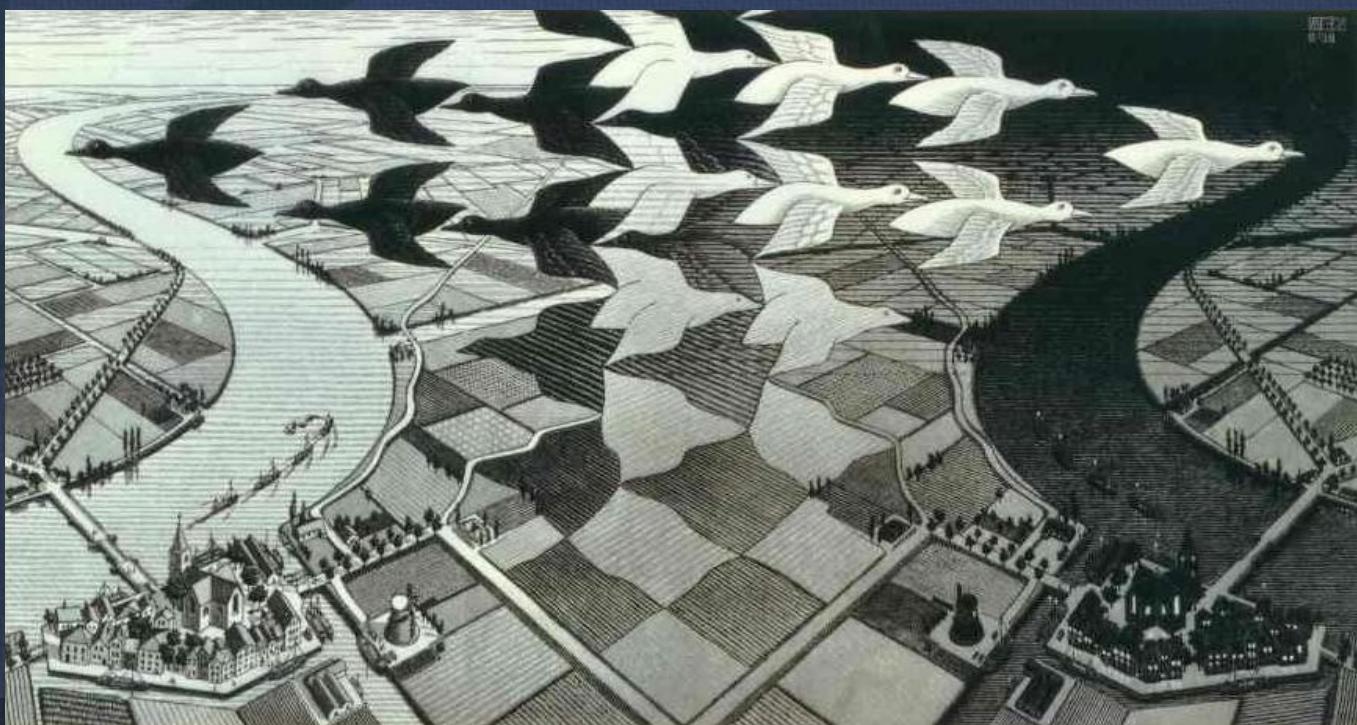


Difference of CP violating parameters in $B \rightarrow K\pi$ Decays at Belle

Kai-Feng Chen
National Taiwan University

for the Belle Collaboration

CERN Joint PP/EP Tuesday Seminar on April 29, 2008



CP Violation in B Physics: A Brief Story

Matter-Antimatter Asymmetry

The universe started from the “Big Bang”



Anti-matter Matter

Governed by the same physics interactions

Our world consists with only matter

Anti-matter is gone!
Only seen in high-energy interactions
(e.g. cosmic ray, accelerators)

⇒ **CP violation** must exist.



Discovery of CP Violation

Discovery in neutral Kaon Decays (1964)

Physics



The Nobel Prize in Physics 1980

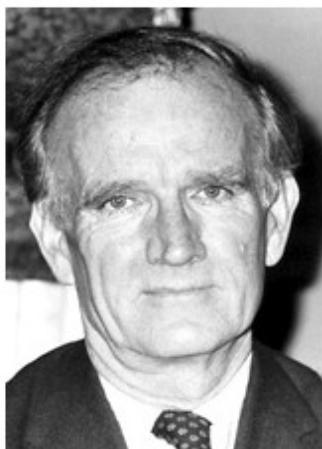
"for the discovery of violations of fundamental symmetry principles in the decay of neutral K-mesons"



James Watson
Cronin

1/2 of the prize

USA



Val Logsdon Fitch

1/2 of the prize

USA

*Once upon a time,
 CP -symmetry was sacred*

Alternative
interpretations in 1960's

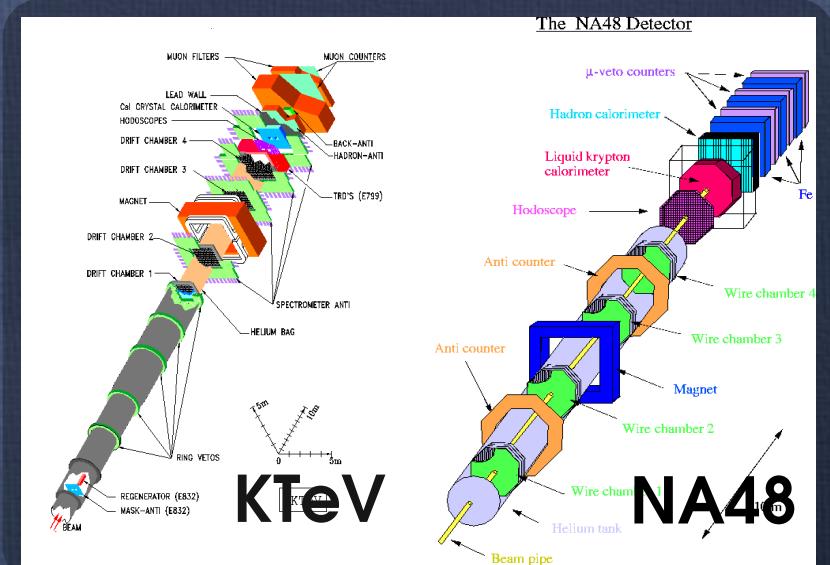
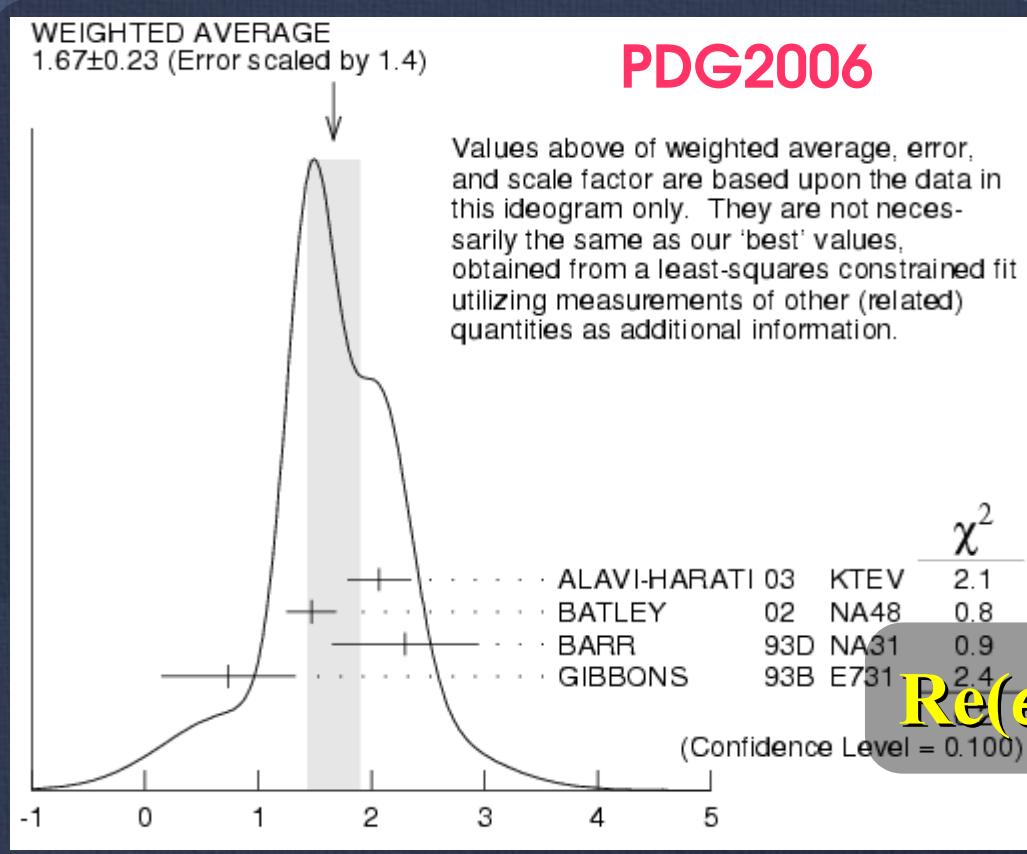
- A new particle X : $K_L \rightarrow K_S + X$?
- A new long-range force?
- Non-linear terms into Schrödinger equ.?
(beyond quantum mechanics!)
- Regeneration of K_S in a fly unfortunately trapped in the helium bag.

Discovery of CP Violation

The “Direct” CP Violation

Discovery in Kaon decays:

$$\Gamma(\bar{K}^0 \rightarrow \pi^+ \pi^-) \neq \Gamma(K^0 \rightarrow \pi^+ \pi^-)$$



$$\text{Re}(\epsilon'/\epsilon) = (1.67 \pm 0.23) \times 10^{-3}$$

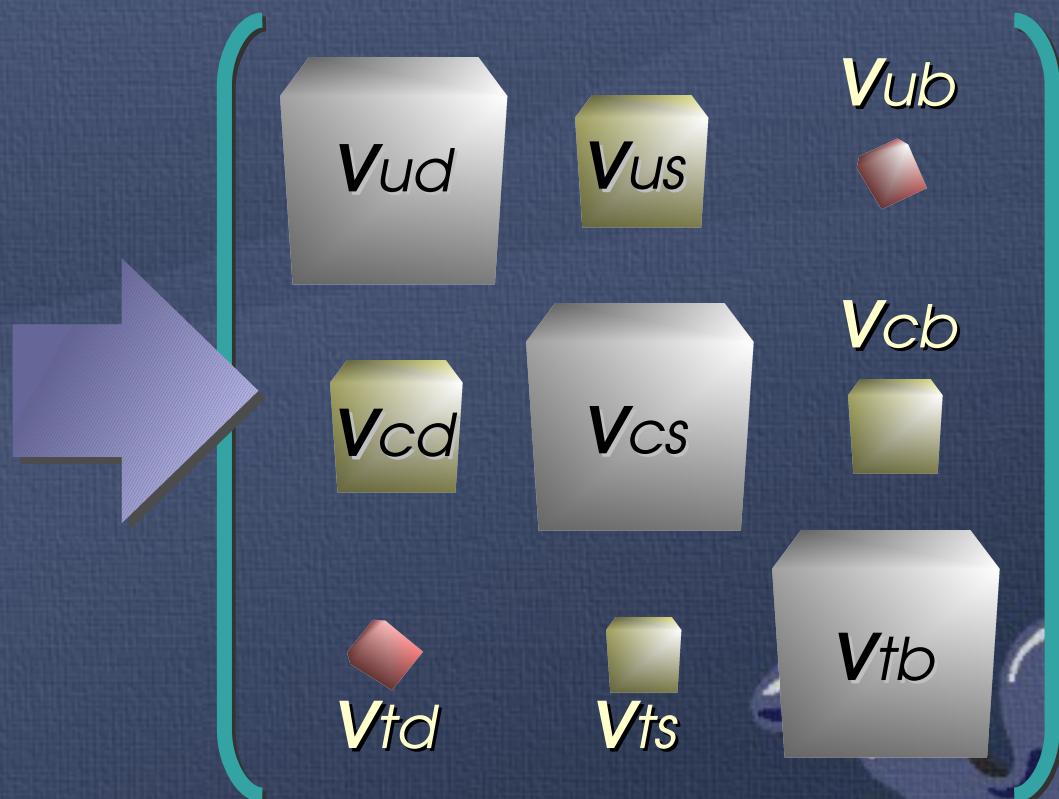
DCPV is tiny in kaon system!

(Slide from M.Hazumi-san's talk)

CP Violation in Standard Model

The KM Model

The Kobayashi-Maskawa ansatz: We need **THREE** generations of quarks to produce the **ONE** irreducible phase representing for the *CP* violation.



CP Violation in *B* Decays

The Original Proposal

NOTES ON THE OBSERVABILITY OF *CP* VIOLATIONS IN *B* DECAYS

I.I. BIGI

Institut für Theor. Physik der RWTH Aachen, D-5100 Aachen, FR Germany

A.I. SANDA¹

Rockefeller University, New York 10021, USA

Received 16 June 1981

***The CP-violation in *B*-system
was proposed 27 years ago.***

We describe a general method of exposing *CP* violations in on-shell transitions of *B* mesons. Such *CP* asymmetries can reach values of the order of up to 10% within the Kobayashi–Maskawa model for plausible values of the model parameters. Our discussion focuses on those (mainly non-leptonic) decay modes which carry the promise of exhibiting clean and relatively large *CP* asymmetries at the expense of a reduction in counting rates. Accordingly we address the complexities encountered when performing *CP* tests with a high statistics *B* meson factory like the Z^0 (and a toponium) resonance.

CP Violation in B Decays

The Unitarity Triangle

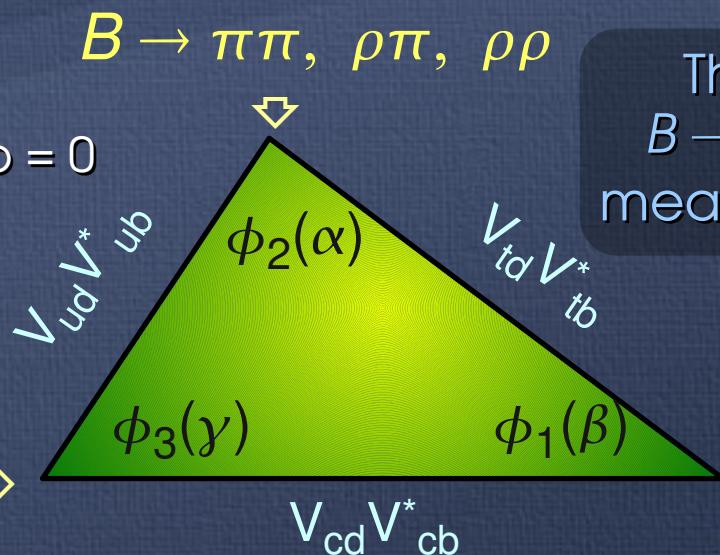
CP symmetry is broken by the complex phase appearing in the quark mixing matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - (\lambda^2/2) & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - (\lambda^2/2) & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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

Take the property of unitarity matrix

$$B \rightarrow D^0 K$$



The idea is to use $B \rightarrow J/\psi K_S$ decays for measuring the ϕ_1 angle.

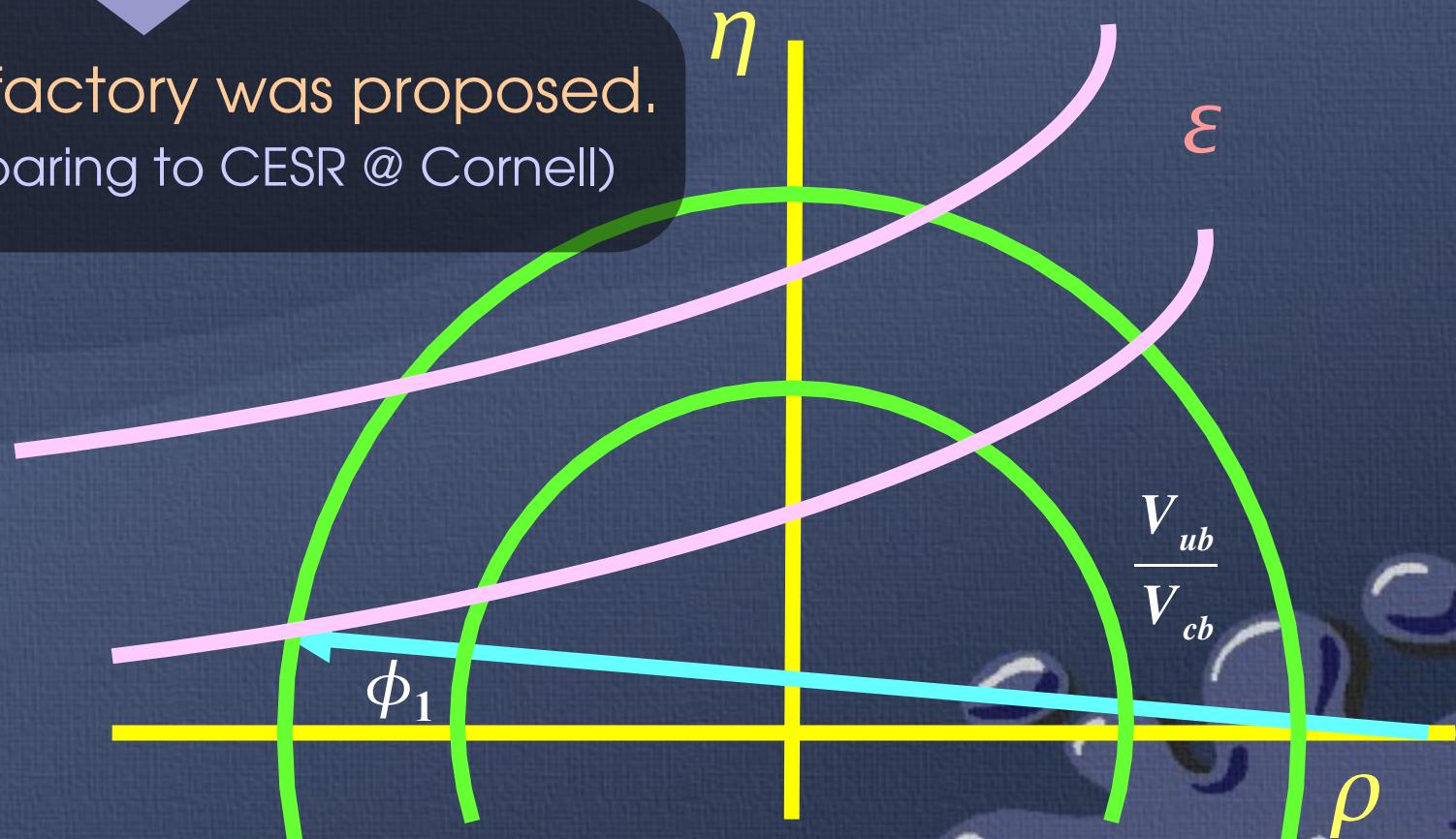
$$\Leftrightarrow B \rightarrow J/\psi K_S$$

Unitarity Triangle in 1980's

- The "known" minimum CP violation in B system is 15%.
- A lot of B mesons are required to measure the ϕ_1 angle.



A $O(10^{34})$ B -factory was proposed.
($\sim 1000x$ comparing to CESR @ Cornell)



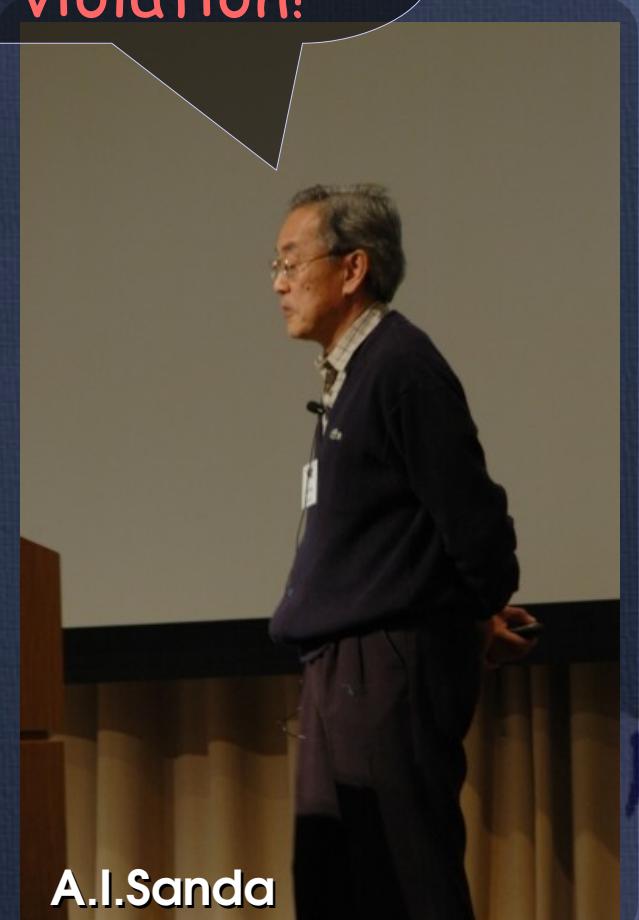
(Slide from A.I. Sanda-san's talk at CKM'06)

Look! This took us
six months!



↳ S.Olsen

We need millions of
B and use them to
search for mixing
and CP violation!



A.I.Sanda

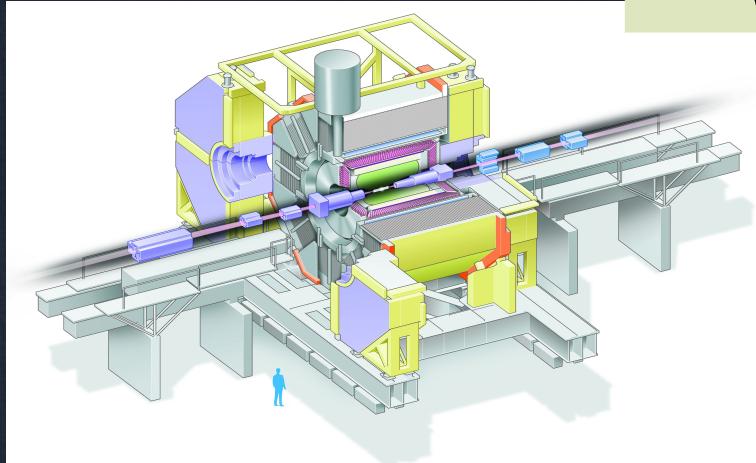


B-Factory Experiments

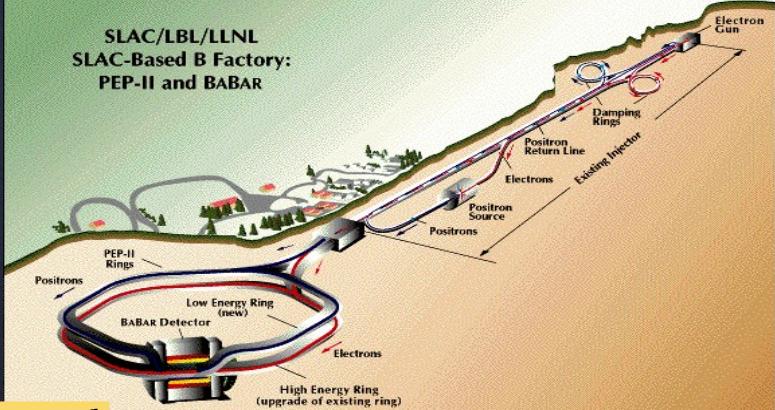
KEK(Japan)



Belle

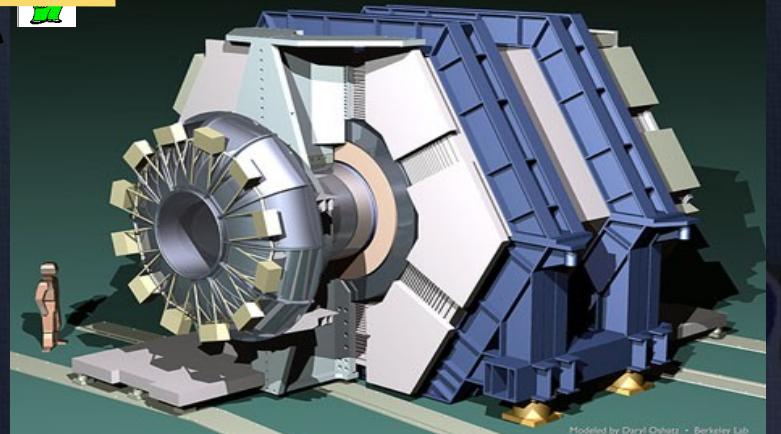


SLAC(Stanford)

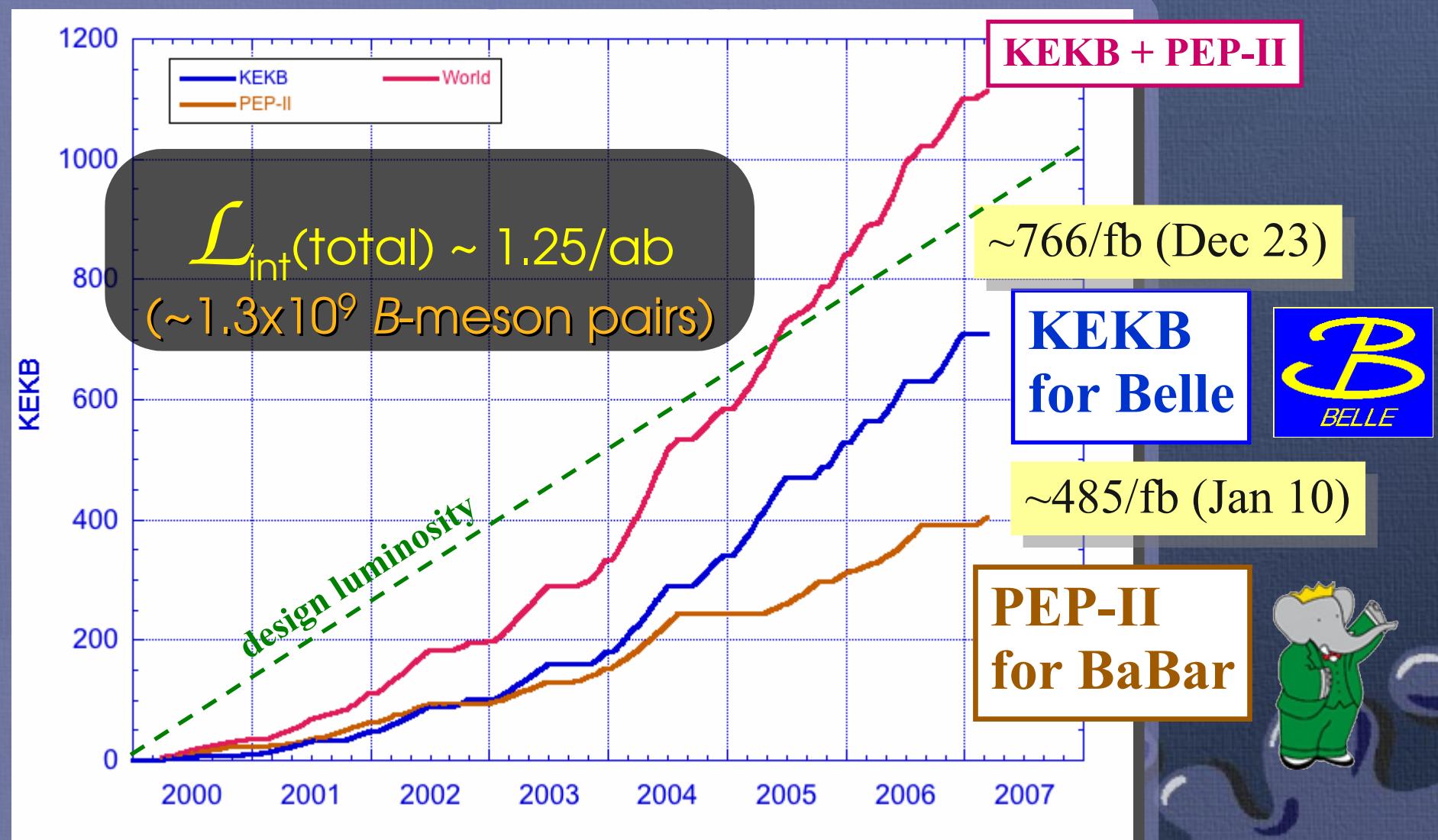


BABAR

BABAR DETECTOR FOR THE PEP-II B FACTORY



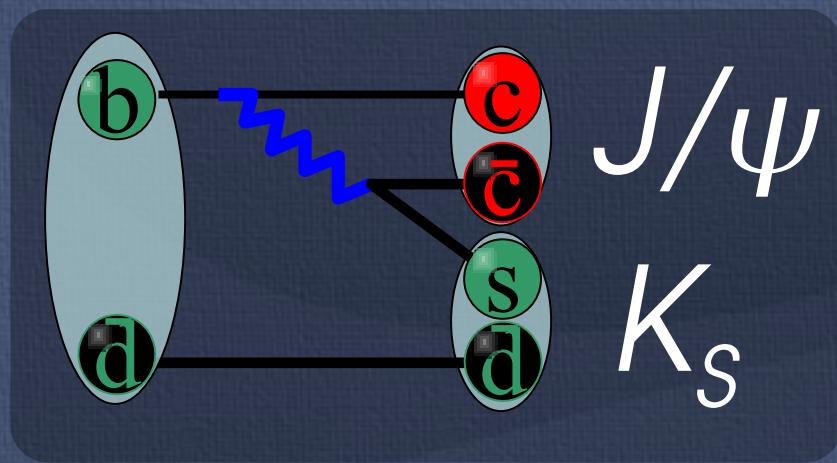
Luminosity Records



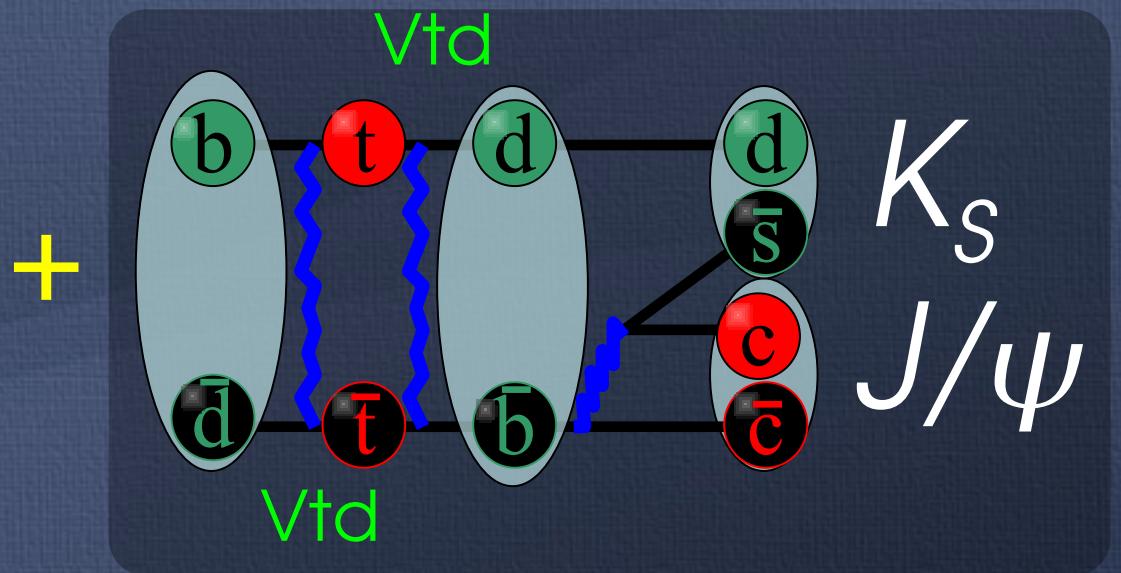
Measurement of $\sin 2\phi_1$

Quantum Interference Between Two Diagrams:

Tree diagram



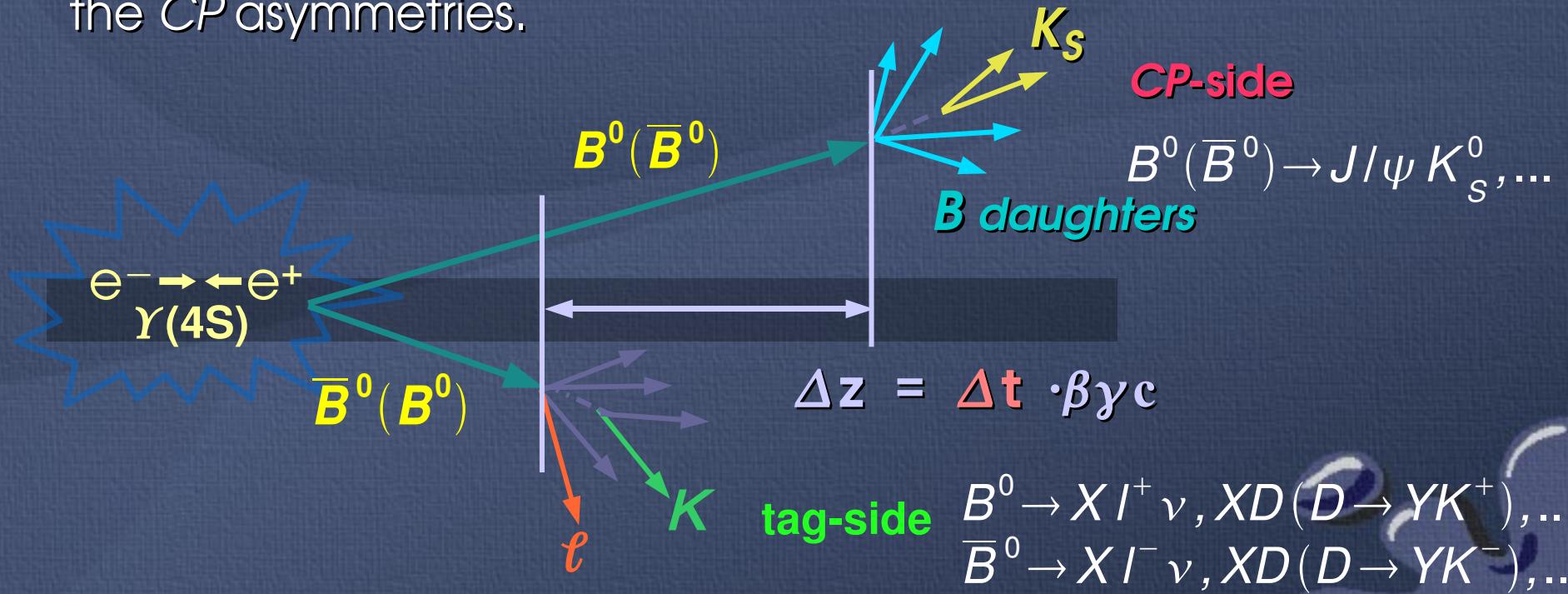
Box diagram + Tree diagram



We have to “wait” (i.e. $\Delta t \neq 0$) to have contributions from the box diagram.

Measurement of $\sin 2\phi_1$

- The experiments take the advantage of energy-asymmetric collider to produce Lorentz boosted B mesons.
- Fully reconstruct a CP eigenstate ($J/\psi K_S$).
- Tags the B flavor from the associated B meson.
- Measures the proper-time difference (Δt), and extract the CP asymmetries.



Measurement of $\sin 2\phi_1$

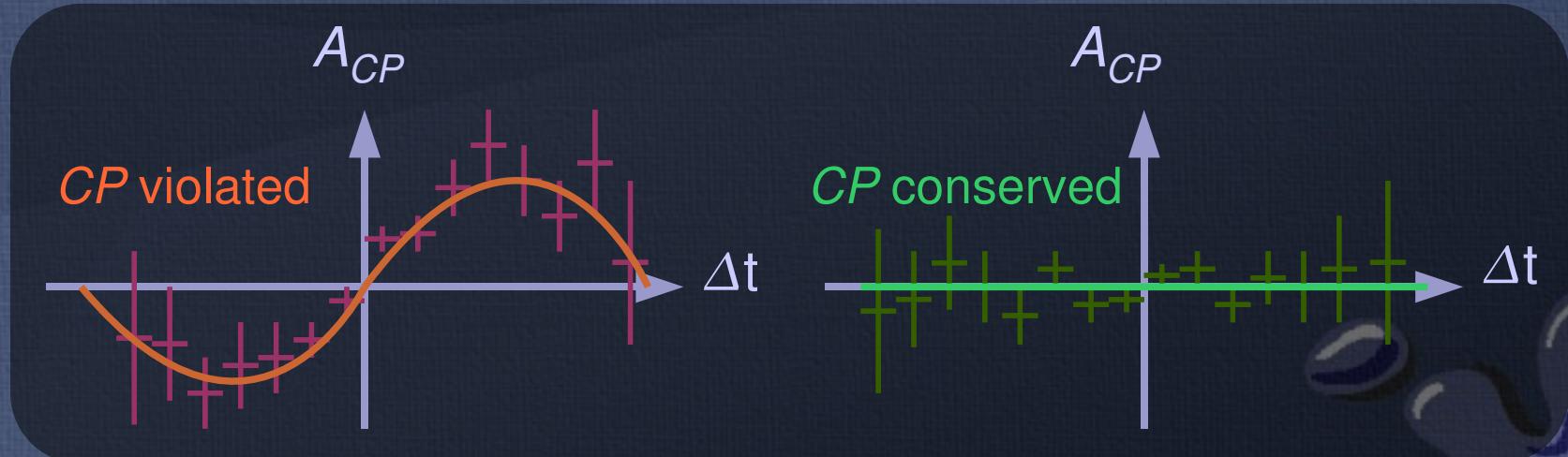
The CP -violating Asymmetries

$$A_{CP}(t) = \frac{\Gamma(\bar{B}^0 \rightarrow f_{CP}; t) - \Gamma(B^0 \rightarrow f_{CP}; t)}{\Gamma(\bar{B}^0 \rightarrow f_{CP}; t) + \Gamma(B^0 \rightarrow f_{CP}; t)} = A_f \cos(\Delta m t) + S_f \sin(\Delta m t)$$

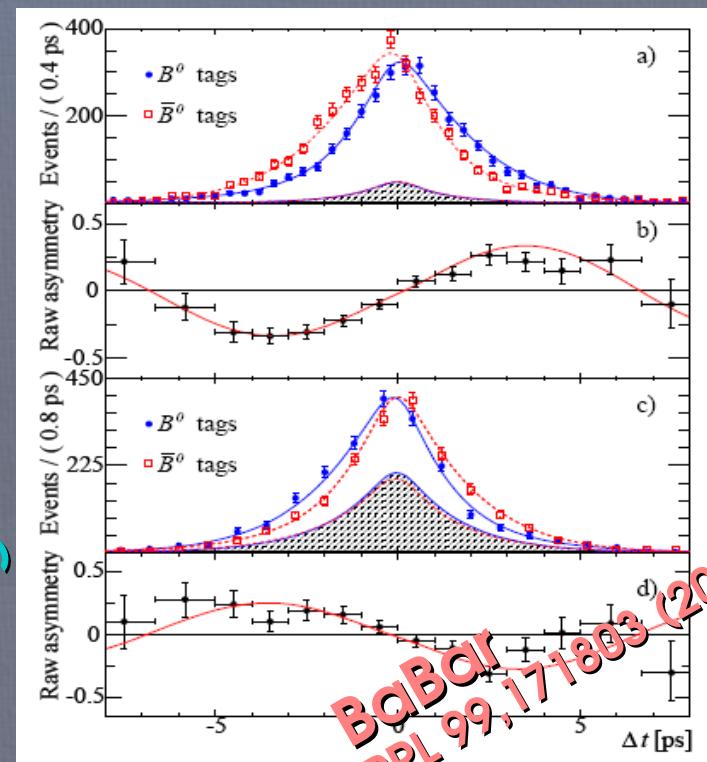
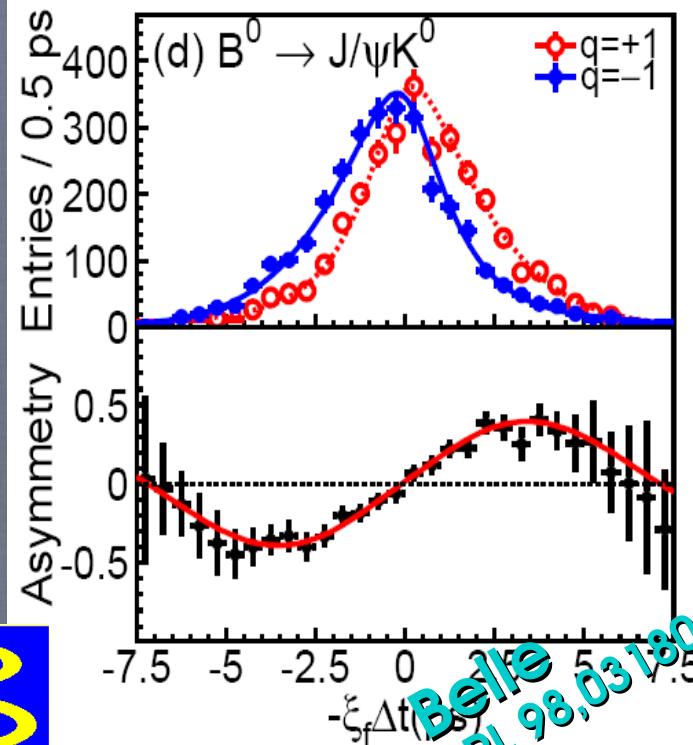
Indicates direct CP violation

$$A_f = 0 \text{ if } f_{CP} = J/\psi K_S \\ (-A_f = C_f \text{ in BaBar})$$

$$S_f = \sin 2\phi_1 \\ \text{if } f_{CP} = J/\psi K_S$$



Measurement of $\sin 2\phi_1$

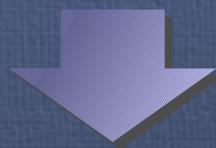


**CP Violation in B system
is already established within
the Standard Model.**

HFAG ($b \rightarrow ccs$): $S_{ccs} = 0.680 \pm 0.025$
($A_{ccs} = 0.012 \pm 0.020$, consists of no DCPV)

The Grand Puzzle

- Q: What is the source of CP violation?
- A: The Kobayashi-Maskawa phase produces CP asymmetry !



- Q: That's all?
- A: NOT YET CLEAR! Since:

Although, the baryon-antibaryon asymmetry is already quite small.

$$\frac{n(B)}{n(\gamma)} = (5.1_{-0.2}^{+0.3}) \times 10^{-10} \quad (\text{WMAP})$$

$$\frac{n(\bar{B})}{n(\gamma)} \simeq 0$$

KM phase only contributes $\sim 10^{-20}$

CPV is far too small in the Standard Model!



The Grand Puzzle

The Standard Model is almost correct at the **tree level**,
but the CP violation is too small.



New source of CPV is required.



Search for non-SM particles with higher order diagrams:
e.g. **$b \rightarrow s, d$ penguin loops**.

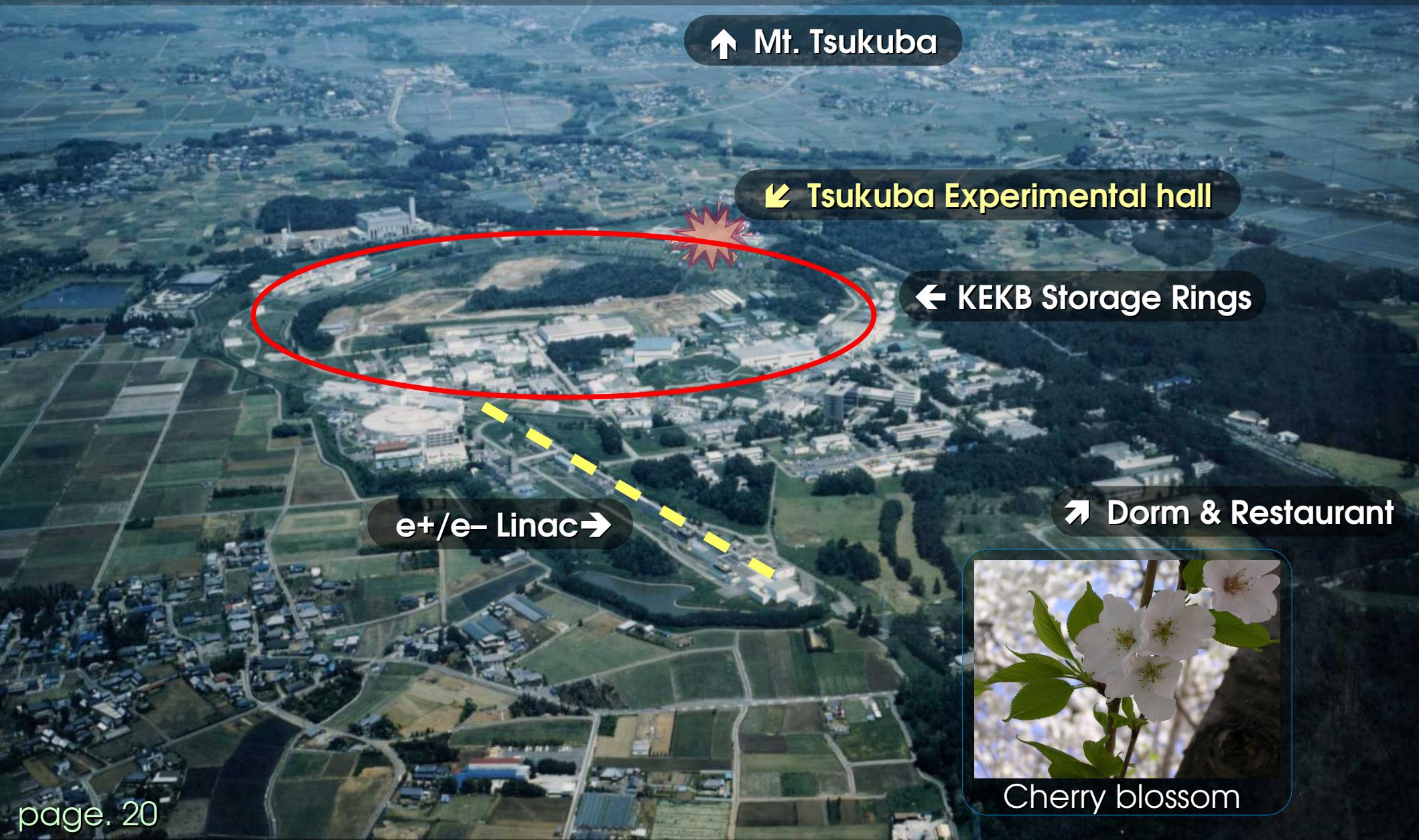


A new mission for the B -factories!



The Belle Experiment & Analysis

The KEKB Factory



The Belle Collaboration

Aomori U.

BINP

Chiba U.

Chonnam Nat'l U.

U. of Cincinnati

Ewha Womans U.

Frankfurt U.

Gyeongsang Nat'l U.

U. of Hawaii

Hiroshima Tech.

IHEP, Beijing

IHEP, Moscow

IHEP, Vienna

ITEP

Kanagawa U.

KEK

Korea U.

Krakow Inst. of Nucl. Phys.

Kyoto U.

Kyungpook Nat'l U.

EPF Lausanne

Jozef Stefan Inst. /

U. of Ljubljana /

U. of Maribor

U. of Melbourne

Nagoya U.

Nara Women's U.

National Central U.

National Taiwan U.

National United U.

Nihon Dental College

Niigata U.

Osaka U.

Osaka City U.

Panjab U.

Peking U.

U. of Pittsburgh

Princeton U.

Riken

Saga U.

USTC

Seoul National U.

Shinshu U.

Sungkyunkwan U.

U. of Sydney

Tata Institute

Toho U.

Tohoku U.

Tohoku Gakuin U.

U. of Tokyo

Tokyo Inst. of Tech.

Tokyo Metropolitan U.

Tokyo U. of Agri. and Tech.

Toyama Nat'l College

U. of Tsukuba

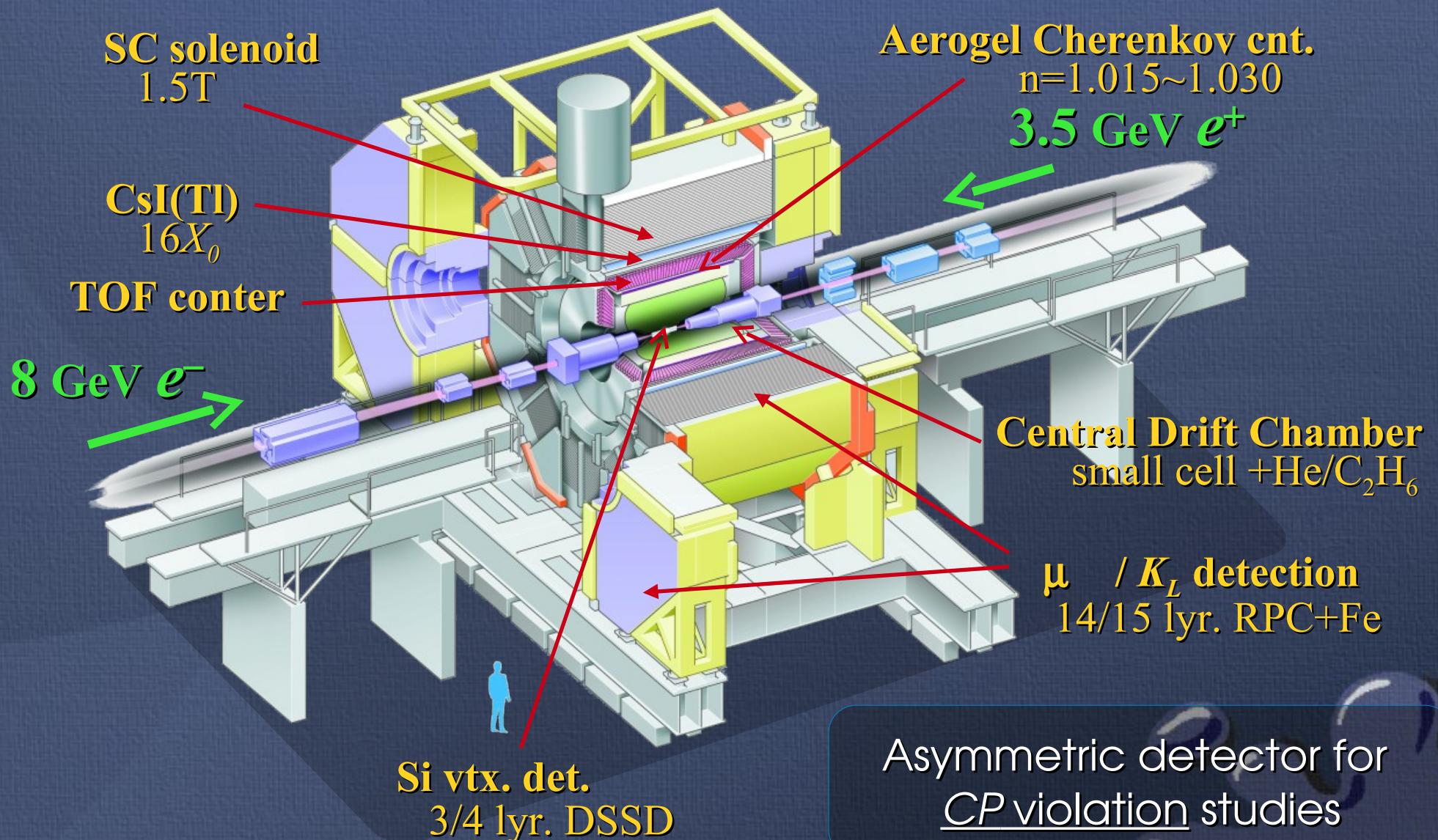
VPI

Yonsei U.

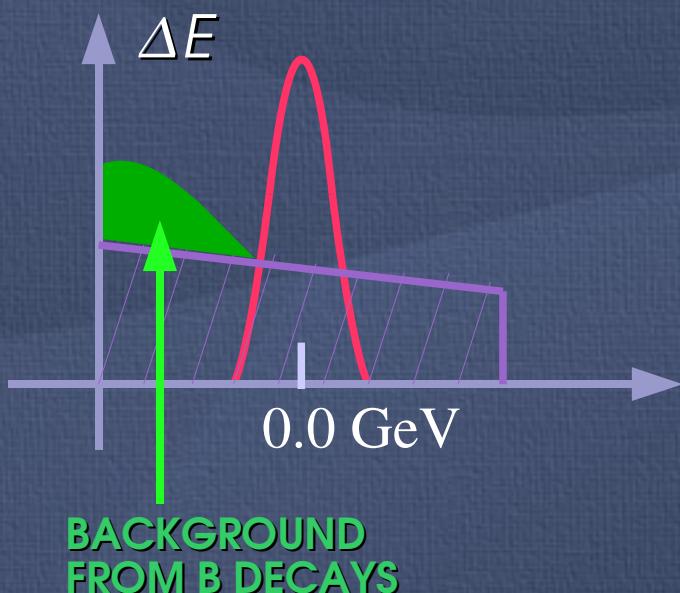
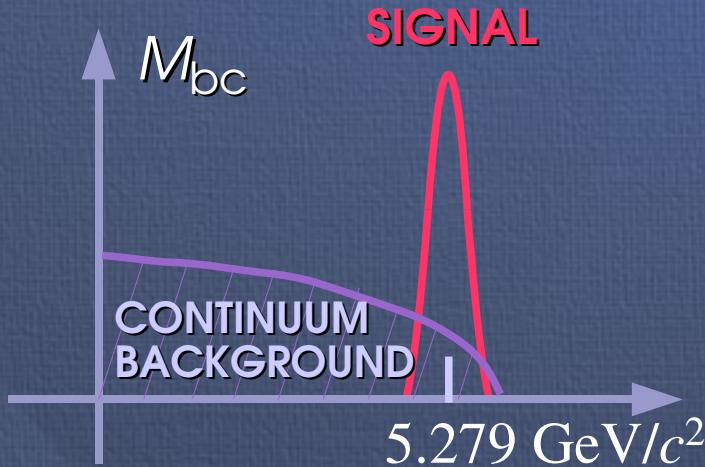


13 countries,
55 institutes,
~400 collaborators

The Belle Detector



Analysis Technique



- B candidates are identified by Beam-constrained mass:

$$M_{bc} = \sqrt{E_{beam}^2 - (\mathbf{P}_B^*)^2}$$

Energy difference:

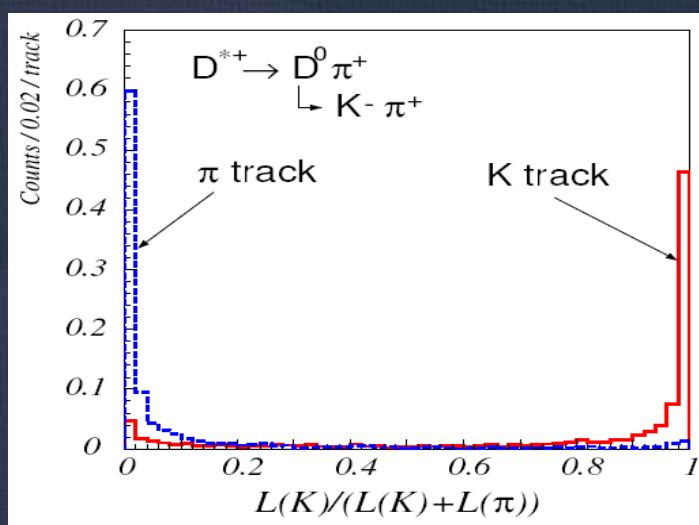
$$\Delta E = E_B^* - E_{beam}$$

E_B^* and \mathbf{P}_B^* are the reconstructed B energy and momentum in the CM frame.

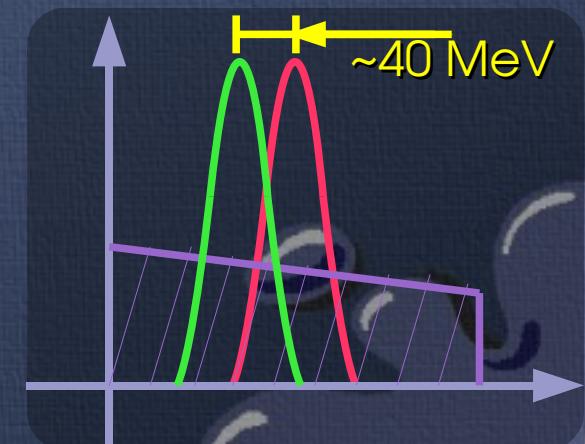
- Dominated background: continuum $e^+e^- \rightarrow qq$ processes, and suppressed by event shapes.
- Other background from B decays are examined by MC simulations.

Active K/π Separation

- Combining the information from 3 active detectors:

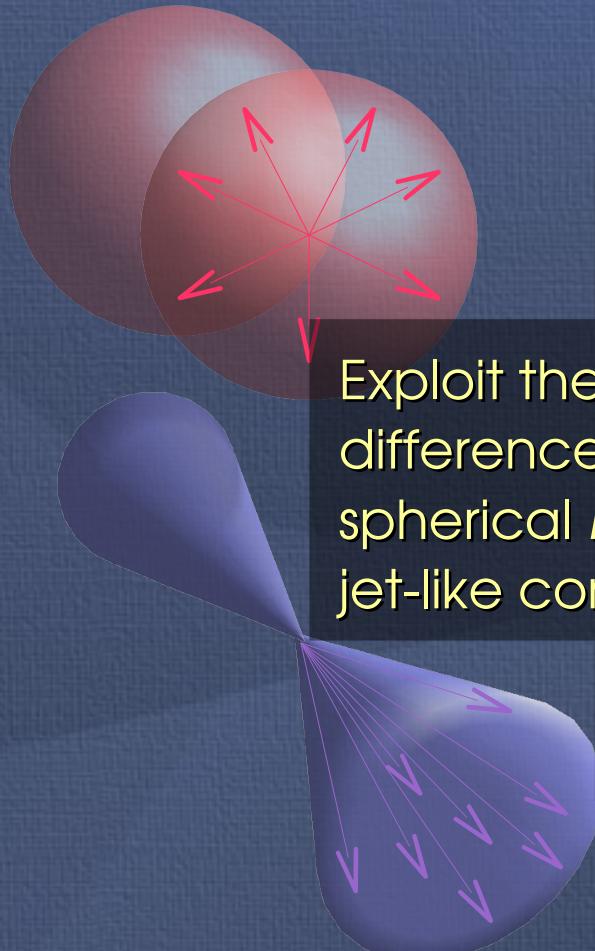


- Stable performance up to 4 GeV/c.
- Extra separation power from ΔE (if the KID fails).



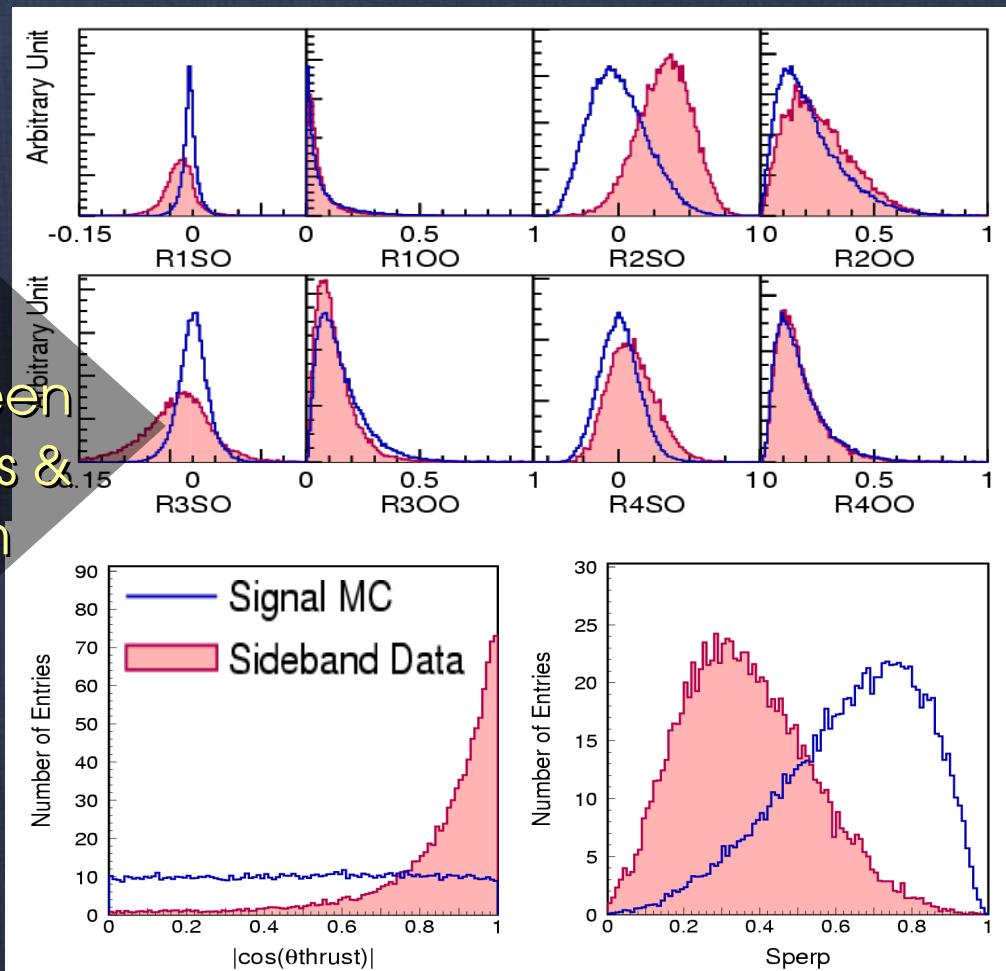
Background Suppression

Signal (spherical)

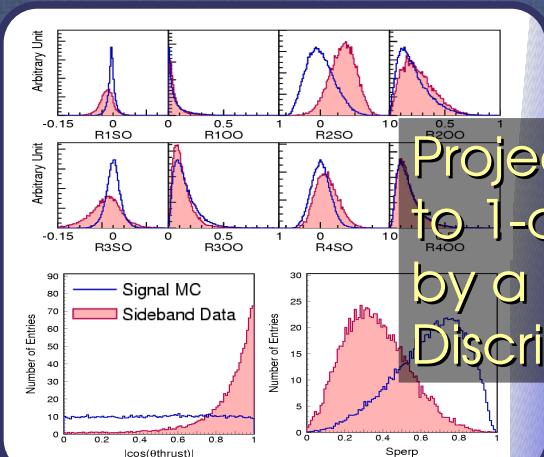


Exploit the difference between spherical B events & jet-like continuum

Variables:
(e.g. Modified Fox-Wolfram moments, etc.)

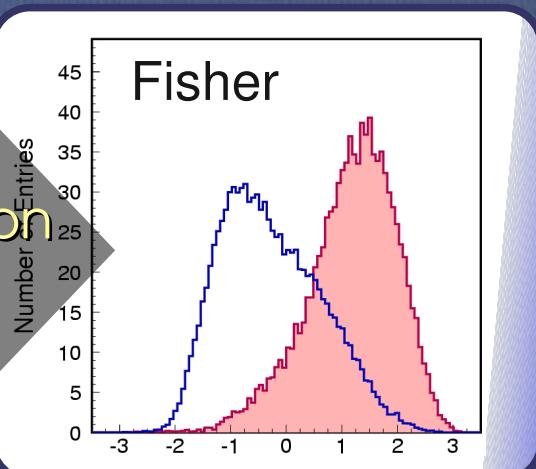


Background Suppression

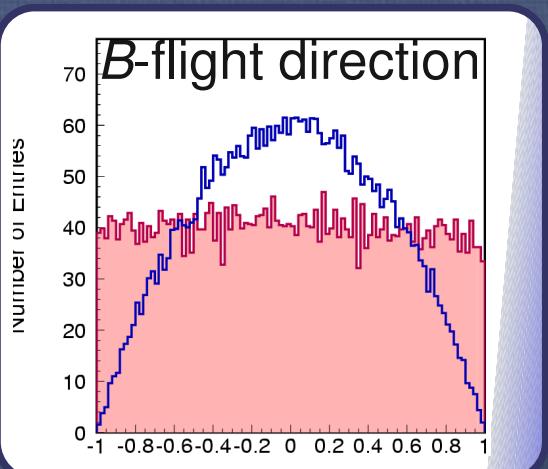


Project
to 1-dimension
by a Fisher
Discriminant

Combined event topology



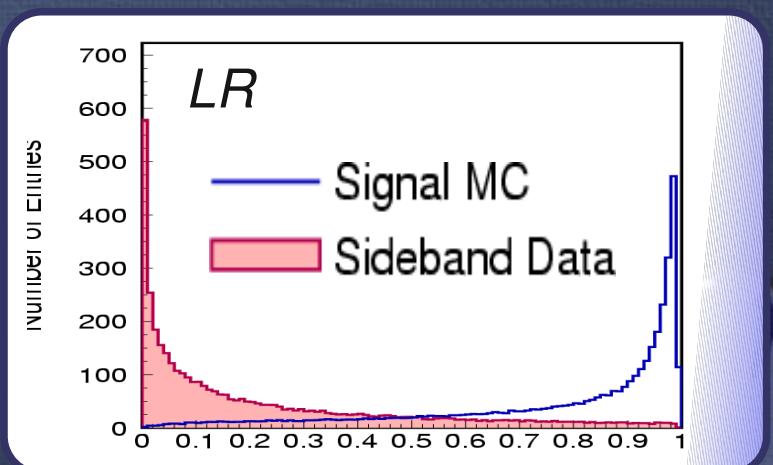
J^P conservation in γ decay



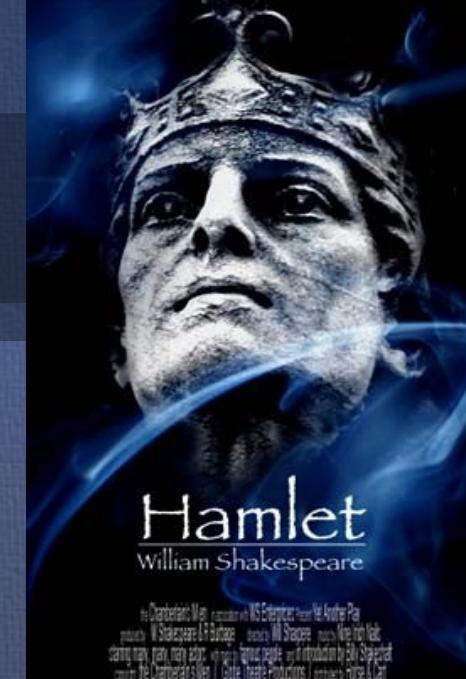
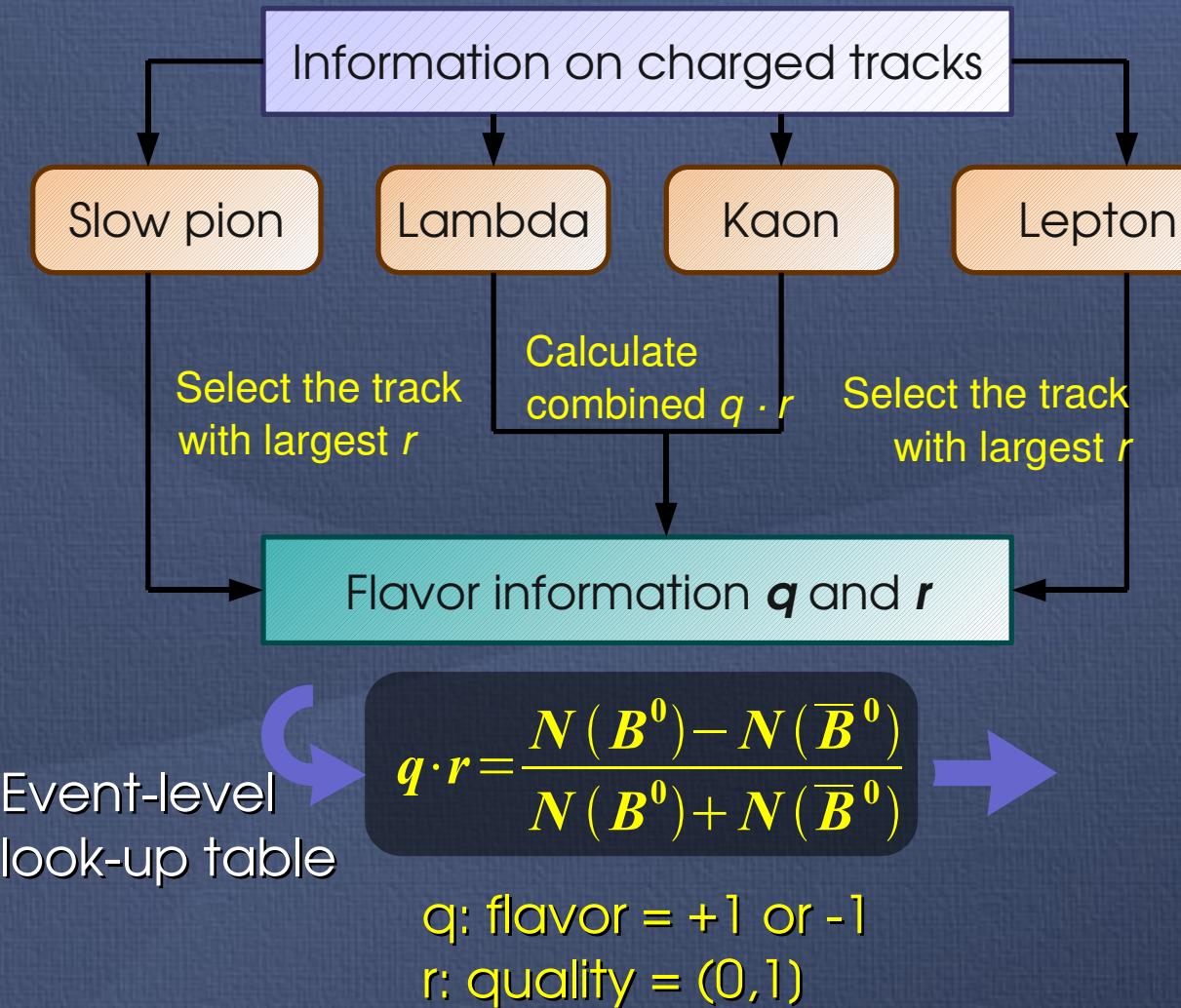
- We use a likelihood ratio to combine all the information:

$$LR = \frac{L_{sig}}{L_{sig} + L_{bkg}}$$

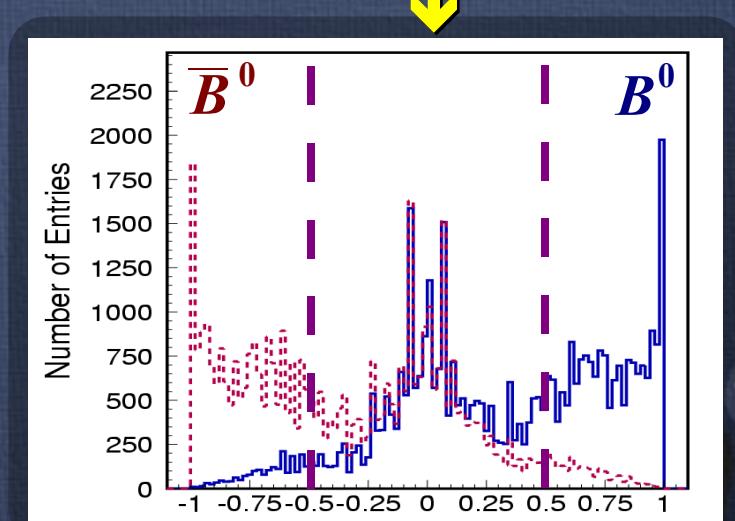
- Selection applied on LR with the dependence on **b-tagging quality**.



b Flavor Tagging



To **B** or not to **B**, that's a question



Looser LR cut for good tags

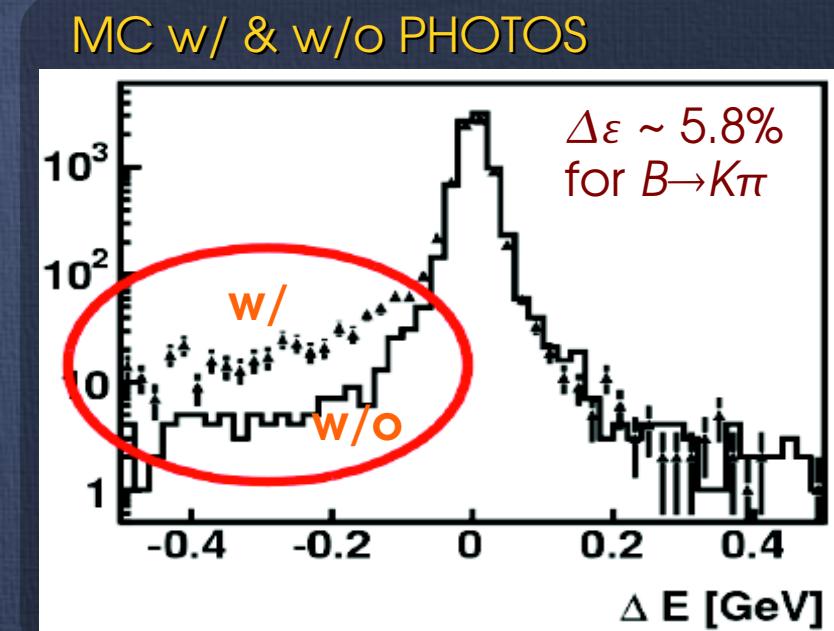
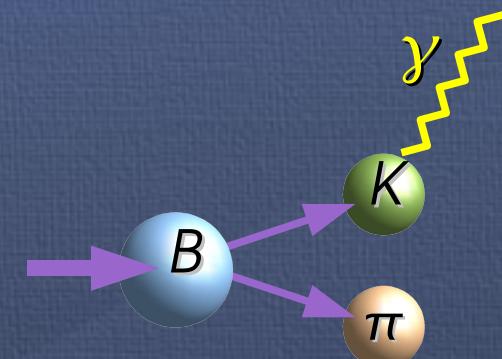
“PHOTOS” Effects

- Final state radiation (FSR) effects:
PHOTOS v2.13 has been included in the MC simulations.

→ Interference is on.
→ Double photon on, with $E_{cut} = 26$ MeV.

(E. Barberio and Z.Was Comput. Phys. Comm. 79, 291 (1994))

- Systematic uncertainty of PHOTOS in $B \rightarrow K\pi$ decays has been calculated $\sim 1/\text{million}$
→ Negligible for current statistics.
(G. Nanava and Z.Was hep-ph/0607019)





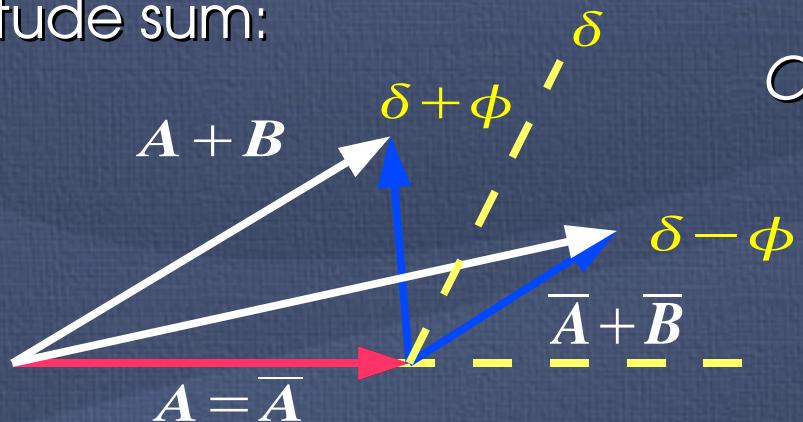
Charmless Two-body $B \rightarrow K\pi$ Decays

Direct CP Violation: Ingredients

- CP transformation:
weak phase: $\phi \rightarrow -\phi$
strong phase: $\delta \rightarrow \delta$



- Amplitude sum:



CP Asymmetry:

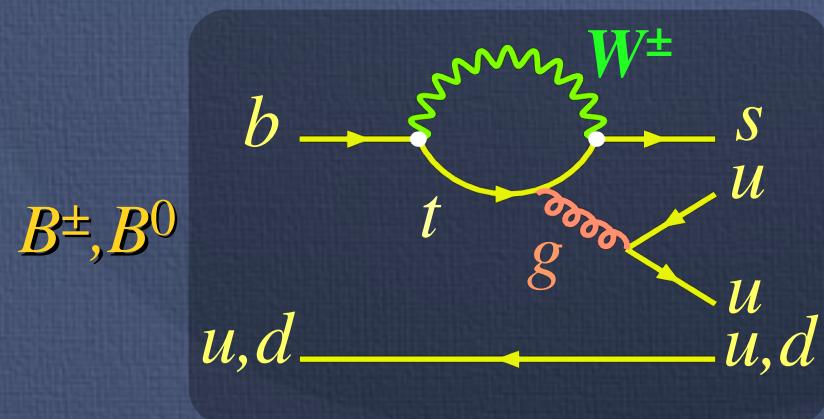
$$A + B \neq \bar{A} + \bar{B}$$
$$A_{CP} \propto |A||B|\sin\delta\sin\phi$$

- Ingredients for direct CP asymmetry:

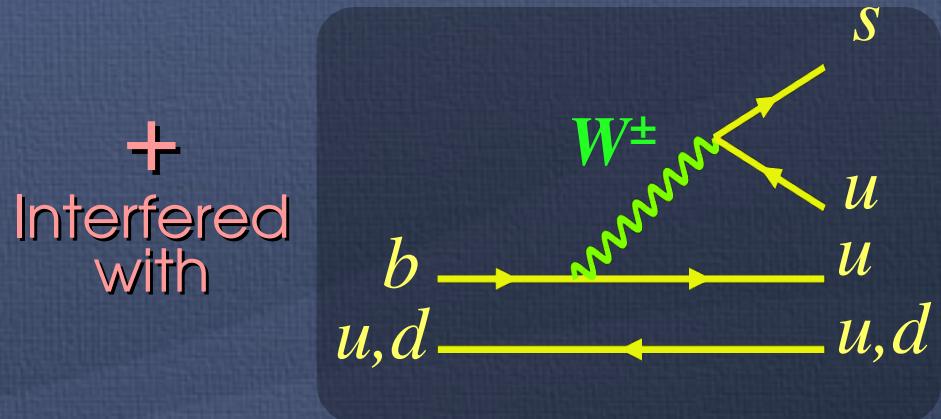
- 1. Two interfered amplitudes with similar order of magnitude.
- 2. Non-vanished strong phase & weak phase.

$B \rightarrow K\pi$ Decays

- Sizeable direct CP asymmetry could be generated by the interference between penguin & tree amplitudes:



$b \rightarrow s$ Penguin: suppressed by the loop (2nd order).



+
Interfered with

$b \rightarrow u$ Tree: suppressed by small V_{ub}

- Sensitive to the ϕ_3 angle: $A_{CP}(B \rightarrow K\pi) \propto |T||P| \sin \delta \sin \phi_3$
- Similar DCPV expected for $B^\pm \rightarrow K^\pm \pi^0$ and $B^0 \rightarrow K^\pm \pi^\mp$ decays.
(since they are sharing the same diagrams!)

$B \rightarrow K\pi$ Decays

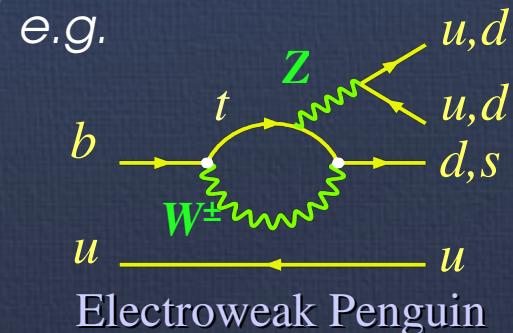
- Ratios of branching fractions for testing sub-dominance diagrams.
(theoretical uncertainties are canceled)

$$R = \frac{\Gamma(K^+ \pi^-)}{\Gamma(K^0 \pi^+)}$$

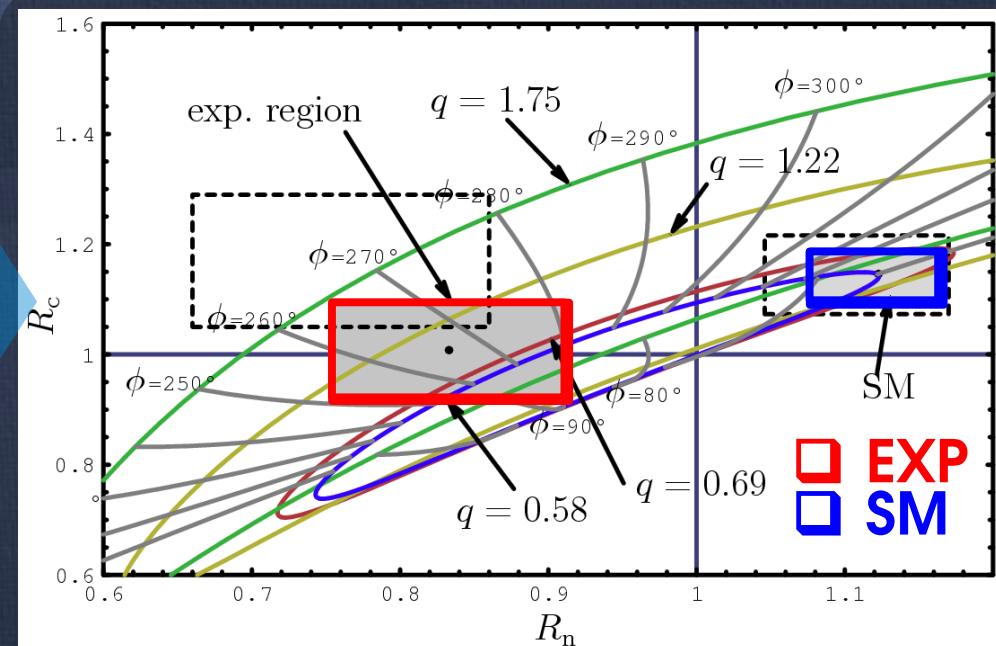
$$R_c = 2 \frac{\Gamma(K^+ \pi^0)}{\Gamma(K^0 \pi^+)}$$

$$R_n = \frac{1}{2} \frac{\Gamma(K^+ \pi^-)}{\Gamma(K^0 \pi^0)}$$

coefficients from Isospin relations



Ref. A.J. Buras, et al. Phys. J. C 45, 701–710 (2006)

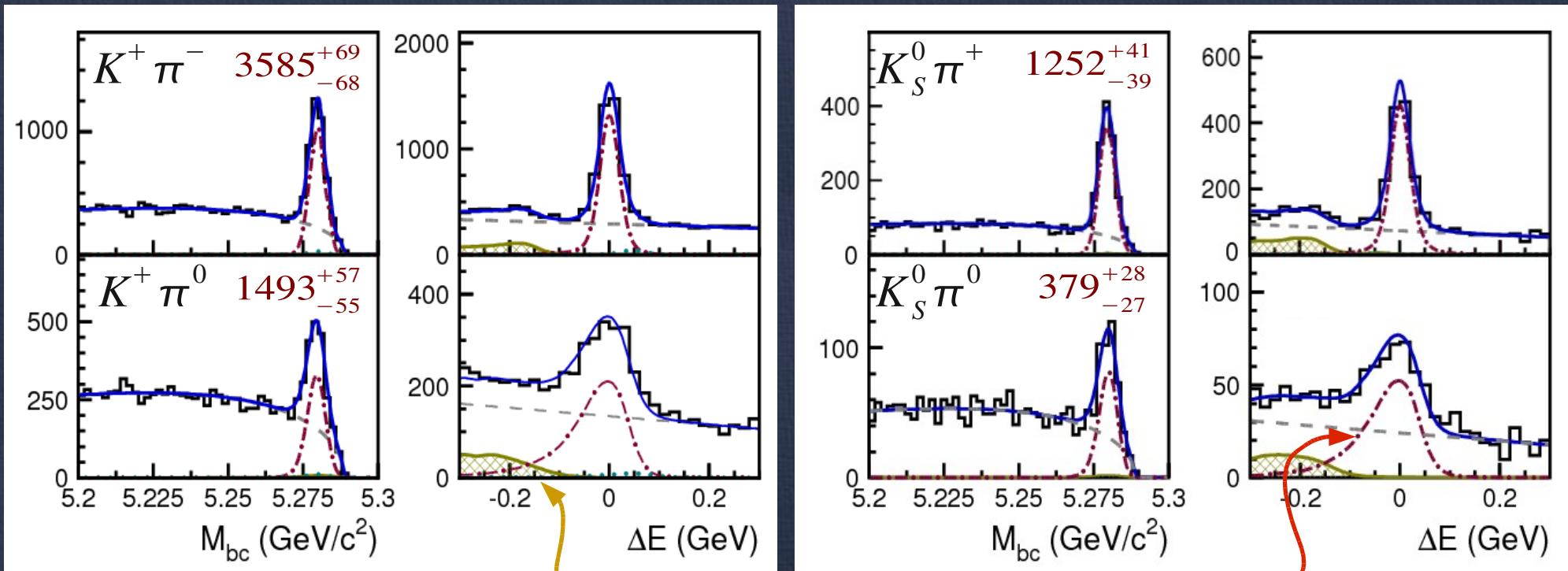


$K\pi$ R_n puzzle !?

$B \rightarrow K\pi$ Signals

- Signal extracted by fits to ΔE and M_{bc} (in 2-dimensions).
- Simultaneous fits with $K^+\pi^0 \Leftrightarrow \Leftrightarrow \pi^+\pi^0$ & $K_S\pi^+ \Leftrightarrow \Leftrightarrow K_SK^+$

Large and clean signal found w/ 449M B -meson pairs!

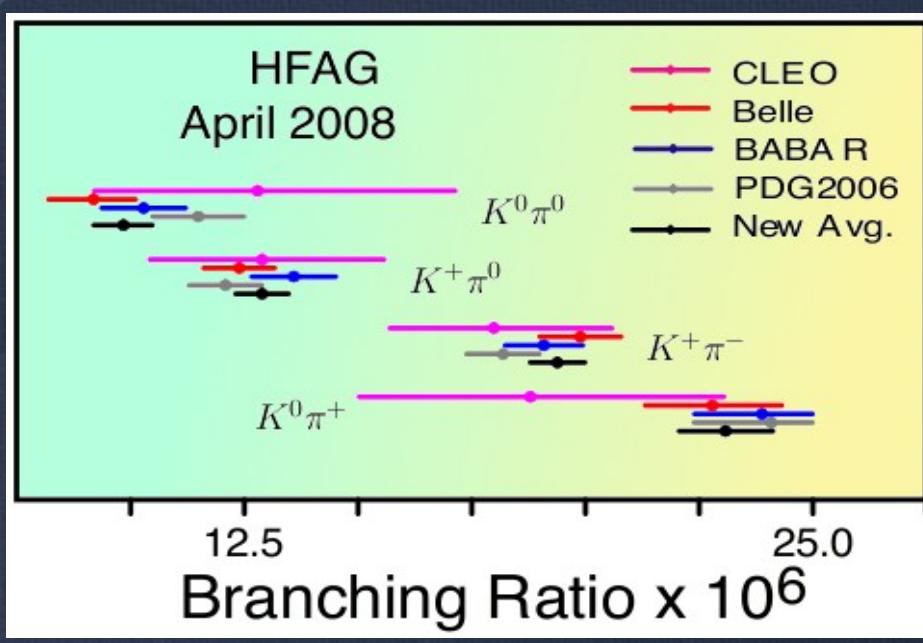


$B \rightarrow Khh$ 3-body background

Larger tail due to the energy-loss for π^0 .

$B \rightarrow K\pi$ Branching Fractions

Process	Belle (10^{-6})	BaBar (10^{-6})	HFAG Avg. (10^{-6})
$B^+ \rightarrow K^0 \pi^+$	$22.8^{+0.8}_{-0.7} \pm 1.3$	$23.9 \pm 1.1 \pm 1.0$	23.1 ± 1.0
$B^0 \rightarrow K^+ \pi^-$	$19.9 \pm 0.4 \pm 0.8$	$19.1 \pm 0.6 \pm 0.6$	19.4 ± 0.6
$B^+ \rightarrow K^+ \pi^0$	$12.4 \pm 0.5 \pm 0.6$	$13.6 \pm 0.6 \pm 0.7$	12.9 ± 0.6
$B^0 \rightarrow K^0 \pi^0$	$9.2 \pm 0.7^{+0.6}_{-0.7}$	$10.3 \pm 0.7 \pm 0.6$	9.9 ± 0.6



All the results are in good agreement!

- Ref. (Belle Coll. PRL 98, 181804 (2007))
- (Belle Coll. PRL 99, 121601 (2007))
- (Babar Coll. PRL 97, 171805 (2006))
- (Babar Coll. PRD 75, 012008 (2007))
- (Babar Coll. PRD 76, 091102 (2007))
- (Babar Coll. PRD 77, 012003 (2008))

$B \rightarrow K\pi$ Ratios of Branching Fractions

Belle Results

$$R_c = 1.08 \pm 0.06 \pm 0.08$$

$$R_n = 1.08 \pm 0.08^{+0.09}_{-0.08}$$

BaBar Results

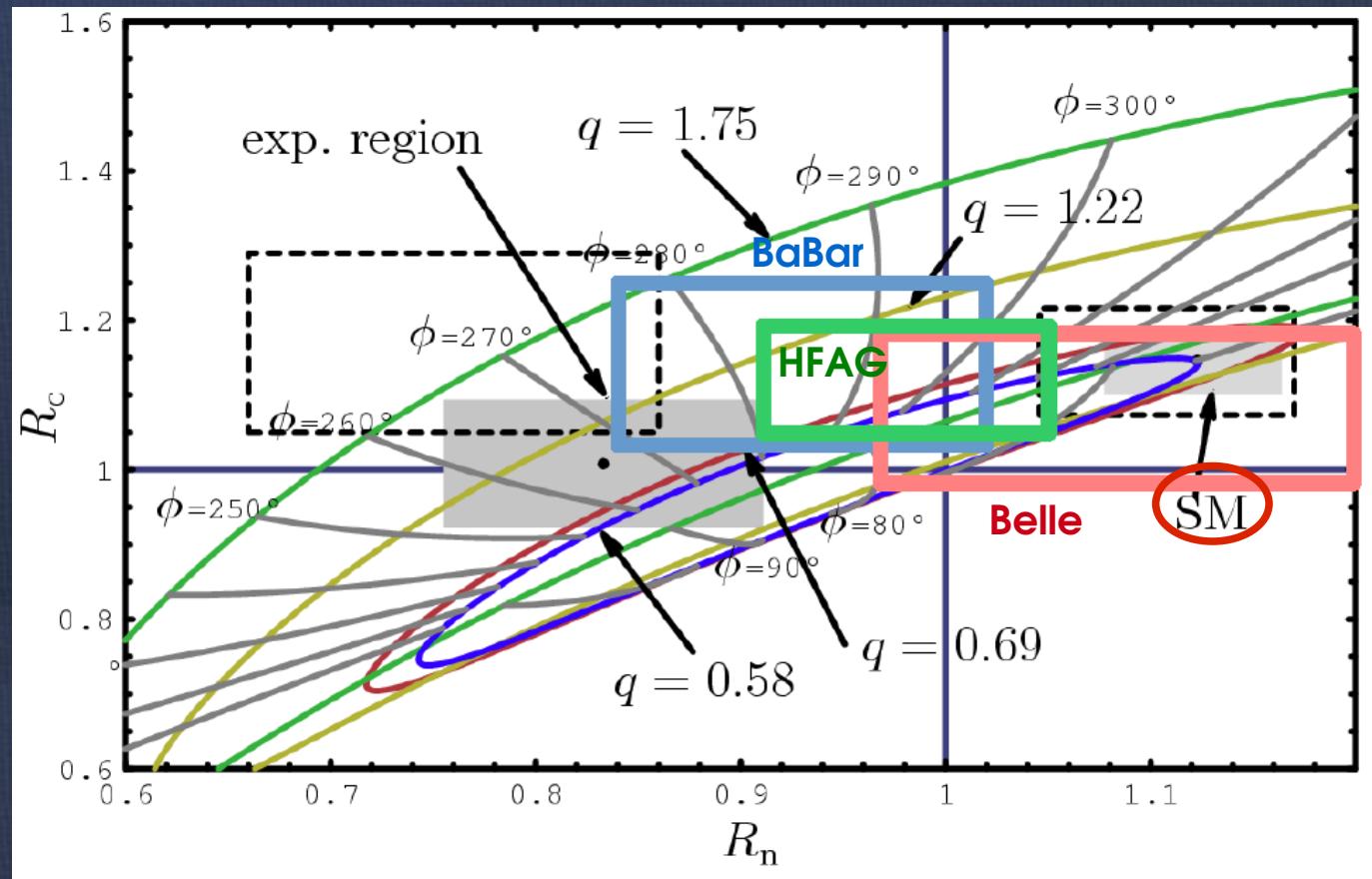
$$R_c = 1.14 \pm 0.07 \pm 0.08$$

$$R_n = 0.93 \pm 0.07 \pm 0.06$$

HFAG Averages

$$R_c = 1.12 \pm 0.07$$

$$R_n = 0.98 \pm 0.07$$



~~$K\pi R_n$ puzzle!?~~

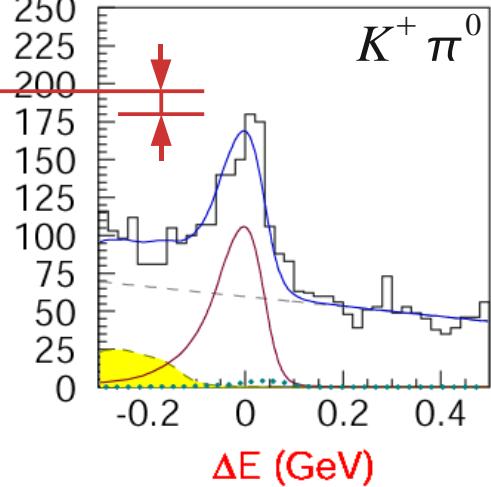
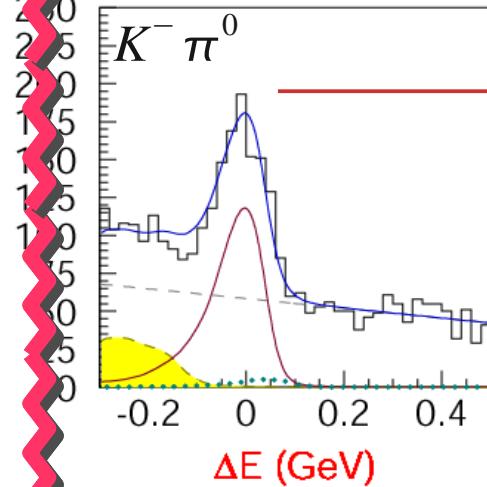
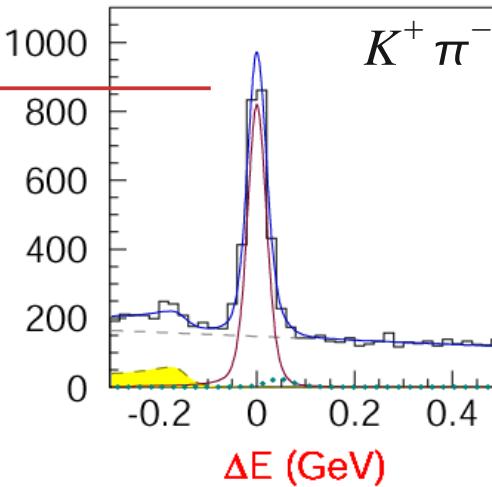
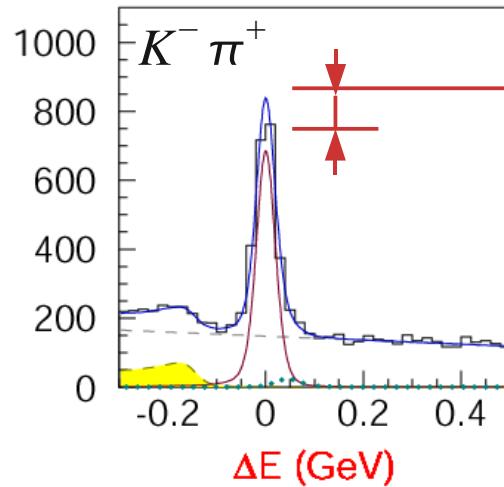
The ratios are now more or less consistent with the SM ($\sim 1\sigma$ for HFAG).

$B \rightarrow K\pi$: Direct CP Violation



Belle
535M

Similar DCPV are expected for
 $B^0 \rightarrow K^\pm \pi^\mp$ and $B^\pm \rightarrow K^\pm \pi^0$ decays



$$A_{CP}(K^+ \pi^-) = -9.4 \pm 1.8 \pm 0.8 \%$$

(4.8 σ away from 0)

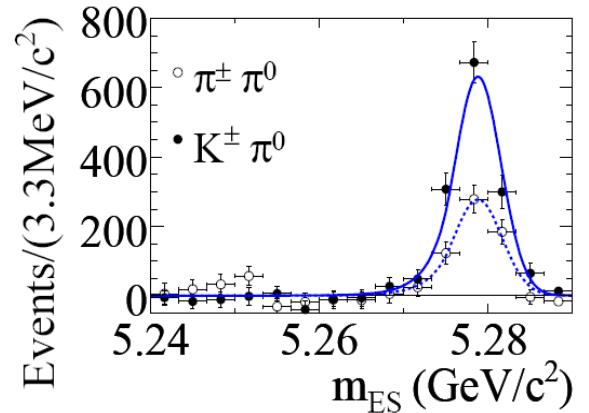
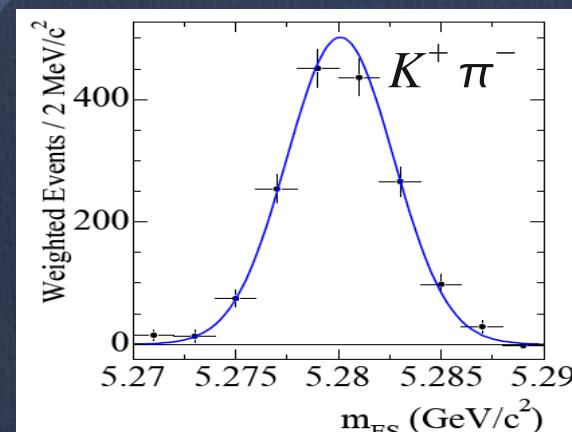
$$A_{CP}(K^+ \pi^0) = +7 \pm 3 \pm 1 \%$$

The difference is well established : $16.4 \pm 3.7\% (4.4\sigma)$

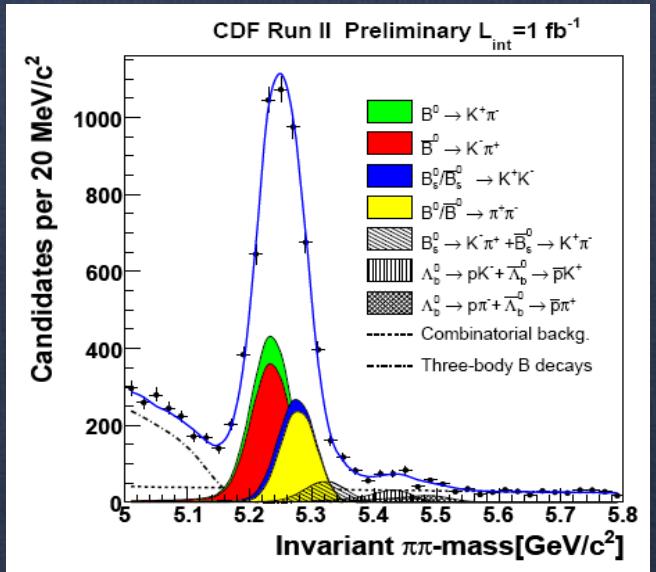
Clearly there is a big puzzle!

$B \rightarrow K\pi$: Direct CP Violation

BaBar data



CDF data



Excellent consistency between experiments:

Process	Belle	BaBar	CDF	HFAG Avg.
$K^\pm \pi^\mp$	$-9.4 \pm 1.8 \pm 0.8 \%$	$-10.7 \pm 1.8^{+0.7}_{-0.4} \%$	$-8.6 \pm 2.3 \pm 0.9 \%$	$-9.7 \pm 1.2 \%$
$K^\pm \pi^0$	$+7. \pm 3. \pm 1. \%$	$+3.0 \pm 3.9 \pm 1.0 \%$		$+5.0 \pm 2.5 \%$

Ref. (Babar Coll. PRL 99, 021603 (2007))
(Babar Coll. PRD 76, 091102 (2007))
(CDF Coll. hep-ex/0612018)

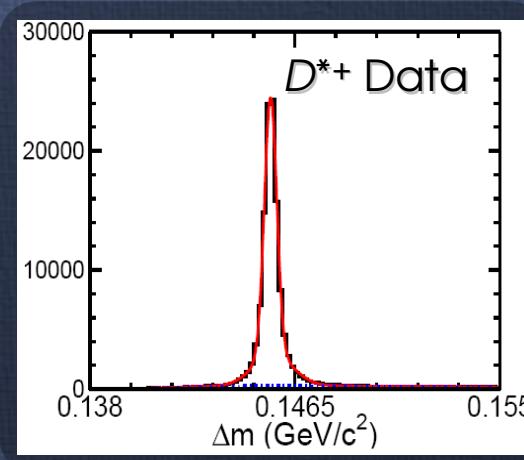
Differ by $5.3\sigma!!$

$B \rightarrow K\pi$: Direct CP Violation

Systematic Uncertainties

Systematic Source	$K^\pm \pi^\mp$	$K^\pm \pi^0$
Signal PDF	+0.03/-0.02 %	$\pm 0.04 \%$
Charmless B fraction	$\pm 0.01 \%$	+0.06/-0.04 %
$\pi^+ \pi^-$ amount	+0.03/-0.01 %	—
Fake rate ($\pi^+ \pi^- \rightarrow K^+ \pi^-$)	$\pm 0.13 \%$	—
Detector bias	$\pm 0.81 \%$	$\pm 0.56 \%$
Total	$\pm 0.82 \%$	$\pm 0.56 \%$

The uncertainty is only dominated by the detector bias (checked by $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K\pi$ sample.):



Most of the uncertainties are tiny ($\leq 0.1\%$)!

almost background free!

$B \rightarrow K\pi$: Direct CP Violation

The deviation in direct CP violation is firmly measured:

- Simple analysis: just count the number of B -mesons.
- Very good agreement with other experiments.
- Tiny systematic uncertainties.



No space for mistakes in experiments



How to interpret this deviation is the job!

Contributions from the sub-dominance diagrams?
Hadronic effects? How about the NLO calculations?
or, New physics?

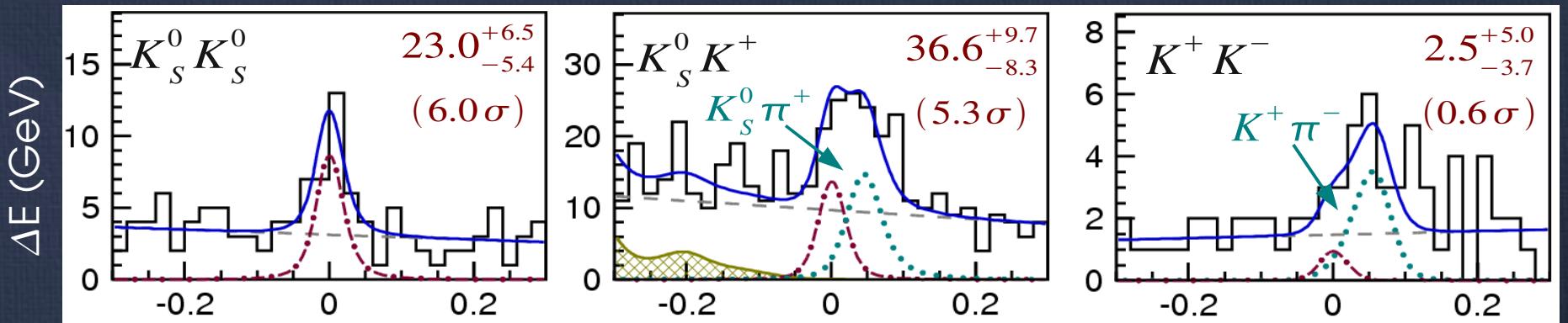
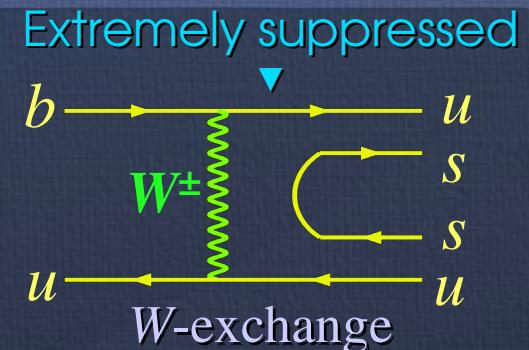
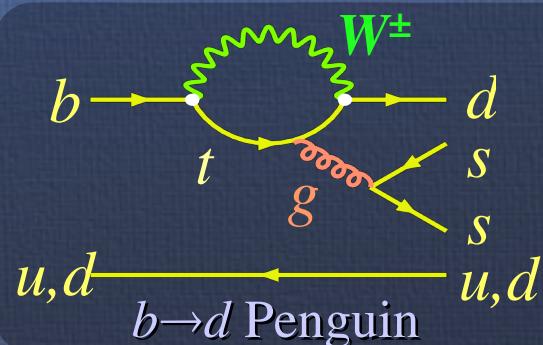




Discussions

How about other $B \rightarrow hh$ Decays?

- $B \rightarrow K_S K_S$ and $K_S K^+$ are only dominated by $b \rightarrow d$ penguins.
- $K^+ K^-$ is proceeded by the W -exchange.



$$Bf(K^0 K^0) : 0.87^{+0.25}_{-0.20} \pm 0.09 \times 10^{-6}$$

$$Bf(K^0 K^+) : 1.22^{+0.32}_{-0.28} {}^{+0.13}_{-0.16} \times 10^{-6}$$

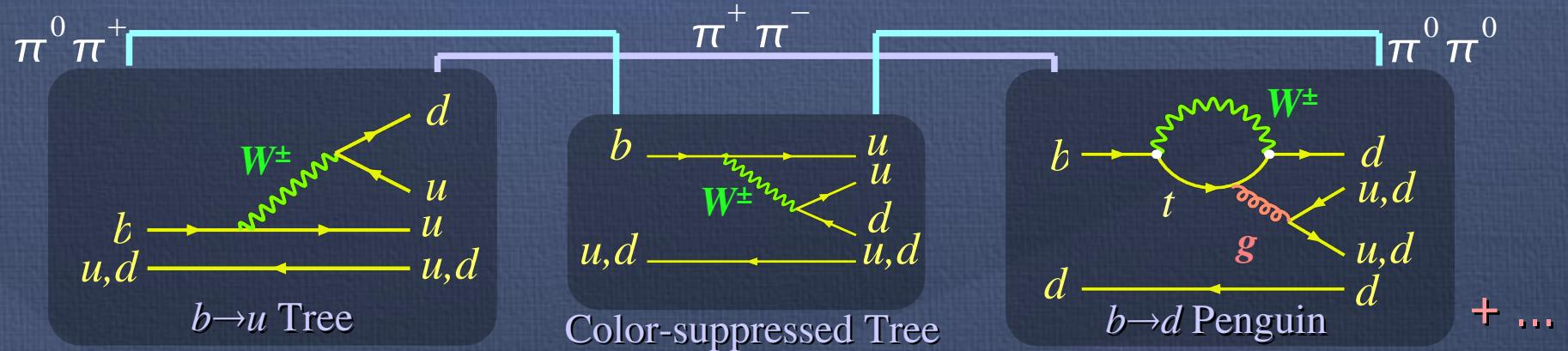
$$Bf(K^+ K^-) < 0.41 \times 10^{-6} \text{ @ 90% C.L.}$$

$Bf(K_S K_S)$ & $Bf(K_S K^+)$ are small.

No signal for $K^+ K^-$

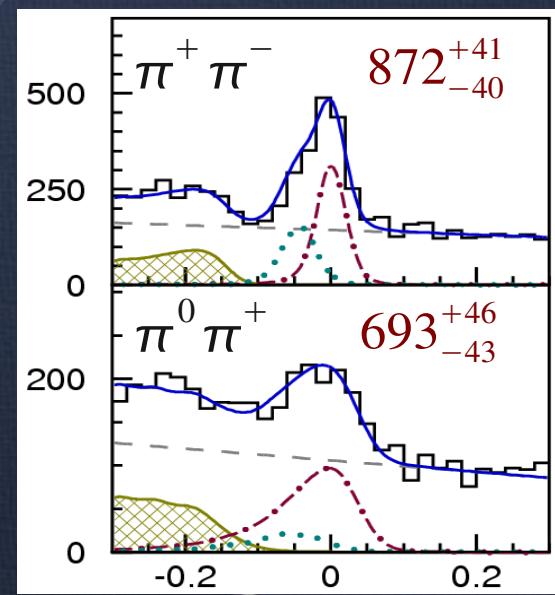
How about other $B \rightarrow hh$ Decays?

- Large $A_{CP}(\pi^+\pi^-)$ could be generated by $b \rightarrow u$ Tree + $b \rightarrow d$ Penguin.
- Small $A_{CP}(\pi^+\pi^0)$ since it should be dominated by $b \rightarrow u$ Tree.



Process	BF ($\times 10^{-6}$)	A_{CP}
$\pi^+\pi^-$	$5.1 \pm 0.2 \pm 0.2$	$+0.55 \pm 0.08 \pm 0.05$
$\pi^0\pi^+$	$6.5 \pm 0.4^{+0.4}_{-0.5}$	$+0.07 \pm 0.06 \pm 0.01$
$\pi^0\pi^0$	$1.1 \pm 0.3 \pm 0.1$	$+0.44^{+0.73+0.04}_{-0.62-0.06}$

Ref. (Belle Coll. PRL 98, 181804, 2007)
(Belle Coll. PRL 99, 121601, 2007)



How about other $B \rightarrow hh$ Decays?

The Complete Table (Belle Data)

Process	$BF (\times 10^{-6})$	A_{CP}
$K^0 \pi^+$	$22.8^{+0.8}_{-0.7} \pm 1.3$	$+0.03 \pm 0.03 \pm 0.01$
$K^+ \pi^-$	$19.9 \pm 0.4 \pm 0.8$	$-0.094 \pm 0.018 \pm 0.008$
$K^+ \pi^0$	$12.4 \pm 0.5 \pm 0.6$	$+0.07 \pm 0.03 \pm 0.01$
$K^0 \pi^0$	$9.2 \pm 0.7^{+0.6}_{-0.7}$	$-0.05 \pm 0.14 \pm 0.05 (*)$
$\pi^+ \pi^-$	$5.1 \pm 0.2 \pm 0.2$	$+0.55 \pm 0.08 \pm 0.05 (*)$
$\pi^0 \pi^+$	$6.5 \pm 0.4^{+0.4}_{-0.5}$	$+0.07 \pm 0.06 \pm 0.01$
$\pi^0 \pi^0$	$1.1 \pm 0.3 \pm 0.1$	$+0.44^{+0.73 + 0.04}_{-0.62 - 0.06}$
$K^0 K^0$	$0.86^{+0.24}_{-0.21} \pm 0.09$	$-0.38 \pm 0.38 \pm 0.05 (*)$
$K^0 K^+$	$1.22^{+0.33 + 0.13}_{-0.28 - 0.16}$	$+0.13^{+0.23}_{-0.24} \pm 0.02$
$K^+ K^-$	< 0.25	N/A

Dominated by
 $b \rightarrow s$ penguins (+EWP),
No A_{CP} .

The $A_{CP}(K\pi)$ Puzzle!

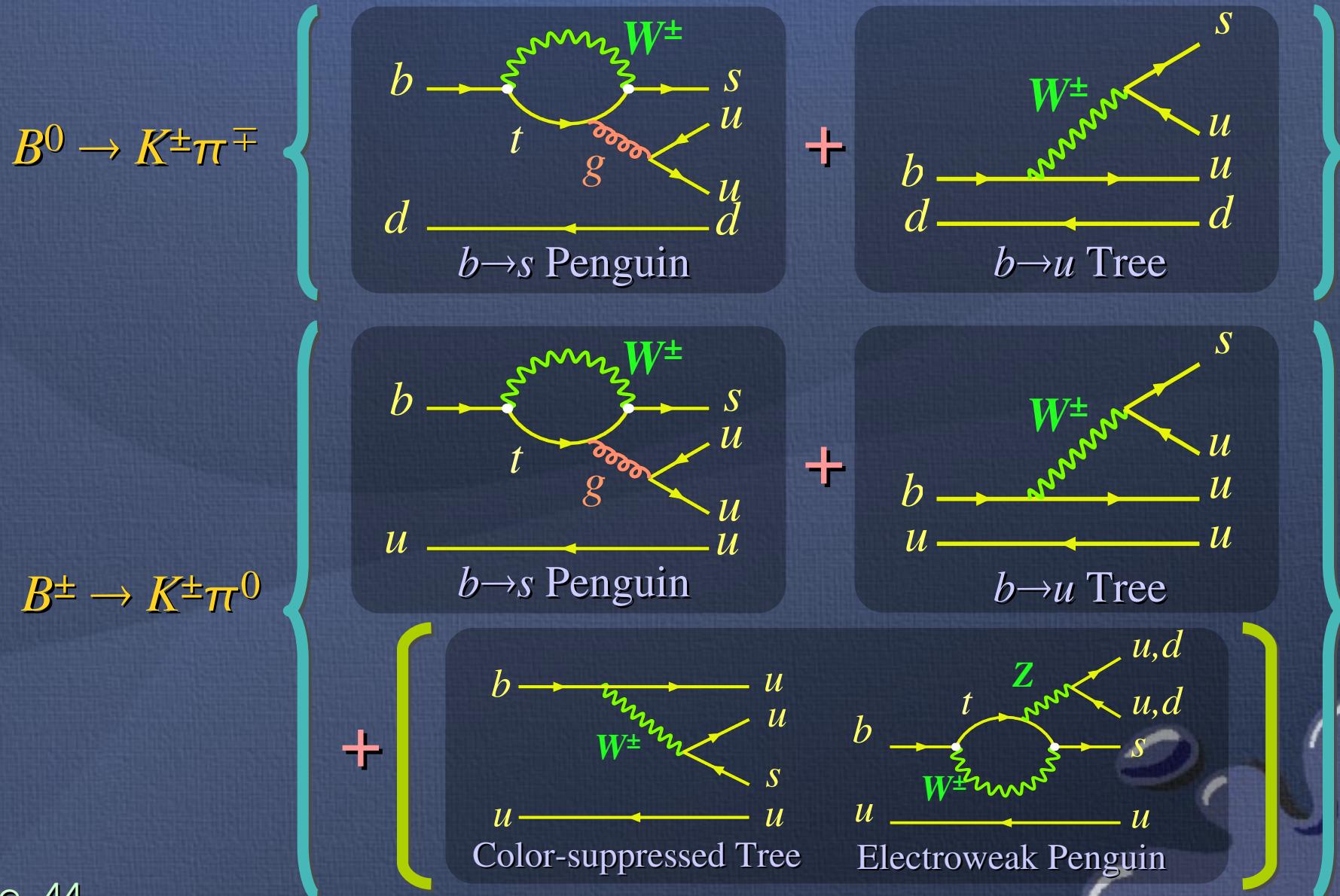
Contributed by $b \rightarrow s$ penguin
& Color suppressed Tree;
Need more data to verify.

Dominated by
 $b \rightarrow u$ trees (+Color-suppress),
No A_{CP} .

Small branching fractions,
need more data.

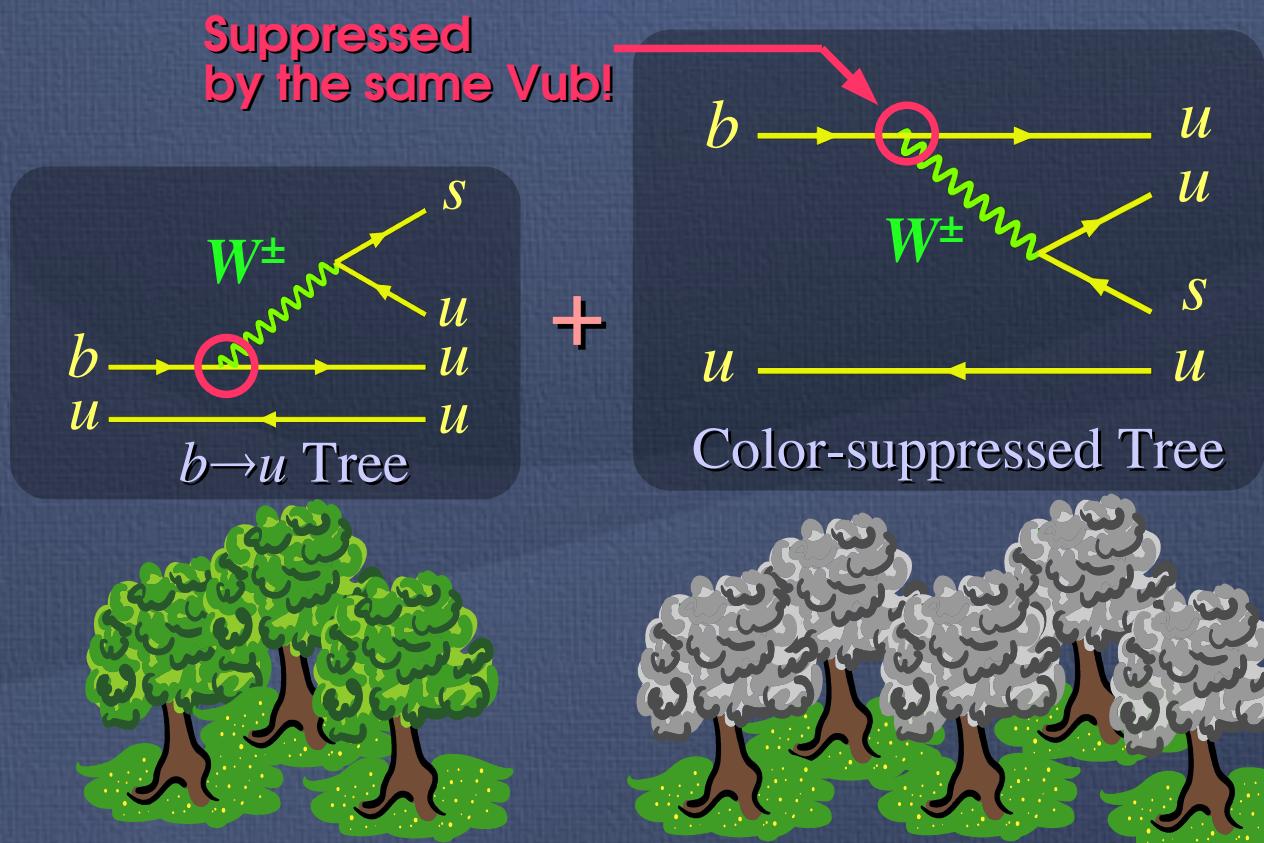
(*) from TCPV analysis

How about sub-dominance diagrams?



How about sub-dominance diagrams?

- Resolution to the puzzle: enhance (or blow up) the contributions from sub-dominance diagram(s). e.g.:



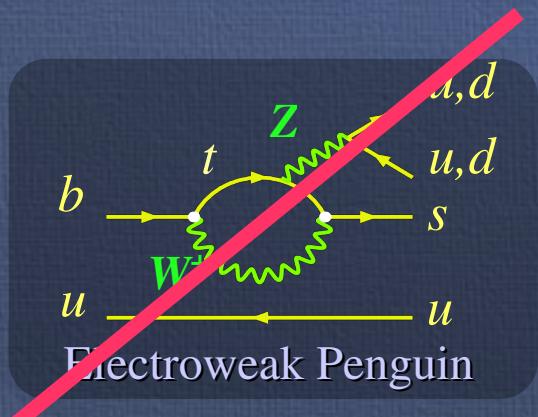
One can resolve the $A_{CP}(K\pi)$ puzzle by enlarge the C/T from ~ 0.3 to ~ 1.6 .

NLO calculations do support a larger C, but not for a break down of the whole picture: **C>T**

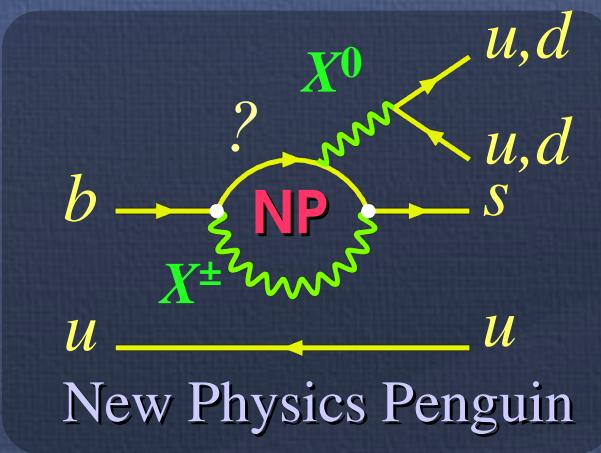
Ref. (Chiang et al, PRD 70, 034020 (2004)), (Chang et al, PRD 71, 014036 (2005))
(Baek et al., PLB 653, 249–253 (2007).), (Li, et al, PRD 72, 114005 (2005))

How about sub-dominance diagrams?

- Electroweak penguin: negligible CP violating phase in SM.



Hard to change much
 A_{CP} within SM



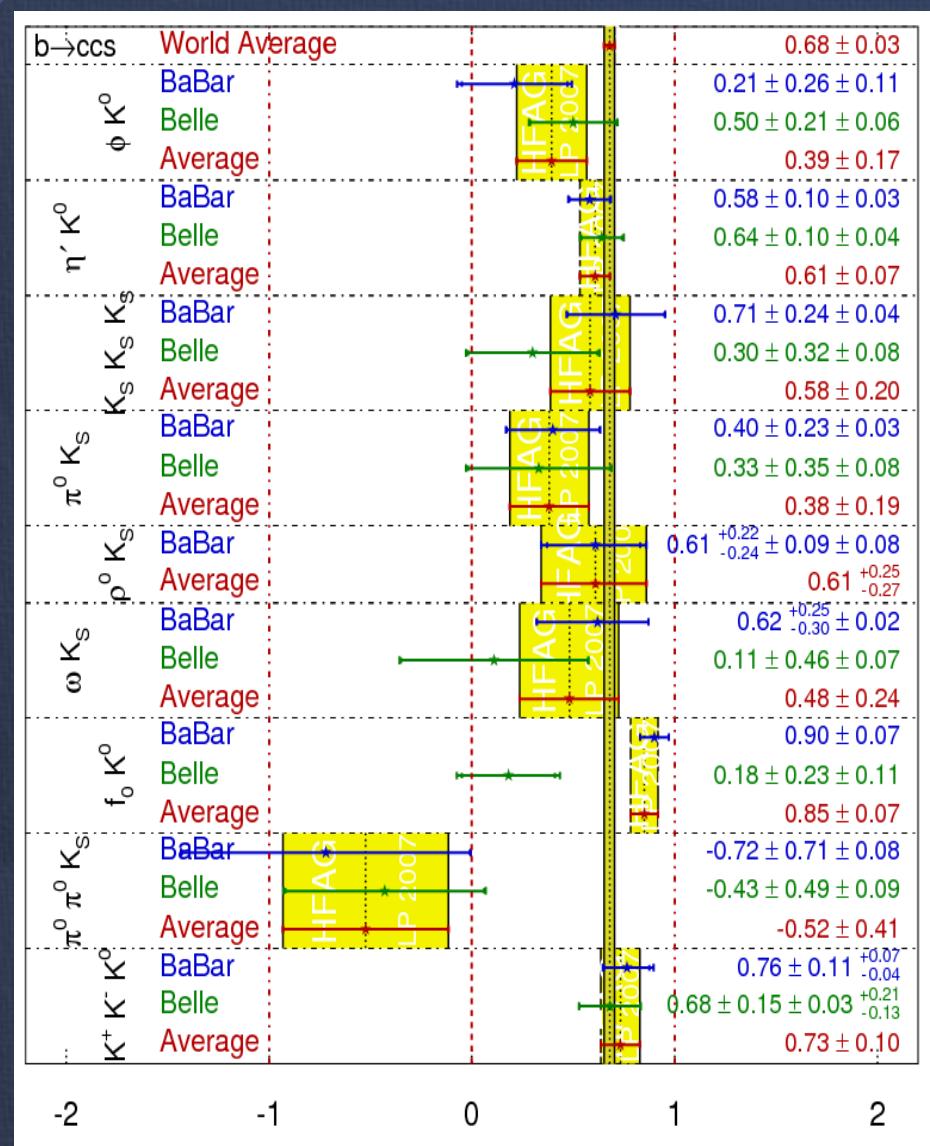
The $b \rightarrow s$ penguin
may pick up
new CP violating
phase from the
physics beyond SM.

Model independent fits yield an EWP like NP amplitude:
Ref. Baek et al, PRD 71, 057502 (2005); PLB 653, 249-253 (2007)

Fourth generation quarks in the loop:
Ref. Hou et al, PRL 95, 141601 (2005)

The NP in EWP sector should also effect other measurements, e.g.
TCPV in $b \rightarrow s$ penguin modes, CPV in B_s mixing, etc.

Other “Hints” with $b \rightarrow s$ Transitions



$\sin 2\phi_1^{\text{eff}}$ with
 $b \rightarrow s$ penguin Modes

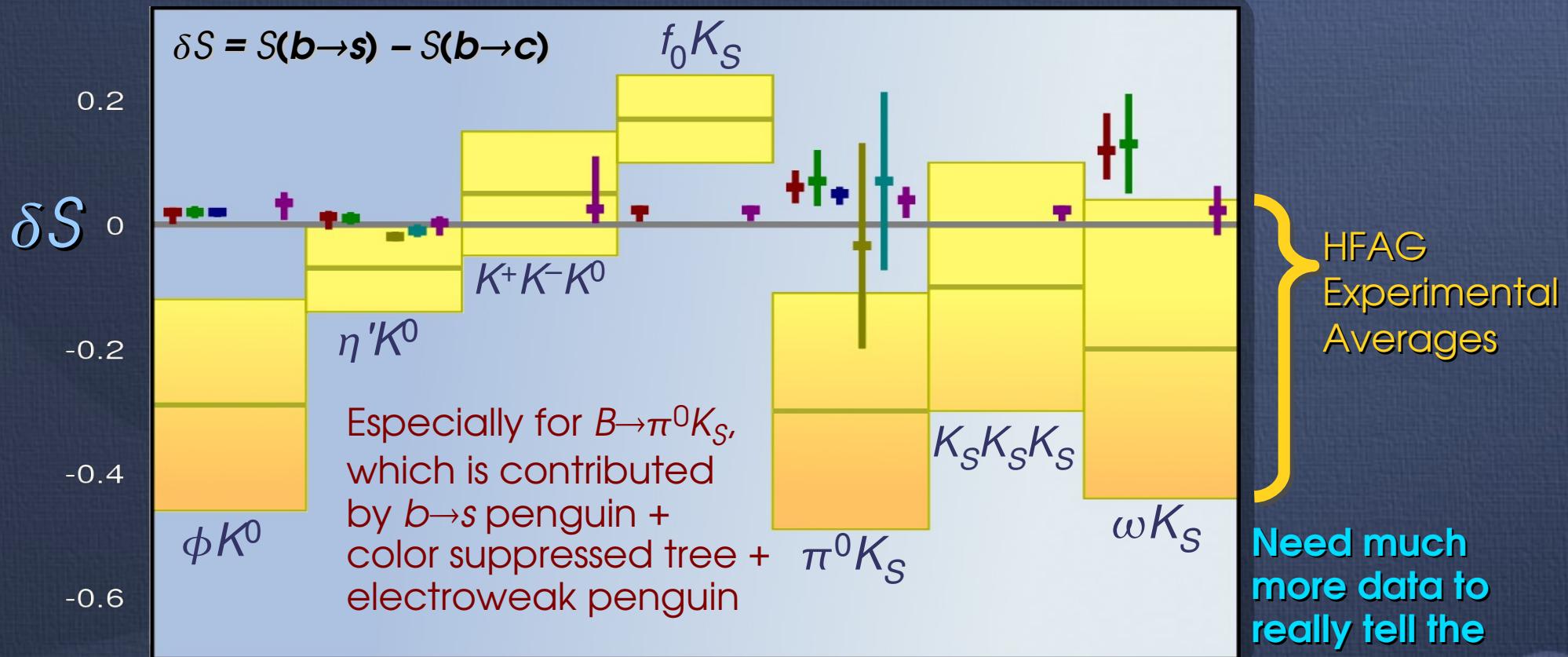
- A gold medal search for NP

(theoretically very clean): measuring $S_{CP} = (\sin 2\phi_1^{\text{eff}})$ using the $b \rightarrow s$ penguin modes (ϕK_S , $\eta' K_S$, etc.), and compare them with the $\sin 2\phi_1$ from $b \rightarrow ccs$ tree processes.

- A global shift to the lower side is found in data (except the outlying $f^0 K_S$ from BaBar Dalitz analysis).

- Opposite sign to the theoretical predictions.

Other “Hints” with $b \rightarrow s$ Transitions



- QCDF (Cheng-CKC-Soni), ■ QCDF+FSI (Cheng-CKC-Soni)
- QCDF (Beneke), ■ pQCD (Mishima-Li)
- SCET (Williamson-Zupan) Solution 1 / ■ Solution 2

Need much more data to really tell the difference (SuperB + LHCb).

Other “Hints” with $b \rightarrow s$ Transitions

CP Violation in B_s Decays

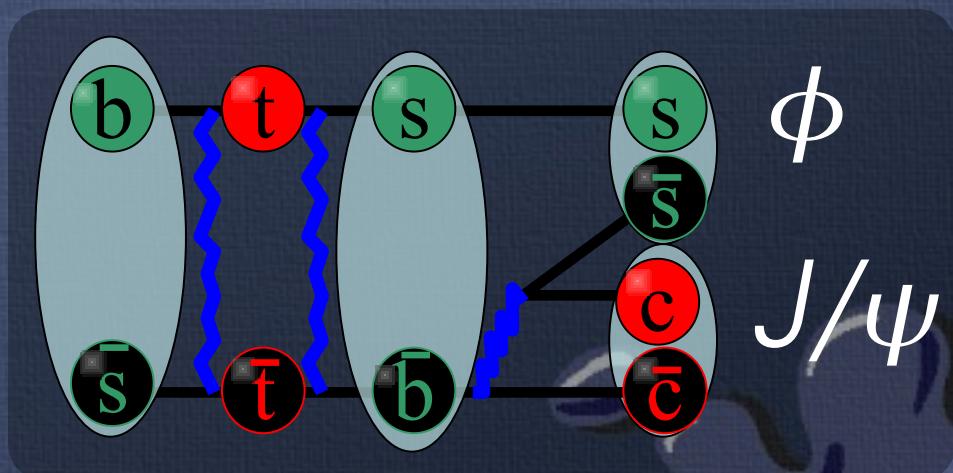
Corresponding to B_s or \bar{B}_s

$$\Gamma(t) \sim \cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos(\phi_s) \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) \pm \sin(\phi_s) \sin(\Delta M_s t)$$

- Time-dependent + angular analysis using $B_s \rightarrow J/\psi \phi$ decays.
- SM predicts negligible B_s mixing phase: $\sim 2^\circ$.
- Tevatron results:

DØ: $\phi_s = -0.57^{+0.24}_{-0.30} {}^{+0.07}_{-0.02}$ (rad)

CDF: Prob = 15% (1.5σ) for a deviation from SM

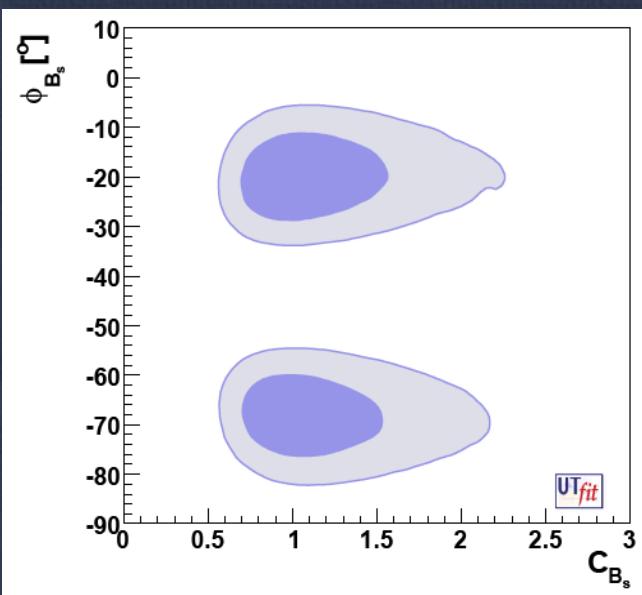


Other “Hints” with $b \rightarrow s$ Transitions

Result from UTfit group

FIRST EVIDENCE OF NEW PHYSICS IN $b \leftrightarrow s$ TRANSITIONS (UTfit Collaboration)

M. Bona,¹ M. Ciuchini,² E. Franco,³ V. Lubicz,^{2, 4} G. Martinelli,^{3, 5} F. Parodi,⁶ M. Pierini,¹
P. Roudeau,⁷ C. Schiavi,⁶ L. Silvestrini,³ V. Sordini,⁷ A. Stocchi,⁷ and V. Vagnoni⁸



- ➊ Evidence of New Physics:
Combining results from DØ and CDF
get a **3.7σ deviation from SM** (Bayesian).
- ➋ The issue could be fully sorted at LHCb
 $\sigma(\phi_s) \sim 0.02$ rad @ 2/fb.

Wait and see:
Last from Tevatron & New from LHC

Summary: Hints to New Physics

- The mechanism of CP violation is well-established within the framework of the Standard Model. But it is known to be too small to account for the matter-dominated Universe.
- **A large deviation in direct CP violation is firmly measured in $B \rightarrow K\pi$ decays at Belle (4.4σ)**. Combining the result with other experiments will give a deviation of 5.3σ .
- Although it is susceptible to the hadronic effects and it needs further clarification, this large deviation would be **an indication of new sources of CP violation in $b \rightarrow s$ penguin loops**.



Summary: Hints to New Physics



Keeping investigating
the data recorded at
B-factories & Tevatron



*Open the box, and then
observe New Physics at LHC*