New Physics Effects in *B* Decays

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National Taiwan University
for the Belle Collaboration

XXVIII Physics in Collision 2008
Perugia, Italy, June 25-28

The Major Players

The B-Factories

Tsukuba, Japan

L_{peak}=1.71 x 10^{34} /cm^2/s^2

3.5 GeV e^+ on 8 GeV e^-

W_{CM} = M(Y(4s))

3km circumference

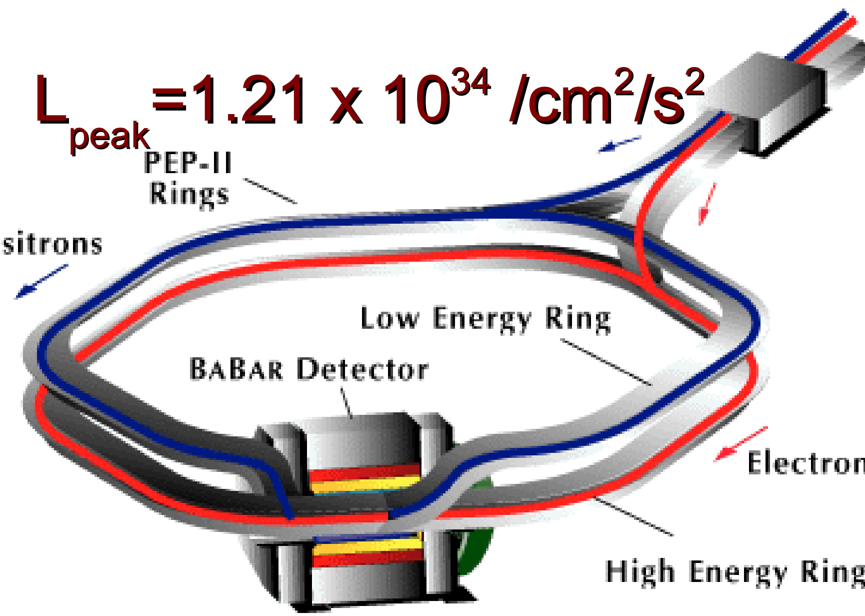
~11mrad crossing angle

PEP II: Stanford, USA

3.1 GeV e^+ on 9 GeV e^-

W_{CM} = M(Y(4s))

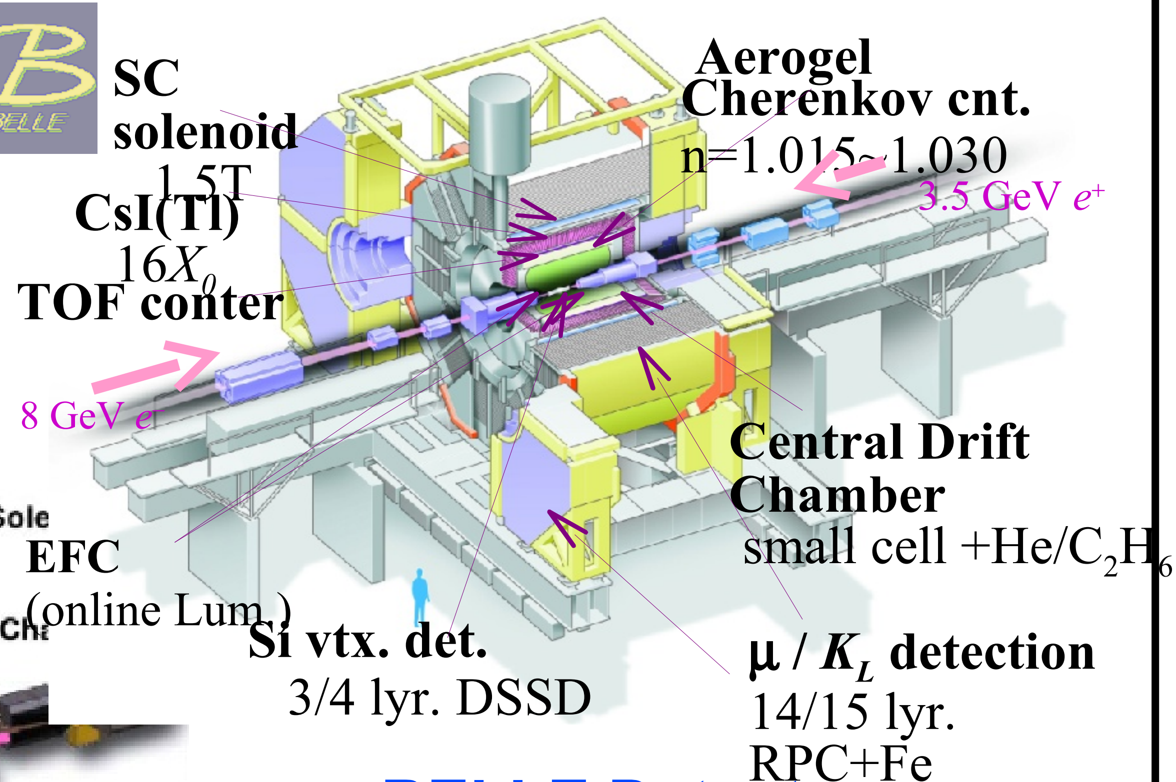
CMS boost <βγ>=0.56



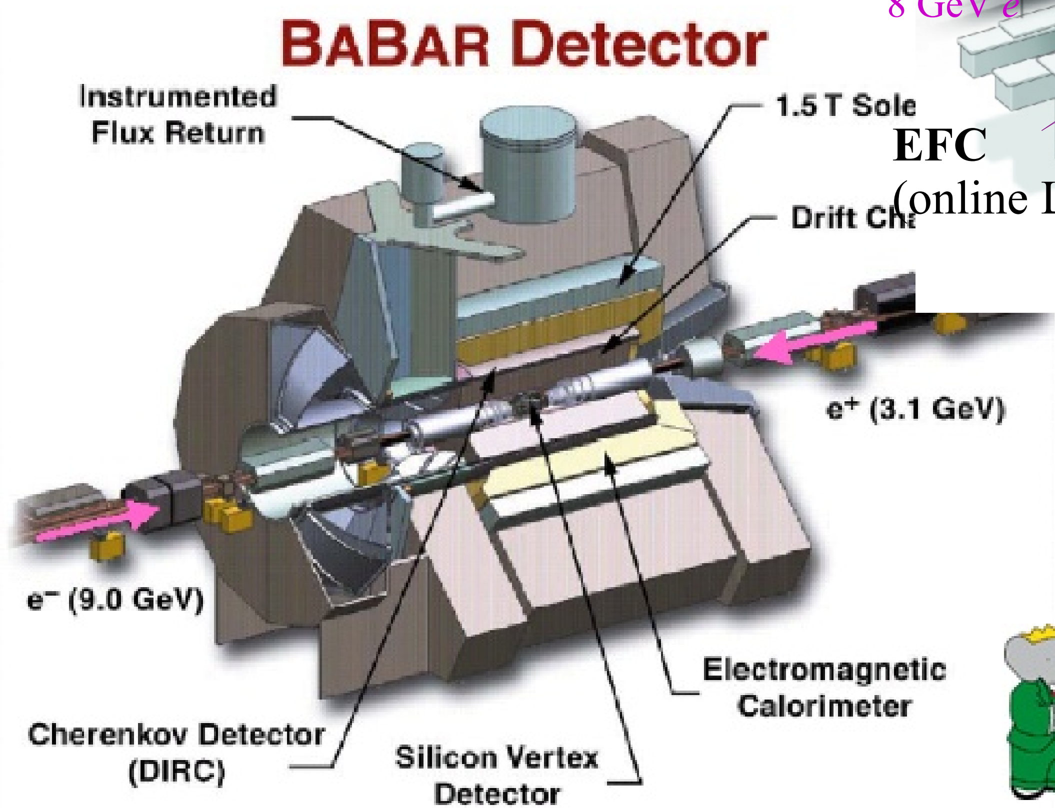
L_{peak}=1.21 x 10^{34} /cm^2/s^2

The B-Factories

- Similar design
- Cross-checking on each other

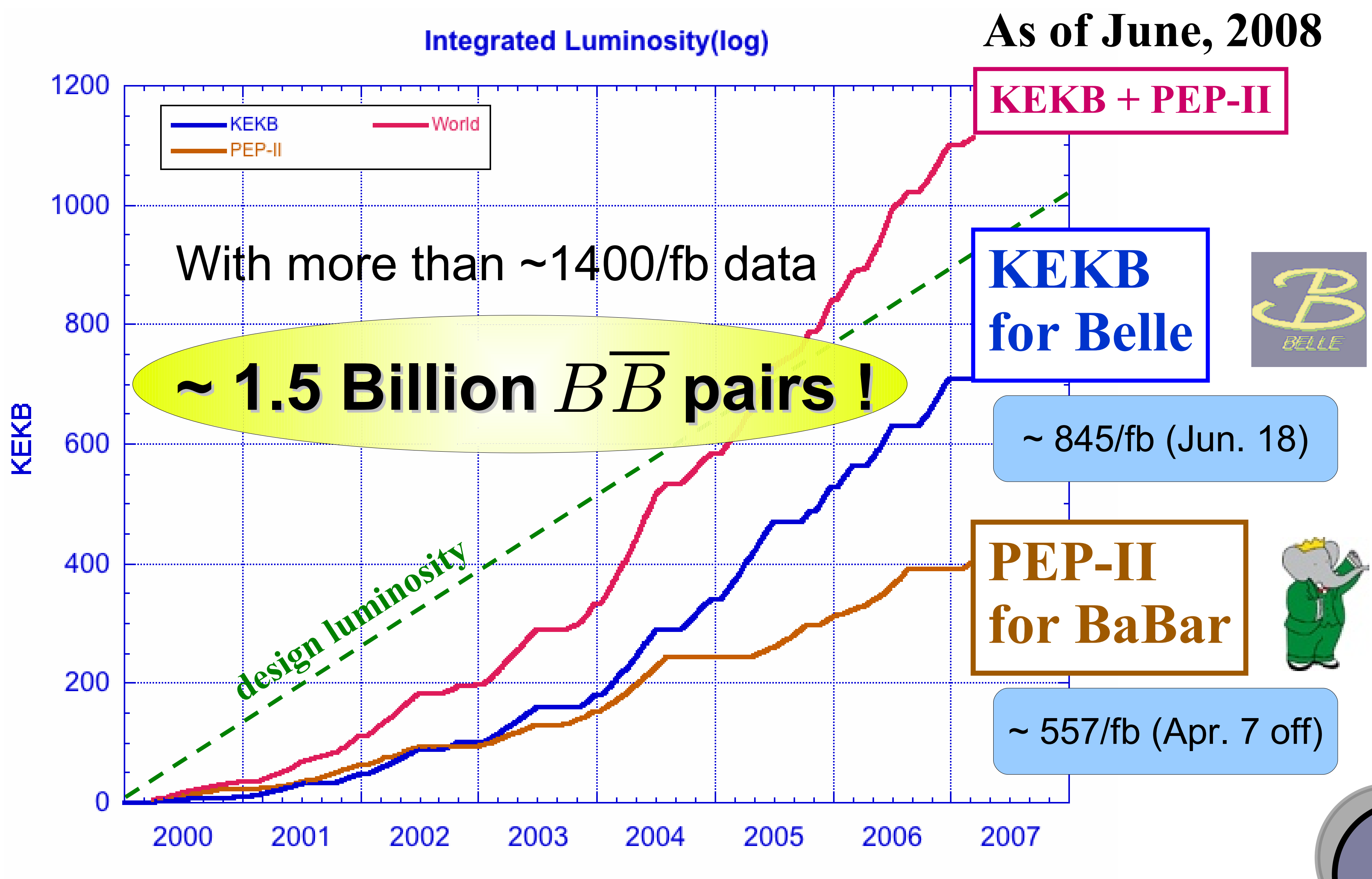


BELLE Detector



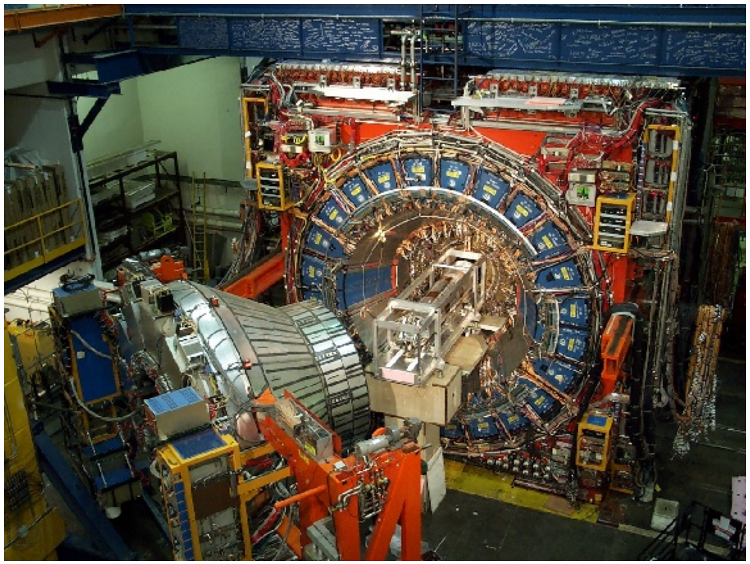
- Accelerators and detectors suppressed performance goals at both labs

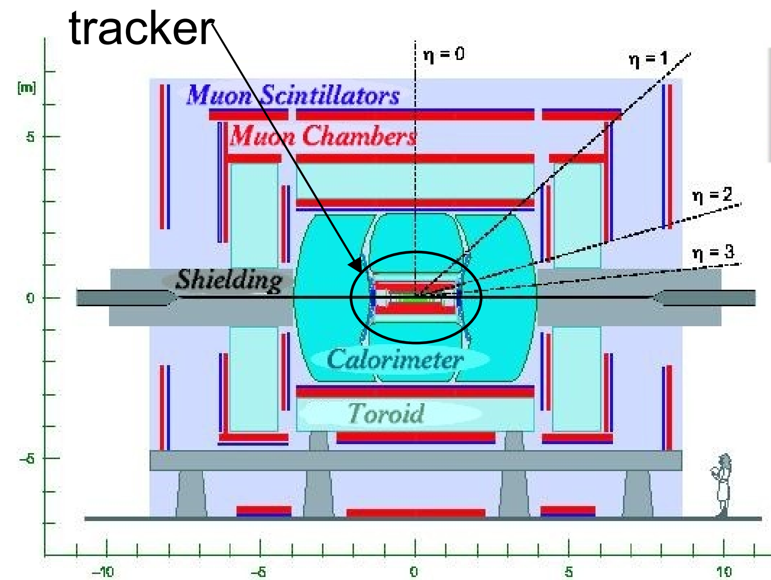
Integrated Luminosity

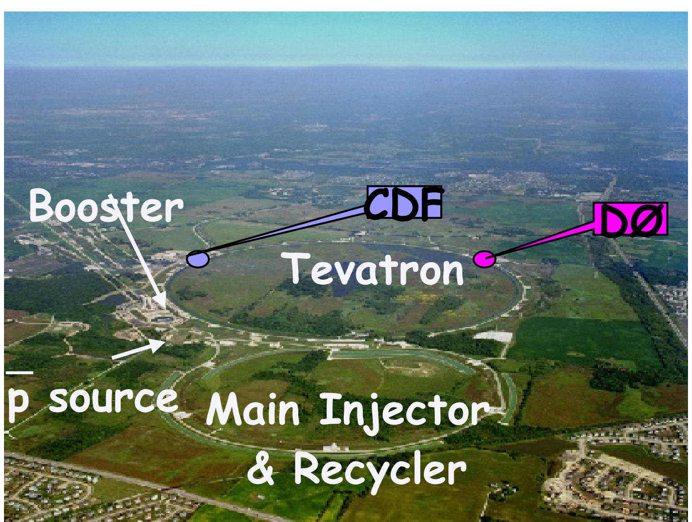


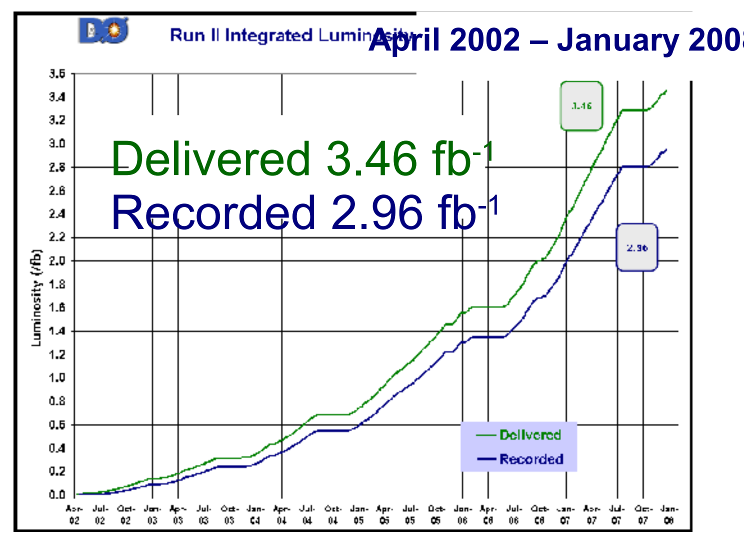
Tevatron

- Also contributing valuable results in *B* decays









What we learned from B Factories

- Most of the results are consistent with SM
  - Needs precise measurements for verification
  - Good large statistics & good analysis tools needed
- Many unanticipated particles discovered
  - The X, Y, and Z's → See J. Brodzicka's talk
- Some small room for New Physics
  - Deviations from SM in phases and magnitudes
  - Several possible contributions from various theoretical models

    → Needs experimental validation
- Sorry, but won't cover all interesting topics
  - Also won't go over most details

Direct CP Violation in $B \rightarrow hh$

DCPV in B→hh

- Decay amplitudes can be described as:

$$\mathcal{A}(B \to f) = \sum_i \mathcal{A}_i e^{i(\delta_i + \phi_i)}$$

$$\bar{\mathcal{A}}(\overline{B} \to \overline{f}) = \sum_{i'} \bar{\mathcal{A}}_i e^{i(\delta_{i'} + \phi_{i'})}$$

- CP violating asymmetry is then defined as

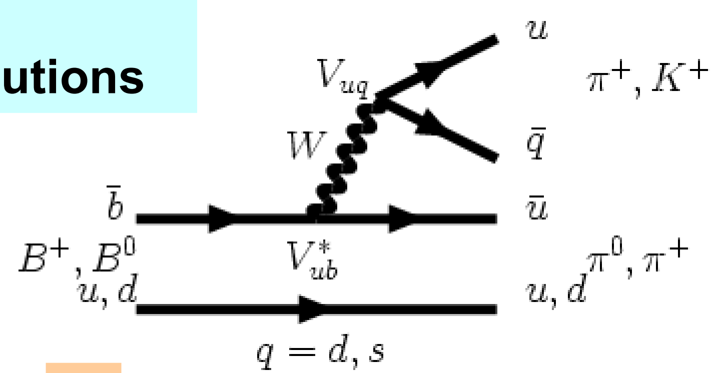
$$\mathcal{A}_{CP}(B \to f) = \frac{|\bar{\mathcal{A}}|^2 - |\mathcal{A}|^2}{|\bar{\mathcal{A}}|^2 + |\mathcal{A}|^2} \propto \sum_{i,j} \mathcal{A}_i \mathcal{A}_j \sin(\delta_i - \delta_j) \sin(\phi_i - \phi_j)$$

- A non-zero A_{CP} needs the following conditions:
  - More than 2 amplitudes
  - Non-zero strong phase diff.: $\Delta\delta = \delta_i - \delta_j \neq 0$
  - Non-zero weak phase diff.: $\Delta\phi = \phi_i - \phi_j \neq 0$

DCPV in B→hh

- DCPV in B → Kπ giving rise from the interference between Tree and Penguin:

Major contributions



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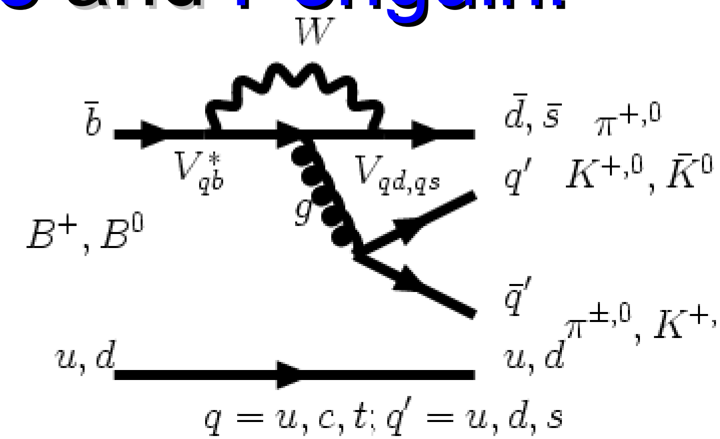


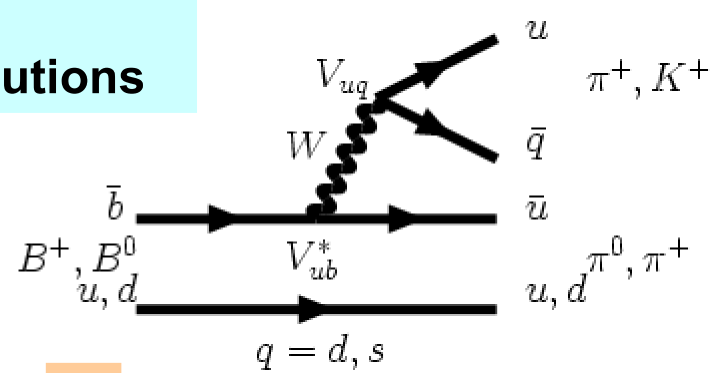
P

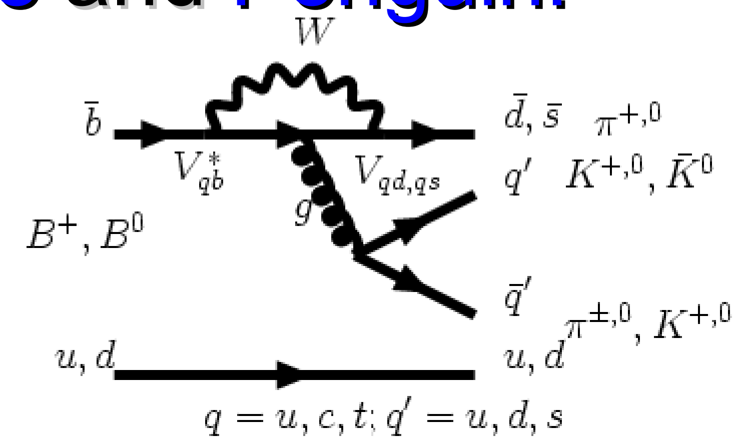
- Navïely expect similar A_{CP} for $B^0 \to K^+\pi^-$ & $B^\pm \to K^\pm\pi^0$

DCPV in B→hh

- DCPV in B → Kπ giving rise from the **interference** between **Tree** and **Penguin:**

Major contributions





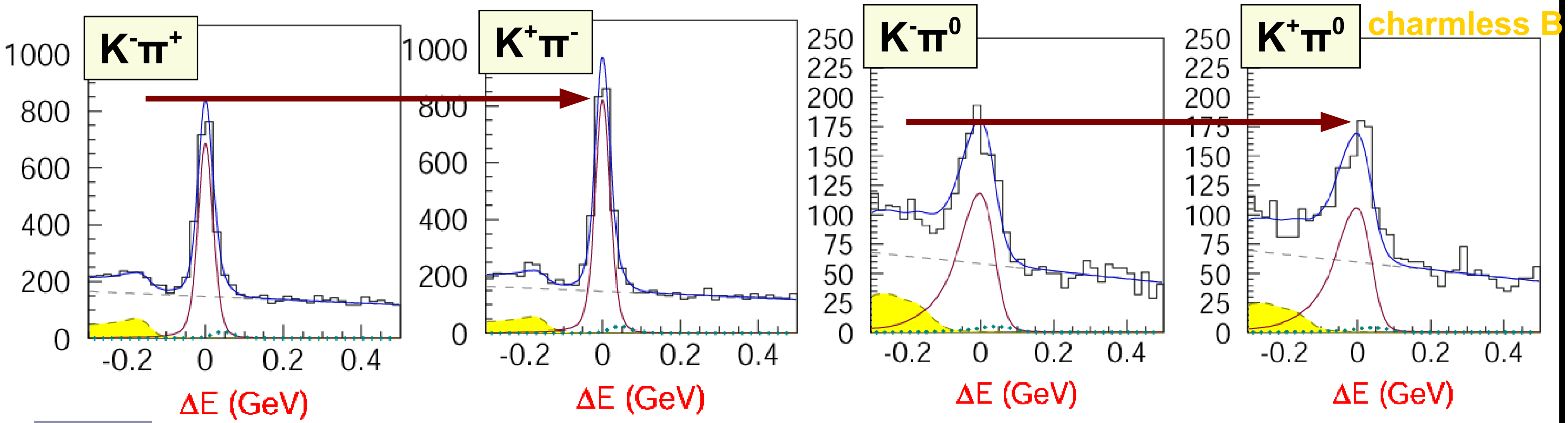
T

P

- **Navïely** expect **similar** A_{CP} for $B^0 \to K^+\pi^-$ & $B^\pm \to K^\pm\pi^0$

The Kπ "Puzzle"

- A_{CP} results from the B factories:



Belle: A_{cp}=-0.094±0.018±0.008

BaBar: A_{cp}=-0.107±0.018±0.006

CDF: A_{cp}=-0.086±0.023±0.009

Belle: A_{cp}=+0.07±0.03±0.001

BaBar: A_{cp}=+0.03±0.04±0.01

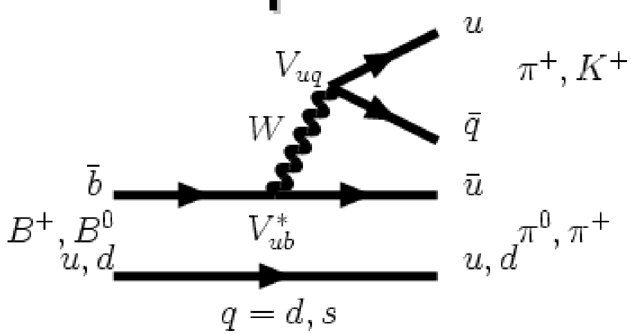
Deviation ≈ 5.2σ !

- HFAG w.a.: A_{cp}=-0.086±0.023±0.009 ≠ A_{cp}=+0.03±0.04±0.01

The Kπ "Puzzle"

- Two more amplitudes for $K^+\pi^0$

T



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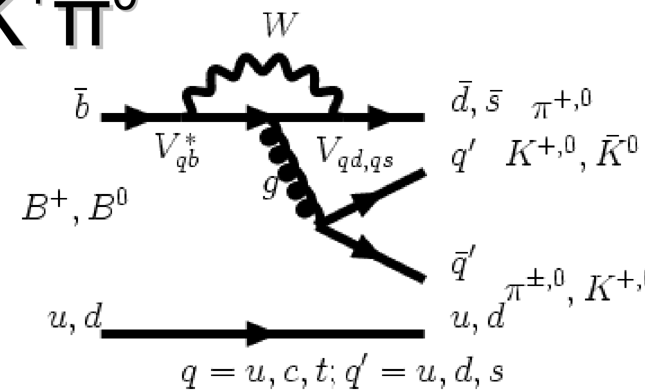

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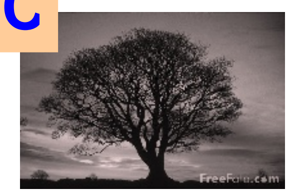
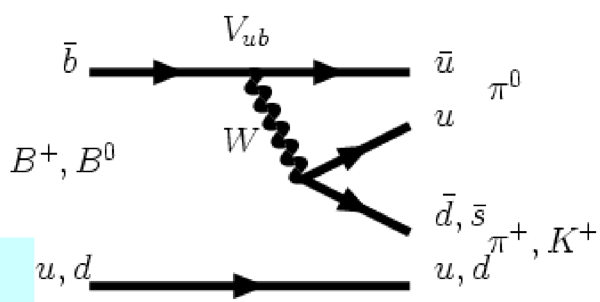
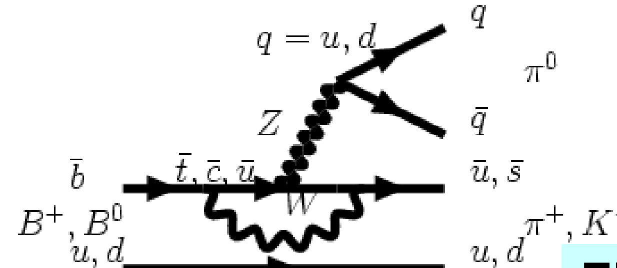




Color suppressed Tree

P_{EW}

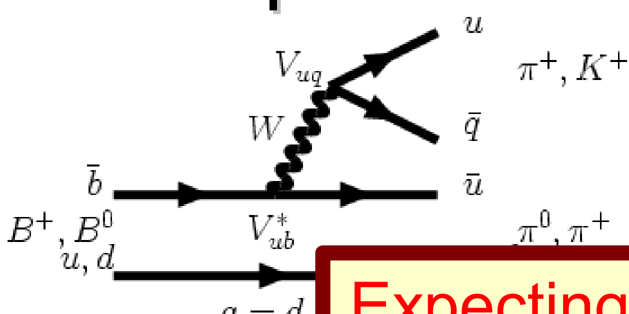


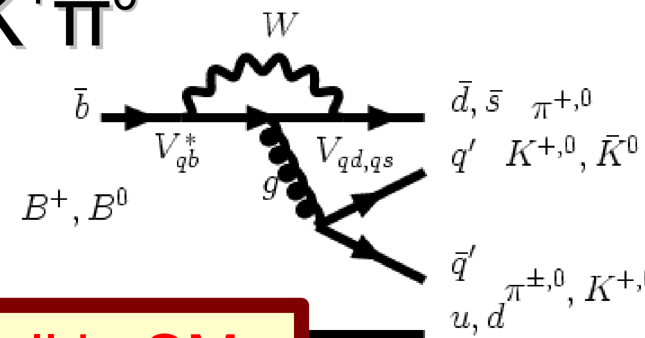
Electro Weak Penguin

The Kπ "Puzzle"

- Two more amplitudes for $K^+\pi^0$

T

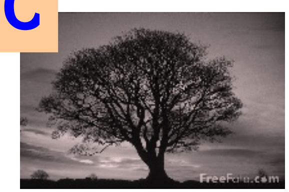


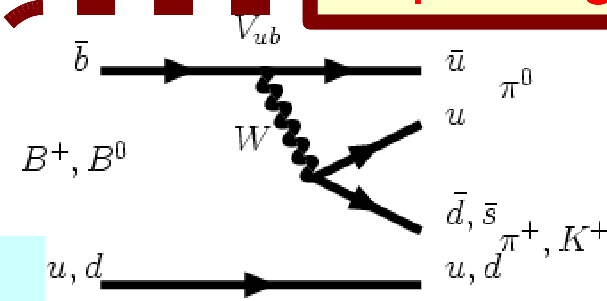


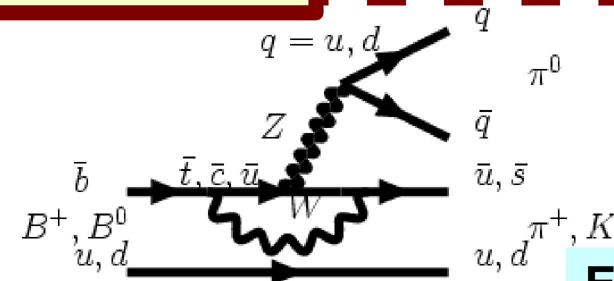
P

Expecting small in SM

C







P_{EW}

Color suppressed Tree

Electro Weak Penguin

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- Two more amplitudes for $K^+\pi^0$

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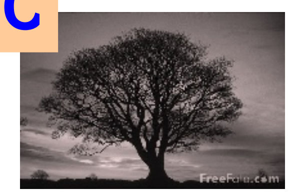

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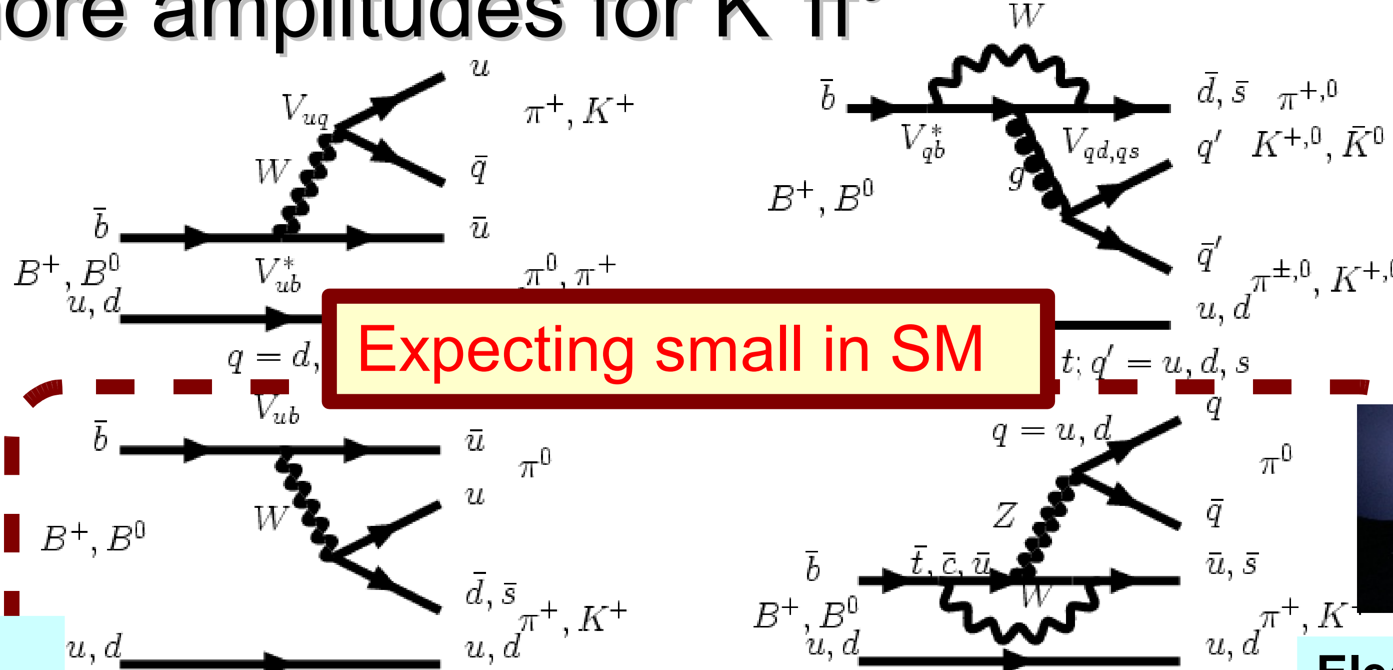
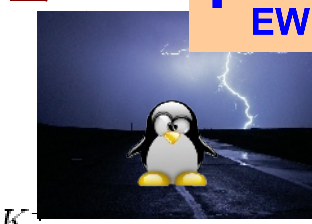


Expecting small in SM

P

$\mathbf{P_{EW}}$



Electro Weak Penguin

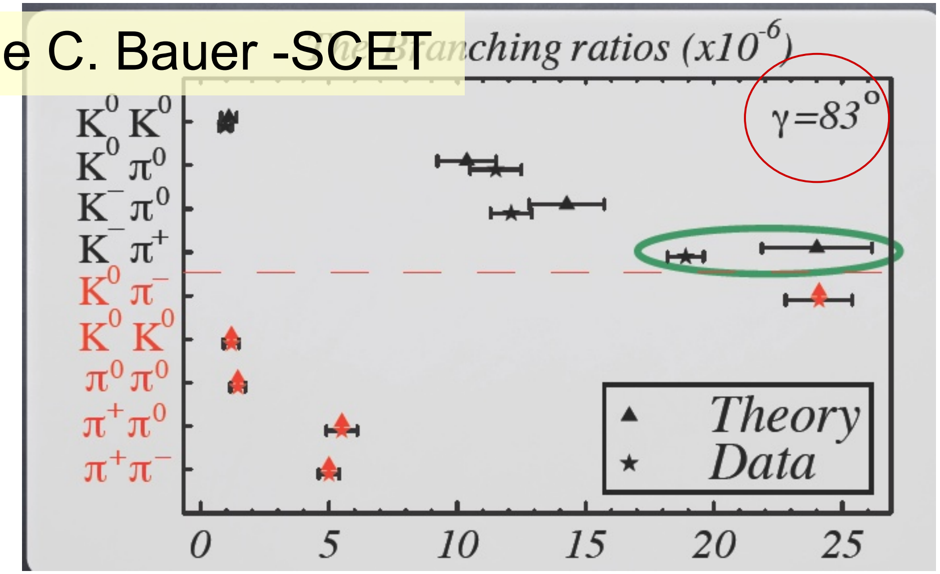
$\Delta A_{CP} \sim 0$ if C and P_{EW} are neglected

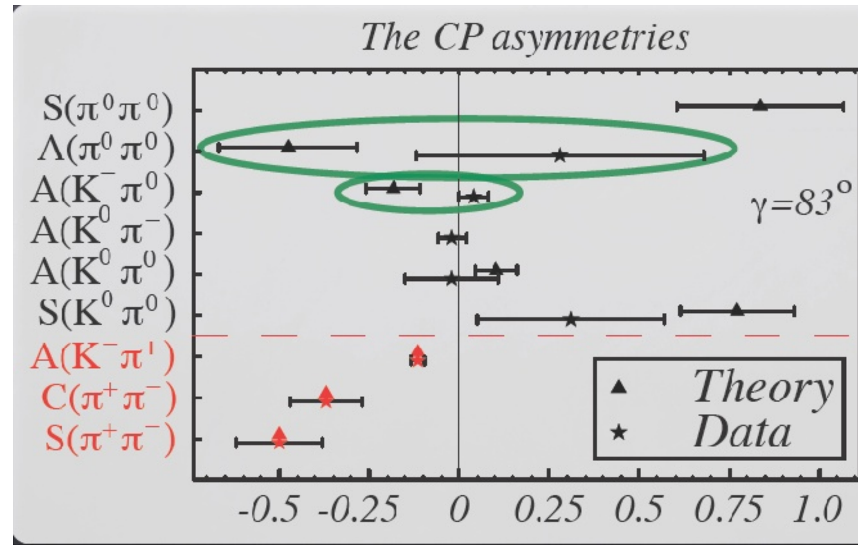
- C.-W.Chaing, et al., PRD 70, 034020
- Y.-Y.Charng, et al., PRD 71, 014036
- C. Chua, et al., PRA 18, 1763
- W.-S.Hou, et al., PRL 95, 141601
- S.Baek, et al., PRD 71, 057502
- S.Baek, et al., PLB 653, 249
- H.-n.Li,et al., PRD 72, 114005
- etc…

- Enhancement of **C** ?
  → C > T is needed?
- Enhancement of $\mathbf{P_{EW}}$?
  → Would indicate NP. 4th generation?
- Due to poor understanding of strong int.?
  → Final State Interactions? NLO in pQCD?

Benchmark BR & DCPV B→ππ/Kπ

See C. Bauer -SCET





See S. Mishima-PQCD

$Br(10^{-6})$, $A_{CP}(10^{-2})$	Exp. HFAG	LO Keum,Sanda(03)	NLO
$Br(B^0 \to \pi^\mp\pi^\pm)$	4.9 ± 0.4	$5.9 \sim 11.0$	$6.5^{+6.7}_{-3.8}$
$Br(B^\pm \to \pi^\pm\pi^0)$	5.5 ± 0.6	$2.7 \sim 4.8$	$4.0^{+3.4}_{-1.9}$
$Br(B^0 \to \pi^0\pi^0)$	1.45 ± 0.29	$0.10 \sim 0.65$	$0.29^{+0.50}_{-0.20}$
$A_{CP}(B^0 \to \pi^\mp\pi^\pm)$	37 ± 10	$16.0 \sim 30.0$	18^{+20}_{-12}
$A_{CP}(B^+ \to \pi^+\pi^0)$	1 ± 6	0.0	0 ± 0
$A_{CP}(B^0 \to \pi^0\pi^0)$	28^{+40}_{-39}	$20.0 \sim 40.0$	63^{+35}_{-34}

$Br(10^{-6})$, $A_{CP}(10^{-2})$	Exp. HFAG	LO Keum,Sanda(03)	NLO
$Br(B^\pm \to \pi^\pm K^0)$	24.1 ± 1.3	$14.4 \sim 26.3$	$23.6^{+14.5}_{-8.4}$
$Br(B^\pm \to \pi^0 K^\pm)$	12.1 ± 0.8	$7.9 \sim 14.2$	$13.6^{+10.3}_{-5.7}$
$Br(B^0 \to \pi^\mp K^\pm)$	18.9 ± 0.7	$12.7 \sim 19.3$	$20.4^{+16.1}_{-8.4}$
$Br(B^0 \to \pi^0 K^0)$	11.5 ± 1.0	$4.5 \sim 8.1$	$8.7^{+6.0}_{-3.4}$
$A_{CP}(B^\pm \to \pi^\pm K^0)$	-2 ± 4	$-1.5 \sim -0.6$	0 ± 0
$A_{CP}(B^\pm \to \pi^0 K^\pm)$	4 ± 4	$-17.3 \sim -10.0$	-1^{+3}_{-6}
$A_{CP}(B^0 \to \pi^\mp K^\pm)$	-10.8 ± 1.7	$-21.9 \sim -12.9$	-10^{+7}_{-8}
$A_{CP}(B^0 \to \pi^0 K^0)$	2 ± 13	$-1.03 \sim -0.90$	-7^{+3}_{-4}

TH & EXP agree in some areas, but not all-

& TH errors still too large

Discussion on the "Puzzle"

- Is the ΔA_{CP} "puzzle" settled?
  - Experimental validations on theoretical predictions needed
- Sum rule relation proposed (M. Gronau, PLB 672, 82-88)
  - A more precise relation derived from $\boldsymbol{H}_{\text{eff}}$

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

Violation of the sum rule would be an unambiguous evidence of NP

Mode	$\mathcal{A}_{CP}$	$\mathcal{S}(\sigma)$
$K^+\pi^-$	$-0.094 \pm 0.018 \pm 0.008$	4.8
$K^+\pi^0$	$+0.07 \pm 0.03 \pm 0.01$	2.3
$K^0\pi^+$	$+0.03 \pm 0.03 \pm 0.01$	
$K^0\pi^0$	$-0.05 \pm 0.14 \pm 0.05$	

The sum rule predicts $A_{CP}(K^0\pi^0) = -0.15 \pm 0.06$

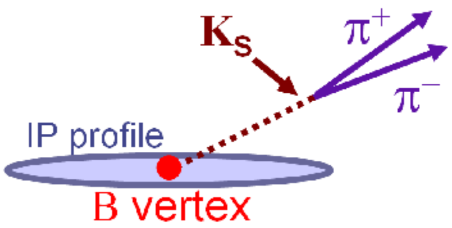
→ –15% DCPV in $K^0\pi^0$???

→ $\delta A_{CP}(K^0\pi^0)$ is still too large to claim a discrepancy.

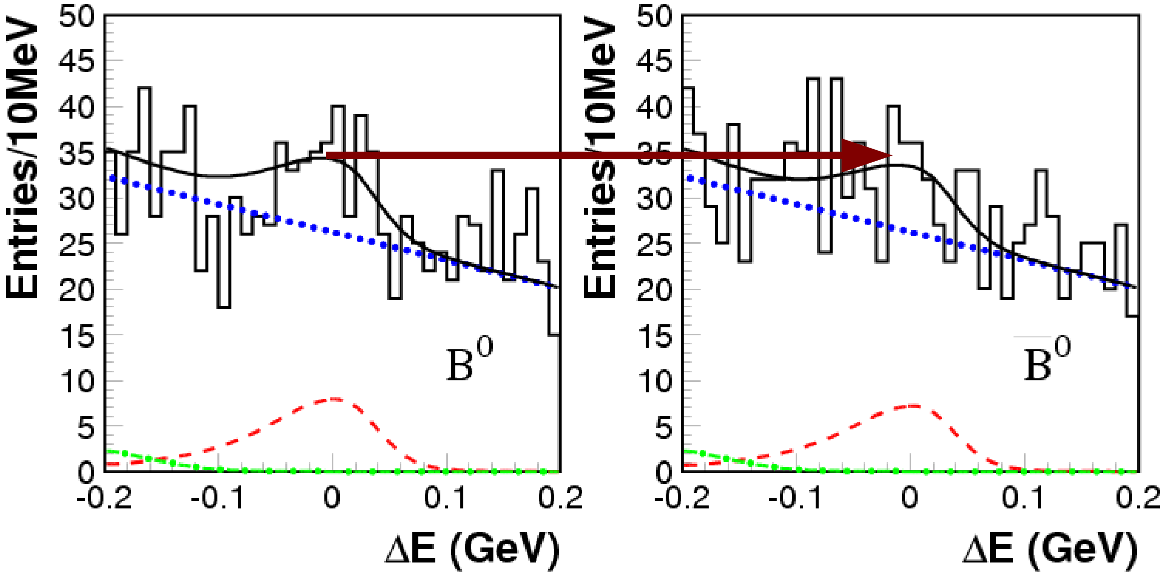
→ Have to examine this with larger statistics

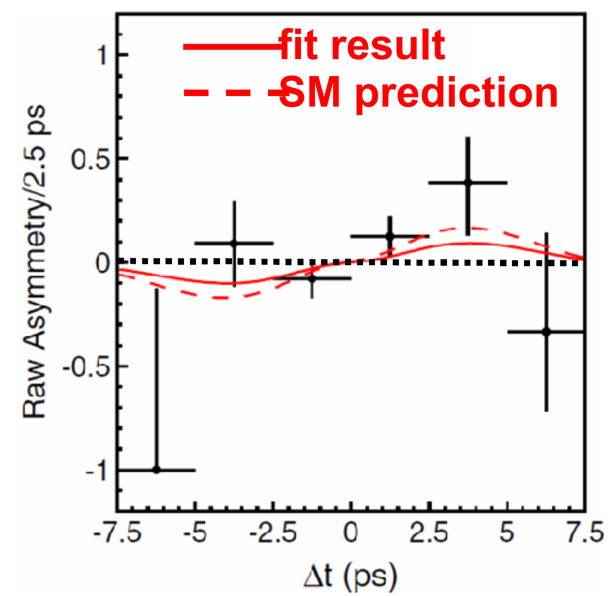
$A_{CP}(B^0 \to K^0\pi^0)$

PRD 76, 091103(2007)



- $A_{CP}(K^0\pi^0)$ and $S(K^0\pi^0)$ with time-dependent CP analysis
- *b* flavor tagging efficiency =~30%
- B vertex from K_S trajectory and IP : efficiency =~ 30%



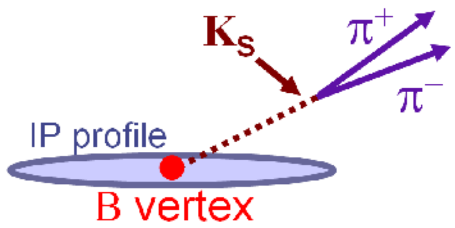


$A_{CP}(K^0\pi^0)$=+0.05±0.14±0.05
"$\sin 2\phi_1$" = +0.33±0.35±0.08

$A_{CP}(K^0\pi^0)$=+0.24±0.15±0.03
"$\sin 2\phi_1$" = +0.40±0.23±0.03

$A_{CP}(B^0 \rightarrow K^0\pi^0)$

PRD 76, 091103(2007)



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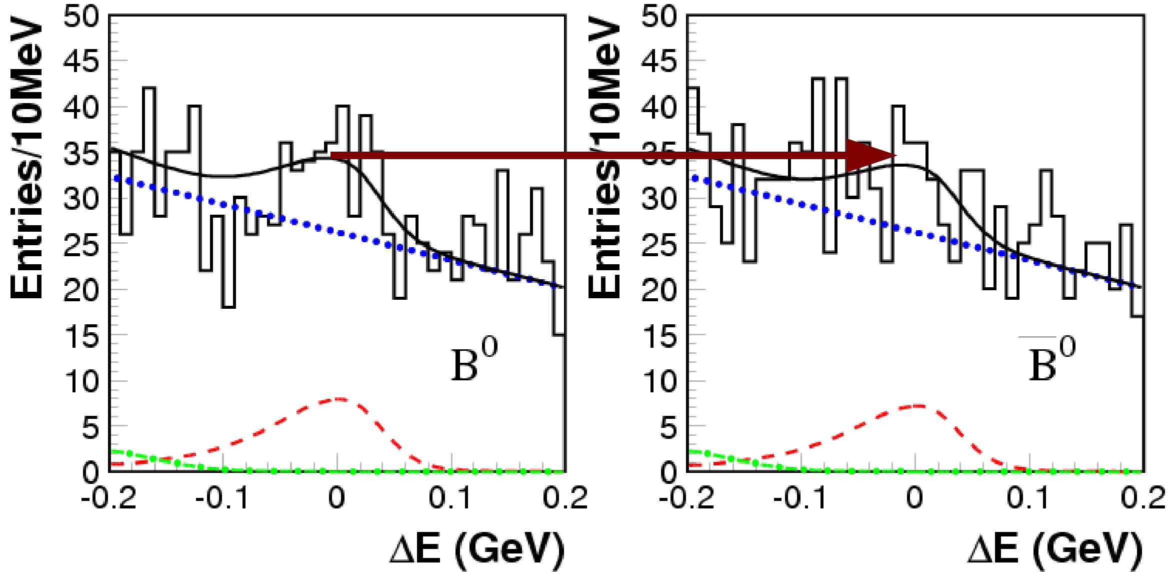

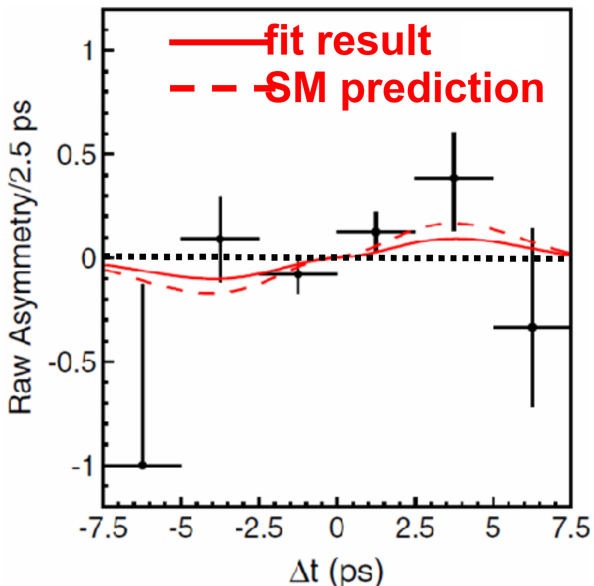

- $A_{CP}(K^0\pi^0) = -0.14\pm0.11$
- "$\sin2\phi_1$" = $+0.38\pm0.19$

HFAG W.A.

consistent with HFAG Ave: $\sin2\phi_1 = +0.668\pm0.026$

A Recent Publication

$$\Delta A_{CP} = A_{CP}(K^+\pi^0) - A_{CP}(K^+\pi^-) = +0.164 \pm 0.037 \ @ \ 4.4\sigma$$

What is happening with $\mathbf{A_{CP}(K^+\pi^-)}$ and $\mathbf{A_{CP}(K^+\pi^0)}$?

nature
Vol 452|20 March 2008|doi:10.1038/nature06827

LETTERS

Difference in direct charge-parity violation between charged and neutral *B* meson decays

The Belle Collaboration*

Equal amounts of matter and antimatter are predicted to have been produced in the Big Bang, but our observable Universe is clearly matter-dominated. One of the prerequisites[1] for understanding this elimination of antimatter is the nonconservation of charge-parity (CP) symmetry. So far, two types of CP violation have been observed in the neutral *K* meson (K^0) and *B* meson (B^0) systems: CP violation involving the mixing[2] between K^0 and its antiparticle $\bar{K}^0$ (and likewise[3,4] for B^0 and $\bar{B}^0$), and direct CP violation in the decay of each meson[5–8]. The observed effects for both types of CP violation are substantially larger for the B^0 meson system. However, they are still consistent with the standard model of particle physics, which has a unique source[9] of CP violation that is known to be too small[10] to account for the matter-dominated Universe. Here we report that the direct CP violation

source of CP violation. CP violation may arise from the interference between these two amplitudes, similar to two waves interfering with each other to produce a combined wave. However, this still depends on the detailed dynamics of each process. It is a theoretical challenge to describe how the quark-level decay evolves into the observed mesons. One of the advantages of studying a direct CP-violating asymmetry, which is a ratio of decay rates, is that many of the experimental systematic uncertainties cancel. Consequently, CP-violating asymmetries provide information about the dynamics of *B* meson decay, test different theoretical approaches, and probe new physics beyond the standard model.

Compared to the dominant $b \to c$ decay amplitudes, the amplitude of Fig. 1a is suppressed by the smallness of $|V_{ub}/V_{cb}|$, while Fig. 1b is suppressed by the quantum loop amplitude. However, the two

Published in Nature

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March 2008 | doi:10.1038/nature06827

tion between

in Nature

Vol 452 | 20 March 2008

nature

NEWS & VIEWS

PARTICLE PHYSICS

Song of the electroweak penguin

Michael E. Peskin

An unexpected imbalance in how particles containing the heaviest quarks decay might reveal exotic influences — and perhaps help to explain why matter, rather than antimatter, dominates the Universe.

Elsewhere in this issue, the Belle collaboration, based at the electron–positron particle collider of the high-energy accelerator laboratory KEK in Japan, announces their measurement of an anomalous asymmetry in the decay rates of exotic particles known as B mesons (Lin *et al.*, page 332)[1]. Combined with recent measurements of the same decays from the BaBar collaboration[2,3], a similar experiment at the Stanford Linear Accelerator Center (SLAC) in California, the new finding provides a tantalizing glimpse of a possible new source for a very fundamental asymmetry: the dominance of matter over antimatter in our Universe.

The two great principles of modern physics, quantum mechanics and Einstein's relativity, together imply that every particle in nature — among them the quarks and the leptons, the elementary particles of matter — has an antimatter counterpart with exactly the same mass,

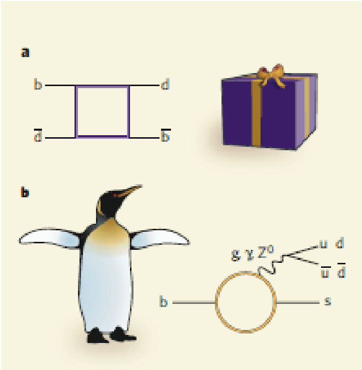
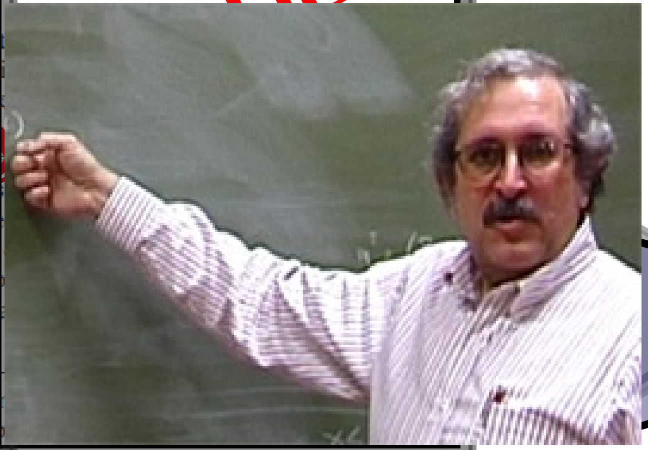


Figure 1 | Weakly decaying. A Feynman diagram represents the time evolution of a particle process (shown here from left to right). **a**, In a standard 'box' diagram of weak quark-mixing

time only three types of quark were known: up (u), down (d) and strange (s). But in the following decades, three more were discovered: charm (c), and the heavy bottom (b) and top (t) quarks. This astounding success led to the proposal[6,7] that specific experiments on B mesons — quark–antiquark pairings in which one of the particles is a b quark or $\bar{b}$ antiquark — could test the Kobayashi–Maskawa (KM) theory directly. The idea, proposed by Pier Oddone, that these experiments could be performed by colliding two beams of different energies, one of electrons and one of positrons (the antiparticle of the electron), motivated the construction of new accelerators at KEK and SLAC. In 2002, both BaBar[8] and Belle[9] reported the first observation of a KM asymmetry in a B-meson decay.

Since then, evidence accumulated by BaBar and Belle, in a data set of more than 1.2 bil-



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$$\Delta A_{CP} = A_{CP}(K^+\pi^0) - A_{CP}(K^+\pi^-) = +0.164 \pm 0.037 \text{ @ } 4.4\sigma$$

What is happening wit

The new results[1–3] are not conclusive, but they are tantalizing. They might be due to properties of standard b-quark weak interactions that we cannot quite yet estimate precisely, but it is equally possible that this is the first hint of an entirely new mechanism for particle–antiparticle asymmetry. In the next few years, these ideas will be tested, both through the analysis of the huge Belle and BaBar data set, and from the hunt for exotic particles at the LHC. We do not yet know whether it is penguins or even more unusual creatures that produce our Universe made of matter and not antimatter. ■

ature

Vol 452|20 March 2008

PARTICLE PHYSICS

Song of the electrowe

Michael E. Peskin

An unexpected imbalance in how particles containing the h
influences — and perhaps help to explain why matter, rathe

Elsewhere in this issue, the Belle collaboration, based at the electron–positron particle collider of the high-energy accelerator laboratory KEK in Japan, announces their measurement of an anomalous asymmetry in the decay rates of exotic particles known as B mesons (Lin *et al.*, page 332)[1]. Combined with recent measurements of the same decays from the BaBar collaboration[2,3], a similar experiment at the Stanford Linear Accelerator Center (SLAC) in California, the new finding provides a tantalizing glimpse of a possible new source for a very fundamental asymmetry: the dominance of matter over antimatter in our Universe.

The two great principles of modern physics, quantum mechanics and Einstein's relativity, together imply that every particle in nature — among them the quarks and the leptons, the elementary particles of matter — has an anti-matter counterpart with exactly the same mass,

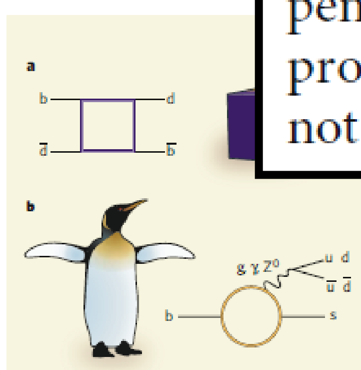
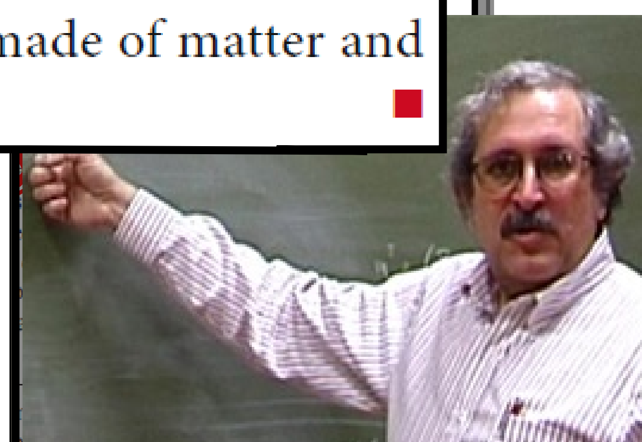


Figure 1 | Weakly decaying. A Feynman diagram represents the time evolution of a particle process (shown here from left to right). **a**, In a standard 'box' diagram of weak quark-mixing

which one of the particles is a b quark or b anti-quark — could test the Kobayashi–Maskawa (KM) theory directly. The idea, proposed by Pier Oddone, that these experiments could be performed by colliding two beams of different energies, one of electrons and one of positrons (the antiparticle of the electron), motivated the construction of new accelerators at KEK and SLAC. In 2002, both BaBar[8] and Belle[9] reported the first observation of a KM asymmetry in a B-meson decay.

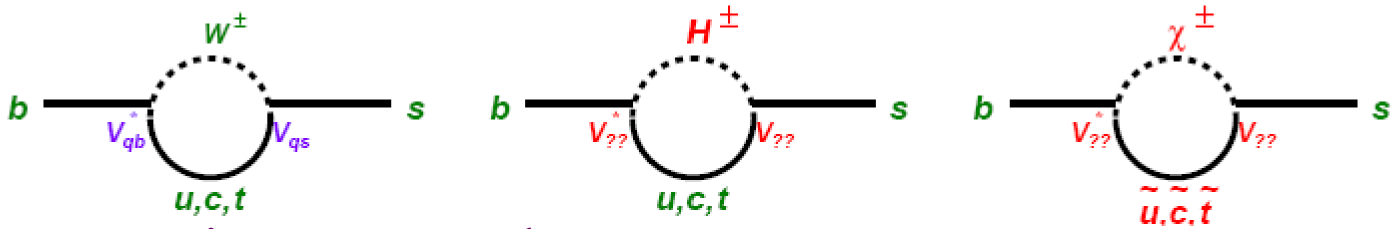
Since then, evidence accumulated by BaBar and Belle, in a data set of more than 1.2 bil-



Radiative and Electroweak Penguins

b→sγ Decays

- Most powerful mode to constrain new physics!
- Example discussed: modifications to the rate



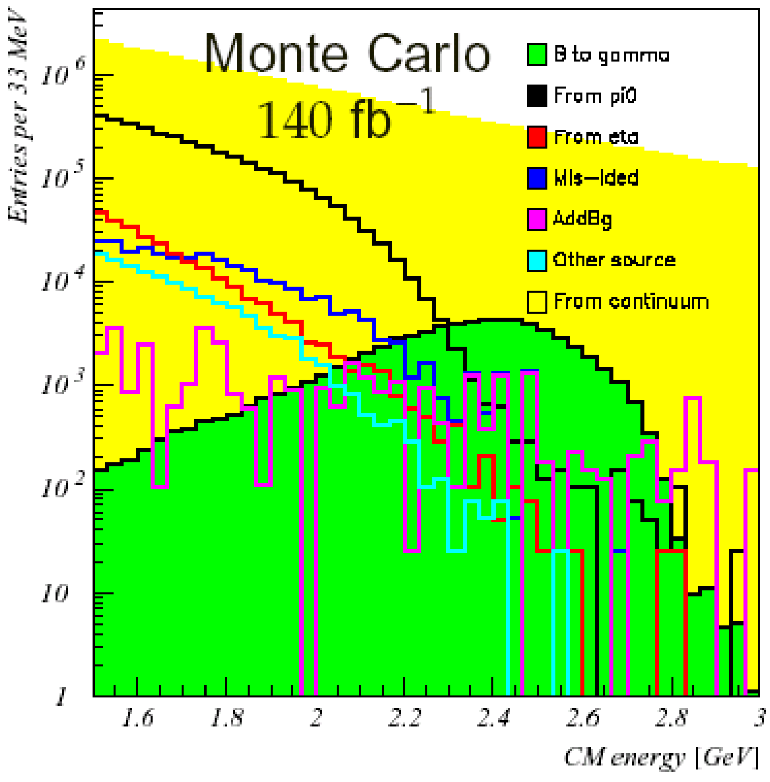
Measure primary γ only:
monochromatic Eγ spectrum

Huge Background (semi-log)
⇒ experimental challenge

Background suppression

- continuum: event shape
- π^0/η veto

Important to measure low Eγ
to reduce model dependence

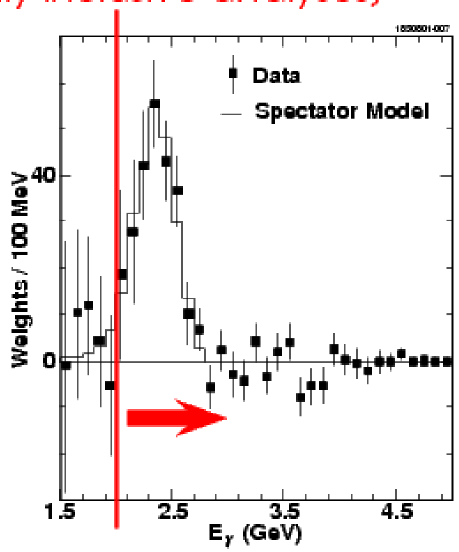


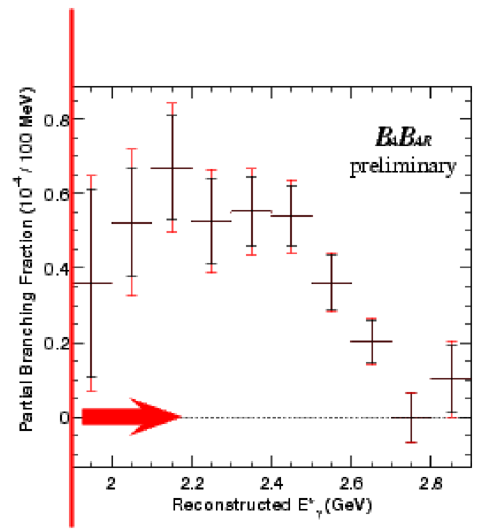
Inclusive measurements

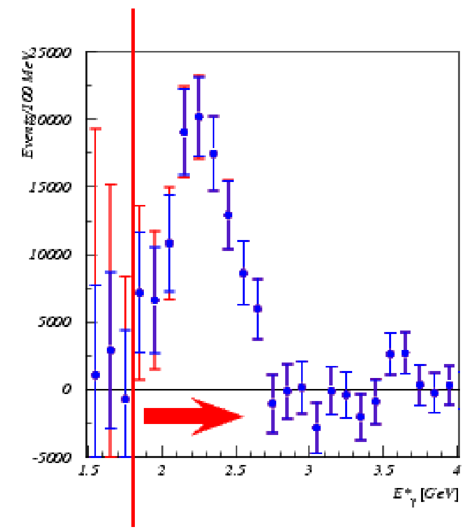
- Two methods so far:

  fully inclusive and **sum of exclusives**
- Photon energy cut around 1.8-2.0 GeV

(fully inclusive analyses)

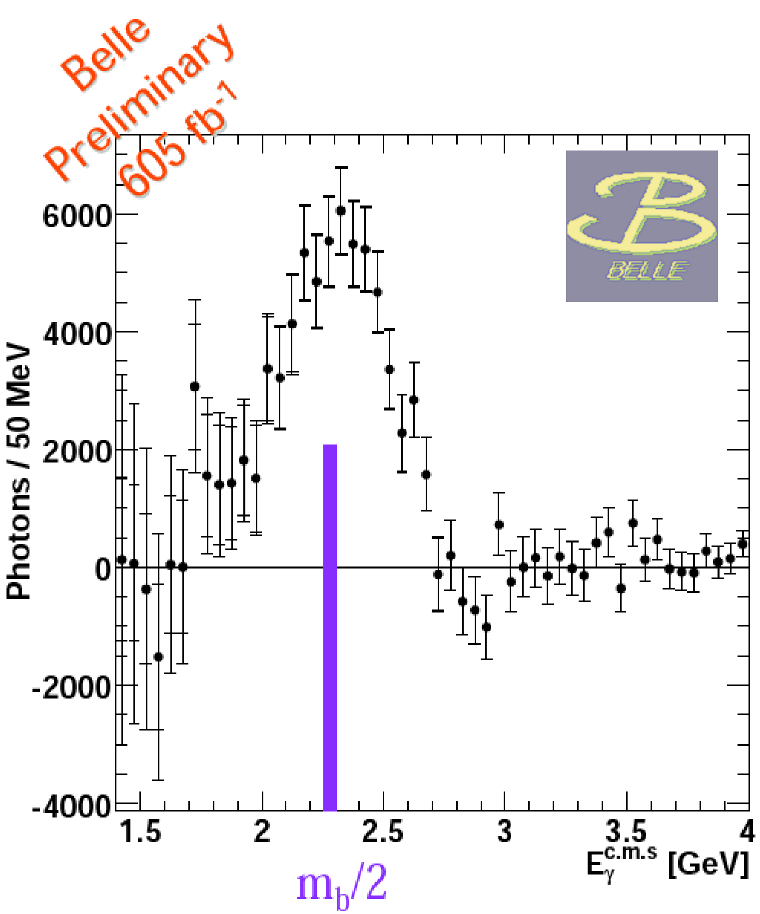






CLEO	BaBar	Belle
$9.1\ \mathrm{fb}^{-1}$ on $\Upsilon(4S)$	$81.5\ \mathrm{fb}^{-1}$ on $\Upsilon(4S)$	$140\ \mathrm{fb}^{-1}$ on $\Upsilon(4S)$
$-4.4\ \mathrm{fb}^{-1}$ off-resonance	$-9.6\ \mathrm{fb}^{-1}$ off-resonance	$-15\ \mathrm{fb}^{-1}$ off-resonance
$E_\gamma > 2.0$ GeV	$E_\gamma > 1.9$ GeV	$E_\gamma > 1.8$ GeV
(PRL87,251807(2001))	(hep-ex/0507001)	(PRL93,061803(2004))

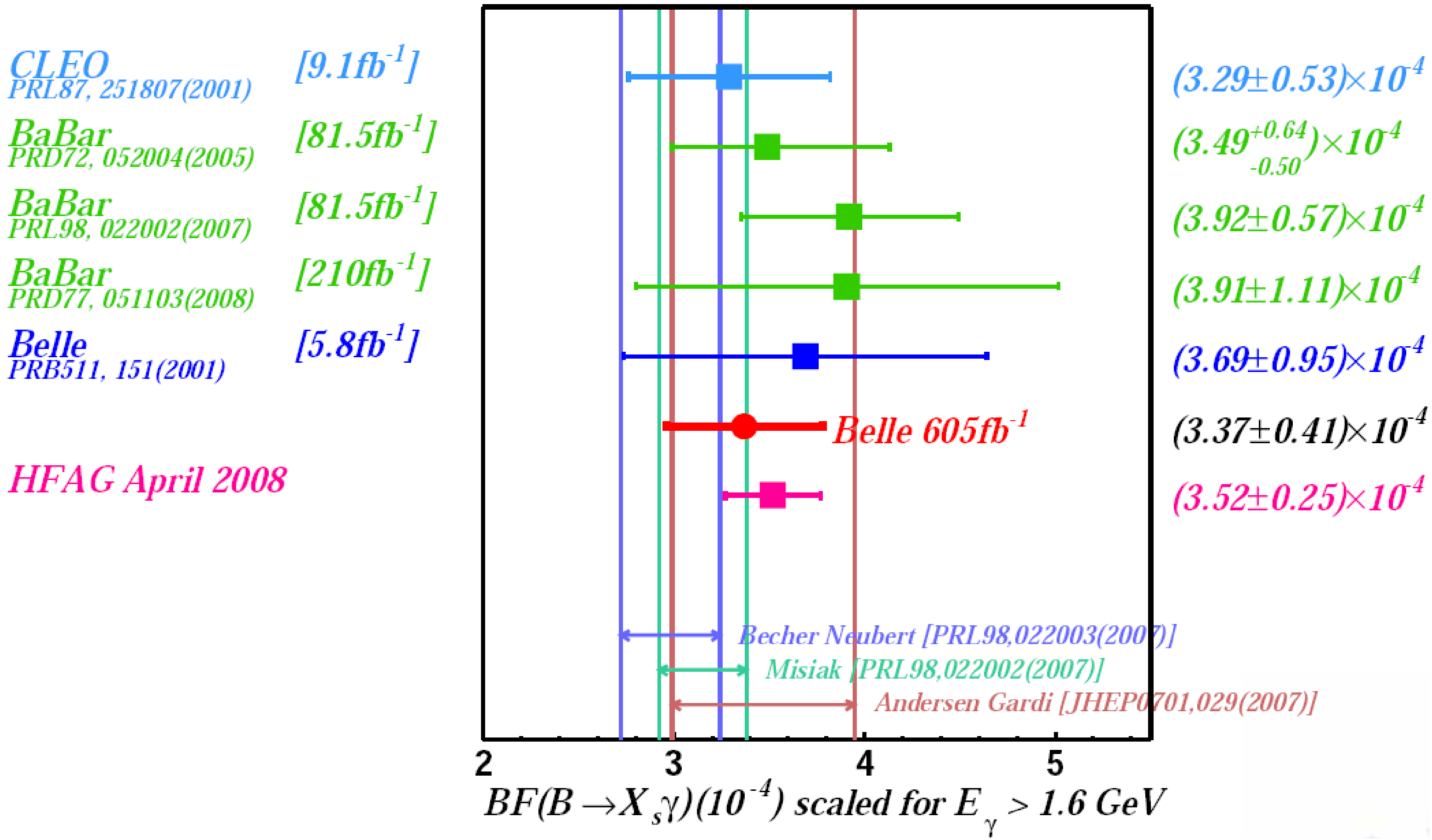
New Updates from Belle



- Inclusive approach
  - Reconstruct **only** the photon
  - B.G. suppress with **lepton tag**
- Yield above endpoint from B decay is **consistent with zero**
  - Background properly subtracted
- **Peaks** at half the mass of b-quark
- Significant signal at **1.7<Eγ<2.8 GeV**
- B.F.$(B \to X_s \gamma) =$

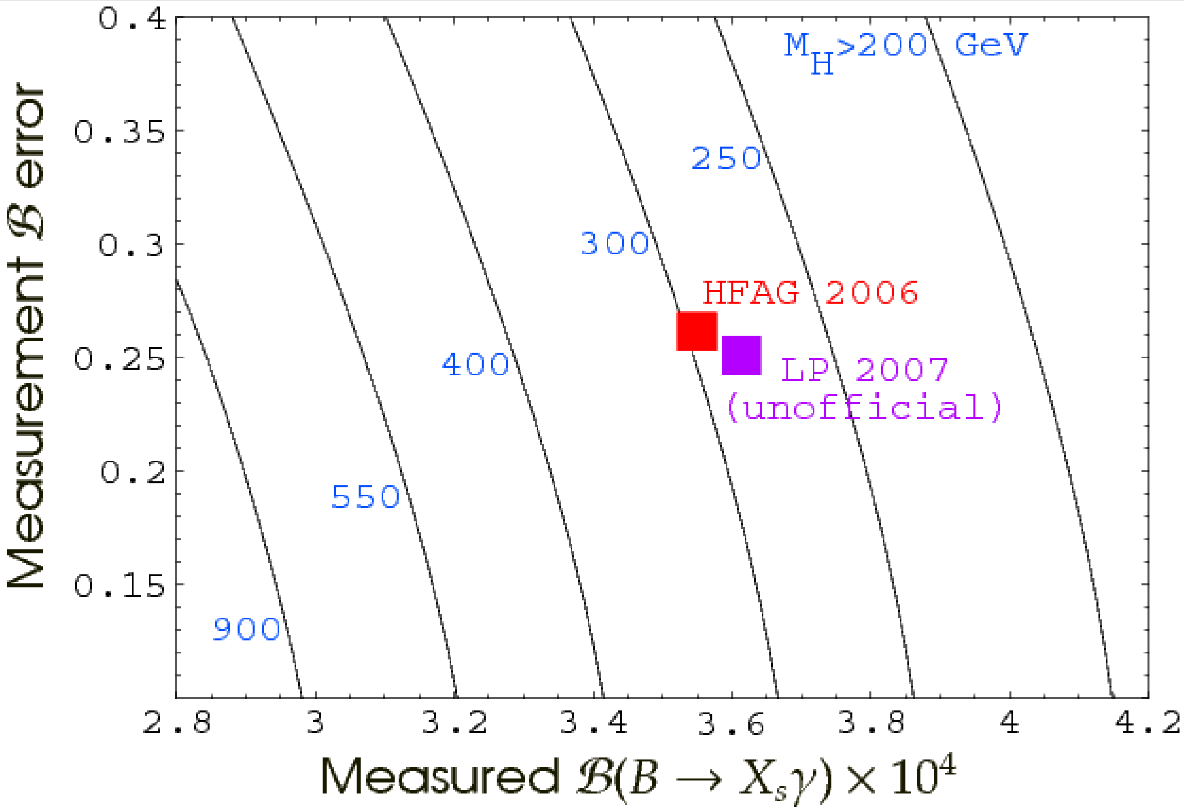
  $(3.31\pm0.19\pm0.37\pm0.01) \times 10^{-4}$
- Eγ cut extended to 1.7 GeV
- The current **most precise** measurement

b→Xsγ Summary



- The NNLO calculations agreement has been degraded
- Tension between average and NNLO calculations?
  - Note: NNLO calculations are not final
  - Andersen-Gardi error is quite large

Charged Higgs bound



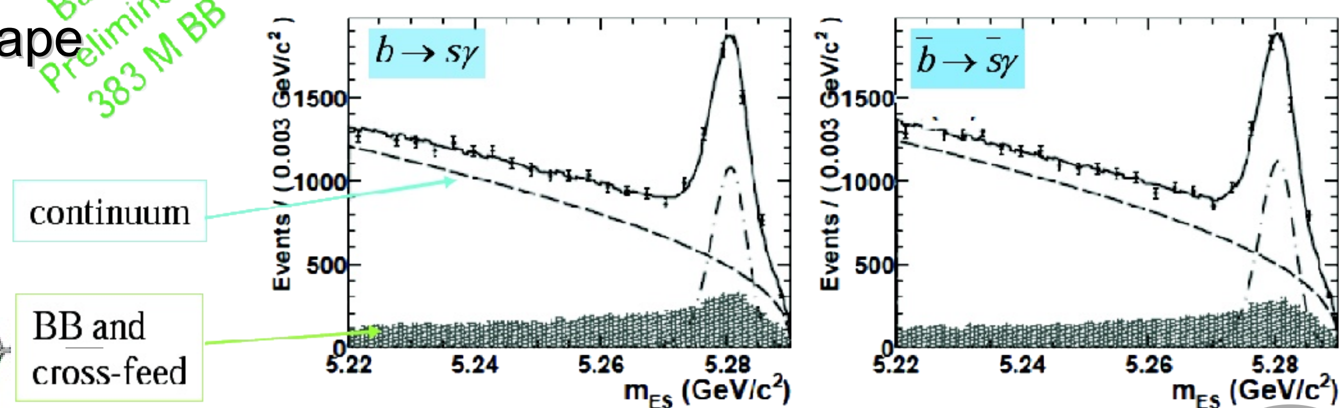
from Misiak et al, PRL98,022002('07)

- Lower limit on type-II charged Higgs mass for any $\tan\beta$
  $M_{H^+} > 295$ GeV (95% CL), or $M_{H^+} \sim 650$ GeV (best-fit) for HFAG'06
- Also room for other new physics
- Need to decrease the experimental error!
  looser constraint with LP'07 average, for a higher central value

DCPV for B→Xsγ

- New result from Babar
  - Fully reconstruct **16 exclusive modes**
- Main background: π^0 and η from continuum, ISR
  - **Vetos** the daughter photons from good π^0 and η
- Extract yields from M_{ES} fit to signal region
  - Background modeled with **MC**
- Sidebands and B→Xsπ^0 **control sample** for:
  - Detector bias study
  - $B\bar{B}$ Background shape
  - Continuum shape

BaBar Preliminary 383 M BB



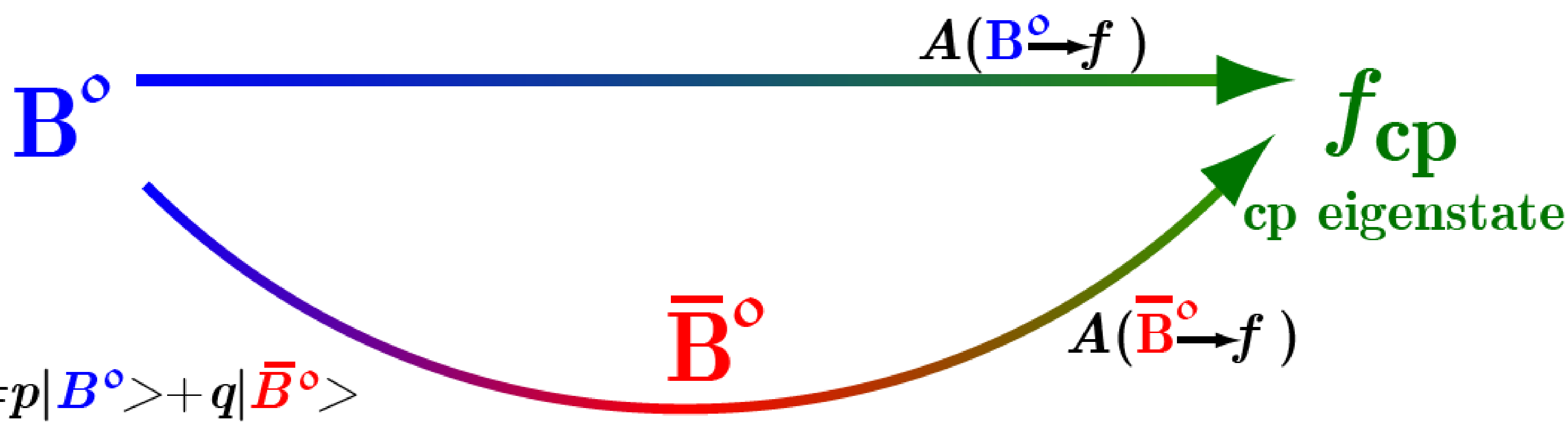
Select candidates with $|\Delta E| < 0.10$ GeV

$$\mathcal{A}_{CP} = -0.012 \pm 0.030(\text{stat}) \pm 0.019(\text{syst})$$

Time-dependent CPV in $b \rightarrow s$ Channels

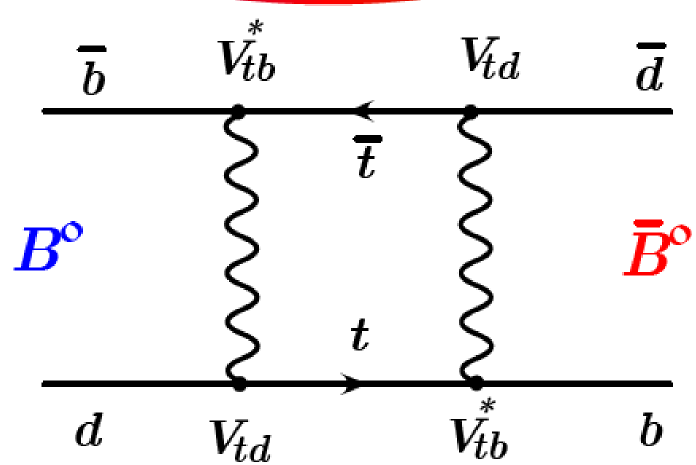
CP Asym. from mixing

Interference between $B^\circ \rightarrow f_{cp}$ & $B^\circ \rightarrow \bar{B}^\circ \rightarrow f_{cp}$



$B_H> = p|B^\circ> + q|\bar{B}^\circ>$

$B_L> = p|B^\circ> - q|\bar{B}^\circ>$

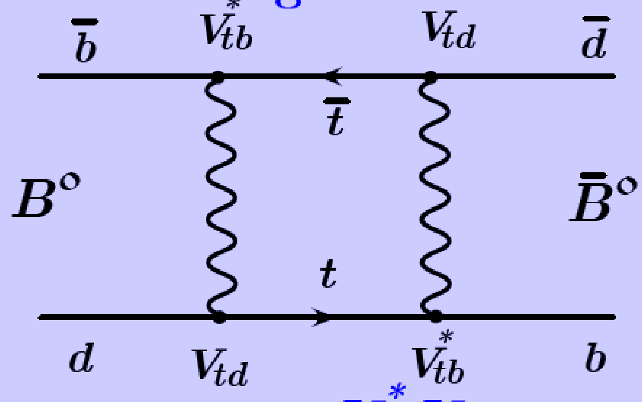


$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

$$= e^{-i2\phi_1}$$

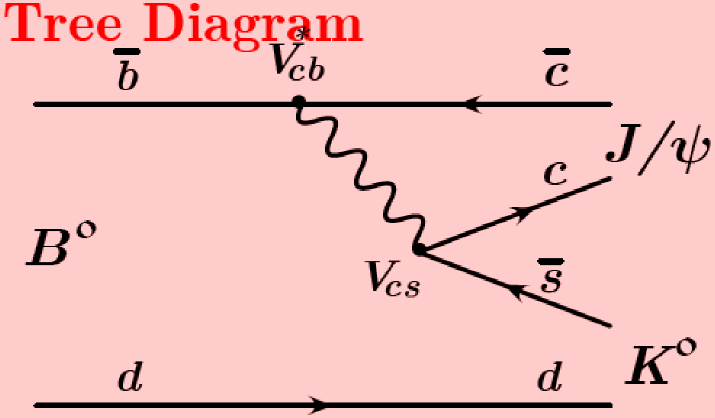
Time-dept. CP Asym.

$B^0\bar{B}^0$ Mixing



$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

Tree Diagram



$$A \propto V_{cb}^* V_{cs}$$

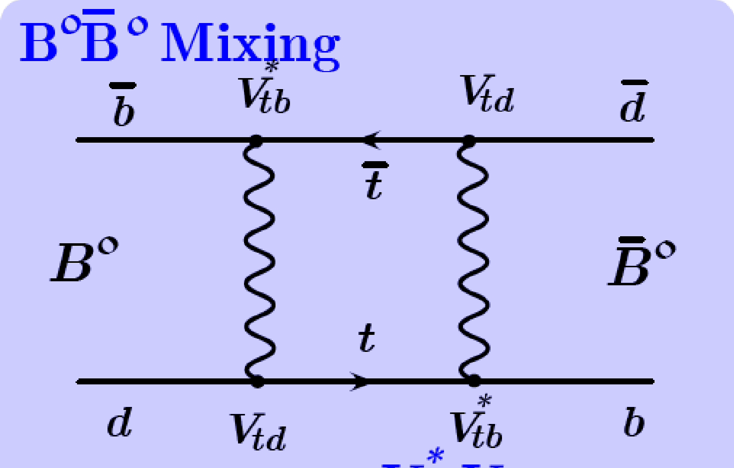
$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = \eta_{cp} e^{+i2\phi_1} \longrightarrow \begin{array}{l} \mathcal{S} = -\eta_{cp}\sin 2\phi_1 \\ \mathcal{A}(-\mathcal{C}) = 0 \end{array}$$

Belle BaBar

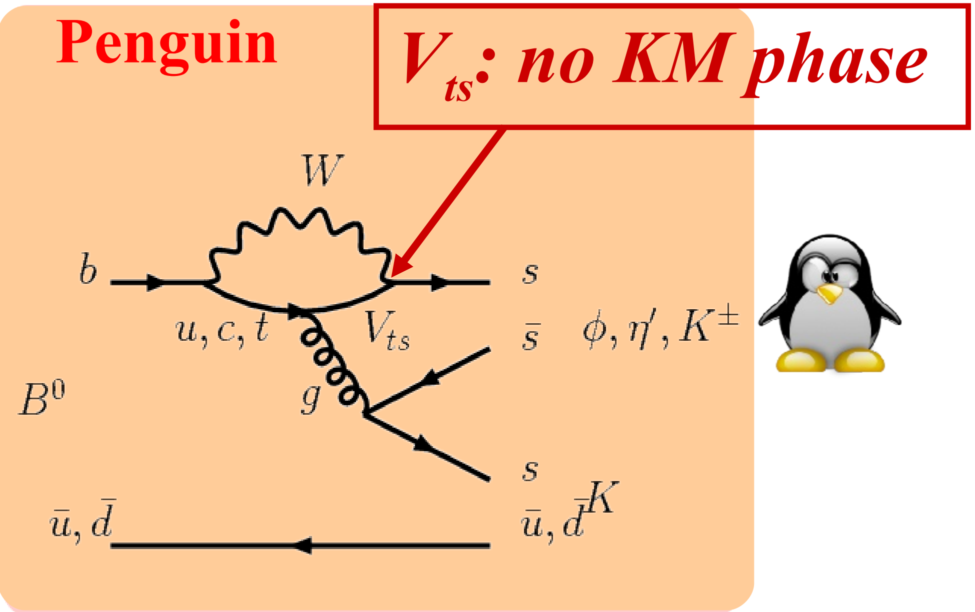
η_{cp} : CP eigenvalue $= \mp 1$

$$\mathcal{A}(\Delta t) = -\eta_{cp} \sin 2\phi_1 \sin(\Delta m \cdot \Delta t)$$

Time-dept. CP Asym.



$$\frac{q}{p} \propto \frac{V_{tb}^{*} V_{td}}{V_{tb} V_{td}^{*}}$$



$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = \eta_{cp} e^{-i2\phi_1} \rightarrow \begin{array}{l} S = -\eta_{cp}\sin 2\phi_1 \\ A(-C) = 0 \end{array}$$

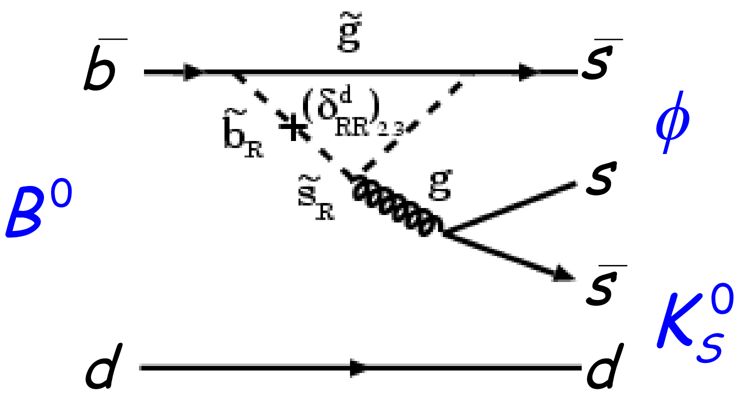
Belle BaBar

SM: $\sin 2\phi_1^{eff} = \sin 2\phi_1$ *from* $B \rightarrow J/\psi K^0$ $(b \rightarrow c\,\bar{c}\,s)$

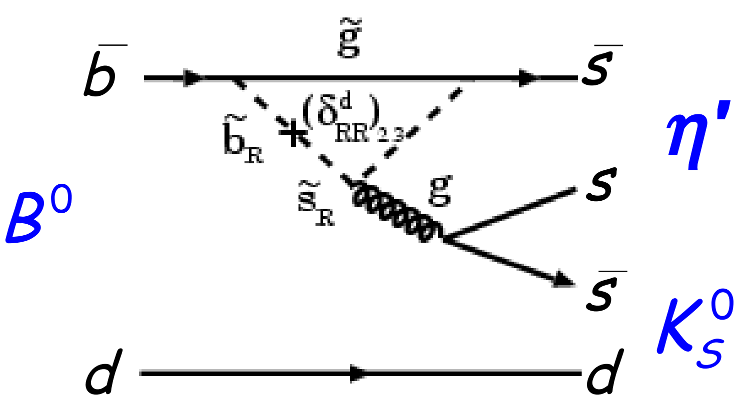
unless there are other, non-SM particles in the loop

How New Physics may enter *b*→*s*

New physics in loops?

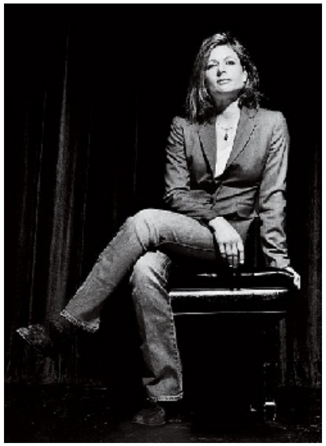


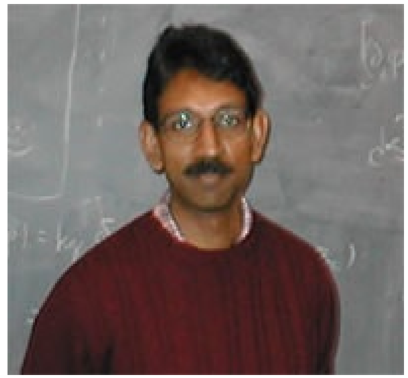
Many new phases are possible in SUSY



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

Extra Dimensions

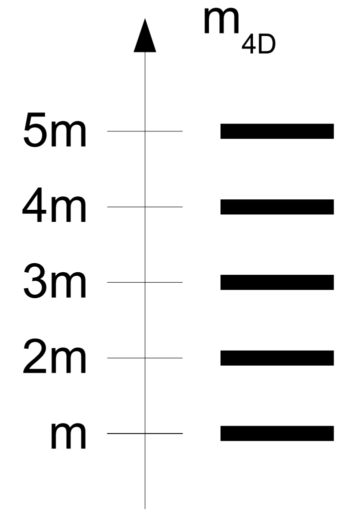




(by Randall + Sundrum)

New Kaluza-Klein (K.K) particles are associated with the extra dimension.

("Tower of states")



<u>Some may induce new phases and flavor-changing neutral currents.</u>

e.g. K.Agashe, G. Perez, A. Soni, PRD 71, 016002 (2005)

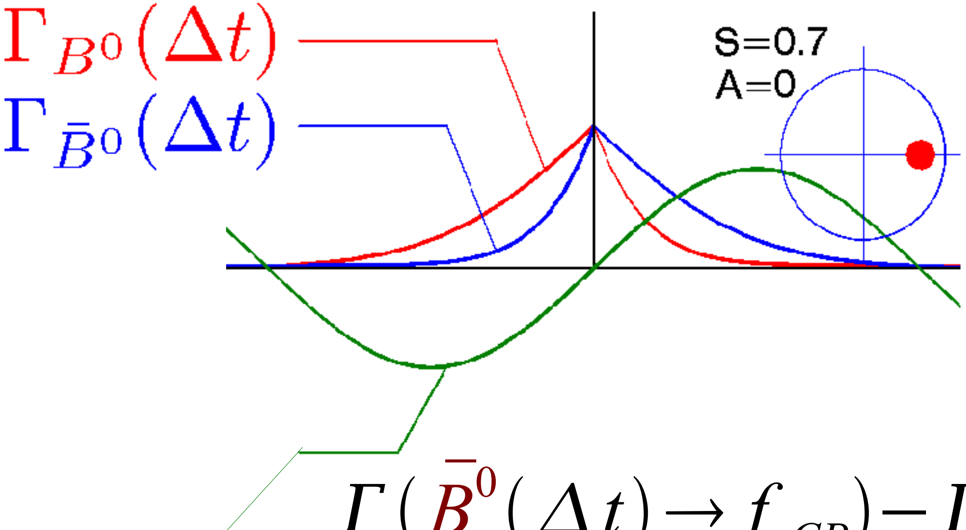
	$S_{B_s\to\psi\phi}$	$S_{B_d\to\phi K_s}$	$Br[b\to sl^+l^-]$	$S_{B_{d,s}\to K^*,\phi\gamma}$	$S_{B_{d,s}\to\rho,K^*\gamma}$
RS1	$O(1)$	$\sin 2\beta \pm O(.2)$	$Br^{SM}[1+O(1)]$	$O(1)$	$O(1)$
SM	λ_c^2	$\sin 2\beta$	Br^{SM}	$\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$	$\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$

++CPV in D decay

Const. ε_K ?

Model: K.K. Gluon near 3 TeV

Time-dept. CP Asym.



Δt: proper time

Δm: mass difference

$$A(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})}$$

$$= \frac{2\Im\lambda}{1+|\lambda|^2}\sin(\Delta m \cdot \Delta t) + \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m \cdot \Delta t)$$

$$\lambda = \frac{q}{p}\frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)}$$

$\mathcal{S}$

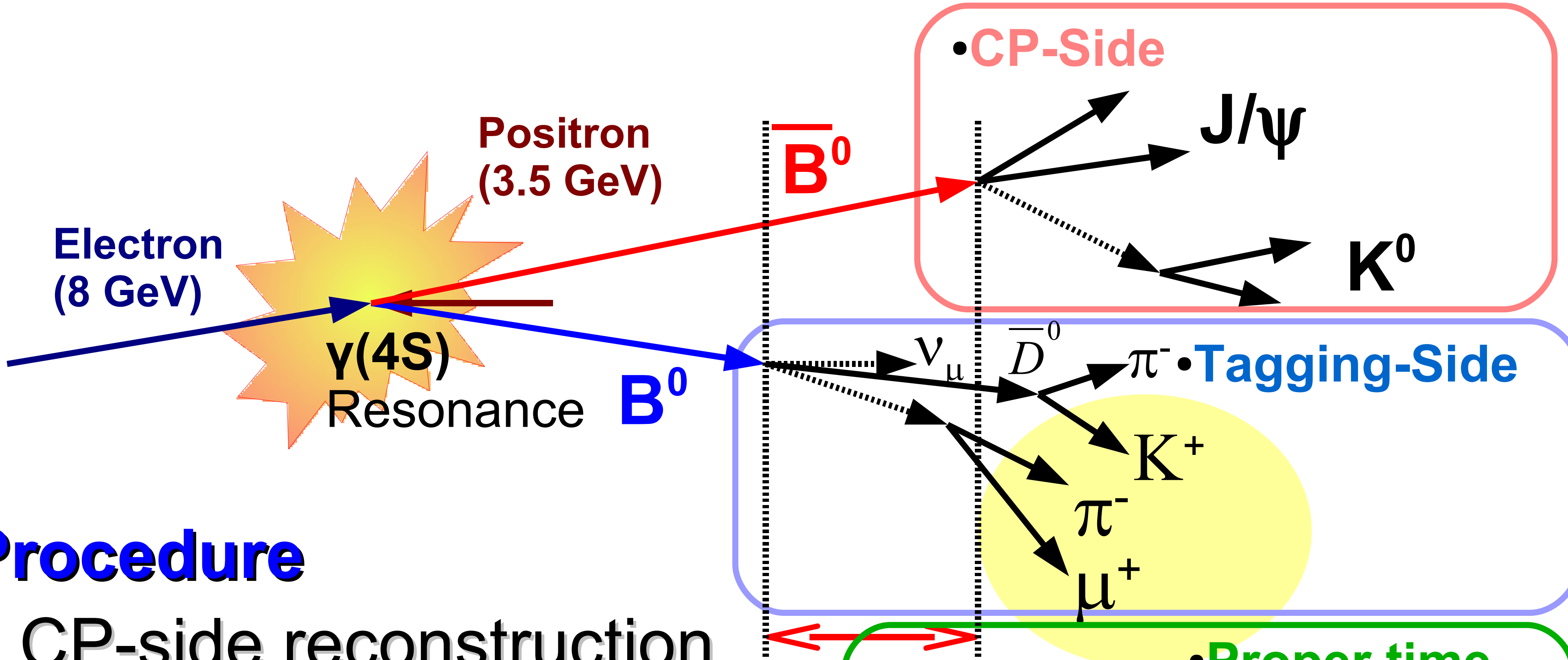
Mixing-induced CPV

$\mathcal{A}(=-\mathcal{C})$

Belle **BaBar**

Direct CPV

Analysis Procedure



•Proper time

$$\Delta z = \Delta t \beta \gamma c \sim 200 \mu m$$

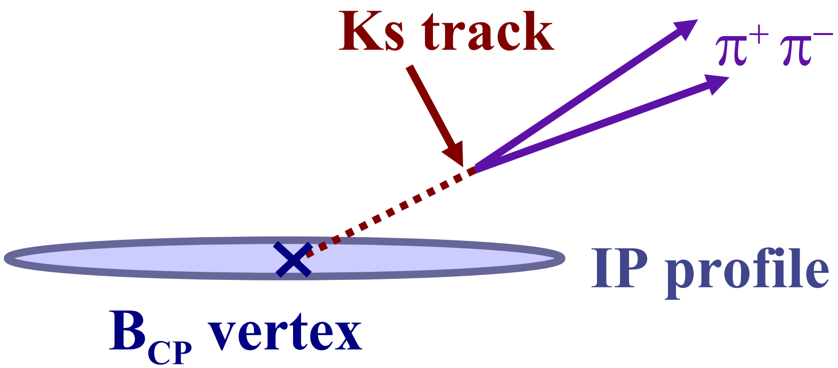
$$\beta \gamma c = 0.43$$

Procedure

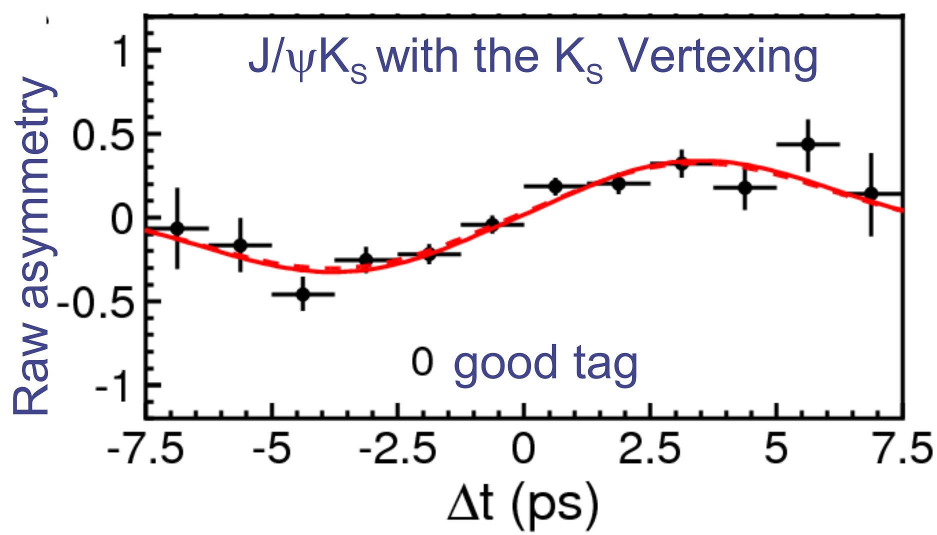
- CP-side reconstruction
- Flavor tagging & vertexing
- $\Delta z = \Delta t \beta \gamma c$

  Proper time measurement

Vertex Reconstruction with K_s



- Extrapolate K_S track to the Interaction Point (IP)
  - Vertex recon. eff. ~33%
- Events w/o the vertex can still be used to measure $\mathcal{A}$



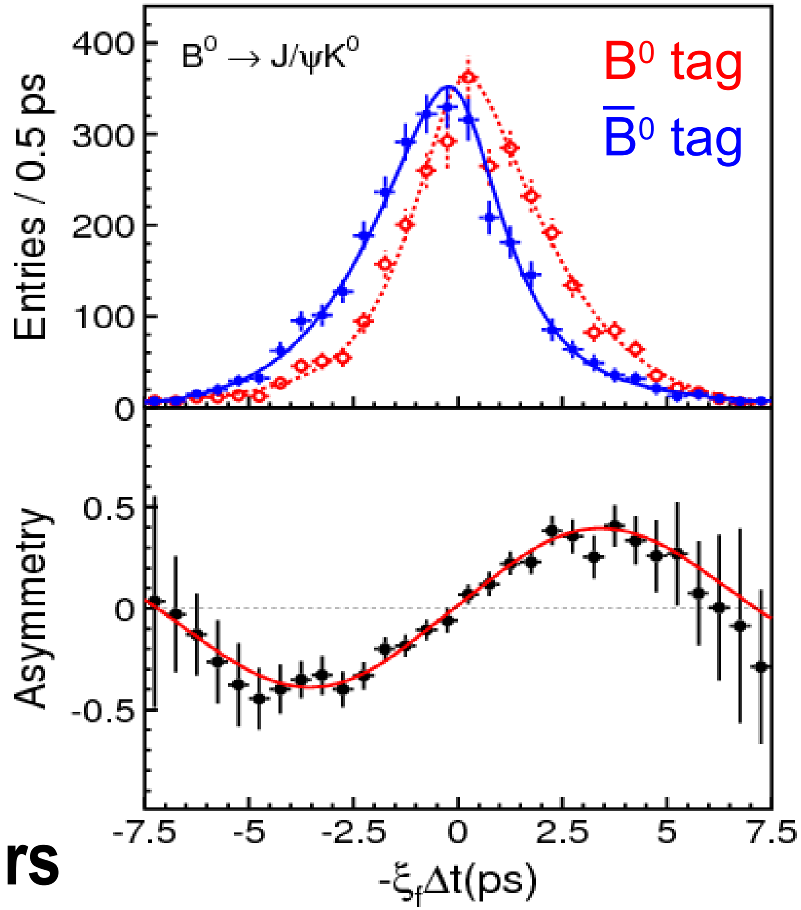
The validity confirmed with the $J/\psi K_S$ control sample.

B^0 Lifetime τ:1.503+/-0.036 ps

$\sin 2\phi_1$=+0.68+/-0.06

The Golden Mode

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



535 M $B\overline{B}$ pairs

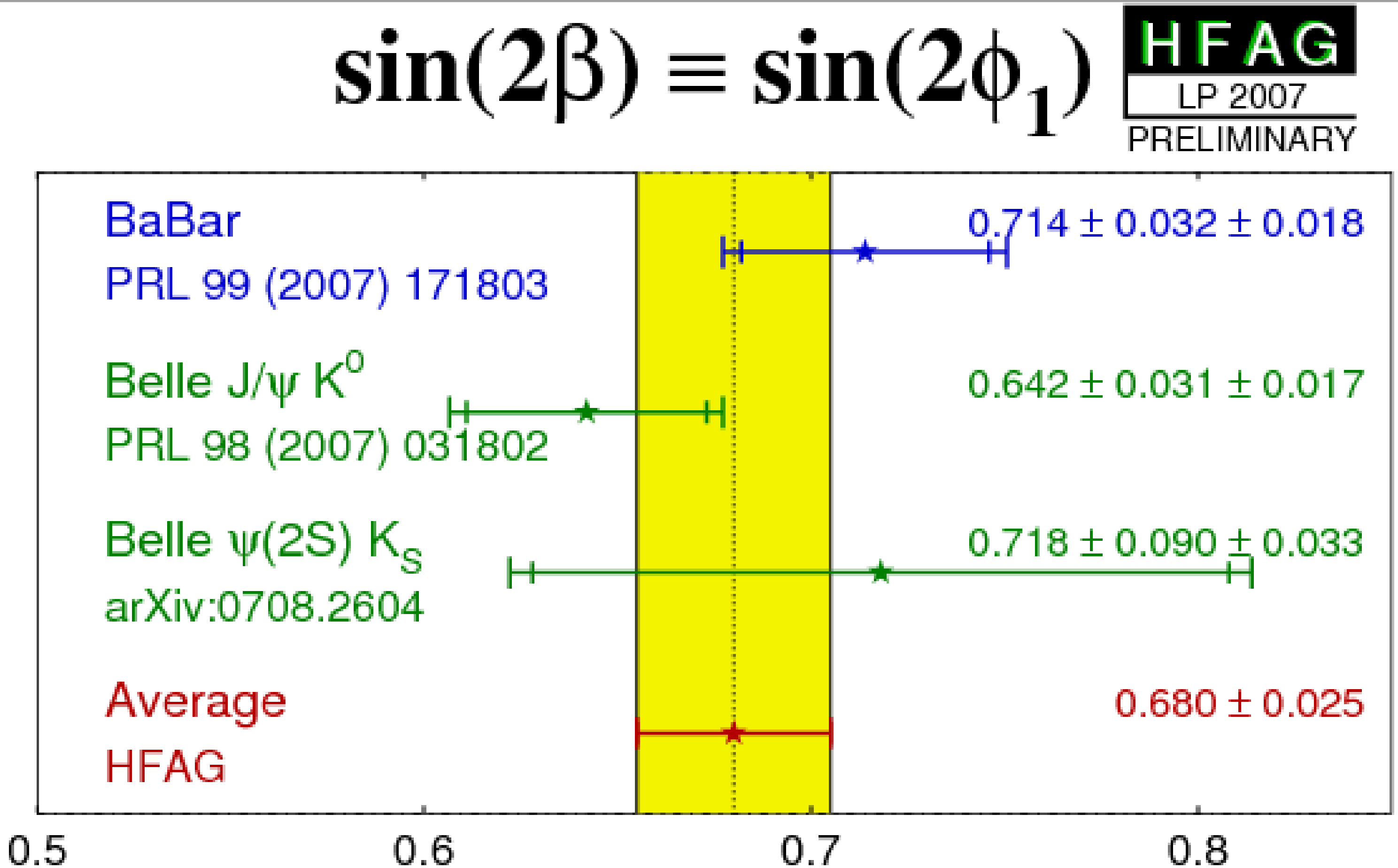
previous measurement
$\sin 2\phi_1 = 0.652 \pm 0.044$
(388 M $B\overline{B}$ pairs)

$\sin 2\phi_1 = 0.642 \pm 0.031$ (stat) ± 0.017 (syst)
$A = 0.018 \pm 0.021$ (stat) ± 0.014 (syst)

hep-ex/0608039, PRL

$\sin 2\phi_1$: *BaBar + Belle*

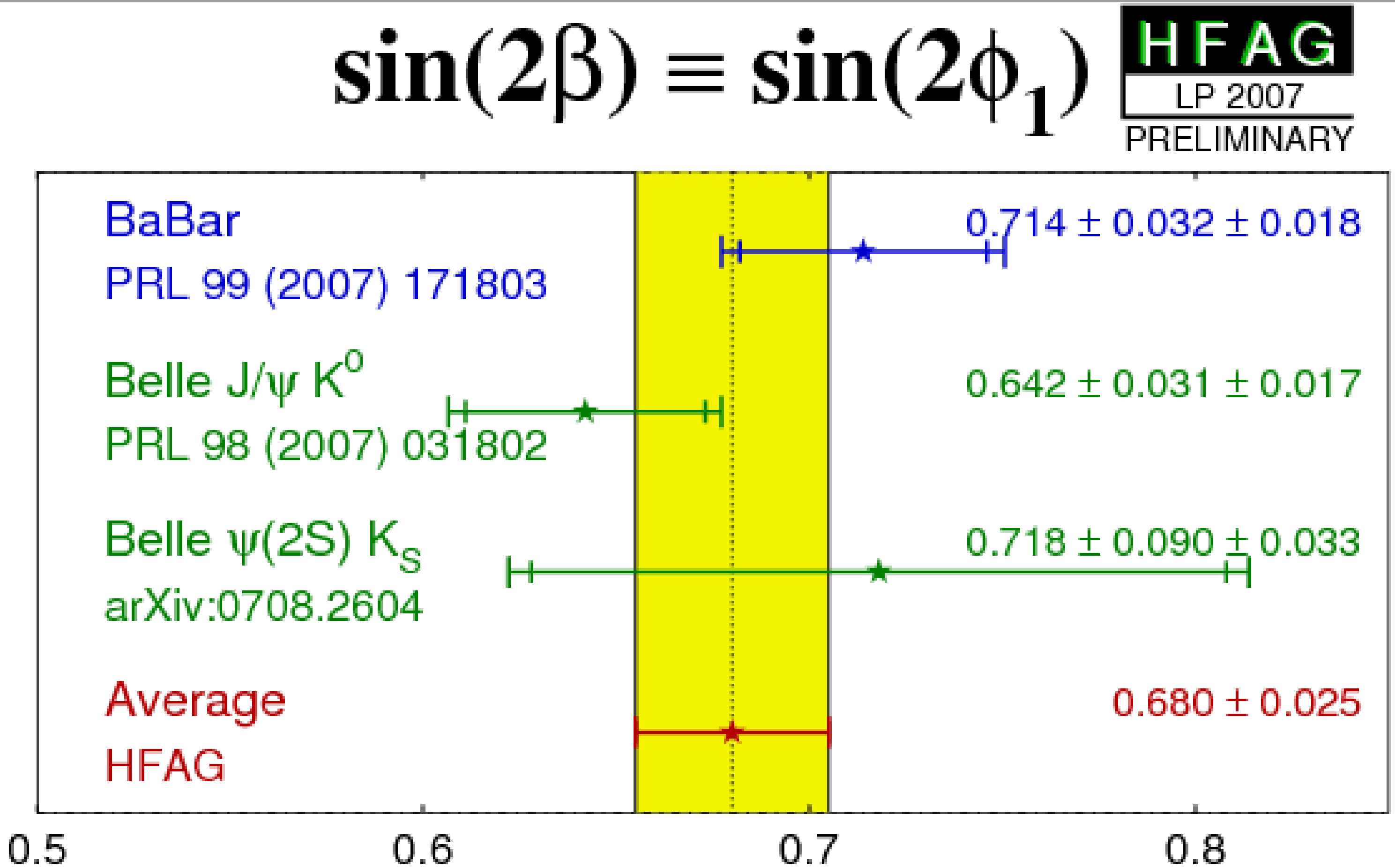
$$\sin(2\beta) \equiv \sin(2\phi_1)$$



A precise measurement of the phase of B_d mixing **(< 4 % error)**

Reference Point for NP search

$\sin 2\phi_1$: *BaBar + Belle*



"Yesterday's sensation is today's calibration and tommorow's background."- Val Telegdi

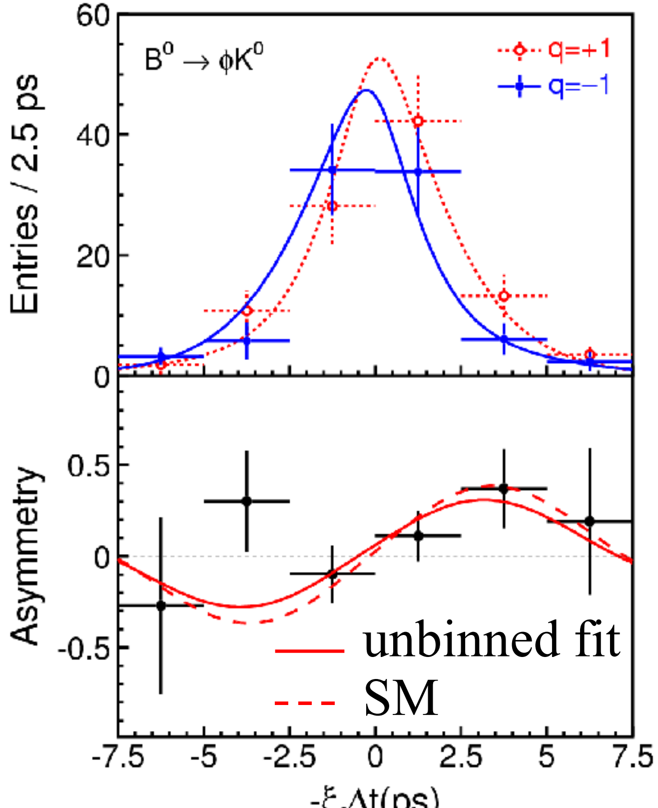
Belle: t*CPV* in $B^0 \to \phi K^0$

535M $B\bar{B}$

"$\sin 2\phi_1$" = +0.50 ± 0.21(stat) ± 0.06(syst)

a.k.a sin(2 β)

Δt distributions and asymmetry



- Consistent with the SM (~1σ lower)
- Consistent with Belle 2005

(Belle2005: "$\sin 2\phi_1$" = +0.44±0.27±0.05)

- ϕK_S and ϕK_L combined
- background subtracted
- good tags
- $\Delta t \to -\Delta t$ for ϕK_L

hep-ex/0608039, PRL 98, 031802(2007)

BaBar: ϕK^0 using $B^0 \to K^+K^-K^0$

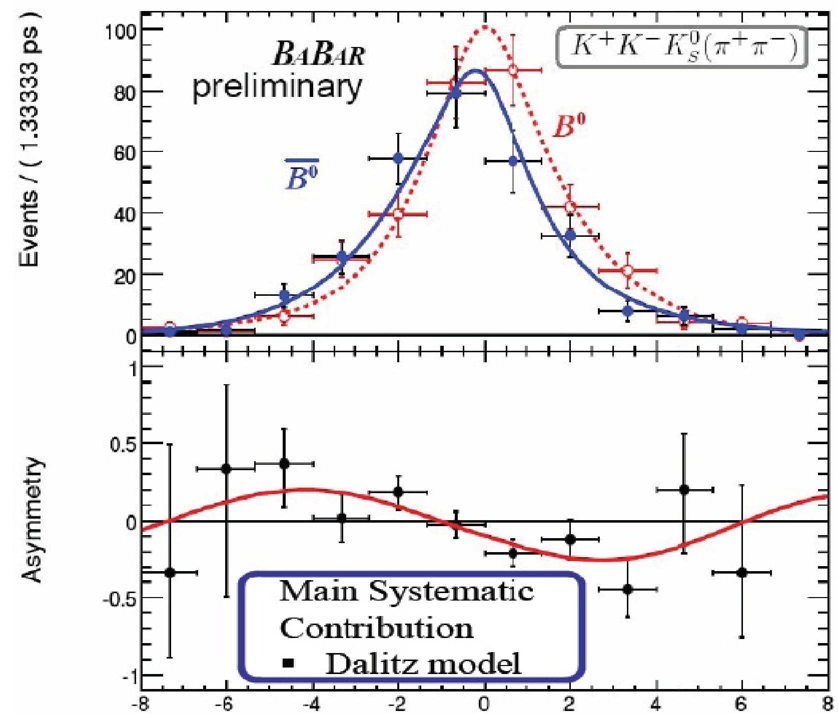
347M $B\bar{B}$

[hep-ex/0607112]

Fit to low mass K^+K^- region (<1.1 GeV) to extract ϕK^0 and $f_0(980)K^0$ CPV parameters

$\mathcal{A}_{CP}(\phi K^0)$	$-0.18 \pm 0.20 \pm 0.10$
$\beta_{eff}(\phi K^0)$	$0.06 \pm 0.16 \pm 0.05$

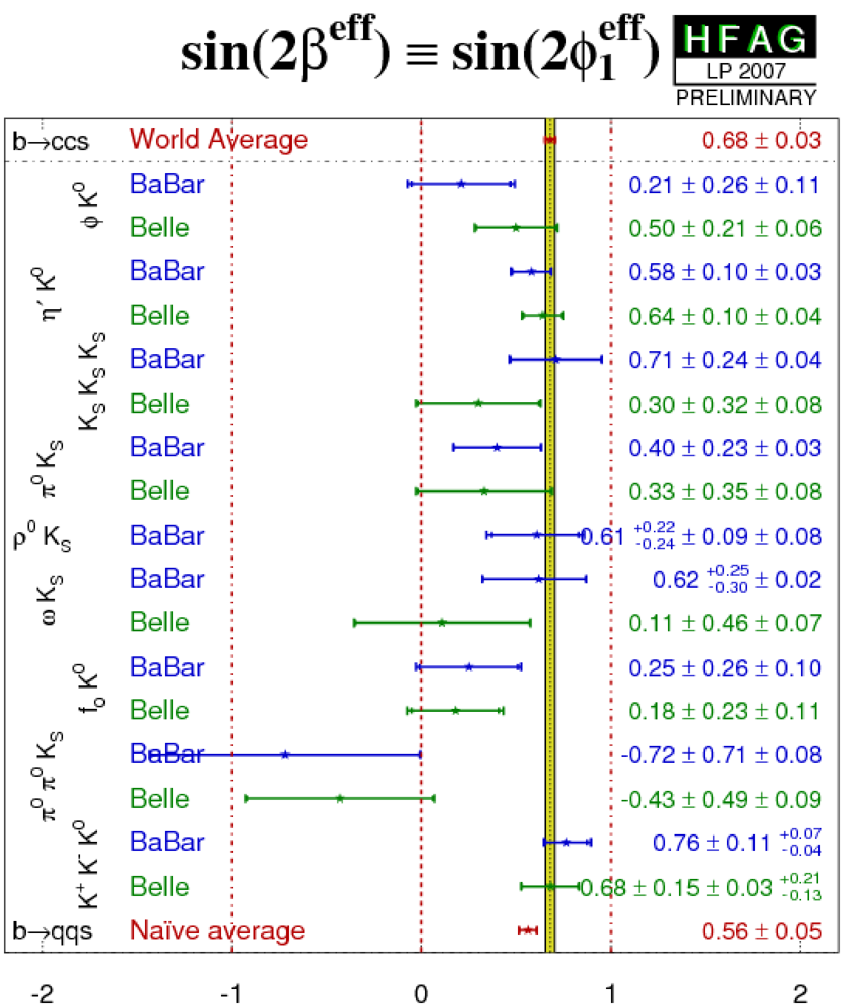
β measurement (not sin2β)



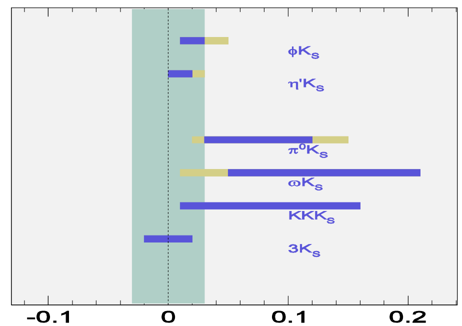
ϕK^0: $\sin2\beta_{eff} = +0.12 \pm 0.31(\text{stat}) \pm 0.10\ (\text{syst})$

a.k.a. $\sin(2\,\varphi_1)$

$\phi_1(\beta)$ from $b \to s$ Penguins



- Smaller than $b \to c\bar{c}s$ in 7 of the 9 modes
- Theorists tend to predict ***positive shifts*** on $\sin 2\beta_{eff}$ (phase in V_{ts})



QCD factorization calculation of ΔS

Naïve average of all $b \to s$ modes

$\sin 2\beta^{eff} = +0.56 \pm 0.05$

2.2 σ deviation between

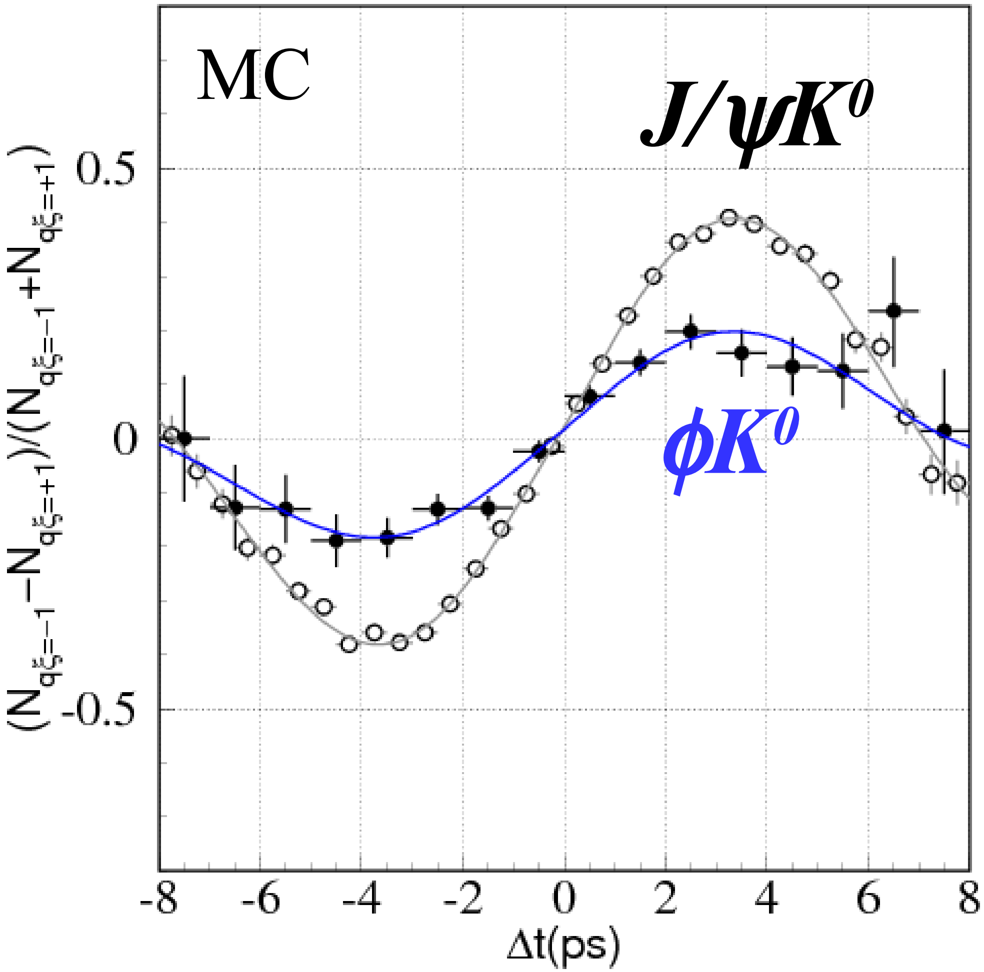
Penguin and **Tree** (CL=3%)

($b \to s$) ($b \to c$)

More statistics are crucial in each studied mode

Extrapolation: $B \to \phi K^0$ at 50/ab

With present WA values



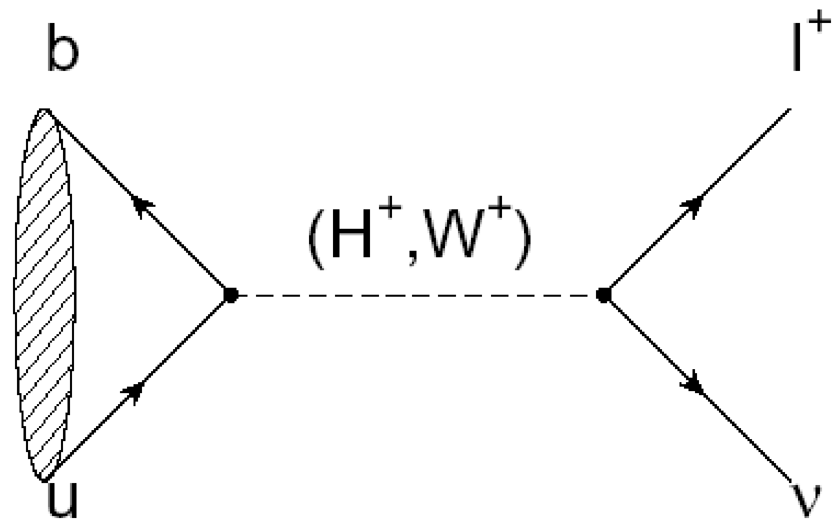
This would establish the existence of a NP phase

Compelling measurement in a clean mode

Decays with
Large Missing Energy

Motivation for $B^+ \to \tau^+ \nu$

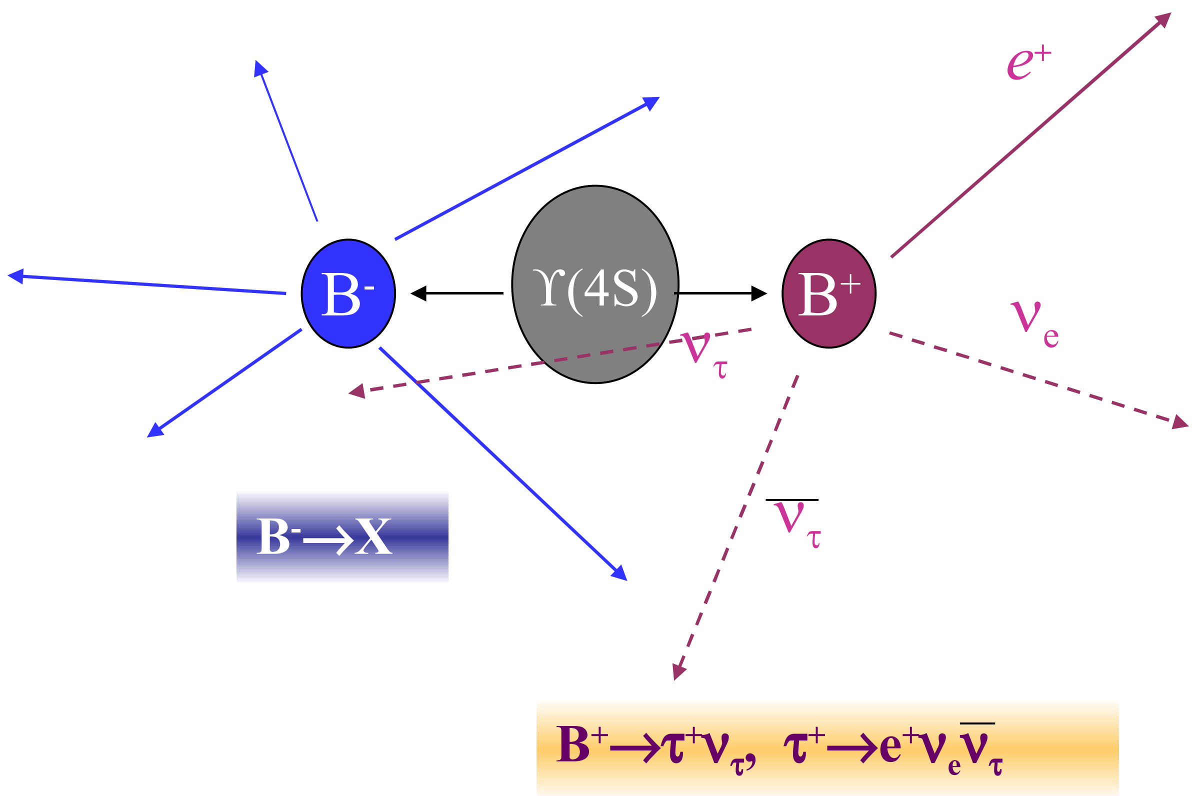
Sensitivity to new physics from charged Higgs if the B decay constant is known



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

The B meson decay constant, determined by the B wavefunction at the origin

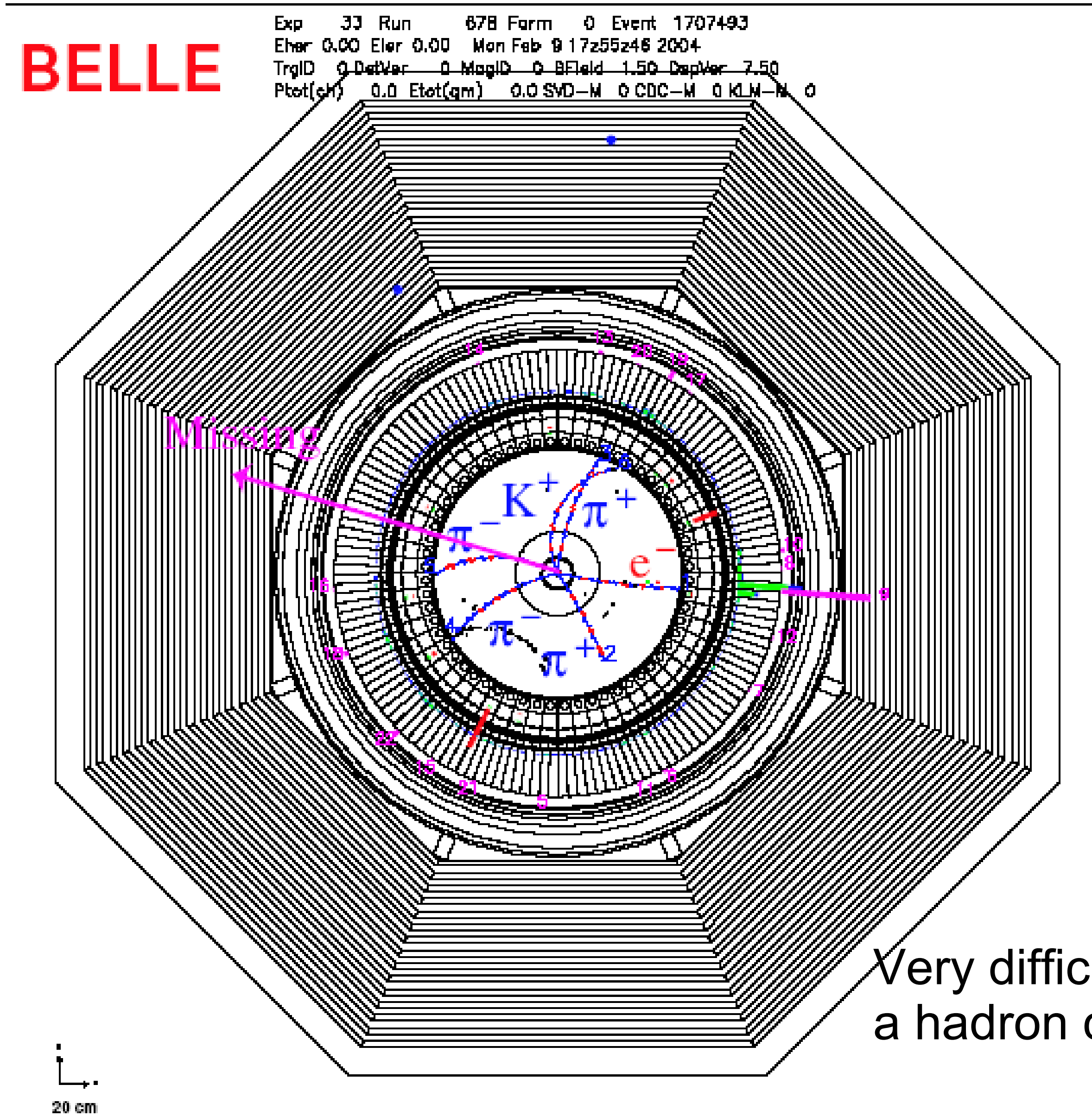
Why measuring $B \to \tau \nu$ non-trivial



Most of the sensitivity is from tau modes with 1-prong

The experimental signature is rather difficult: B decays to a single charged track + nothing

Example of a $B \rightarrow \tau \nu$ candidate



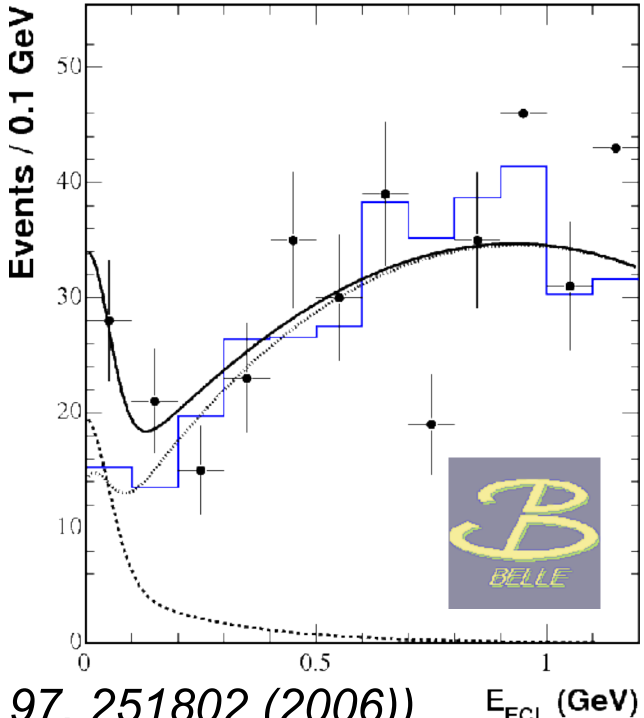
Tag: $B \rightarrow D^0 \pi$,

$D^0 \rightarrow K\pi\pi\pi$

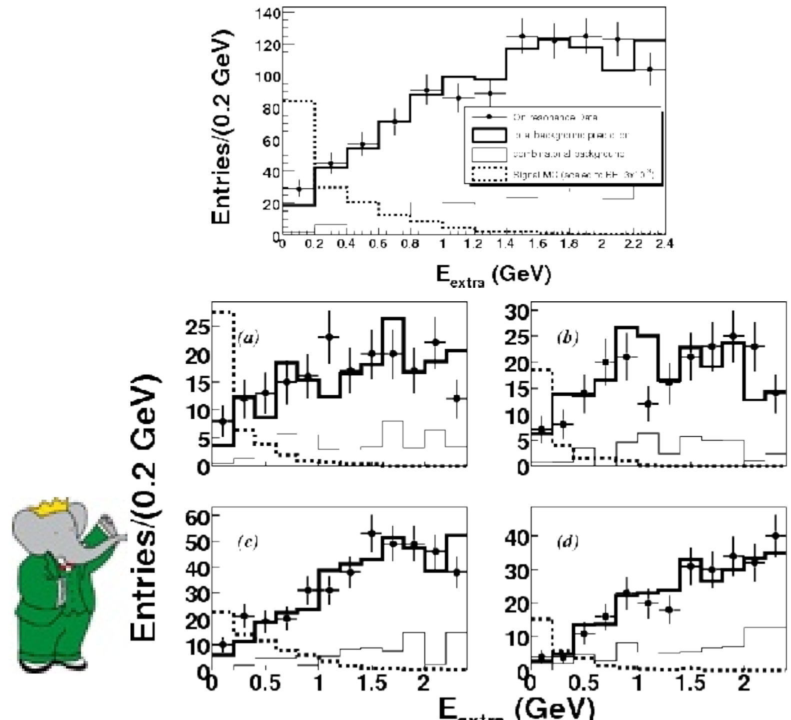
Very difficult or impossible at a hadron collider

Results from Babar and Belle

- Hadronic tagged $B_{\rm tag} \to D^{(*)}[\pi, \rho, a_1, D_s^{(*)}]$



(PRL 97, 251802 (2006))



(PRD77, 011107 (2008))

$$\mathcal{B}(B \to \tau\nu) = (1.8 \pm 0.6 \pm 0.5) \times 10^{-4}$$

$$f_B \cdot |V_{ub}| = (10.1 \pm 1.5 \pm 1.2) \times 10^{-4} GeV$$

$$f_B = 229^{+36+30}_{-31-34} MeV$$

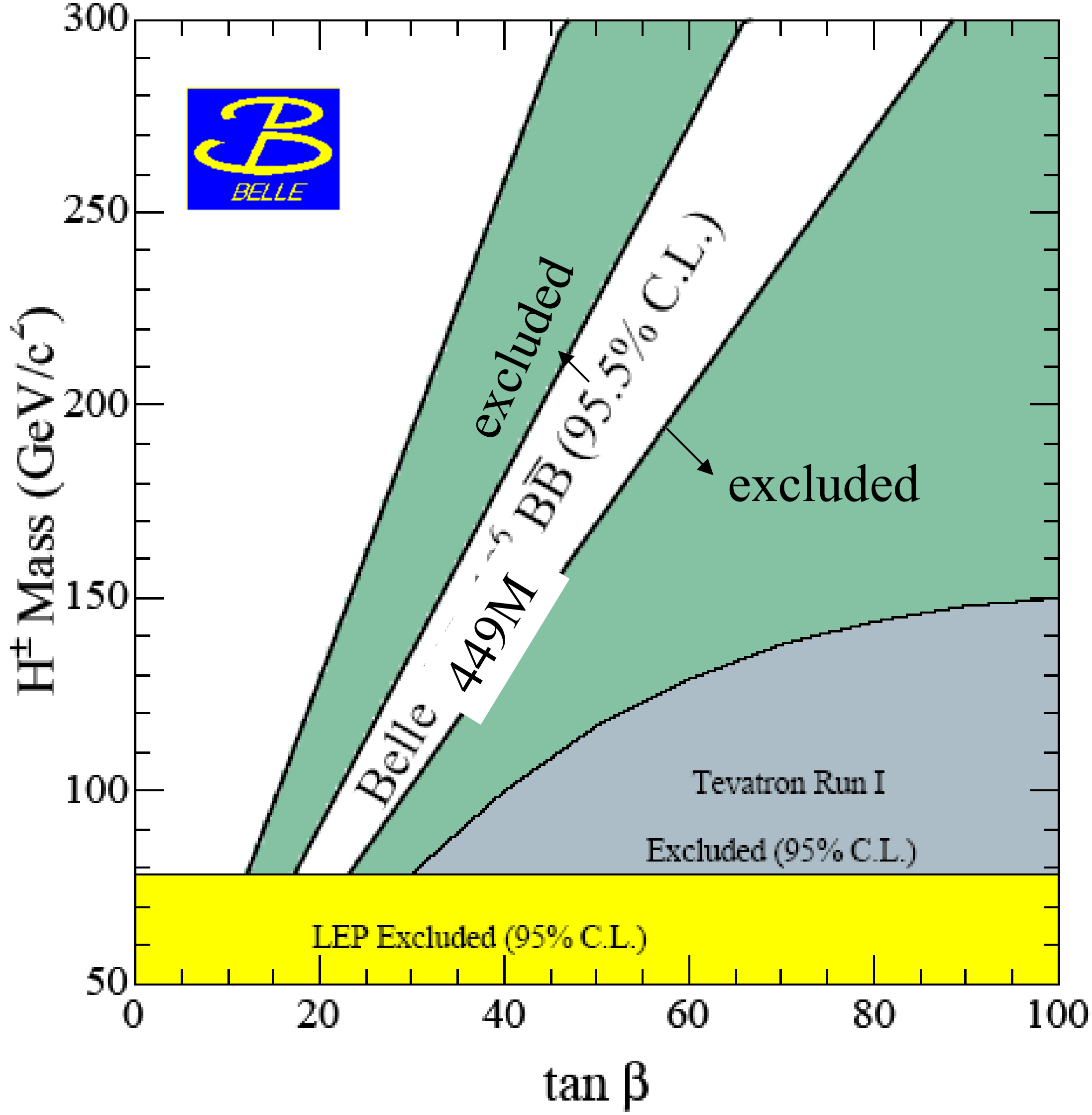
$$\mathcal{B}(B \to \tau\nu) = (1.2 \pm 0.4 \pm 0.4) \times 10^{-4}$$

$$f_B \cdot |V_{ub}| = (10.1 \pm 2.4 \pm 1.4) \times 10^{-4} GeV$$

$$f_B = 216 \pm 0.22 MeV$$

HPQCD, PRL 95, 212001 (2005)

Constraints on Charged Higgs mass



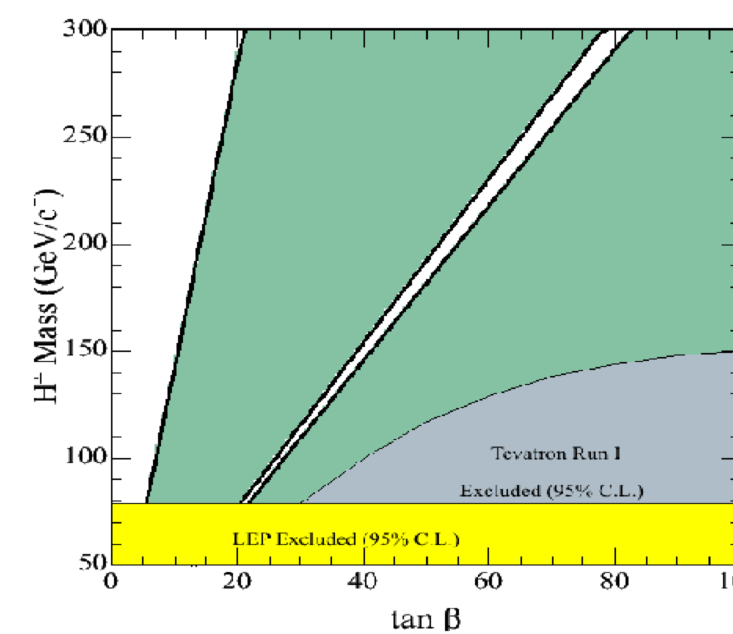
Compare to direct searches for H^+

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

Ratio to the SM BF.

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

$r_H = 1.13 \pm 0.51$



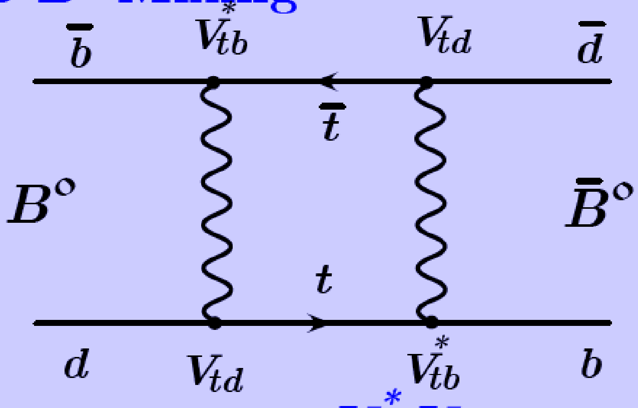
At 50 ab^{-1}

New results from Tevatron

B_s mixing

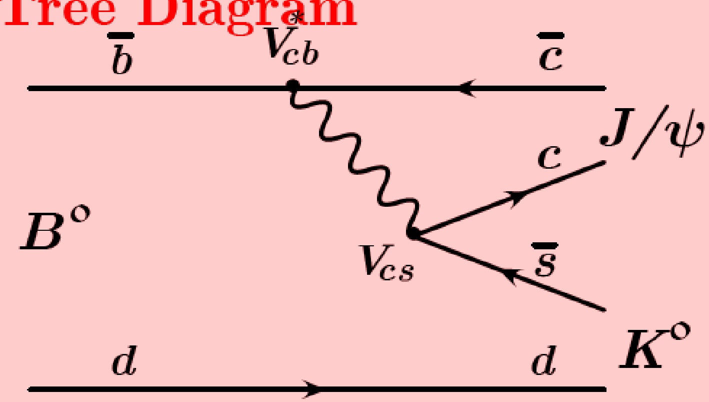
Time-dept. CP Asym. in Bs

$B^0\bar{B}^0$ Mixing



$$\frac{q}{p} \propto \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}$$

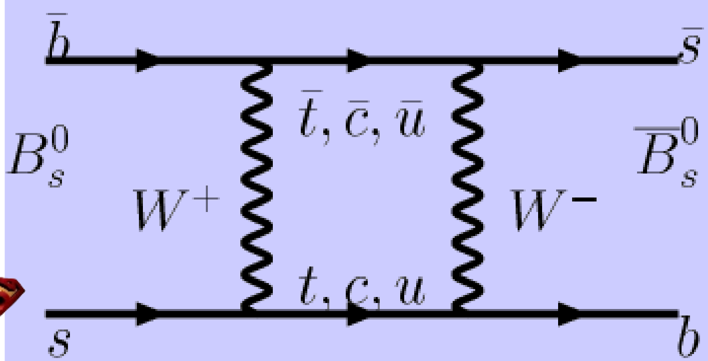
Tree Diagram



$$A \propto V_{cb}^* V_{cs}$$

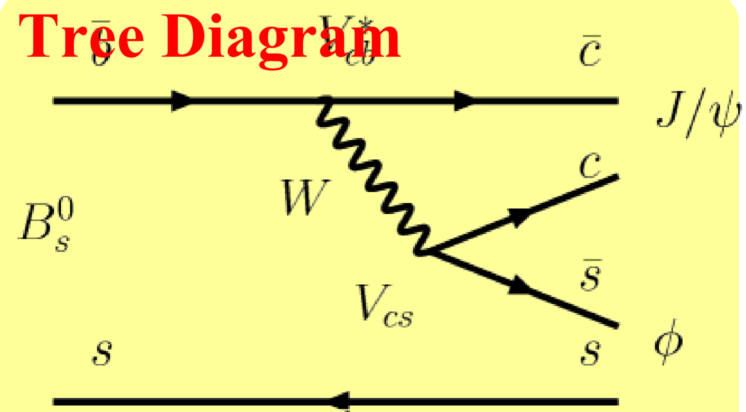
Time-dept. CP Asym. in Bs

$B_s^0\overline{B}_s^0$Mixing



$$\frac{q}{p} \propto \frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}^*}$$

Tree Diagram



$$A \propto V_{cb}^* V_{cs}$$

- CP phase ${\phi_{1s}}^{\rm SM}$ in SM is expected to be very small

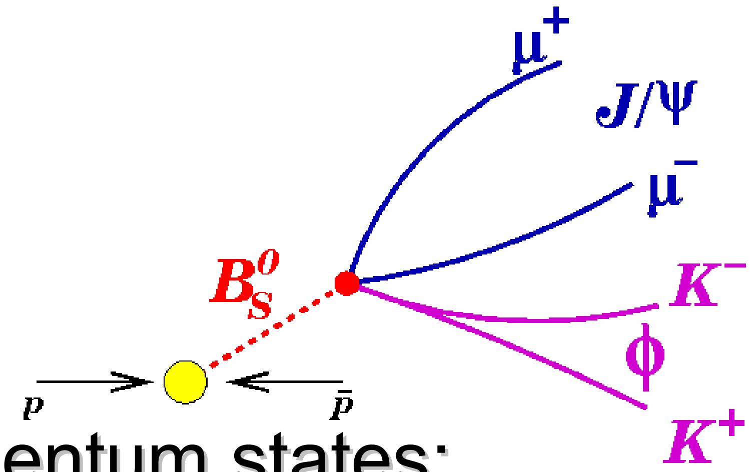
$$\phi_{1s}^{\rm SM}(\beta_s^{\rm SM}) = arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \sim 0.02$$

- New Physics effect as: $2\,\phi_{1s} = 2\,{\phi_{1s}}^{\rm SM} - {\phi_s}^{\rm NP}$
- If NP phase ${\phi_s}^{\rm NP}$ dominates $\rightarrow$ $2\,\phi_{1s} = -\,{\phi_s}^{\rm NP}$

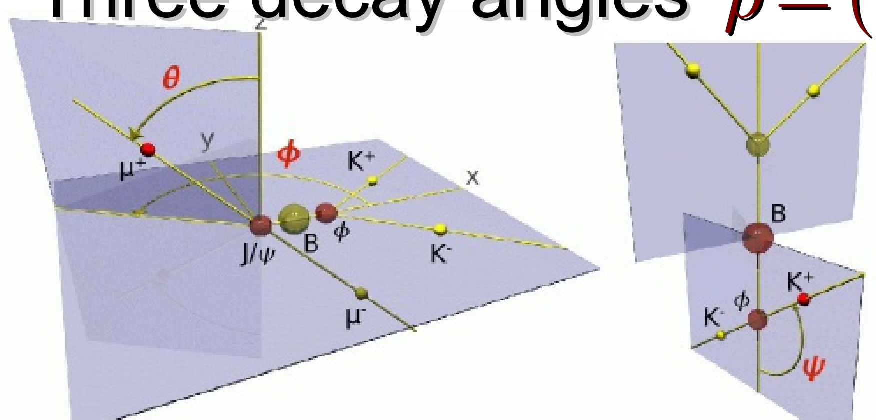
$B_s \to J/\psi\, \phi$ Decay Analysis

- Extremely physics-rich channel
- Measuring lifetime, decay width with known Δm, CP phase
- Decay of B_s (spin 0) to J/ψ , ϕ

(spin1) leads to three angular momentum states:



  - L=0 (s-wave), 2 (d-wave) → CP even $\overset{\Phi_s \approx 0}{\sim} |B_s^L\rangle$
  - L=1 (p-wave) → CP odd $\overset{\Phi_s \approx 0}{\sim} |B_s^H\rangle$
- Three decay angles $\vec{\rho} = (\theta, \phi, \psi)$ describe directions of final decay products



J/Ψ rest frame

φ rest frame

Bs $\rightarrow$ J/ΨΦ decay rate

- Decay rate as a function of time:

$$\frac{d^4 P(t,\vec{\rho})}{dt d\vec{\rho}} \propto |A_0|^2 \mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2 \mathcal{T}_+ f_2(\vec{\rho}) + |A_\perp|^2 \mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp| \mathcal{U}_+ f_4(\vec{\rho}) + |A_0||A_\parallel| \cos(\delta_\parallel) \mathcal{T}_+ f_5(\vec{\rho}) + |A_0||A_\perp| \mathcal{V}_+ f_6(\vec{\rho}),$$

time dependence terms

angular dependence terms

terms with β_s dependence

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta \sin(2\beta_s)\sin(\Delta m_s t)],$$

terms with Δm_s dependence due to initial state flavor tagging

$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

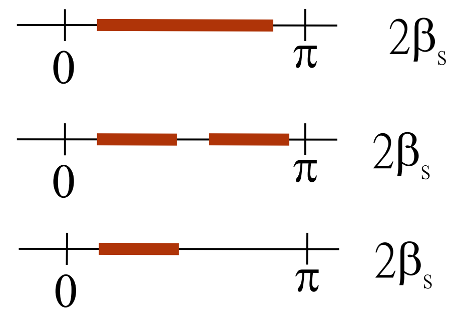
The 'strong' phases:

$$\delta_\parallel \equiv \arg(A_\parallel^* A_0)$$
$$\delta_\perp \equiv \arg(A_\perp^* A_0)$$

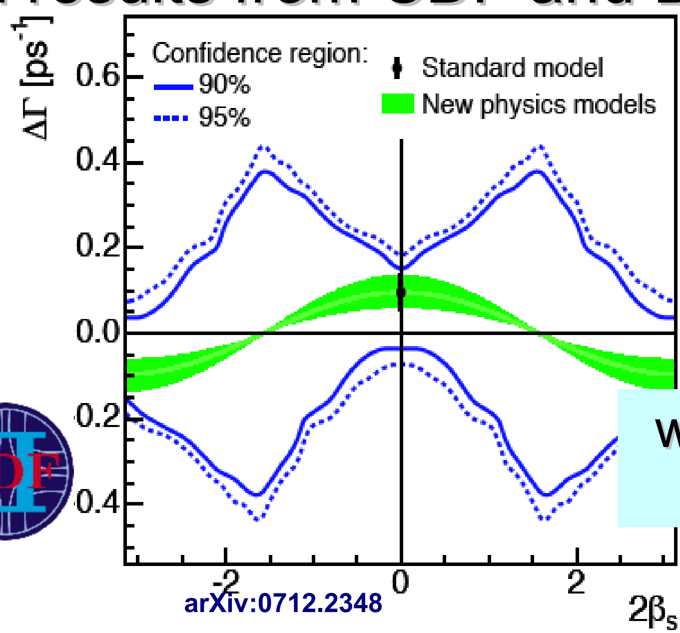
Tagging $\rightarrow$ better sensitivity to β_s

β_s in $B_s \to J/\psi\,\phi$ Decay

- 1D Feldman-Cousins procedure w/o external constraints:
  $2\beta_s$ in [0.32, 2.82] at the 68% C.L.
- With theoretical input $\Delta\Gamma$ = 0.096+/- 0.039
  $2\beta_s$ in [0.24, 1.36] U [1.78, 2.90] at 68% C.L.
- With external constrains on strong phase, lifetime and $\Delta\Gamma$
  $2\beta_s$ in [0.40, 1.20] at 68% C.L.

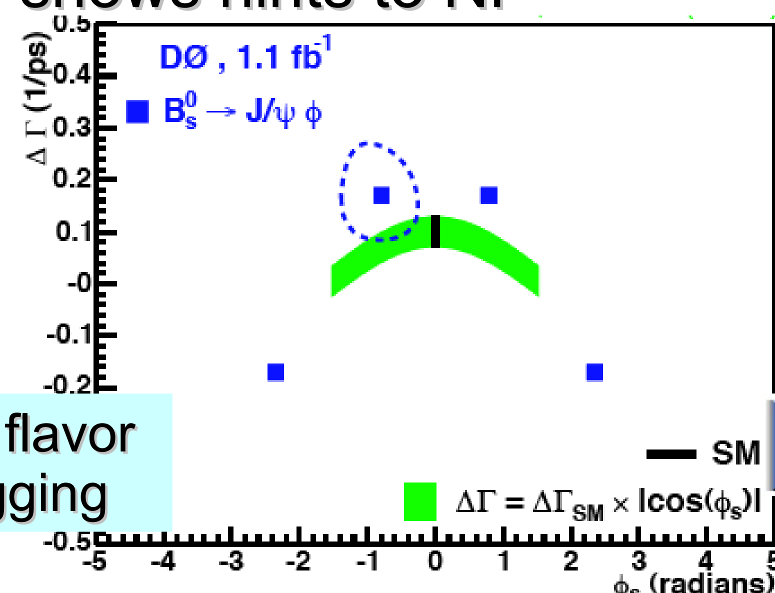


- Both results from CDF and DØ shows hints to NP



arXiv:0712.2348

w/o flavor tagging



arXiv:0802.2255

β_s in $B_s \to J/\psi\,\phi$ Decay

- 1D Feldman-Cousins procedure w/o external constraints:
  - $2\beta_s$ in [0.32, 2.82] at the 68% C.L.
- With theoretical input $\Delta\Gamma$ = 0.096+/- 0.039
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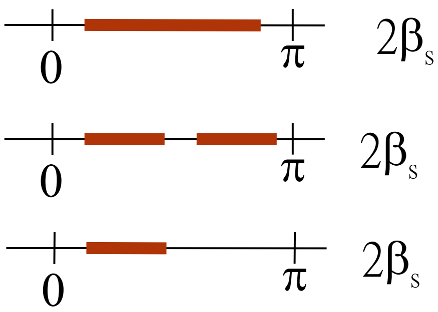
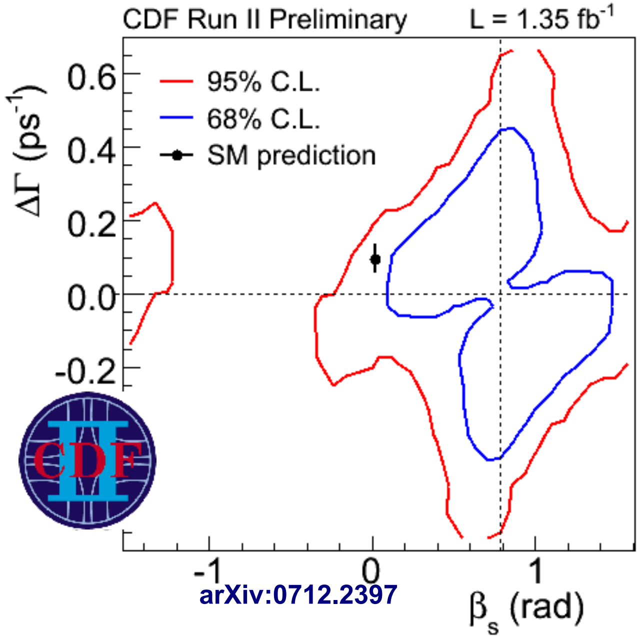
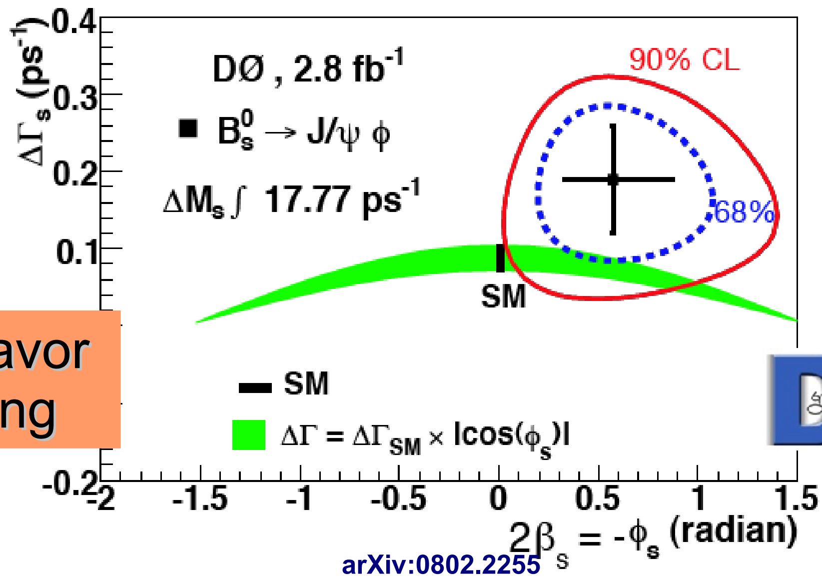


- Both results from CDF and DØ shows hints to NP



arXiv:0712.2397

with flavor tagging



arXiv:0802.2255

Summary

Summary and Future Prospects

- The success of *B*-factories
  - Many fruitful physical results
  - Unexpected challenges to the SM
- Hints to NP
  - $B \to hh$ BRs and A_{CP}
  - Gluonic and radiative penguins
  - $\sin 2\phi_{1s}$ ($\sin 2\beta_s$)
  - ... many others not covered
- More statistics needed for further clarification
  - Super B-Factory proposed
  - Look forward to up-coming results in the LHC era