Recent Charmonium Results from Belle

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Joint Meeting of Pacific Region Particle Physics Communities

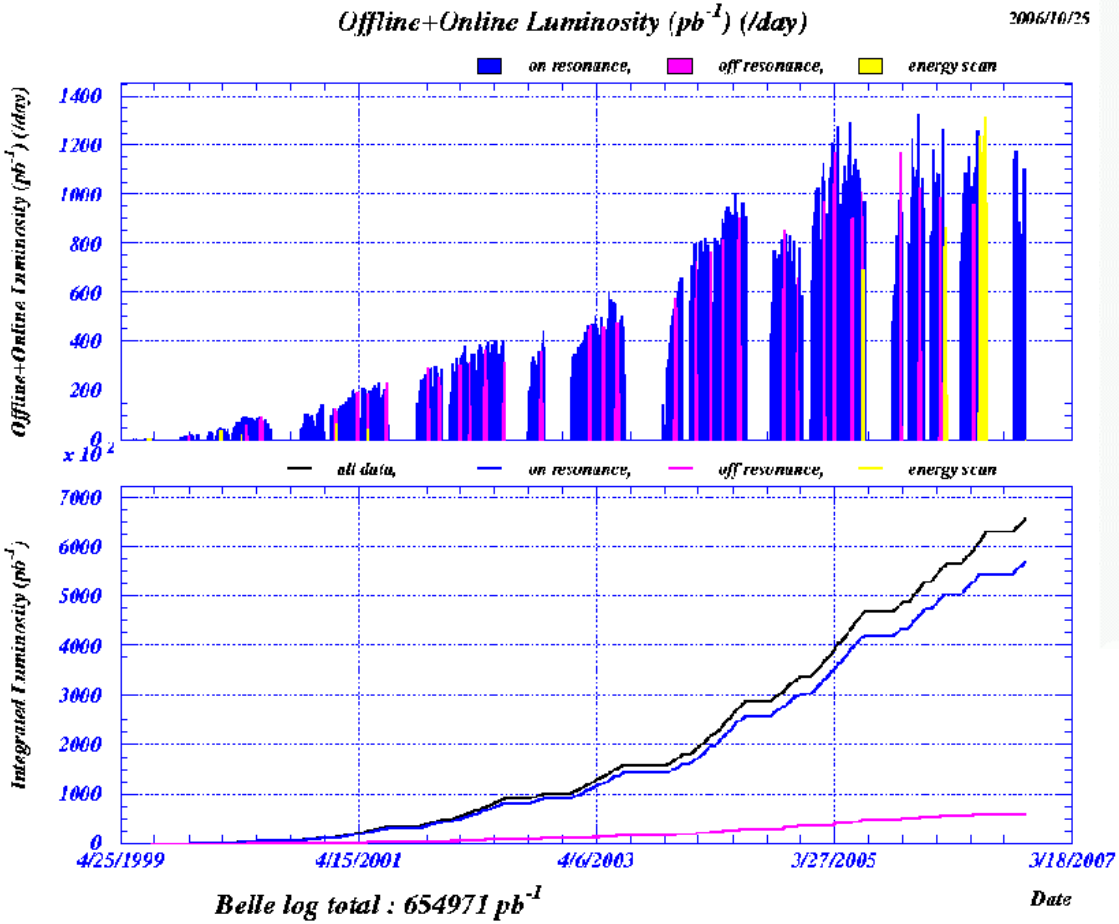
31 October 2006

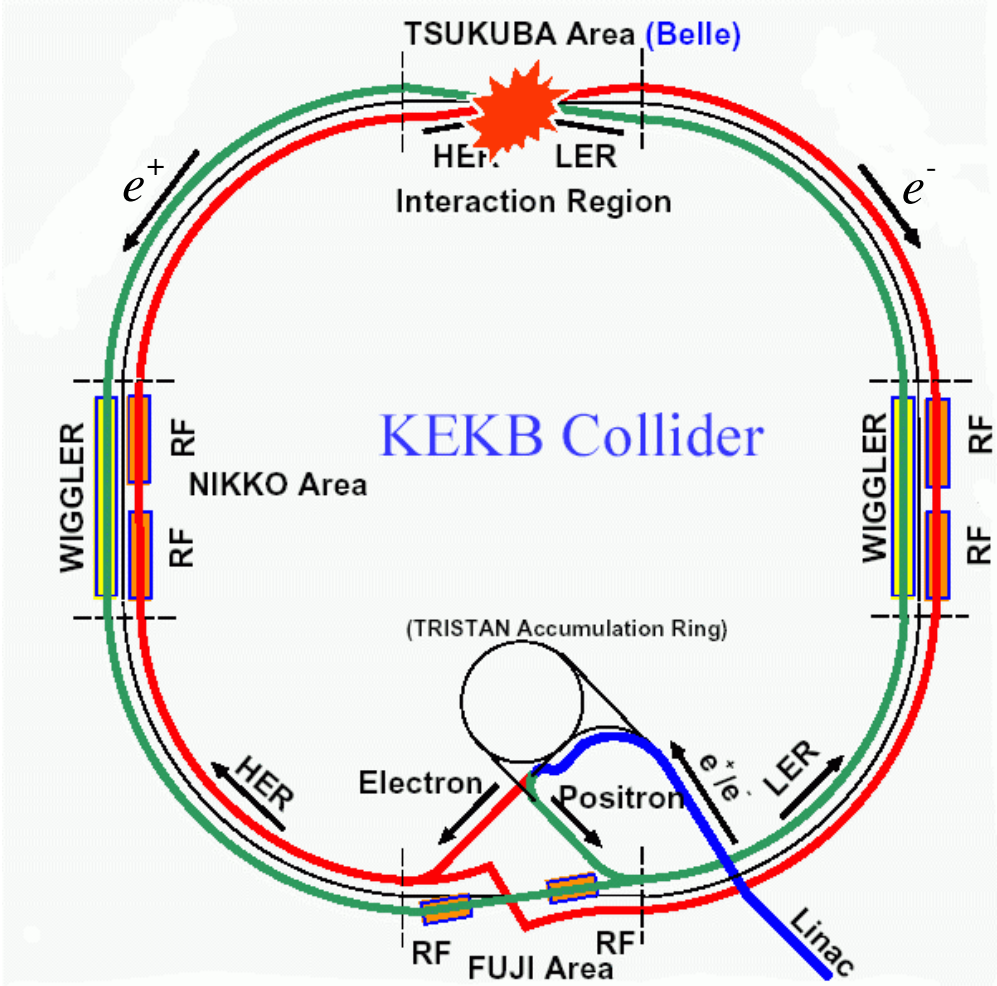
- Brief overview of KEKB and Belle
- First observation of $B^{\pm} \to \chi_{c1} \pi^{\pm}$
- First observation of $B^{0} \to J/\psi\, \eta$
- Search for $B \to J/\psi\, \eta'\, K$
- Charmonium branching fractions through $B \to \phi\, \phi\, K$
- Conclusions

KEKB

$$L_{\text{peak}} = 1.65 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$$

$$\int L\,dt = 649\,\text{fb}^{-1}$$





The analyses presented here are based on 388-449 million B-pairs

The Belle Detector

SVD vertex resolution: (first $152\times10^6\,B$-pairs)

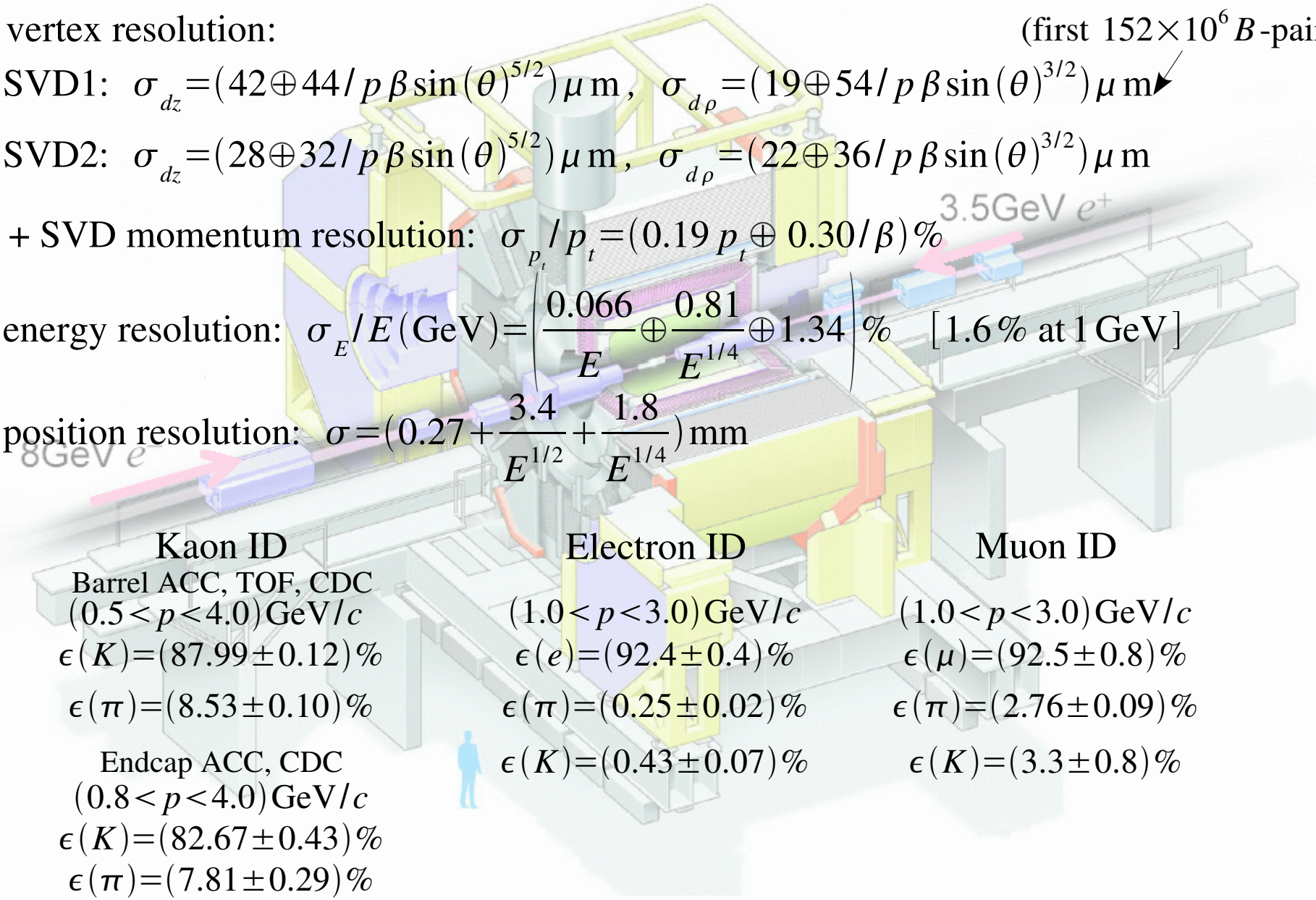
SVD1: $\sigma_{dz}=(42\oplus44/p\beta\sin(\theta)^{5/2})\,\mu\mathrm{m}$, $\sigma_{d\rho}=(19\oplus54/p\beta\sin(\theta)^{3/2})\,\mu\mathrm{m}$

SVD2: $\sigma_{dz}=(28\oplus32/p\beta\sin(\theta)^{5/2})\,\mu\mathrm{m}$, $\sigma_{d\rho}=(22\oplus36/p\beta\sin(\theta)^{3/2})\,\mu\mathrm{m}$

CDC + SVD momentum resolution: $\sigma_{p_t}/p_t=(0.19\,p_t\oplus0.30/\beta)\%$

ECL energy resolution: $\sigma_E/E(\mathrm{GeV})=\left(\frac{0.066}{E}\oplus\frac{0.81}{E^{1/4}}\oplus1.34\right)\%$ [1.6% at 1 GeV]

ECL position resolution: $\sigma=(0.27+\frac{3.4}{E^{1/2}}+\frac{1.8}{E^{1/4}})\,\mathrm{mm}$



Kaon ID

Barrel ACC, TOF, CDC

$(0.5<p<4.0)\,\mathrm{GeV}/c$

$\epsilon(K)=(87.99\pm0.12)\%$

$\epsilon(\pi)=(8.53\pm0.10)\%$

Endcap ACC, CDC

$(0.8<p<4.0)\,\mathrm{GeV}/c$

$\epsilon(K)=(82.67\pm0.43)\%$

$\epsilon(\pi)=(7.81\pm0.29)\%$

Electron ID

$(1.0<p<3.0)\,\mathrm{GeV}/c$

$\epsilon(e)=(92.4\pm0.4)\%$

$\epsilon(\pi)=(0.25\pm0.02)\%$

$\epsilon(K)=(0.43\pm0.07)\%$

Muon ID

$(1.0<p<3.0)\,\mathrm{GeV}/c$

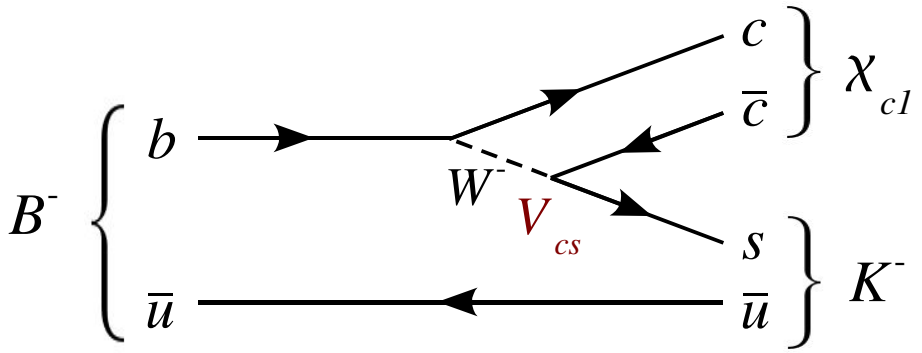
$\epsilon(\mu)=(92.5\pm0.8)\%$

$\epsilon(\pi)=(2.76\pm0.09)\%$

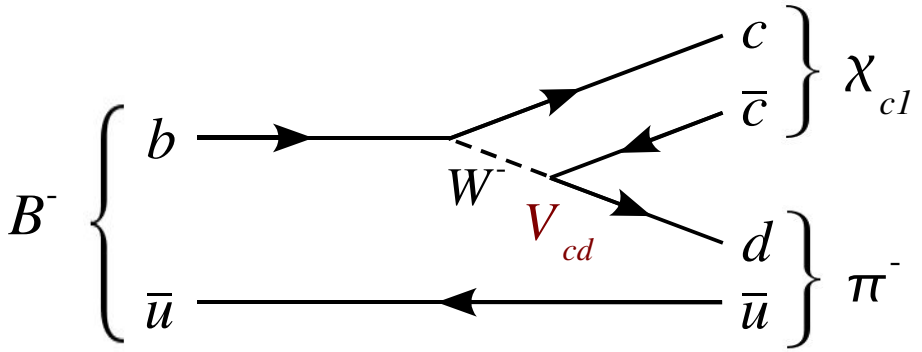
$\epsilon(K)=(3.3\pm0.8)\%$

First Observation of $B^{\pm} \to \chi_{c1}\pi^{\pm}$

- The decay $B^{\pm} \to \chi_{c1} K^{\pm}$ has recently been measured by both Belle and BaBar:



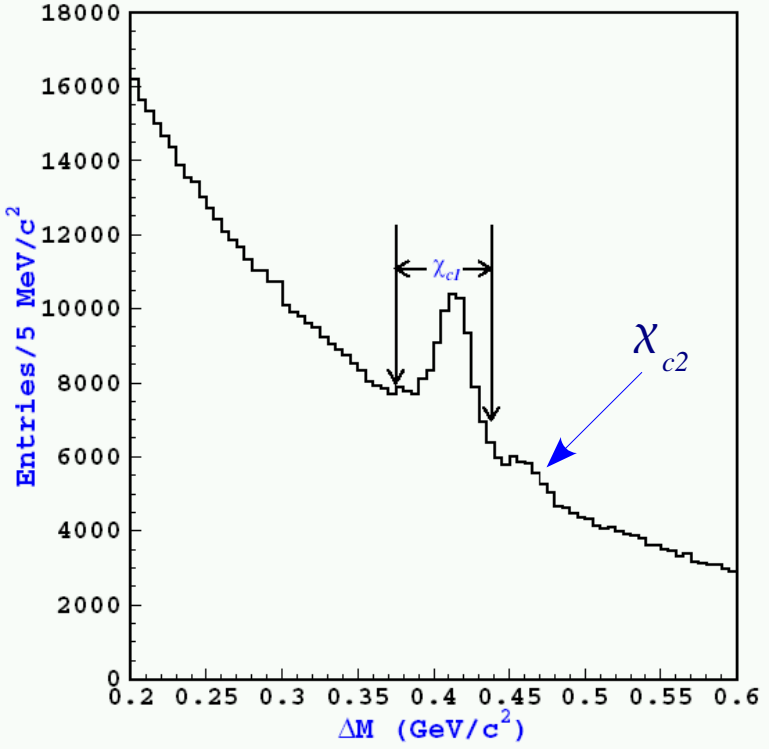
- $B^{\pm} \to \chi_{c1}\pi^{\pm}$, the Cabbibo-suppressed counterpart of $B^{\pm} \to \chi_{c1} K^{\pm}$, is expected to occur with a relative branching fraction of $|V_{cd}/V_{cs}|^2 \approx 5\%$



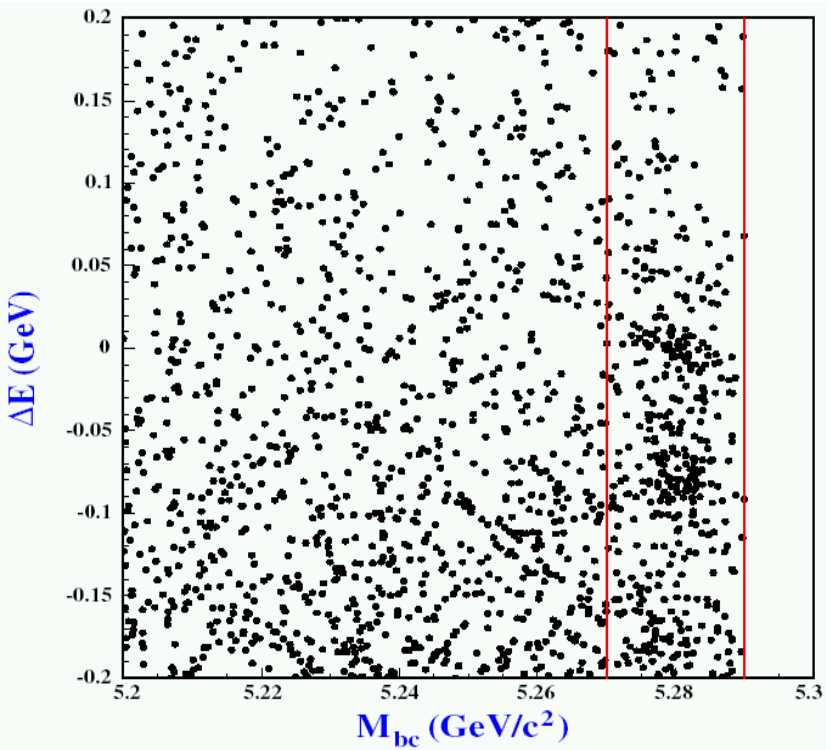
- a $b \to d\,c\,\bar{c}$ penguin contribution may lead to direct CP-violation in $B^{\pm} \to \chi_{c1}\pi^{\pm}$

First Observation of $B^{\pm} \to \chi_{c1}\pi^{\pm}$

- χ_{c1} candidates are reconstructed through the decay $\chi_{c1} \to \gamma J/\psi$
- B-candidates are selected using the kinematic variables $M_{bc} \equiv \sqrt{E_{cm}^2 - p_B^{*2}}$ and $\Delta E \equiv E_B^* - E_{cm}$

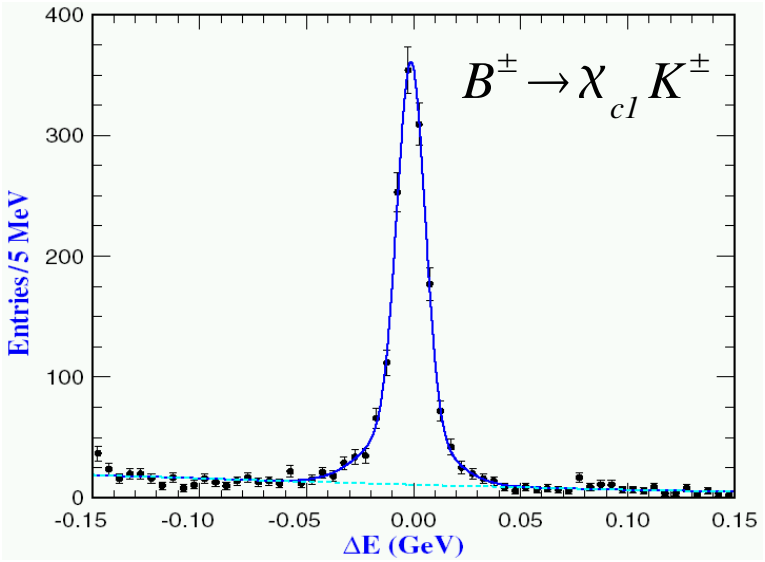


$\Delta M \equiv M(l^+l^-\gamma) - M(l^+l^-)$

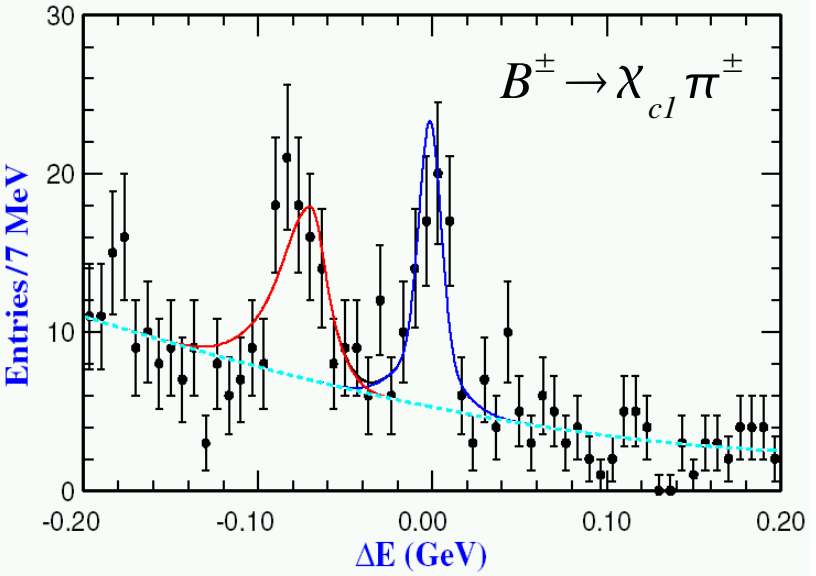


First Observation of $B^{\pm} \to \chi_{c1}\pi^{\pm}$

- Perform a binned maximum likelihood fit to the ΔE distribution.



double gaussian + 2nd-order polynomial
all parameters floated



double gaussian + 3rd-order polynomial
signal shape fixed by $B^{\pm} \to \chi_{c1} K^{\pm}$ fit
misidentified $B^{\pm} \to \chi_{c1} K^{\pm}$ is fit to an asymmetric gaussian using MC

- Observe 1597 ± 48 events for $B^{\pm} \to \chi_{c1} K^{\pm}$, and 55 ± 10 events for $B^{\pm} \to \chi_{c1} \pi^{\pm}$:

$$B(B^{\pm} \to \chi_{c1}\pi^{\pm}) = (2.2 \pm 0.4 \pm 0.3) \times 10^{-5}$$

$$\frac{B(B^{\pm} \to \chi_{c1}\pi^{\pm})}{B(B^{\pm} \to \chi_{c1} K^{\pm})} = (4.3 \pm 0.8 \pm 0.3)\%$$

statistical significance: 6.3σ

based on 388×10^6 $B\bar{B}$ events

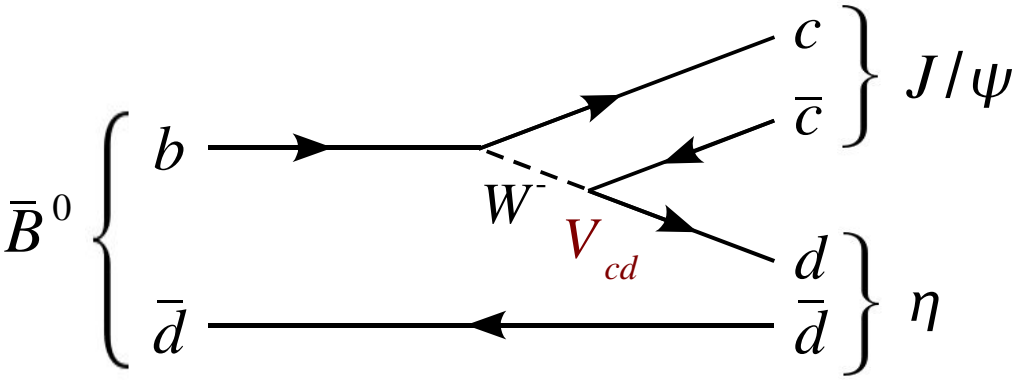
First Observation of $B^{\pm} \to \chi_{c1}\pi^{\pm}$

- Search for direct CP violation:

Mode	N_-	N_+	$A_{CP} = \frac{N_- - N_+}{N_- + N_+}$
$B^{\pm} \to \chi_{c1}\pi^{\pm}$	29 ± 7	25 ± 7	$0.07 \pm 0.18 \pm 0.02$
$B^{\pm} \to \chi_{c1}K^{\pm}$	792 ± 31	807 ± 31	$-0.01 \pm 0.03 \pm 0.02$

- This represents the first observation of $B^{\pm} \to \chi_{c1}\pi^{\pm}$
- Measured branching fraction:
  - is consistent with the factorization hypothesis
  - indicates that the tree-level diagram is dominant
- Published in PRD **74**, 051103 (2006)

First Observation of $B^0 \to J/\psi\,\eta$

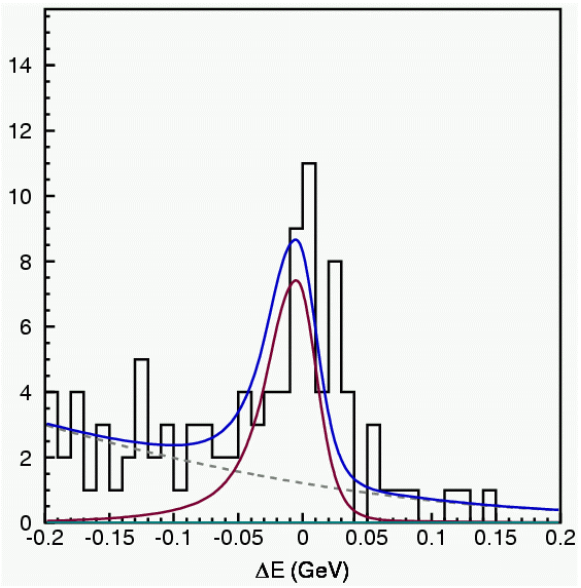


- CP eigenstate
- If the main contribution to this decay is the tree-level diagram, then, assuming factorization and a pseudoscalar mixing angle of -17°, we can expect the branching fraction for $B^0 \to J/\psi\,\eta$ to be ~63% of that for $B^0 \to J/\psi\,\pi^0$, $B(B^0 \to J/\psi\,\pi^0) = (2.2 \pm 0.4) \times 10^{-5}$ (PDG 2006)
- Provides a test for higher-order contributions such as penguin pollution
- Previous studies were able to yield only upper limits, but the statistics available now make a branching-fraction measurement possible.

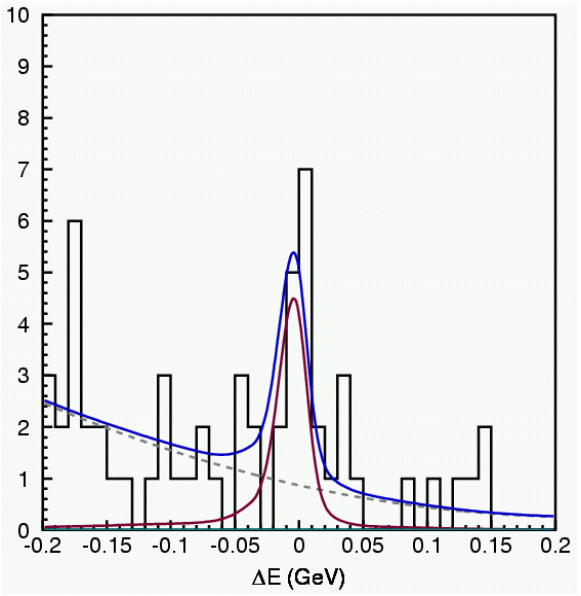
First Observation of $B^0 \to J/\psi\,\eta$

- Reconstruct η through its decays $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$
- Perform unbinned maximum likelihood fit to the ΔE spectrum
- Observe 43.1 ± 8.9 events with $\eta \to \gamma\gamma$, and 16.6 ± 5.8 events with $\eta \to \pi^+\pi^-\pi^0$

$B^0 \to J/\psi\,\eta(\eta \to \gamma\gamma)$



$B^0 \to J/\psi\,\eta(\eta \to \pi^+\pi^-\pi^0)$



double gaussian + Crystal Ball function + 2nd-order polynomial

signal and background shapes fixed based on MC

statistical significance: $8.1\,\sigma$

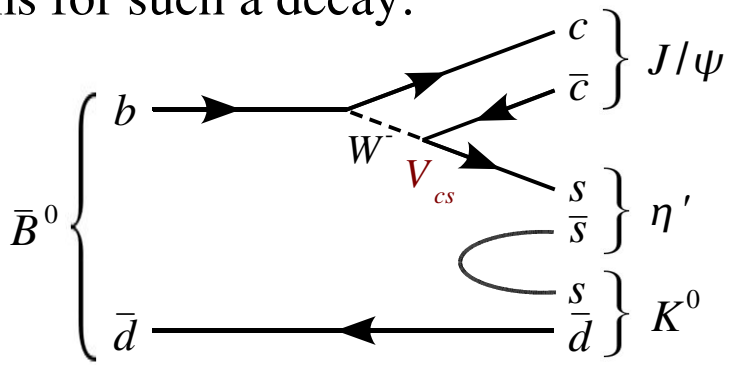
based on $449 \times 10^6\, B\bar{B}$ events

First Observation of $B^0 \to J/\psi\,\eta$

- Measured branching fractions:
  - $B(B^0 \to J/\psi\,\eta) = (9.5 \pm 2.0) \times 10^{-6}$ for $\eta \to \gamma\gamma$
  - $B(B^0 \to J/\psi\,\eta) = (10.1 \pm 3.5) \times 10^{-6}$ for $\eta \to \pi^+\pi^-\pi^0$
  - combined: $B(B^0 \to J/\psi\,\eta) = (9.6 \pm 1.7 \pm 0.7) \times 10^{-6}$
- This represents the first observation of $B^0 \to J/\psi\,\eta$
- Branching fraction is $(44 \pm 12)\%$ of that for $B^0 \to J/\psi\,\pi^0$
  - consistent with expectations based on factorization and the quark model
  - tree-level contribution appears to be dominant
- posted as hep-ex/0609047

Search for B → J/ψ η' K

- This decay requires the creation of an $s\bar{s}$ quark pair in the final state.
- Two possible mechanisms for such a decay:
  - Three-body decay:



  - $B^{\pm} \to \psi_g K$, $\psi_g \to J/\psi\,\eta'$, where ψ_g is a hybrid charmonium state (*i.e.*, $c\bar{c}\,g$)
- The similar decay $B \to J/\psi\,\phi\,K$ was observed by CLEO in 2000, with a branching fraction $\mathcal{B}(B \to J/\psi\,\phi\,K) = (8.8\,^{+3.5}_{-3.0} \pm 1.3) \times 10^{-5}$ [PRL **84**, 1393 (2000)]
- More recently, BaBar measured the branching fractions:

$$\mathcal{B}(B^{\pm} \to J/\psi\,\eta\,K^{\pm}) = (10.8 \pm 2.3 \pm 2.4) \times 10^{-5}$$

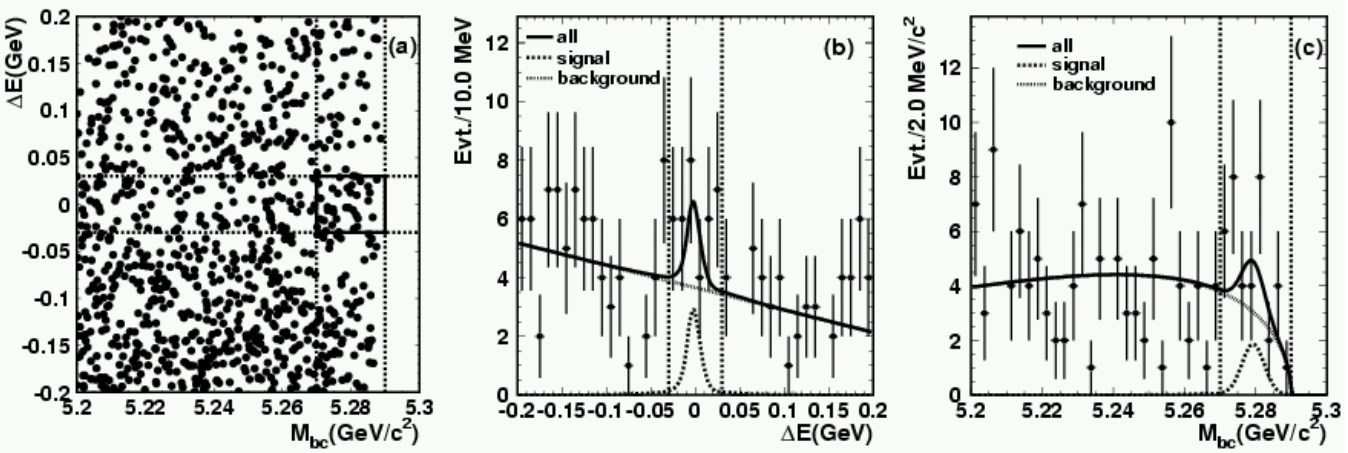
$$\mathcal{B}(B^{0} \to J/\psi\,\eta\,K^{0}_{S}) = (8.4 \pm 2.6 \pm 2.7) \times 10^{-5}$$

  Note that these include $B \to \psi(2S)K$, $\psi(2S) \to J/\psi\,\eta$.
- Hybrid charmonium states may also be involved in $X(3872)$, $Y(4260)$, etc.

Search for B → J/ψ η' K

$B^{\pm} \to J/\psi\, \eta'\, K^{\pm}$

- Results of 2-D unbinned maximum-likelihood fit to ΔE and M_{bc}:

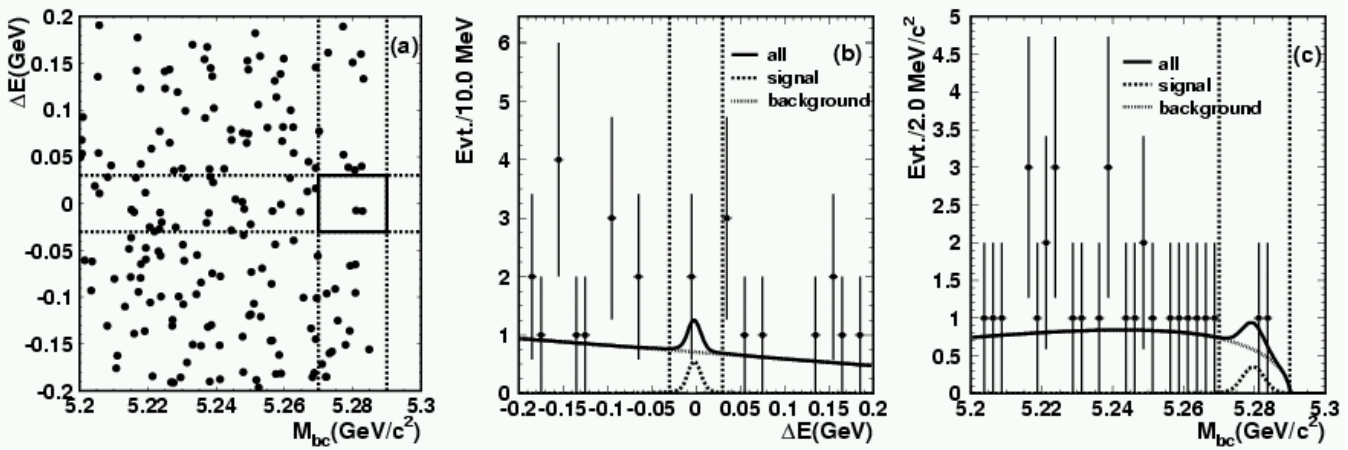


- $B(B^{\pm} \to J/\psi\, \eta'\, K^{\pm}) < 8.8 \times 10^{-5}$ at 90% confidence level
- based on $388 \times 10^{6}\, B\bar{B}$ events
- worth revisiting in two years with $\sim 1\,\text{ab}^{-1}$

Search for B → J/ψ η' K

$B^0 \to J/\psi\,\eta'\,K_S^0$

- Results of 2-D unbinned maximum-likelihood fit to ΔE and M_{bc}:

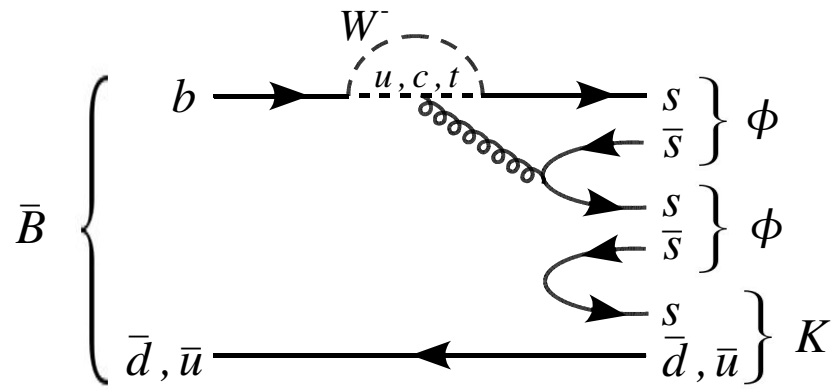


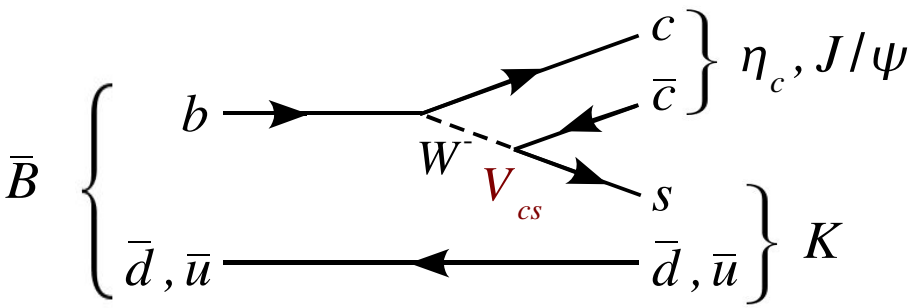
- $B(B^0 \to J/\psi\,\eta'\,K_S^0) < 2.5\times10^{-5}$ at 90% confidence level
- based on $388\times10^6\, B\bar{B}$ events
- unlikely to see anything even with twice as much data

to be submitted to PRL

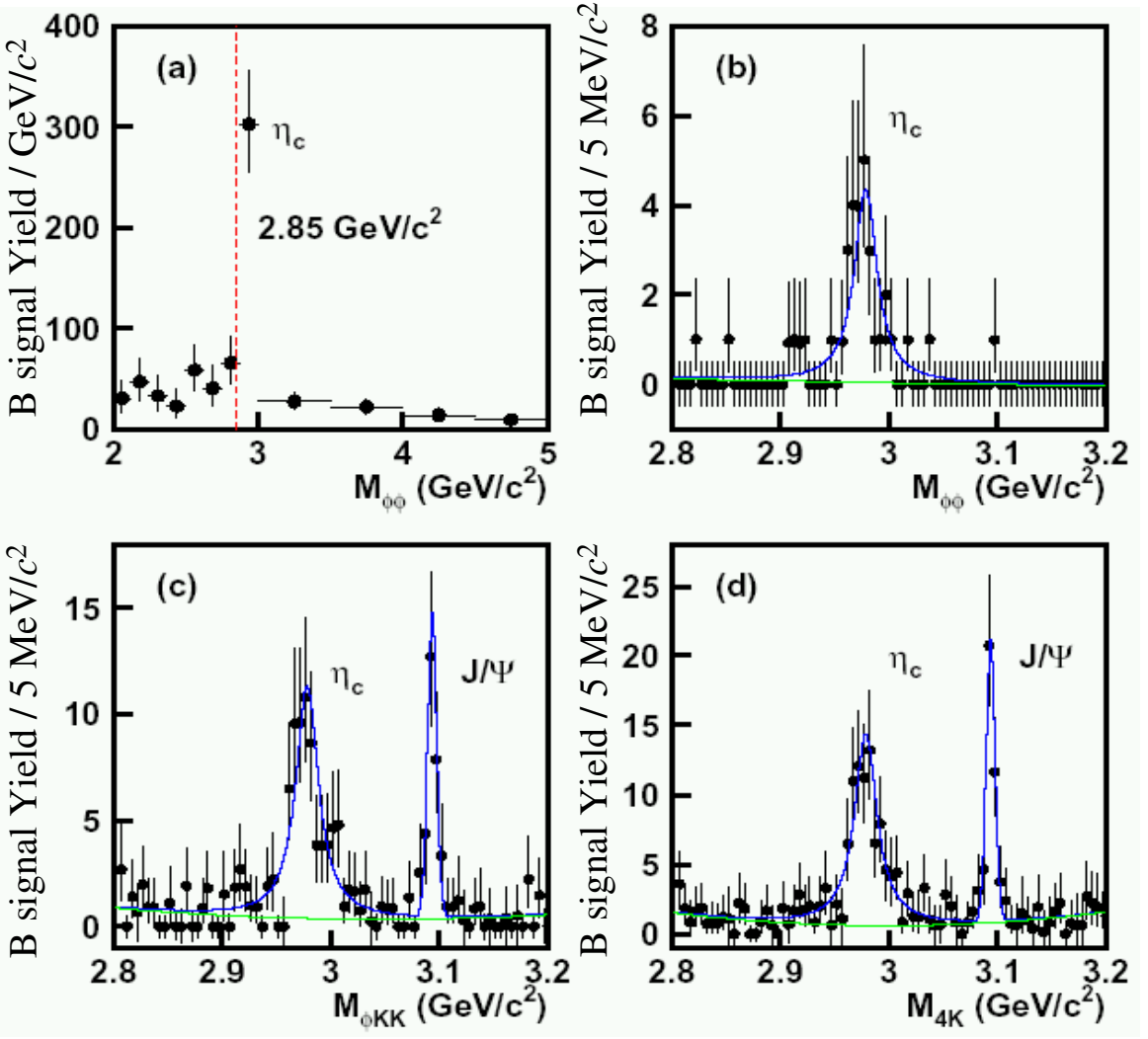
Charmonium via $B \to \phi\,\phi\,K$

- A high-statistics analysis has been performed for $B^{\pm} \to \phi\,\phi\,K^{\pm}$





based on $449 \times 10^6\, B\bar{B}$ events



Charmonium via B → φ φ K

- Fitting the spectra and using the known branching fractions for $B^{\pm} \to \eta_c K^{\pm}$ and $B^{\pm} \to J/\psi K^{\pm}$ yields the following charmonium branching fractions:

mode	measured branching fraction	PDG 2006
$\eta_c \to \phi\phi$	$(2.7^{+0.6}_{-0.5} \pm 0.4) \times 10^{-3}$	$(2.7 \pm 0.9) \times 10^{-3}$
$\eta_c \to \phi K^+ K^-$	$(3.9^{+0.7}_{-0.6} \pm 0.6) \times 10^{-3}$	$(2.9 \pm 1.4) \times 10^{-3}$
$\eta_c \to 2(K^+ K^-)$	$(2.6^{+0.5}_{-0.4} \pm 0.4) \times 10^{-3}$	$(1.5 \pm 0.7) \times 10^{-3}$
$J/\psi \to \phi K^+ K^-$	$(1.2 \pm 0.3 \pm 0.1) \times 10^{-3}$	$(1.83 \pm 0.24) \times 10^{-3}$
$J/\psi \to 2(K^+ K^-)$	$(9.7^{+1.7}_{-1.6} \pm 1.0) \times 10^{-4}$	$(7.08 \pm 1.4) \times 10^{-4}$

- contributed to ICHEP 2006

Conclusions

- We have observed several Cabbibo-suppressed B decays to charmonium.
  - First observation of $B^{\pm} \to \chi_{c1} \pi^{\pm}$:

$$\frac{B(B^{\pm} \to \chi_{c1} \pi^{\pm})}{B(B^{\pm} \to \chi_{c1} K^{\pm})} = (4.3 \pm 0.8 \pm 0.3)\%$$, consistent with S. M. prediction

  - First observation of $B^0 \to J/\psi \eta$:

$$B(B^0 \to J/\psi \eta) = (9.6 \pm 1.7 \pm 0.7) \times 10^{-6}$$, consistent with S. M. prediction

  - So far, no significant direct CP-violation observed.

Conclusions

- Various multi-body B decays to charmonium have also been studied:
  - Upper limits at 90% confidence level for $B \to J/\psi \eta' K$:

    $B(B^{\pm} \to J/\psi \eta' K^{\pm}) < 8.8 \times 10^{-5}$

    $B(B^{0} \to J/\psi \eta' K^{0}_{S}) < 2.5 \times 10^{-5}$
  - Branching fractions have been obtained for η_c and J/ψ decays to $\phi\phi$, $\phi K^+ K^-$, and $2(K^+ K^-)$ by studying $B^{\pm} \to 2(K^+ K^-) K^{\pm}$

- See also A. Imoto's poster presentation on $B^0 \to J/\psi \pi^+ \pi^-$.
- Stay tuned for more charmonium results from Belle!