$\Upsilon(5S)$ decays to B^0 and B^+ mesons and scan around $\Upsilon(5S)$

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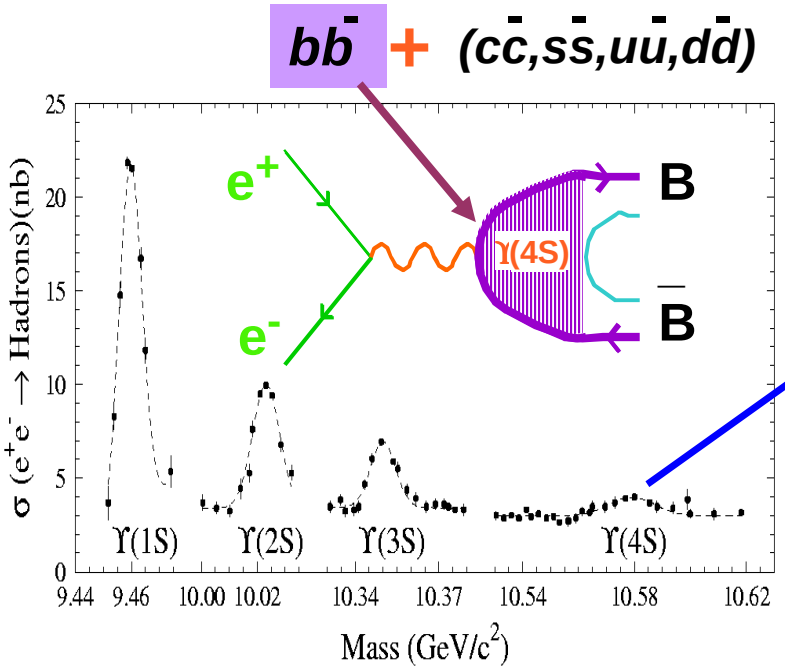
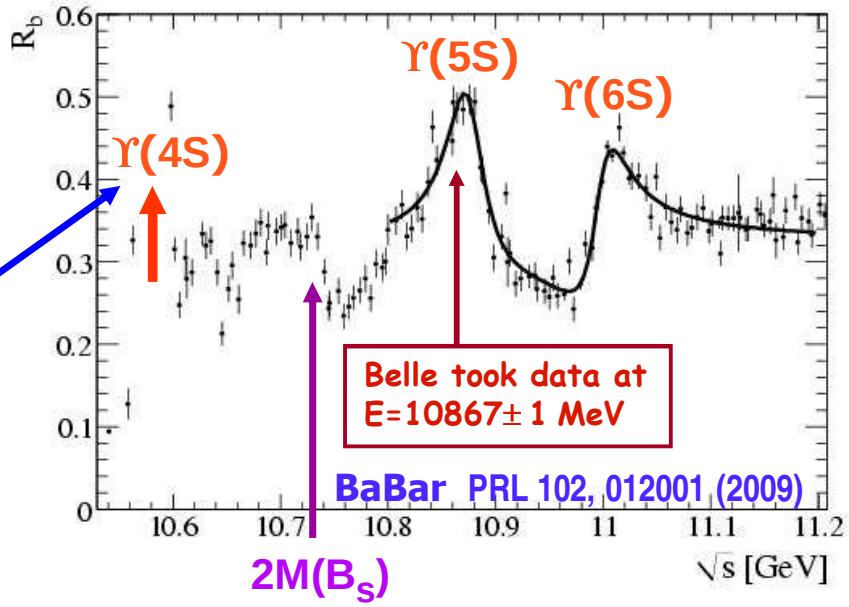
$e^+ e^-$ hadronic cross section





$e^+ e^-$ -> Υ(4S) -> $B\bar{B}$, where B is B^+ or B^0 meson

M(Υ(5S)) = 10876 ± 2 MeV/c^2

Γ(Υ(5S)) = 43 ± 4 MeV/c^2 (BaBar)

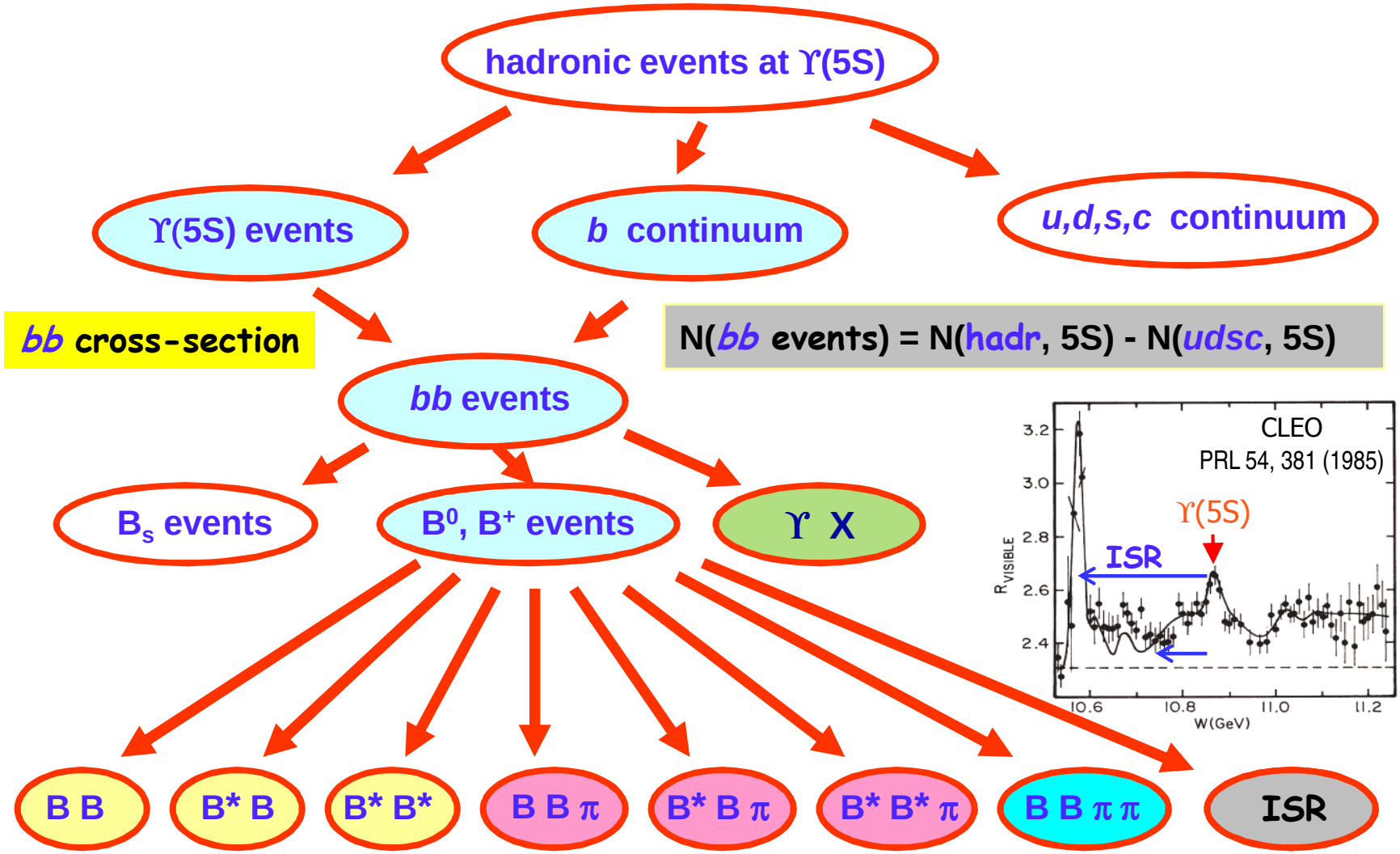
$e^+ e^-$ -> $b\bar{b}$ (Υ(5S)) -> $B^{(*)}\bar{B}^{(*)}$, $B^{(*)}\bar{B}^{(*)}\pi$, $B\bar{B}\pi\pi$, $B_s^{(*)}\bar{B}_s^{(*)}$, Υ(1S)ππ , Υ X …

where B^* -> B γ and B_s^* -> B_s γ

CLEO: 2003: ~0.42 fb^{-1}

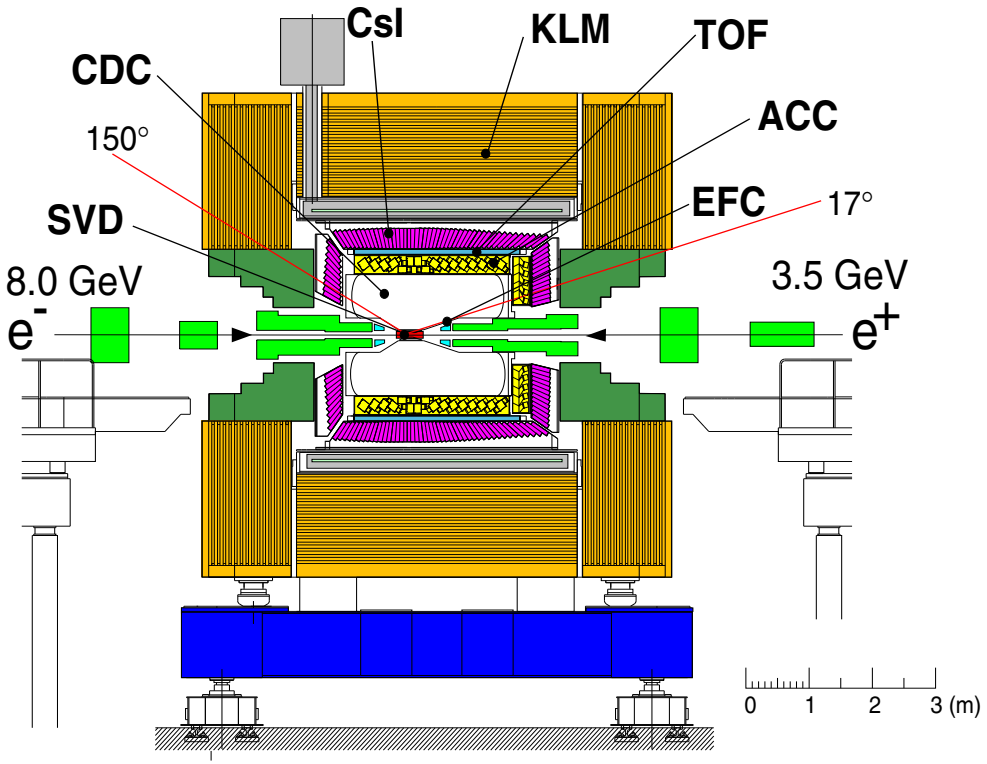
Belle: 2005 1.86 fb^{-1}, 2006 21.7 fb^{-1},
2008 ~27 fb^{-1}, 2009 ~71 fb^{-1}

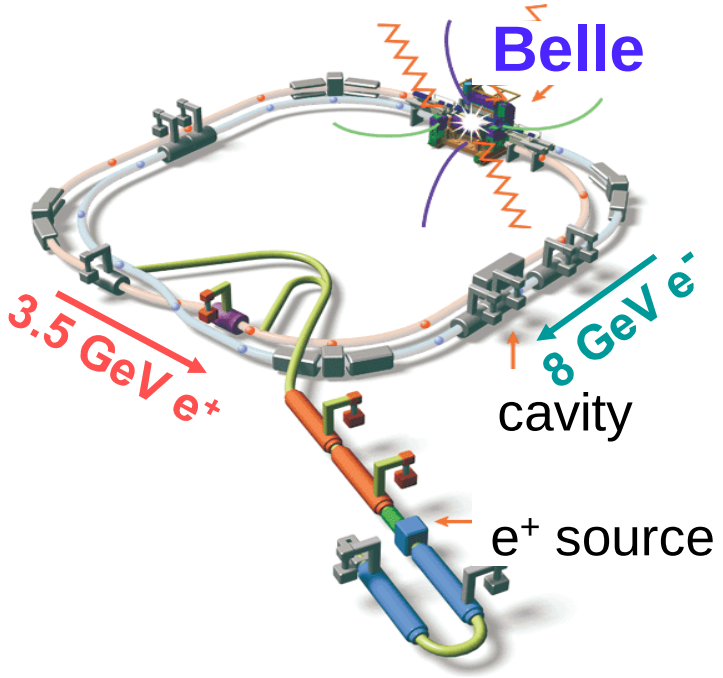
Hadronic event classification at Υ(5S)



Belle data taking at $\Upsilon(5S)$

Belle detector





E(e+): 3.500 GeV -> 3.595 GeV,
E(e-) : 7.996 GeV -> 8.211 GeV.

No modifications are required for Belle detector, trigger system or software to move $\Upsilon(4S)$ -> $\Upsilon(5S)$.

Electron and positron beam energies are increased by 2.7% (same Lorentz boost $\beta\gamma$=0.425) to move from $\Upsilon(4S)$ to $\Upsilon(5S)$.

Theoretical model for $\Upsilon(5S)$ decays to $B\bar{B}$ pairs

Cornell model modified for bottomonium arXiv:0812.4402 [hep-ph]

Decay rate of $\Upsilon(5S)$ with spin s=1 and mass M to $B^{(*)}B^{(*)}$-pair with spins s_1+s_2:

$$\Gamma = (1/8\pi)\ (P/M)\ E_1\ E_2\ C(s\,s_1s_2)\ |A_{5S}(P)|^2$$

where P, E_1, E_2 – momentum and energies of final B mesons in CM.

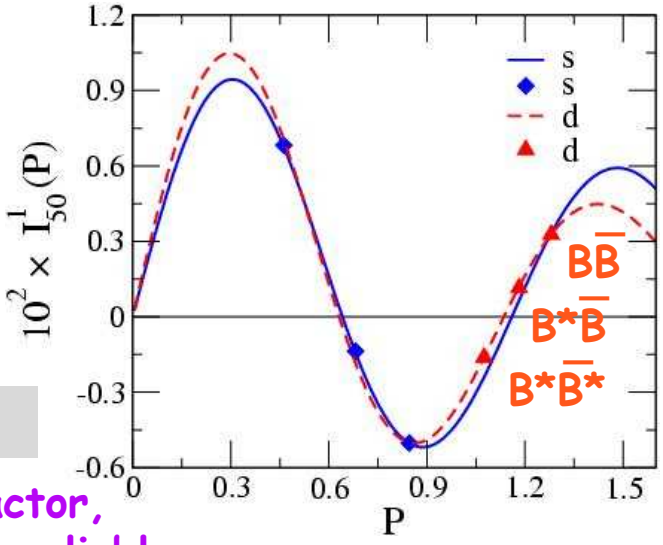
$C(s\,s_1s_2)$ spin counting factor => 1/3 : 4/3 : 7/3 for $B\bar{B}$, $B^*\bar{B}$, $B^*\bar{B}^*$

Decay amplitude:

$$A_{5S}(P) = 4\pi\ f_q\ I_{nL}^{\,l}(P)$$

where f_q includes only quark masses

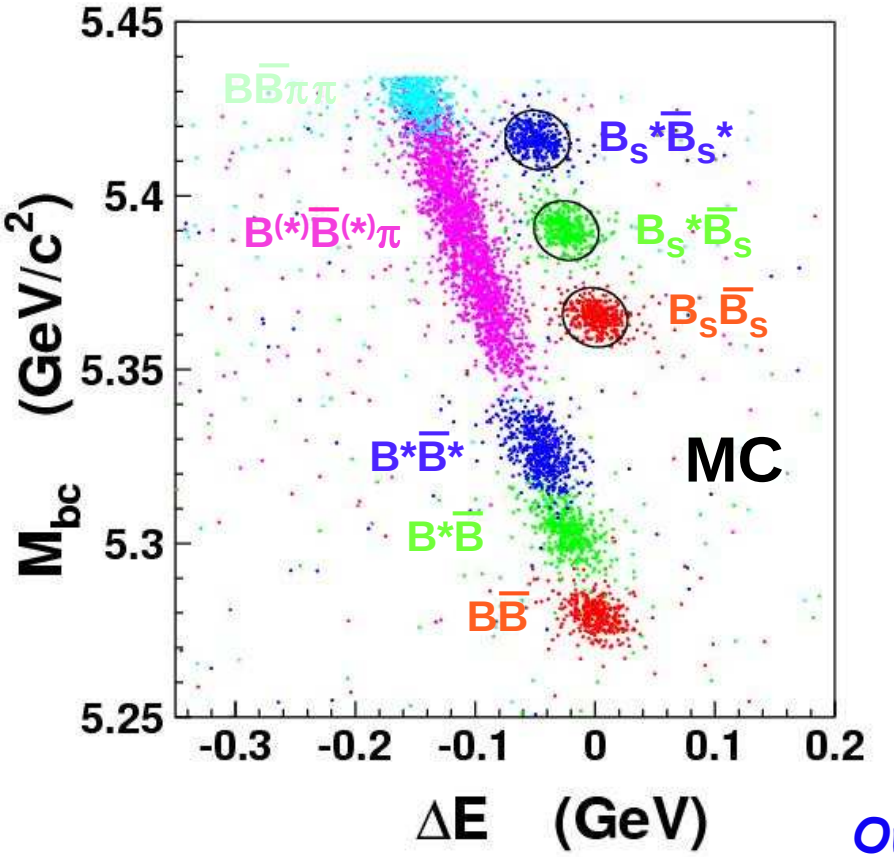
Problem: amplitude oscillates fast, nodes



Two heavy quarks: calculations should be reliable

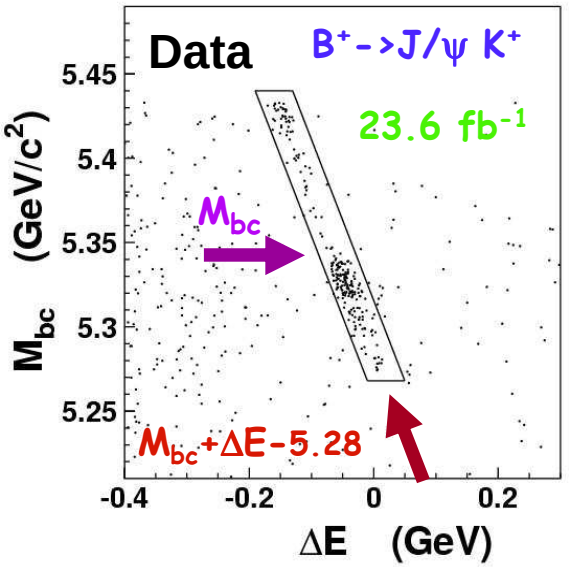
3-body final states: ratio $\sigma(3)/\sigma(2)$: pion form-factor, large model and parameter uncertainties, not very reliable

Signature of fully reconstructed B decays



$e^+ e^- \to \Upsilon(5S) \to B^{(*)}B^{(*)}(\pi)(\pi)$,

where $B^* \to B\gamma$



Only one B meson is reconstructed

Two variables calculated: $M_{bc} = \sqrt{E^*_{beam}{}^2 - P^*_B{}^2}$, $\Delta E = E^*_B - E^*_{beam}$

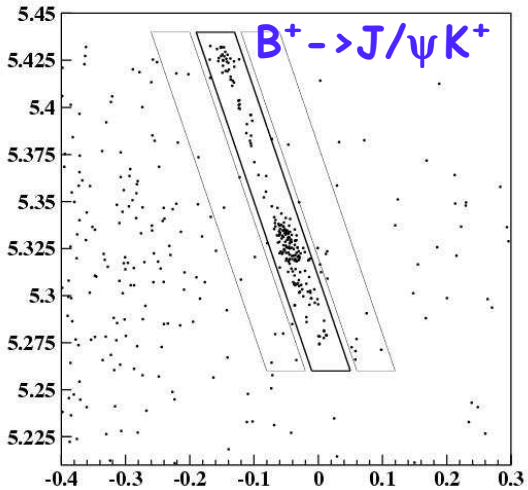
B energy (E^*_B) and momentum (P^*_B) are reconstructed; no rec. γ from B^*

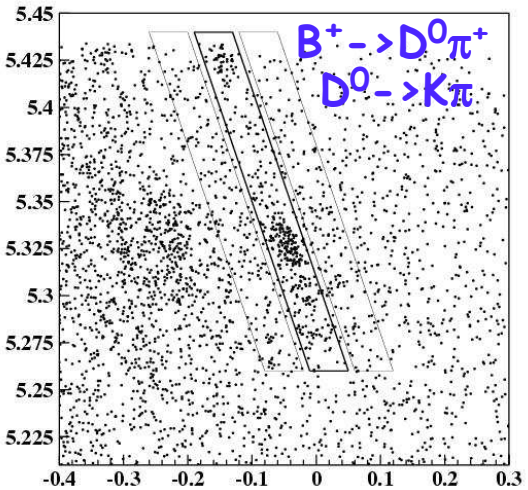
ΔE vs M_{bc} distributions

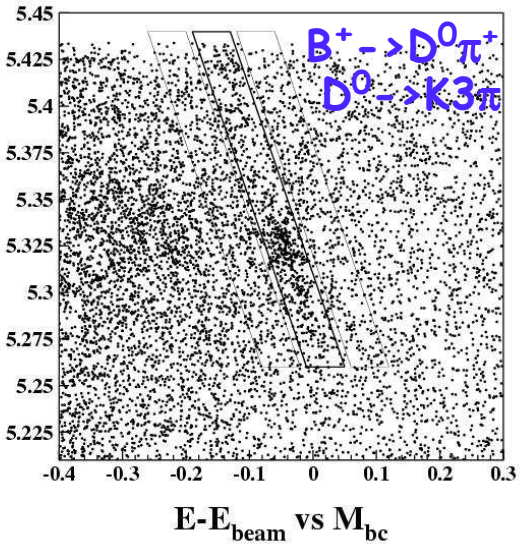
L=23.6 fb^{-1}

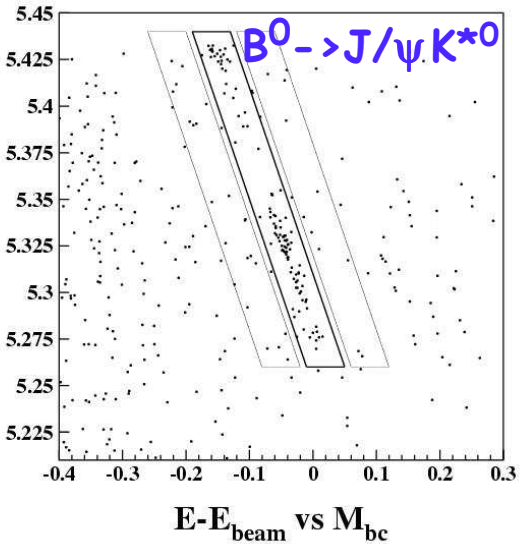
Five B modes are studied: only charged tracks in final state, PDG branching fraction errors are 3-5% => small systematic errors

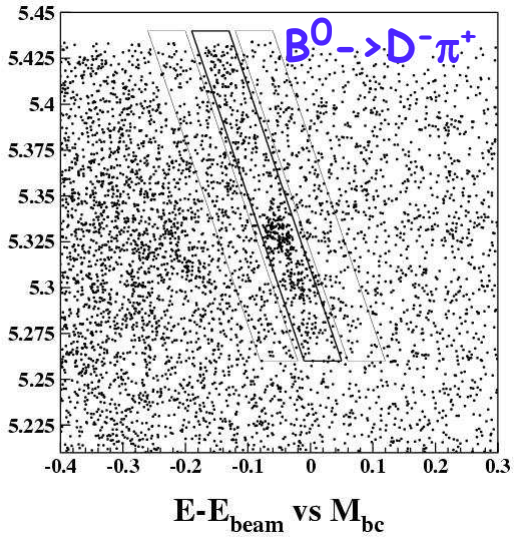
Clear B signals are seen in signal regions for all 5 studied B decays.





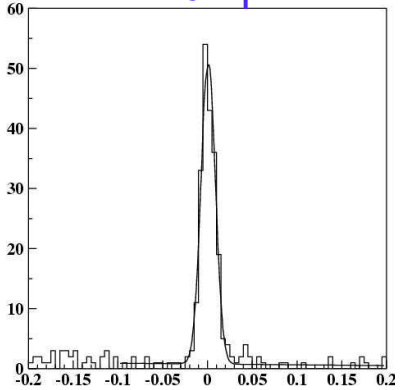




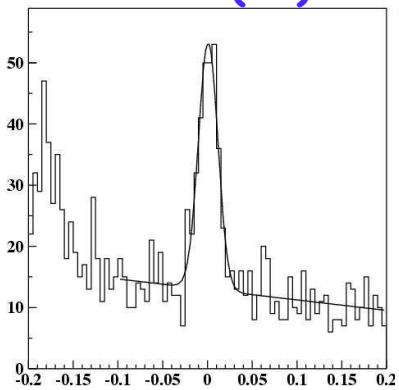


$M_{bc}+\Delta E-5.28$ projections

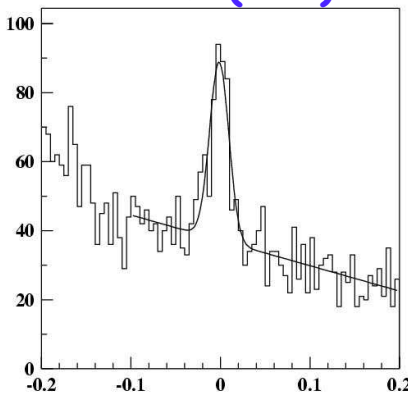
$B^+ \to J/\psi K^+$



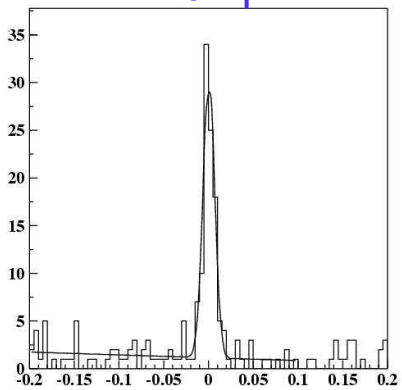
$B^+ \to D^0(K\pi)\pi^+$



$B^+ \to D^0(K3\pi)\pi^+$



$B^0 \to J/\psi K^{*0}$



$f(X)=N(X)/N(b\bar{b})$

$B^+ \to J/\psi K^+$	$89.0 \pm {}^{6.3}_{6.1} \pm 8.0$ %
$B^+ \to D^0(K\pi)\pi^+$	$64.0 \pm 6.2 \pm 4.9$ %
$B^+ \to D^0(K3\pi)\pi^+$	$68.3 \pm {}^{8.0}_{8.1} \pm 6.4$ %
$B^0 \to J/\psi K^{*0}$	$85.3 \pm {}^{9.2}_{8.8} \pm 8.8$ %
$B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$	$72.9 \pm 7.4 \pm 6.4$ %

B+

$72.1 \pm {}^{3.9}_{3.8} \pm 5.0$ %

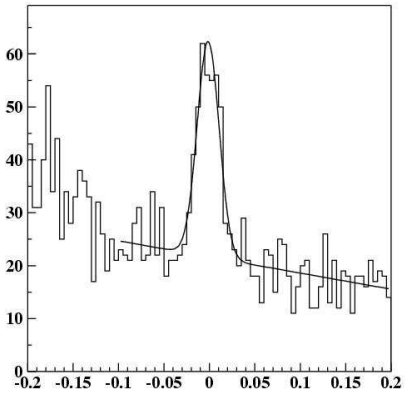
B^0

$77.0 \pm {}^{5.8}_{5.6} \pm 6.1$ %

Σ

$73.7 \pm 3.2 \pm 5.1$ %

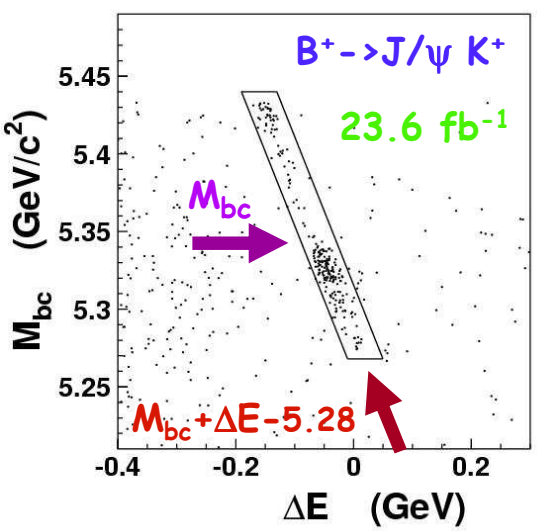
$B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$

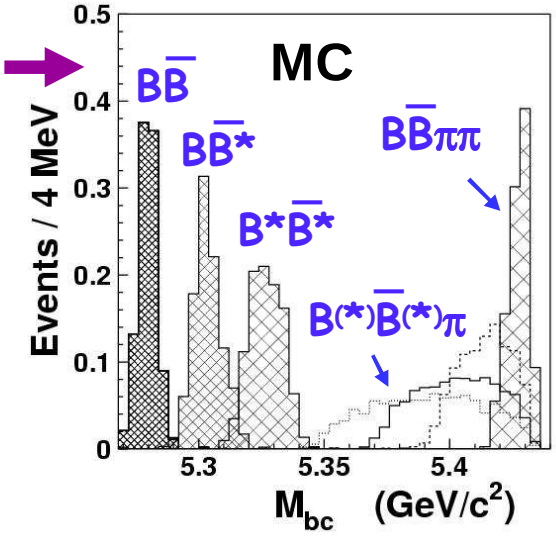


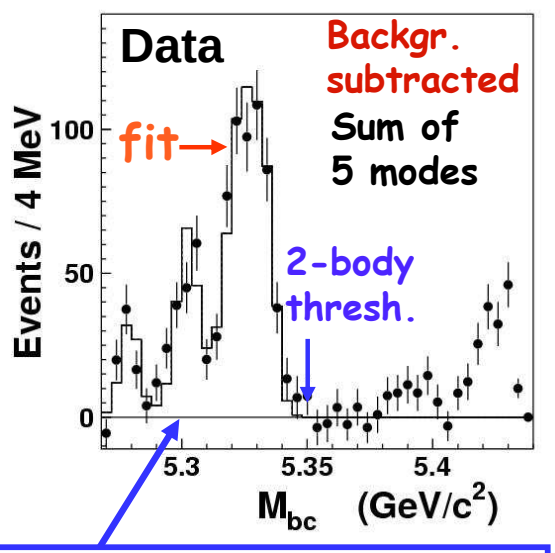
58.9 ± 10.0 ± 9.2 % (CLEO 2006)

Sum B_s: $19.5 \pm {}^{3.0}_{2.2}$ % (PDG, Belle+CLEO).

Υ(5S) decays to B^0 and B^+ mesons







Simultaneous fit of 5 B modes in $M_{bc} < 5.35\,GeV/c^2$ region

Channel fractions per *bb*-pair:

$B\bar{B}$: $5.5 \pm ^{1.0}_{0.9} \pm 0.4$ %

$B^*\bar{B}$: $13.7 \pm 1.3 \pm 1.1$ %

$B^*\bar{B}^*$: $37.5 \pm ^{2.1}_{1.9} \pm 3.0$ %

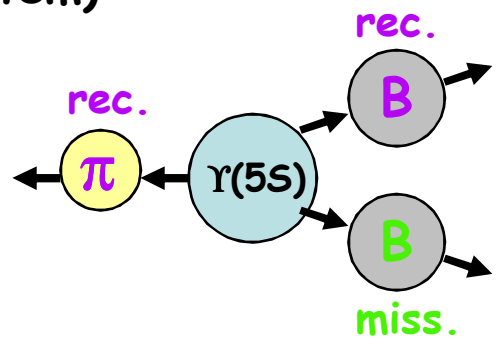
$M_{bc} > 5.35$ GeV/c: $17.5 \pm ^{1.8}_{1.6} \pm 1.3$ % => not 2-body channels, why so large?

Theory: channel $B^*\bar{B}^*$ is dominant, 30-69%

Results should be used to adjust theory

Decomposition of 3-body channels

We reconstruct directly produced pion in $B^{(*)}\bar{B}^{(*)}\pi^+$ channels.
Then we calculate parameters (all in CM system):



Reconstructed B meson:

M_{bc}, ΔE ; $\Delta X(rec) = M_{bc} + \Delta E - 5.28$

Missing B meson:

use momentum $P(B\pi)$ and energy $E(B\pi)$ of reconstructed B and π:

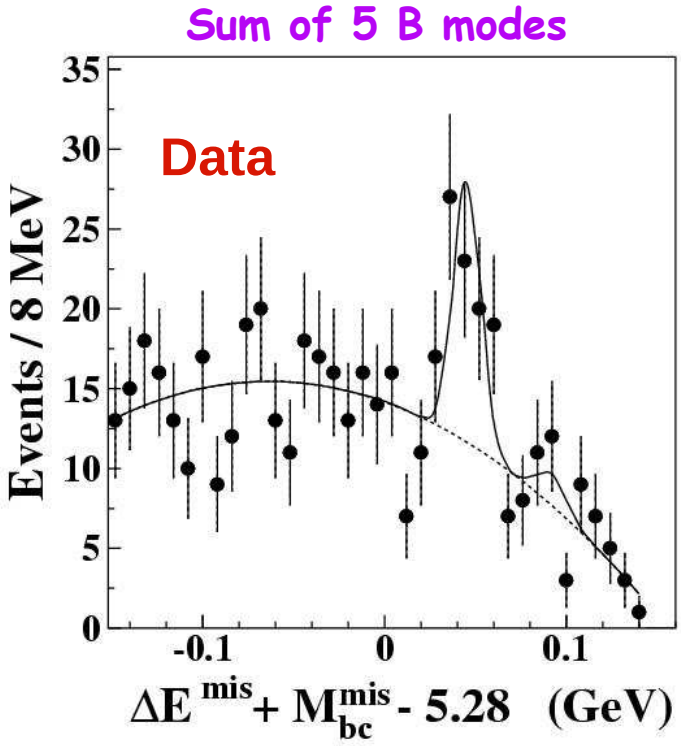
$M_{bc}^{miss} = sqrt(E^2_{beam} - P(B\pi)^2)$, because $P(B_{miss}) = P(B\pi)$

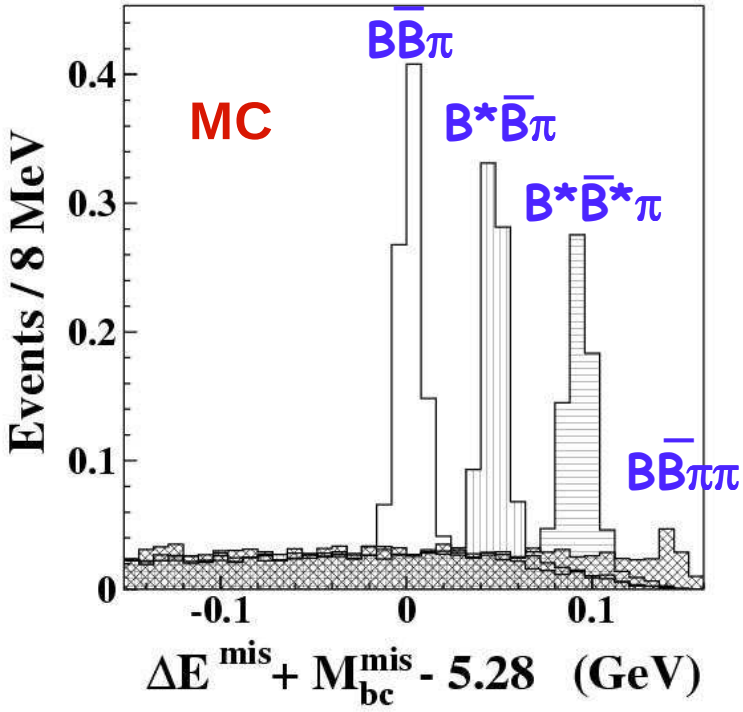
$\Delta E^{miss} = E_{beam} - E(B_{miss}) = E(B\pi) - E_{beam}$

$\Delta X(miss) = M_{bc}^{miss} + \Delta E^{miss} - 5.28$

$\Delta X(corr) = \Delta X(miss) + \Delta X(rec)$ -> to decrease uncertainty

Decomposition of 3-body channels





Only B candidates from signal region with M_{bc}^{rec}>5.37 MeV/c^2

We assume Clebsch-Gordan coefficients: Fr($\pi^{\pm}$)/Fr(π^0)=2:1

Decomposition of 3-body channels

Fractions for different components averaged over 5 studied B decays (assuming equal B+ and B^0 production):

	Events	Fraction over M>5.37	Fraction over $b\bar{b}$
$B\bar{B}\pi^+$	$0.2 \pm {}^{7.2}_{6.9}$	$(0.2 \pm {}^{6.8}_{6.5})\%$	$(0.0 \pm 1.2 \pm 0.3)\%$
$B^*\bar{B}\pi^+$	$38.3 \pm {}^{10.5}_{9.8}$	$(41.6 \pm {}^{12.1}_{11.4})\%$	$(7.3 \pm {}^{2.3}_{2.1} \pm 0.8)\%$
$B^*\bar{B}^*\pi^+$	$4.8 \pm {}^{6.4}_{5.9}$	$(5.9 \pm {}^{7.8}_{7.2})\%$	$(1.0 \pm {}^{1.4}_{1.3} \pm 0.4)\%$
Residual		$(52.3 \pm {}^{15.9}_{15.0})\%$	$(9.2 \pm {}^{3.0}_{2.8} \pm 1.0)\%$
All	$228.7 \pm {}^{22.9}_{22.3}$	100%	$(17.5 \pm {}^{1.8}_{1.6} \pm 1.3)\%$

Channel $B^*\bar{B}\pi$ decays in S-wave ($1^-0^-0^-$), $B\bar{B}\pi$ decays with 2 P-waves ($0^-0^-0^-$)

Large fraction of 3-body $B^*\bar{B}\pi^+$ => not predicted by theory

Theory, 3-body fractions:
~0.3% : L.Lellouch et al Nucl Phys B405:55,1993
~0.03% : Yu.Simonov et al hep-ph:0805.4518

Residual is too large for $B\bar{B}\pi\pi$ channel. We calculated probability of ISR and got ~10% (~4% to $\Upsilon(4S)$ and ~6% above $\Upsilon(4S)$). Reasonable agreement with residual.

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

K.-F. Chen et al. (Belle coll), PRL 100, 112001 (2008)

L= 21.7 fb^{-1}

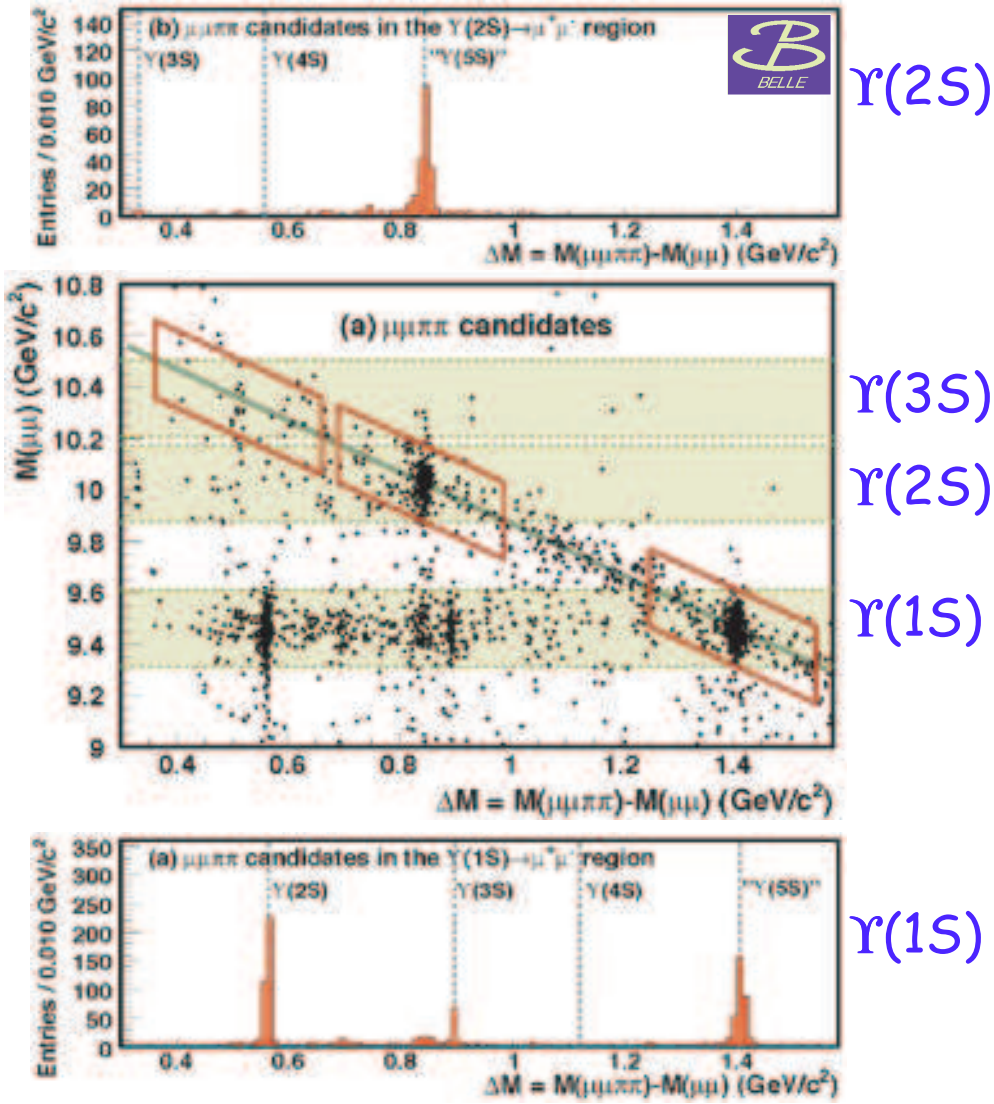
-> look for: $\mu^+\mu^- h^+ h^-$

$e^+e^- \to \Upsilon(1S)\,\pi^+\pi^- X$

$e^+e^- \to \Upsilon(2S)\,\pi^+\pi^- X$

$e^+e^- \to \Upsilon(3S)\,\pi^+\pi^- X$

In contrast to expectations significant fraction of $\Upsilon(5S)$ ($b\bar{b}$) decays to non-$B\bar{B}$ states.



$\Upsilon(5S)$ decays to bottomonium

4 modes seen : $\Upsilon(5S) \to \Upsilon(nS)\, h^+ h^-$

Process	σ(pb)	$\mathcal{B}(\%)$	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

Process	Γ_{total}	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2

Possible explanations:

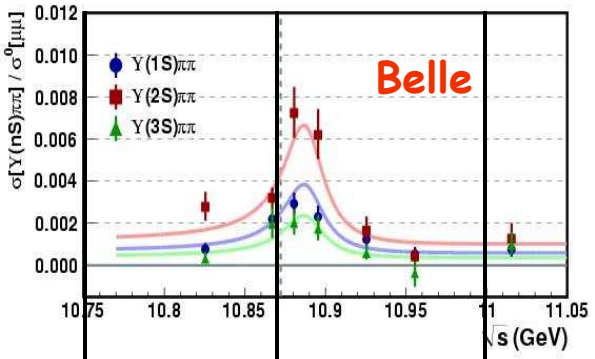
1. Rescattering mechanism $\Upsilon(5S) \to B'B'\pi\pi \to \Upsilon(1S)\pi\pi$, suppressed at $\Upsilon(4S)$ (Simonov)
2. It comes not from $\Upsilon(5S)$, but from near Y_b- analog of hybrid $Y_c(4260)$ (Hou)

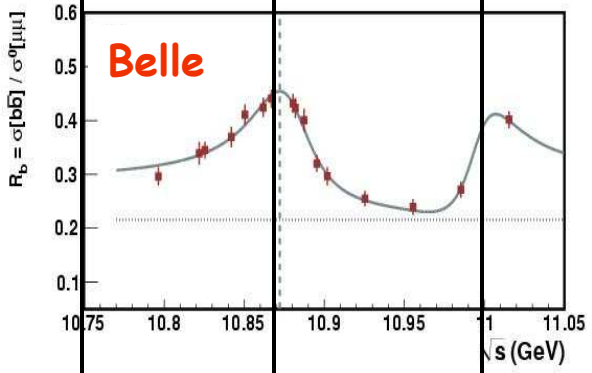
Energy scans

Motivated by large Bf(Υ(5S)->Υ(1S)$\pi\pi$), Belle performed energy scan to search for non-Υ(5S) resonance (Y_b hybrid?) decaying into Υ(1S)$\pi^+\pi^-$, Υ(2S)$\pi^+\pi^-$ and Υ(3S)$\pi^+\pi^-$.

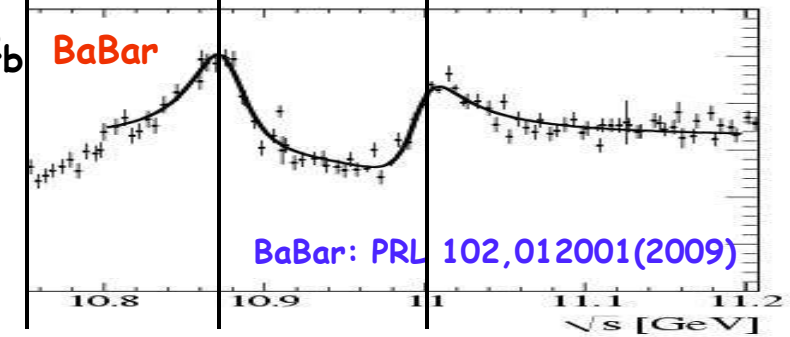
BaBar also did energy scan (R_b:*b*-events)

Y(5S)	Mass (MeV)	Width (MeV)
Belle(comb)	$10888.4 \pm {}^{3.0}_{2.9}$	$30.7 \pm {}^{8.7}_{7.7}$
Belle(hadr, R_b)	10879 ± 3	$46 \pm {}^{9}_{7}$
BaBar(hadr,R_b)	10876 ± 2	43 ± 4





Belle: arXib:0808.2445



Υ(nS)$\pi\pi$ peak is shifted by 3.2σ from R_b

Υ(nS)$\pi\pi$ has zero level, R_b level is ~0.2

Y_b : difference in shapes is very small ?

Υ(5S) -> B'B'$\pi\pi$ -> Υ(1S)$\pi\pi$: why zero level?

Conclusions

- Y(5S) decays to B^0 and B^+ mesons are studied (preliminary results).
- Two-body fractions are precisely measured. Theory should be adjusted using these results.

  $B\bar{B}$: $5.5 \pm ^{1.0}_{0.9} \pm 0.4$ % $B^*\bar{B}$: $13.7 \pm 1.3 \pm 1.1$ % $B^*\bar{B}^*$: $37.5 \pm ^{2.1}_{1.9} \pm 3.0$ %
- Three-body fractions are measured. Large fraction is obtained for $B^*\bar{B}\pi$ channel. Theory predicted very small fractions for 3-body channels. Contradiction should be resolved.

  $B\bar{B}\pi^+$: $(0.0 \pm 1.2 \pm 0.3)$ % $B^*\bar{B}\pi^+$: $(7.3 \pm ^{2.3}_{2.1} \pm 0.8)$ % $B^*\bar{B}^*\pi^+$: $(1.0 \pm ^{1.4}_{1.3} \pm 0.4)$ %
- Unexpectedly large fractions for $\Upsilon(5S) \to \Upsilon(1S,2S,3S)\pi^+\pi^-$ decays are observed. Energy scan was performed around $\Upsilon(5S)$. Difference in shapes is found for $\Upsilon(5S)$ peak in hadronic *bb* cross section and peaks in $\Upsilon(1S,2S,3S)\pi^+\pi^-$ final states. No clear explanation.
- Theory cannot predict well behaviors of ("simple") *bb*-system

Background slides

Decomposition of 3- and 4-body channels