Recent Update in Belle

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KEK

KEKB Review

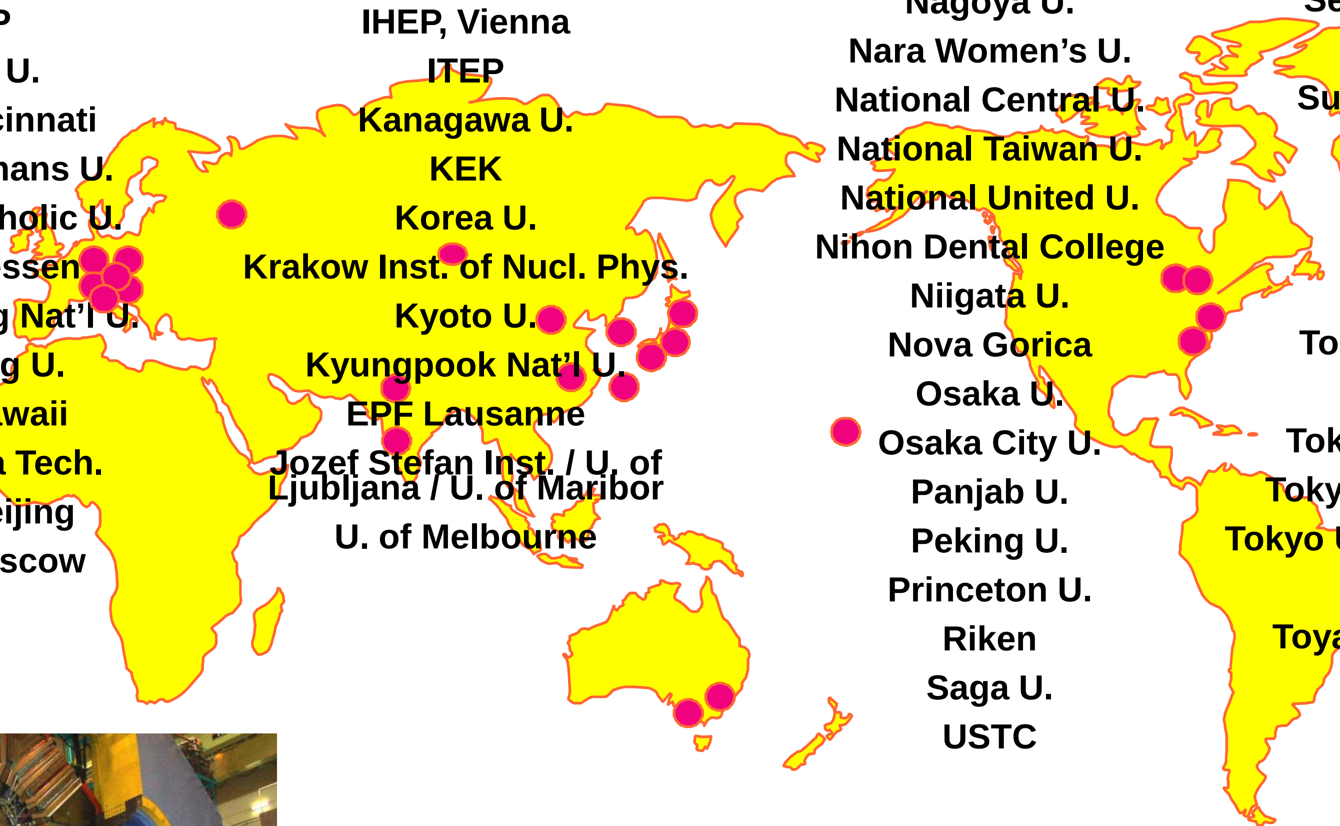
Dec. 3, 2007

Contents

- Introduction
- $B^0 \to D^{*-}\tau^+\nu$ (another missing energy decays)
- Discovery of more New Particles.
- Results from $\Upsilon(5S)$ data.
- D^0-$\overline{D}^0$ mixing
- Summary

There are many other new results in mixing induced CP violations, rare decays, charm and τ physics …, which cannot be covered in this talk.

Belle Collaboration



BINP
Chiba U.
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Ewha Womans U.
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Gyeongsang Nat'l U.
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U. of Sydney
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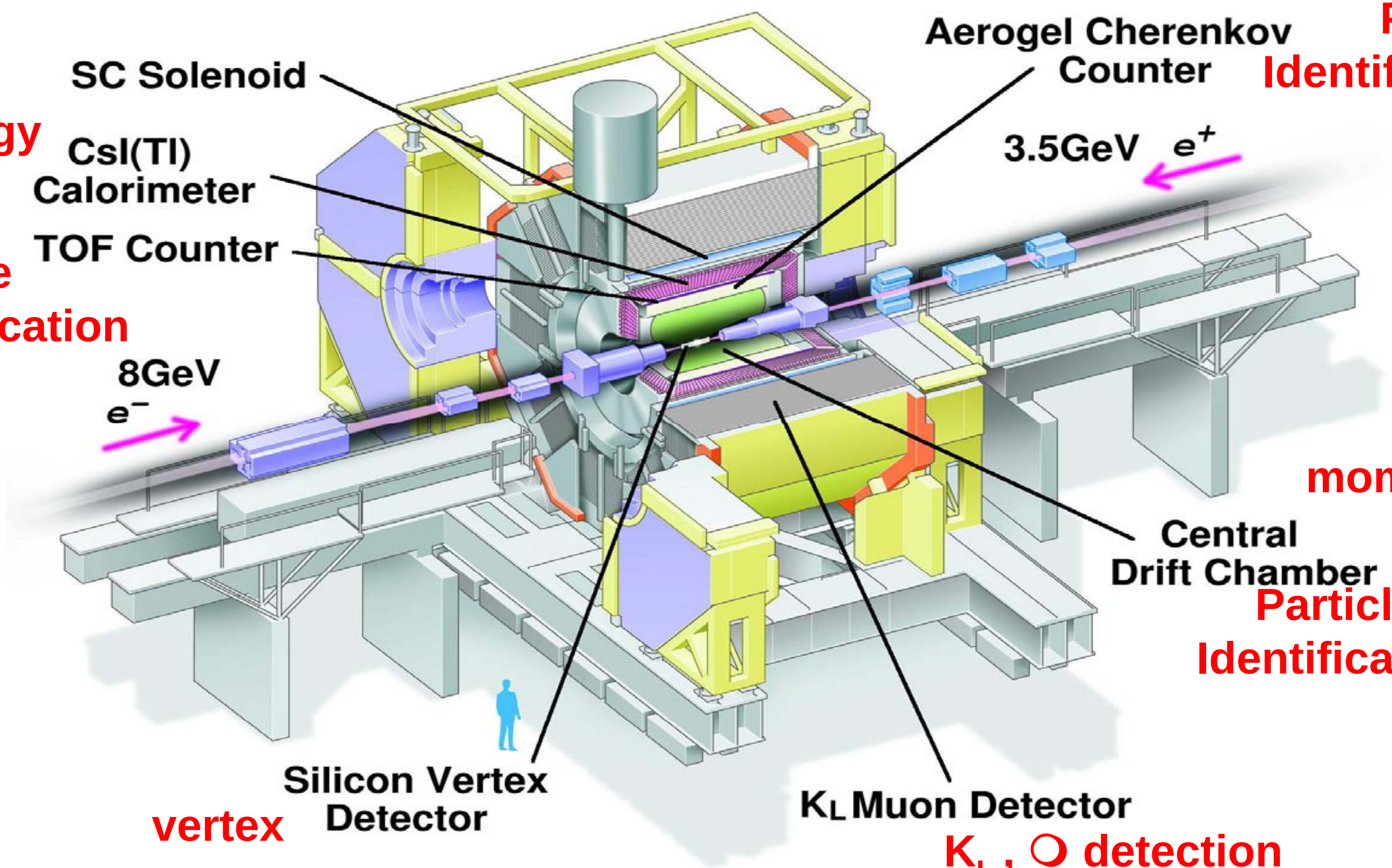
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries, 55 institutes, ~400 collaborators

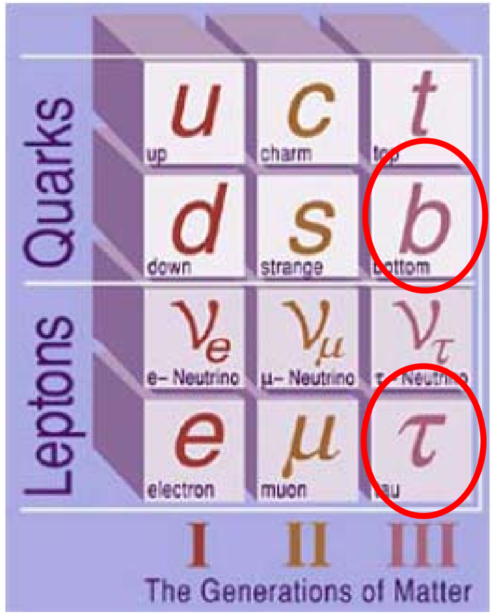
Belle Detector



General purpose detectors for various B, charm, τ physics.

$B^0 \to D^{*-}\tau^+\nu$

Decay of B meson to τ lepton.



- Interaction of quark and lepton in 3rd generation
  - ✓ Test of the Standard Model.
  - ✓ Sensitive to the New Physics.
- Last year, Belle founds the evidence of $B^- \to \tau^-\nu$ decays.

However, this kind of measurement is experimentally very challenging

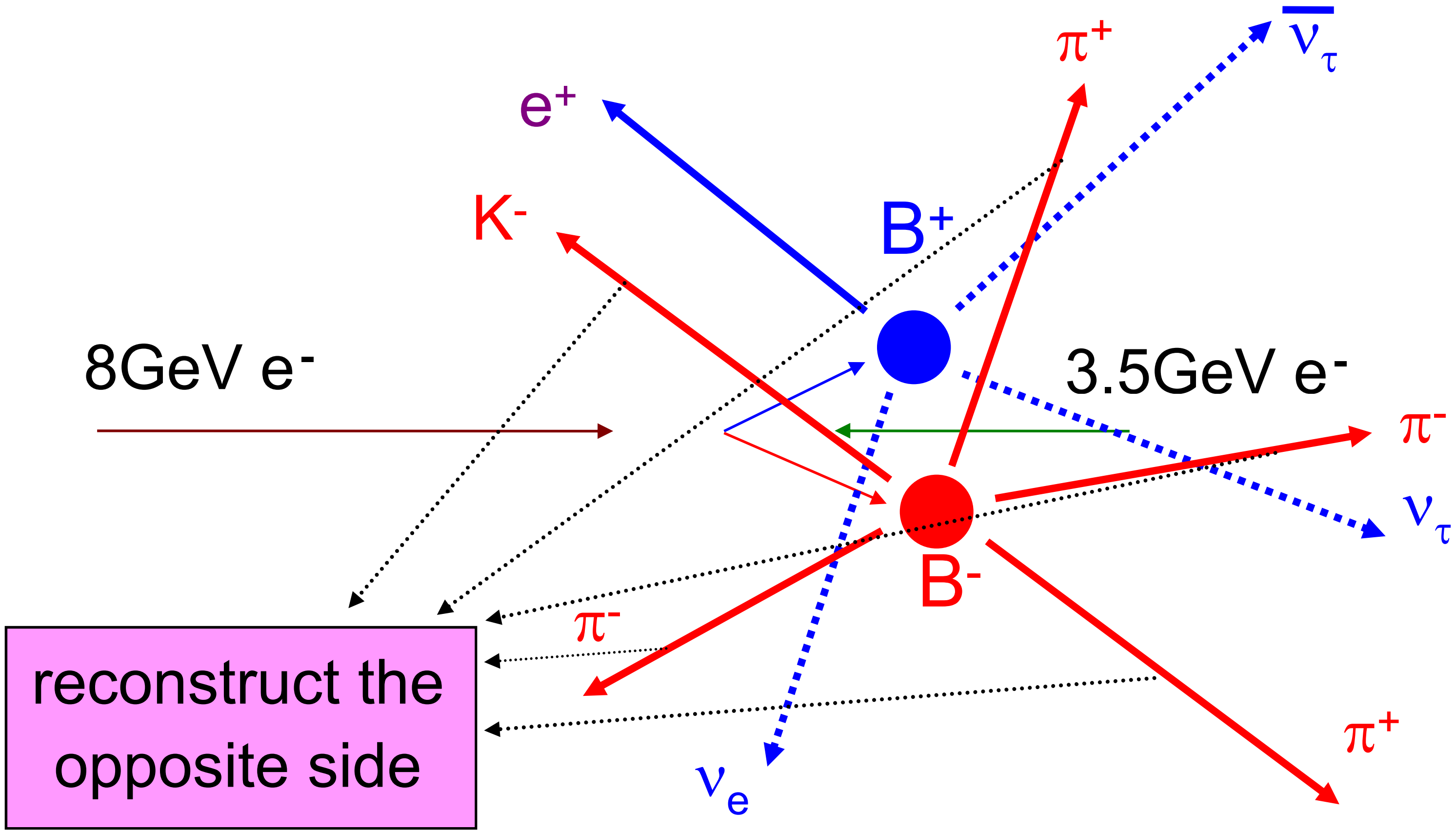
$$B^+ \to \tau^+\nu_\tau$$
$$\tau^+ \to e^+\nu_e\overline{\nu}_\tau$$
$$\to \pi^+\overline{\nu}_\tau$$

Always more than 1 neutrinos in the final state

$B^0 \to D^{*-}\tau^+\nu$

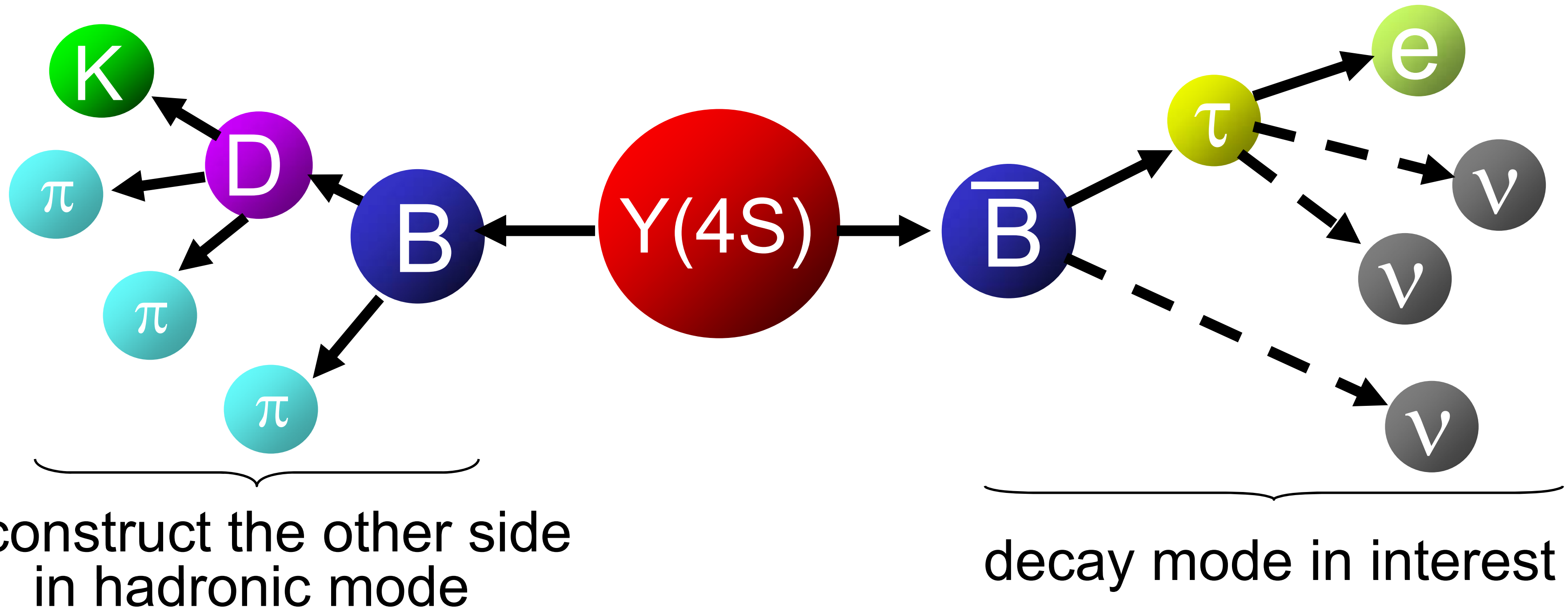
Full reconstruction technique

(the example below is based on $B \to \tau\nu$)



In usual analyses, we only look at the signal side. However, in the mode with >1 neutrinos, we also reconstruct the opposite site B.

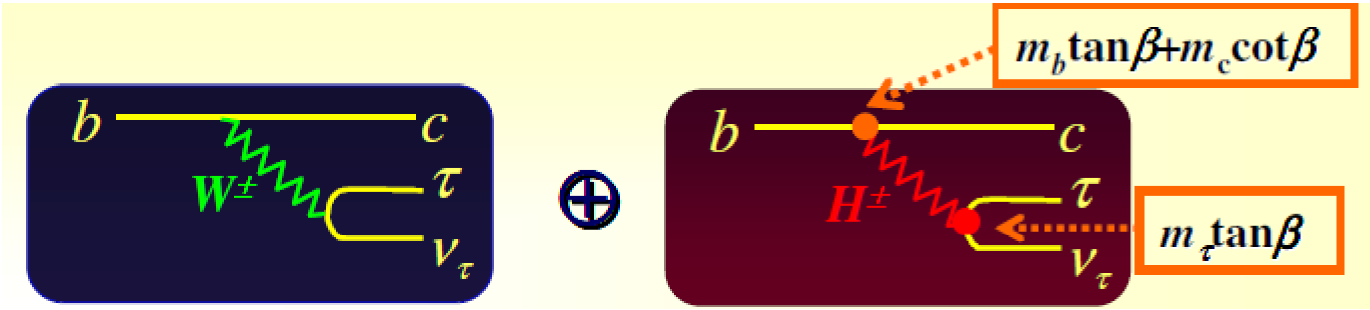
$B^0 \to D^{*-}\tau^+\nu$



- This method is possible only in B factory experiments.
- The drawback of this method is very low efficiency (~ O(0.1%)) of the B reconstruction.
- However, still possible thanks to excellent luminosity of KEKB!!

$B^0 \to D^{*-}\tau^+\nu$

$B^0 \to D^{*-}\tau^+\nu$



- Sensitive to charged Higgs.
- New Physics at Tree level.
- Some sensitive observables (e.g. τ polarization)
- Expected branching fraction : 1.2% ~ 1.6%

Analysis strategy

clean signature $D^{*-}e^{+}$ + p_{mis} → reconstruct B_{tag} inclusively

Slightly different approach compared to $B^- \to \tau^-\nu$

Signal sub-decay modes:

$D^{*-} \to \bar{D}^0\pi^-$

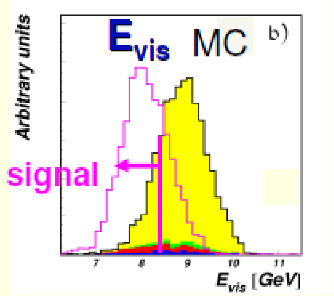
$\tau \to e\nu\nu$, $\bar{D}^0 \to K^+\pi^-$

$\tau \to e\nu\nu$, $\bar{D}^0 \to K^+\pi^-\pi^0$

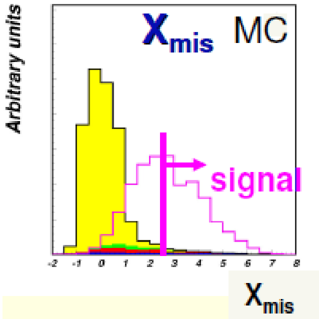
$\tau \to \pi\nu$, $\bar{D}^0 \to K^+\pi^-$

$B^0 \to D^{*-}\tau^+\nu$

Background suppression using visible energy / missing mass



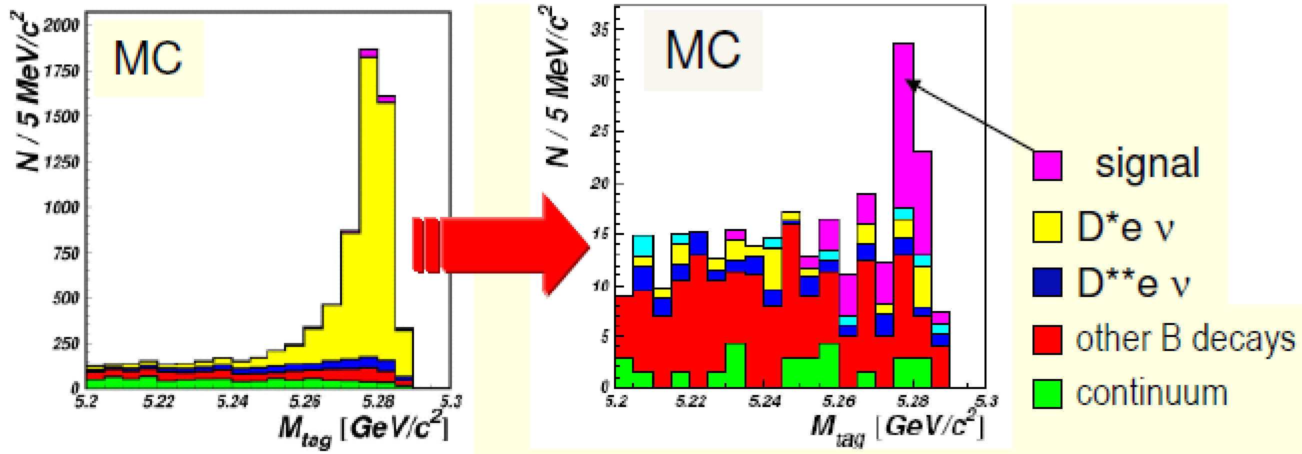
visible energy: E_{vis}<8.3 GeV



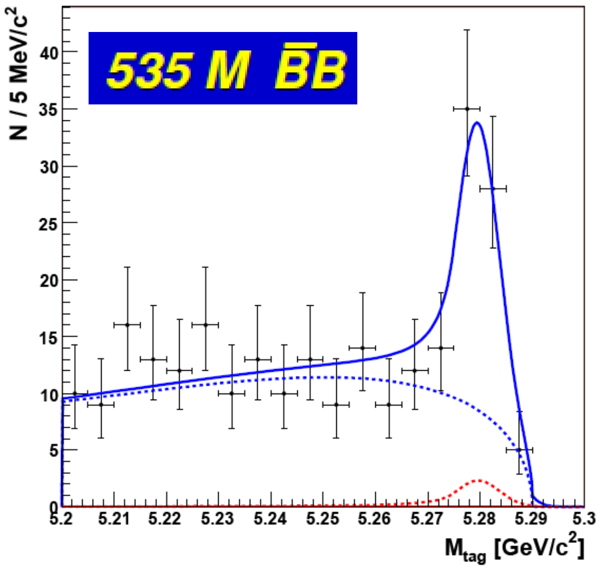
X_{mis}>2.75

before cut

after cut



Result



SIGNAL YIELD $N_s = 60^{+12}_{-11}$ 6.7σ (5.2σ with syst.)

$$BF(B^0 \to D^{*-}\tau^+\nu_\tau) = (2.02^{+0.40}_{-0.37}(stat) \pm 0.37(syst)) \times 10^{-2}$$

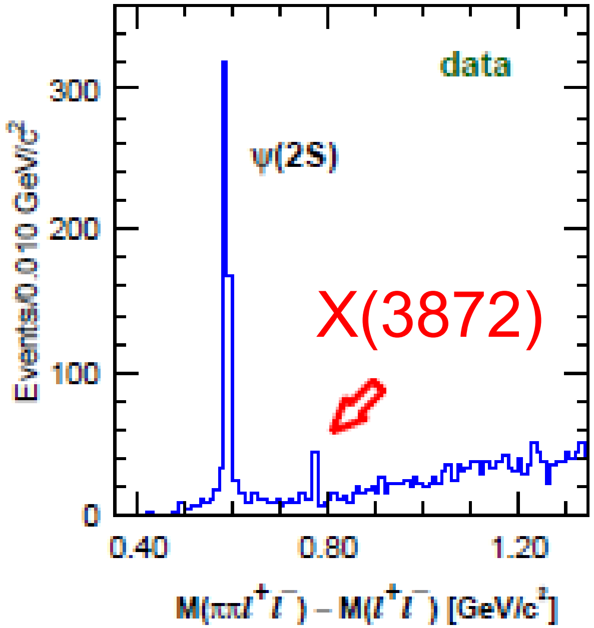
First observation !

[PRL 99, 191807 (2007)]

X(3872)

B Factories have been found new particle (resonances).

- X(3872) was first observed by Belle in 2003, and was confirmed by BaBar, CLEO and CDF.
- Decays to $\pi\pi J/\psi$, $\pi\pi\pi^0 J/\psi$, $\gamma J/\psi$, $D^0 D^0 \pi^0$ are known.
- X(3872) is naively considered to be made of $c\bar{c}$.
- However, there seems to be no corresponding quarkonium state according to the theoretical calculation.
- Possible explanation:
  - DD* meson molecular state
  - 4-quark state
  - hybrid ($c\bar{c}g$), glue ball (gg)



X(3872)

What Belle can do is to measure properties of this exotic state.

e.g) X(3872) is likely to have $J^{PC} = 1^{++}$, because

- X decays to $\gamma J/\psi$, and hence C=+1
- Angular distribution favors $J^P = 1^+$

X(3872) in B decays:

- In some models, the mass of X(3872) is different between B^0 and B^+ decays, if X is a 4-quark state.
  $\Delta m \equiv m(X_{B+}) - m(X_{B0}) = (8 \pm 3)$ MeV
- The decay from B^0 is suppressed if it's a D*D molecular state.
  $R \equiv B(B^0 \to K^0X)/B(B^+ \to K^+X) < 0.1$

X(3872)

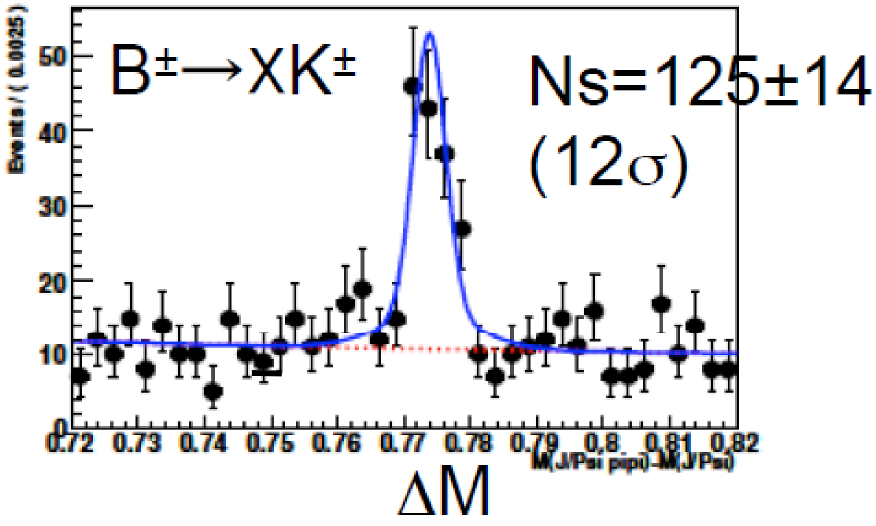
New Belle result with 657M $B\bar{B}$ data sample

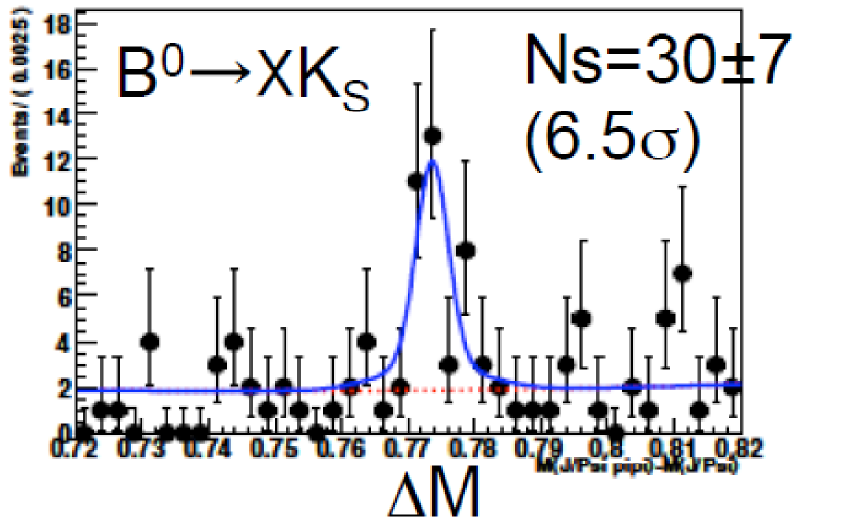
- X(3872) is reconstructed via $J/\psi\pi^+\pi^-$
- First observation of $B^0 \to K^0 X(3872)$
- No mass splitting

$$\Delta m \equiv m(X_{B+}) - m(X_{B0})$$
$$= (0.22 \pm 0.90 \pm 0.27)\ \text{MeV}$$

- Neutral mode is not suppressed

$$R \equiv B(B^0 \to K^0X)/B(B^+ \to K^+X)$$
$$= 0.94 \pm 0.24 \pm 0.10$$

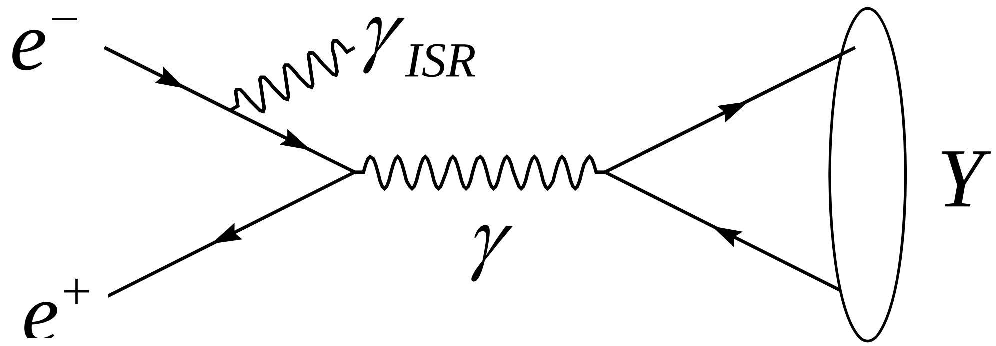




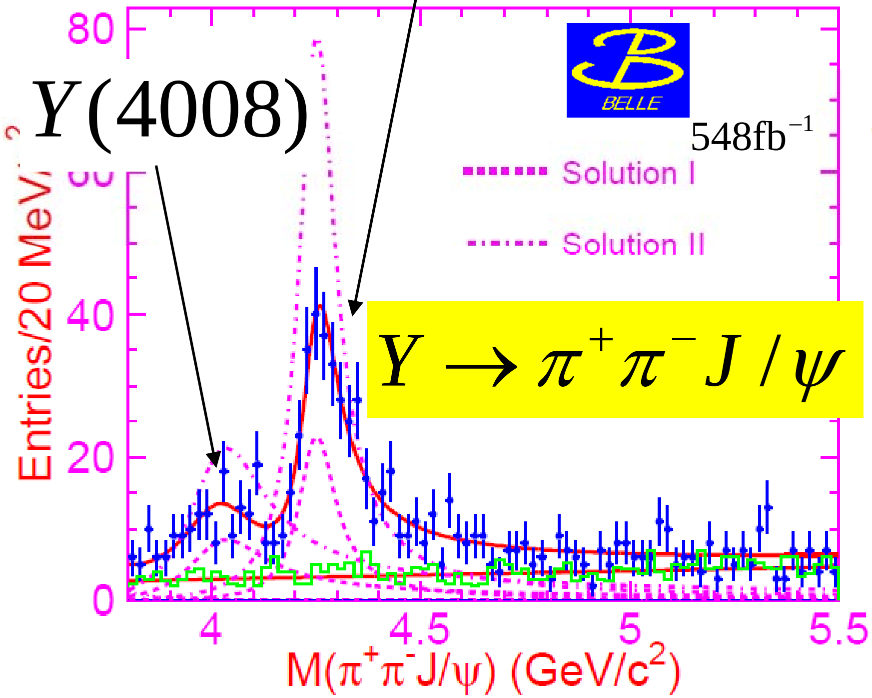
$\Delta M \equiv m(X) - m(J/\psi)$

Friends of Y(4260)

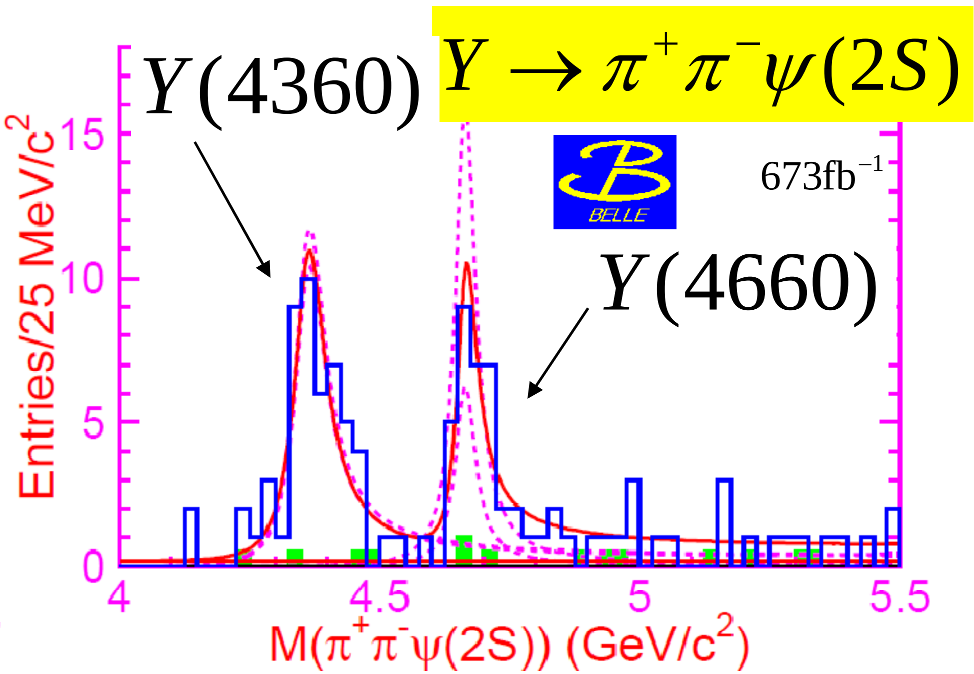
New resonances are also searched for by using ISR process. $e^+e^- \to \gamma_{ISR} Y$



Y(4260) discovered by BABAR

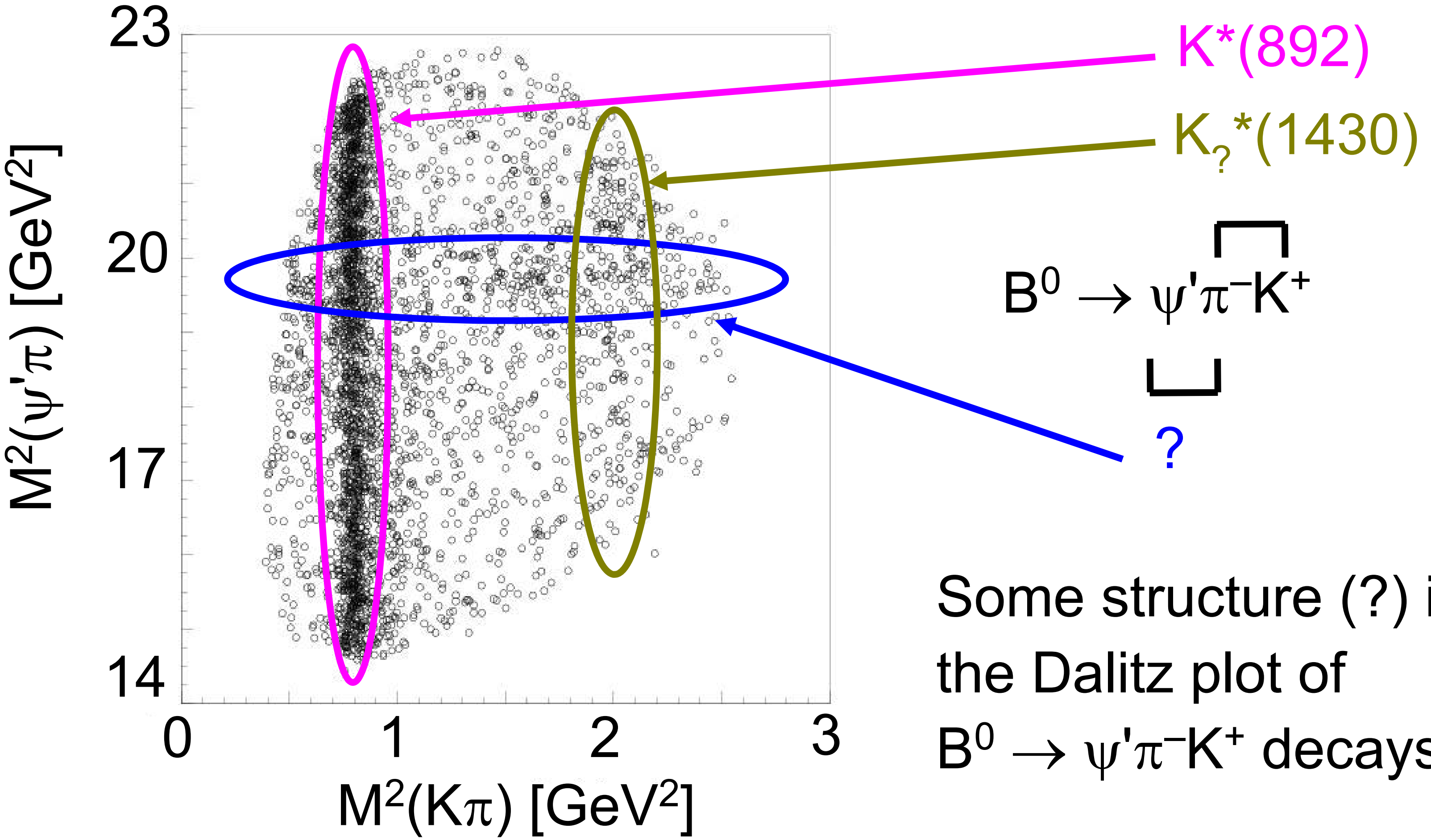


[PRL 99, 182004 (2007)]



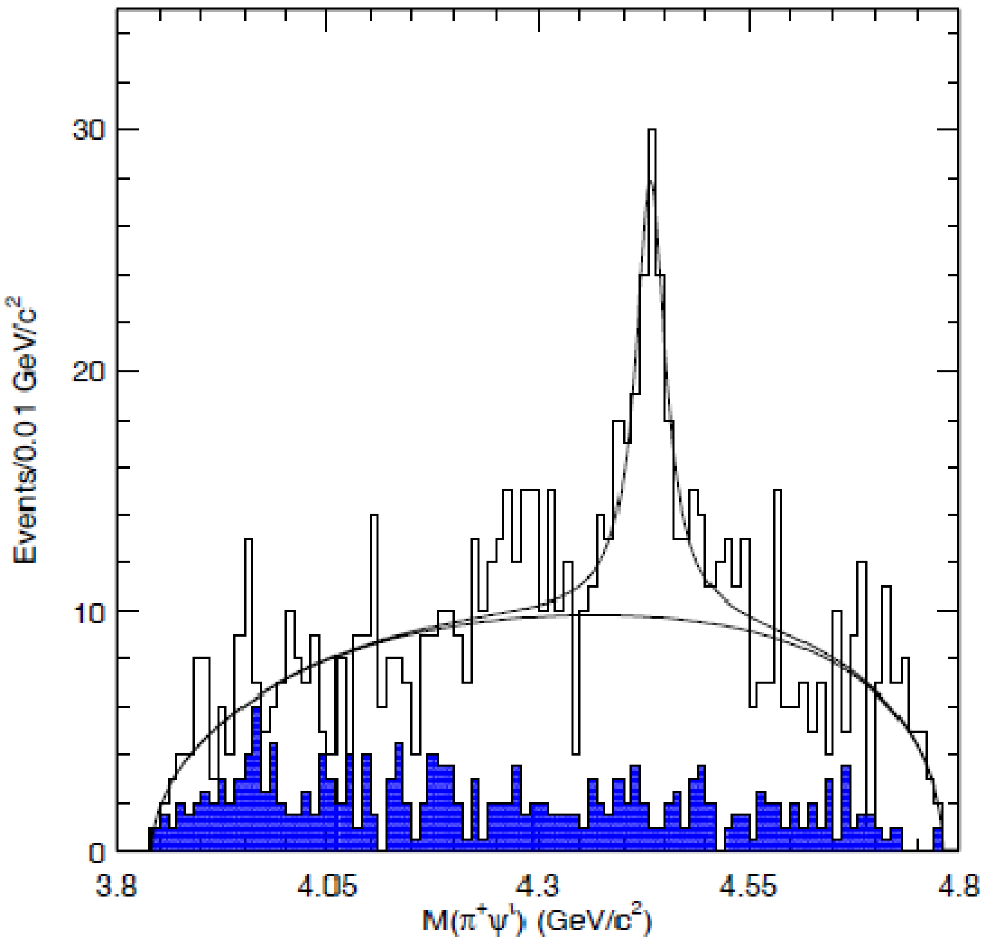
[arXiv:0707.3699]

New resonances are also searched in many other decays of B meson, and is found in the $\psi'\pi^+K^-$ final state:



Some structure (?) is seen in the Dalitz plot of $B^0 \to \psi'\pi^-K^+$ decays

Z(4430)



Clear signature of a resonance at 4430 MeV!!

$\rightarrow$ named as Z(4430)

- Npeak = 124 ± 30 events
- M = 4433 ± 4 ± 1 MeV
- $\Gamma = 44 ^{+17}_{-13} {}^{+30}_{-11}$ MeV

Z(4430) is a charged particle!!

- Not $c\bar{c}$ (because of charge)
- Likely to be 4-quark state!

Physics at $\Upsilon(5S)$

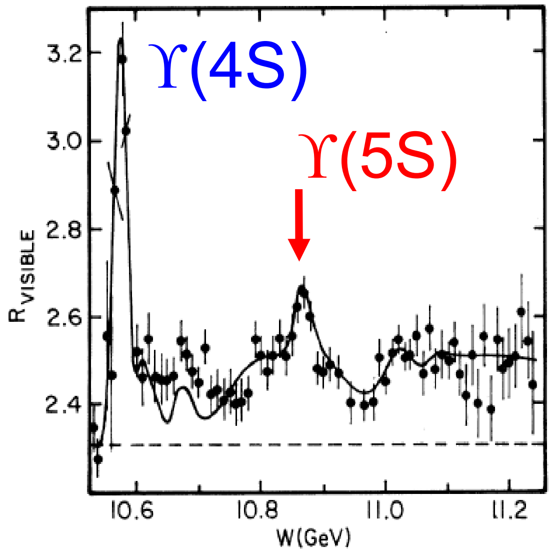
Belle accumulated ~23 fb^{-1} $\Upsilon(5S)$ data.

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ $(B = B^+, B_d^0)$

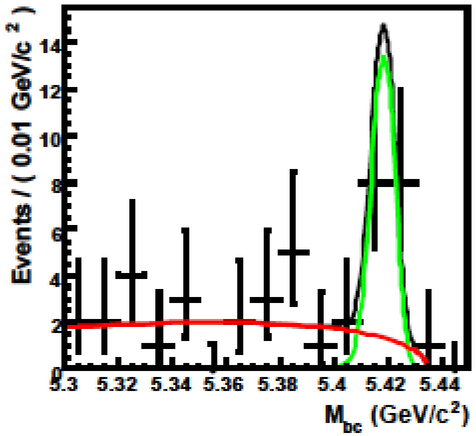
$e^+e^- \rightarrow \Upsilon(5S) \rightarrow B\bar{B}, B^*\bar{B}, B^*\bar{B}^*, B\bar{B}\pi, B\bar{B}\pi\pi, B_s\bar{B}_s, B_s^*\bar{B}_s, B_s^*\bar{B}_s^*$

$(B^* \rightarrow B\gamma, B_s^* \rightarrow B_s\gamma)$

Opened a new window to Bs physics.



New result: first observation of radiative Bs decays!!



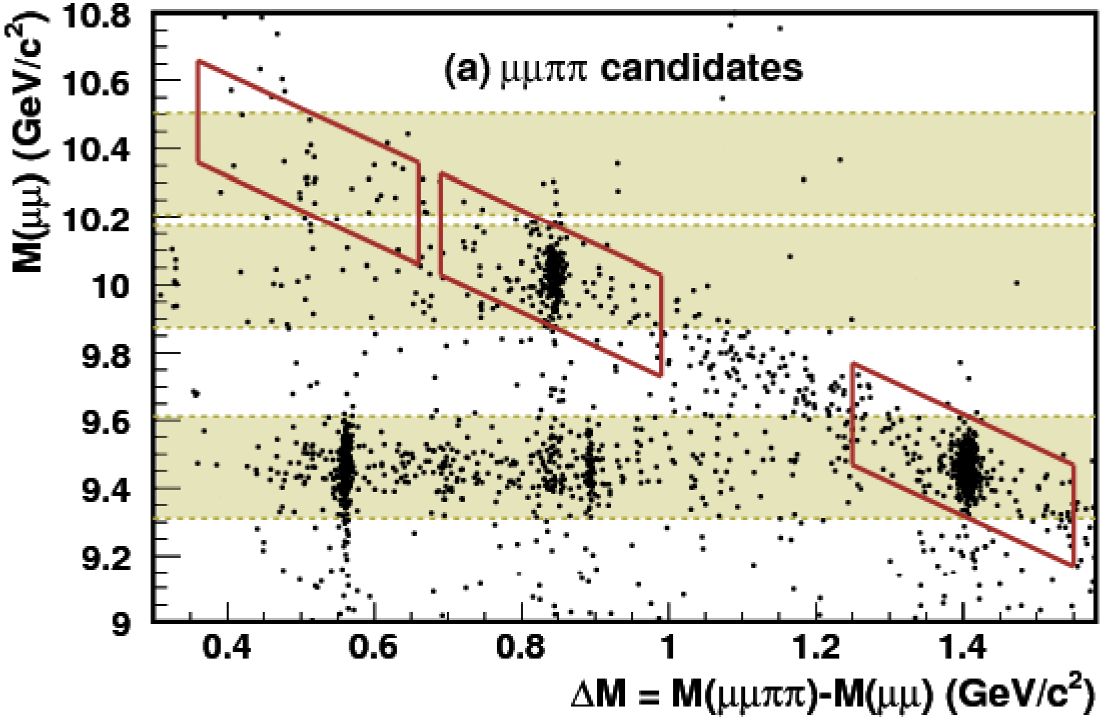
$\mathcal{B}(B_s \rightarrow \phi\gamma) = (5.7 ^{+1.8}_{-1.5} {}^{+1.2}_{-1.7}) \times 10^{-5}$ (5.5σ)

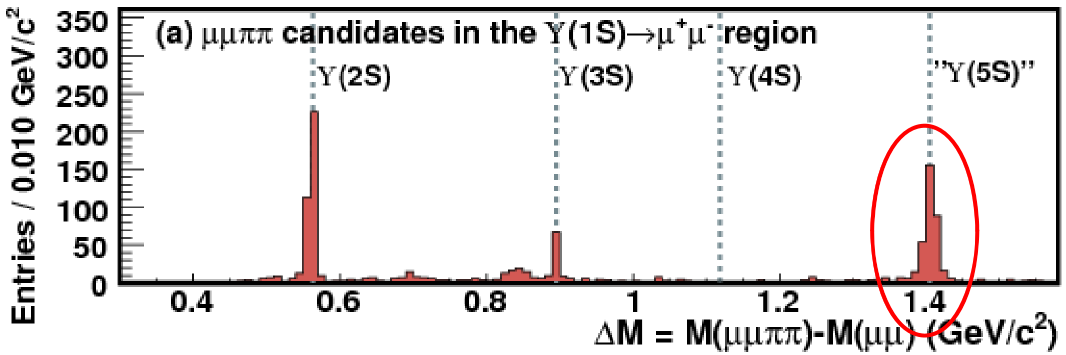
Signal yield 18 ± 6.

SM: $\mathcal{B}(B_s \rightarrow \phi\gamma) = (3.94 \pm 1.07 \pm 0.53) \times 10^{-5}$

$\Upsilon(5S) \to \Upsilon(1S,2S)\pi^+\pi^-$

Υ(5S) decay can also be studied.





$\mathcal{B}(\Upsilon(4S) \to \Upsilon(1S,2S)\ \pi^+\pi^-) \sim 1 \times 10^{-4}$

So, the expectation is

$\mathcal{B}(\Upsilon(5S) \to \Upsilon(1S,2S)\ \pi^+\pi^-) \sim 2 \times 10^{-5}$

However, we are seeing the Υ(5S) signal in data!!

If the signal comes from Υ(5S)

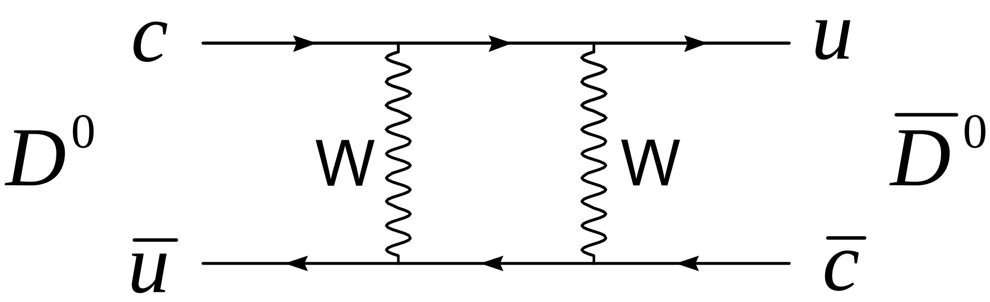
$\mathcal{B}(\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-)$
$= (0.53 \pm 0.03 \pm 0.05)\%$

$\mathcal{B}(\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-)$
$= (0.78 \pm 0.06 \pm 0.11)\%$

Maybe, bottom version of "Y" resonance (Yb) ??
Need scan!

D^0 Mixing

Mixing of neutral mesons was observed in K^0, B_d^0, B_s^0, but not in D^0 meson.



- Too small in the SM.
- D^0 mixing has been searched in B factories.

B factories are also charm factories!

D^0 mixing is often expressed in terms of two parameters, x and y.

$$|D^0(t)\rangle = e^{-(\Gamma/2+im)t}\left\{\cosh\left[(y+ix)\Gamma t/2\right]|D^0\rangle - \left(\frac{q}{p}\right)\sinh\left[(y+ix)\Gamma t/2\right]|\overline{D}^0\rangle\right\}$$

$$|\overline{D}^0(t)\rangle = e^{-(\Gamma/2+im)t}\left\{\cosh\left[(y+ix)\Gamma t/2\right]|\overline{D}^0\rangle - \left(\frac{p}{q}\right)\sinh\left[(y+ix)\Gamma t/2\right]|D^0\rangle\right\}$$

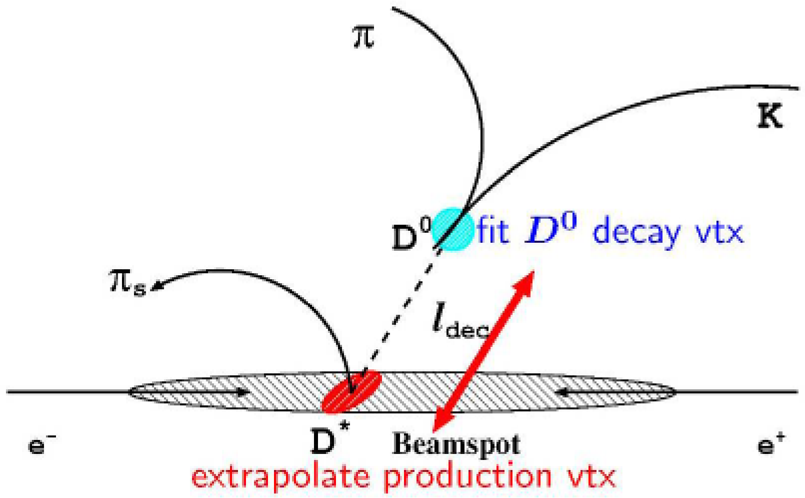
$$x \equiv 2\frac{m_1 - m_2}{\Gamma_1 + \Gamma_2} \qquad y \equiv \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$$

- non-zero x or y = mixing
- In SM, both x and y is < 1%.

D^0 Mixing

One of the way to measure D^0 mixing is to measure lifetime difference:

$$y_{CP} = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1$$



τ = 410.1±1.5 fs

- Decay time is measured from the positions of D* vertex and D vertex.
- K^-K^+ is CP even final state.
- In case of no CP violation in D^0 system, $y = y_{CP}$.

Other approach:

- $D^0 \to K^{(*)}\ell\nu$
- $D^0 \to K^+\pi^-$
- $D^0 \to K_S\pi^+\pi^-$ $\quad x = 0.80 \pm 0.29^{+0.09+0.10}_{-0.07-0.14} \quad y = 0.33 \pm 0.24^{+0.08+0.06}_{-0.12-0.08}$ (2.4σ)

D^0 Mixing

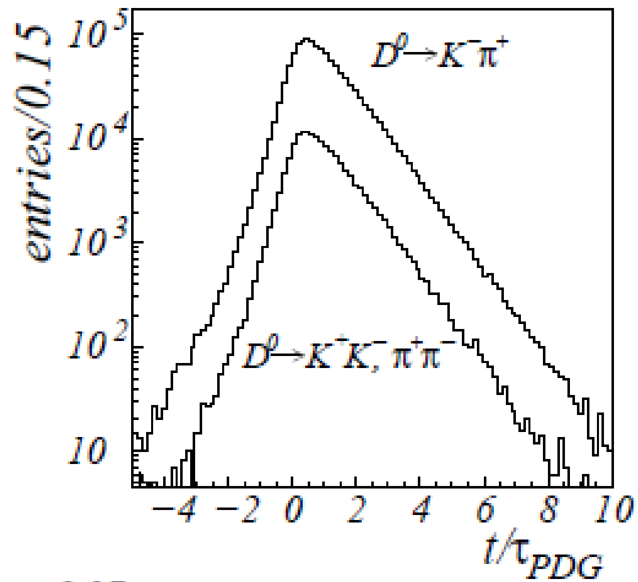
Result: first evidence!!

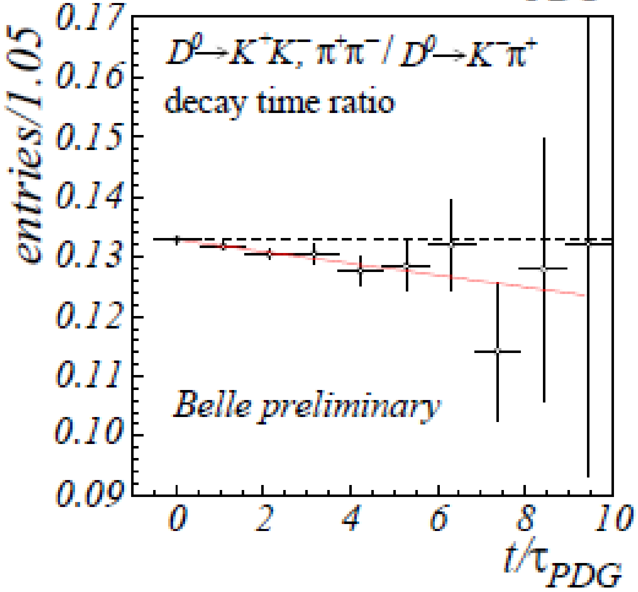
$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

(Siginficance 3.2σ)

[PRL 98, 211803 (2007)]

If we combine other measurements, mixing is established with ~5σ





高エネ研

D中間子の混合現象を発見

新理論の可能性に期待

D中間子の「混合現象」

高エネ機構加速器で観測

反粒子の「混合」
D中間子で発見
高エネ研チーム

宇宙に現在存在する粒子と、電気的な性質などが反対の反粒子が移り変わる「混合現象」が、D中間子で初めて見つかった。高エネルギー加速器研究機構（茨城県つくば市）の大型加速器「Bファクトリー」の国際実験チームが十三日、韓国で開かれた国際会議で発表した。米スタンフォード線形加速器センターの国際実験チームも別の測定方法で発見し、同会議で発表した。Bファクトリー実験の共同代表、山内正則高エネ研教授は「現在の素粒子物理学の標準理論を超える新理論や未知の新粒子を探る手掛かりになる」と話している。

混合現象は、電気的に中性で、素粒子のクォーク二個で構成される中間子に特有の現象。K中間子ではほぼ100％、B中間子では約70％の確率で起こることが知られるが、残るD中間子では未発見だった。

Summary

- First observation $B^0 \to D^{*-}\tau^+\nu$
- Evidence of D^0-$\overline{D}^0$ mixing

  Precise test of the standard model and probe to New Physics

- More new (charmoniuum-like) particles.
- New charged Z(4430) is a 4-quark state (?).
- New results on Bs decays using Belle's data at $\Upsilon(5S)$.
- Anomalously large rate to $\Upsilon(1S,2S)\pi^+\pi^-$

More analyses are going on.
Stay tuned with new results!

Backup

CP Violation in the SM

Complex phase in the quark mixing matrix
→ source of CPV in Weak Interactions

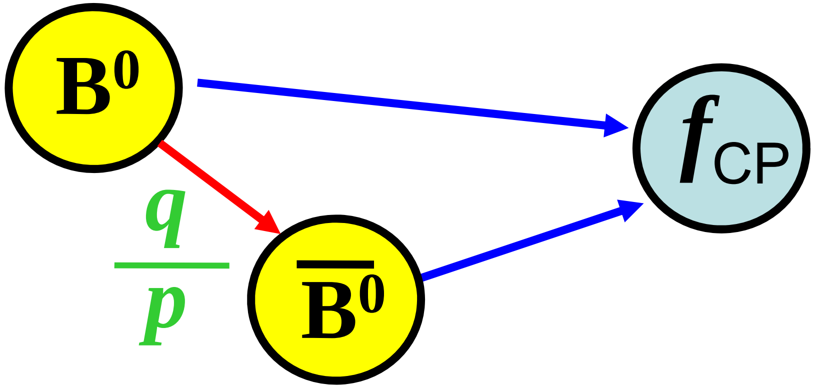
Kobayashi-Maskawa
Theory (1973)

Requires 3 (or more) generation of quarks

- only 3 quaks (u, d, s) were known at that time!
  - all 6 quarks are discovered.

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

CKM Matrix



CP **Violation manifests itself in proper-time difference (Δt) distributions of two *B* meson decays.**

$$A_{CP} \equiv \frac{\Gamma\left(\overline{B_d^0}(\Delta t) \to f_{CP}\right) - \Gamma\left(B_d^0(\Delta t) \to f_{CP}\right)}{\Gamma\left(\overline{B_d^0}(\Delta t) \to f_{CP}\right) + \Gamma\left(B_d^0(\Delta t) \to f_{CP}\right)}$$

$$= \mathbf{S} \sin(\Delta m \Delta t) + \mathbf{A} \cos(\Delta m \Delta t)$$

Mixing induced CPV   Direct CPV

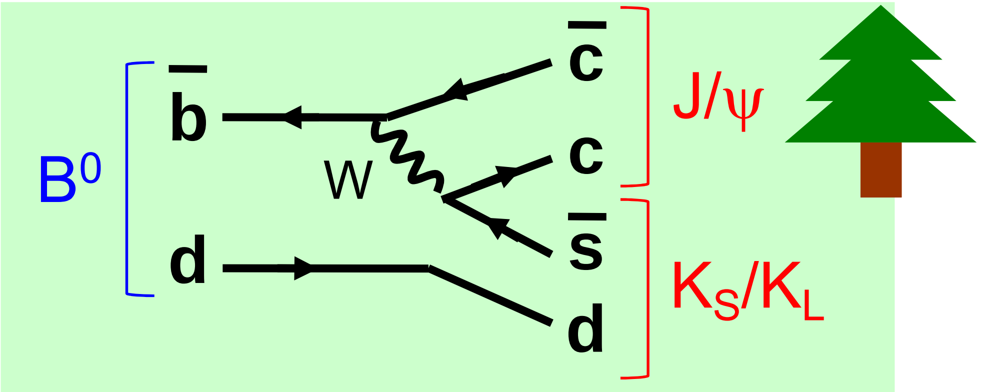
$$\mathbf{S} = \frac{2\mathrm{Im}\lambda_{CP}}{1 + |\lambda_{CP}|^2}$$

$$\mathbf{A} = \frac{|\lambda_{CP}|^2 - 1}{|\lambda_{CP}|^2 + 1}$$

$$\lambda_{CP} = \frac{q}{p} \frac{A(B^0 \to f_{CP})}{A(\overline{B^0} \to f_{CP})}$$

Measurement of $\sin 2\phi_1$

$B^0 \rightarrow J/\psi\, K_{S/L}$



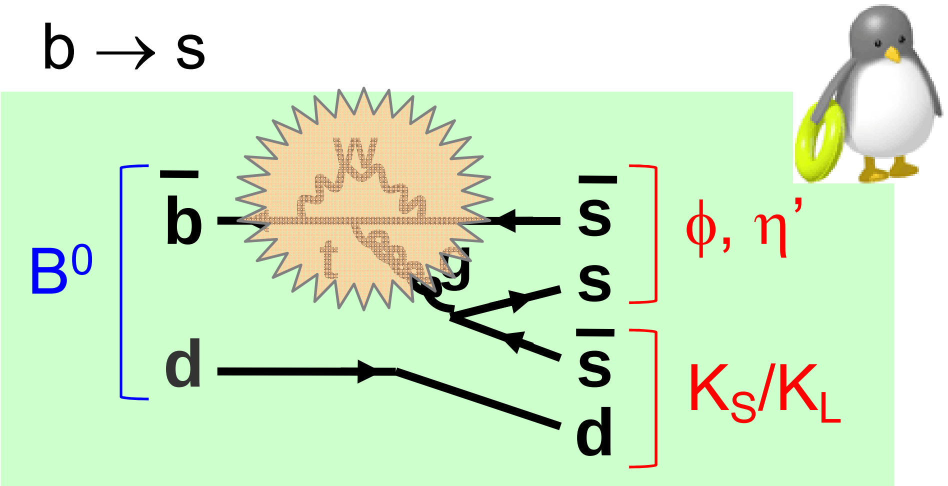
$A_{CP}(\Delta t) = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$

$S = -\xi \sin(2\phi_1)$ (ξ : CP eigenstate)

$A = 0$

precise measurement of ϕ_1

$b \rightarrow s$



In the SM,

$S = -\xi \sin(2\phi_1)$

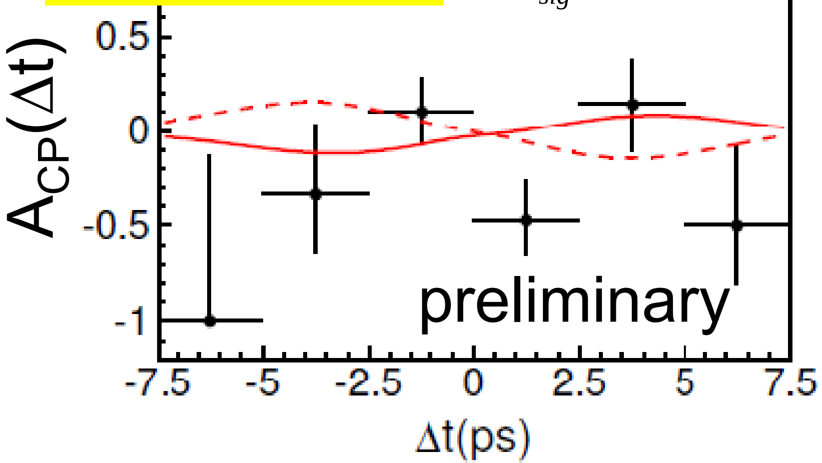
However, the value will change with non-SM contribution to the loop

Search for New Physics

CPV in penguin

$\bar{b} \to \bar{s}$ penguin

$B^0 \to K_S^0 \pi^0 \pi^0$



$S = +0.43 \pm 0.49 \pm 0.09$

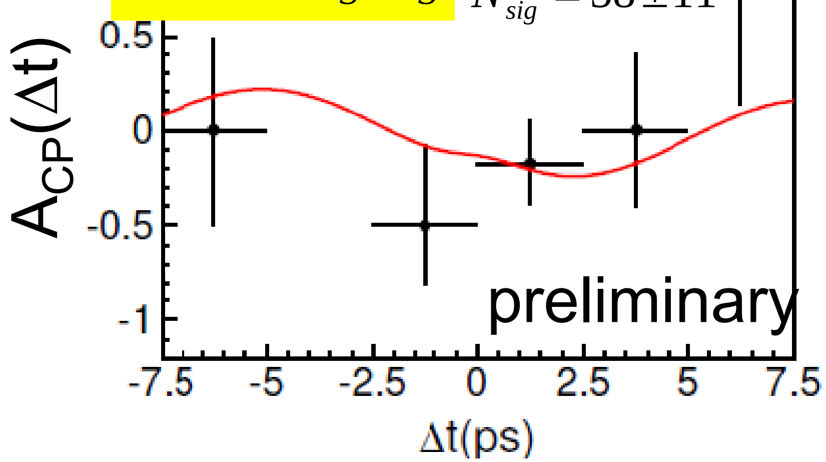
$A = -0.17 \pm 0.24 \pm 0.06$

2.0σ difference from the SM

predicton:
$S = -\sin 2\phi_1 \simeq -0.68$

$\bar{b} \to \bar{d}$ penguin

$B^0 \to K_S^0 K_S^0$



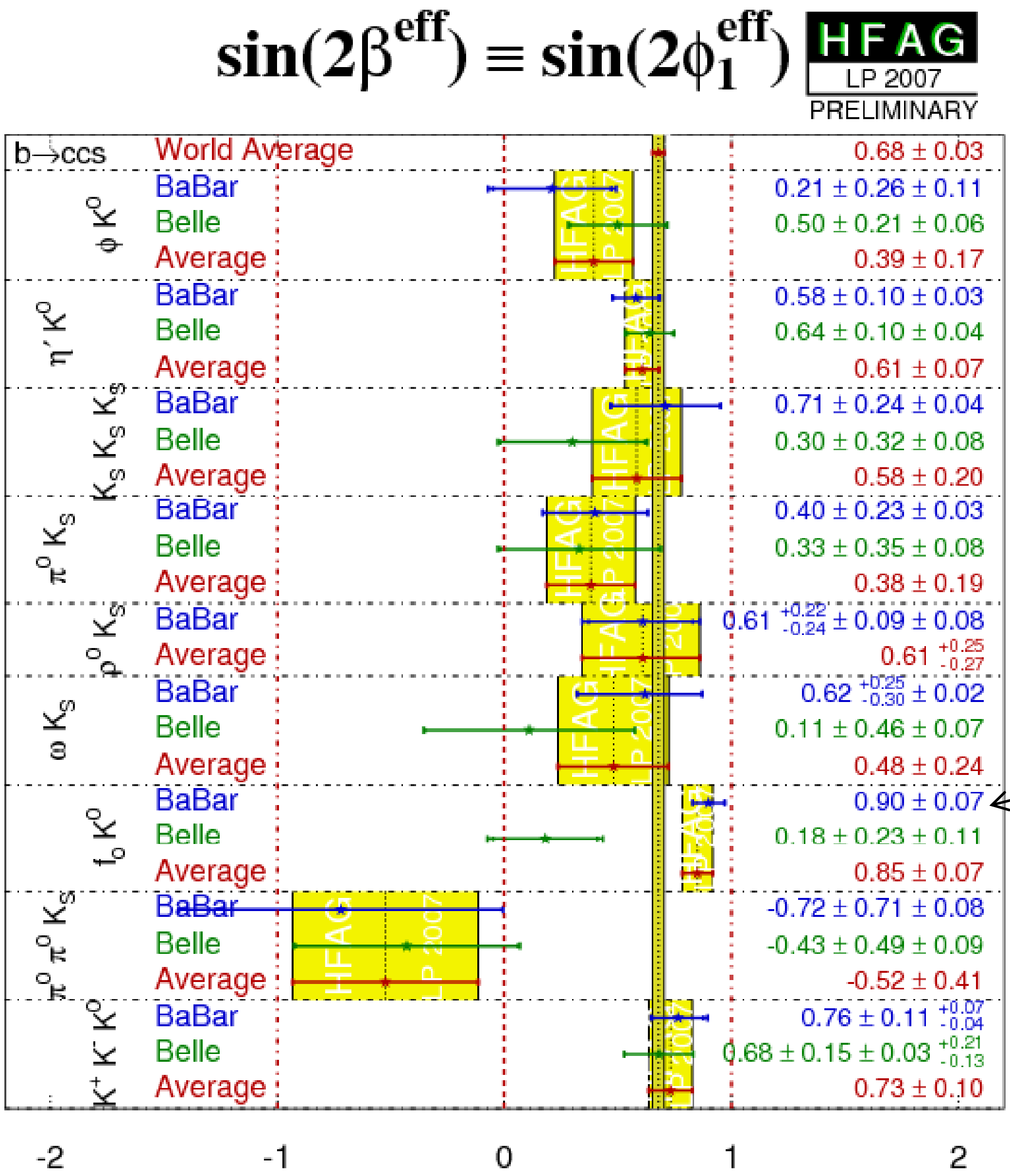
$S = -0.38 \pm 0.77 \pm 0.08$

$A = -0.38 \pm 0.38 \pm 0.05$

Consistent with the SM

arXiv:0708.1845

$\sin 2\phi_1$ Summary



Tree-penguin difference is now 0.1σ

the difference is 2.2σ if we exclude this result: simple average is too naïve because the error is non-gaussian

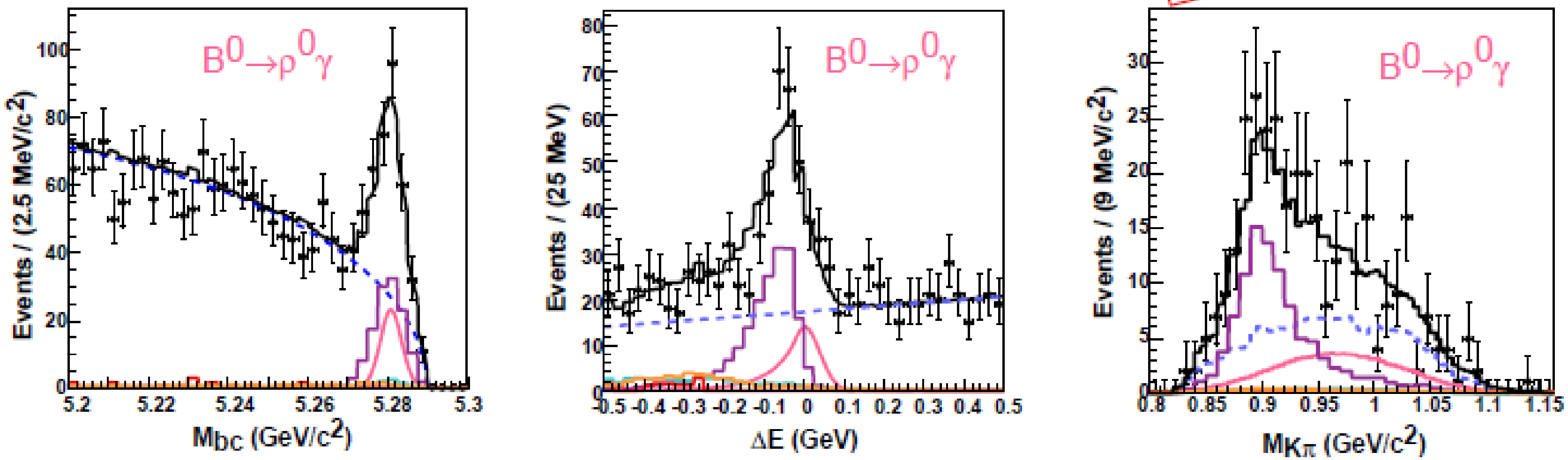
B → ργ, ωγ

First observed by Belle, confirmed by BaBar, now with 1.7x data

- $B \to K^{*}\gamma$ is a severe background
  K-id fake rate > $\mathcal{B}(B \to \rho\gamma)/\mathcal{B}(B \to K^{*}\gamma)$
- $M_{K\pi}$ now in the fit for $B^0 \to \rho^0\gamma$ (M_{bc}-ΔE-$M_{K\pi}$ fit)
  $M_{K\pi}$: $\pi\pi$ mass with m_K assignment for π / ΔE: separation of ~ 50 MeV
- Excellent sample to fix signal (and background) shape

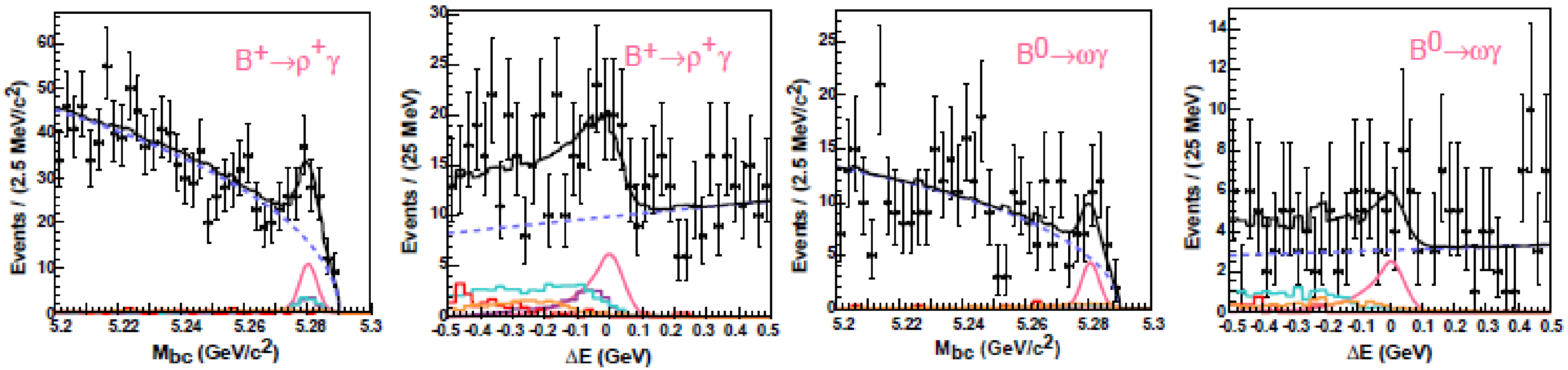
PRELIMINARY

$B^0 \to \rho^0\gamma$ — $(74\,^{+17}_{-16})$ events



$B \to \rho\gamma, \omega\gamma$

$B^+ \to \rho^+\gamma$ — $(44\,^{+15}_{-14})$ events $\quad$ $B^0 \to \omega\gamma$ — $(17\,^{+8}_{-7})$ events



	Belle		BaBar	
	$\mathcal{B}\,(10^{-7})$	(Σ)	$\mathcal{B}\,(10^{-7})$	(Σ)
$B^+ \to \rho^+\gamma$	$8.6\,^{+3.0}_{-2.8}\,^{+0.7}_{-0.8}$	(3.2σ)	$11.0\,^{+3.7}_{-3.3} \pm 0.9$	(3.8σ)
$B^0 \to \rho^0\gamma$	$7.6 \pm 1.7 \pm 0.6$	(4.9σ)	$7.9\,^{+2.2}_{-2.0} \pm 0.6$	(4.9σ)
$B^0 \to \omega\gamma$	$4.2\,^{+2.0}_{-1.8} \pm 0.4$	(2.6σ)	$4.0\,^{+2.4}_{-2.0} \pm 0.5$	(2.2σ)
$B \to \rho\gamma$	$11.9 \pm 2.4 \pm 1.2$	(5.5σ)	$13.6\,^{+2.9}_{-2.7} \pm 0.9$	(6.0σ)
$B \to (\rho,\omega)\gamma$	$11.3 \pm 2.0 \pm 1.1$	(5.9σ)	$12.5\,^{+2.5}_{-2.4} \pm 0.9$	(6.4σ)

Combined $\mathcal{B}$ with assumption: $\Gamma_{B\to(\rho,\omega)\gamma} = \Gamma_{B\to\rho\gamma} = \Gamma_{B^+\to\rho^+\gamma} = 2\Gamma_{B^0\to\rho^0\gamma} = 2\Gamma_{B^0\to\omega\gamma}$