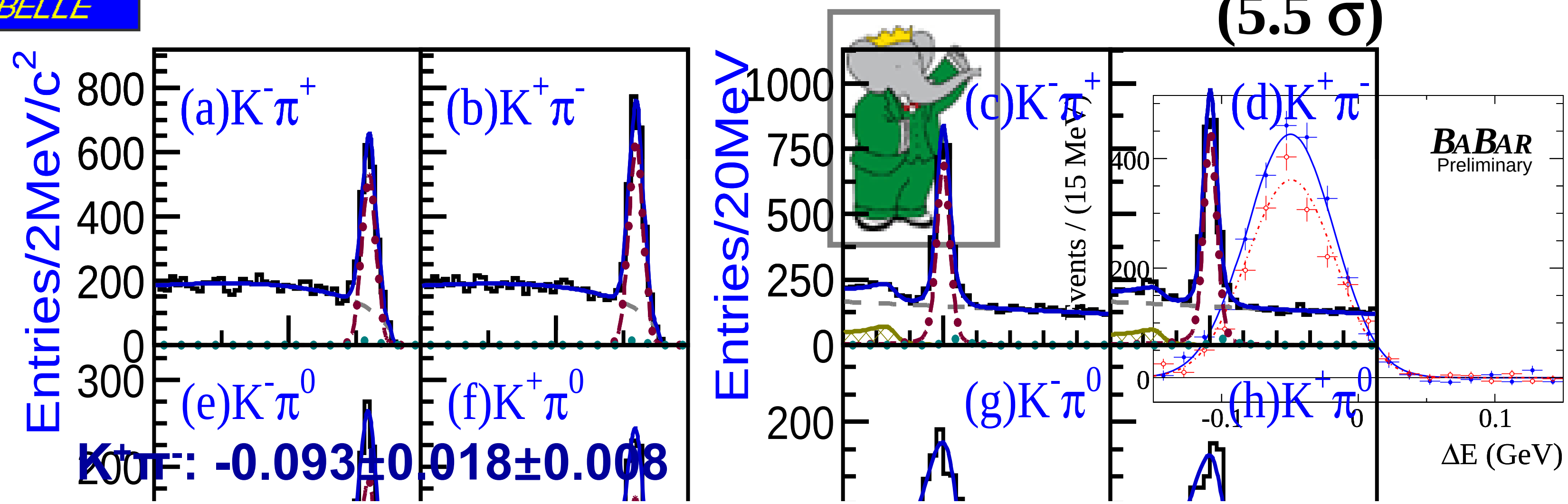
Improved Br(B → τν) meas. important to disentangle possible origins of the "Vub tension"

Direct CPV in $B^0 \to K^+\pi^-$ (established in 2004)

hep-ex/0608049

$$\mathcal{A}_{K\pi} = -0.107 \pm 0.018\,(\text{stat})^{+0.007}_{-0.004}\,(\text{syst})$$

(5.5 σ)



Kπ: -0.093±0.018±0.008

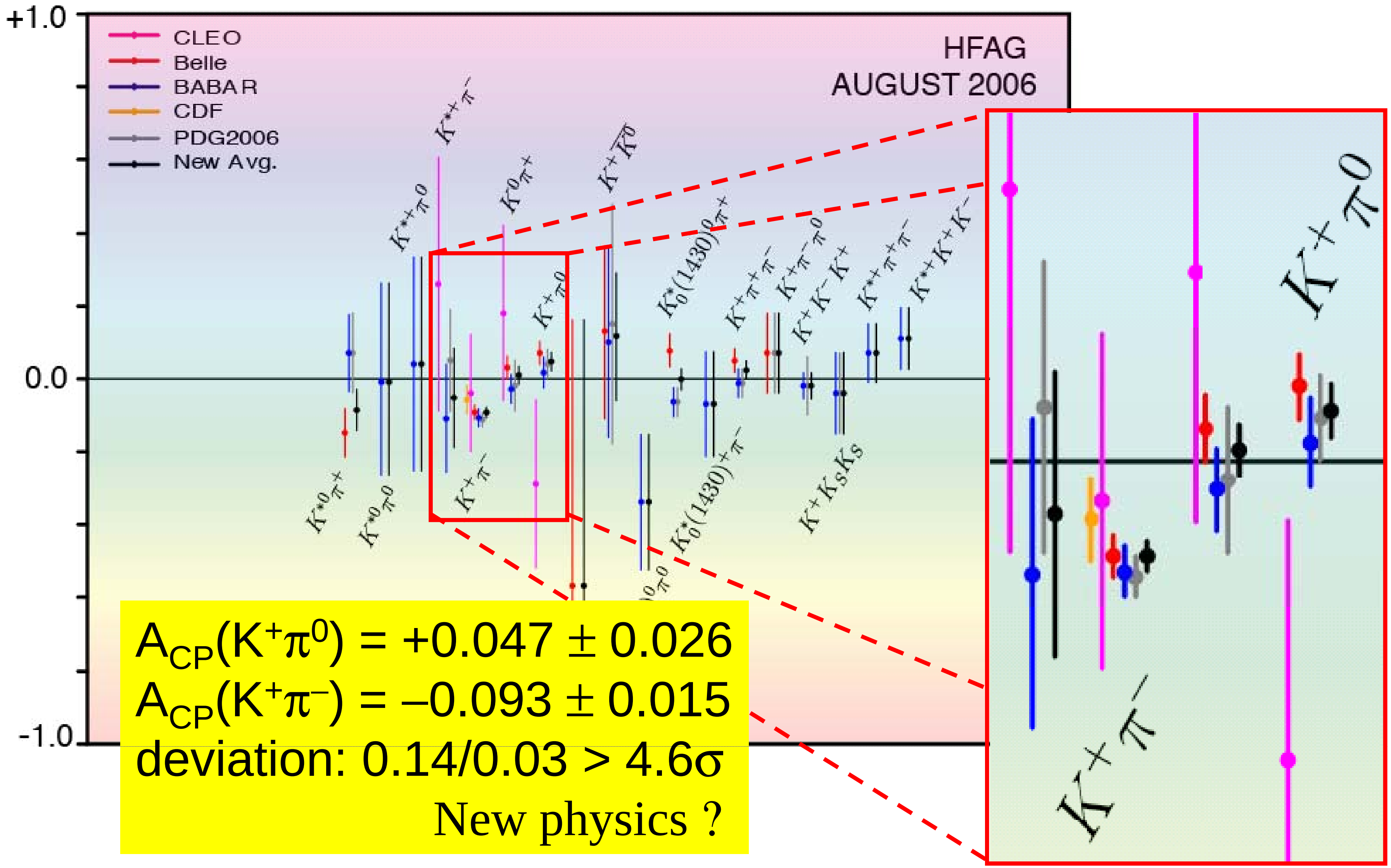
(4.7σ)

hep-ex/0703016

- Direct CPV already observed in K decays. Important to see it in B decays ? → Yes ! There are well-motivated "B-superweak" models.
  - e.g. Superstring-inspired "B-superweak" model that also allows SUSY EW baryogenesis [M. Brhlik et al., PRL 84, 3041 (2000)].

M_{bc} (GeV/c²) ΔE (GeV)

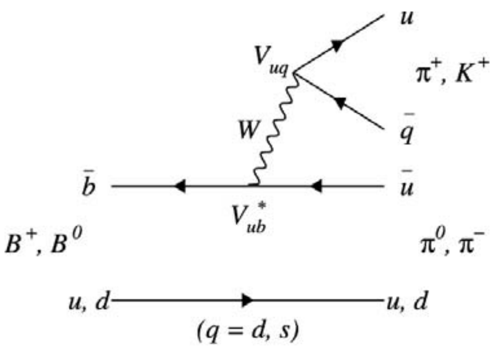
$A_{CP}(K\pi)$ puzzle ?



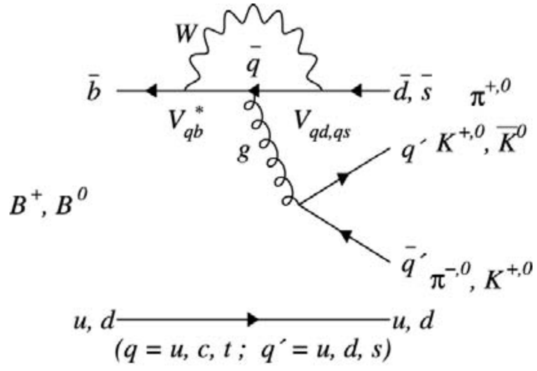
$A_{CP}(K^+\pi^0) = +0.047 \pm 0.026$
$A_{CP}(K^+\pi^-) = -0.093 \pm 0.015$
deviation: 0.14/0.03 > 4.6σ

New physics ?

$A_{CP}(K\pi)$ puzzle ?



T



P

- Naive expectation, $A_{CP}(K^+\pi^0) \sim A_{CP}(K^+\pi^-)$, is too crude and is not adequate for new physics search. ☹
  - Large color-suppressed tree may exist.
- "Sum rule" offers more precise tests. ☺

D. Atwood, A. Soni, PRD58 (1998) 036005

M. Gronau, PLB627 (2005) 82

$$\mathcal{A}(K^+\pi^-)+\mathcal{A}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}+\mathcal{A}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

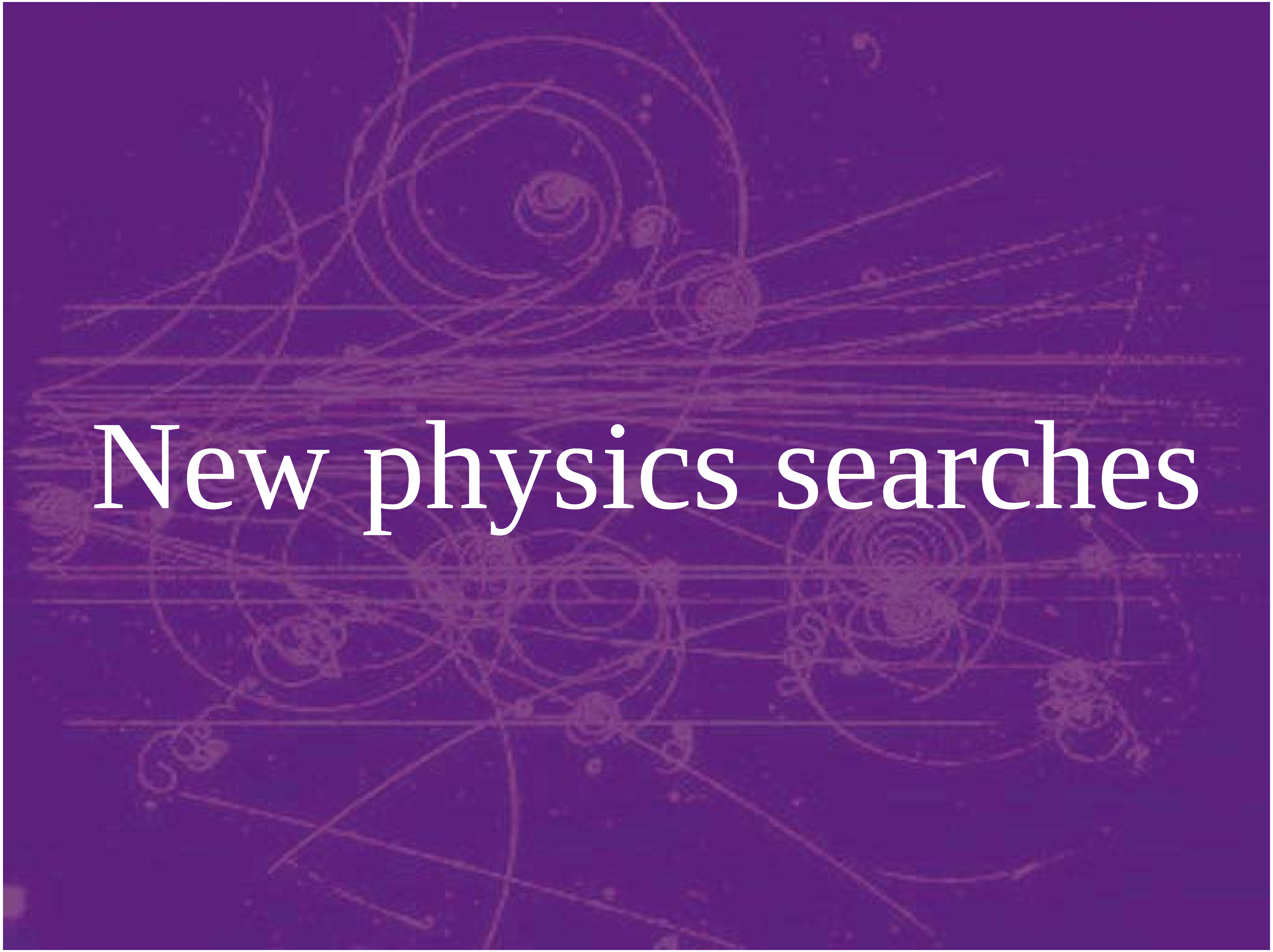
$\mathcal{A}(K^0\pi^0) = -0.16\pm0.04$ (from sum rule)

$\mathcal{A}(K^0\pi^0) = -0.12\pm0.11$ (tCPV meas.)

(as of Aug.2006)

Summary of CPV and CKM

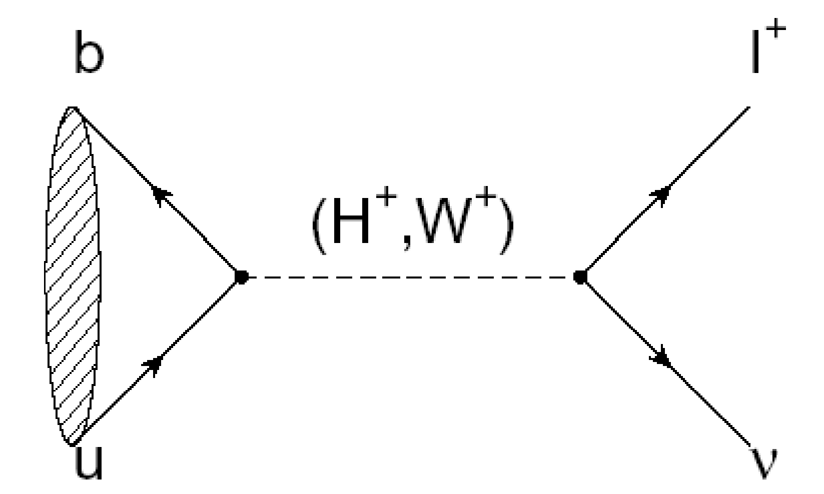
- **Kobayashi-Maskawa model of CP violation has been established, just like Newtonian mechanics was established.**
- **Yet there are several inconsistencies that are uncomfortable for the Standard Model.**
  - **b → s tCPV (2.6σ)**
  - **Vub tension (2.9σ if you think b → s tCPV anomaly is a statistical fluctuation and use combined sin2ϕ_1)**
- **Only more data will tell us the truth. At the same time, theoretical improvements are also important.**



New physics searches

$B^{\pm} \to \tau^{\pm} \nu$

Decays w/ "Missing E(>1ν)"



SM :

$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

B decay constant ↔ Lattice QCD

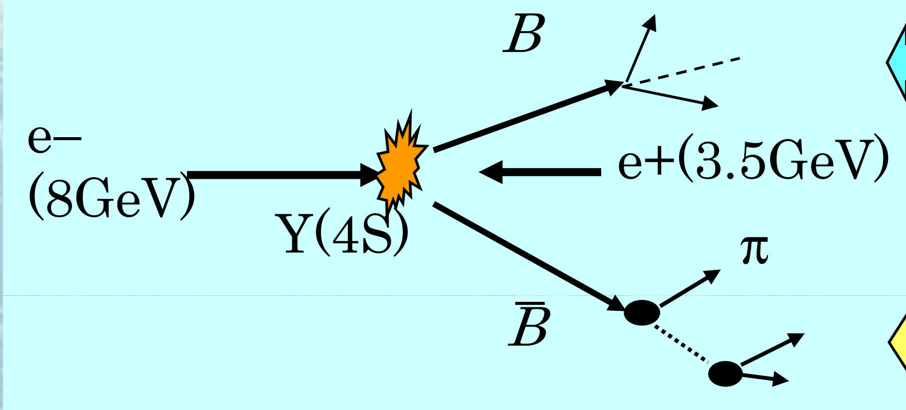
BSM : sensitive to New Physics from $H^{\pm}$

W. S. Hou, PRD48, 2342 (1993)

Full Reconstruction Method

- Fully reconstruct one of the B's to tag
  - B production
  - B flavor/charge
  - B momentum

Equivalent to "single B meson beam" !



Decays of interests
$B\to Xu\,l\,\nu$,
$B\to K\,\nu\,\nu$
$B\to D\tau\nu$, $\tau\nu$

full (0.1~0.3%) reconstruction
$B\to D\pi$ etc.

Powerful tools for B decays w/ neutrinos

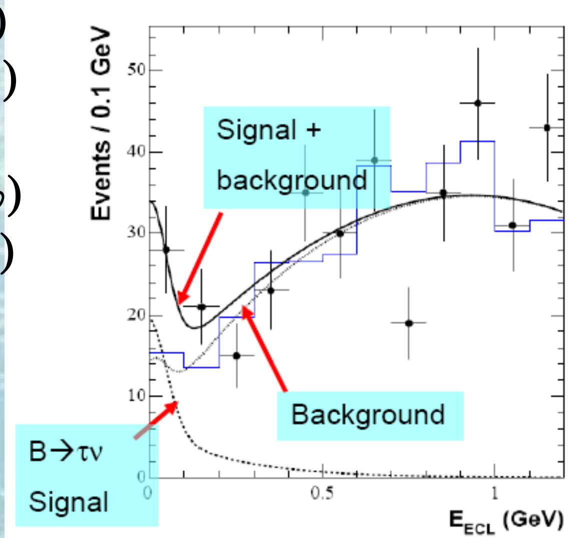
B → τν results

Belle

PRL97, 251802 (2006).

Belle Hadronic tag

e$^+\nu\nu$ (3.6%)
$\mu^+\nu\nu$ (2.4 %)
$\pi^+\nu$ (4.9%)
$\pi^+\pi^0\nu$ (2.0%)
$\pi\pi\pi\nu$ (0.8%)



Signal shape : Gauss + exponential

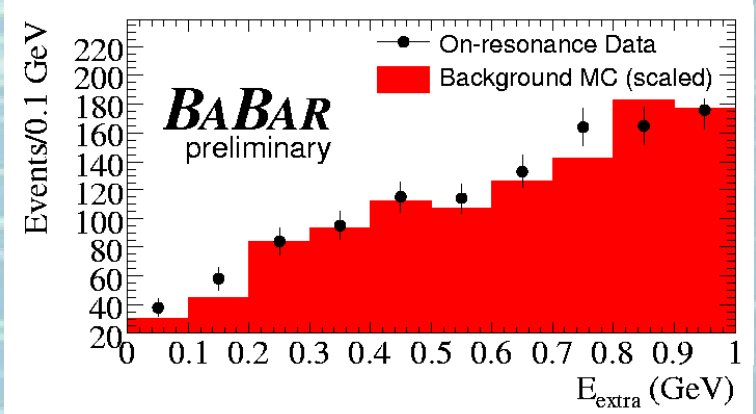
$$Br(B \to \tau\nu) = (1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}) \times 10^{-4}$$

First evidence, 3.5 σ

BaBar

hep-ex/0608019

D l ν tag

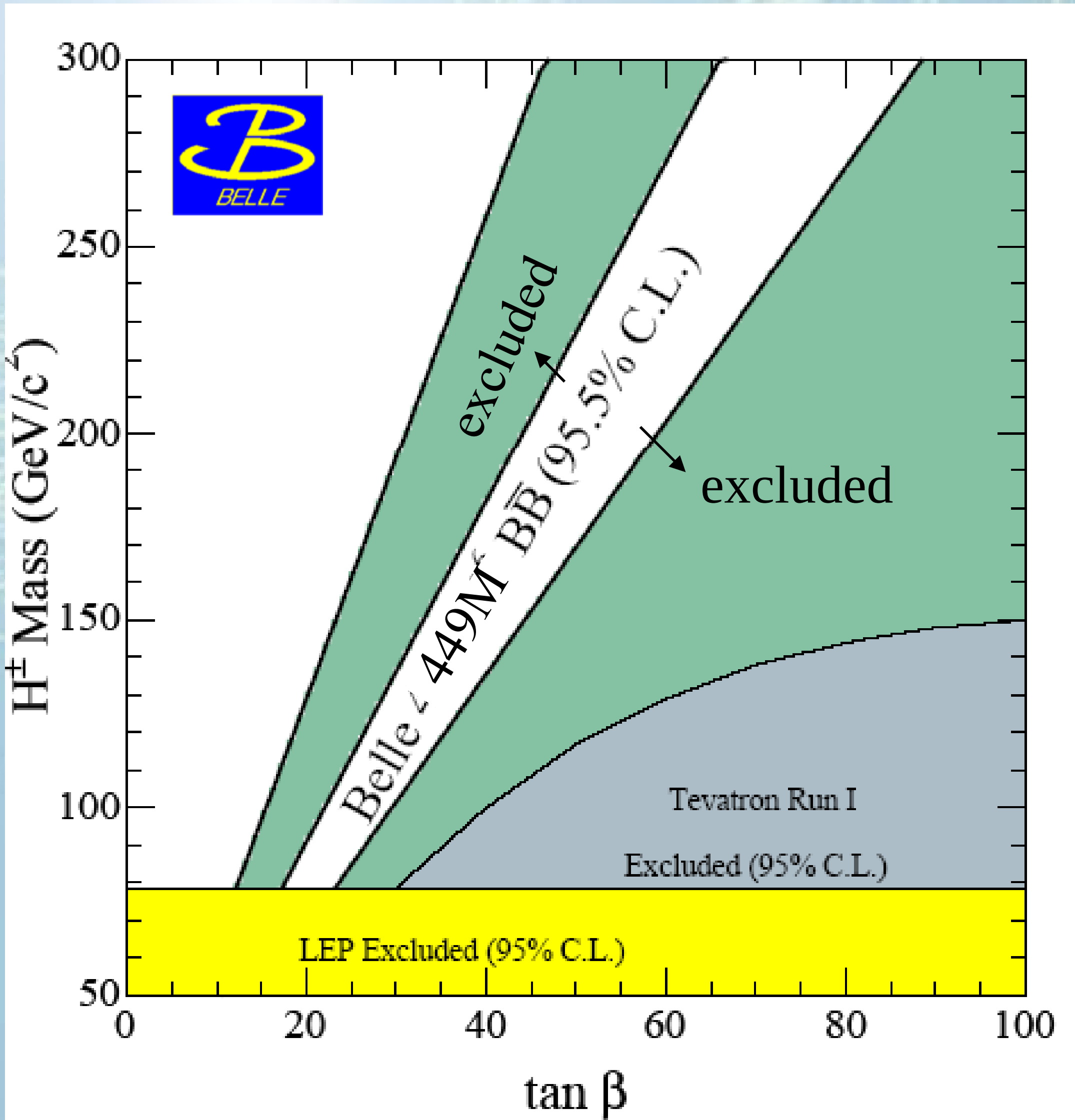


$\tau+ \to$ **e**$^+\nu\nu$ (**eff**: 4.1%), $\mu^+\nu\nu$ (2.4%), $\pi^+\nu$ (4.9%), $\pi^+\pi^0\nu$ (1.2%)

$$(0.88^{+0.68}_{-0.67}(\text{stat.}) \pm 0.11(\text{syst.})) \times 10^{-4}$$

No clear signal

Constraints on $H^{\pm}$ mass



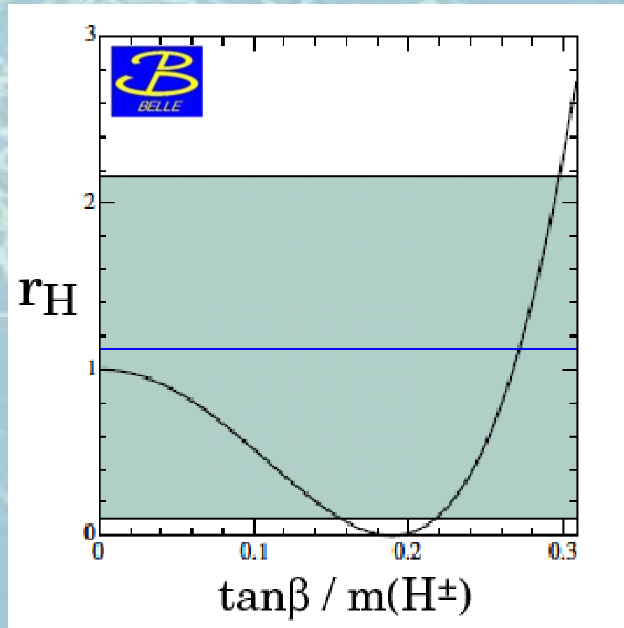
Use known f_B and $|V_{ub}|$

Ratio to the SM BF.

W. S. Hou, PRD48, 2342 (1993)

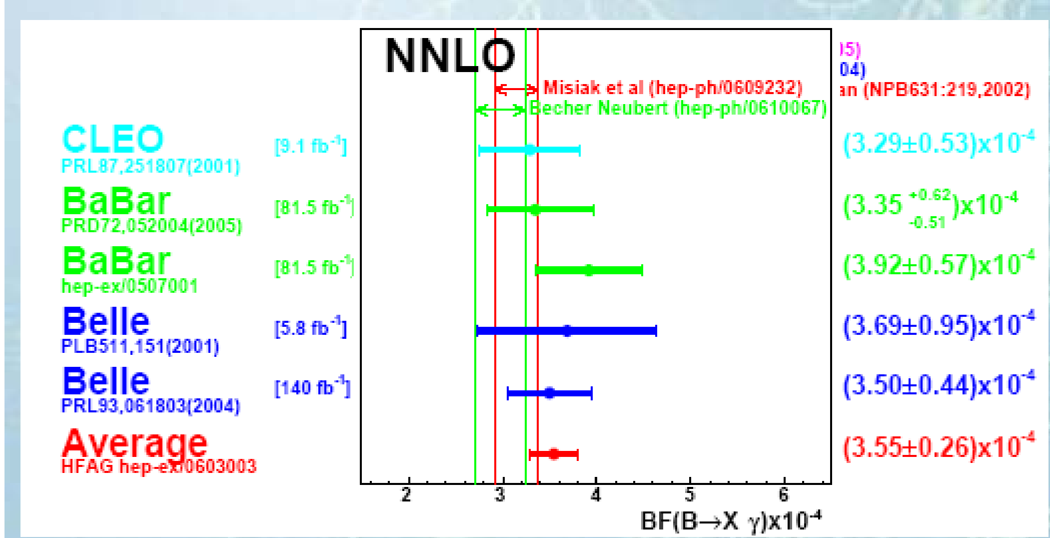
$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

$r_H = 1.13 \pm 0.51$

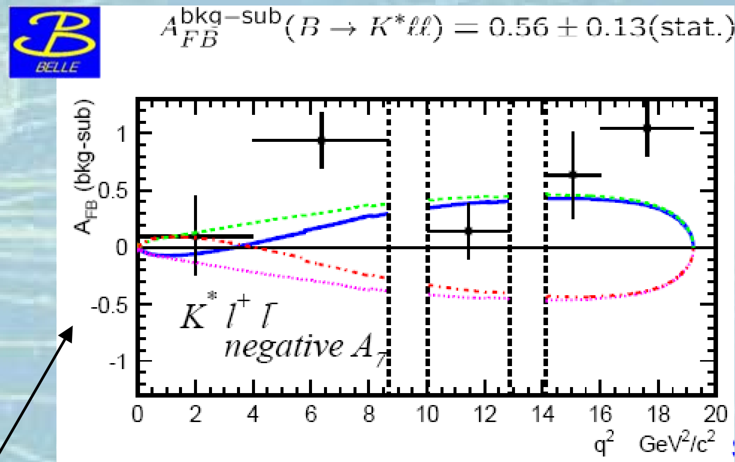


Other searches with B decays

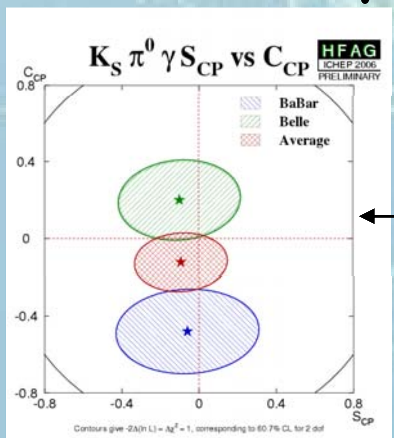
- **Br(b → sγ): best NP killer so far**



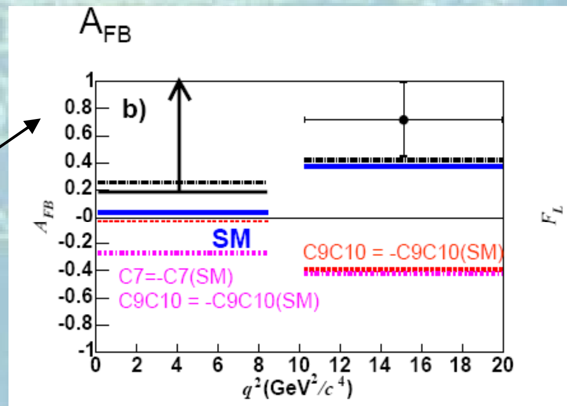
A_{FB}(B → K*ll)



- **B^0 → Ksπ^{0}γ tCPV**



Extreme NP scenarios are already excluded.



Low q^2 : excludes SM at 98% CL
A_{FB} > 0.19 at 95% CL (SM A_{FB} = 0.03)

Tau LFV summary

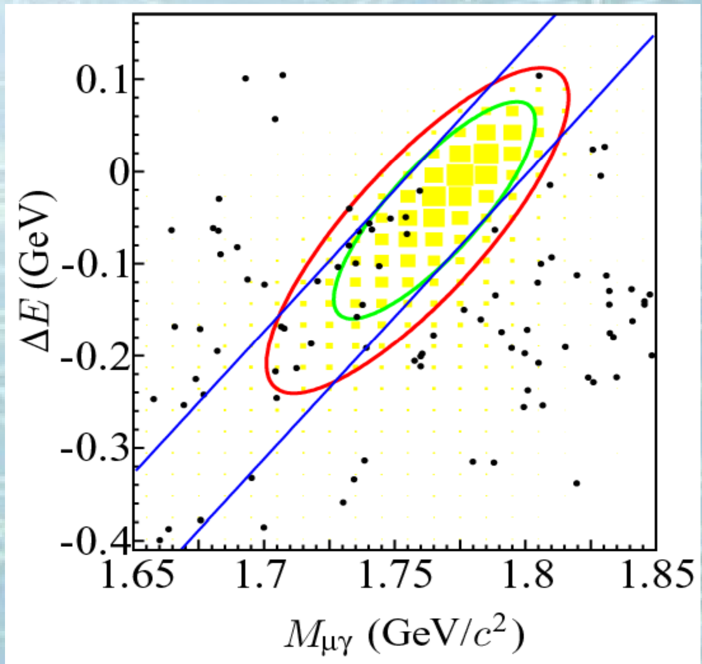
J. Yi, Moriond QCD 2007

BRANCHING FRACTION UPPER LIMITS AT 90% C.L.

	BABAR	BELLE
	BF U.L. x10^{-7} (LUMI FB^{-1})	BF U.L. x10^{-7} (LUMI FB^{-1})
$\tau^{\pm} \to e^{\pm}\gamma$	1.1 (232.2) PRL 96, 41801 (2006)	1.2 (535.0) HEP-EX/0609049
$\tau^{\pm} \to \mu^{\pm}\gamma$	0.7 (232.2) PRL 95, 41802 (2005)	0.5 (535.0) HEP-EX/0609049
$\tau^{\pm} \to e^{\pm}\pi^{0}$	1.3 (339.0) PRL98, 061803 (2007)	0.8 (401.0) HEP-EX/0609013
$\tau^{\pm} \to \mu^{\pm}\pi^{0}$	1.1 (339.0) PRL98, 061803 (2007)	1.2 (401.0) HEP-EX/0609013
$\tau^{\pm} \to e^{\pm}\eta$	1.6 (339.0) PRL98, 061803 (2007)	0.9 (401.0) HEP-EX/0609013
$\tau^{\pm} \to \mu^{\pm}\eta$	1.5 (339.0) PRL98, 061803 (2007)	0.7 (401.0) HEP-EX/0609013
$\tau^{\pm} \to e^{\pm}\eta'$	2.4 (339.0) PRL98, 061803 (2007)	1.6 (401.0) HEP-EX/0609013
$\tau^{\pm} \to \mu^{\pm}\eta'$	1.4 (339.0) PRL98, 061803 (2007)	1.3 (401.0) HEP-EX/0609013

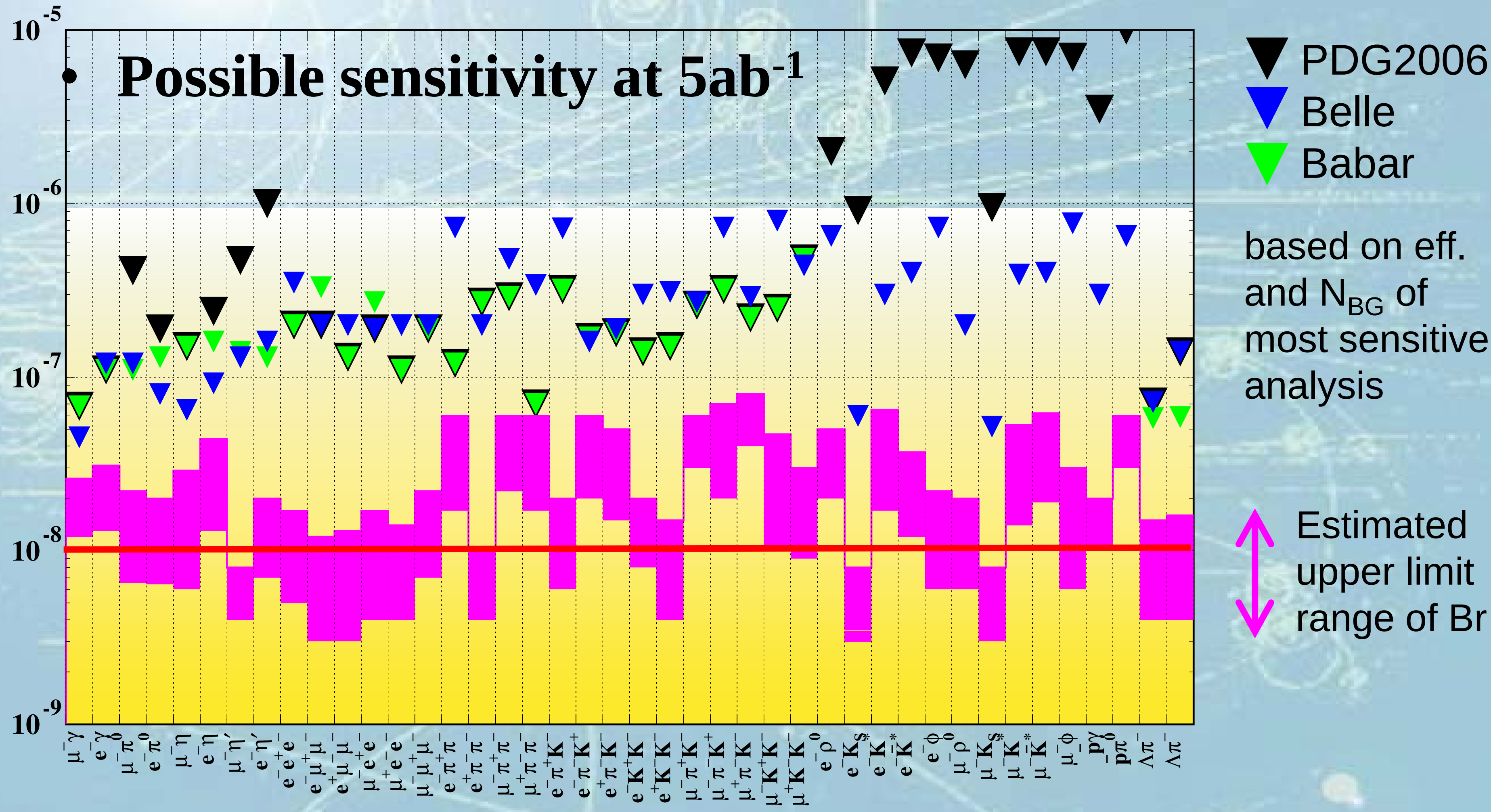
$\tau \rightarrow \mu\gamma$

535/fb



- Dominant background: $\tau \rightarrow \mu\nu\nu$ + ISR (90%)
  - Small contamination of $\mu\mu$ BG in $\Delta E > 0$

(Near) future prospect



based on eff. and N_{BG} of most sensitive analysis

Evidence for D^0 mixing

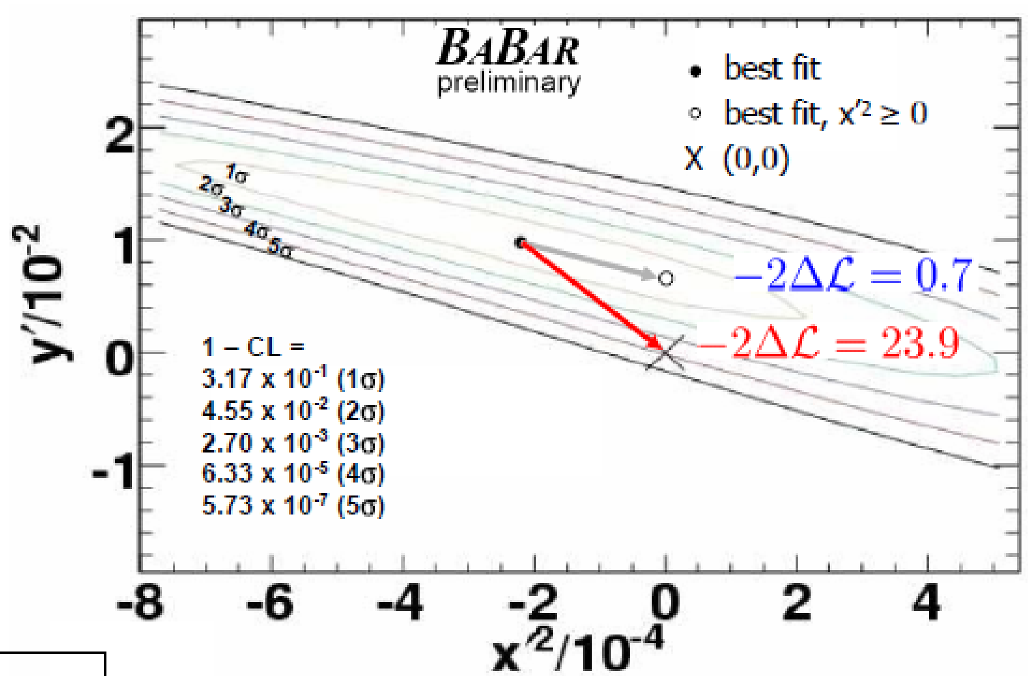
384/fb

$D^{*+} \rightarrow D^0(\rightarrow K^-\pi^+)\ \pi^+_{tag}$

hep-ex/0703020

K. Flood at Moriond EW 2007

- y', x'^2 contours computed by change in log likelihood
  - Best-fit point is in non-physical region $x'^2 < 0$, but 1-sigma contour extends into physical region
  - correlation: -0.94
- Contours include systematic errors



- **Accounting for systematic errors, the no-mixing point is at ~4-sigma contour**

R_D: $(3.03 \pm 0.16 \pm 0.06) \times 10^{-3}$

x'^2: $(-0.22 \pm 0.30 \pm 0.20) \times 10^{-3}$

y': $(9.7 \pm 4.4 \pm 2.9) \times 10^{-3}$

*** No CPV is seen**

Evidence for D^0 mixing

hep-ex/0703036

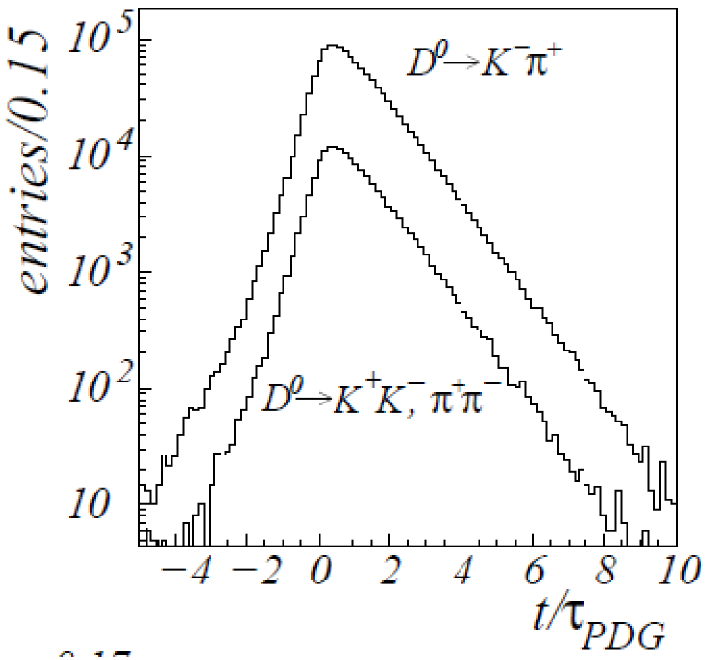
Presented at Moriond EW

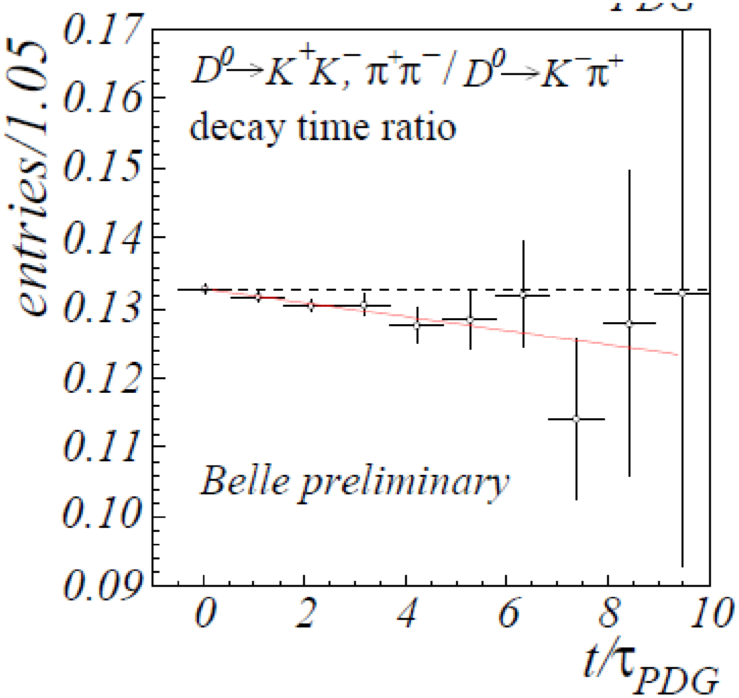
Belle Preliminary

540/fb

$$y_{CP} = 1.31 \pm 0.32 \pm 0.25\ \%$$

$> 3\sigma$ above zero (4.1σ stat. only)





(* No CP violation seen)

Search for light dark matter on Upsilon(3S)

PRL 98, 132001 (2007)

Y(3S) runs : 2.9 fb^{-1}
(Feb, 2006 : 4days) ← better sensitivity than ~7year Y(4S) data

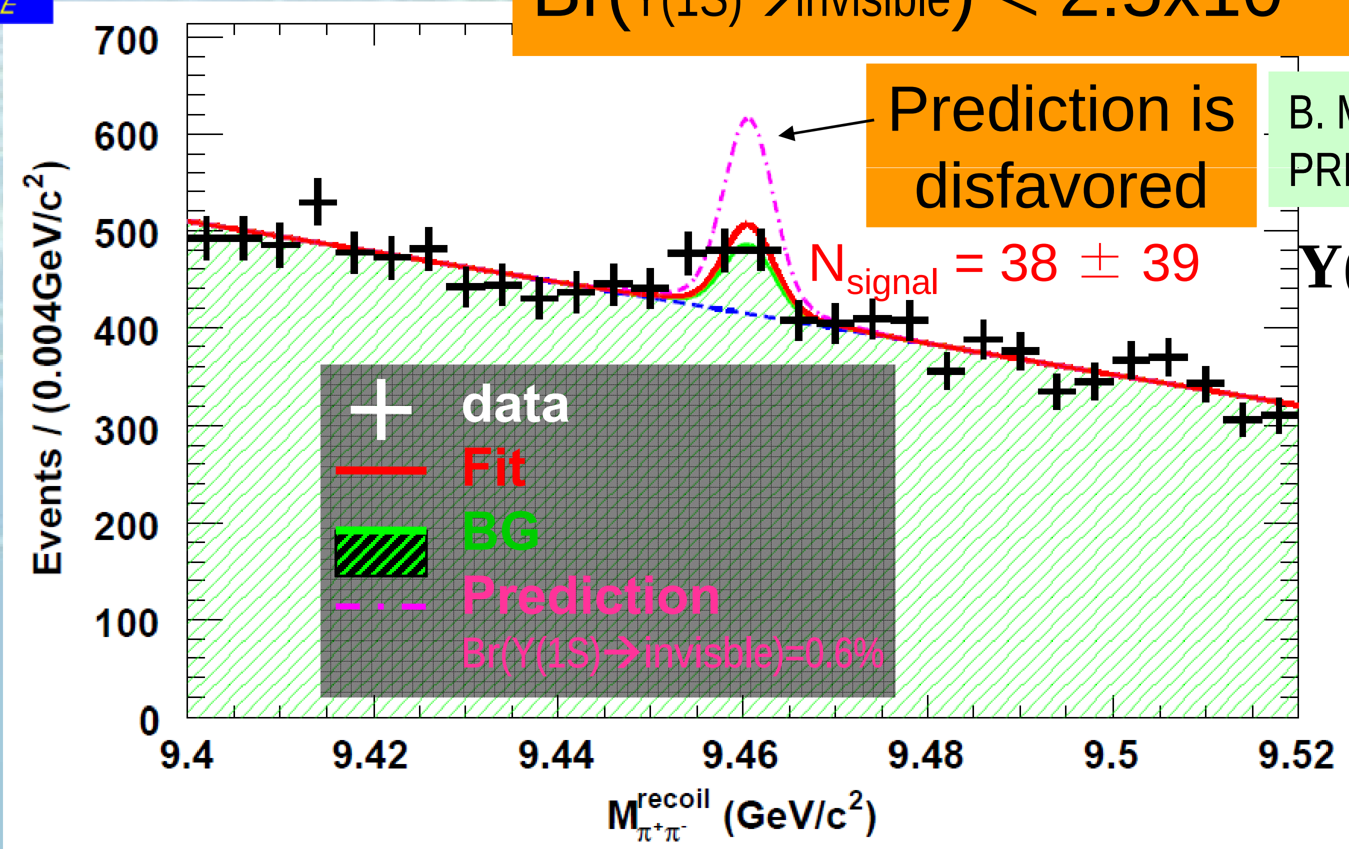
Y(3S) → Y(1S)π+π–

Br(Y(1S)→invisible) < 2.5x10^{-3} (90%C.L.)

Prediction is disfavored

B. McElrath,
PRD 72, 103508 (2005)

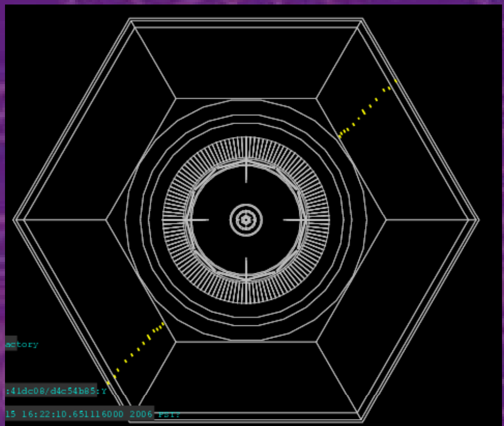
Y(1S) → DM DM



Future prospects

Efforts for improvements never stop !

→ **Oide's talk**



Cosmic-ray μ in newly-installed BaBar LST sextants (Nov.06)
→ better μ detection efficiency

Crab cavities installed (Jan.07)
→ luminosity goal = 3 x 10^{34}/cm^2/s

- ~2/ab from BaBar+Belle by the end of 2008
- BaBar will end in 2008
- Belle proposing a major upgrade (= SuperKEKB)
  - part of the "Japanese HEP master plan"
  - luminosity goal : 8 x 10^{35}/cm^2/s (peak), 50/ab (integrated)

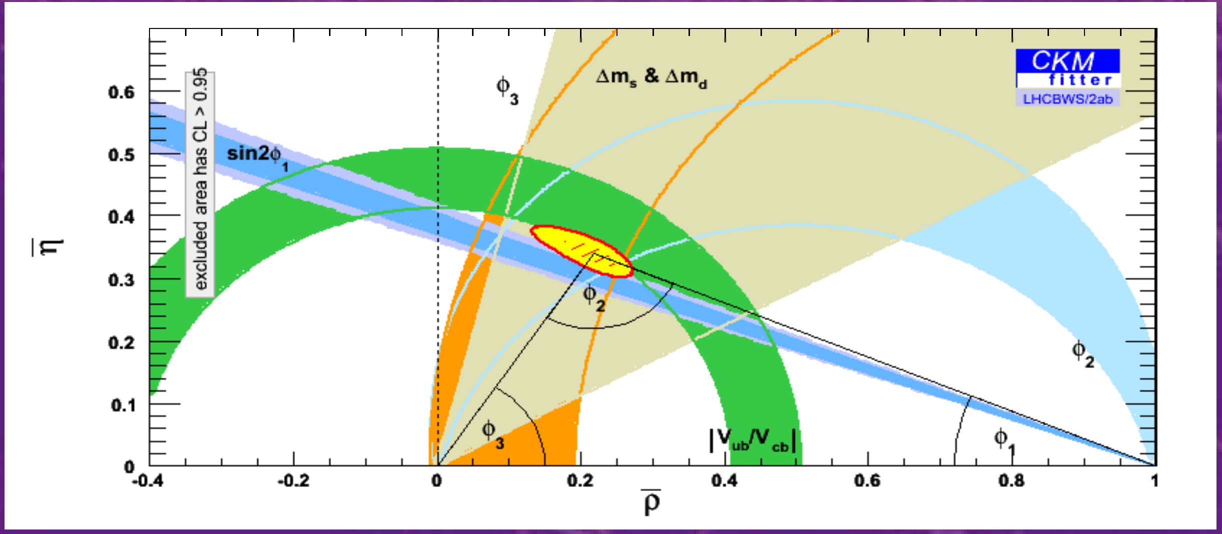
Important topics with 2/ab

- $b \to s$ tCPV: 2.6σ → ~4σ (for the same central values)
- Vub tension: 2.9σ → ? (depend on data + theory)
- Improved measurements of D^0 mixing
- Improved measurements of $B \to \tau\nu$
- Evidence for $B \to \mu\nu$
- More precise angle measurements, in particular ϕ_3 with significant observation in $B \to D^{(*)}K^{(*)}$

Other new physics searches may also find something surprising !

Physics reach at 2/ab

	Today	$2ab^{-1}$
$\sin 2\phi_1/\beta(b\to c)$	0.026	0.020
$\sin 2\phi_1/\beta(b\to s)$	0.05	0.035
ϕ_2	11^o	6^o
ϕ_3	19^o	12^o
V_{ub}(inclusive)	6.3%	4.9%
Δm_d	0.8%	0.8%
$B(B\to(\rho,\omega)\gamma)$	20.4%	10.3%
$B(B\to\tau\nu)$	36%	27%
$A_{FB}(K^*l^+l^-)$	23%	10%



$\delta(\bar{\rho},\bar{\eta})$ = (10.0%,4.4%)

R. Itoh, @LHC upgrade WS, Jan. 2007

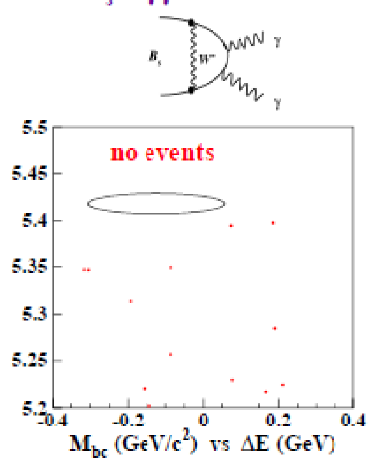
Upsilon(5S) run

World sample: four runs

- 1985 CLEO ~0.1 fb^{-1}
- 2003 CLEOIII 0.42 fb^{-1} → PRL 95, 261801 (2005)
- 2005 Belle 1.9 fb^{-1}
- 2006 Belle 21.7 fb^{-1} (~3 weeks)

- 2 papers on exclusive and inclusive Br
  - PRL 98, 052001 (2007)
  - hep-ex/0610003

$B_s \to \gamma\gamma$:



Br < 0.53x10^{-4} **world best**

- Papers based on 22/fb data set this year

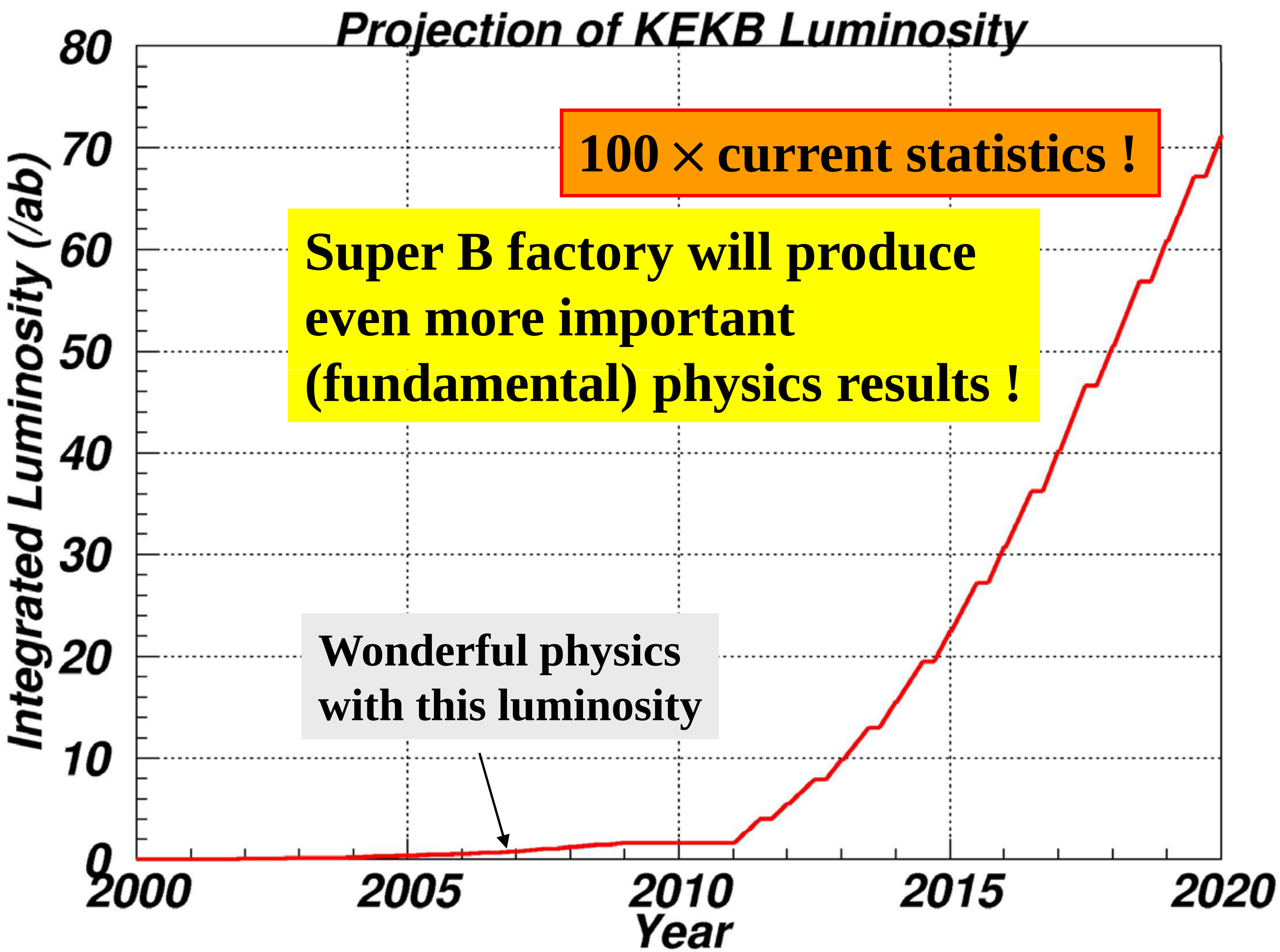
Estimated yields for 100/fb (6months)

Final state	Process	$\mathcal{B}_{est}$	ϵ_{recon} (%)	Events/100 fb^{-1}
$D_s^- \pi^+$	spectator	2.9×10^{-3}	0.81	220
$D_s^{*-} \pi^+$	spectator	2.8×10^{-3}	0.45	120
$D_s^- \rho^+$	spectator	7.7×10^{-3}	0.15	110
$D_s^{*-} \rho^+$	spectator	6.8×10^{-3}	0.081	52
$D_{sJ}^-(2317)\pi^+$	spectator	7.3×10^{-4}	0.28	19
$J/\psi\phi$	color suppressed spectator	1.3×10^{-3}	1.3	180
$J/\psi\eta$	color-suppressed spectator	8.5×10^{-4}	0.56	45
$J/\psi\eta'$	color-suppressed spectator	$xx \times 10^{-3}$	xx	xx
$D_s^+ D_s^-$	spectator	8.0×10^{-3}	0.020	19
$D_s^{*+} D_s^-$	spectator	2.0×10^{-2}	0.0099	19
$D_s^{*+} D_s^{*-}$	spectator	1.9×10^{-2}	0.0052	15
$\phi\gamma$	$b \to s$ penguin	4.0×10^{-5}	5.9	22
$\bar{D}^0 K_S$	color-suppressed spectator	3.0×10^{-4}	1.2	34
$D_s^- K^+$	spectator; ϕ_3	2.0×10^{-4}	0.64	12
$K^- K^+$	$b \to s$ penguin, $b \to u$ spectator	4.0×10^{-5}	9.5	36
$K^+ \pi^-$	$b \to s$ penguin, $b \to d$ penguin	5.0×10^{-6}	8.7	4.1
$\gamma\gamma$	intrinsic penguin	1.0×10^{-6}	20.0	1.9

Why are B factories so successful ?

- Great ideas (tCPV, innovative collider design)
- Clear target luminosity from physics requirement
- Competition between two B factories
- Simple physics goal
  - Discover CP violation in the B meson system !
- Large variety of measurements
  - Different star results every year → press release every year
- New ideas for measurements after the experiments started
  - Dalitz analysis for $\phi 3$
  - 3-body CP eigenstates (KsKsKs etc.)
  - Vertexing with Ks and IP constraint (Ks π^0 etc.)
- Constant improvements
  - continuous injection
  - sophisticated flavor tagging εeff = 20% → 30%

Integrated Luminosity Projection for SuperKEKB

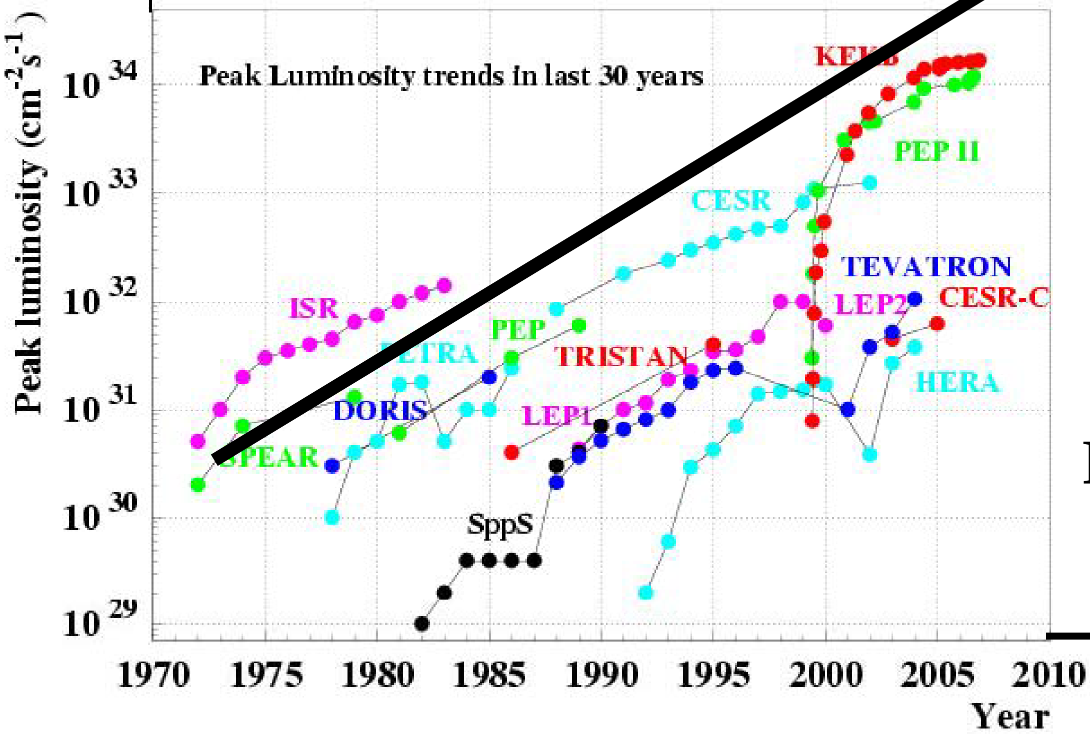


Peak Luminosity History and Prospects

10^{39}

2046

32



2050

L = 10^{39}/cm²/s in 2046 sounds more impressive than 100TeV collider !

Flavor physics will continue beyond your retirement.

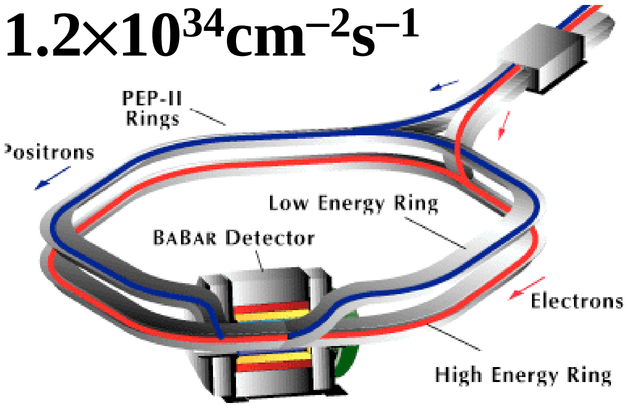
Backup Slides

Two asymmetric-energy *B* factories

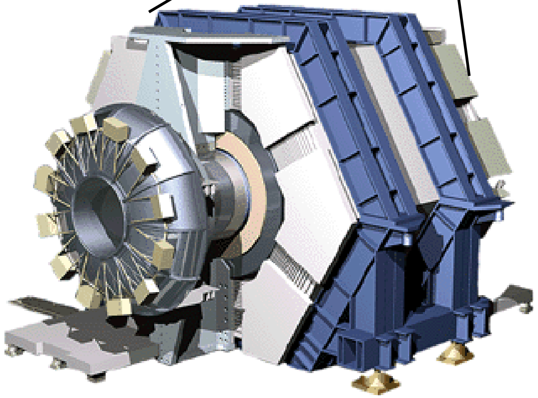
PEP-II at SLAC

9GeV (e^-) $\times$ 3.1GeV (e^+)
peak luminosity:

$1.2\times10^{34}cm^{-2}s^{-1}$

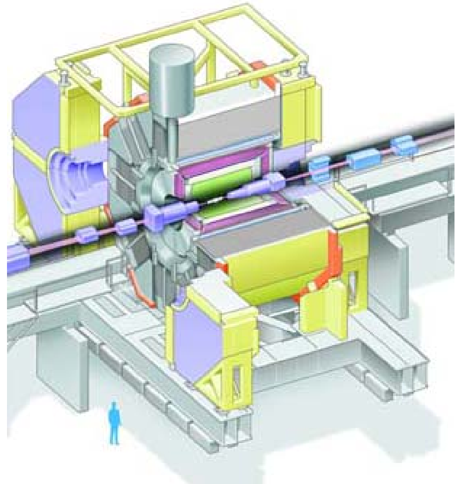


BaBar

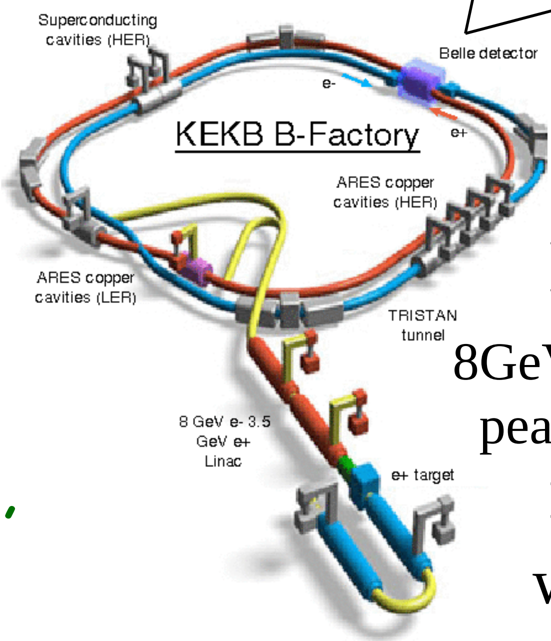


11 nations,
80 institutes,
623 persons

13 countries,
57 institutes,
~400 collaborators



Belle



KEKB at KEK

8GeV (e^-) $\times$ 3.5GeV (e^+)
peak luminosity:

$1.7\times10^{34}cm^{-2}s^{-1}$

world record

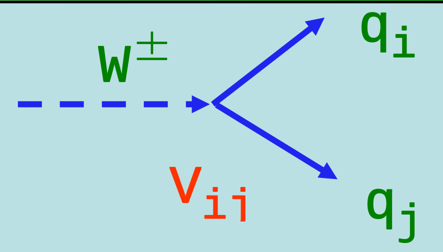
B Factory Physics Program

I. CP Violation in B Decays

II. Fundamental SM Parameters (Complex Quark Couplings)

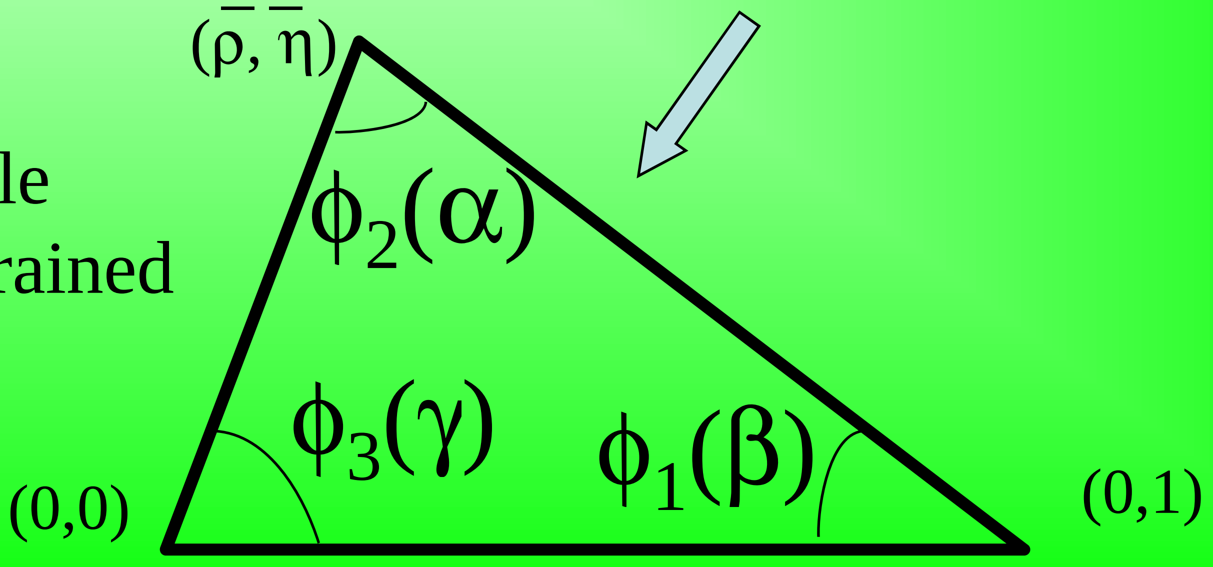
III. Beyond the SM (BSM)

IV. Unanticipated New Particles



Cabibbo-Kobayashi-Maskawa (CKM) matrix

Unitarity Triangle being overconstrained at B factories

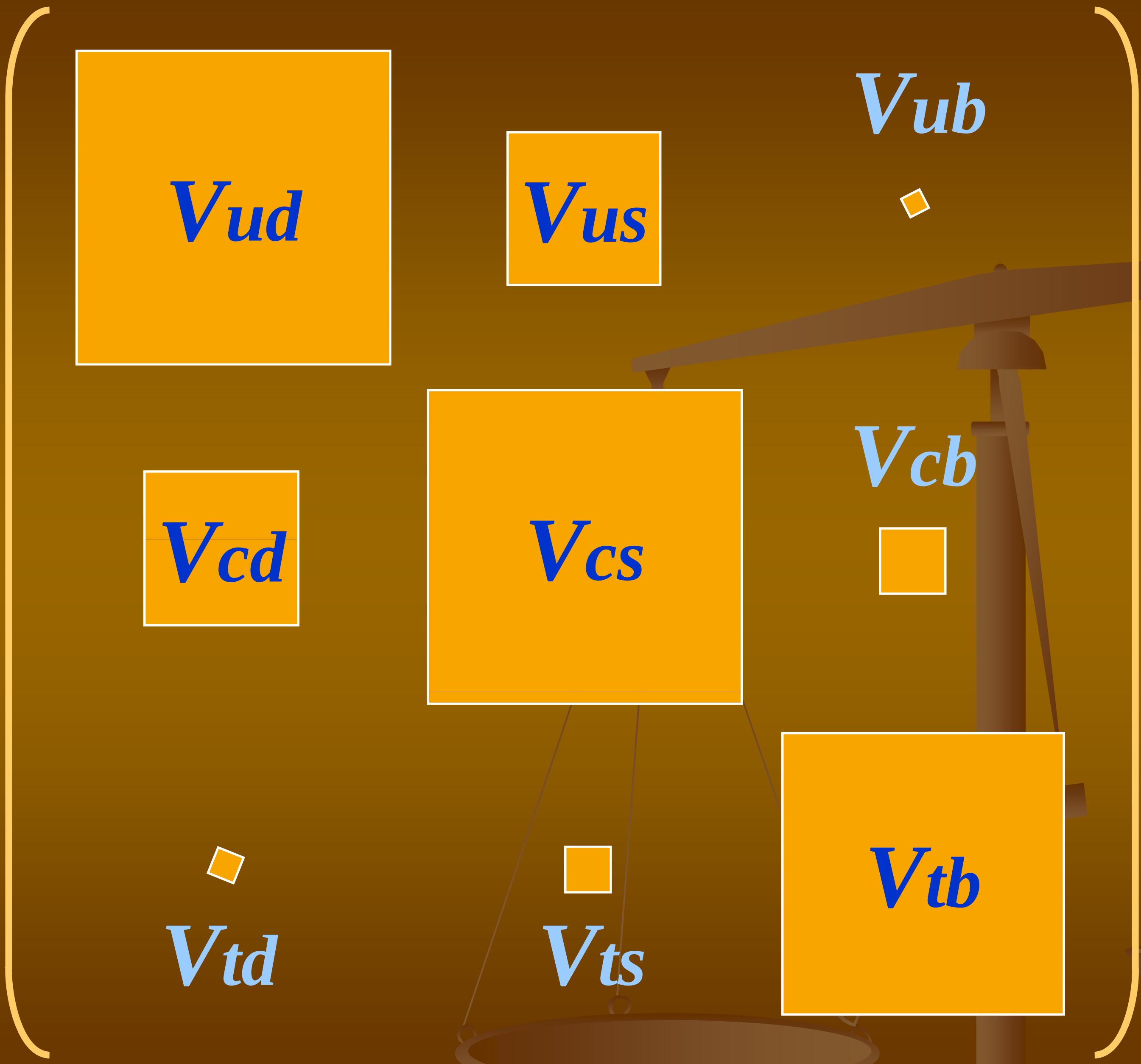


Some Statistics on B Factories

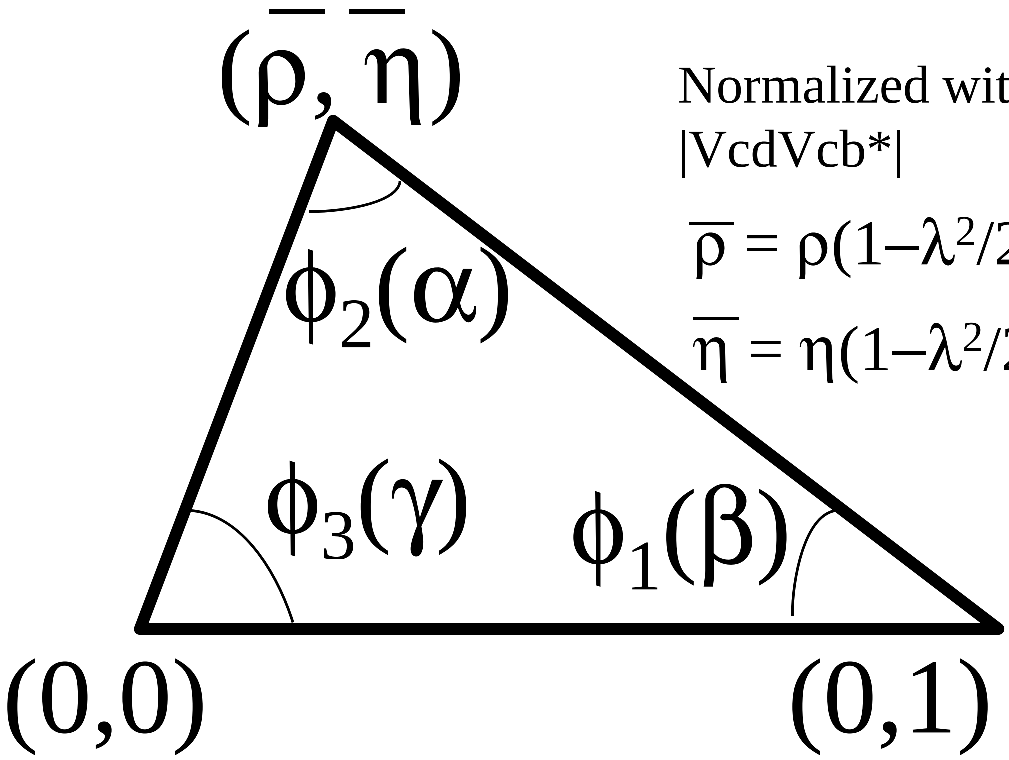
from spires as of Mar. 27, 2007

	BaBar	Belle
# of “well-known” papers (≥50 citations)	33	41
Total # of papers	446	297
Total # of citations	8000	7571

+ many indirect citations through PDG/HFAG citations


Vud
Vus
Vub
Vcd
Vcs
Vcb
Vtd
Vts
Vtb

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



Normalized with |VcdVcb*|

$\bar{\rho} = \rho(1-\lambda^2/2)$

$\bar{\eta} = \eta(1-\lambda^2/2)$

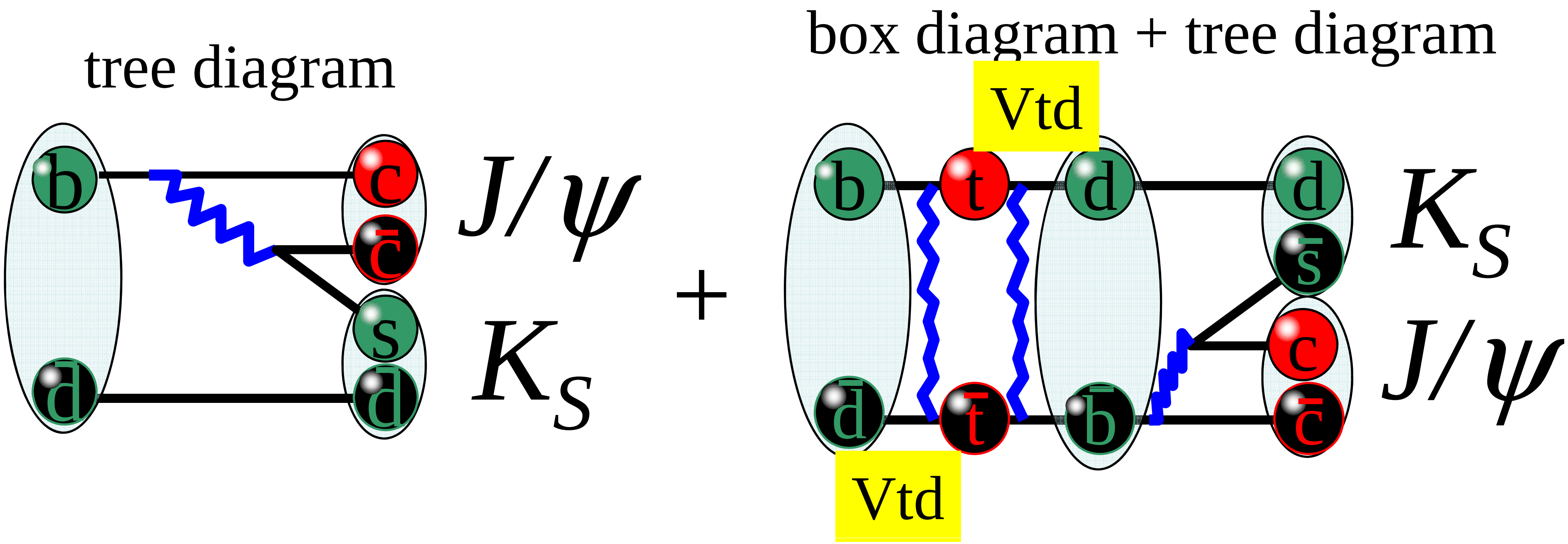
$$V_{ub} = |V_{ub}| \exp(-i\phi_3)$$

$$V_{td} = |V_{td}| \exp(-i\phi_1)$$

Time-dependent *CP* violation (t*CP*V)

"double-slit experiment" with particles and antiparticles

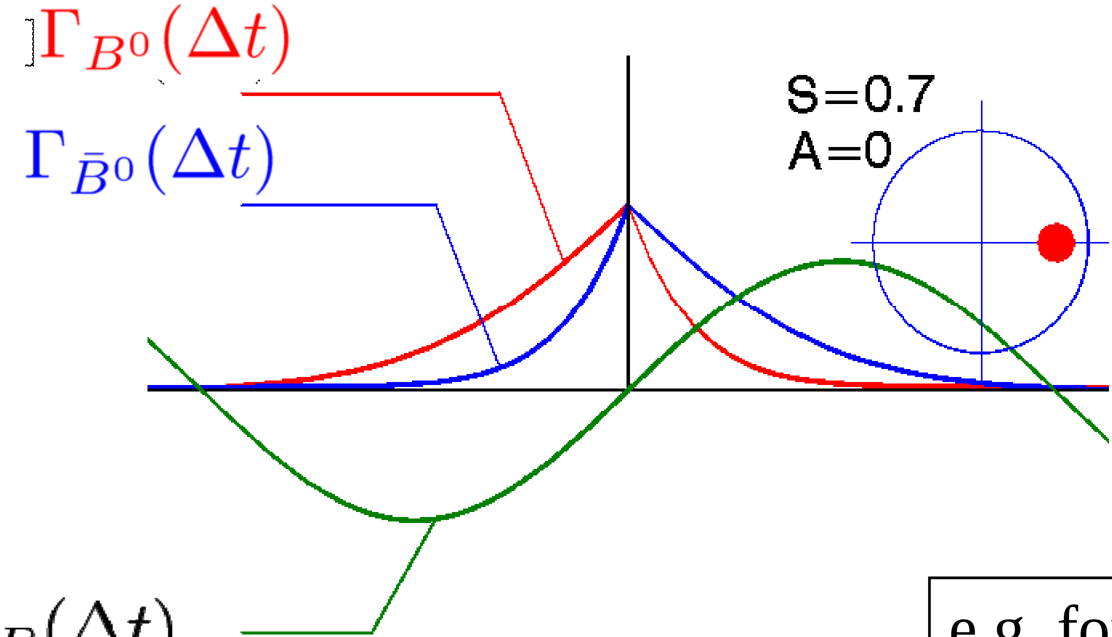
Quantum interference between two diagrams



$$V_{td} = |V_{td}| exp(-i\phi_1)$$

You need to "wait" (i.e. Δt≠0) to have the box diagram contribution.

t*CP*V in B^0 decays



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

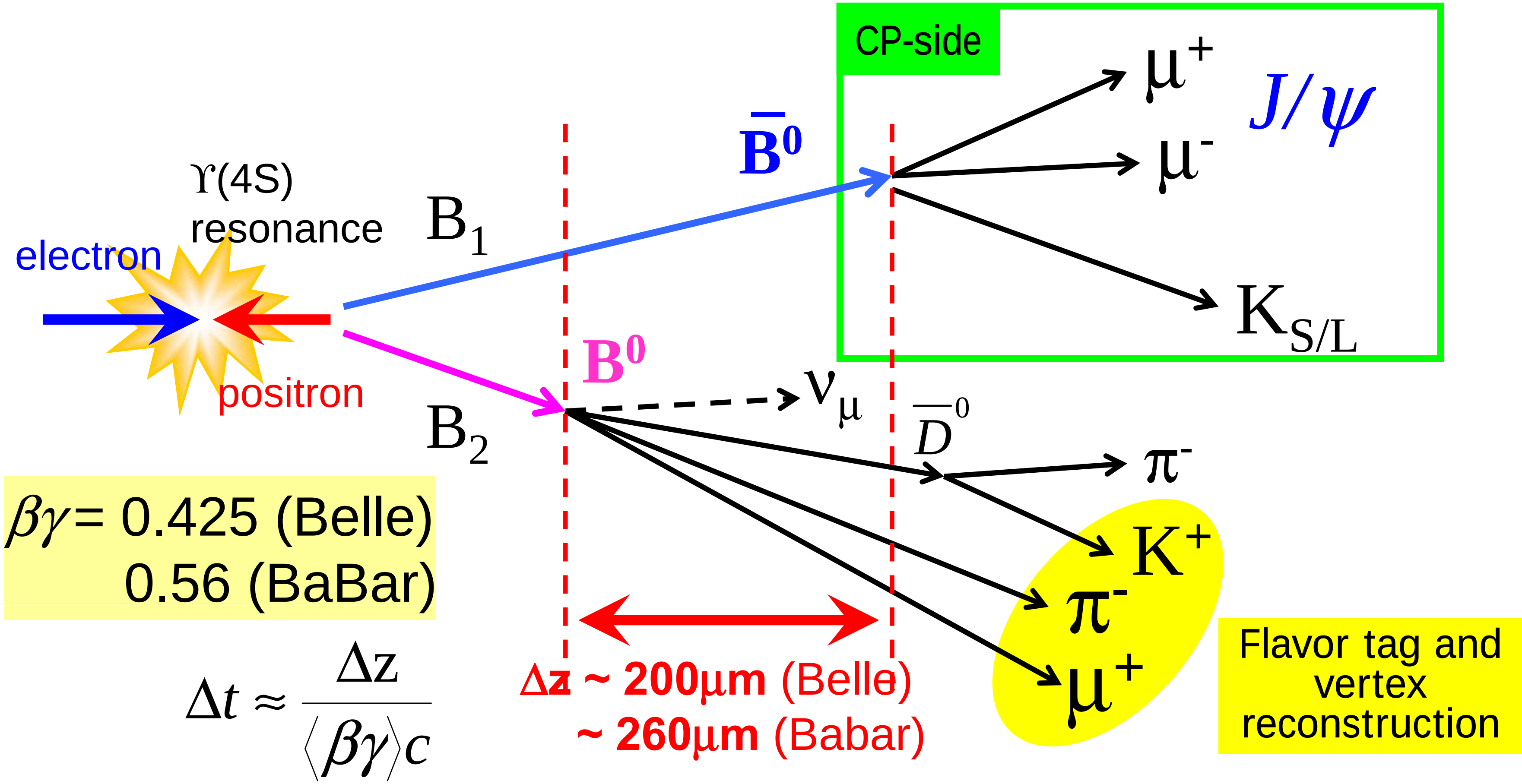
Mixing-induced CPV

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)

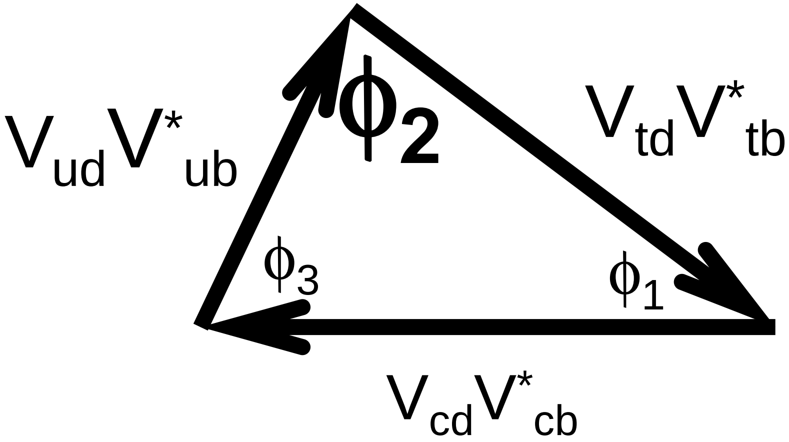
($\mathcal{A} = -C$ a la BaBar)

Principle of t*CP*V measurement



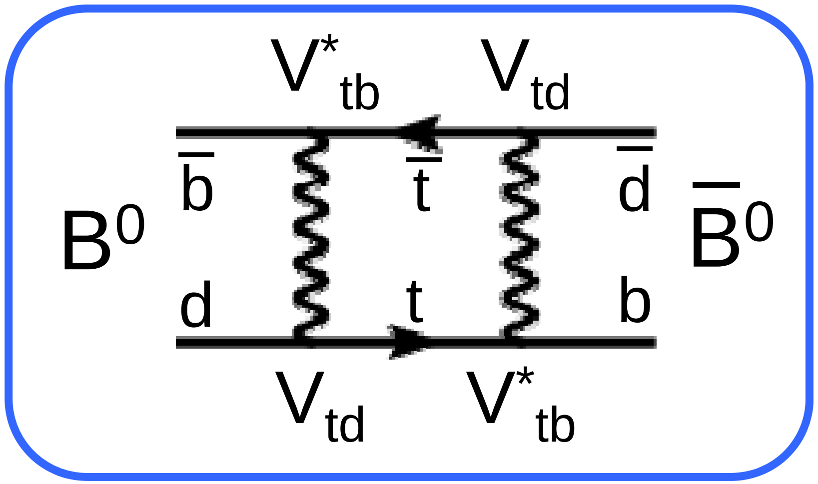
1. Fully reconstruct one B-meson which decays to CP eigenstate
2. Tag-side determines its flavor (effective efficiency = 30%)
3. Proper time (Δt) is measured from decay-vertex difference (Δz)

t*CP*V and ϕ_2 (α)

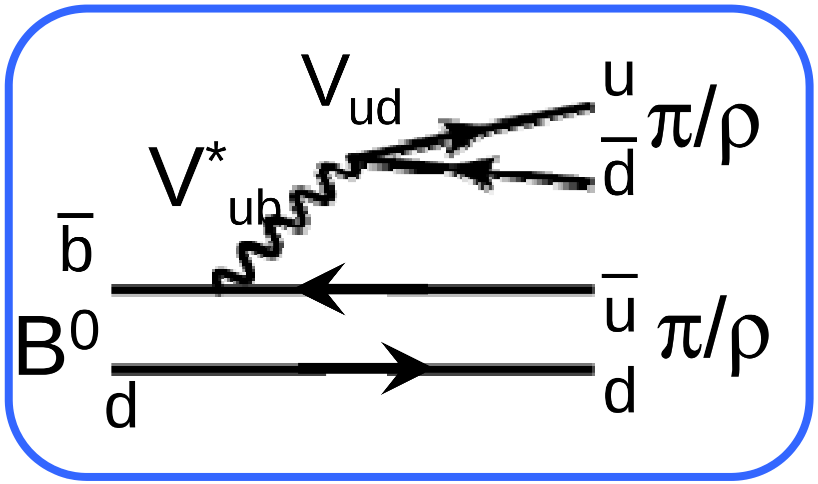


With the tree diagram only

$$\mathcal{S}_{\pi^+\pi^-} = +\sin 2\phi_2$$
$$\mathcal{A}_{\pi^+\pi^-} = 0$$



Mixing diagram

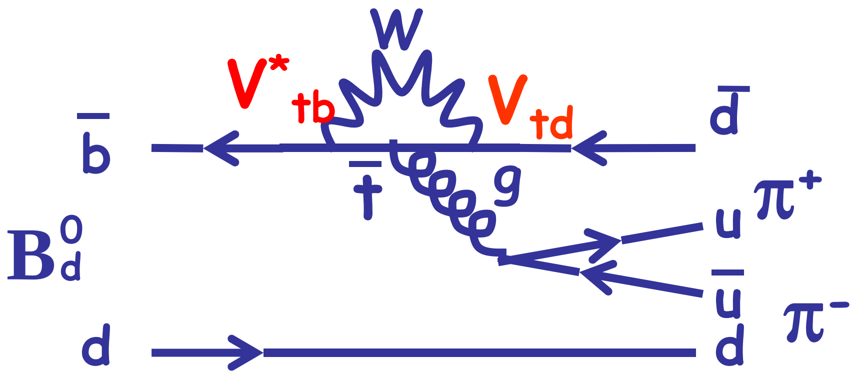


Decay diagram (tree)

3 measurements: $\pi\pi$, $\rho\rho$, $\rho\pi$

ππ :tough bananas

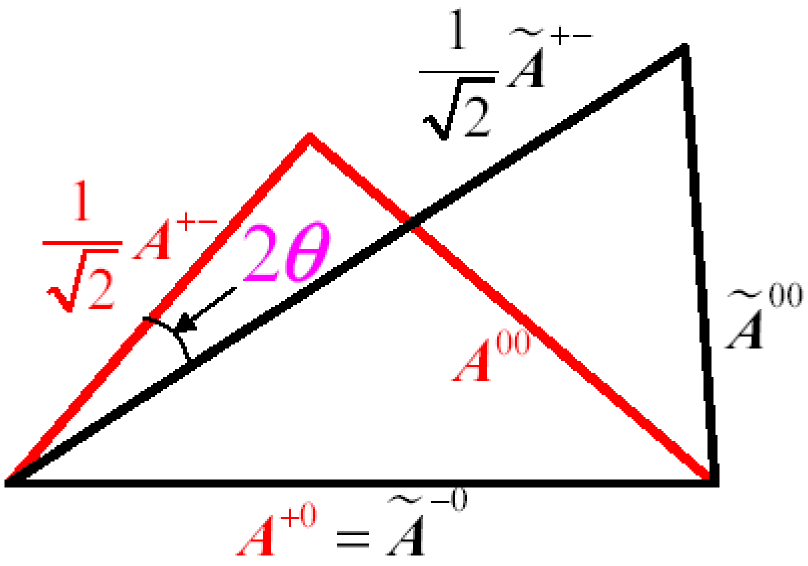
- $\mathcal{A}\pi\pi$ world average → observation of large direct *CP*V
- Large penguin diagram (P) ~ Tree diagram (T)
- Large strong phase difference between P and T



$$S_{\pi\pi} = \sqrt{1 - A_{\pi\pi}^2}\,\sin(2\phi_2^{eff}) \qquad \phi_2^{eff} = \phi_2 + \theta$$

Isospin analysis: flavor SU(2) symmetry

[Gronau-London 1990]



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

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

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

“Penguin pollution” can be removed by isospin analysis

Interpretation: Direct CP violation+SU(3)

The results support the expectation from SU(3) symmetry that

$$A_{CP}(\pi^+\pi^-) \sim -3A_{CP}(K^+\pi^-)$$

N.G. Deshpande and X.-G. He, PRL 75, 1703 (1995)

M. Gronau and J.L. Rosner, PLB 595, 339 (2004)

$$A_{CP}(K^+\pi^-) = -0.093 \pm 0.015$$

HFAG summer 2006

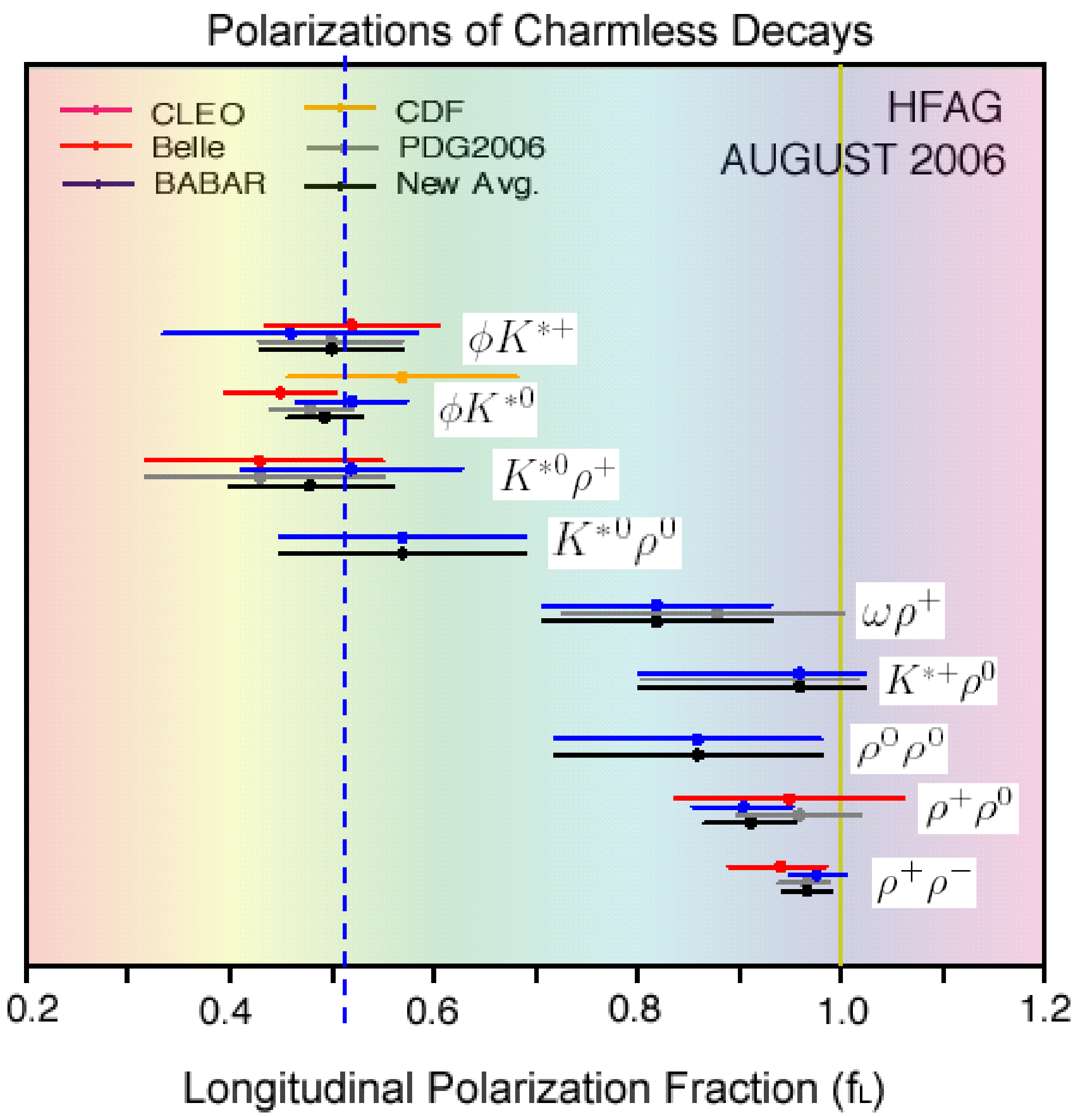
$$\Downarrow$$

$$A_{CP}(\pi^+\pi^-) \sim +0.3$$

ICHEP2006 World Average

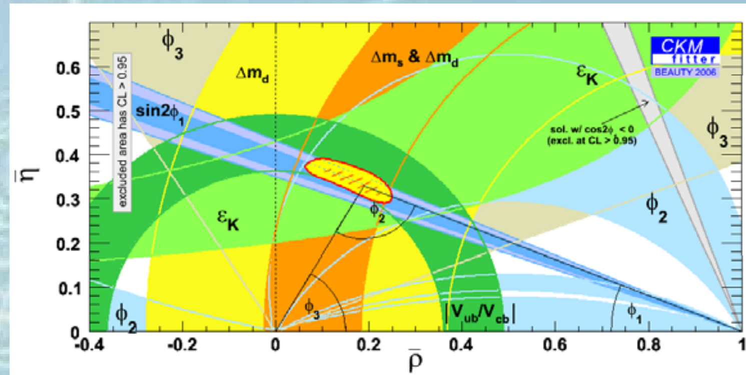
$$A_{CP}(\pi^+\pi^-) \sim +0.39 \pm 0.07$$

VV polarization



Experimental targets today and near future

Kobayashi-Maskawa (KM) model of *CP* violation is now a tested theory. No need to introduce an alternative framework.



Paradigm shift **at the beginning of 21st century thanks to two *B* factories.**

New targets

- **Effects of TeV new physics → deviations from SM**
- **LFV and new source of CPV**
- **Hidden flavor symmetry and its breaking**