Physics of Belle today and tomorrow and the day after tomorrow

Masashi Hazumi (KEK)

February 16, 2004
KEKB Review

Outline

- Today (Feb. 2004)
  - Results with 140 fb^{-1}
- Tomorrow (Aug.2004 ~ Aug. 2007)
  - Prospects up to ~500 fb^{-1}
- The day after tomorrow (2008 ~)
  - SuperKEKB: 5~50 ab^{-1}

Today

results with 140 fb^{-1}

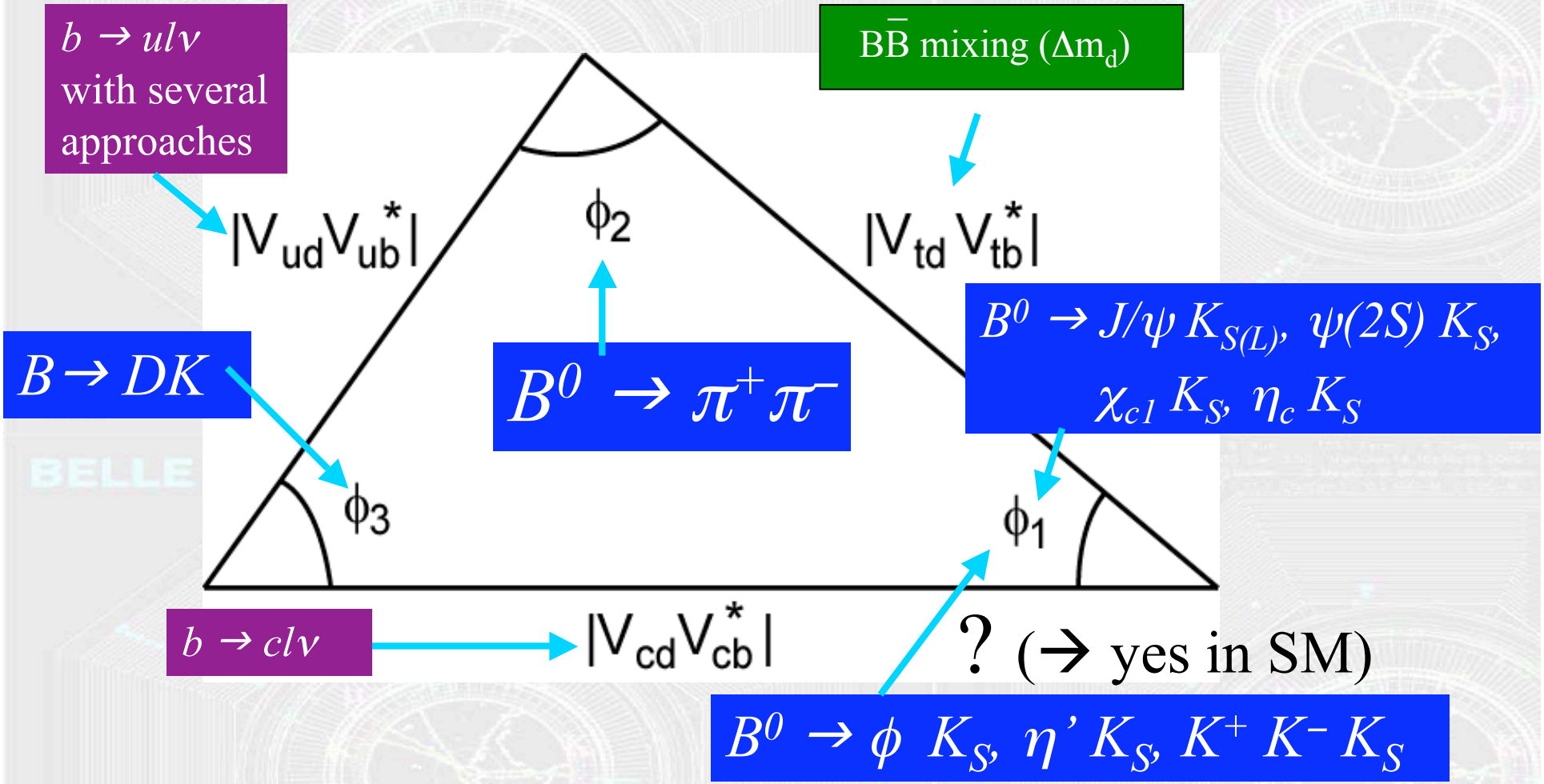
Mission

- Test of Kobayashi-Maskawa model of *CP* violation
  - Time-dependent *CP* violation
  - Unitarity Triangle determination

- Study rare B decays to find a hint of new physics
  - "Penguin" decays

Many other topics (new *B* decays, charm, tau etc.), which I do not have time to show !

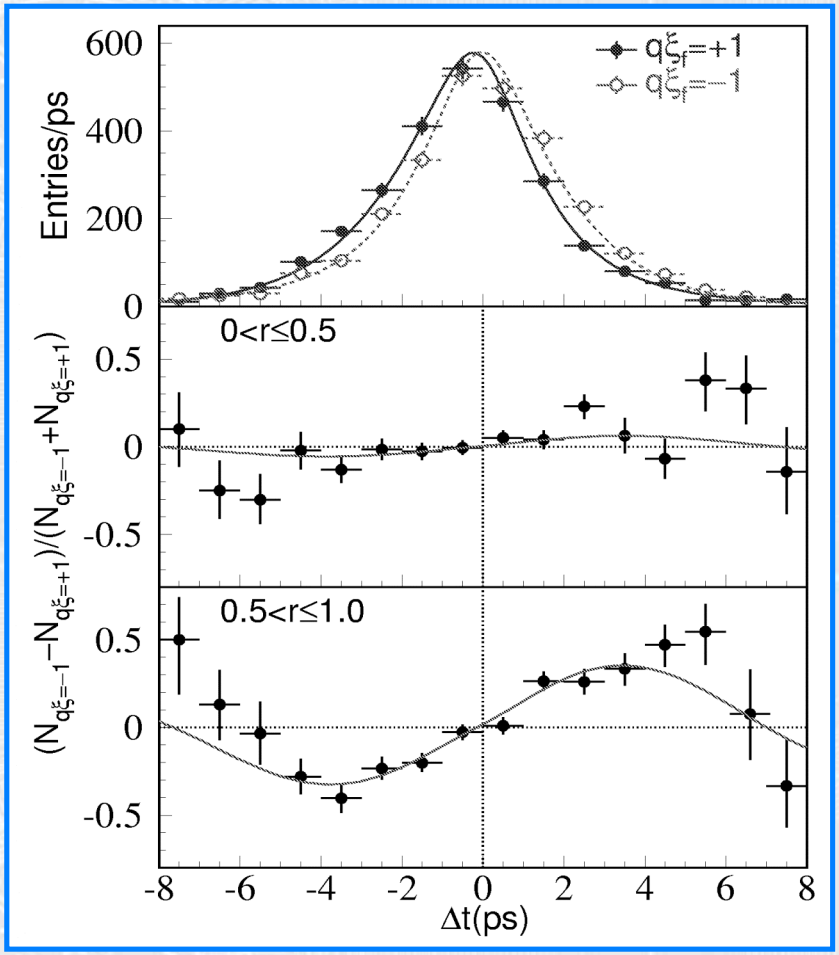
Unitarity Triangle determination at Belle



ϕ_1: Time-dependent *CP* violation in $B^0 \to J/\psi\, Ks$ etc.

$\sin 2\phi_1 = 0.733 \pm 0.057(\text{stat}) \pm 0.028(\text{syst})$

Belle
Aug. 2003



precision
= 9% !

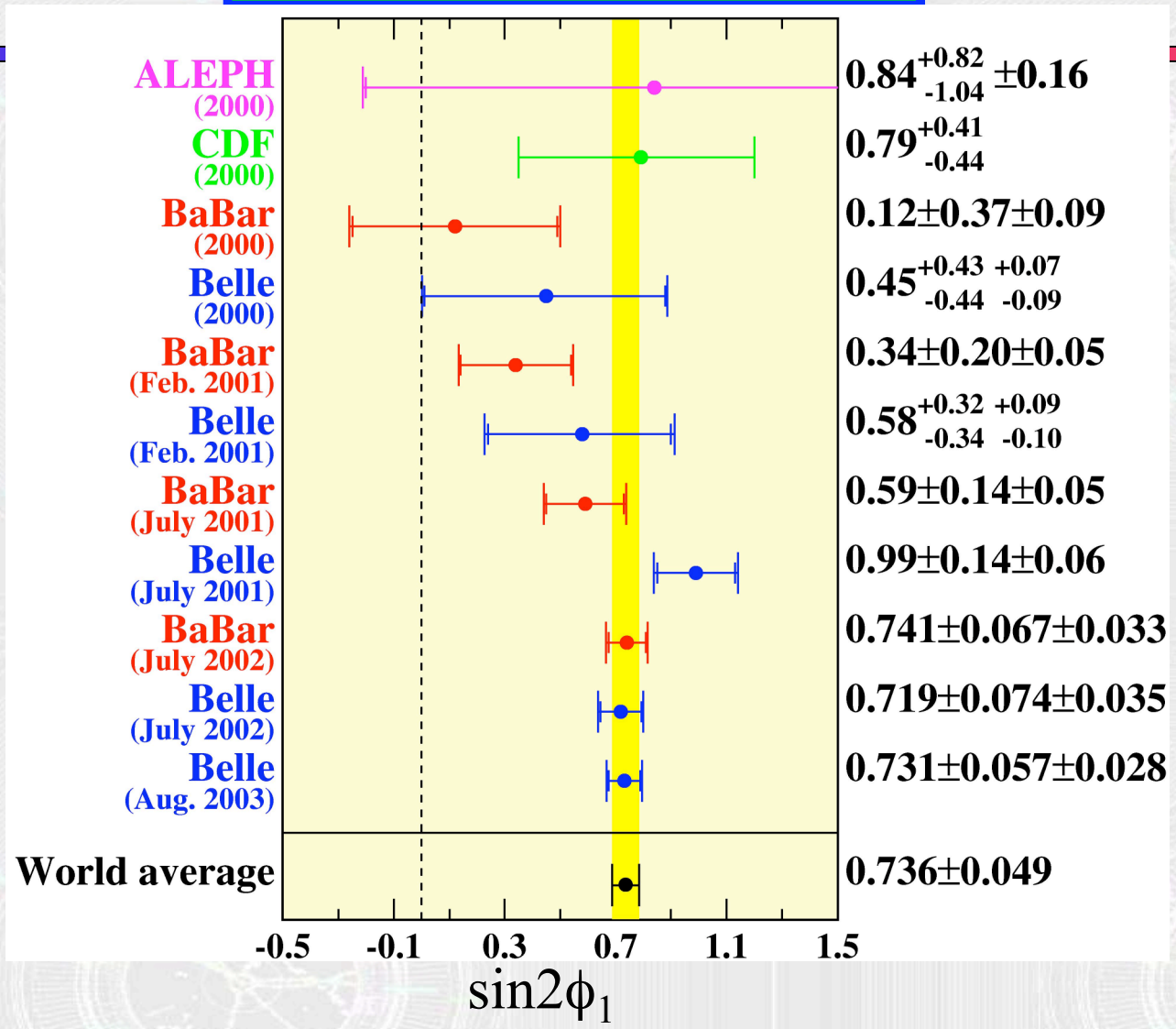
Poor tags

Good tags

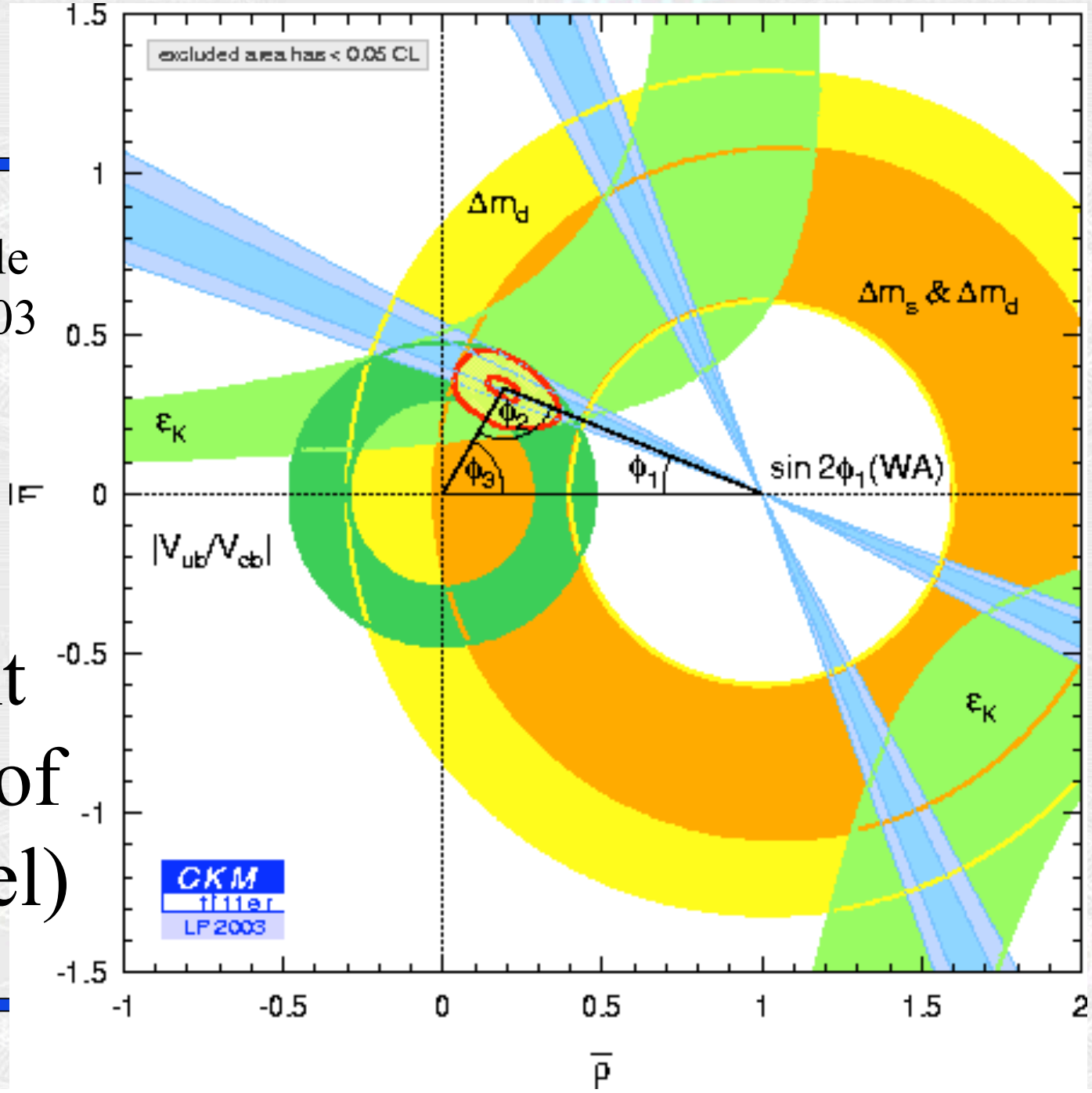
$|\lambda_{ccs}| = 1.007 \pm 0.041(\text{stat})$

i.e., consistent with
no direct CPV.

$\sin 2\phi_1$ history



Unitarity triangle as of August 2003



Beautiful agreement (triumph of KM model)

ϕ_2: Paper submitted in Jan. 04

Belle
140fb^{-1}

hep-ex/0401029,
submitted to PRL
on Jan. 18, 2004

KEK preprint 2003-110
Belle preprint 2004-1

BELLE

Observation of Large CP Violation and Evidence for Direct CP Violation in $B^0 \to \pi^+\pi^-$ Decays

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Observation of Large CP Violation and Evidence for Direct CP Violation in $B^0 \to \pi^+\pi^-$ Decays

Abstract

We report the first observation of CP-violating asymmetries in $B^0 \to \pi^+\pi^-$ decays based on a 140 fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. We reconstruct one neutral B meson as a $B^0 \to \pi^+\pi^-$ CP eigenstate and identify the flavor of the accompanying B meson from its decay products. We apply an unbinned maximum likelihood fit to the distribution of the time intervals between the two B meson decay points. The fit yields the CP-violating asymmetry amplitudes $\mathcal{A}_{\pi\pi} = +0.58 \pm 0.15(\text{stat}) \pm 0.07(\text{syst})$ and $\mathcal{S}_{\pi\pi} = -1.00 \pm 0.21(\text{stat}) \pm 0.07(\text{syst})$. We rule out the CP-conserving case, $\mathcal{A}_{\pi\pi} = \mathcal{S}_{\pi\pi} = 0$, at a level of 5.2 standard deviations. We also find evidence for direct CP violation with a significance at or greater than 3.2 standard deviations for any $\mathcal{S}_{\pi\pi}$ value.

PACS numbers: 11.30.Er, 12.15.Hh, 13.25.Hw

CP violation at 5.2σ

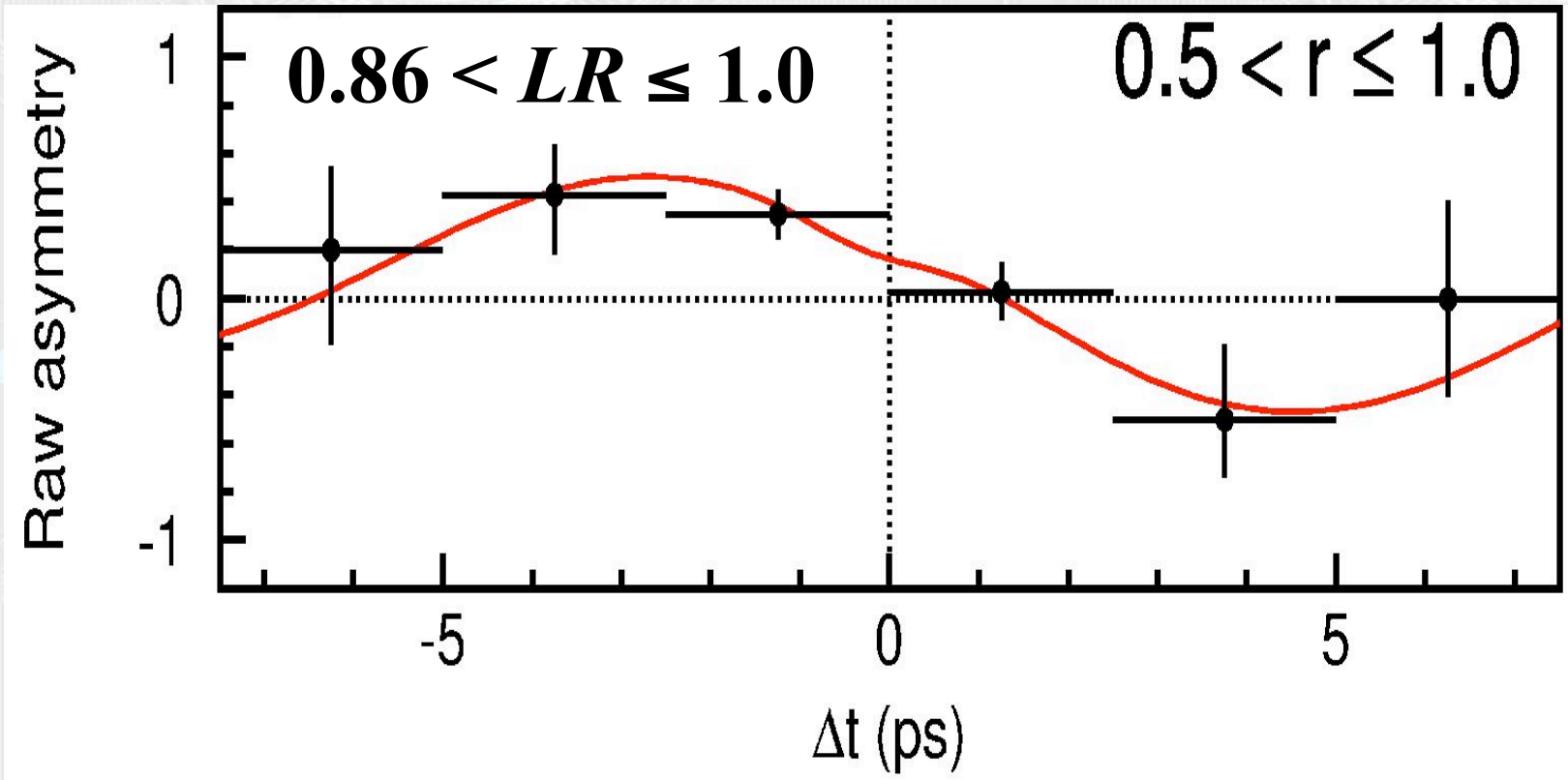
Results

Belle
140fb^{-1}

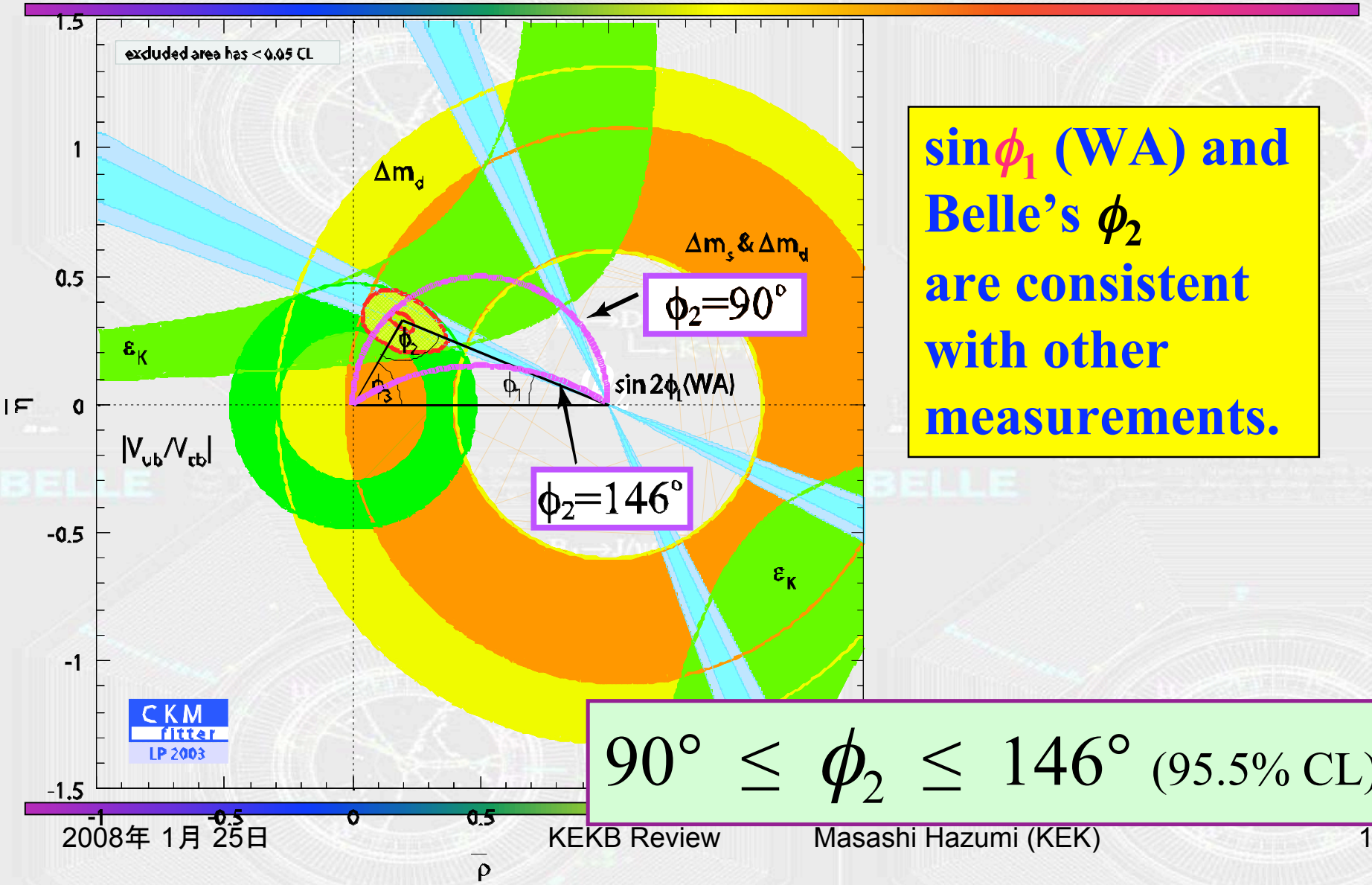
$A_{\pi\pi} = +0.58 \pm 0.15(\text{stat}) \pm 0.07(\text{syst})$

$S_{\pi\pi} = -1.00 \pm 0.21(\text{stat}) \pm 0.07(\text{syst})$

1529 ev.
(all *LR*-*r*
regions)



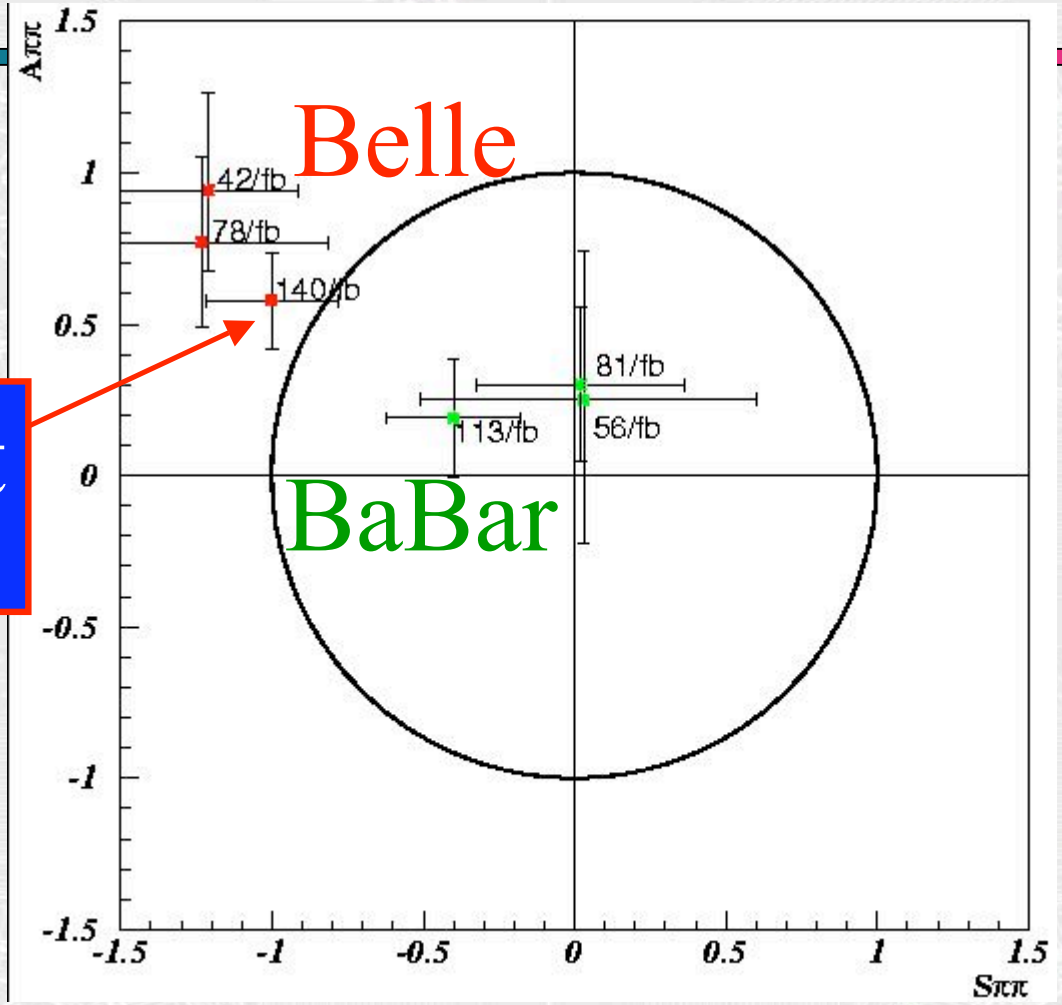
ϕ_2 "banana"



sinϕ_1 (WA) and Belle's ϕ_2 are consistent with other measurements.

$$90° \leq \phi_2 \leq 146° \text{ (95.5\% CL)}$$

History of $A_{\pi\pi}$ and $S_{\pi\pi}$



This result
Belle 140fb^{-1}

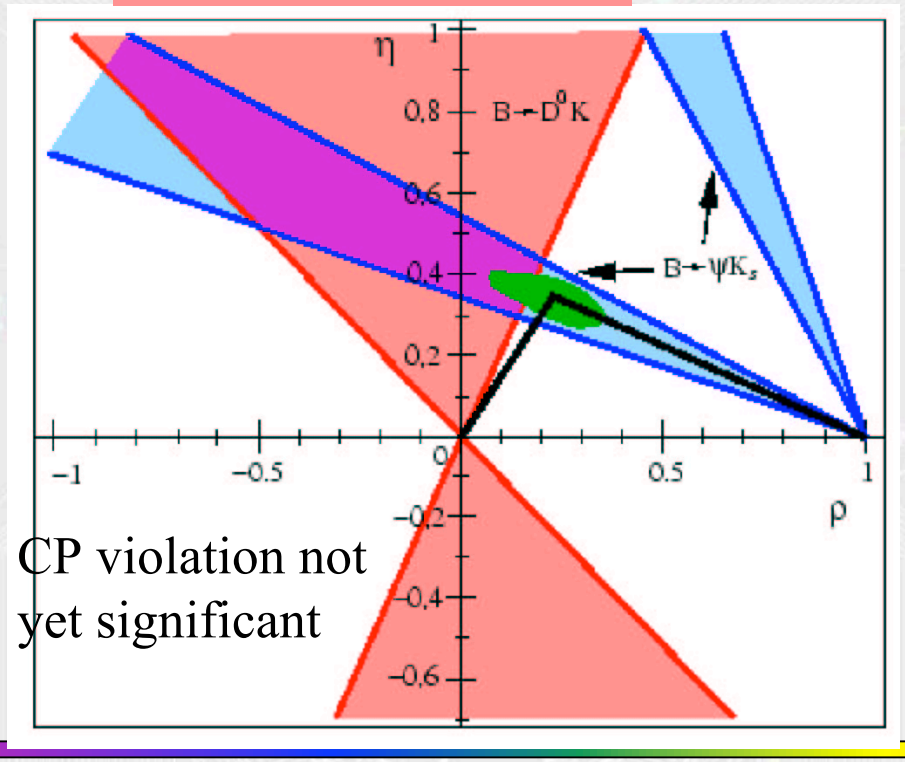
Difference at ~2σ level

ϕ_3 : the first constraint with a new method !

$B^{\pm} \to D(\to K_S\pi^+\pi^-)K^{\pm}$ hep-ex/0308043

140fb^{-1}

ϕ_3 (90% C.L.)



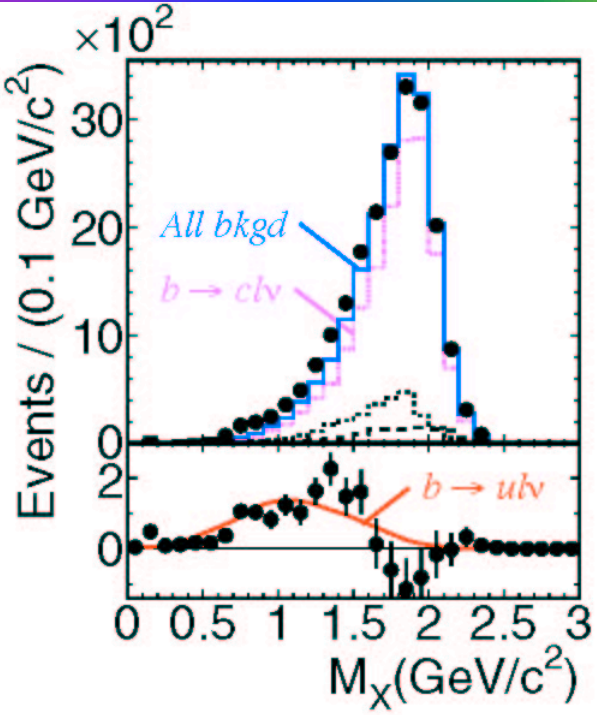
CP violation not yet significant

This is the result shown at the Lepton Photon Symposium in Aug. 2003

An improved results will be shown at Lake Louise this week !

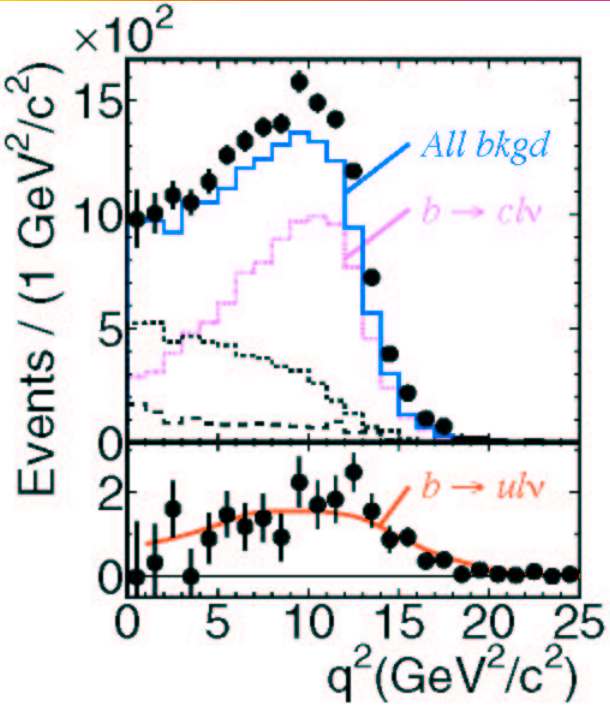
Vub with $B \to X_u\, l\, \nu$

hep-ex/0311048 (accepted by PRL)



8910 events
$(78.1\,\mathrm{fb}^{-1})$

⇐ Signal ⇒



for $q^2 > 8.0\,\mathrm{GeV}^2/c^2$

for $M_X < 1.7\,\mathrm{GeV}/c^2$

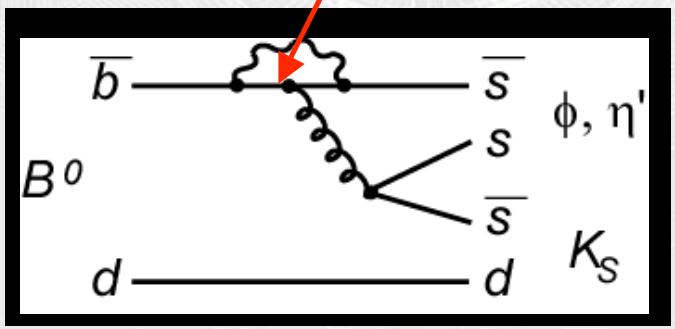
$$\Delta\mathcal{B} = (7.37 \pm 0.89 \pm 1.12 \pm 0.55 \pm 0.24) \times 10^{-4}$$

$$|V_{ub}| = (4.66 \pm 0.28 \pm 0.35 \pm 0.17 \pm 0.08 \pm 0.58) \times 10^{-3}$$

(stat) (syst) $(b \to c)$ $(b \to u)$ (OPE)

Hint of new physics ?: CPV in $b \to \bar{s}ss$

virtual particle (top quark, and more ?)



Penguin diagram

CP violation "same" as $J/\psi Ks$ within the Standard Model

Penguin~$O(\lambda^2)$, Tree~$O(\lambda^4)$

deviation = O(1)%

Breakthrough to New Physics with loop (penguin) diagrams

Motivation

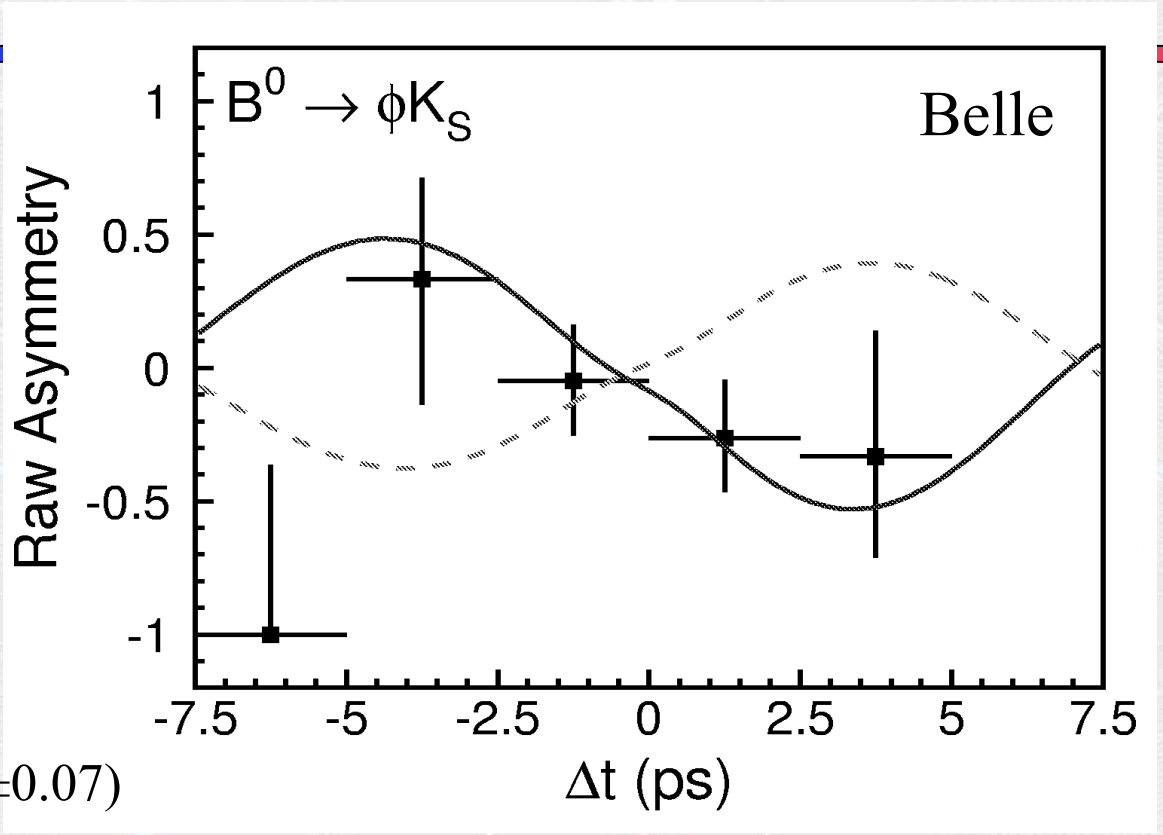
- One of the best places to discover physics beyond the standard model (SM) in the loop process

  Motivated by large θ23 neutrino mixing in GUT context, Atmospheric Neutrinos Can Make Beauty Strange !

- Toward understanding of the baryogenesis
  - More than one *CP* violating phase = breakthrough

Belle 2003: CP Asymmetry in B→φ K_S

140 fb^{-1}



(A=-0.15±0.29±0.07)

3.5σ off

Belle: $\sin 2\varphi_{1\text{eff}} = -0.96 \pm 0.50\ ^{+0.09}_{-0.11}$

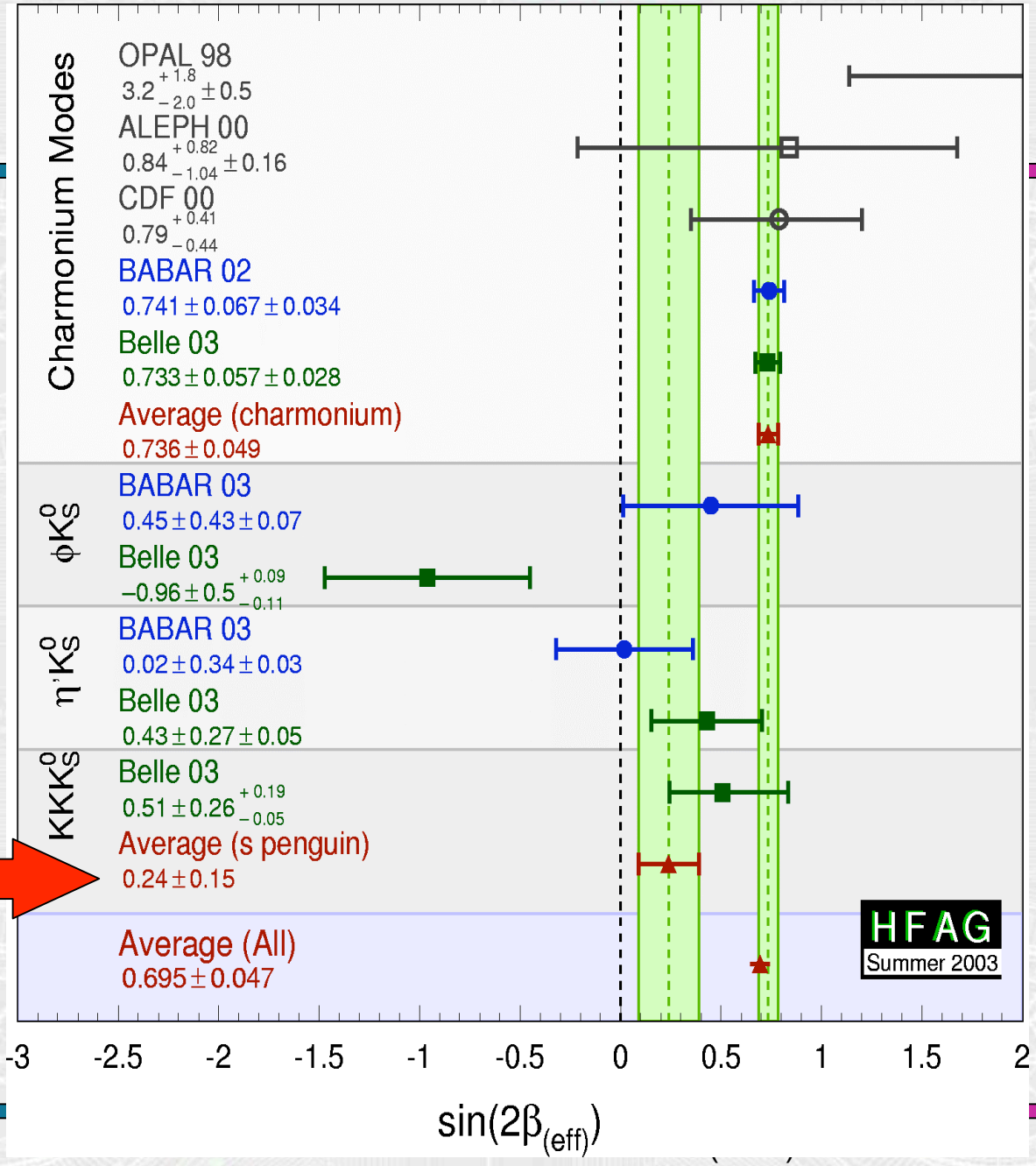
Current WA: $\sin(2\varphi_1)$=0.736±0.049

World average (Aug. 2003)

2.6σ

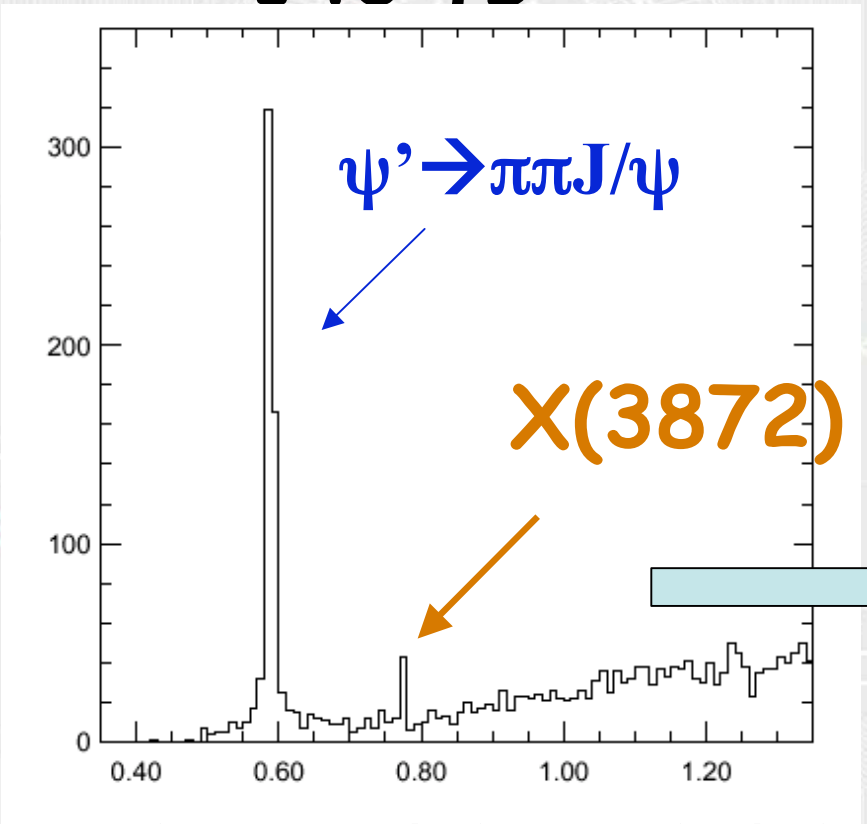
3.1σ

from “charmonium”



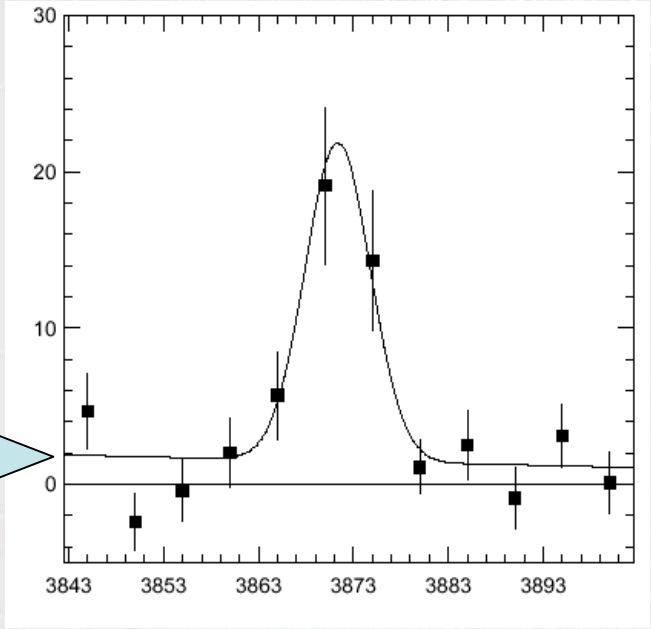
A Bonus: Charm of Belle

140 fb^{-1}



M($\pi^+\pi^-$ J/ψ) –M(J/ψ)

A new narrow resonance in $B^{\pm} \to J/\psi\pi^+\pi^-K^{\pm}$



M_X = 3872 ± 0.6 ± 0.5 MeV
Γ_{tot} < 2.3 MeV (90%CL)

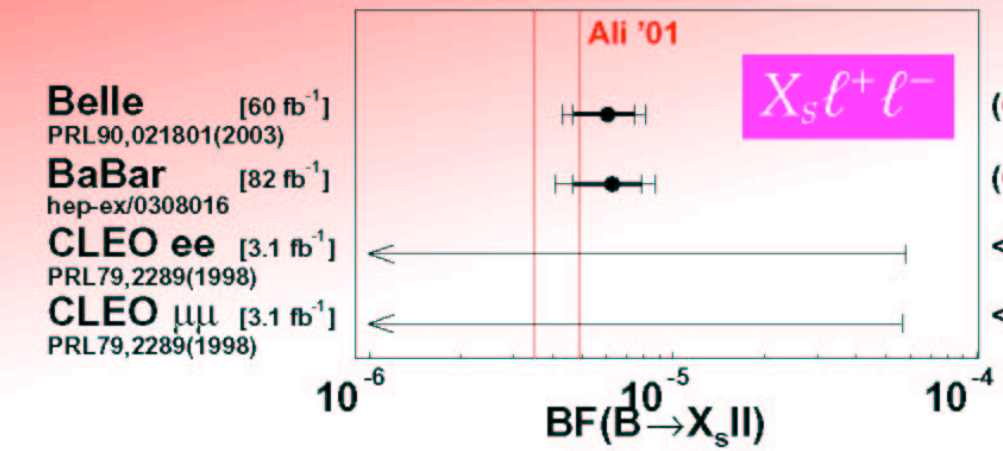
What could X(3872) be ?

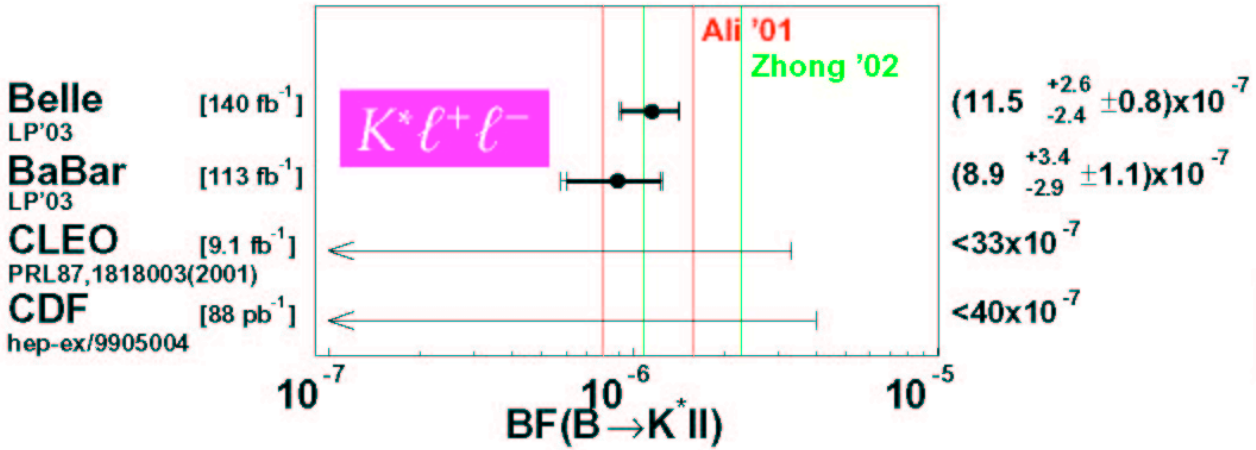
- Still no good charmonium candidate
- X(3872) very near the D*D threshold. Does it imply something ?
- Some more data analyses (e.g angular analysis) is in progress. Stay tuned.

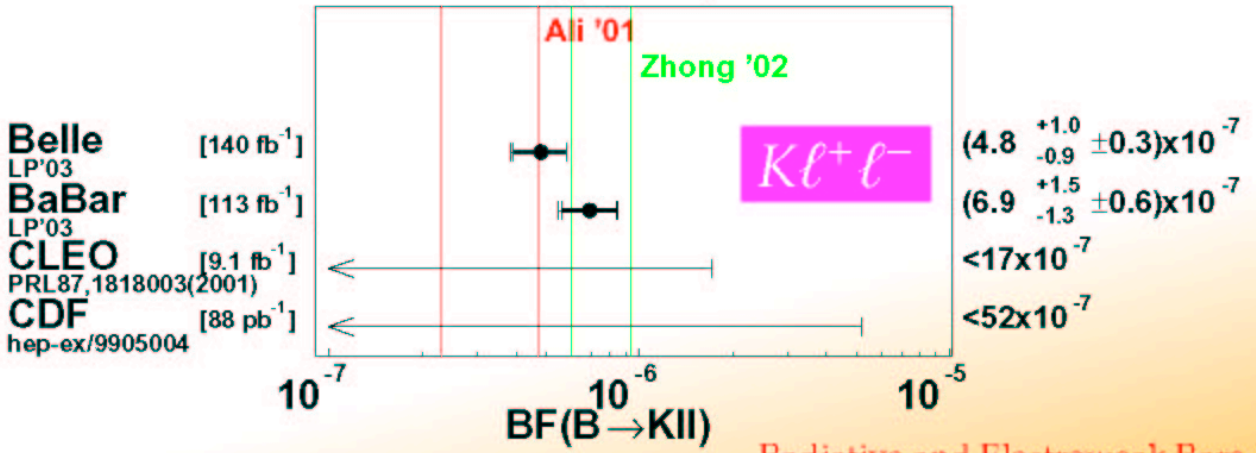
Summary (2003. Feb – 2004. Feb)

- $\sin 2\phi_1$ now measured with 9% accuracy !
- CP violatioin in $B^0 \to \pi^+\pi^-$ observed !
- First constraint on ϕ_3 !
- Improvement in Vub
- Tantalizing hint of new physics in b → s CP asymmetries
- New narrow resonance X(3872) !

… and many more new obesrvations for tomorrow !
(recall it is just a few years from the first obs. of $B^0 \to \phi$ Ks !







$$b \to s l^+ l^-$$

Mission completed!

$K^{(*)}\ell^+\ell^-$ and $X_s\ell^+\ell^-$ are all measured

next target:
Precise $X_s\ell^+\ell^-$,
q^2 and A_{FB}

Tomorrow

prospects up to ~500 fb^{-1}

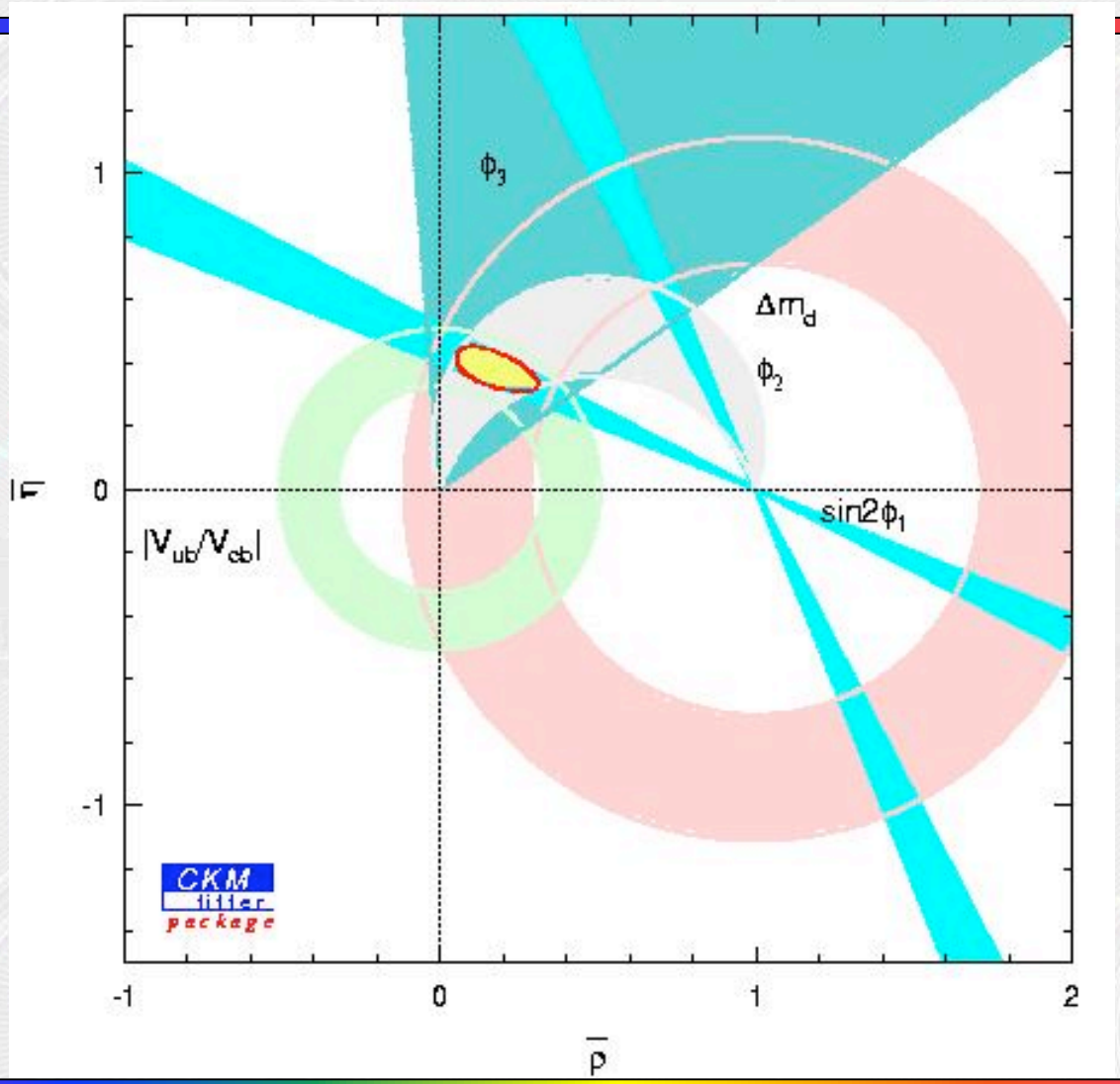
Main targets (2004. Feb – 2007. Aug)

- Global fit of the Unitarity Triangle (ϕ_1,ϕ_2,ϕ_3,Vub)
- Direct CP violatioin in $B^0 \rightarrow \pi^+\pi^-$ and other rare B decays
- Rare *B*, tau, charm decays
  - Search for new physics
  - Understanding QCD effective theories
- New particles
- Observation of a new CP-violating phase in b → s !?

will have exciting (hectic) time each summer

Expectation at 500 fb^{-1}

From Belle alone



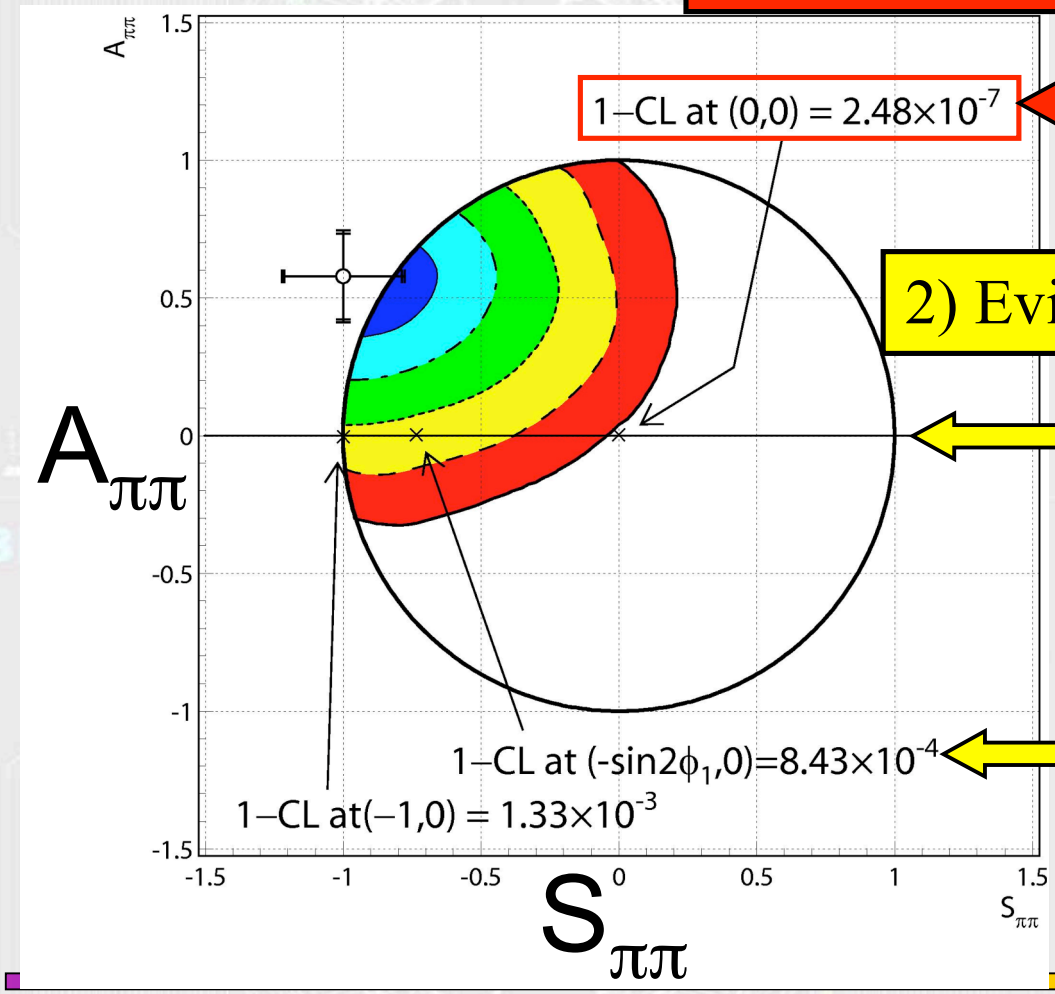
$B^0 \to \pi^+\pi^-$: Significance of *CP* violation

Belle
140fb^{-1}

Feldman-Cousins Analysis

1) Observation of *CP* violation

(5.2σ)



2) Evidence for direct *CP* violation

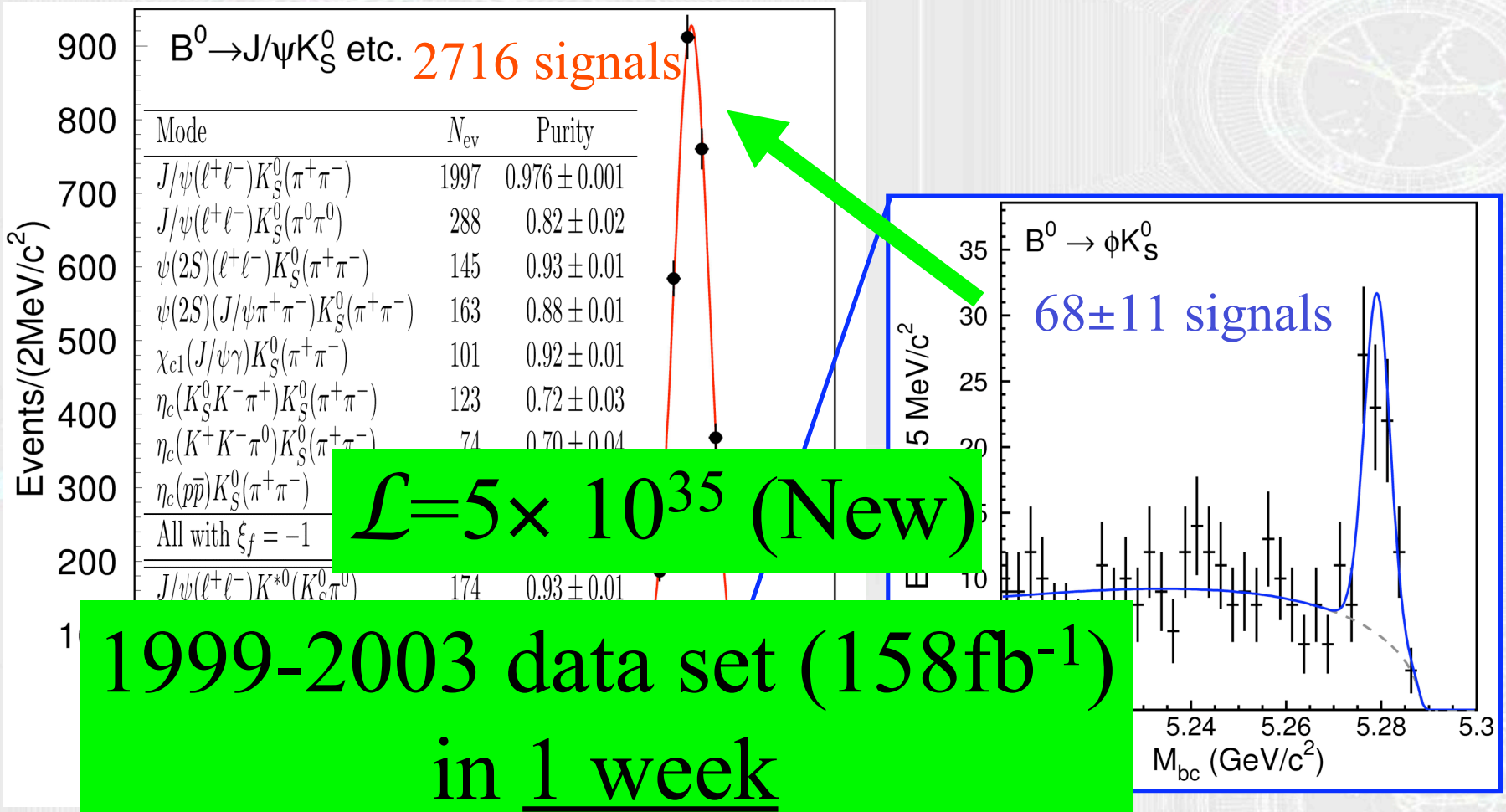
≥3.2σ
for $A_{\pi\pi}$=0 and any S_π

3.3σ
for "superweak" case

The day after tomorrow

SuperKEKB: 5~50 ab^{-1}

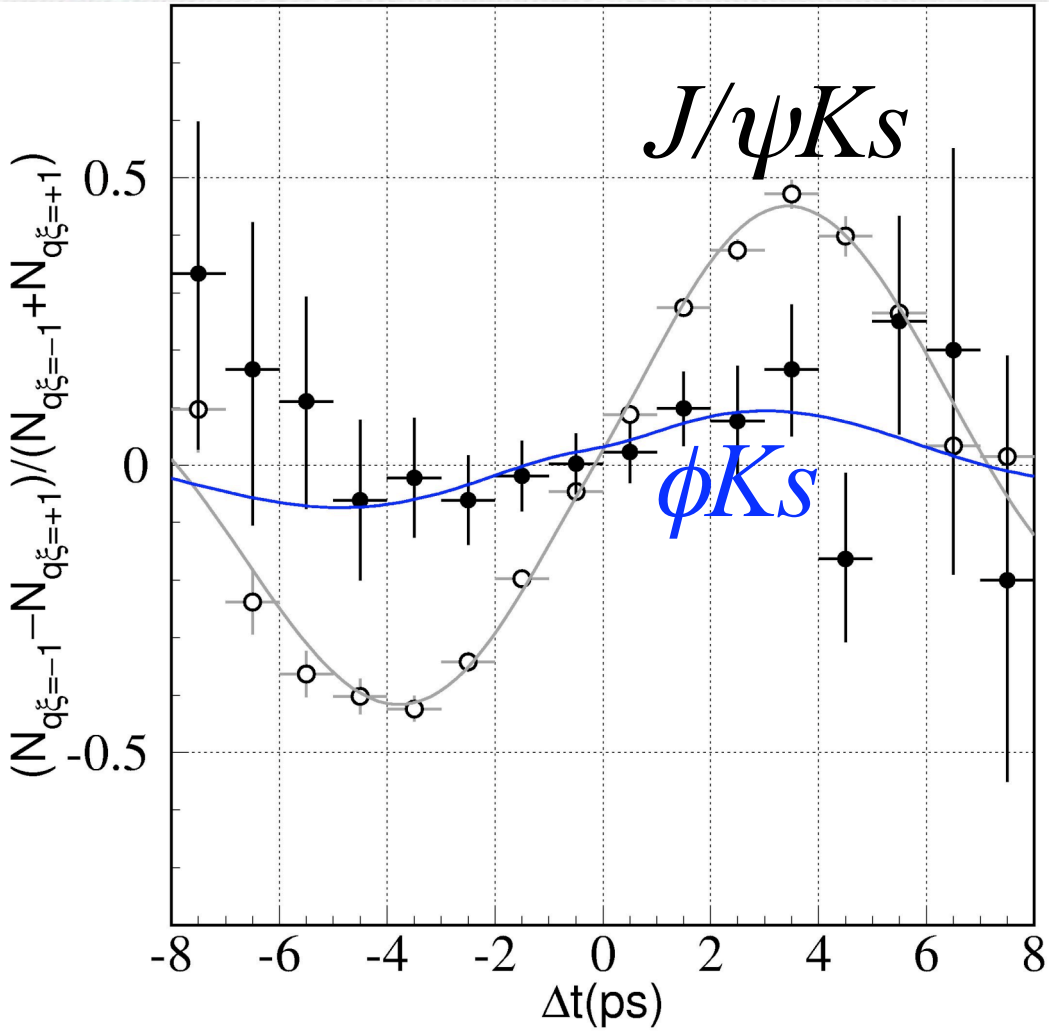
$B^0 \to (c\bar{c})Ks$ vs. $\phi\, Ks$



$\mathcal{L}$=5× 10^{35} (New)

1999-2003 data set (158fb^{-1})
in 1 week

One year operation (5 ab^{-1})

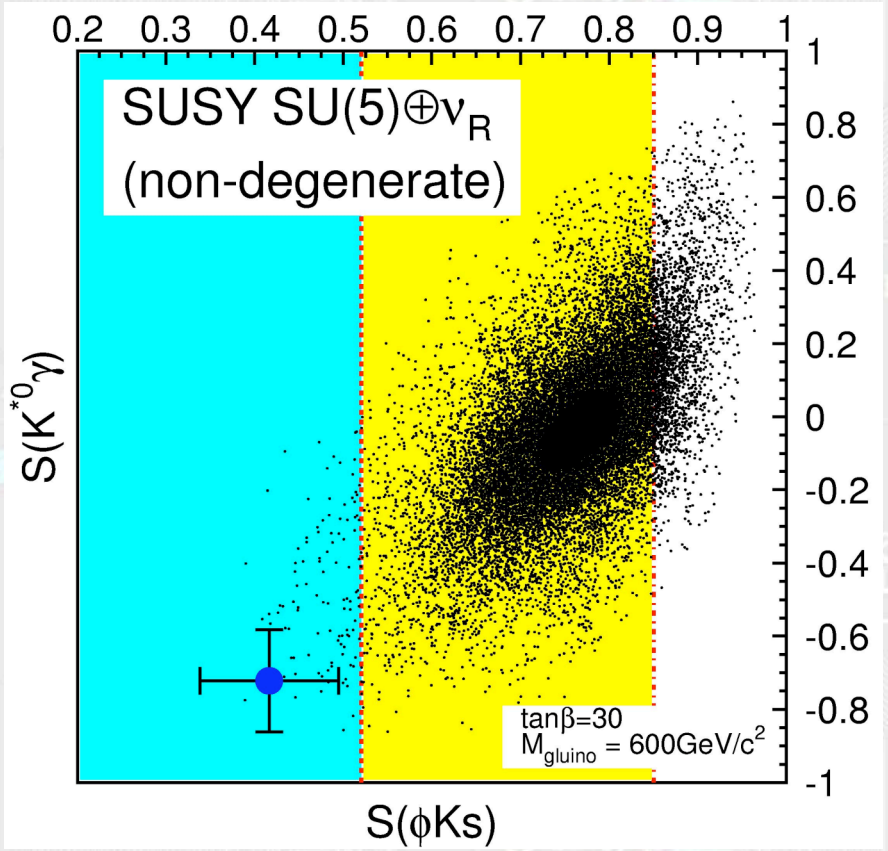


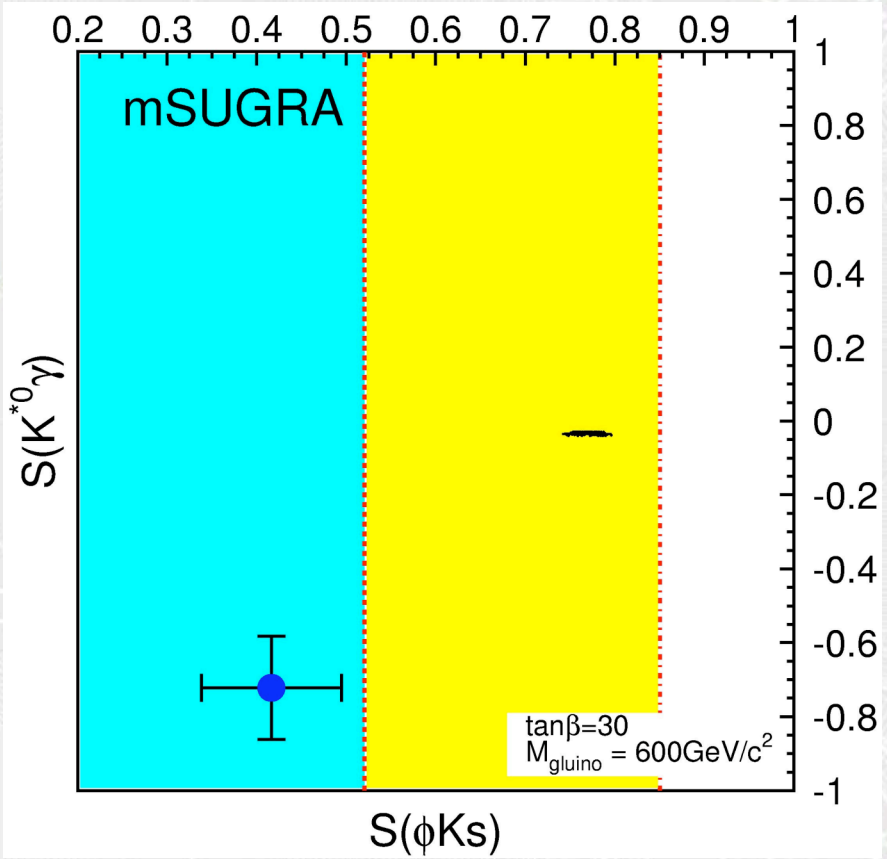
input:
present
b → s average

6.2σ with
ϕKs alone !

Distinguish different new physics models !

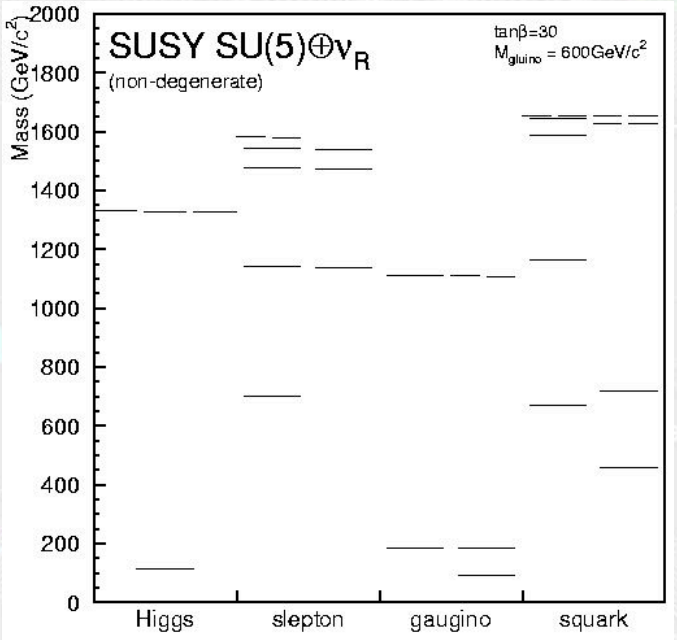
Different SUSY breaking scenarios can be distinguished !

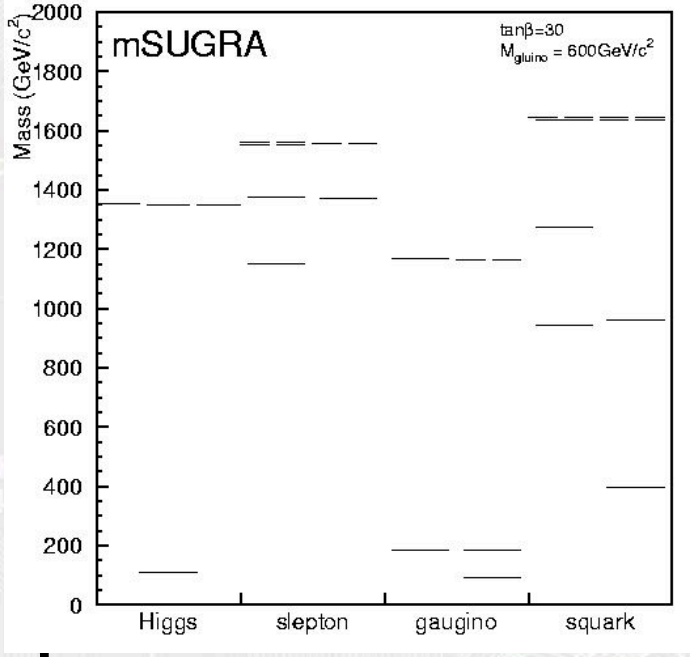




Doable with mass spectrum ?

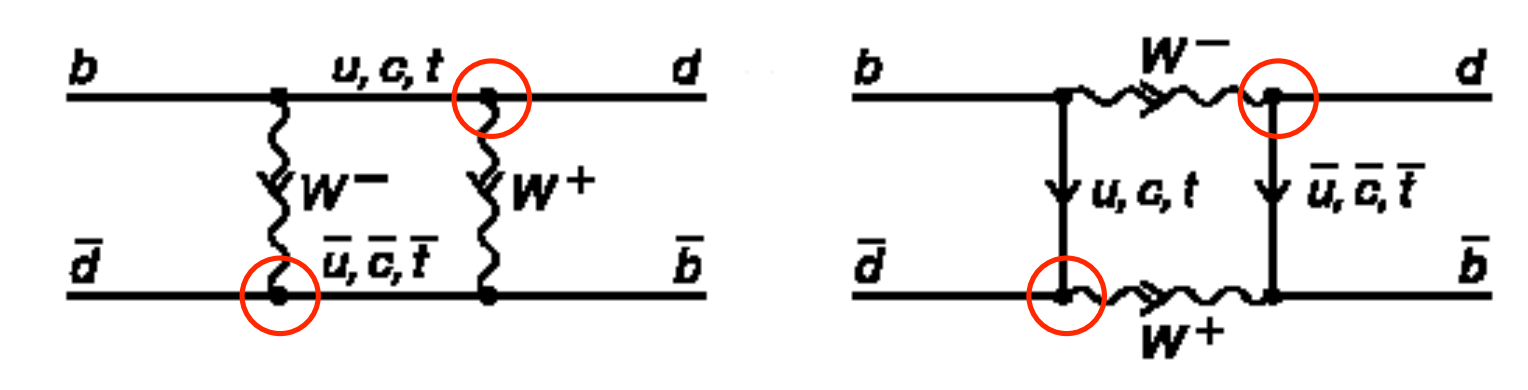
Very hard to distinguish different SUSY breaking scenarios from mass spectrum alone (at LHC)





quite similar

Energy frontier vs. Luminosity frontier



Top-quark physics

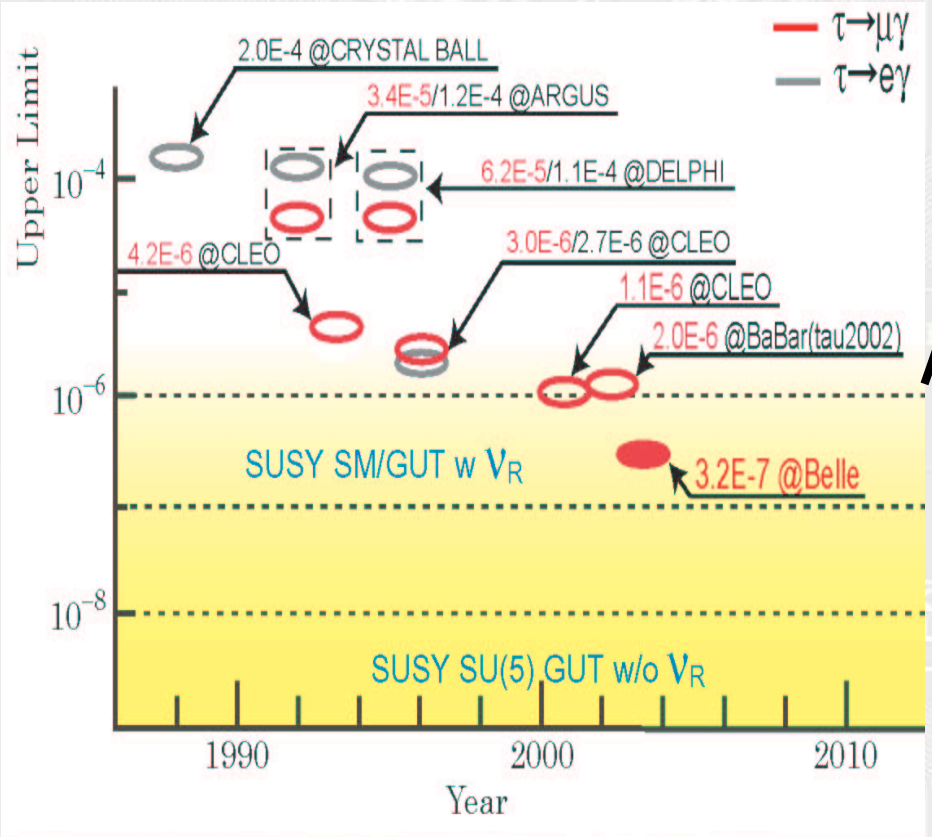
Direct production, Mass, width etc. → CDF/D0

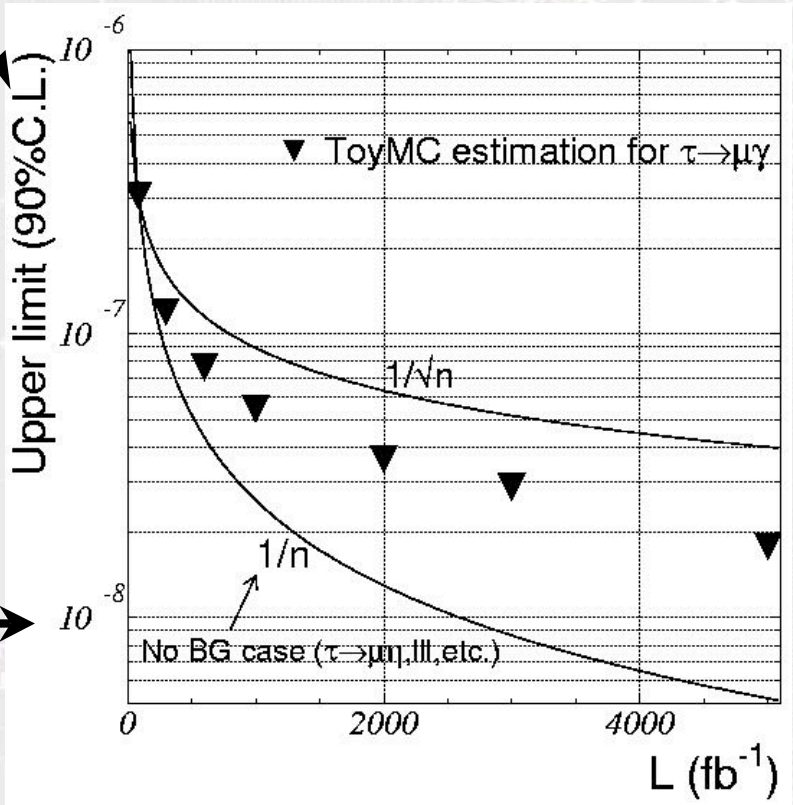
Off-diagonal couplings, phase → BaBar/Belle

This will remain true when a new elementary particle is found at a future energy frontier (e.g. LHC).

e.g. SUSY off-diagonal couplings, phase at a “super” B factory

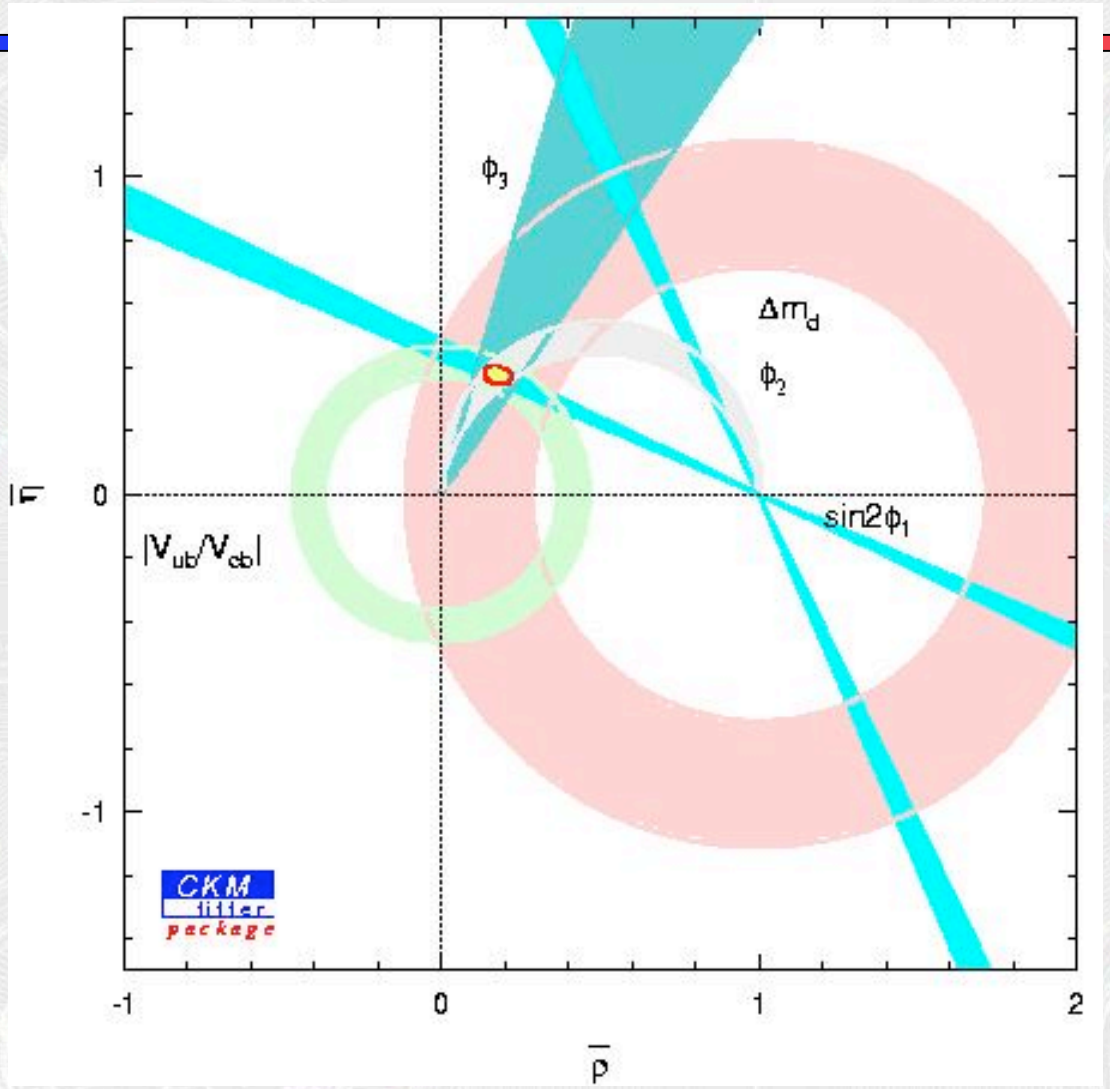
$\tau \rightarrow \mu\gamma$: another weapon





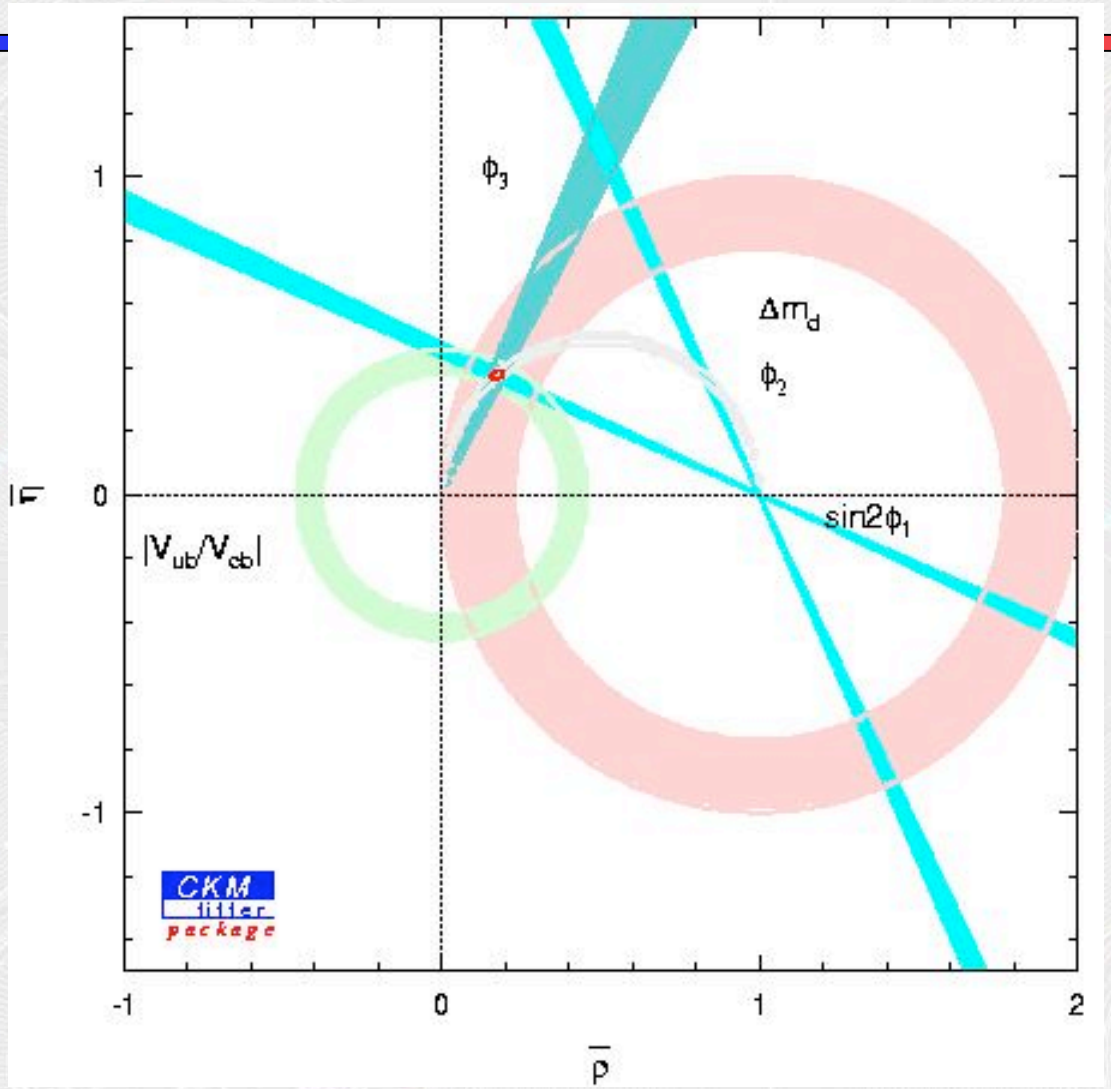
Observable	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	LHCb (0.002ab^{-1})
$\Delta\mathcal{S}_{\phi K^0_S}$	0.079	0.031	0.2
$\Delta\mathcal{S}_{K^+K^-K^0_S}$	0.056	0.026	×
$\Delta\mathcal{S}_{\eta' K^0_S}$	0.049	0.024	×
$\Delta\mathcal{S}_{K^0_S K^0_S K^0_S}$	0.14	0.04	×
$\Delta\mathcal{S}_{\pi^0 K^0_S}$	0.10	0.03	×
$\sin 2\chi$ $(B_s \to J/\psi\phi)$	×	×	0.058
$\mathcal{S}_{K^{*0}\gamma}$	0.14	0.04	×
$\mathcal{B}(B \to X_s\gamma)$	5%	5%	×
$A_{CP}(B \to X_s\gamma)$	0.011	5×10^{-3}	×
C_9 from $A_{FB}(B \to K^*\ell^+\ell^-)$	32%	10%	×
C_{10} from $A_{FB}(B \to K^*\ell^+\ell^-)$	44%	14%	×
$\mathcal{B}(B_s \to \mu^+\mu^-)$	×	×	◯
$\mathcal{B}(B^+ \to K^+\nu\nu)$		5.1σ	×
$\mathcal{B}(B^+ \to D\tau\nu)$	12.7σ	40.3σ	×
$\mathcal{B}(B^0 \to D\tau\nu)$	3.5σ	11.0σ	×
$\sin 2\phi_1$	0.019	0.014	0.022
ϕ_2 ($\pi\pi$ isospin)	3.9°	1.2°	×
ϕ_2 ($\rho\pi$)	2.9°	0.9°	×
ϕ_3 ($DK^{(*)}$)	5°		8°
ϕ_3 ($B_s \to KK$)	×	×	5°
ϕ_3 ($B_s \to D_sK$)	×	×	14°
$\lvert V_{ub}\rvert$ (inclusive)	5.8%	4.4%	×
$\mathcal{B}(\tau \to \mu\gamma)$	$< 1.8\times10^{-8}$		
$\mathcal{B}(\tau \to \mu/e\eta)$	$< 1\times10^{-8}$		
$\mathcal{B}(\tau \to \ell\ell\ell)$	$< 1\times10^{-8}$		

Super-precise Unitarity Triangle



$5ab^{-1}$

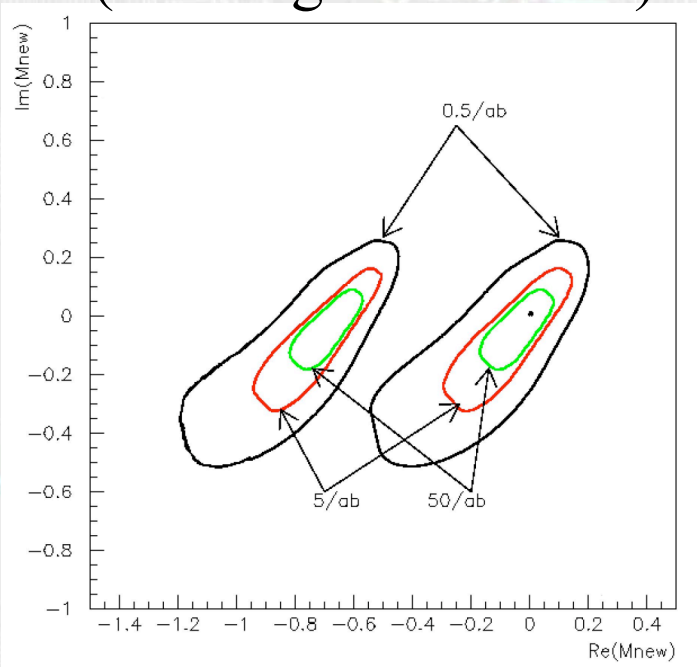
Super-precise Unitarity Triangle



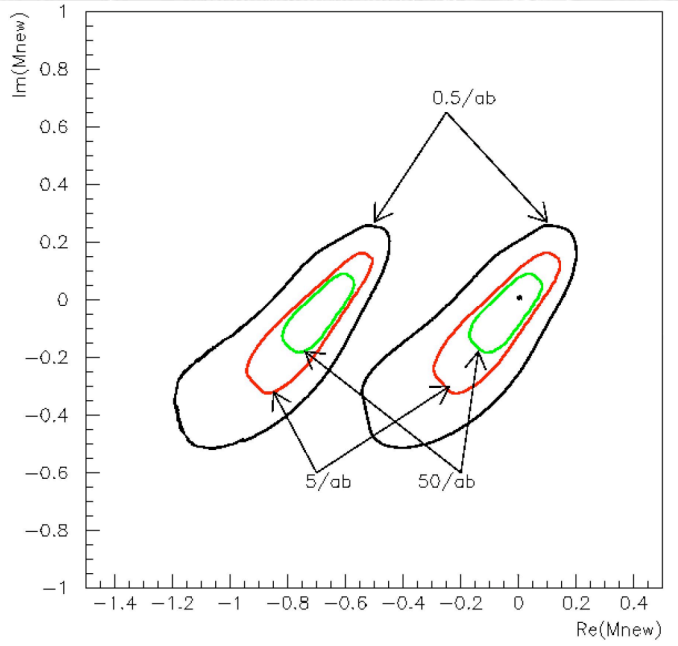
$50ab^{-1}$

If no New Physics in the mixing

SUSY SU(5) w/ ν_R
(non-degenerate case)



mSUGRA



consistent w/ SM even at 1% level: still very important information
Combining this with kaon CP violation and Δm_s → sensible test

Present situation: lucky for SuperKEKB !

- We know that
  - Standard Model (incl. Kobayashi-Maskawa mechanism) is *the* effective low energy description of Nature.
  - However most likely New Physics lies in O(1) TeV region.
    - LHC will start within a few years and (hopefully) discover a new elementary particle.
  - Flavor-Changing-Neutral-Currents (FCNC) suppressed
    - New Physics w/o suppression mechanism excluded up to 10^3 TeV. → ***New Physics Flavor Problem***
    - Different mechanism → different flavor structure in B decays (tau, charm as well)

Luminosity upgrade will be quite effective and essential.

Summary

- Very fruitful and exciting time at Belle !
  - sin2ϕ1 with 9% precision
  - Observation of CP violation in $B^0 \to \pi^+\pi^-$
  - First constraint on f3
  - Hint of new physics !? in b → s CP violation
  - Many rare decays, new resonances, etc. etc.
- Observed anomaly will continue to be the excitement.

- Physics case at SuperKEKB is compelling ! It will be the central place to elucidate the ***new physics flavor problem.***
  - LHC results will serve as important inputs to us (similar to Tevatron)

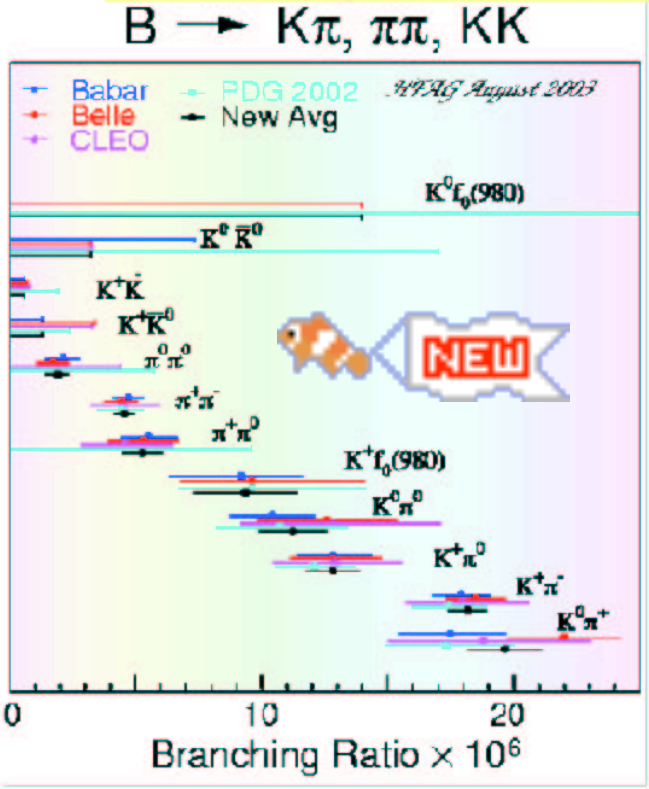
Backup slides

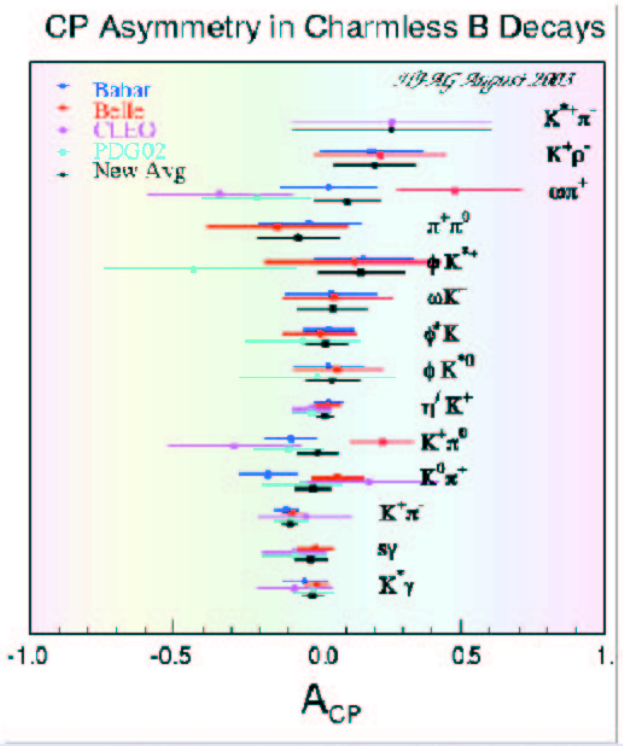
Rare *B* decays

Jawahery (LP03)

Summary of measurements of B→ππ & Kπ Decays

See John Fry's talk this morning for more detail &comparison with Theory





Thanks to Heavy flavor averaging group(HFAG): Rare decays: J. Smith (colorado), J. Alexander(Cornell), P.Chang (KEK)

Evidence Direct CPV ?

$$A_{K\pi} = -0.086 \pm 0.035 \pm 0.014(Belle)$$
$$= -0.107 \pm 0.041 \pm 0.012(BaBar)$$
$$= -0.04 \pm 0.16 \pm 0.02(CLEO)$$
$$Average = -0.09 \pm 0.03$$

V_{ub} measurement