New Results on Heavy Quarks from Belle

Ryosuke Itoh
IPNS, KEK

SLAC Summer Institute 2008
8/5/2008

Overview

1. Introduction
2. Status of KEKB and Belle
3. Latest Belle Results
   - CPV in $b \to s$ transition
   - DCPV in $B \to K\pi$
   - $B^- \to \tau^- \nu$
   - Hunt for Υ_b
4. Beyond Belle: SuperKEKB
5. Summary

1. Introduction

- The B-factory experiments are originally planned and built to discover the CP violation in B decays which is predicted in Kobayashi-Maskawa mixing matrix.

- Two B-factories were built :
  PEPII + BaBar : here at SLAC
  KEKB + Belle : at KEK in Japan
  and started operation in 1999.

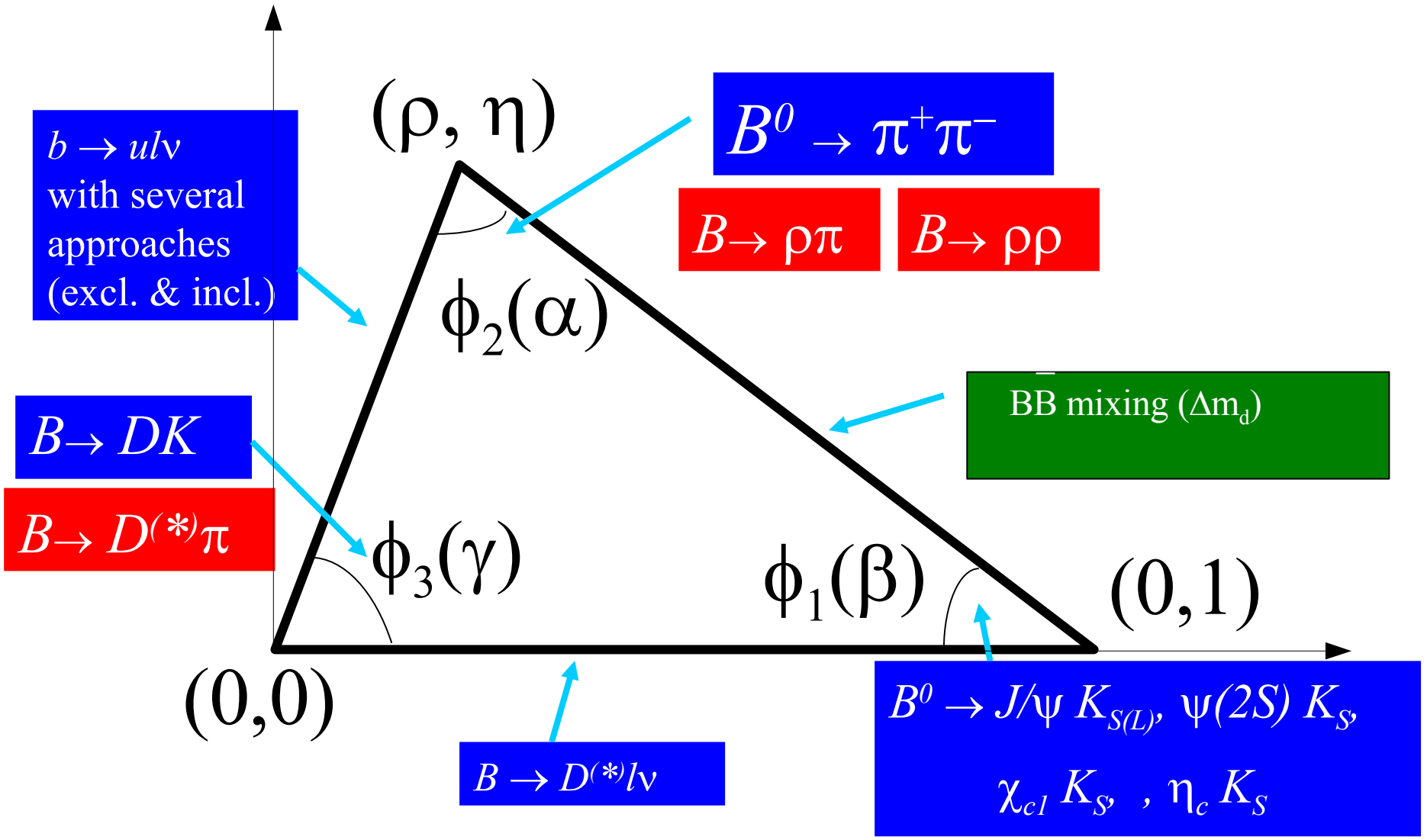
- The CP violation in $b \to c$ transitions was established by both experiments in early 2000's ($\sin 2\phi_1/\beta$ measurement).

The main topics in the current B-factory experiments are:
* Precise determination of the unitarity triangle
* Search for New Physics in rare decays
* Study of new exotic particles : X, Y, Z ....
* Charm and τ physics : ex. $D^0\overline{D}^0$ mixing

and more!

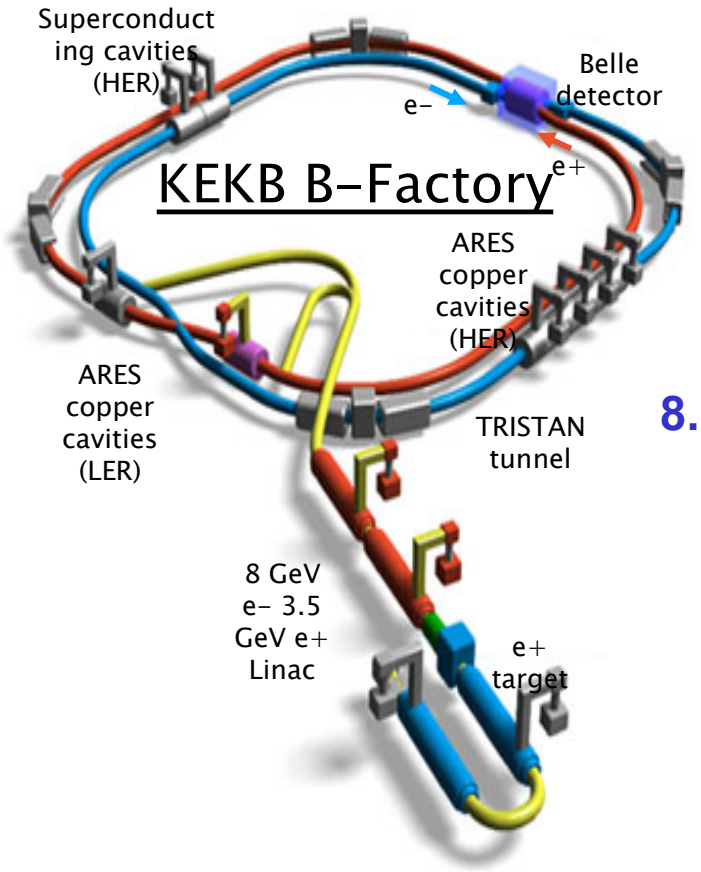
Unitarity Triangle determination at B-factory

$$V_{td}V_{tb}^{*}+V_{cd}V_{cb}^{*}+V_{ud}V_{ub}^{*}=1$$

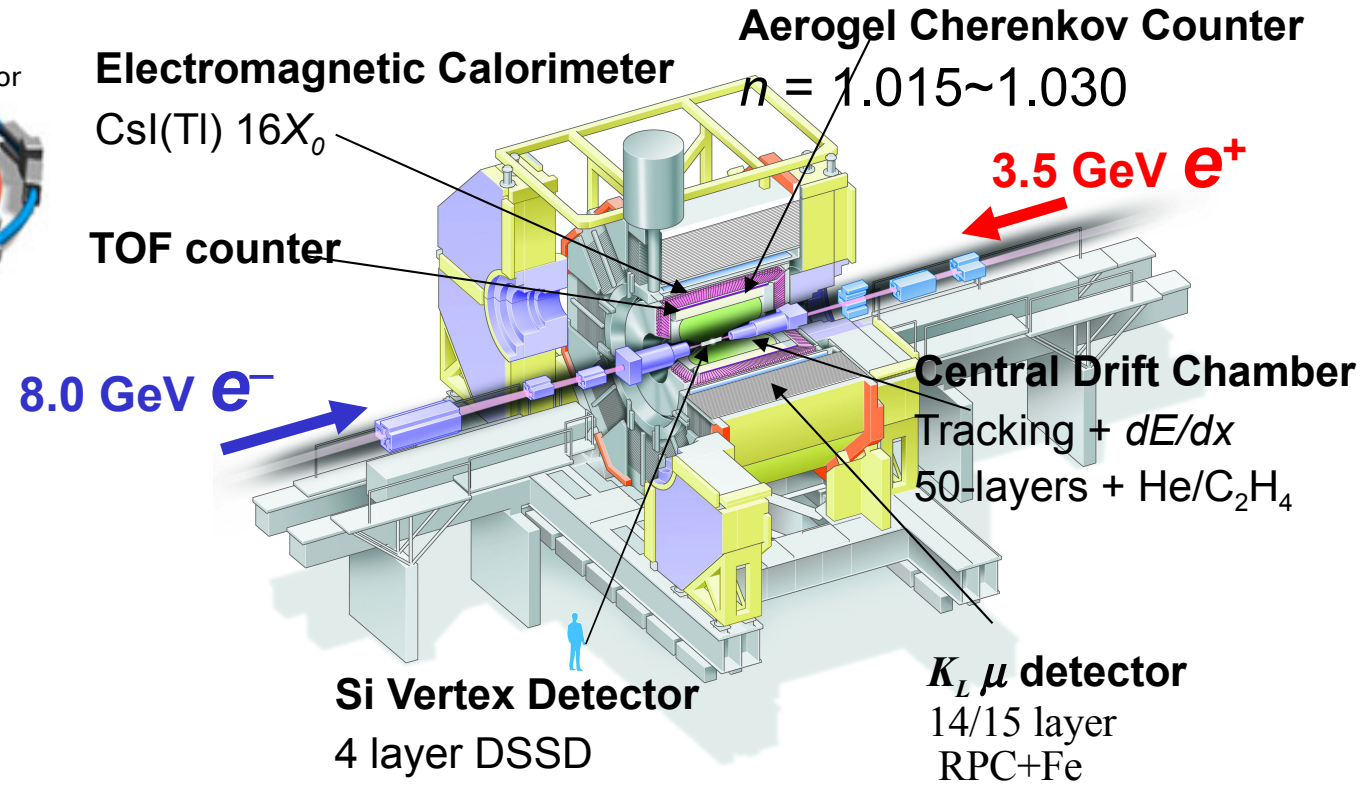


2. Status of KEKB and Belle

KEKB Accelerator



Belle Detector



2. Ex

K

Supercond
ing cavitie
(HER)

ARES
copper
cavities
(LER)

Counter

)

ev e^+

ift Chamber

dE/dx

- He/C_2H_4

ctor

Belle Collaboration

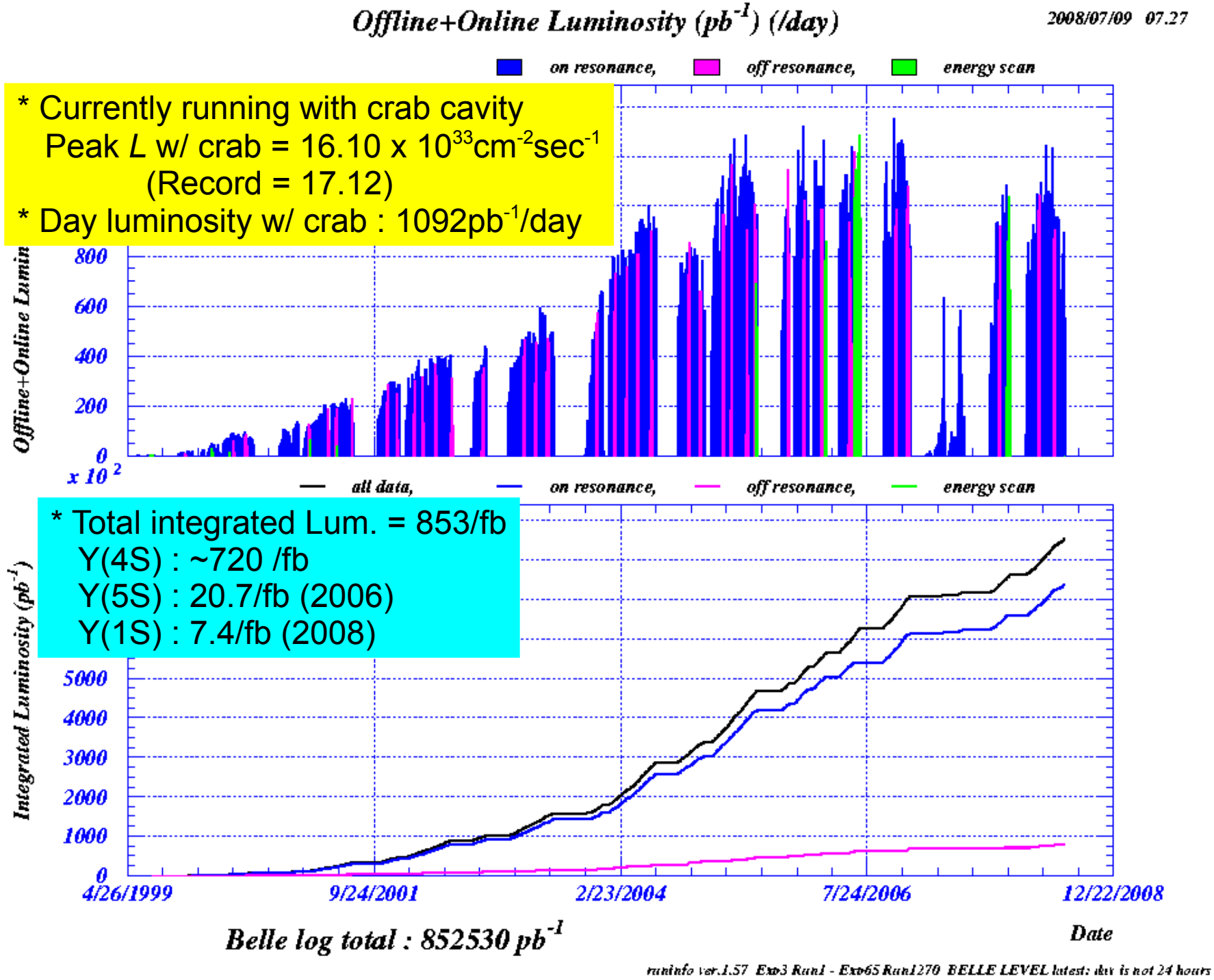
BINP
Chiba U.
U. of Cincinnati
Ewha Womans U.
Fu-Jen Catholic U.
U. of Giessen
Gyeongsang Nat'l U.
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

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.
Nova Gorica
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC

Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries
55 institutes
~400 collaborators

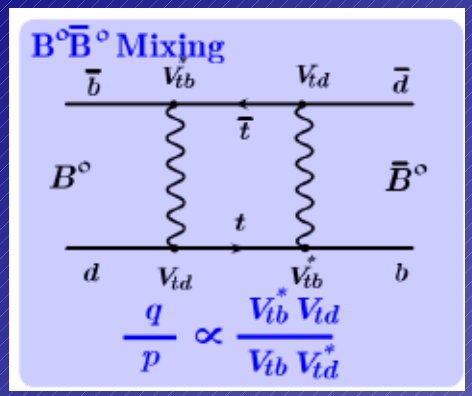


* Currently running with crab cavity
  Peak L w/ crab = 16.10 x $10^{33}cm^{-2}sec^{-1}$
  (Record = 17.12)
* Day luminosity w/ crab : $1092pb^{-1}$/day

* Total integrated Lum. = 853/fb
  Y(4S) : ~720 /fb
  Y(5S) : 20.7/fb (2006)
  Y(1S) : 7.4/fb (2008)

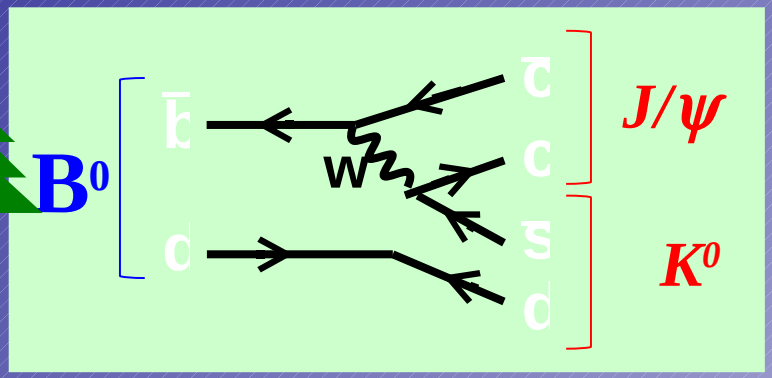
3. Latest Belle Results

a) ϕ_1/β measurement in $b \to s$ transition



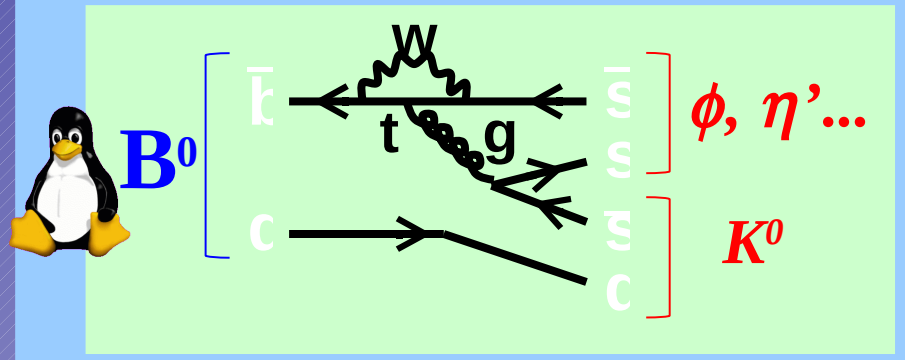
$\sin 2\phi_1/\beta$

+

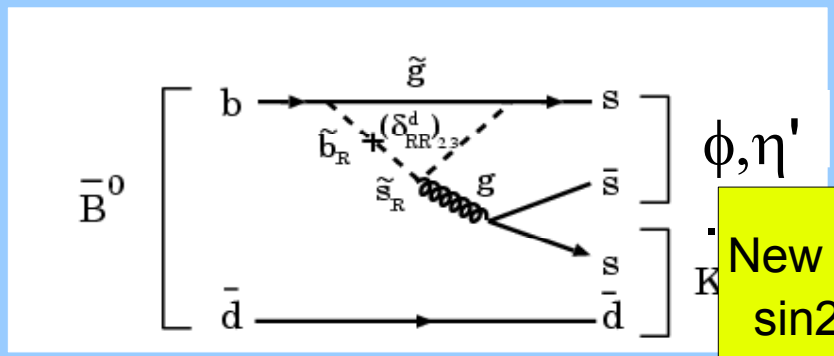


$b \to c$ transition

$b \to s$ transition



+



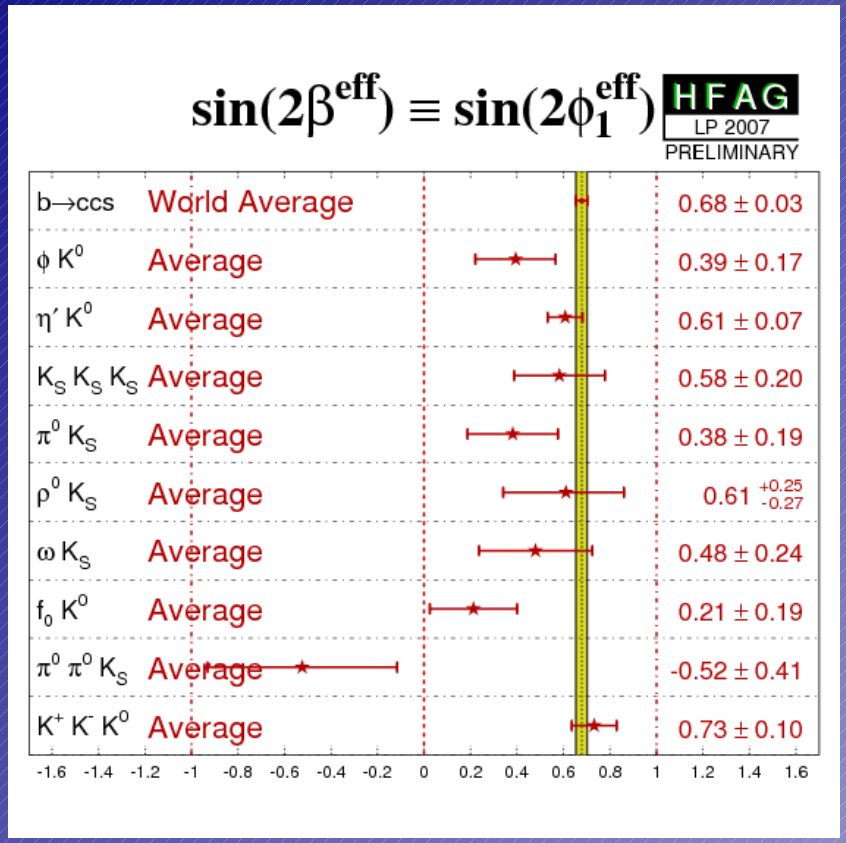
$\Delta S = \sin 2\phi_1(b \to s) - \sin 2\phi_1(b \to c)$

SM: $\Delta S = 0$

* Small discrepancy is expected due to rescatterng, etc..
  $\Delta S > 0$ within 0.05

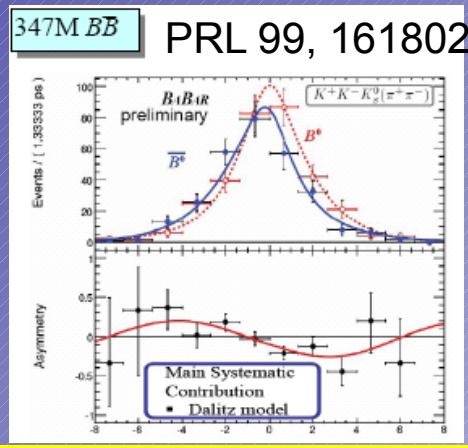
New coupling $\to$New Phase
$\sin 2\phi_1(b \to c) \neq \sin 2\phi_1(b \to s)$

ΔS results before ICHEP 2008



Exclude BaBar's $f_0(\pi^+\pi^-)$ K^0 result: highly non-Gauissan error with the central values close to phys. boundary.

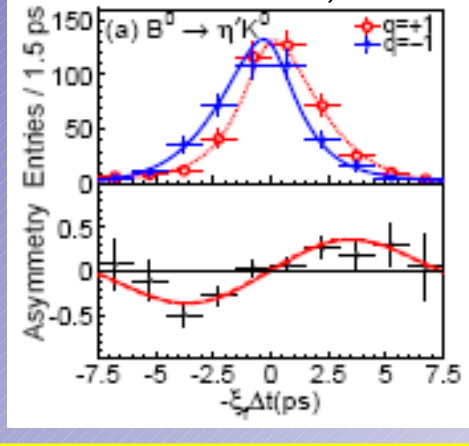
347M $B\bar{B}$ PRL 99, 161802 (2007)



Based on KKK Dalitz analysis

ϕK^0: $\sin 2\beta_{eff} = +0.12 \pm 0.31(stat) \pm 0.10\ (syst)$

535 M PRL 98, 031802 (2007)



$\eta' K^0$: $\sin 2\phi_{1eff}$: +0.64± 0.10 ± 0.04

Naïve ave. of $\sin 2\phi_1$ (b→s): 0.56±0.05 ⇨ $\Delta S = -0.12 \pm 0.06$ (~2σ)

Negative!

Experimental Technique 1: Reconstruction of B meson

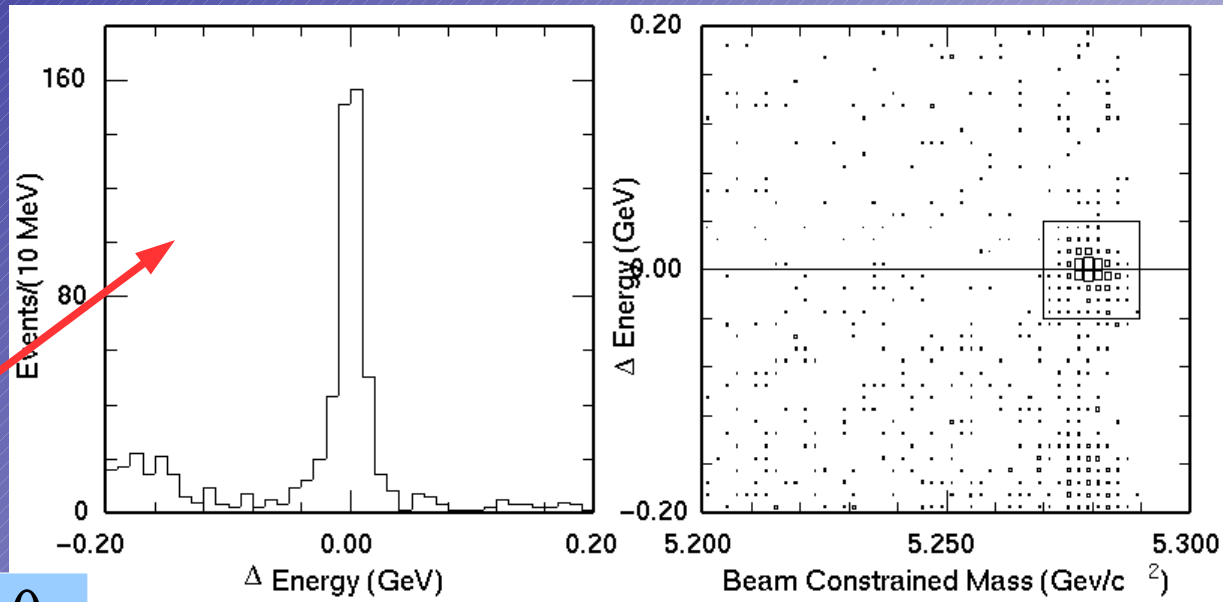
- B mesons are reconstructed from decay products by calculating invariant mass repeatedly.
- Special kinematic constraint is used to improve perform-ance.

Energy difference:

$$\Delta E = (E_{J/\psi} + E_{Ks}) - E_{CM}/2.0$$

energy of B^0 candidate

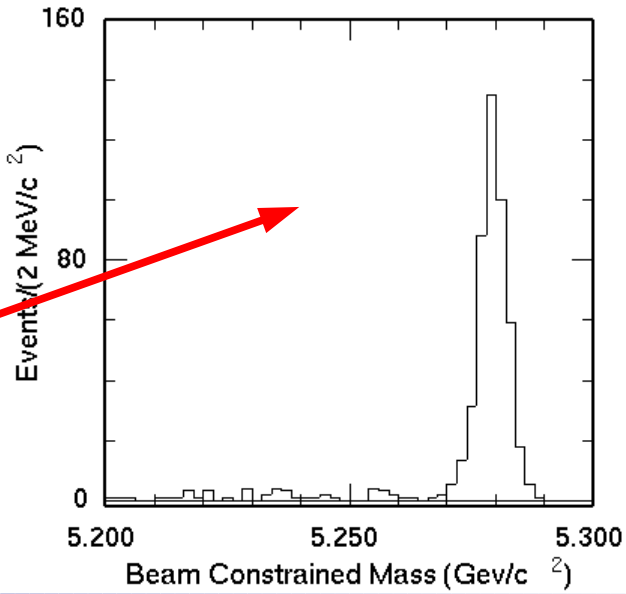
expected energy of B^0



Beam Constrained Mass:

$$M_{bc} = \sqrt{(E_{CM}/2.0)^2 - (p_{J/\psi} + p_{Ks})^2}$$

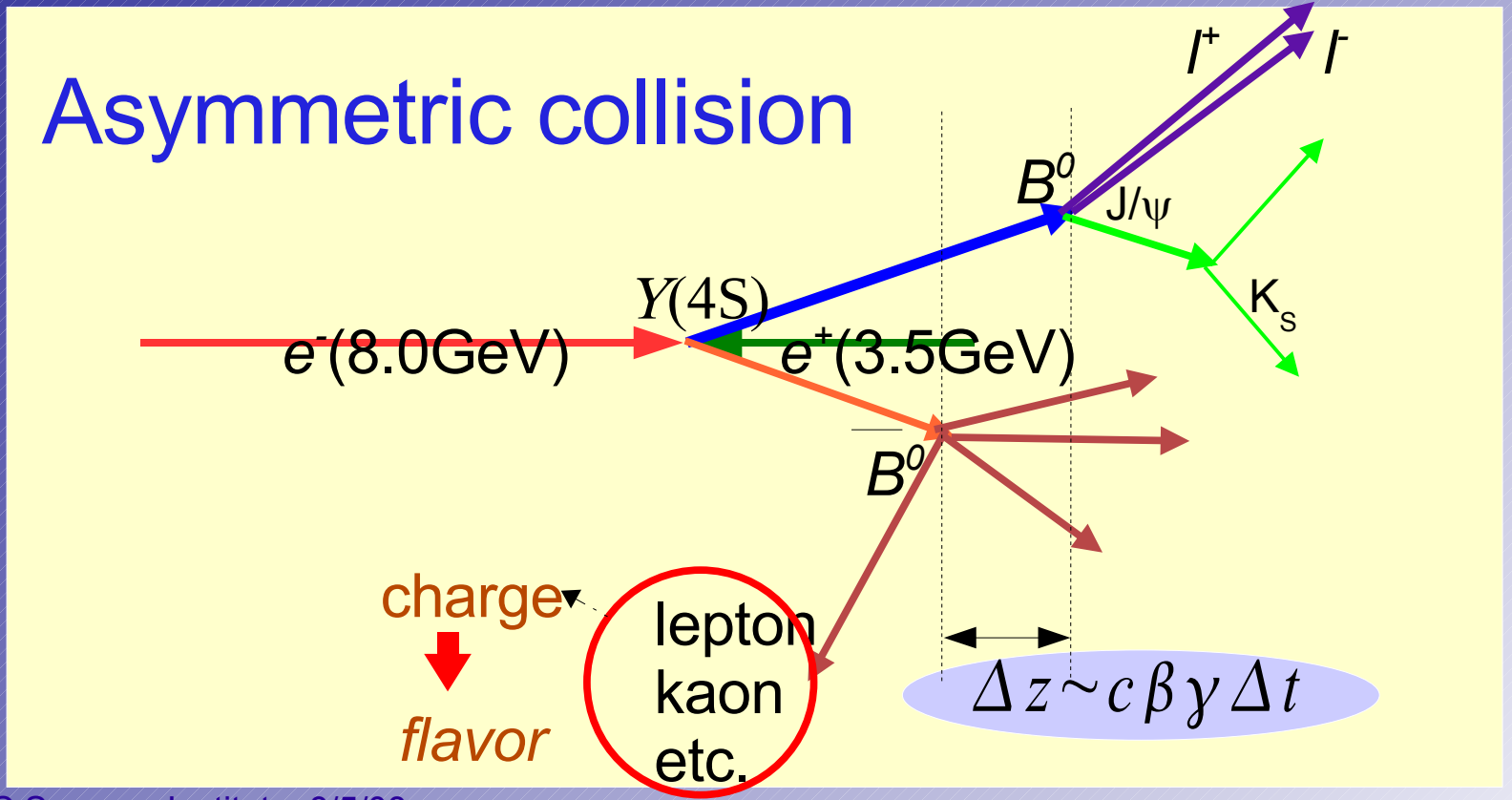
momentum of B^0 candidate



Experimental Technique 2 : $A_{CP}(\Delta t)$ measurement

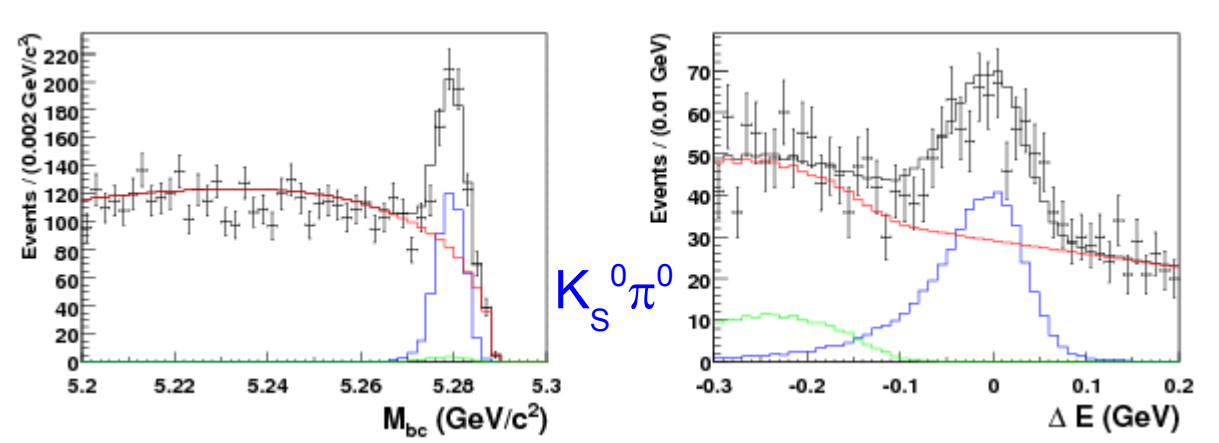
$$A_{CP}(\Delta t)=\frac{\Gamma(B^0_d\to f_{CP})-\Gamma(\overline{B^0}_d\to f_{CP})}{\Gamma(B^0_d\to f_{CP})+\Gamma(\overline{B^0}_d\to f_{CP})}=S_{CP}\sin(\Delta m\Delta t)+A_{CP}\cos(\Delta m\Delta t)$$

- B^0 and $\overline{B^0}$ mesons are produced from $\Upsilon(4S)$ decay at B-factories.
- To measure A_{CP}, we need to know decay time difference (Δt) of two B^0 mesons with the flavor of one tagged.

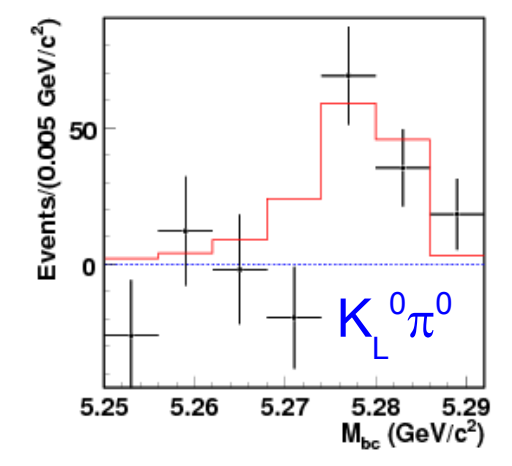


Belle 2008 Measurements with 657M BB events

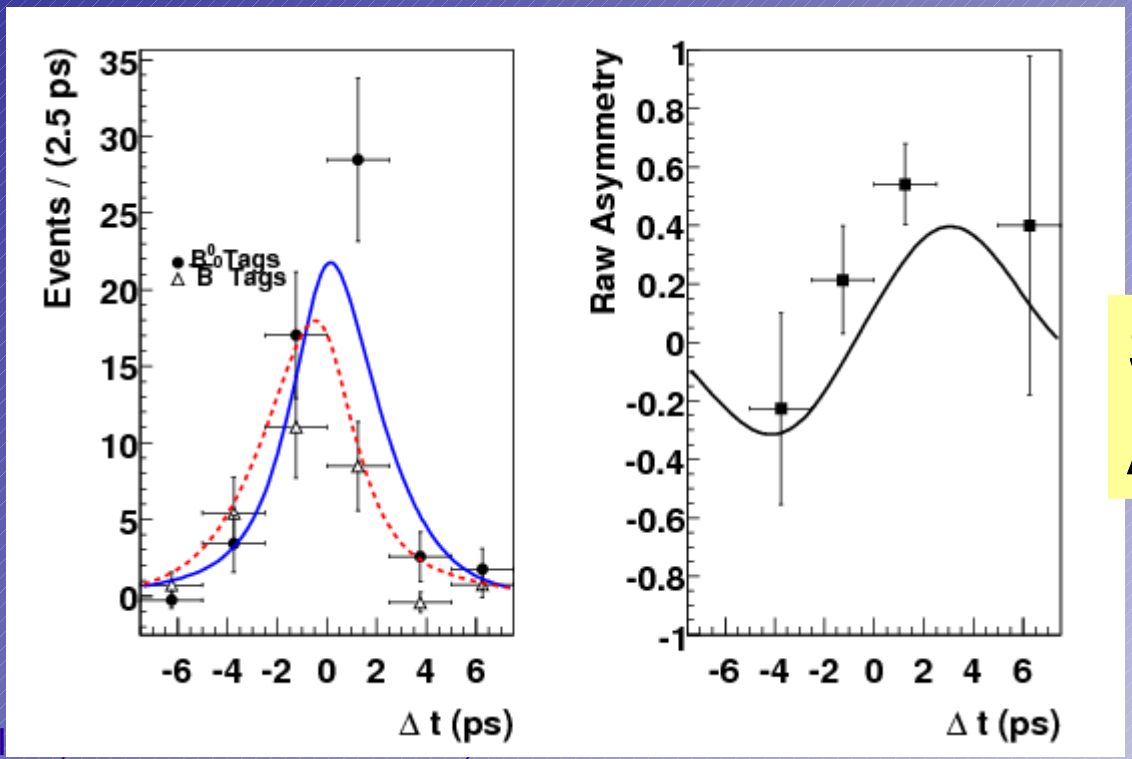
1) $K^0\pi^0$

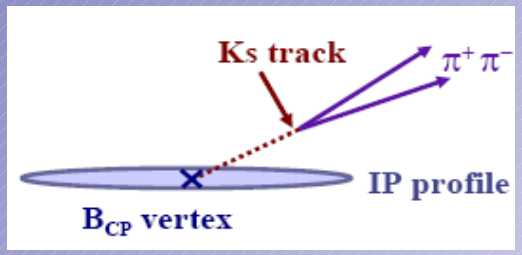


657±37 events



239±47 events





$S = \sin 2\phi_1^{eff} = 0.67 \pm 0.31 \pm 0.08$

$A = 0.14 \pm 0.13 \pm 0.06$

Belle $K_S^0\pi^0$ 2007 (535M):
$S = 0.33 \pm 0.35 \pm 0.08$
HFAG08 winter: $S = 0.38 \pm 0.19$

2) Time-dependent Dalitz analysis for $K_s^0 K^+ K^-$ and $K_s^0 \pi^+ \pi^-$

Previous analysis: peformed by treating $\phi(\rho)$ and K_s as 2-body decay

$\rightarrow$ Interference effects among intermediate states are neglected.

=> may cause shift in measured $\sin 2\phi_1$

Full use of three body decay using Dalitz analysis technique.

* Interference terms in Dalitz density includes the $\cos 2\phi_1$ terms

-> can solve the two fold ambiguity first adopted by BaBar (2007)

$$|\mathcal{A}(\Delta t, q)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \Big[(|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2) - q(|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2) \cos \Delta m_d \Delta t + 2q\Im(\bar{\mathcal{A}}\mathcal{A}^*) \sin \Delta m_d \Delta t \Big]$$

Dalitz decay amplitude

$$\mathcal{A}(s_+, s_-) = \sum_i a_i F_i(s_+, s_-), \quad \bar{\mathcal{A}}(s_+, s_-) = \sum_i \bar{a}_i \bar{F}_i(s_+, s_-)$$

sum of resonances

$$s_\pm = (p_\pm + p_0)^2$$

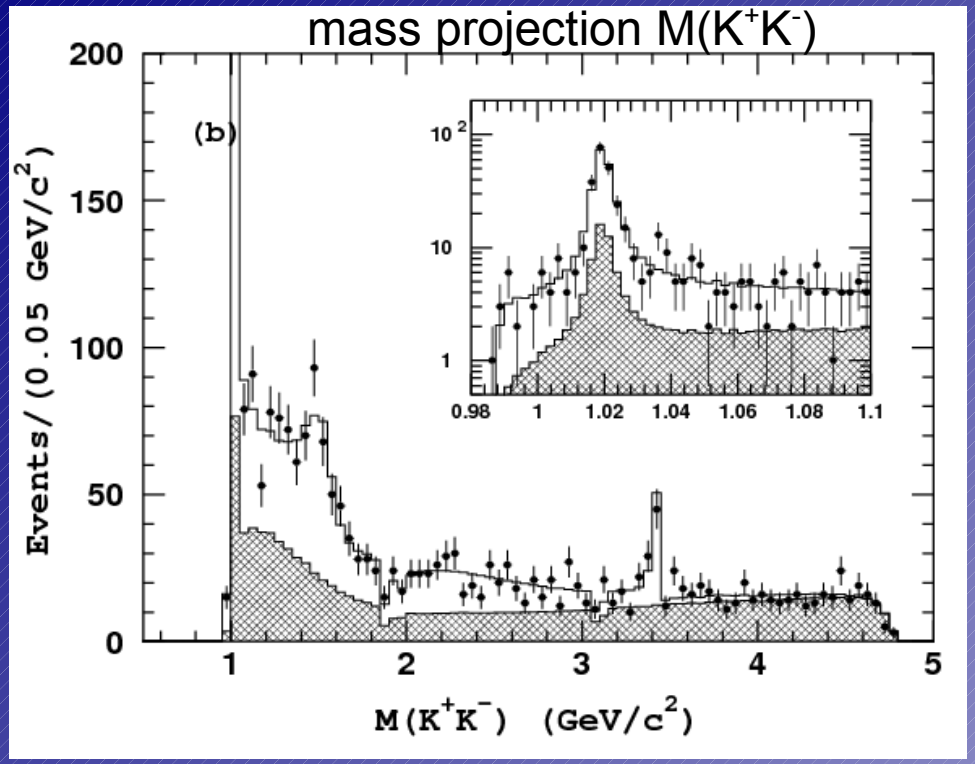
Fit parameters (KsK^+K^-):

B decay model (ϕKs, $f_0 Ks$, $f_x(1500)Ks$, $\chi_{c0} Ks$ and non-resonant) = 12 params.

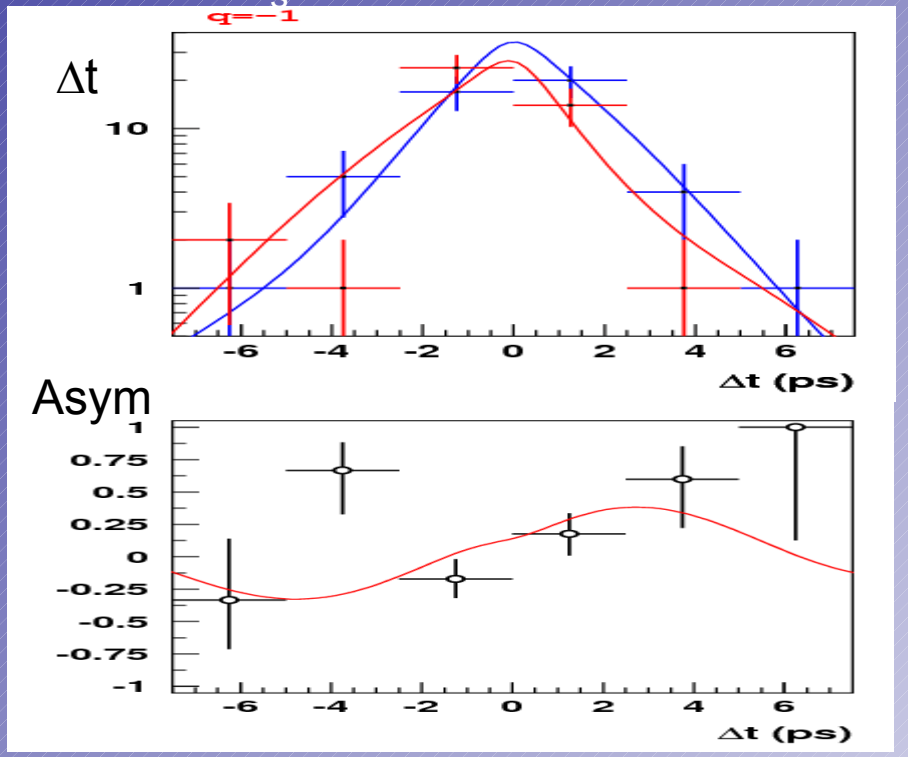
+

CP parameters ϕ_1 and A_{CP} for ϕ,f_0 and rest = 6 params.

Results of the fit to $K_s K^+K^-$



ϕK_s with good tag

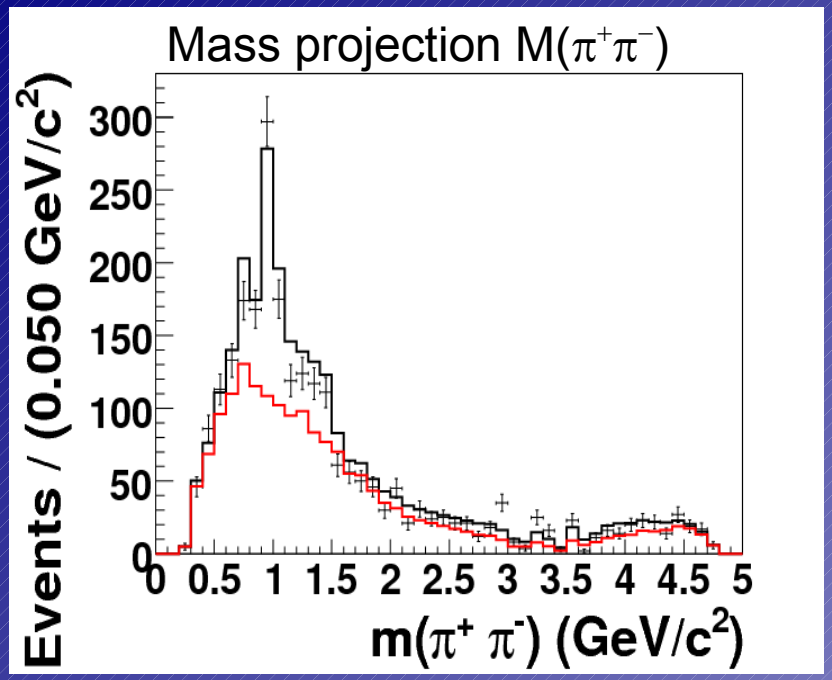


	$\sin 2\phi_1^{eff}$	A
ϕK_s	$0.67^{+0.21}_{-0.30}\pm0.07\pm0.09$	$0.31^{+0.21}_{-0.23}\pm0.02\pm0.09$
$f_0 K_s$	$0.83^{+0.14}_{-0.23}\pm0.07\pm0.09$	$-0.02\pm0.32\pm0.02\pm0.09$
remain	$0.73^{+0.14}_{-0.13}\pm0.07\pm0.09$	$0.00\pm0.14\pm0.02\pm0.09$

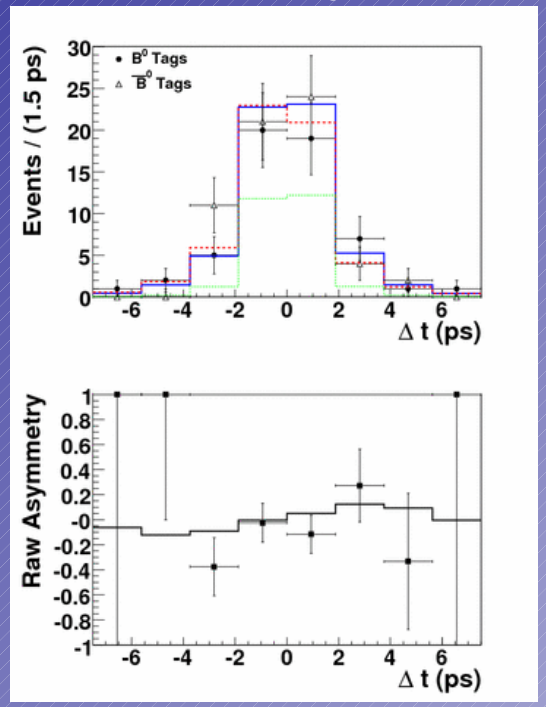
BaBar 2007 (383M): PRL 99, 161802 (2007)

ϕK_s	$0.21\pm0.26\pm0.11$	$-0.08\pm0.18\pm0.04$
$f_0 K_s$	$0.28\pm0.27\pm0.09$	$0.41\pm0.23\pm0.07$

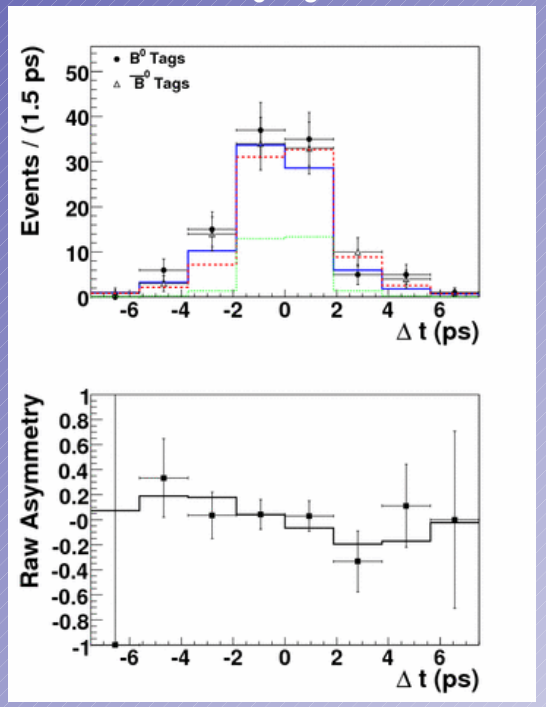
Results of the fit to $K_s\pi^+\pi^-$



$\rho^0 K_s$



$f_0 K_s$



Two solutions depending on the estimated K*(1430) amount

	$\sin 2\phi_1^{eff}$	A	
$\rho^0 K_s$	$0.64^{+0.20}_{-0.25}\pm0.12$	$0.03\pm0.24\pm0.13$	sol.1 (f(K*(1430))=61.6±10.4%)
$f_0 K_s$	$0.43^{+0.20}_{-0.22}\pm0.12$	$-0.06\pm0.17\pm0.08$	
$\rho^0 K_s$	$0.71^{+0.16}_{-0.20}\pm0.13$	$-0.16\pm0.24\pm0.15$	sol.2 (f(K*(1430))=17.4±5.0%)
$f_0 K_s$	$0.49^{+0.21}_{-0.21}\pm0.12$	$0.00\pm0.17\pm0.07$	

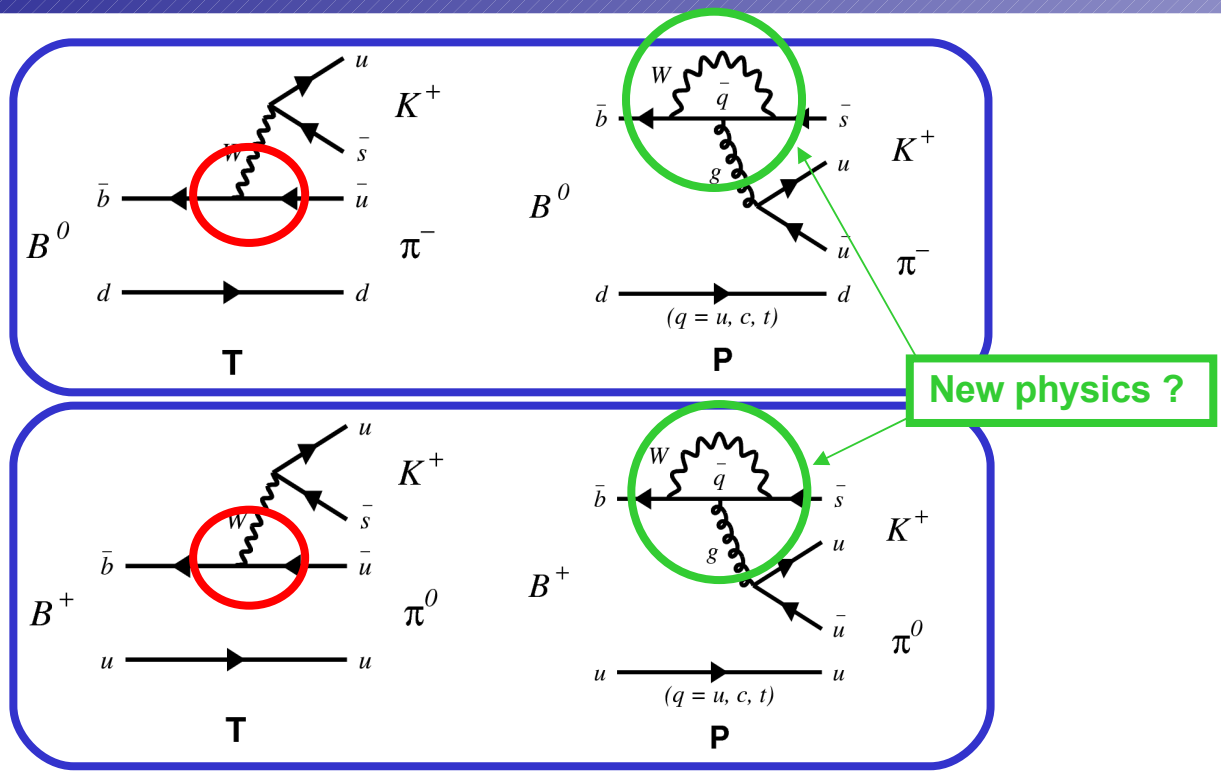
BaBar 2007 (383M) : arXiv:0708.2097

$\rho^0 K_s$	$0.61^{+0.22}_{-0.24}\pm0.09\pm0.08$	$-0.02\pm0.27\pm0.08\pm0.06$
$f_0 K_s$	$0.94\ ^{+0.02}_{-0.07}\ ^{+0.03}_{-0.05}\pm0.02$	$-0.35\pm0.27\pm0.07\pm0.04$ (highly non-gaussian error!)

b) Direct CPV in $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$

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

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



* Direct CPV occurs through the interference between Tree and Penguin diagrams

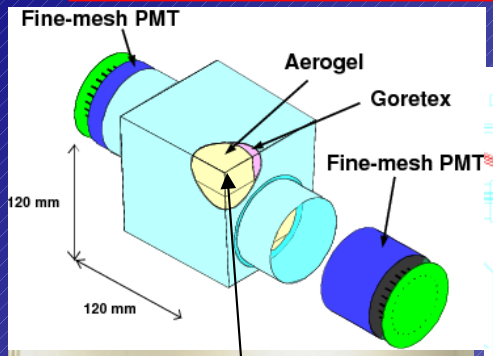
$$\mathcal{A}_{CP}(B^0 \to K^+\pi^-) = \frac{2|P/T|\sin\Delta\delta\sin\phi_3}{1+|P/T|^2+2|P/T|\cos\Delta\delta\cos\phi_3}$$

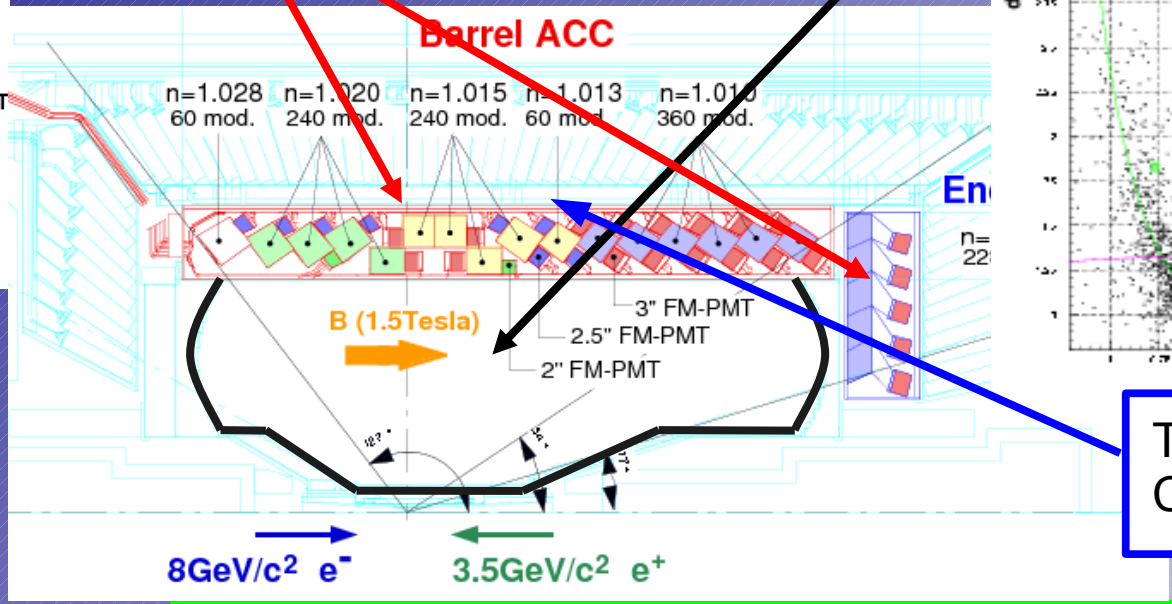
Expected to be $A_{CP}(K^+\pi^-) = A_{CP}(K^+\pi^0)$

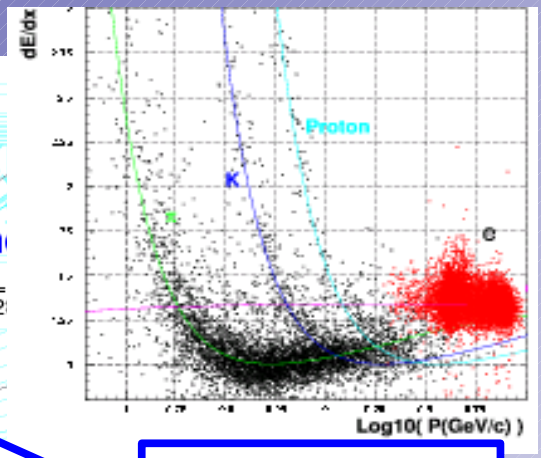
Experimental Technique 3 : Particle ID

Silica Aerogel Cerenkov Counter(ACC)
- 1188 module
- 1788 PMT

dE/dx by Central drift chamber(CDC)
- $He + C_2H_6 = 1 : 1$
- ~ 40000 wires

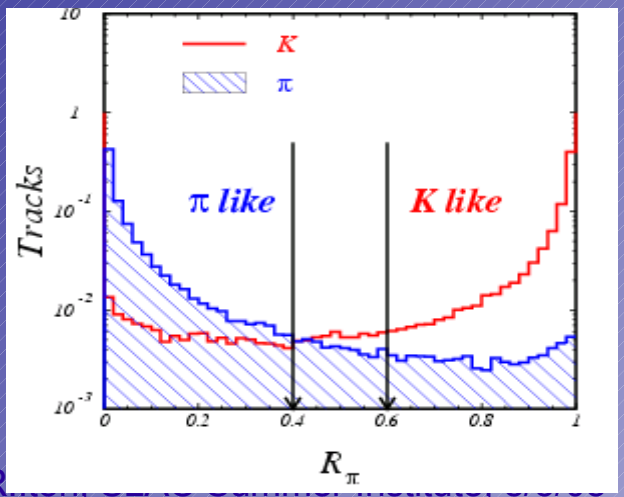


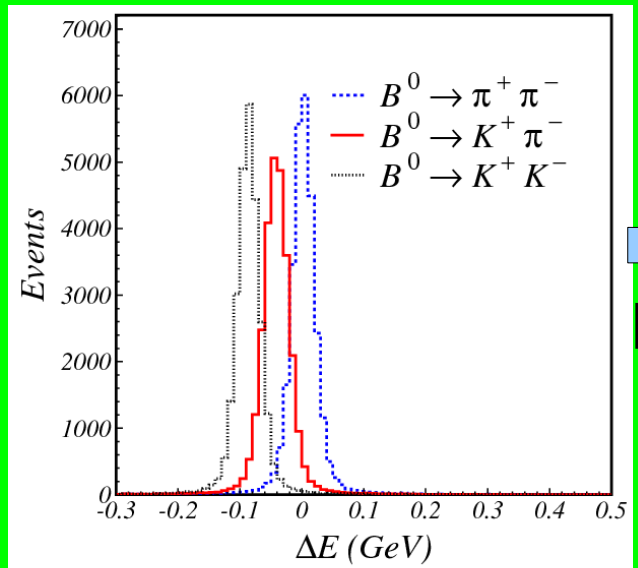




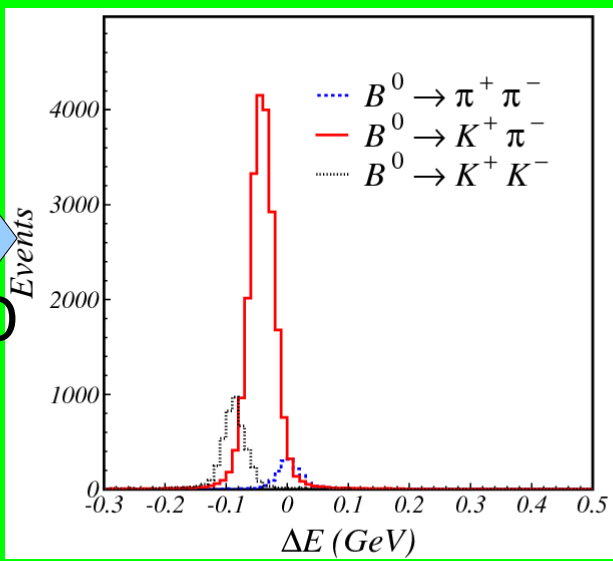
Time of Flight Counter(TOF)

Likelihood is calculated

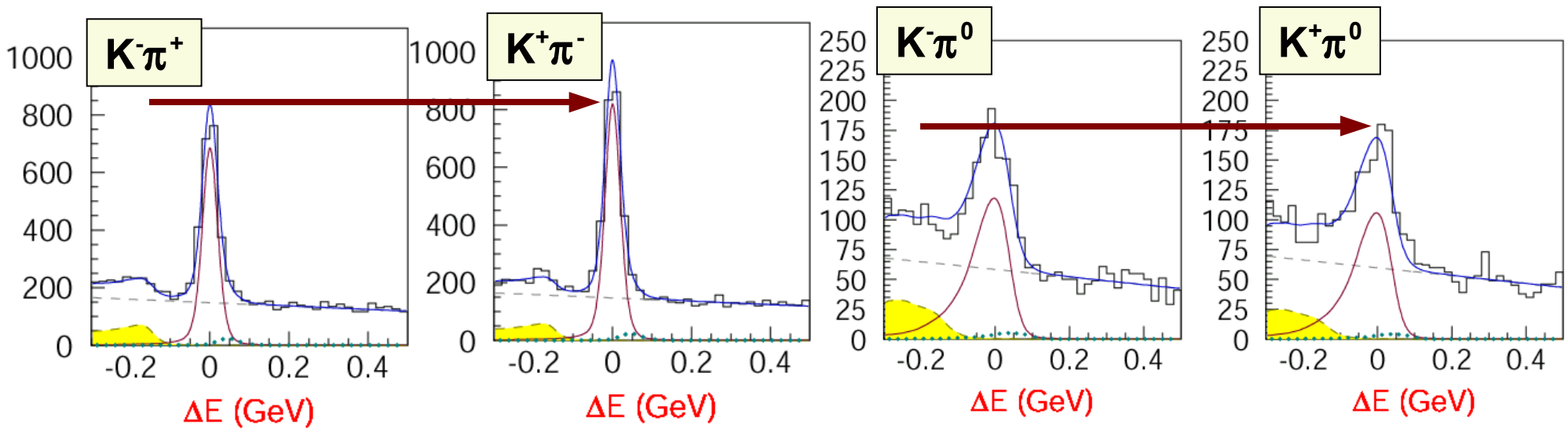




PID



Belle Measurement : 535M BB events



$A_{CP}(K^+\pi^-) = -0.094 \pm 0.018 \pm 0.008$

$A_{CP}(K^+\pi^0) = +0.07 \pm 0.03 \pm 0.01$

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

WA with BaBar, CDF and CLEO : $\Delta A_{CP} = +0.147 \pm 0.028$ @ 5.3σ

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

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 can 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, and a theoretical challenge to describe how the quark level diagram 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

ΔA_{CP} puzzle

Published in Nature

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*

A_{CP} puzzle 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,

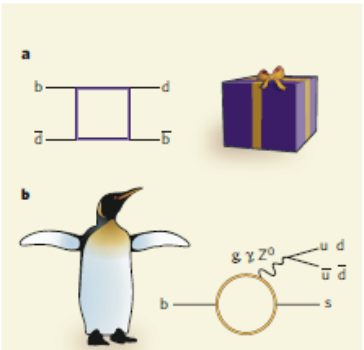
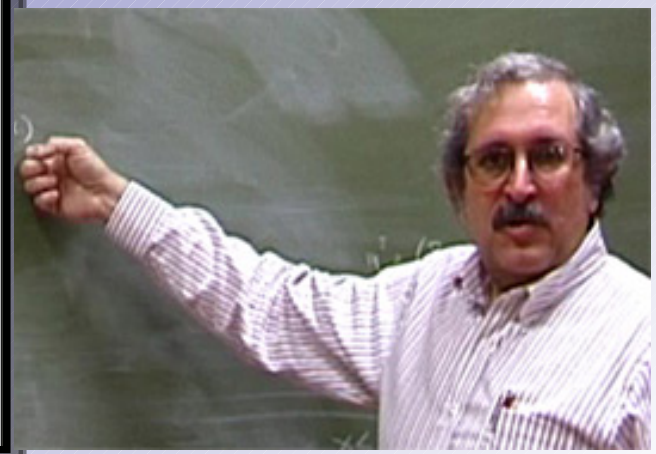


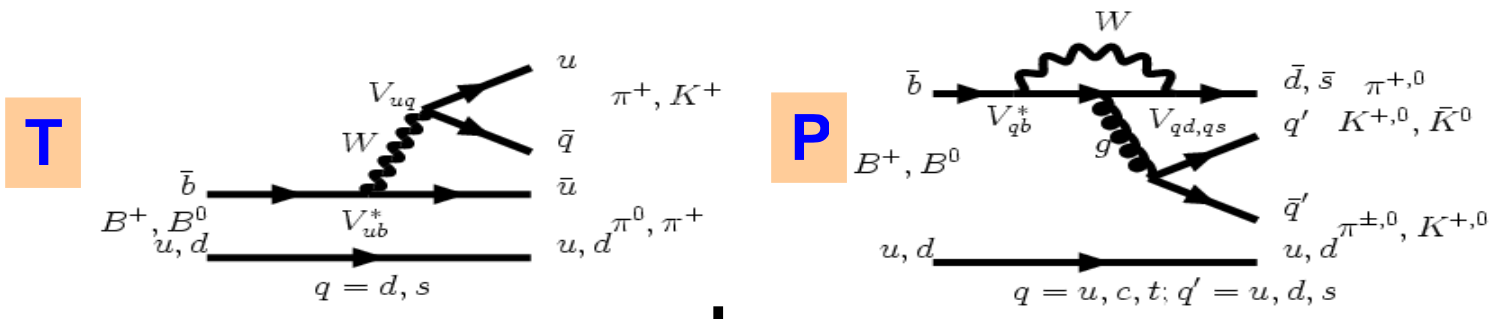
Figure 1 | Weakly decaying. A Feynman diagram represents the time evolution of a particle process (shown here from left to right). **a**, In a standard 'box' diagram of weak quark-mixing

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 b̄ 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-



Possible explanation of $\Delta A_{CP}(K\pi)$ puzzle



Expected to be negligible in SM

- C.-W.Chaing, et al., PRD 70, 034020
- Y.-Y.Charng, et al., PRD 71, 014036
- 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 (C/T = 0.3–0.6 in SM)
  - → breakdown of theoretical understanding
- Enhancement of $\mathbf{P_{EW}}$?
  - → Would indicate new physics.
- Due to poor understanding of strong int.?

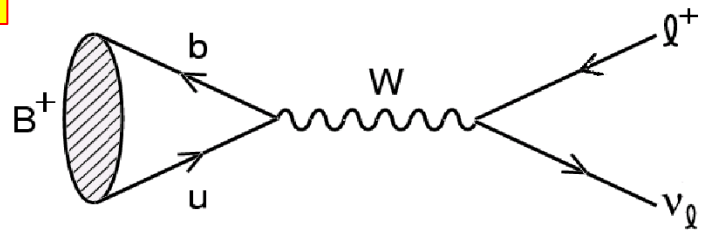
Sum Rule : M. Gronau, PLB 627, 82 (2005); D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998)

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

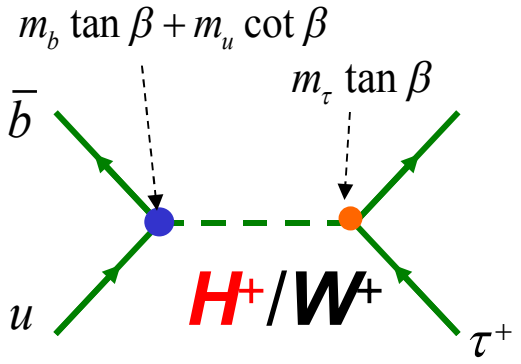
Sum Rule tells $A_{CP}(K^0\pi^0)$ to be -0.15±0.06 ← Belle meas. +0.14±0.13±0.06 → more statistics!

c) B→τν

SM



NP



$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 (1 - \frac{m_\tau^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B \qquad r_H = (1 - \frac{m_B^2}{m_H^2} \tan^2\beta)^2$$

$$Br = Br_{SM} \times r_H$$

* In the framework of Standard Model, the decay is useful for the determination of V_{ub} and f_B
* Also sensitive to New Physics!
  - The existence of charged Higgs can modify SM branching fraction

Experimental Technique 4 : "Full-recon" tag

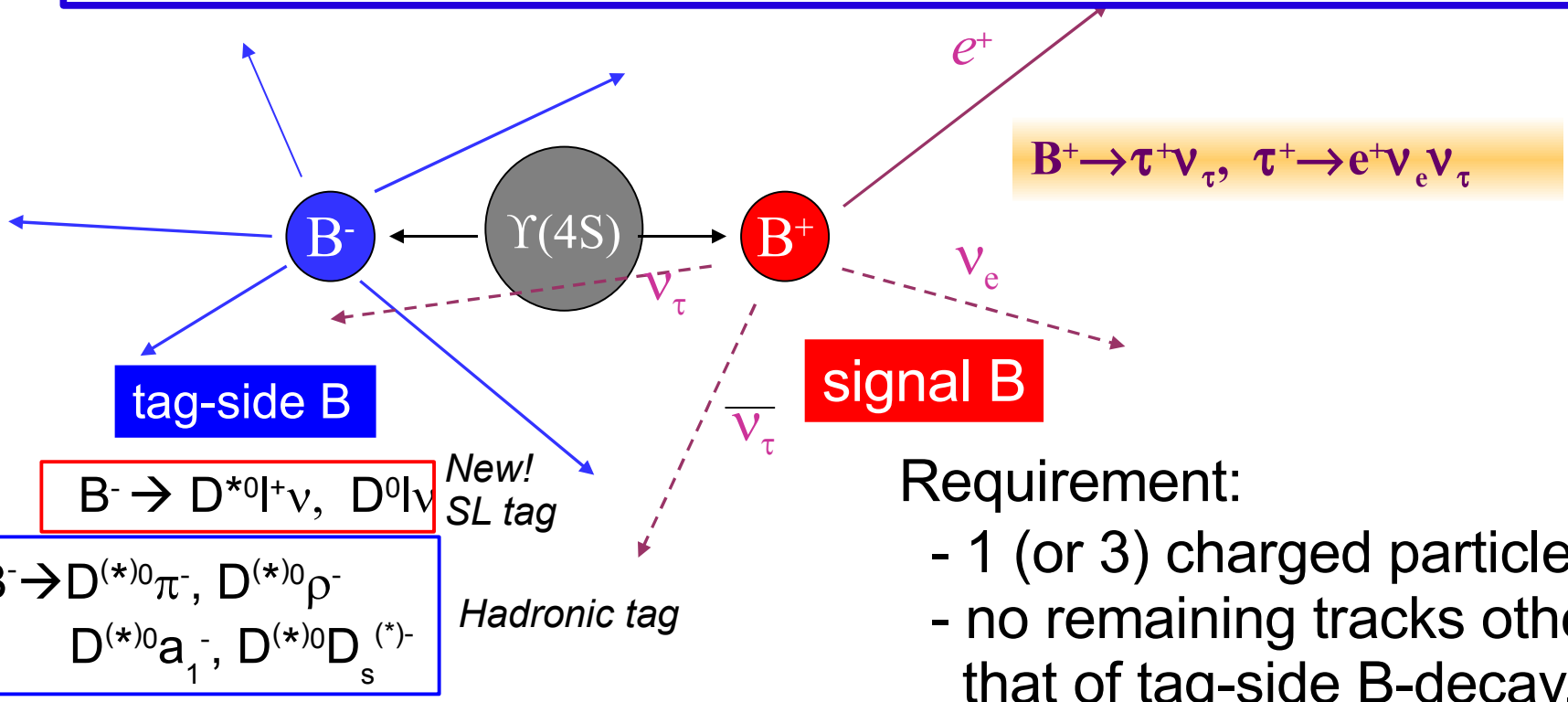
* Decay final state: 1 (or 3) charged particles + 2 or more neutrinos

$B^- \to \tau^- \nu_\tau$; $\tau^- \to l^- \nu_l \nu_\tau, \pi^- \nu_\tau, [\pi^- \pi^0 \nu_\tau, \pi^- \pi^+ \pi^- \nu_\tau]$ ← not used with SL tag

→ difficult to identify

* The B meson is produced in $\Upsilon(4S)$ decay with the other B.

- Full reconstruction of the other B meson decay (tag B).
- Remaining tracks are used to identify $B \to \tau\nu$ decay
- Semi-leptonic tagged events are newly added in 2008 analysis.

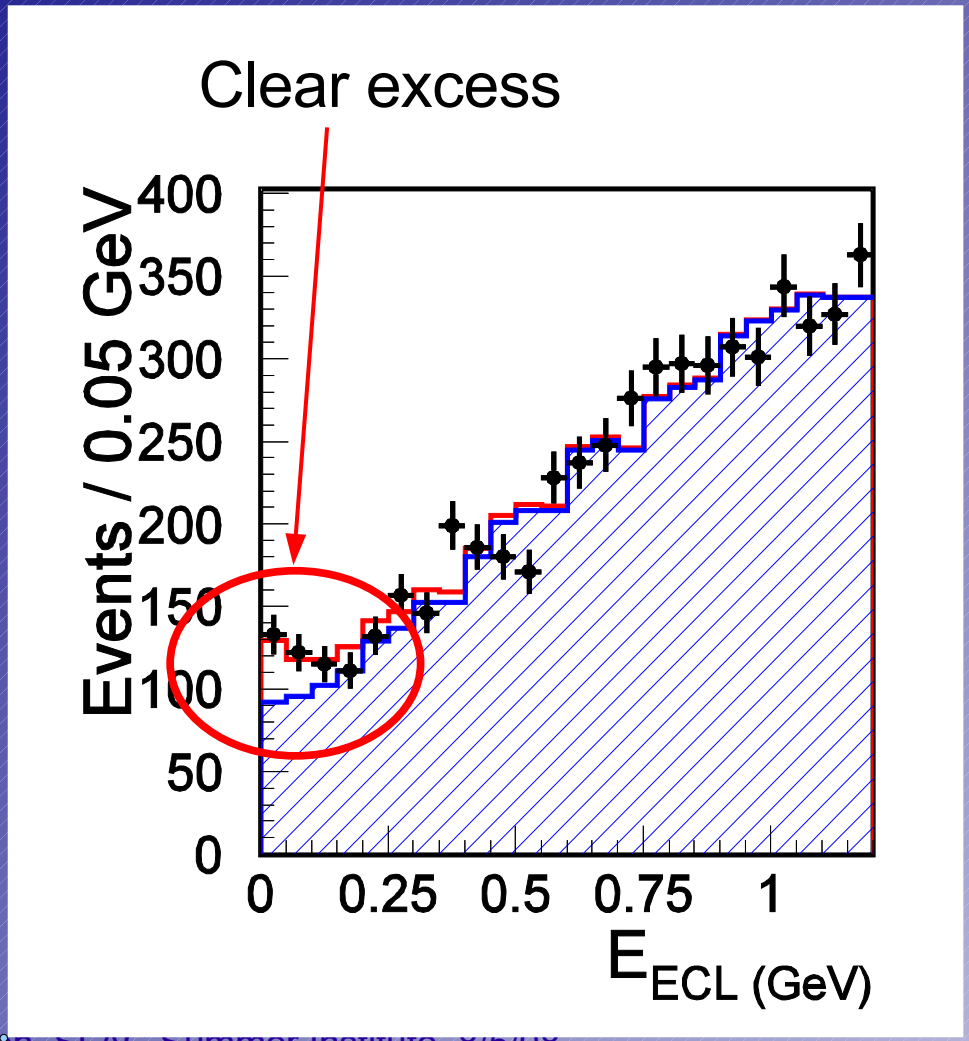


Requirement:

- 1 (or 3) charged particle (+π^0)
- no remaining tracks other than that of tag-side B-decay.

Results with 657M BB events

- Signal is identified by looking at the energy clusters in the calorimeter (ECL) which are associated with neither signal nor tag B meson decay products.
  * No energy deposit is expected in signal events.



$N_{sig} = 154^{+36}_{-35}(stat)^{+20}_{-22}(syst)$

@ 3.8σ (4.7σ w/o syst.) significance

$Br(B\to\tau\nu)=(1.65^{+0.38}_{-0.37}{}^{+0.35}_{-0.37})\times10^{-4}$

Previous Belle result with 449M events
$Br=1.79^{+0.56}_{-0.49}(stat)^{+0.46}_{-0.51}(syst)$

$f_B = 242^{+28}_{-27}\pm33$ MeV
taking $V_{ub} = (3.99^{+0.35}_{-0.30})\times10^{-5}$
(HFAG07)

Constraint on charged Higgs mass

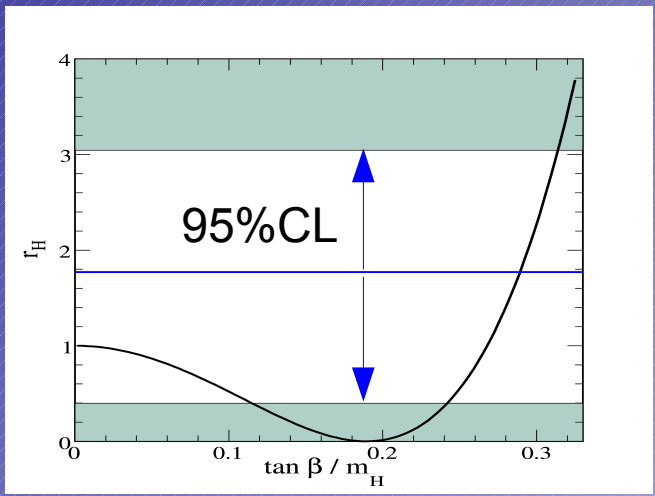
$$Br(B\to\tau\nu) = Br_{SM}(B\to\tau\nu)\times r_H$$

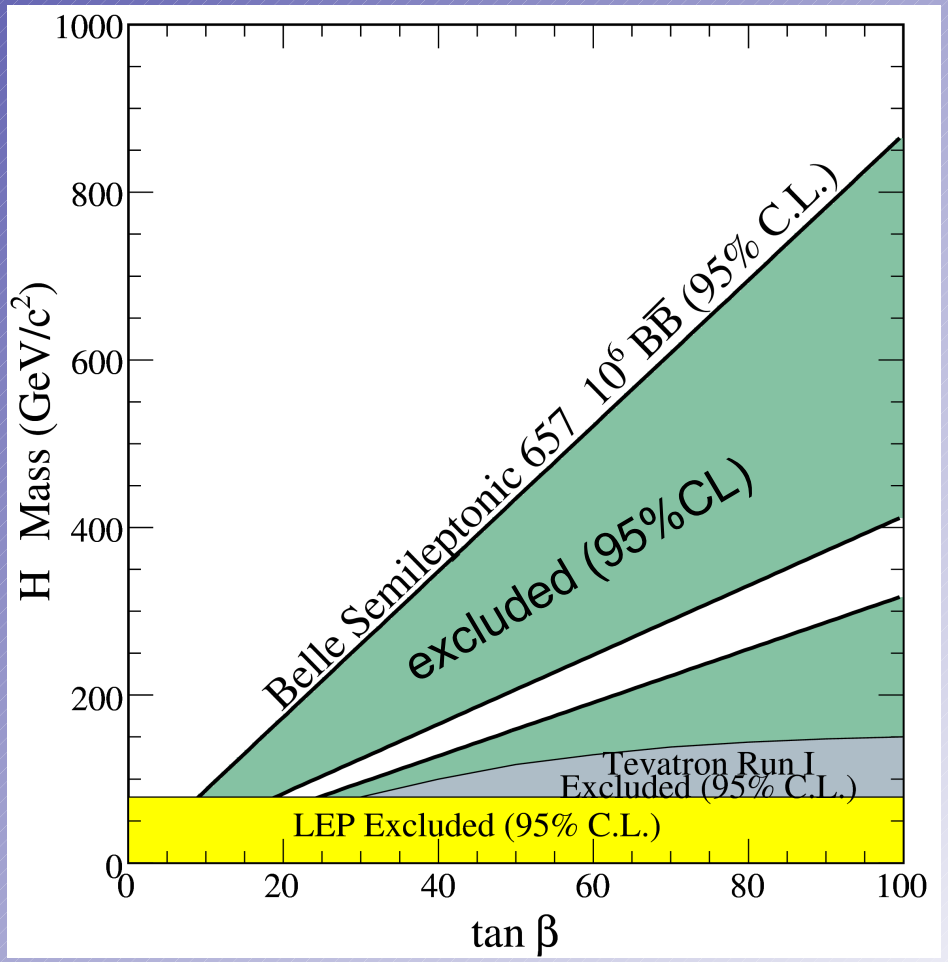
$$r_H = (1-\frac{m_B^2}{m_H^2}\tan^2\beta)^2$$

$$\mathcal{B}(B\to\tau\upsilon) = (1.65^{+0.38+0.35}_{-0.37-0.37})\times10^{-4}$$

$$\mathcal{B}(B\to\tau\upsilon)_{SM} = (0.93^{+0.12}_{-0.11})\times10^{-4}$$

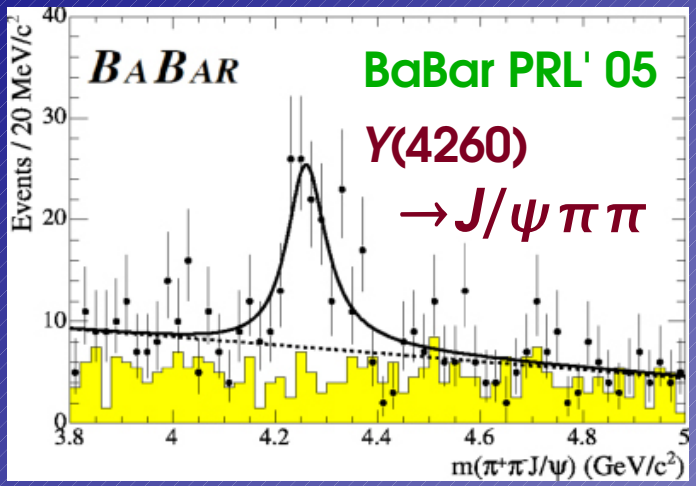
$r_H = 1.77 \pm 0.65$

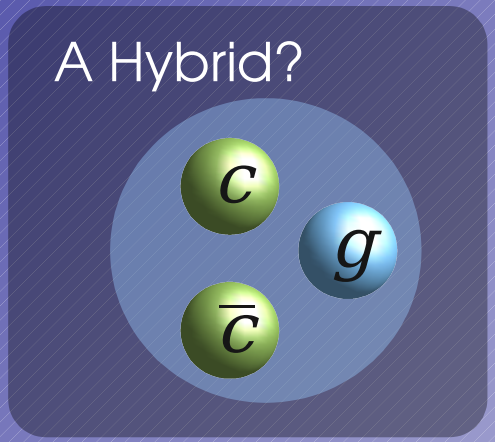




d) New resonance in $\Upsilon(nS)\pi^+\pi^-$ production

* BaBar observed $Y(4260)$ in $e^+e^- \to J/\psi\pi^+\pi^-\ \gamma_{ISR}$





The interpretation of $Y(4260)$ is controversial.
Hybrid? 4-quarks?
$D^{*}_{s}{}^{+}D^{*}_{s}{}^{-}$ molecule?
But it should contain two charms.

* Bottom counter-part of Y (= Y_b) may exist at the energy higher than $\Upsilon(4S)$. Can be searched for in $\Upsilon(5S)\to\Upsilon(nS)\pi^+\pi^-$

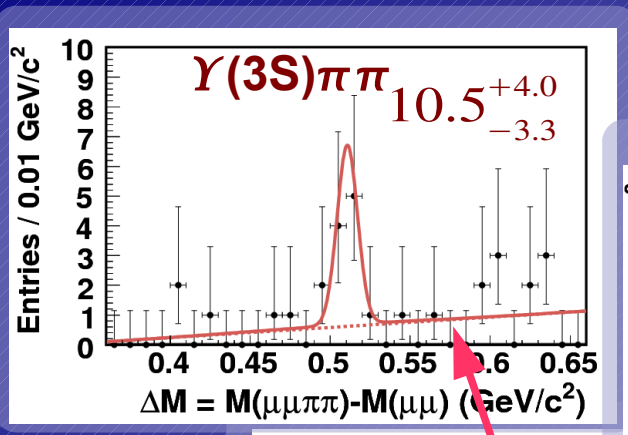
(ex. W.S.Hou, PRD 74 017504 (2006))

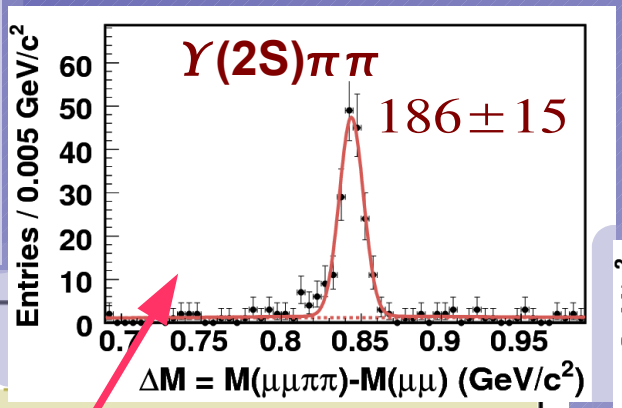
- PDG: $Br(\Upsilon(4S)\to\Upsilon(1S)\pi^+\pi^-)= 9.0 \times 10^{-5}$, $Br(\Upsilon(2S)\pi^+\pi^-)=8.8 \times 10^{-5}$
- Expectation at $\Upsilon(5S)$: Br ~ 2×10^{-5}

assuming $\Gamma[\Upsilon(4S)\to\Upsilon(1S)\pi\pi]\approx\Gamma[\Upsilon(5S)\to\Upsilon(1S)\pi\pi]$

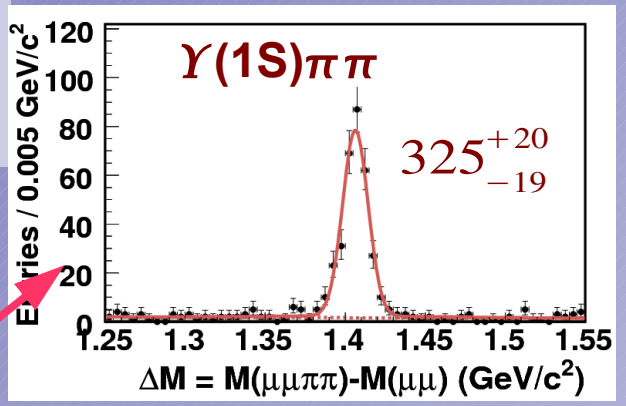
Belle acquired ~20.7/fb data on $\Upsilon(5S)$
- take a look at $\Upsilon(5S)\to\Upsilon(nS)\pi^+\pi^-$ decays in the data
- $\Upsilon(5S)\to\Upsilon(1s)\pi^+\pi^-$: expectation : ~3 events

What we observed: huge $\Upsilon(nS)\pi^+\pi^-$ signals at "$\Upsilon(5S)$" energy

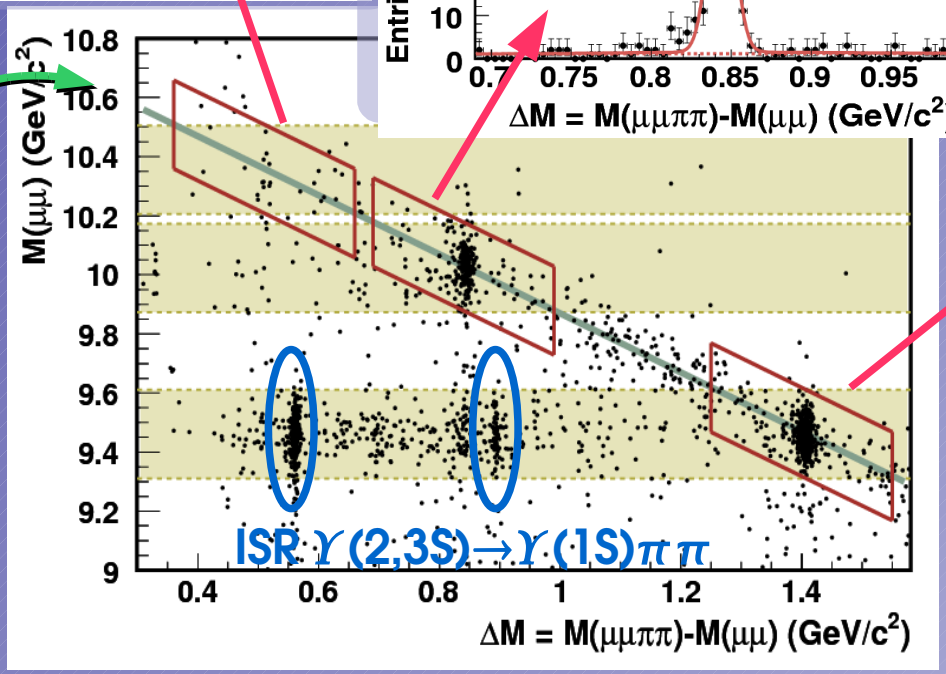




$M(\Upsilon(nS)\pi\pi)$ = Ecm ~ 10869 MeV.



Kinematic boundary for Ecm



Belle
2006 5S data
21.7/fb

Possibilities:
1. Anomalous $\Upsilon(5S)$ decay?
2. Y_b near $\Upsilon(5S)$ energy?

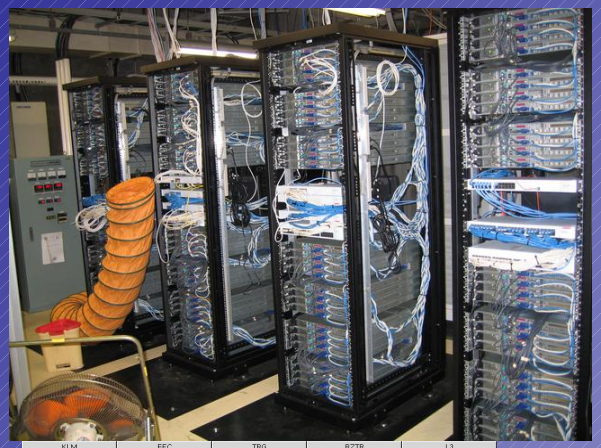
→ Energy scan around $\Upsilon(5S)$ peak

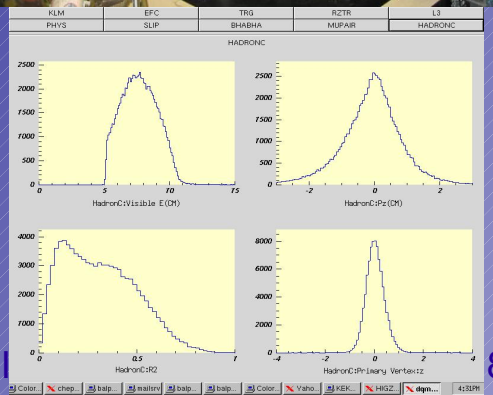
Experimental Technique 5: Interactive energy scan

- Need to minimize accelerator occupation
- However, the peak position of the resonance is unknown.

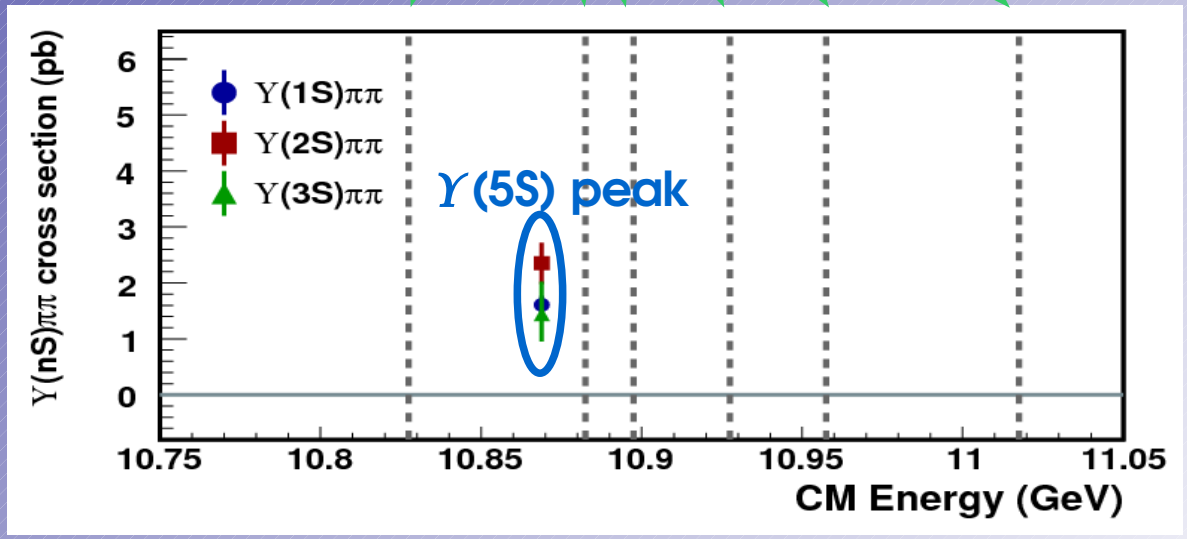
"On the fly" decision of next scanning energy by real time monitoring

* Belle DAQ system is equipped with "RFARM" = real time reconstruction farm where the full event reconstruction can be performed on-line for all taken events.
* The farm has the same software environment as that in off-line.
  → Offline analysis software was incorporated to RFARM and the resulting histograms (like M(μμππ)-M(μμ)) were monitored on the fly!



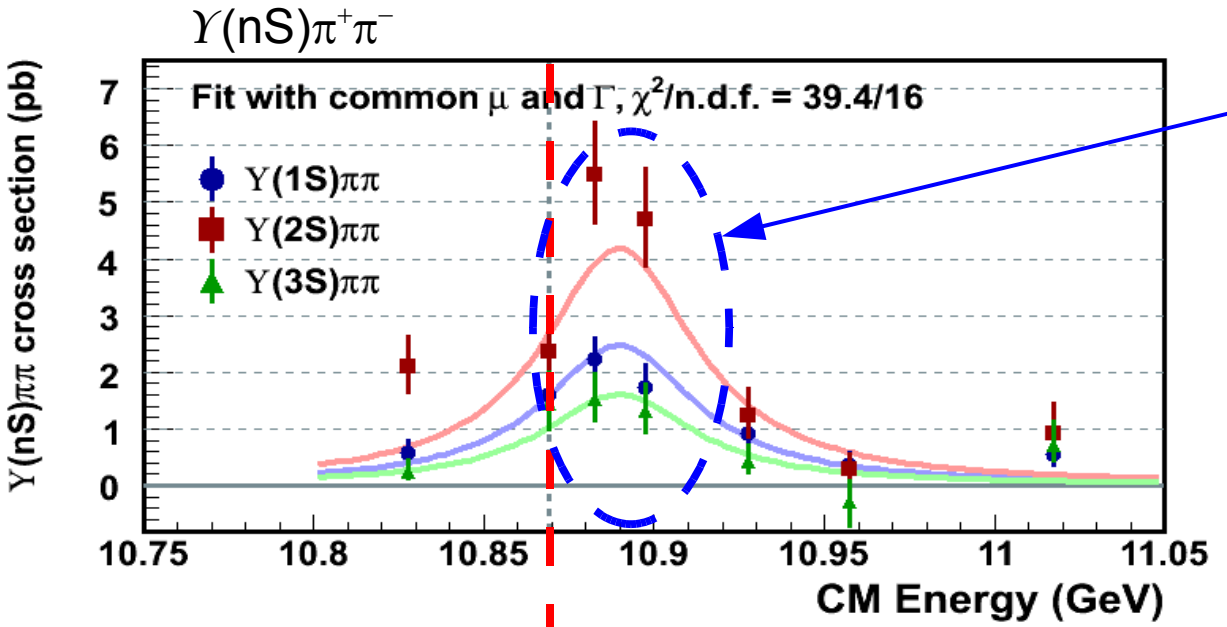


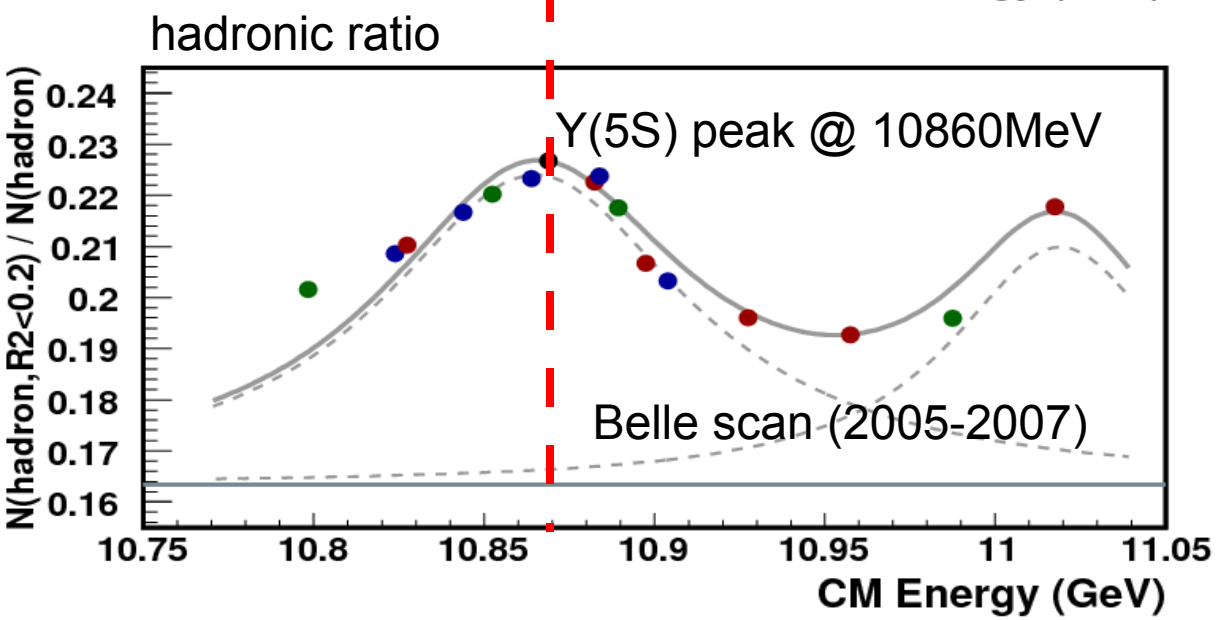
6 points with ~1/fb were taken!



Taken data : ~7.9/fb in total

Result of scan





Peak position is ~20MeV higher than $\Upsilon(5S)$!

* Width is narrower (half of $\Upsilon(5S)$)

Fit with BW functions (common peak/width and separate normalizations)

Peak : 10889.6 ± 1.8 ± 1.5 MeV
Width : $54.7\ ^{+9.5}_{-7.2} \pm 2.6$ MeV

What is the peak????

- Effect of FSI?
- Y_b ?

Need theoretical assessment!!

What I could not show today.....

- New measurements with $B \to X_s \gamma$, $\rho/\omega \gamma$ update

- New results on charmless decays (K^*K, f_L in ρ/ω K^* decays, $\rho^0\rho^0$)

- New measurements with $B \to K^*ll$ (A_{FB}, Isospin asym. ....)

- New ϕ_3 measurements by ADS and Dalitz methods

- New B_s results obtained by $\Upsilon(5S)$ run

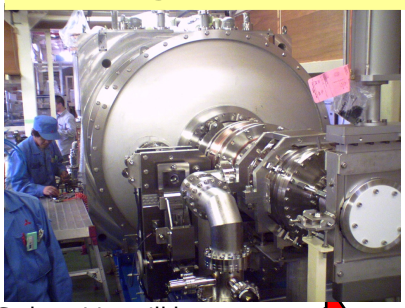
- New resonances (Z(4430), Z_1, Z_2....)

... and much more!

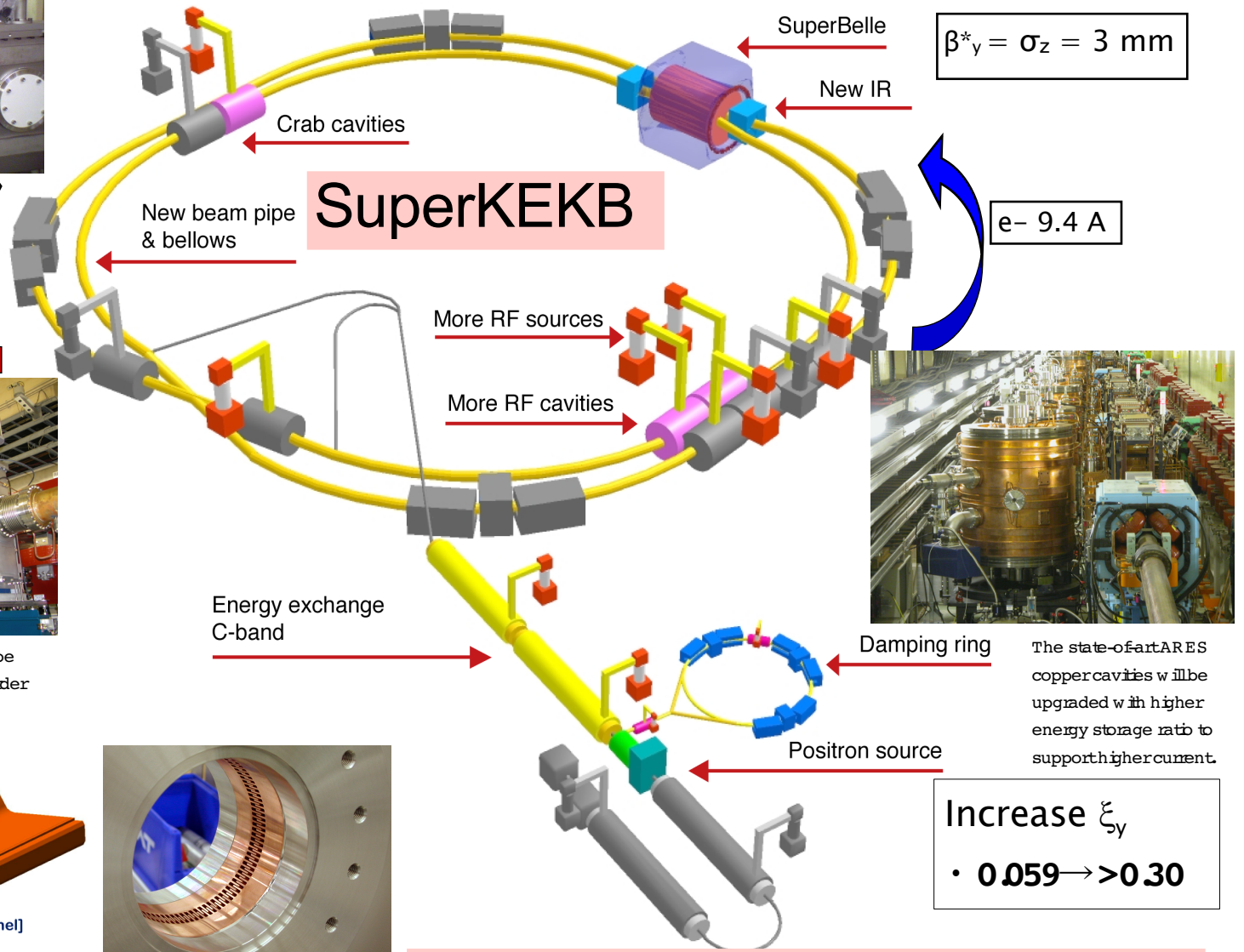
Please check at ICHEP08 conference site for details
http://ichep08.com

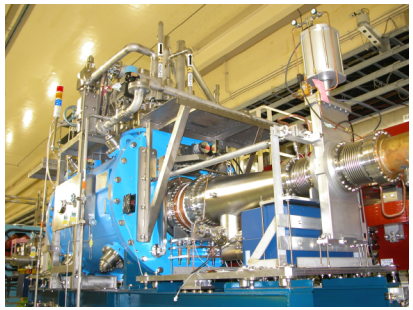
4. Beyond Belle: SuperKEKB

The upgrade of current KEKB accelerator to SuperKEKB is being planned for the further studies of *B* and other flavor physics.



Crab cavities will be installed and tested with beam in 2006.



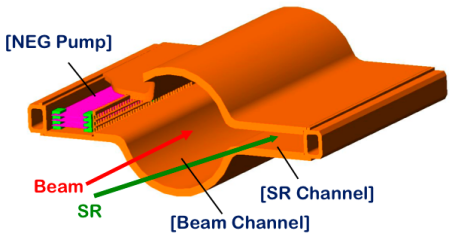


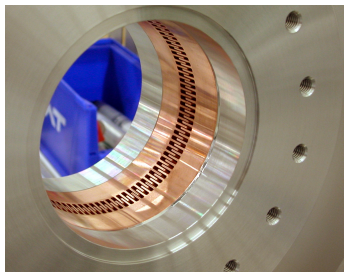
The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.

The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.

Increase ξ_y

- 0.059 → >0.30



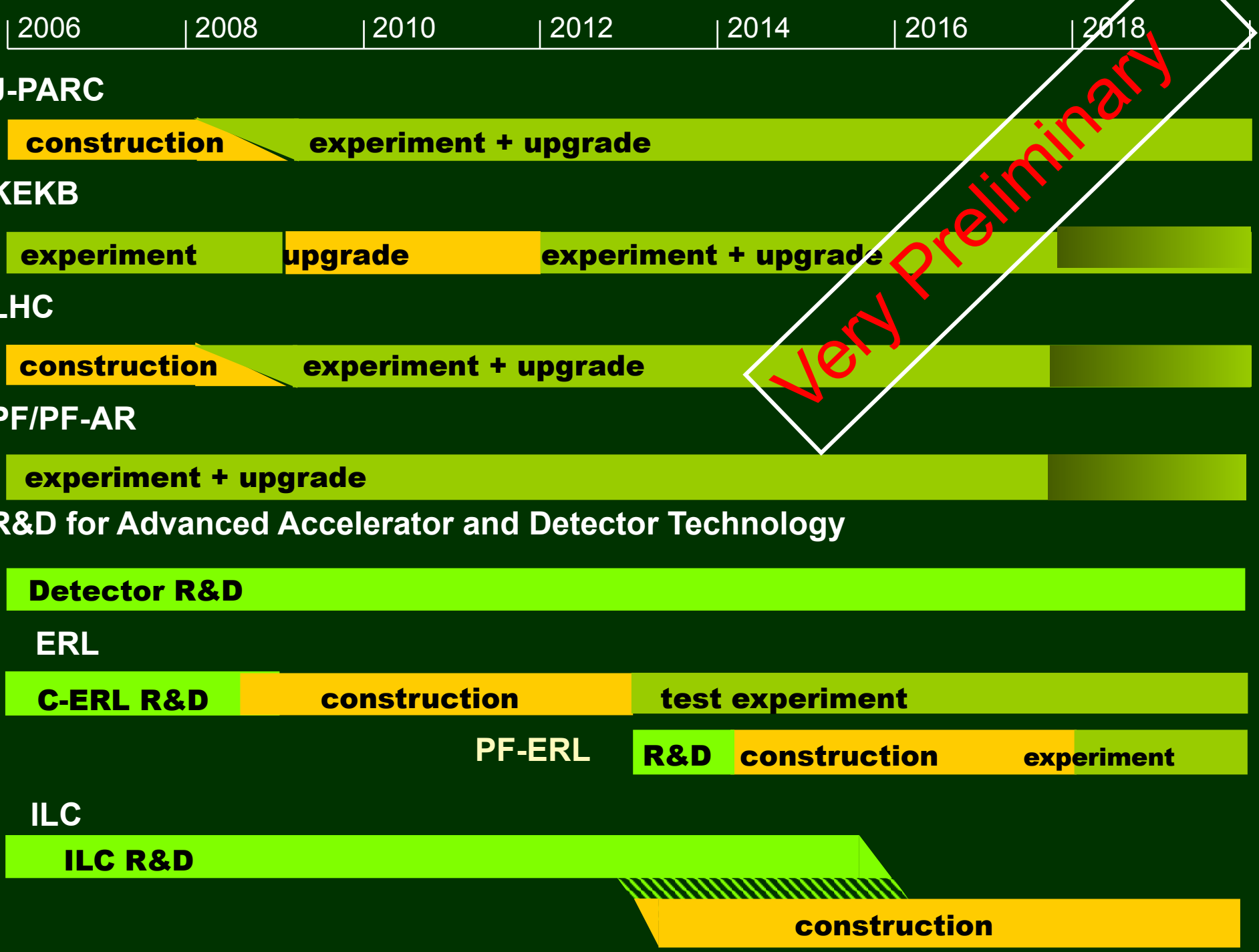


The beam pipes and all vacuum components will be replaced with higher-current-proof design.

will reach 8×10^{35} cm^{-2}s^{-1}.

A.Suzuki (KEK DG)

KEK Roadmap



A.Suzuki (KEK DG)

KEK Roadmap

2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018

Preliminary

- J-PARC
  - construction
  - experiment + upgrade
- KEKB
  - experiment
  - upgrade
  - experiment + upgrade
- LHC
  - co
- PF/
  - e
- R&D
  - D
  - E
  - C
  - ILC
  - ILC R&D
  - construction

- Two proto-collaboration meetings were held.
  - 1st : Mar. 19 and 20, 2008
  - 2nd : Jul. 3 and 4, 2008
- First SuperKEKB collaboration meeting
  - Dec. 10-12, 2008 at KEK
- Aiming at finalizing detector design in a year or so from now.

Key Physics at SuperKEKB

1. Hunt for New Physics
   - Study of CPV in $b \to s$ penguin : New CP phase from NP
   - Charged Higgs search in $B \to \tau\nu$, $B \to D^{(*)}\tau\nu$
   - NP search in radiative inclusive decays: $b \to s\gamma$, $d\gamma$, sll ....

2. High precision study of Standard Model
   - Ultra precise measurement of Unitarity Triangle:

     V_{ub}, V_{cb}, V_{td}/V_{ts}, ϕ_1, ϕ_2, ϕ_3 ....
   - Study of "loop vs. tree" in DCPV
   - Physics at Υ(nS)

3. Rich non-B physics
   - Charm physics : CPV in D^0-D^0 mixing
   - LFV search in τ decays
   - New exotic resonances: *X, Y, Z .....*

Advantage to LHC :
No energy limit by looking at virtual NP effect in loop

5. Summary

- KEKB/Belle has been successfully running from 1999 and has acquired the integrated luminosity of 850fb^{-1} by now.

- Four selected results from the latest analyses are reported:
  a) New measurements of CPV in $b \to s$ transition,
  b) $\Delta A_{CP}(K\pi)$ puzzle,
  c) $B \to \tau\nu$, and
  d) Anomalous peak in $\Upsilon(nS)\pi^+\pi^-$.

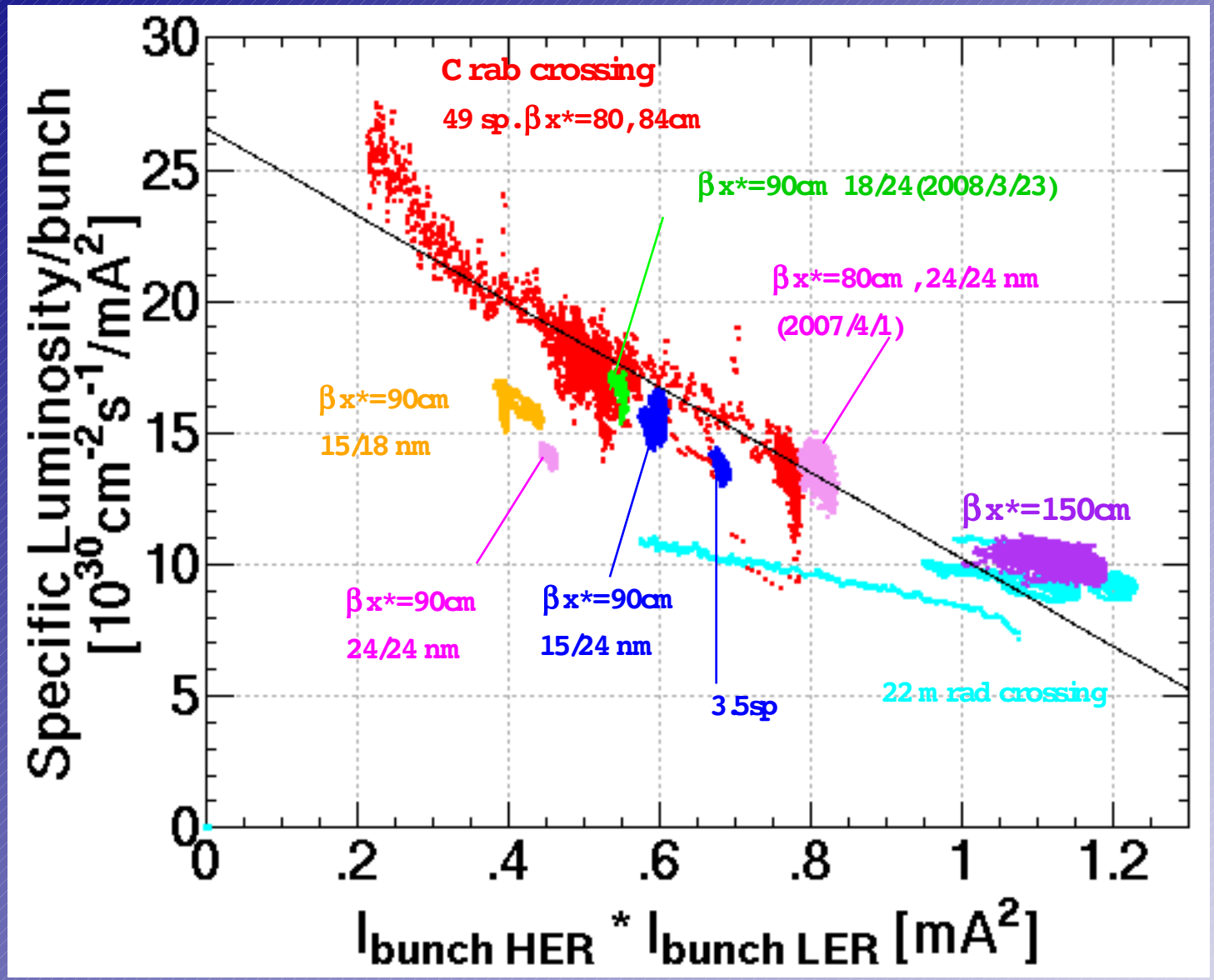
- Various experimental techniques used in the analyses are discussed.

- Still statistically limited to hunt for New Physics.

- We are starting the upgrade of KEKB/Belle to SuperKEKB to obtain O(100) higher statistics for the further studies.

Backup Slides

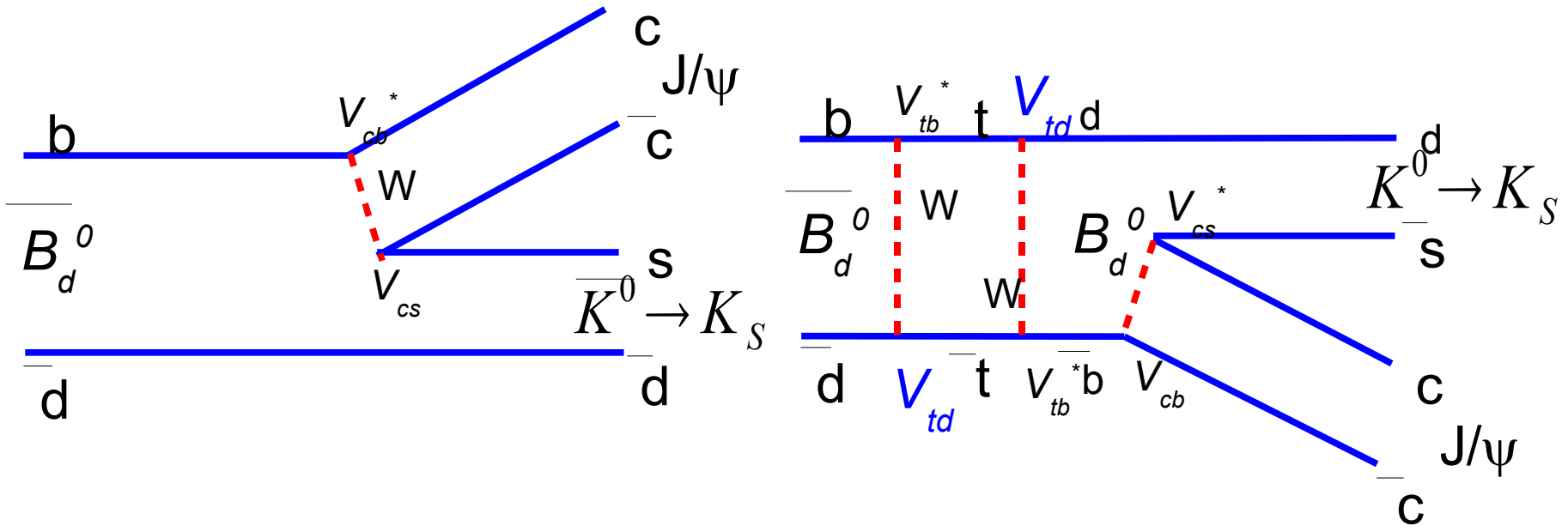
Specific Luminosity



"Indirect" CP violation in B meson decay

Sanda, Carter and Bigi

Golden Mode $B^0_d \to J/\psi\, K_S$



Phase difference between two diagrams:

$$\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \cdot \frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}^*} \cdot \frac{V_{cd}^* V_{cs}}{V_{cd} V_{cs}^*} = e^{-2i\phi_1}$$

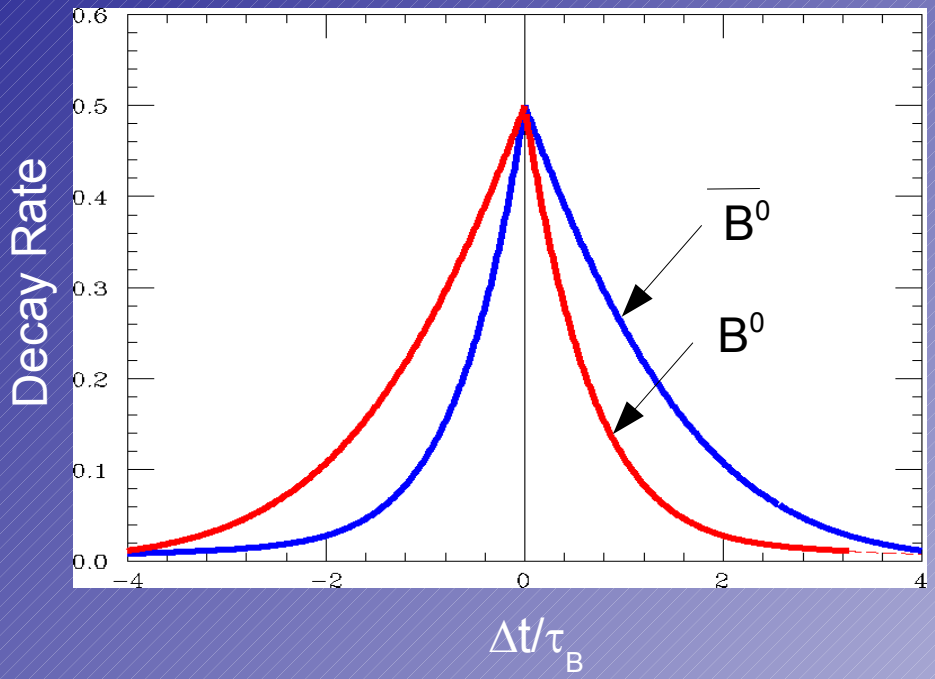
$2\phi_1$

CP Asymmetry

$$A(\Delta t)=\frac{[\Gamma(B^0_d\to J/\psi K_S)-\Gamma(\overline{B^0}_d\to J/\psi K_S)]}{[\Gamma(B^0_d\to J/\psi K_S)+\Gamma(\overline{B^0}_d\to J/\psi K_S)]}=\sin 2\phi_1 \sin \Delta m \Delta t$$

Δm : mass difference between 2 B^0 mass eigenstates (B_1 and B_2)

Δt = t (B_0 decay) - $\overline{t}$(B_0 decay)



Time integrated asymmetry becomes 0 at the $\Upsilon(4S)$!

need to know:
1. initial flavor of B
2. decay time

Direct CP violation

$$A(B \to f) = \sum_i A_i e^{i(\delta_i + \phi_i)}$$
$$\overline{A}(\overline{B} \to \overline{f}) = \sum_i A_i e^{i(\delta_i - \phi_i)}$$

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

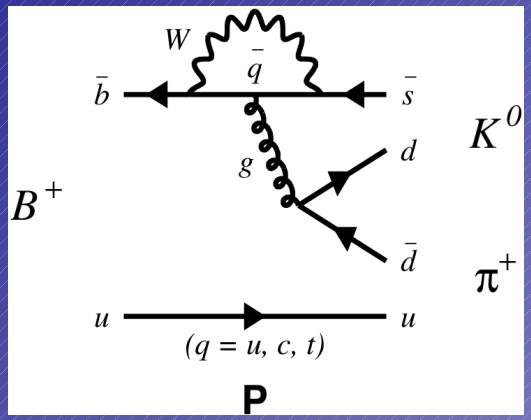
Non-zero A_{CP} :
- More than two amplitudes
- Non-zero strong phase
- Non-zero weak phase

Expectation from Isospin Sum Rule

M. Gronau, PLB 627, 82 (2005); D. Atwood & A. Soni, Phys. Rev. D 58, 036005(1998).

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

$B^+ \longrightarrow K^0\,\pi^+$



P dominants. $\Rightarrow A_{cp}(K^0\pi^+) \sim 0$

World Average

$A_{cp}(K^0\pi^+) = 0.009 \pm 0.025$

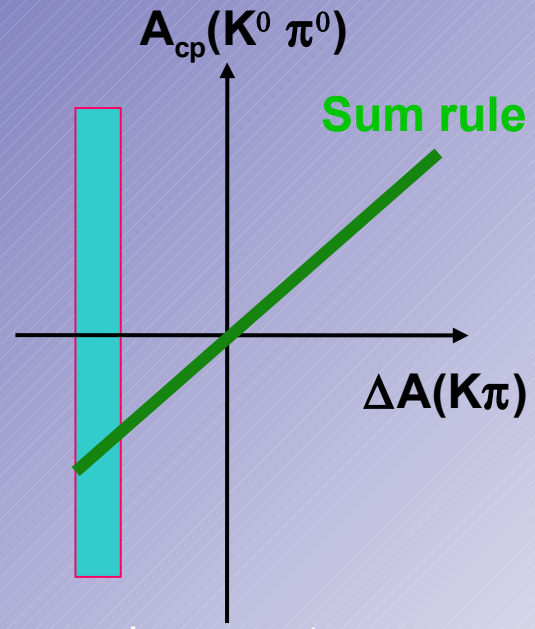
$B^0 \longrightarrow K^0\,\pi^0$

A = –0.24 ± 0.15 ± 0.03

New

A = +0.14 ± 0.13 ± 0.03

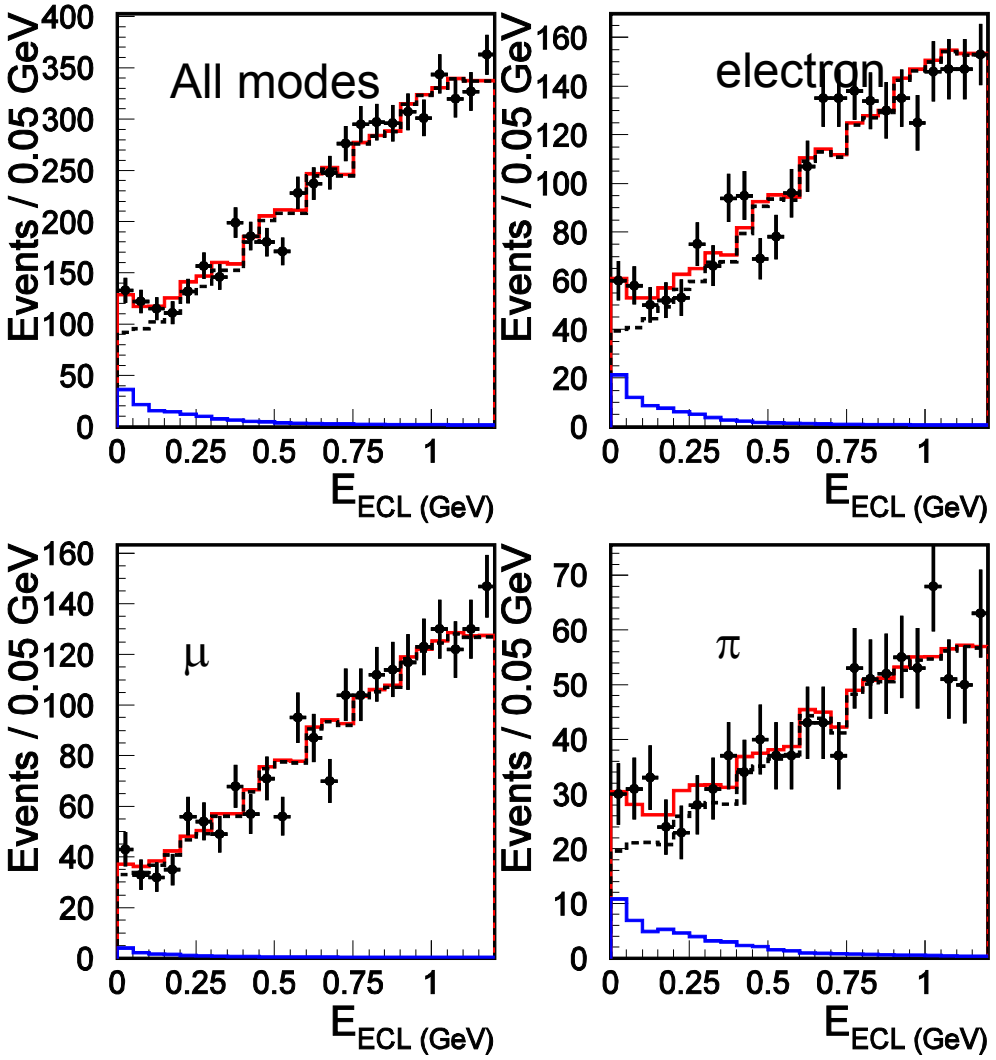
Important topic for Super B factory



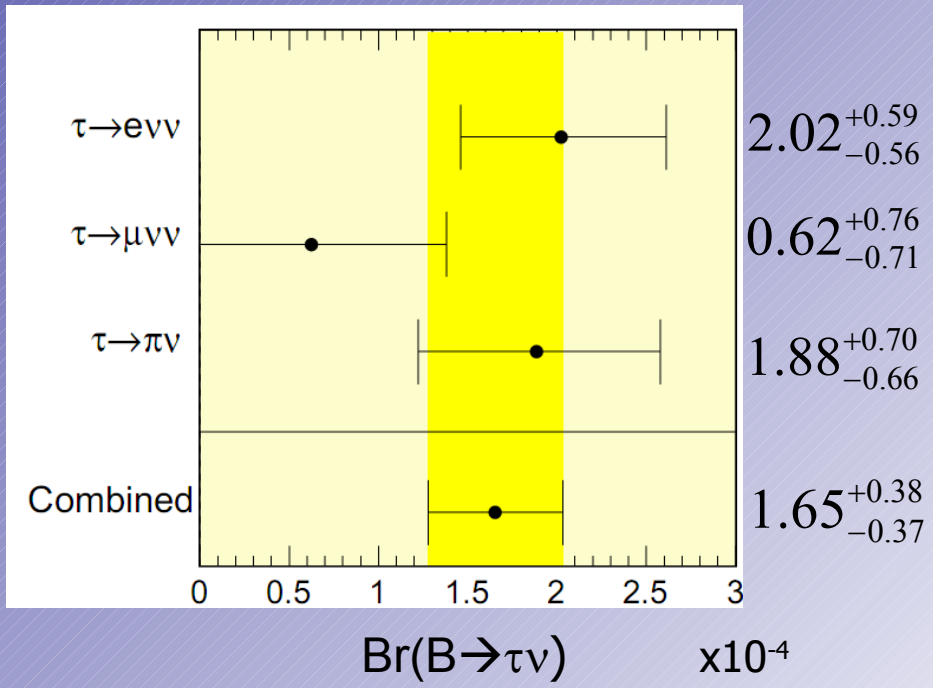
Sum rule expects

$A_{cp}(K^0\pi^0) = -0.151 \pm 0.043$

B→τν: Mode by mode results



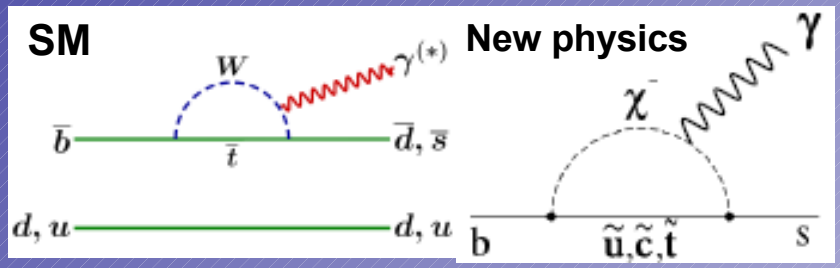
* All results are consistent.

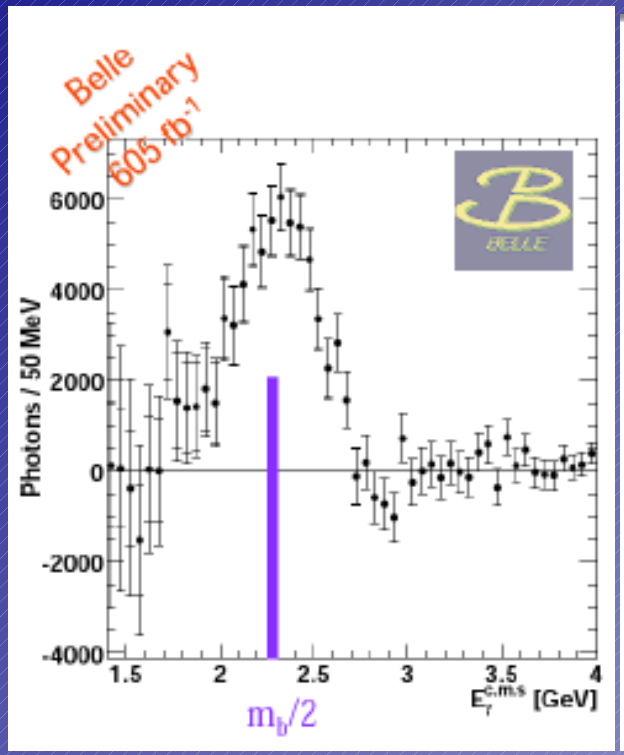


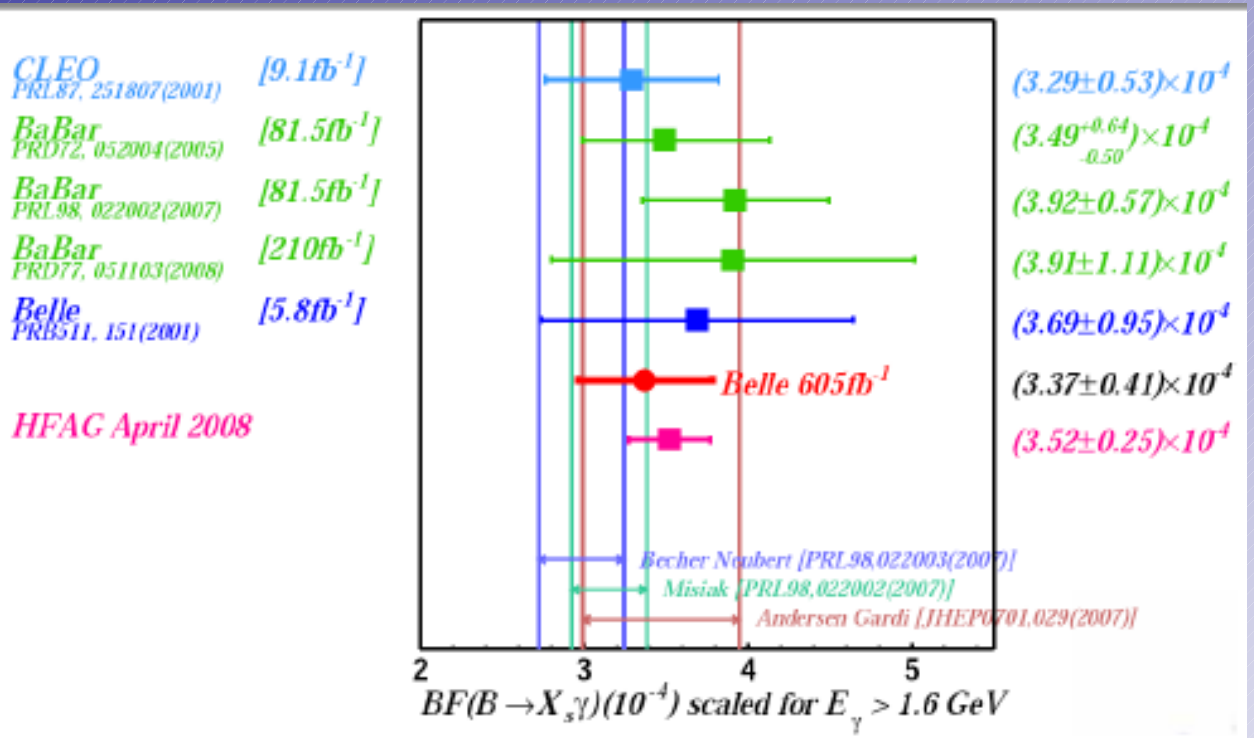
(statistical error only)

$B \to X_s \gamma$

Belle update with E_γ >1.7 GeV: arXiv:0804.1580







SM NNLO calculation:

$\mathcal{B}(B \to X_s\gamma)|_{E_\gamma > 1.6\ \mathrm{GeV}} =$

- (3.15±0.23)x10^{-4} Misiak et al.
- (2.98±0.26)x10^{-4} Becher Neubert
- (3.47±0.49)x10^{-4} Anderson Gardi

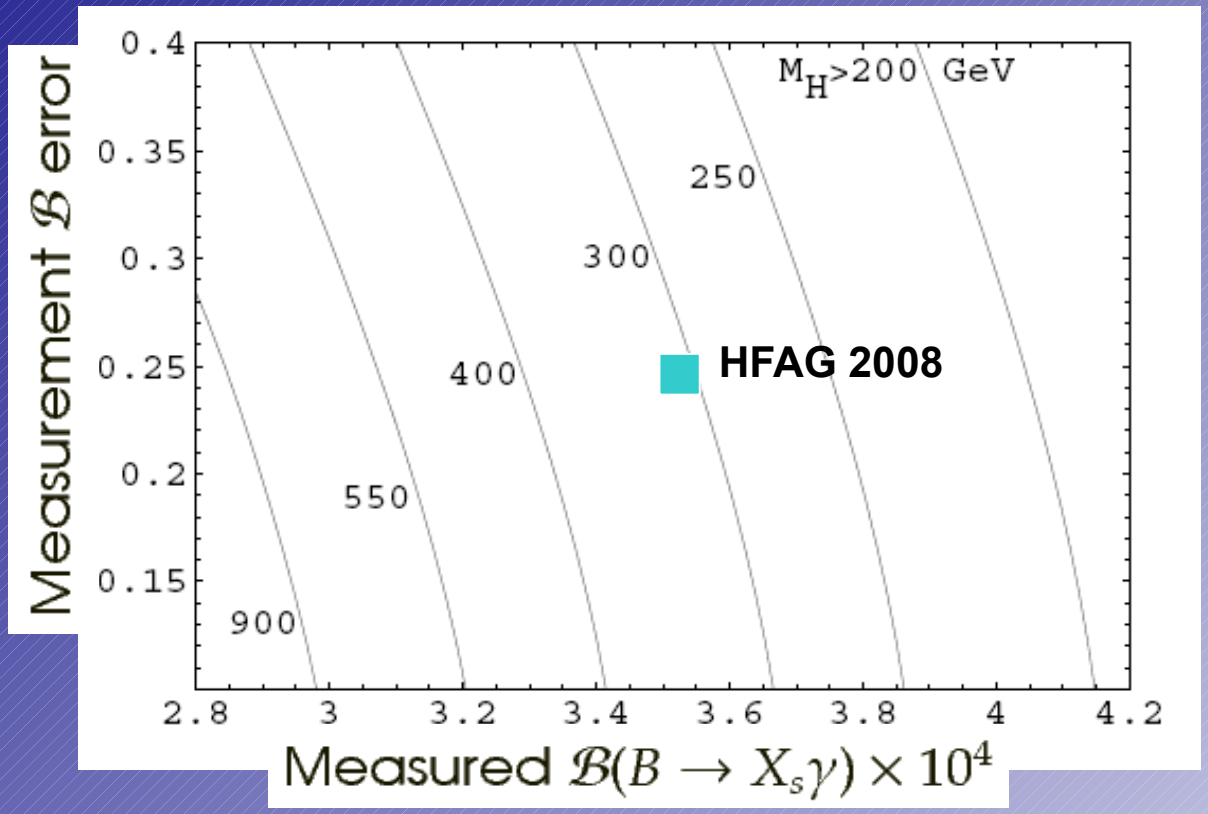
HFAG 2008:

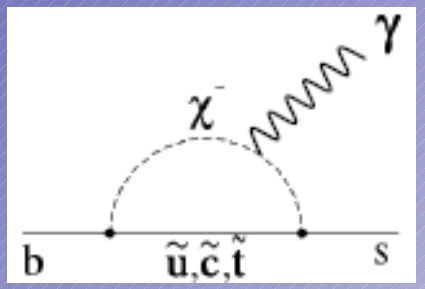
$\mathcal{B}(B \to X_s\gamma)|_{E_\gamma > 1.6\ \mathrm{GeV}} = (3.52 \pm 0.25) \times 10^{-4}$

Large theoretical improvement not for seen in the future.

$B \to X_s \gamma$ constraint to charged Higgs mass

The 95% lower bound of charged Higgs mass as a function of $\mathcal{B}(B \to X_s \gamma)$ and its error.





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

- **Lower limit on type II charged Higgs mass for any tanβ.**
- **M_{H^+} > 300 GeV/c2 @ 95% C.L.**

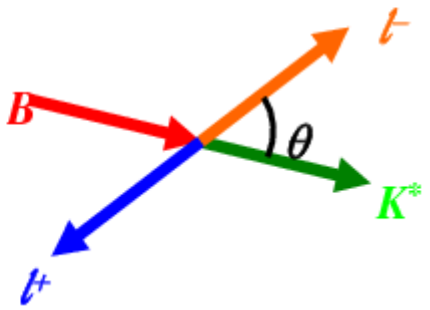
$A_{FB}(B \to K^* ll)$

$$\frac{d}{d\hat{s}}(\Gamma_F^{K^*} - \Gamma_B^{K^*}) = -\frac{G_F^2 \alpha^2 m_B^5}{2^8 \pi^5} |V_{ts}^* V_{tb}|^2 \, \hat{su}(\hat{s})^2 \times \left[\mathrm{Re}(C_9^{eff}) C_{10} V A_1 + \frac{\hat{m}_b}{\hat{s}} C_7^{eff} C_{10} (V T_2 (1 - \hat{m}_{K^*}) + A_1 T_1 (1 + \hat{m}_{K^*})) \right].$$

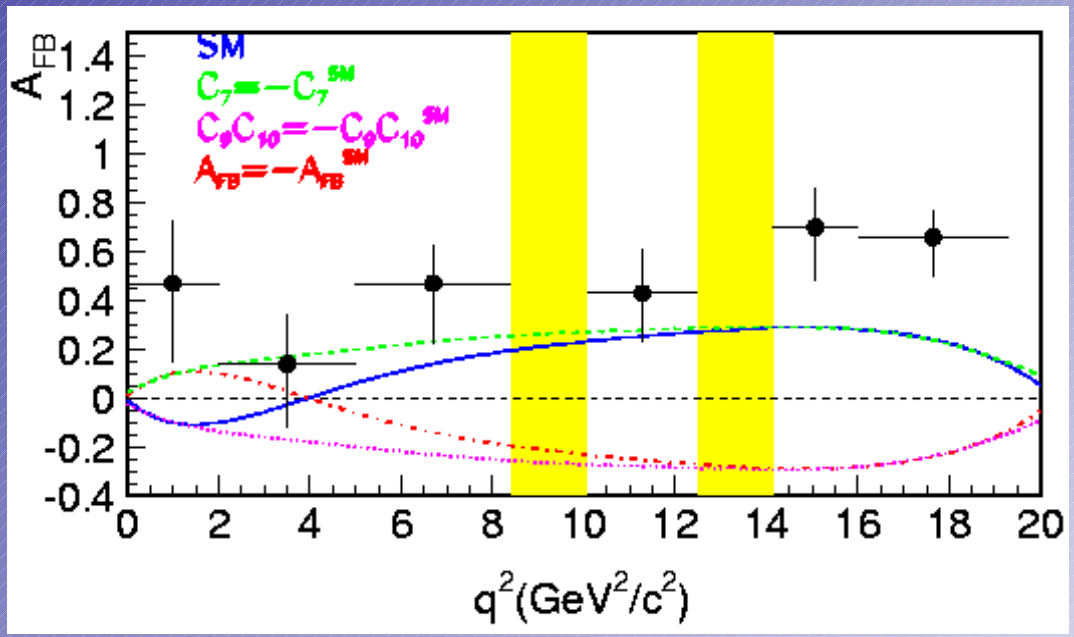
Definition of A_{FB}

$$A_{FB}(q^2) = \frac{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) - \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}{\Gamma(q^2, \cos\theta_{B\ell^-} > 0) + \Gamma(q^2, \cos\theta_{B\ell^-} < 0)}$$

θ_{Bl^-} : angle btw B and l^- in the dilepton rest frame



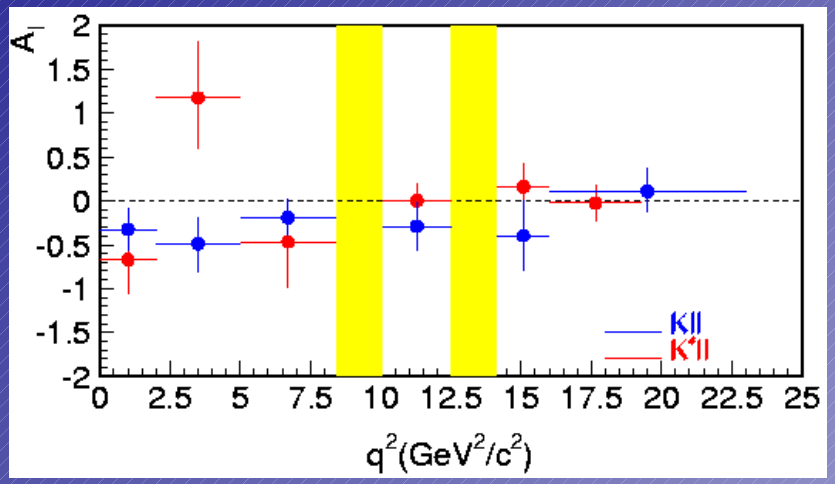
* Sensitive to NP thru. determination of Wilson Coeff (C_7,C_9 and C_{10})

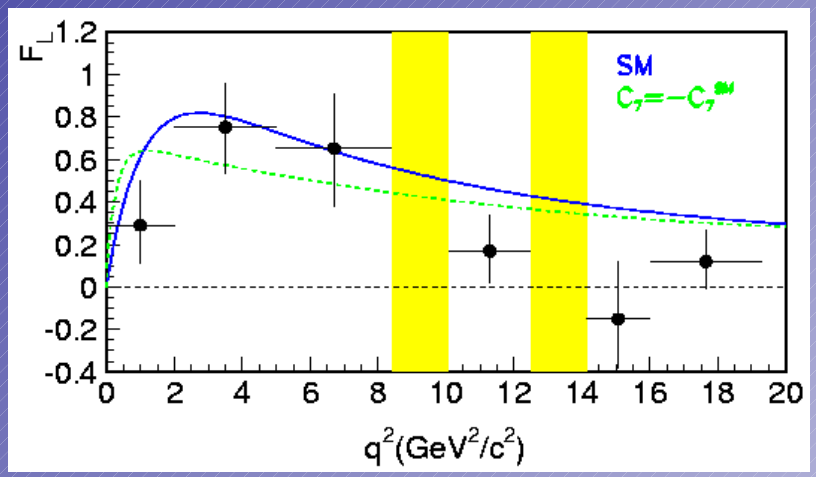


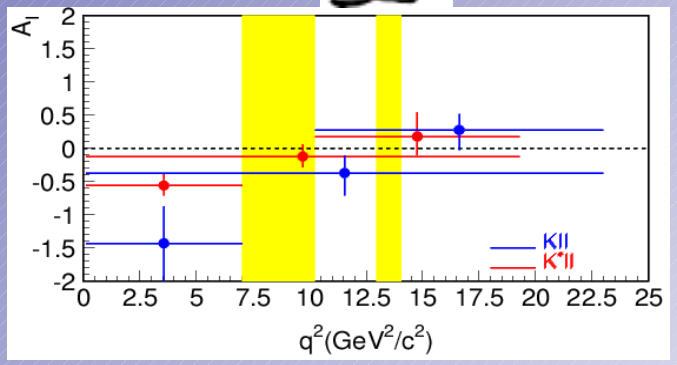
657 M $B\bar{B}$

Isospin and K* Helicity on B→ K(*) ll

$$A = \frac{1.071 \times BF(B^0 \to K^{(*)0} ll) - BF(B^\pm \to K^{(*)\pm} ll)}{1.071 \times BF(B^0 \to K^{(*)0} ll) + BF(B^\pm \to K^{(*)\pm} ll)}$$

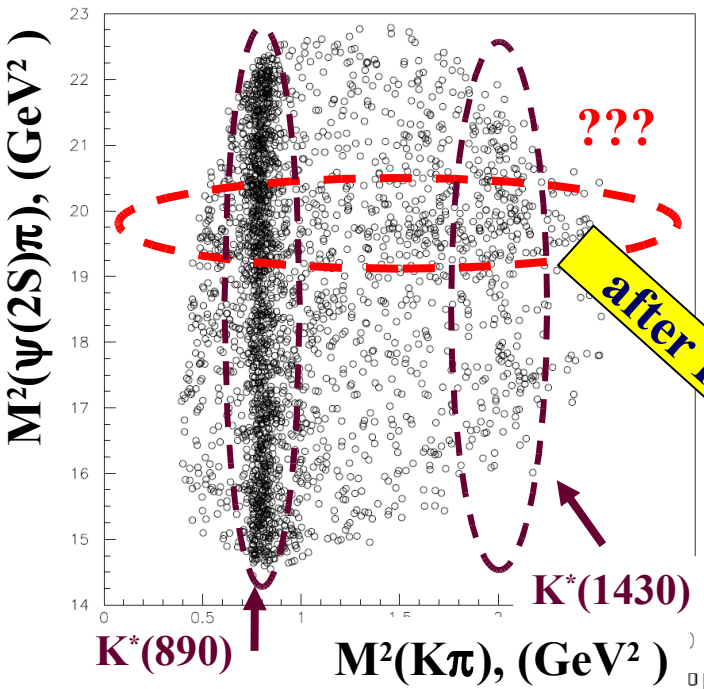






$Z(4430)^+$ first charged charmonium like state

Dalitz Plot, selected events



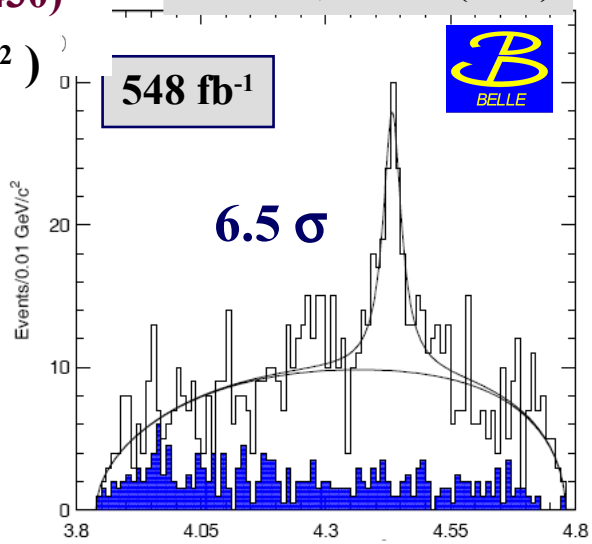
No chance to be conventional charmonium or hybrid

$B \to KZ,\ Z(4430)^+ \to \pi^+\psi(2S)$

$K=K^-,K^0_s$; $\psi(2S) \to \ell^+\ell^-, \pi^+\pi^- J/\psi$

- **Too narrow to be reflection or interferation between Kπ partial waves**

PRL 100, 142001 (2008)



Fit: S-wave BW + phase space like func

$M = (4433 \pm 4 \pm 2)$ MeV

$\Gamma = (45^{+18}_{-13}{}^{+30}_{-13})$ MeV

$BF_\pm/BF_0 = 1.0 \pm 0.4$

Poor statistics to determine J^P

$BF(B \to KZ) \times BF(Z \to \psi(2S)\pi) = (4.1 \pm 1.0 \pm 1.3)\ 10^{-5}$

Interpretations:

S –wave D^*D_1 threshold effect

J.L.Rosner ; D.V.Bugg

D^*D_1 molecular state

Meng C. et al; X.Lui et al.; Lee S.H. et al

radially excited tetraquark

L.Maiani, A.D.Polosa, V.Riquer

baryonium state

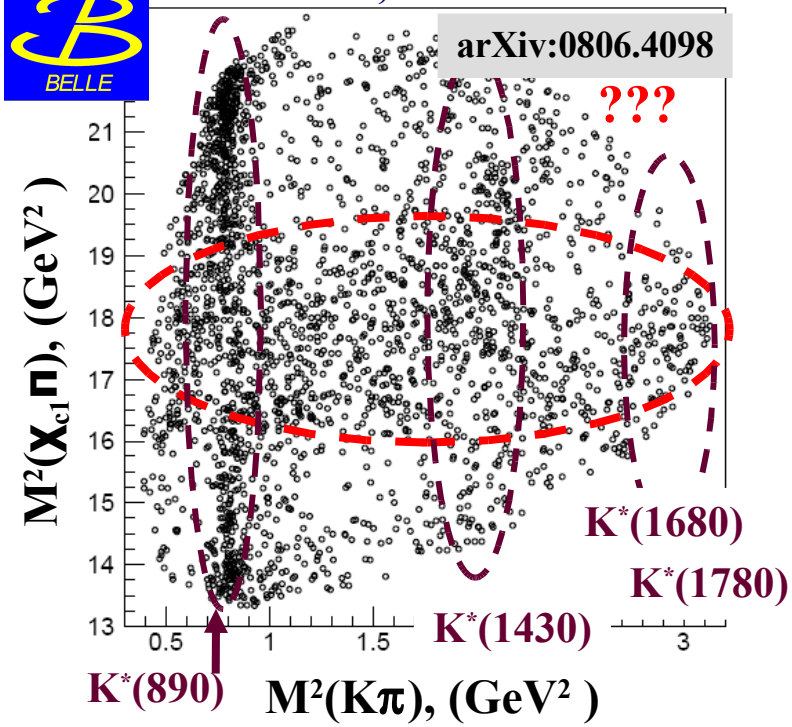
C.F.Qiao

hadro-charmonium

S.Dubinskiy,M.B.Voloshin

$Z^+_{1,2} \to \chi_{c1}\pi^+$

Dalitz Plot, selected events

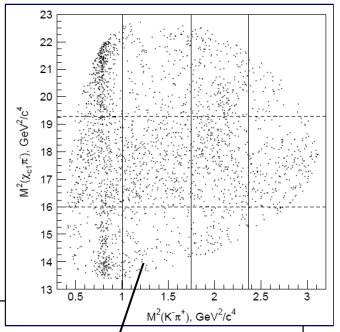


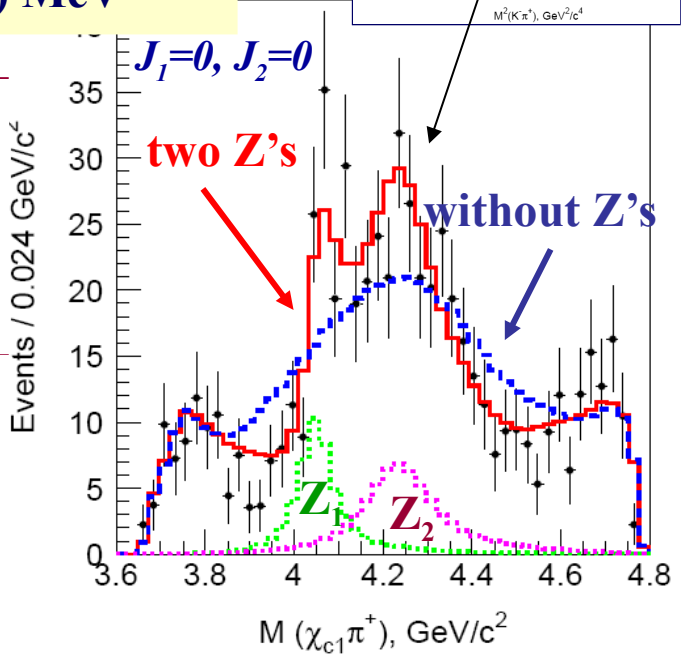
$B^0 \to \chi_{c1}\pi^+K^-$; $\chi_{c1} \to J/\psi\gamma$

Dalitz analysis : fit $B^0 \to \chi_{c1}\pi^+K^-$ amplitude by coherent sum of RBW contributions

- known $K\pi$ resonances
- K^*'s + one $(\chi_{c1}\pi)$ resonance
- K^*'s + two $(\chi_{c1}\pi)$ resonances

$M_1=(4051\pm14^{+20}_{-41})$ MeV/c²
$\Gamma_1=(82^{+21}_{-17}{}^{+47}_{-22})$ MeV
$M_2=(4248^{+44}_{-29}{}^{+180}_{-35})$ MeV/c²
$\Gamma_1=(177^{+54}_{-39}{}^{+316}_{-61})$ MeV





- Hypothesis of two Z's resonances is favored over one Z resonance at 4.9σ
- Spin of $Z_{1,2}$ is not determined: J=0 and J=1 result in comparable fit qualities

$$\mathcal{B}(\overline{B}^0 \to K^- Z_1^+) \times \mathcal{B}(Z_1^+ \to \pi^+ \chi_{c1}) = (3.1^{+1.5+3.7}_{-0.9-1.7}) \times 10^{-5},$$

$$\mathcal{B}(\overline{B}^0 \to K^- Z_2^+) \times \mathcal{B}(Z_2^+ \to \pi^+ \chi_{c1}) = (4.0^{+2.3+19.7}_{-0.9-\ 0.5}) \times 10^{-5}.$$

No chance to be conventional charmonium or hybrid

Comparison of Machine Parameters

symbol	SuperB		SuperKEKB		unit
E	4.0	7.0	3.5	8.0	GeV
C	1.8		3.02		km
I	1.85	1.85	9.4	4.1	A
n_b	1251		5018		
N/bunch	5.5		11.8	5.1	$x10^{10}$
ε_x	2.8	1.6	12		nm
$\varepsilon_y/\varepsilon_x$	0.4		0.5		%
β_x^*	35	20	200		mm
β_y^*	0.22	0.39	3		mm
σ_z	5		3		mm
θ_x^*	48		30 to 0		mrad
ξ_x	0.0043	0.0025	0.27		
ξ_y	0.15		0.30		
RF Power	17		64		MW
L	10 (Weak-Strong)		5.5[*1] (Strong-Strong[*2])		$x10^{35}cm^{-2}s^{-1}$

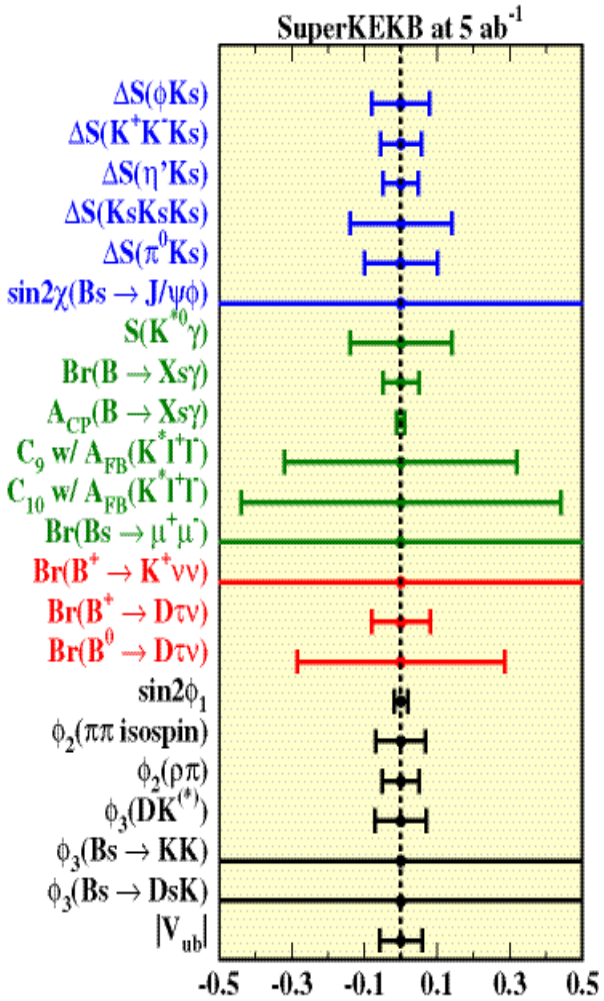
[*1] ν_x=.505 and 10 MW AC power reduction. Final goal is still $8x10^{35}$. [*2] more reliable than W-S.

50

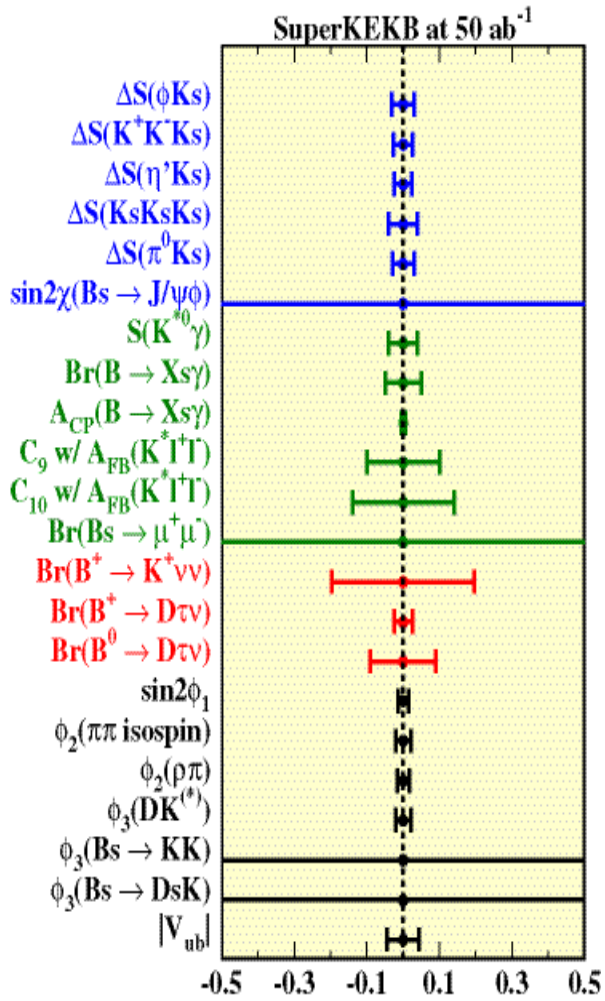
Physics Reach at SuperKEKB

		SuperKEKB (5 ab^{-1})	(50 ab^{-1})
CPV (b→s)		0.079	0.031
		0.056	0.026
		0.049	0.024
		0.14	0.04
		0.10	0.03
		×	×
FCNC		0.14	0.04
		5%	5%
		0.011	5×10^{-3}
		32%	10%
		44%	14%
		×	×
w/ ν			5.1σ
		8%	2.5%
		3.5σ	9%
CKM		0.019	0.014
		3.9°	1.2°
		2.9°	0.9°
		4°	1.2°
		×	×
		×	×
		5.8%	4.4%

5ab^{-1}



50ab^{-1}



Physics at Super B Factory (hep-ex/0406071)