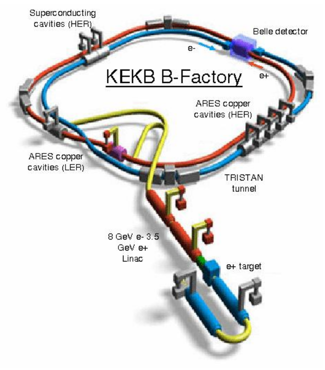
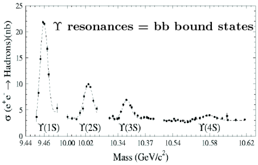
Recent Results from Belle

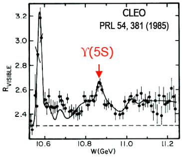
A.Bożek

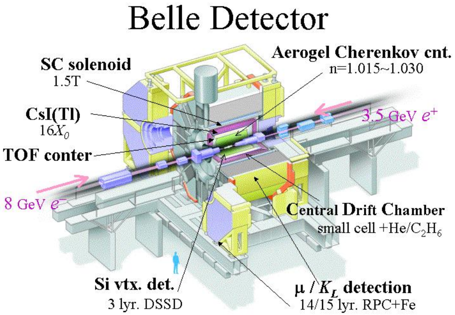
1. CKM angles
   - ϕ_1/β measurements
   - ϕ_3/γ measurements
2. DCPV in charmless B decays
   - Direct CP Violation in $B \to K\pi$
3. Semileptonic B decays
   - $B \to D_s^{(*)} K \ell \nu$
4. Physics at $\Upsilon(5S)$:
   - $h_b(nP)$ and Z_b's states

Outline





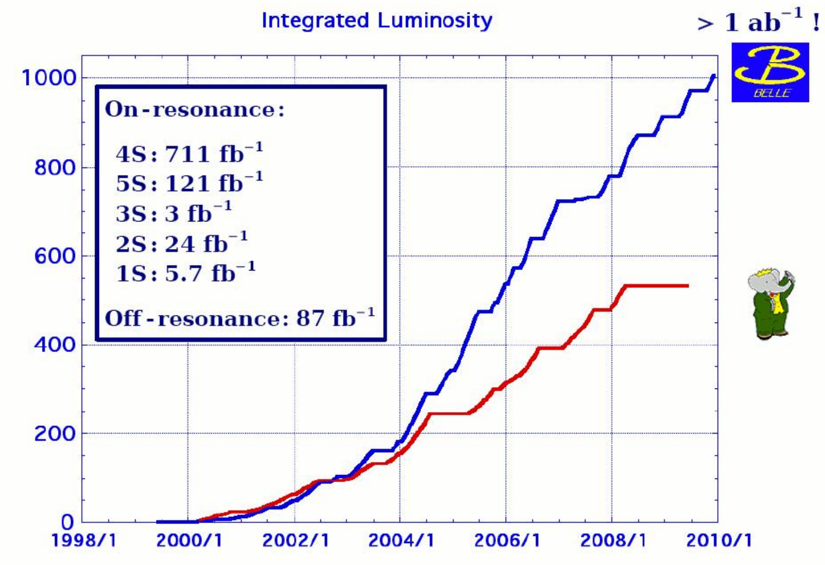




- World luminosity record L $= 2.11x10^{34} cm^{-1}s^{-1}$
- Data taken at $\Upsilon(4S)$, below $\Upsilon(4S)$(continuum), at $\Upsilon(5S)$, and above $\Upsilon(5S)$(scan)
- $\Upsilon(4S)$ is right on $B\bar{B}$ threshold
- $\Upsilon(5S)$ is just above $B_s\bar{B}_s$ threshold

Integrated Luminosity

Belle/KEKB Integrated luminosity passed 1000 fb-1



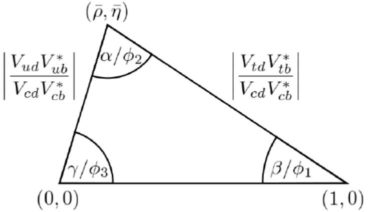
CKM matrix

- CKM matrix describes transition between quarks.
- Wolfenstein parametrization (expansion in powers of $\lambda \approx 0.22$) of the unitary CKM matrix:

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

3 real parameters (A, λ, ρ) + one complex phase (η) $\rightarrow$ irreducible phase, source of the CP violation in SM.

- Unitarity of matrix imposes 6 relations, e.g. $V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0$, which can be representated as triangles in the complex plane.



$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

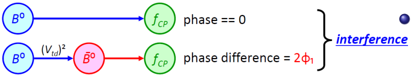
$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Experimental determination of the angles is closely related to measurements of CP asymmetries

Principle of Time-dependent CP Violation Measurements

Mixing induced CP Violation

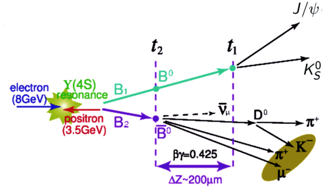


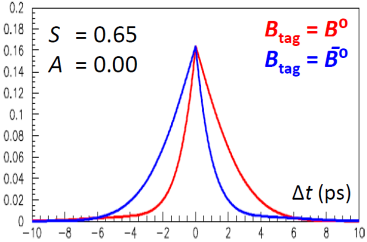
Mixing induced CPV manifests itself in a signed time duration "$\Delta t = t_{B_{CP}} - t_{B_{tag}}$", and a B meson flavor q, where

- $t_{B_{CP}}$: time when one B decays to the CP eigenstate.
- $t_{B_{tag}}$: time when the other B decays to the flavor-specific state.
- q : $+1$ for $B_{tag} = B^0$ and -1 for $B_{tag} = \bar{B}^0$.

There is an interference in ($B^0 \to f_{CP}$) process between a direct ($B^0 \to f_{CP}$) decay and a decay through the mixing as ($B^0 \to \bar{B}^0 \to f_{CP}$).

Mixing induced CP Violation





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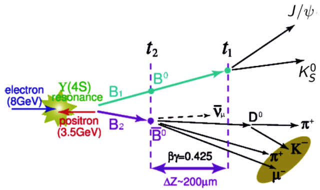
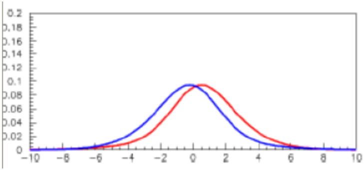
$$P_{sig}(\Delta t, q; S, A) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times [1 \pm q(A cos \Delta m_d \Delta t + S sin \Delta m_d \Delta t)]$$

Mixing induced CP Violation





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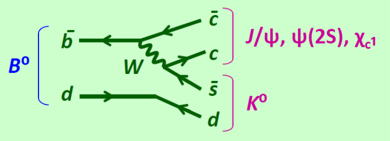
$$P_{sig}(\Delta t, q; S, A) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times [1(1-2\mathcal{W}) \pm q(A cos \Delta m_d \Delta t + S sin \Delta m_d \Delta t)] \bigotimes \mathcal{R}$$

- $\mathcal{W}$ wrong tag probability
- $\mathcal{R}$ Δt resolution

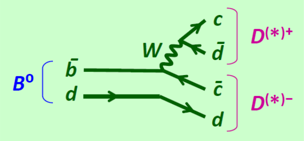
- $B^0 \to (c\bar{c})K^0$

($b \to c\bar{c}s$ tree transition)



- $B^0 \to D^{(*)+}D^{(*)-}$

($b \to c\bar{c}d$ tree transition)

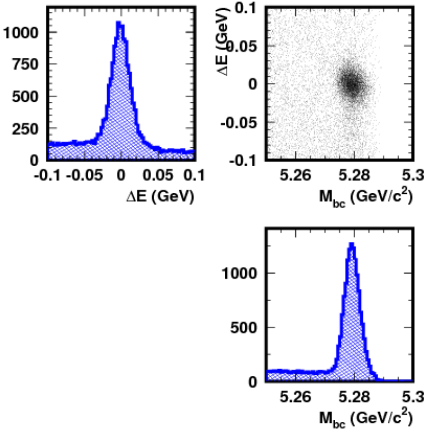


Both decays are mainly mediated by a tree diagram.
SM prediction: $S = -\eta_{CP} sin2\phi_1, A \approx 0$
$\eta_{CP} = \pm 1$ - CP eigenvalue of the final state.

In $\Upsilon(4S)$ decays, pairs of B mesons are produced near threshold.
$E_B = E_{CM}/2$, small CM momentum (300 MeV/c).

Selection variables:

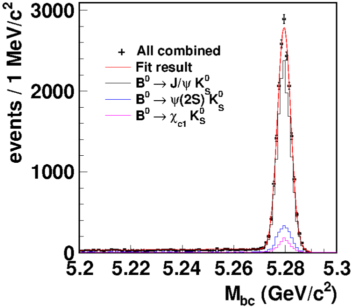
- CM energy difference $\Delta E = \Sigma E_i - E_{CM}/2$
- Beam-constrained mass of the B meson: $M_{bc} = \sqrt{(E_{CM}/2)^2 - (\Sigma p_i)^2}$

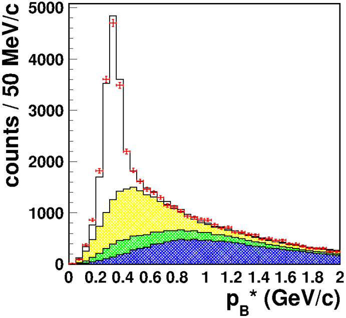


Missing information about K_L^0 momentum: K_L^0 cluster reconstructed in ECL or KLM, match it with the K_L^0 direction from kinematical constraints.

$B^0 \to (c\bar{c})K^0$ reconstruction

Improvement due to reprocessing with better tracking algorithm in addition to $\approx 40\%$ increase in $N_{B\bar{B}}$.

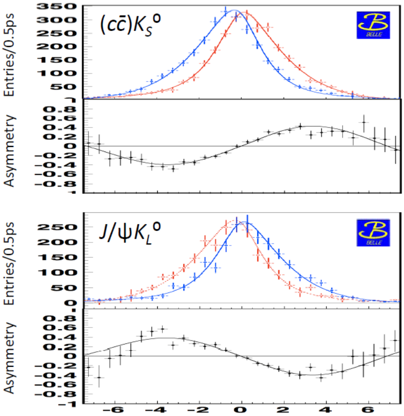


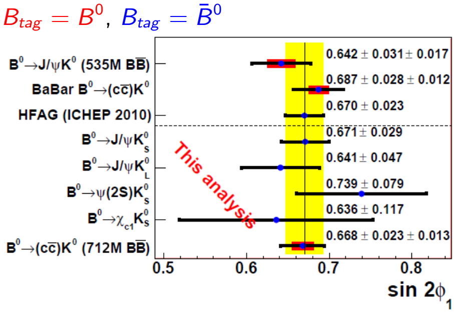


	$J/\psi K_S^0$	$J/\psi K_L^0$	$\psi(2S) K_S^0$	$\chi_{c1} K_S^0$	$N_{B\bar{B}}$ (x 10^6)
Signal yield	**12727±115**	**10087±154**	**1981±46**	**943±33**	**772**
Purity [%]	**97**	**63**	**93**	**89**	
Signal yield (ICHEP06)	7484±87	6512±123	–	–	535
Purity (ICHEP06) [%]	97	59	–	–	

from $772 \text{x} 10^6$ $B\bar{B}$ pairs = final Belle data sample

$B^0 \to (c\bar{c})K^0$ reconstruction





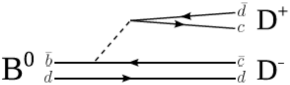
- The CP violation is observed in each charmonium mode.
- The most accurate measurement of UT parameters.

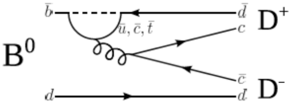
Belle with 772×10⁶ BB:

$$\mathcal{A} = 0.007 \pm 0.016\,(\text{stat}) \pm 0.013\,(\text{syst})$$

$$\sin(2\phi_1) = 0.668 \pm 0.023 \pm 0.013$$

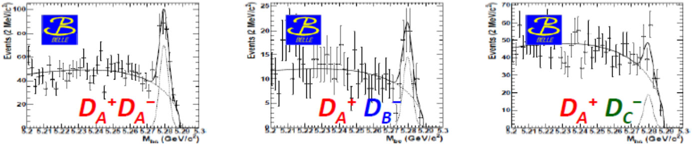
preliminary





Similar diagrams for $B^0 \to D^{*+}D^{*-}$

- Dominant contribution is from tree-diagram.
- SM predicts $S = -sin2\phi_1$ and $A = 0$
- Penguins can also contribute, changes values of S and A by few%.
- large deviation can be a clear sign of New Physics.

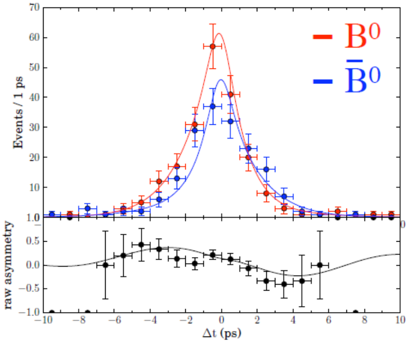


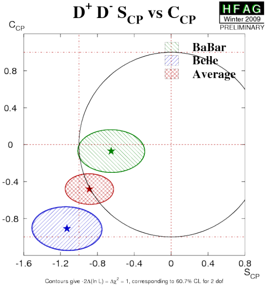
N_{sig}=221.4±18.6 BF=(2.16±0.18)x10^{-4} — N_{sig}=48.0±8.9 BF=(1.96±0.36)x10^{-4} — N_{sig}=54.1±14.6 BF=(1.83±0.49)x10^{-4}

$(K^-\pi^+\pi^+)(K^+\pi^-\pi^-)$ $(K^-\pi^+\pi^+)(K_S^0\pi^-)$ $(K^-\pi^+\pi^+)(K_s^0\pi^-\pi^0)$

$$B(B^0 \to D^+D^-) = (2.09 \pm 0.15 \pm 0.18)x10^{-4}$$

from $772x10^6$ $B\bar{B}$ pairs = final Belle data sample





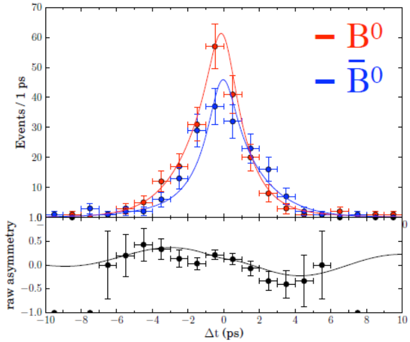
$K\pi\pi$ and $K_S\pi$ modes are used for CPV

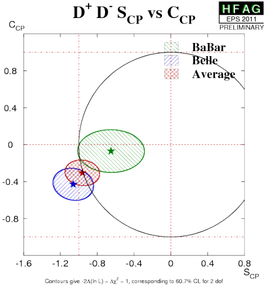
$S = -1.06 \pm 0.21 \pm 0.07$

$A = +0.43 \pm 0.17 \pm 0.04$

from 772x10^6 $B\bar{B}$ pairs = final Belle data sample

CPV in $B^0 \to D^+ D^-$ decays





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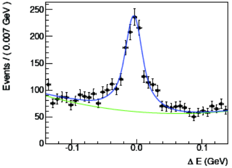
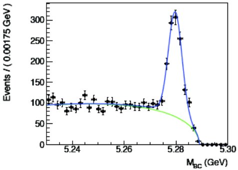
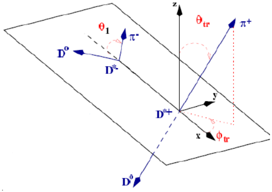




$B^0 \to D^{*+}(\to D^+\pi^0)D^{*-}(\to \bar{D}^0\pi^-)$
$B^0 \to D^{*+}(\to D^0\pi^+)D^{*-}(\to D^-\pi^0)$
$B^0 \to D^{*+}(\to D^0\pi^+)D^{*-}(\to \bar{D}^0\pi^-)$
$N_{sig} = 1225 \pm 59$

$$B(B^0 \to D^{*+}D^{*-}) = (7.82 \pm 0.38 \pm 0.60)x10^{-4}$$

- $B^0 \to D^{*+}D^{*-}$: mixture of CP-even and CP-odd ($P \to VV$ decay)
- Angular analysis is performed to extract CP violation parameters.
- Distributions of angles θ_{tr} and θ_1 give polarization amplitude ratios R_0 and $R_\perp$.
- We determine S, A, R_0 and $R_\perp$ simultaneously from a five-dimensional fit to the ΔE, M_{bc}, $cos\theta_{tr}$, $cos\theta_1$ and Δt distributions.



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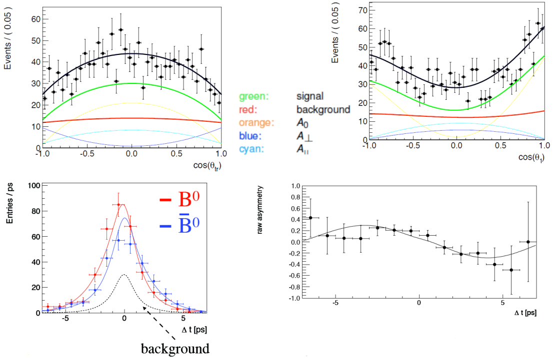
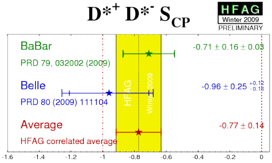
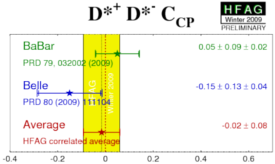
CPV in $B^0 \to D^{*+}D^{*-}$ decays







$A = -C_{CP}$

$\mathcal{S} = -0.79 \pm 0.13(\text{stat}) \pm 0.03(\text{syst})$

$\mathcal{A} = +0.15 \pm 0.08(\text{stat}) \pm 0.02(\text{syst})$

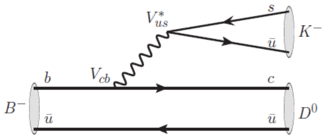
$\mathcal{R}_0 = 0.62 \pm 0.03(\text{stat}) \pm 0.01(\text{syst})$

$\mathcal{R}_\perp = 0.14 \pm 0.02(\text{stat}) \pm 0.01(\text{syst})$

Measurement of ϕ_3 in $B \to DK$ decays

Tree-level determination of ϕ_3 from interference of $B \to DK(b \to c\bar{u}s)$ and $B \to \bar{D}K(b \to u\bar{c}s)$ amplitudes

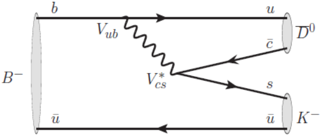
$B^- \to D^0 K^-$:



$A \sim V_{cb} V^*_{us} \sim A\lambda^3$

$+$

$B^- \to \bar{D}^0 K^-$:



$A \sim V_{ub} V^*_{cs} \sim A\lambda^3(\rho - i\eta)$

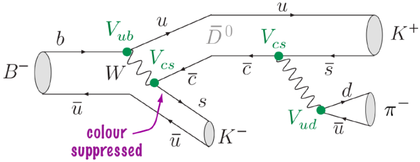
D^0 and $\bar{D}^0$ decay into the same final state: $|D> = |D^0> + re^{i\theta}|\bar{D}^0>$

Relative phase in $B^+ \to DK^+ : \theta = +\phi_3 + \delta$
$B^- \to DK^- : \theta = -\phi_3 + \delta$

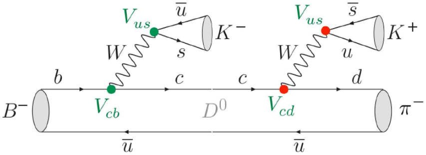
$$r = \left|\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)}\right| = \left|\frac{V_{ub} V^*_{cs}}{V_{cb} V^*_{us}}\right| \times [\text{ Color supp}] \approx 0.1$$

Three techniques to measure ϕ_3

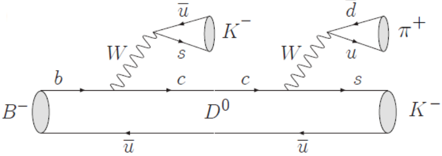
- GLW: uses CP eigenstates (Gronau and London, PLB 253, 483 (1991), Gronau and Wyler, PLB 265, 172 (1991))
- ADS: uses a final state f such that $D^0 \to f$ is Cabibbo-favored (CF) and $\bar{D}^0 \to f$ is doubly-Cabibbo-suppressed (DCS). (Atwood, Dunietz and Soni, PRL 78, 3257 (1997))
- GGSZ: uses Dalitz analysis when $D \to K^0_S \pi^+ \pi^-$ (Giri, Grossman, Soffer and Zupan, PRD 68, 054018 (2003))



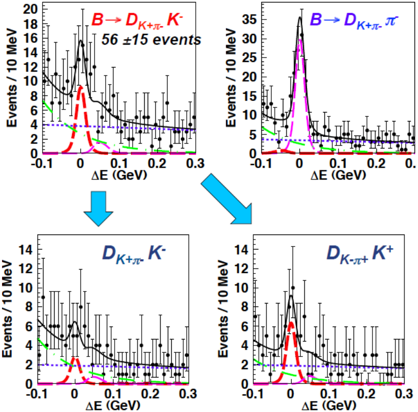
Cabibbo favoured D decay



doubly Cabibbo suppressed D decay



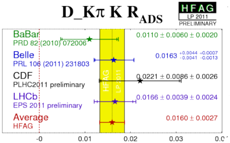
$$R_{DK} = \frac{\Gamma([K^+\pi^-]K^-)+\Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-)+\Gamma([K^+\pi^-]K^+)}$$
$$= r_B^2 + r_D^2 + 2r_B r_D cos(\delta_B + \delta_D) cos\phi_3$$
$$A_{DK} = \frac{\Gamma([K^+\pi^-]K^-)-\Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-)+\Gamma([K^+\pi^-]K^+)}$$
$$= 2r_B r_D sin(\delta_B + \delta_D) sin\phi_3 / R_{DK}$$

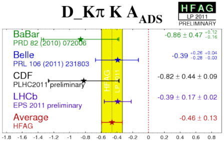


- Use a neural network (NN) to reject continuum $q\bar{q}$ background; include NN output in unbinned ML fit.
- for $B \to D_{K^+\pi^-} K^-$ 4.1σ excess of events

$$\mathcal{R}_{\rm ADS} = \left[1.63\,^{+0.44}_{-0.41}\,({\rm stat})\,^{+0.07}_{-0.13}\,({\rm syst})\right]\,\%$$

$$\mathcal{A}_{\rm ADS} = -0.39\,^{+0.26}_{-0.28}\,({\rm stat})\,^{+0.04}_{-0.03}\,({\rm syst})$$





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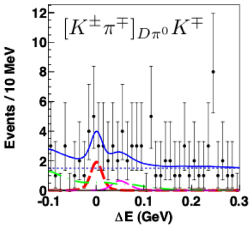
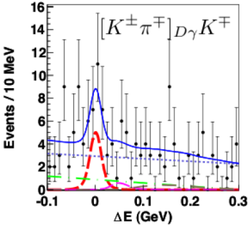
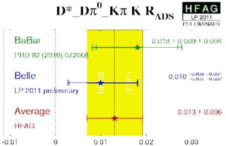
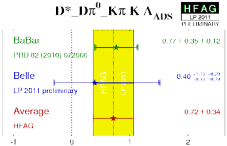
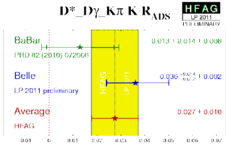
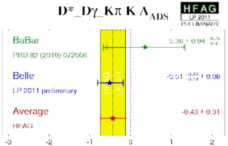






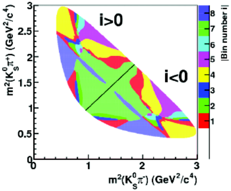






from $772 x 10^6$ $B\bar{B}$ pairs = final Belle data sample

GGSW method measures ϕ_3 via the interference in $B^- \to [K_S\pi^+\pi^-]_D K^-$ decays at every point in the D Dalitz plot



$$M_i^\pm = h\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i + y_\pm s_i)\}$$

$$x_\pm = r_B \cos(\delta_B \pm \phi_3) \quad y_\pm = r_B \sin(\delta_B \pm \phi_3)$$

$M_i^\pm$: numbers of events in $D \to K_S^0\pi^+\pi^-$ bins from $B^\pm \to DK^\pm$
K_i: numbers of events in bins of flavor $\overline{D}^0 \to K_S^0\pi^+\pi^-$ from $D^* \to D\pi$.
c_i, s_i contain information about strong phase difference between symmetric Dalitz plot points $(m^2_{K_S^0\pi^+}, m^2_{K_S^0\pi^-})$ and $(m^2_{K_S^0\pi^-}, m^2_{K_S^0\pi^+})$:

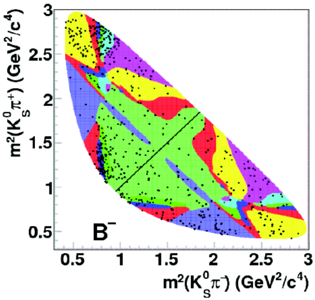
$$c_i = \langle\cos\Delta\delta_D\rangle, \quad s_i = \langle\sin\Delta\delta_D\rangle$$

PRD 81, 112002 (2010) former results for the unbinned Dalitz analysis for $B \to D^{(*)}$ from 657 million $B\bar{B}$ events: $\phi_3 = (78^{+11}_{-12} + \pm 4 \pm 9)^\circ$

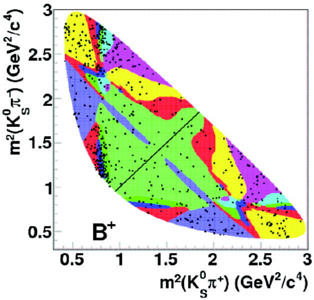
- new model-independent approach at Belle [EPJC 55, 51 (2008)]:

- bin Dalitz plot and use in each bin strong phase difference obtained in measurements on quantum-correlated D^0 decays in $\psi(3770) \to DD$ by CLEO

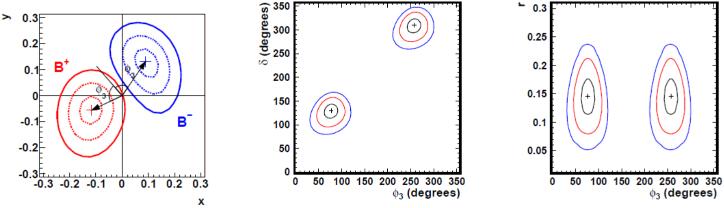
$B^- \to D^0 K^-$:



$B^+ \to D^0 K^+$:



Simultaneous fit to signal selection variables in all bins. Free parameters: (x, y), normalization, background fractions in bins.



Measurement of ϕ_3 in $B \to DK$ decays

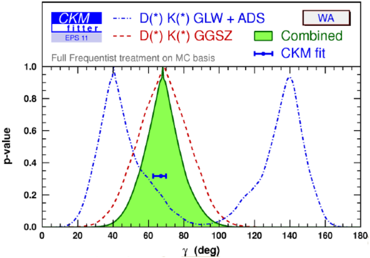
Belle Preliminary

$$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.2 \pm 4.3)^\circ$$
$$r_B = 0.145 \pm 0.030 \pm 0.011 \pm 0.011$$

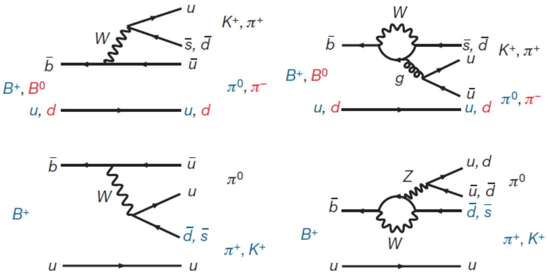
hep/ex 1106.4046

- 9° Model uncertainty replaced with 4.3° statistical uncertainty from CLEO
- Precision comparable to model-dependent analysis
- First try of novel procedure to be used at LHCb and Super B factories.

New ϕ_3 average
$\phi_3 = (68^{+13}_{-14})$ degrees



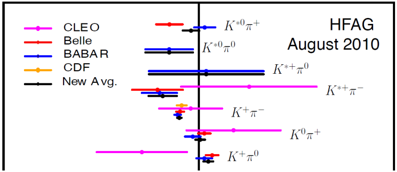
from $772x10^6$ $B\bar{B}$ pairs = final Belle data sample



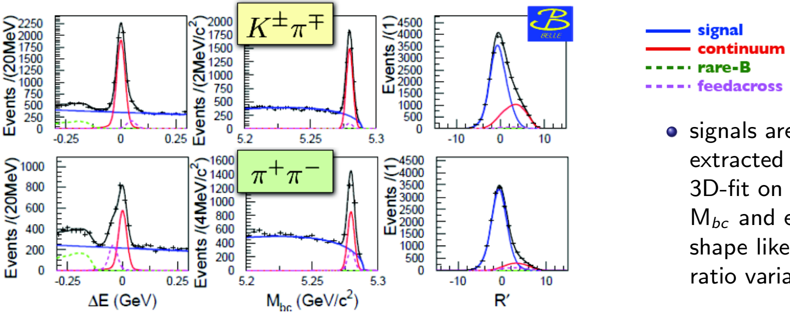
Tree-penguin interference a source of Direct CP Violation (DCPV)

- extract the CKM angle ϕ_2
- the "$K\pi$ puzzle": $\Delta A_{k\pi} \equiv A_{CP}(K^-\pi^0) - A_{CP}(K^-\pi^+) \neq 0$

A_{CP}



$B^0 \to K^\pm\pi^\mp$ and $\pi^+\pi^-$ decays



- signals are extracted by 3D-fit on ΔE; M_{bc} and event shape likelihood ratio variables

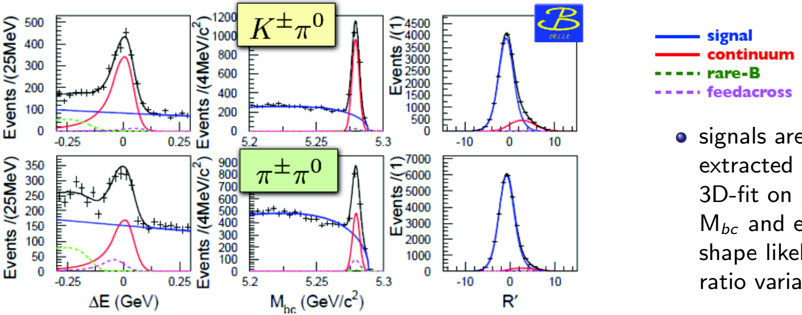
$B^0 \to K^\pm\pi^\mp$

- $N = 7527 \pm 127$
- $B = (20.00 \pm 0.34 \pm 0.63)x10^{-6}$
- $A_{CP} = (-0.069 \pm 0.014 \pm 0.007)$

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

- $N = 2111 \pm 89$
- $B = (5.04 \pm 0.21 \pm 0.19)x10^{-6}$

$B^0 \to K^{\pm}\pi^0$ and $\pi^+\pi^0$ decays



- signals are extracted by 3D-fit on ΔE; M_{bc} and event shape likelihood ratio variables

$B^0 \to K^{\pm}\pi^0$

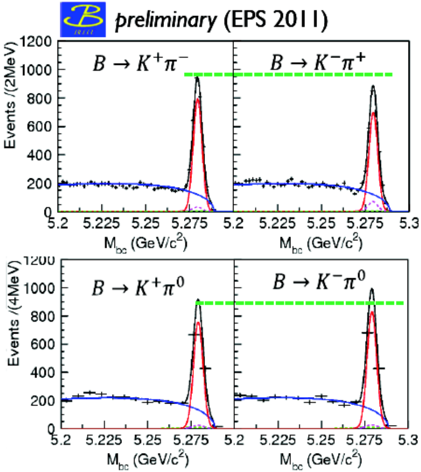
- $N = 3731 \pm 92$
- $B = (12.62 \pm 0.31 \pm 0.56)x10^{-6}$
- $A_{CP} = (+0.043 \pm 0.024 \pm 0.002)$

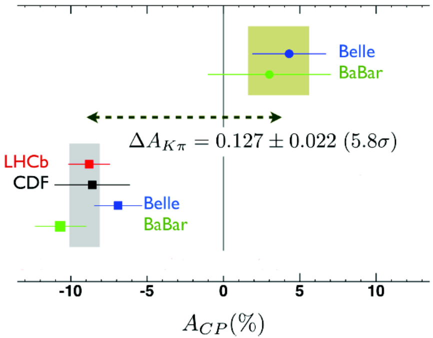
$B^0 \to \pi^+\pi^0$

- $N = 1846 \pm 82$
- $B = (5.86 \pm 0.26 \pm 0.38)x10^{-6}$
- $A_{CP} = (+0.025 \pm 0.043 \pm 0.007)$

The "$K\pi$ puzzle" remains, and has not been fully understood yet:

- enhanced color-suppressed tree?
- EW penguin?
    - negligible CP phase in SM) cannot affect ΔA by much
    - perhaps, picking up a new phase from NP?

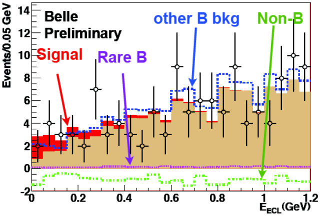




The big advantage of e^+e^- machines is that we have a well define final state. We are able to measure chanels with invisible energy, even with several missing neutrinos (up to 3). There are several tagging methods based on: inclusive or exclusive hadronic decays, semileptonic decays or flavor only tagging. Over the previous years we were able to present results on several channels basicaly not possible in hadronic machines:

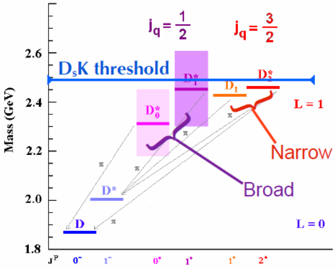
- $B^0 \to D^{(*)}\ell\nu$ measurement V_{cb} (new result this year)
- $B^0 \to X_c\ell\nu$ measurement V_{cb}
- $B^0 \to \pi\ell\nu$ measurement V_{ub} (new result this year)
- $B^0 \to X_u\ell\nu$ measurement V_{ub}
- $B \to D^{(*)}\tau\nu$ search for charged Higgs (first measurment)
- $B^+ \to \tau\nu_\tau$ - measurement V_{ub}, new physics search (first measurement)
- Search for $B^+ \to \ell\nu_\ell$
- Search for $B \to$ invisible -new physics search (new result this year)

$$B(B \to \nu\nu) < 1.3x10^{-4} \text{ at } 90\% \text{ C.L.}$$



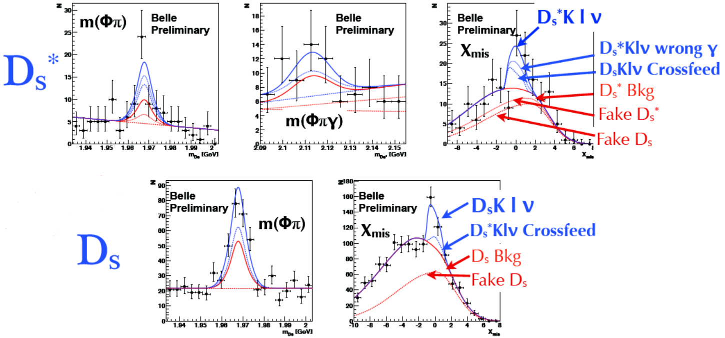
Puzzle: Measured sum of exclusive mode BR's $X_c = D + D^* + D^{**}$ doesn't match inclusive BR ($10-15\%$ unaccounted).

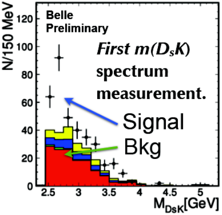
- Explore mass region above m($D_s K$) = 2.46 GeV where resonant and non-resonant contributions are present.
- Disentangling $D_s K l \nu$ and $D_s^* K l \nu$ gives new insights for modelling this region.
- Background to $B_s \to D_s X l \nu$ at $\Upsilon(5S)$ and hadron colliders. e.g. at LHCb $(f_u + f_d)/f_s \approx 6$



- Select B_{sig} in $D_s(\gamma)Kl^+(D_s \to \phi\pi)$.
- Remaining particles must be consistent with semileptonic B decay (B_{tag}).
- Minimal signal side selection to limit model dependence.
- Signal extraction based on $X_{mis} = \frac{(E_{beam} - E_{vis}) - p_{vis}}{\sqrt{E_{beam}^2 - M_B^2}}$ and $m(D_S^{(*)})$.
- Measure $D_s K$ and $D_s^* K$ modes simultaneously to measure cross feed.

$B \to D_s K l \nu$





Belle Preliminary

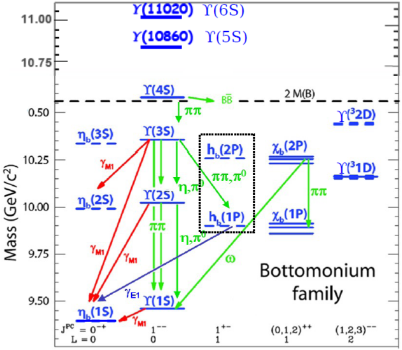
$$B(B \to D_s K l \nu) = (3.0 \pm 1.2^{+1.1}_{-0.8})x10^{-4}$$
$$B(B \to D_S^* K l \nu) = (2.9 \pm 1.6^{+1.1}_{-1.0})x10^{-4}$$

Combine significance 6σ

from $657x10^6$ $B\bar{B}$ pairs

$\Upsilon(5S)$ is over threshold to decay on $B_S\bar{B}_s$.

- Several interesting results on B_S decays:
  - $B_s \to J/\psi f_0(980)$ observation
  - Evidence for $B_s \to J/\psi f_0(1370)$
  - Clear observation of $B_s \to J/\psi\eta$
  - $B_S \to D_s^{(*)} D_s^{(*)} \to$ constraint on $\Delta\Gamma_S/\Gamma_S$
- strong interaction physics $\to$



in total 121 fb^{-1} data was taken on $\Upsilon(5S)$

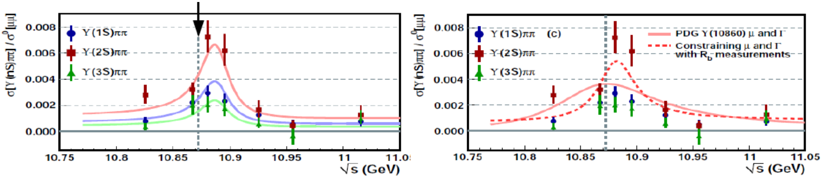
Anomalously large $\Upsilon(nS)\pi\pi$ transitions at the $\Upsilon(5S)$ (on-resonance)

Process	Γ_{total} [MeV]	$\Gamma_{e^+e^-}$ [keV]	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$ [MeV]
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032	0.612	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020	0.443	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5	0.272	0.0019
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	110	0.31	0.59

- 2007: 6-points scan (~1fb^{-1} per point)

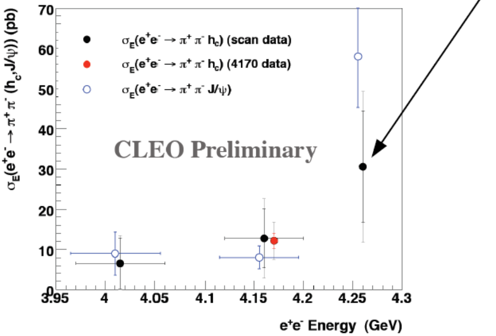
>100x larger

Maximum of Hadrons production



- Υ_b particle: analog to Y(4260) that has anomalously large $\Gamma(J/\psi\pi\pi)$
- Rescattering of $\Upsilon(5S) \to B\bar{B}\pi\pi \to \Upsilon(nS)\pi\pi$

- CLEO observed $e^+e^- \to h_c \pi^+\pi^-$
  - h_c production cross-section seems to be **enhanced near Y(4260)**



- Do we have more chance of seeing h_b at $\Upsilon(5S)$ if it is in fact Y_b?

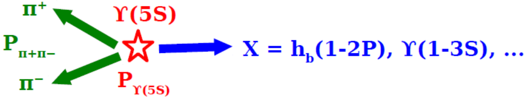
J. Wicht: $h_b(nP)$ and Z_b's at $\Upsilon(5S)$

Observation of $h_b(nP)$ at $\Upsilon(5S)$

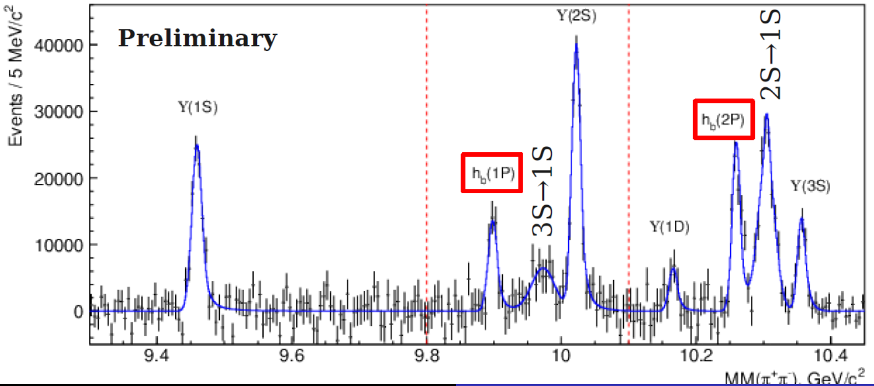
Analysis procedure:

- Implicit reconstruction of h_b thanks to e^+e^- annihilation constraints

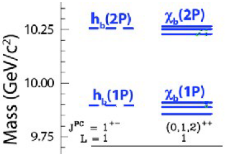
$$e^+e^- \rightarrow \Upsilon(5S) \rightarrow X\pi\pi$$



$$MM(\pi^+\pi^-) \equiv M_X = \sqrt{(P_{\Upsilon(5S)} - P_{\pi^+\pi^-})^2}$$



	Yield $[10^3]$	Mass $[\mathrm{MeV/c^2}]$	Significance
$\Upsilon(1S)$	$105.2 \pm 5.8 \pm 3.0$	$9459.42 \pm 0.53 \pm 1.02$	18.2
$h_b(1P)$	$50.4 \pm 7.8^{+4.5}_{-9.1}$	$9898.25 \pm 1.06^{+1.03}_{-1.07}$	5.5
$\Upsilon(3S) \to \Upsilon(1S)$	55 ± 19	9973.01	2.9
$\Upsilon(2S)$	$143.4 \pm 8.7 \pm 6.8$	$10022.25 \pm 0.41 \pm 1.01$	16.6
$\Upsilon(1D)$	22.1 ± 7.8	10166.2 ± 2.4	2.4
$h_b(2P)$	$84 \pm 7^{+23}_{-10}$	$10259.76 \pm 0.64^{+1.43}_{-1.03}$	11.2
$\Upsilon(2S) \to \Upsilon(1S)$	$151.6 \pm 9.7^{+9.0}_{-20.0}$	$10304.57 \pm 0.61 \pm 1.03$	15.7
$\Upsilon(3S)$	$44.9 \pm 5.1 \pm 5.1$	$10356.56 \pm 0.87 \pm 1.06$	8.5



- Could the observed states be $\chi_{b1}(nP)$? no
  - Measured masses are $\approx 3\sigma$ off compared to $\chi_{b1}(nP)$
  - $\Upsilon(5S) \to \chi_{b1}(nP)\pi^+\pi^-$ violates isospin (strong interaction)
- Mass are in very good agreement with CoG of $\chi_{b1}(nP)$ states
  - $h_b(1P)$:$\Delta M = 1.62 \pm 1.52 MeV/c^2$
  - $h_b(2P)$:$\Delta M = 0.48 \pm 1.57 MeV/c^2$

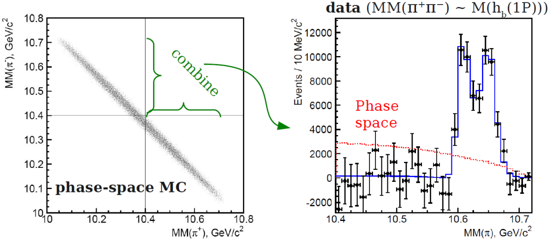
Consistent with hyperfine interaction.

Decays to h_b should be suppressed due to spin-flip $S(h_b(nP)) = 0$, $S(\Upsilon(nP)) = 1$

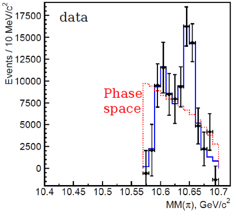
$$\frac{\Gamma(\Upsilon(5S)\to h_b(nP)\pi^+\pi^-)}{\Gamma(\Upsilon(5S)\to\Upsilon(2S)\pi^+\pi^-)} = \begin{cases} 0.407 \pm 0.07^{+0.043}_{-0.076} & \text{for } h_b(1P) \\ 0.78 \pm 0.09^{+0.22}_{-0.10} & \text{for } h_b(2P) \end{cases}$$

- $\Upsilon(5S) \rightarrow h_b\pi\pi$ decays dynamics

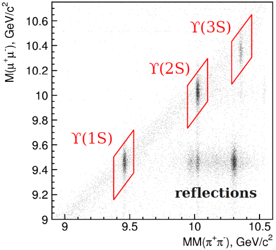
  Look at the missing mass of a single pion $MM(\pi^-) \equiv M(h_b\pi^+)$



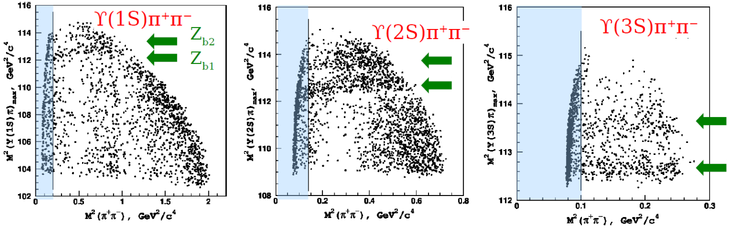
For $MM(\pi^+\pi^-) \approx M(h_b(2P)$, the allowed phase space is smaller but still two structure can be seen.



Observation of charged Z_b's states at $\Upsilon(5S)$

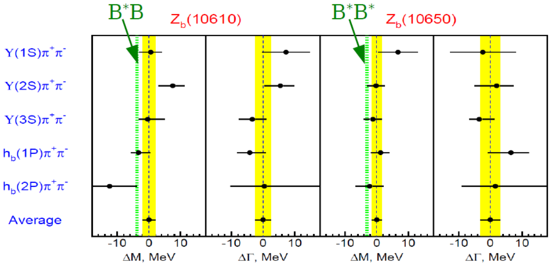


If you select $\Upsilon(5S) \to \Upsilon(nS)(\to \mu^+\mu^-)\pi^+\pi^-$ exclusive events. Perform Dalitz Plot analysis.



Exclude region with large bkg from photon conversions

Z_b parametres

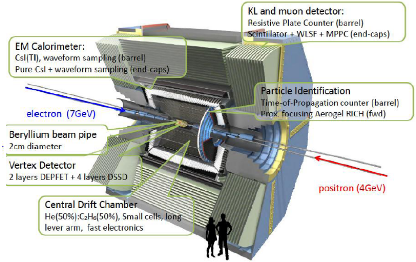


	$Z_b(10610)$	$Z_b(10650)$
M	10608.4±2.0	10653.2±1.5
Γ	15.6±2.5	14.4±3.2

- Parameters consistent between all five studied final states
- Masses just above B^*B and B^*B^* thresholds
- Relative phases swapped between Υ ($\approx 0^\circ$) and h_b ($\approx 180^\circ$)

Indicates Z_b's could be molecules

- We will start SuperKEKB accelerator from 2014
  - x40 time higher luminosity ($8x10^{35} cm^{-2}s^{-1}$)
  - The final integrated luminosity will be over 50 ab^{-1}
- Improved detector Belle II - data taking from 2015
  - better hermeticity
  - granularity - to sustain higher event rates.
  - improved particle identification →
  - less material before electromagnetic calorimeter.
  - faster response time



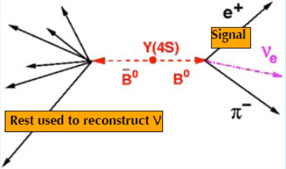
Summary

- Many new Belle results have been reported this year.
  - the best $sin2\phi_1$ measurement
  - the first model independent ϕ_3 measurement
  - new results on DCPV; $\Delta A(K\pi)$ remains large
  - new results for semileptonic B decays
  - Observation of h(1P) and h(2P) and two charged bottomonium-like states in $\Upsilon(5s)$
  - .... and many others:
    - CPV: $B^0 \to \phi K_S \gamma$ decays (arXiv:1104.5590), GLW ϕ_3 results for $B \to D_{CP} K$ (LP 2011)
    - Rare decays: $B \to h^+ h^-, h^+ h^0$, $B \to \eta\pi^-, \eta K^-, \eta K_S^0$ (LP2011)
    - CKM : V_{ub} with $\pi^{\pm}\ell\nu$ (arXiv:1012.0090), V_{cb} with $D^{*+}\ell\nu$ (arXiv:1010.5620)
    - $\Upsilon(5S)$ sample: $B_S \to D_S^{(*)} D_S^{(*)}$ (DPF 2011), evidence for $B_S \to J/\psi f_0(1370)$ (arXiv:1102.2759), Observation of $B_S \to J/\psi\eta($ EPS 2011), $B_S \to \Lambda_c^- \pi^+ \Lambda$ (EPS 2011)
    - Charm decays : Search for CP Violation in $D \to K_S^0 P$ (arXiv:1101.3365), ΔA_{CP} between $D^+ \to \phi\pi^+$ and $D_S^+ \to \phi\pi^+$ (EPS 2011), $D^+ \to h^+\eta, h^+\eta'$ (arXiv:1107.0553), Search for $1P \to 1S$ radiative transitions of D (ICHEP 2011), $\gamma\gamma \to \eta_c(2S) \to 6$ prong (ICHEP 2011)
    - New Particles: Observation of $X(3872) \to J/\psi\gamma$ and Search for $X(3872) \to \psi'\gamma$ (arXiv:1008.1774), $X(3872) \to J/\psi\pi^+\pi^-$ (arXiv:1107.0163), Search for $Y(4260) \to J/\psi\pi^0\pi^0$ (EPS 2011)
    - τ decays: Search for LFV τ decay into $\ell V^0 (V^0 = \rho, \phi, \omega, K^{*0}, \bar{K}^{*0})$ (arXiv:1101.0755), Search for LFV τ decay into $\ell P^0 (P^0 = \pi^0, \eta, \eta')$ (ICHEP 2010), CPV in $\tau \to K_S \pi\nu$ (arXiv:1101.0349), $\tau \to \ell h h' (h, h' = \pi^+, K^+)$ (FPCP 2011), $\tau \to \Lambda h, \bar{\Lambda} h$ (EPS 2011)
    - $\Upsilon(1,2,3S)$: Limits on $\Upsilon(1S) \to \gamma R$, where R is $\chi_{c0}, \chi_{c1}, \chi_{c2}, \eta_C, X(3872), X(3915)$ and $Y(4140)$ (arXiv:1008.1774), Limits on $\Upsilon(2S) \to \gamma R$, where R is $\chi_{cJ}, \eta_C, X(3872), X(3915), Y(4140), X(4350$ (EPS 2011), $\Upsilon(2S) \to \Upsilon(1S)\eta$ (EPS 2011)
- looking forward for even more results based on full, improved, reprocessed data
- and SuperKEKB and Belle 2

Backup

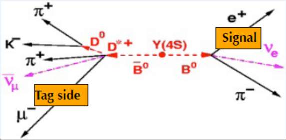
Untagged

Initial 4-momentum known
missing 4-momentum = one ν
Reconstruct B → X_q l ν
using m_B (beam-constrained)
and $\Delta E = E_B - E_{beam}$



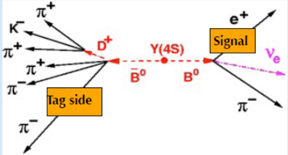
Semileptonic Tag

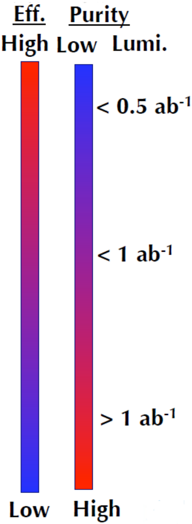
One B reconstructed in $D^{(*)}$ l ν modes.
Two missing ν in event.



Full Reconstruction Tag

One B reconstructed completely in a known b → c mode without ν.

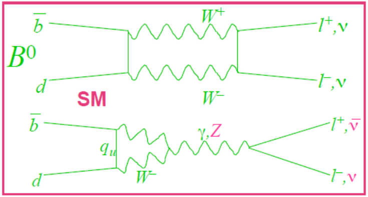




- **SM** strongly helicity suppressed by factor of order $(m_\nu/m_B)^2$

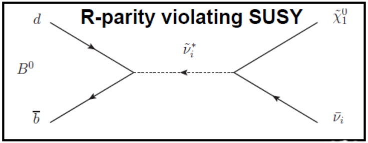
$$\mathcal{B}(B^0 \to \nu\overline{\nu}) = \tau_{B^0}\frac{G_F^2}{\pi}\left(\frac{\alpha}{4\pi \sin^2\Theta_W}\right)^2 F_{B^0}^2 m_\nu^2 m_{B^0} \times \sqrt{1-4m_\nu^2/m_{B^0}^2}\,|V_{tb}^* V_{td}|^2 Y^2(x_t),$$

G. Buchalla, A.J. Buras, Nucl. Phys. B 400,225(1993)



- **Any signal is a sign of New physics**
- Several New Physics models predict significant BRs for invisible decay of B^0
  - e.g. **R-parity** violating models:

$$10^{-7} < \mathcal{B}(B^0 \to \bar{\nu}\tilde{\chi}_1^0) < 10^{-6}$$

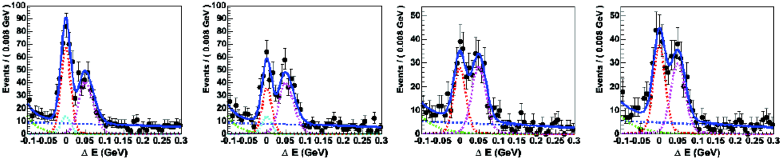


NuTeV Collab., T. Adams et al., PRD 65, 015001
A. Dedes, H. Dreiner, and P. Richardson, PRL 87 41801

New at Lepton Photon 2011 [740 fb^{-1}]

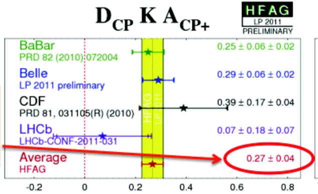
CP even: $D^0 \to K^+K^-, \pi^+\pi^-$

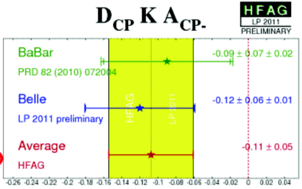
CP odd: $D^0 \to K_S\pi^0, K_S\phi$



$R_+ = 1.03 \pm 0.07 \pm 0.03$
$A_+ = 0.29 \pm 0.06 \pm 0.02$

$R_- = 1.13 \pm 0.09 \pm 0.05$
$A_- = -0.12 \pm 0.06 \pm 0.01$





CP Violation Clearly Established

- Fit Δt distribution by allowing CPT violation.
  - $J/\psi K_S$, $J/\psi K_L$ $\Rightarrow$ Re(z), $\Delta\Gamma_d/\Gamma_d$
  - $D^-\pi^+$, $D^{*-}\pi^+$, $D^{*-}l^+\nu$ $\Rightarrow$ Im(z)
  - $D^0\pi^+$, $J/\psi K^+$ $\Rightarrow$ Δt resolution

$$P(\Delta t, q; z) = \frac{\Gamma_d}{2} e^{-\Gamma_d|\Delta t|}\left[\frac{|\eta_+|^2+|\eta_-|^2}{2}\cosh\frac{\Delta\Gamma_d}{2}\Delta t - \mathrm{Re}(\eta_+\eta_-^*)\sinh\frac{\Delta\Gamma_d}{2}\Delta t + \frac{|\eta_+|^2-|\eta_-|^2}{2}\cos\Delta m_d\Delta t - \mathrm{Im}(\eta_+\eta_-^*)\sin\Delta m_d\Delta t\right]$$

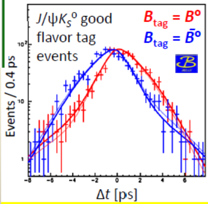
- CPT violating parameter: z

If Re(z) and /or Im(z) $\neq$ 0, CPT is violated.

$$\eta_+ \equiv A_1\bar{A}_2 - \bar{A}_1 A_2,$$
$$\eta_- \equiv \sqrt{1-z^2}\left(\frac{p}{q}A_1A_2 - \frac{q}{p}\bar{A}_1\bar{A}_2\right)$$
$$A_1 \equiv \langle f_1|H_d|B^0\rangle, \quad \bar{A}_1 \equiv \langle f_1|H_d|\bar{B}^0\rangle,$$
$$A_2 \equiv \langle f_2|H_d|B^0\rangle, \quad \bar{A}_2 \equiv \langle f_2|H_d|\bar{B}^0\rangle,$$

$$\mathrm{Re}(z) = (+1.9 \pm 3.7 \pm 3.2)\times 10^{-2}$$
$$\mathrm{Im}(z) = (-5.7 \pm 3.3 \pm 6.0)\times 10^{-3}$$
$$\Delta\Gamma_d/\Gamma_d = (-1.7 \pm 1.8 \pm 1.1)\times 10^{-2}$$

535 x 10^6 $B\bar{B}$ pairs



Light lines indicate Re(z) = +0.2 Im(z) = +0.0 case.

No CPT violation is observed.

$h_b(nP)$ properties

$b\bar{b}$ states, spin 0, L=1, $J^{PC}=1^{+-}$

- Expected mass of $h_b(nP)$ at the **Center of Gravity** (CoG) of χ_b states
  - Test of **hyperfine** splitting
- **Radiative transition to $\eta_b(nS)$**
  - BaBar has obtained evidence of $h_b(1P)$ in $\Upsilon(3S)\to\pi^0 h_b(1P)\to\pi^0\gamma\eta_b(1S)$