Upsilon(nS) decays at Belle

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Belle Collaboration

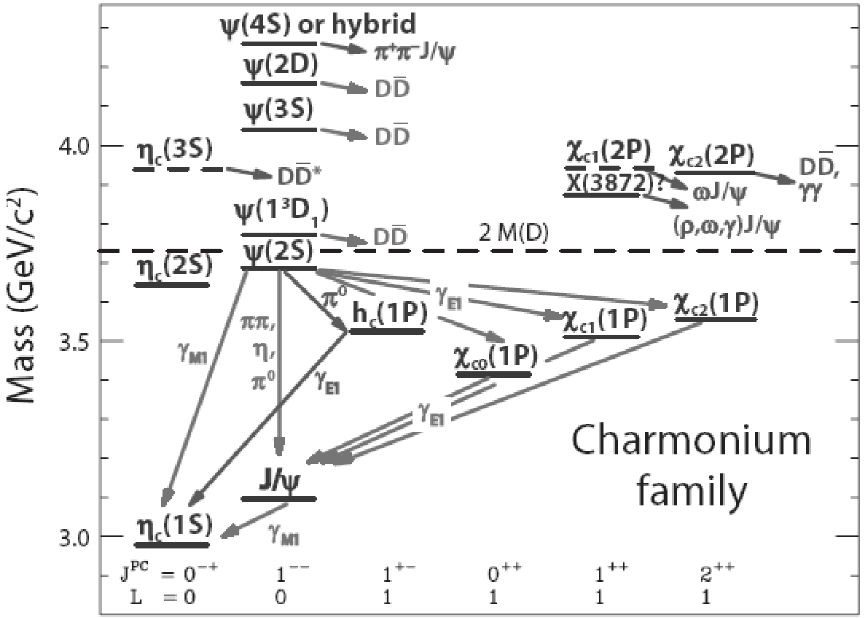
QCD10, 07-02-2010

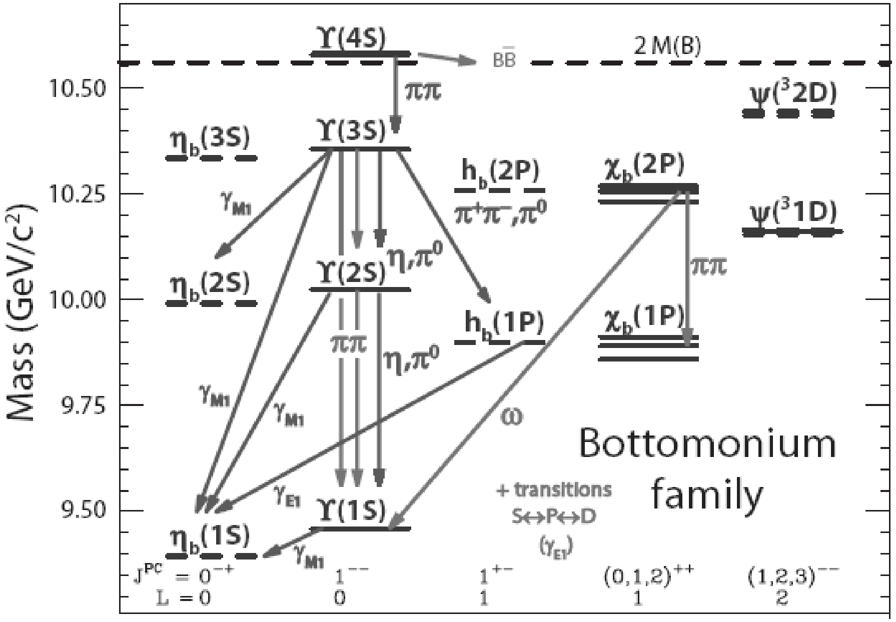
Outline

- Introduction
- Part I : Upsilon(1,2S) decays
- Part II : Upsilon(5S) decays
- Summary

Introduction

- Quarkonia – Successful story of QCD.
- Charmonia – Well studied at C and B factories. But, what are charmonium-like states?!
- Bottomonia – not so well.
- B factories, after 10 years on CPV, are paying more attention to bottomonia.





Eichten et al: Rev. Mod. Phys. 80, 1611(2008)

Part I

Upsilon(1,2S) decays

data sample

- $\Upsilon(1S)$ sample:

  5.7 fb^{-1} @ Υ(1S), 1.8 fb^{-1}@ 9.43 GeV

✓ The determination of the number of Υ(1S) events:

R(9.43 GeV) = 3.544 $\pm$ 0.006 (stat. only)

(R_{CLEO} = 3.54 $\pm$ 0.02, PRD76,072008(2008))

✓ Preliminary result: N(Υ(1S)) = (101.5 $\pm$ 1.6)$\times 10^6$.

✓ Worth to study charmonium(-like) states in exclusive decays.

- $\Upsilon(2S)$ sample:

  24.7 fb^{-1} @ Υ(2S), 1.7 fb^{-1}@ 9.993 GeV

✓ Based on $\Upsilon(2S) \rightarrow \Upsilon(1S)\, \pi^+\pi^-$, preliminary result:

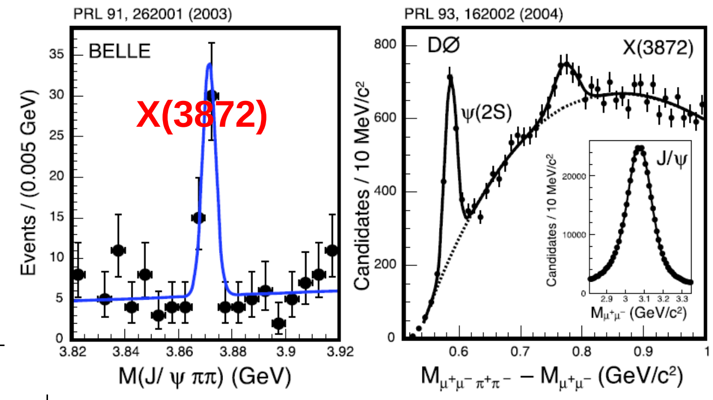
N(Υ(2S)) = 170 $\times 10^6$.

Υ (1S) radiative decays

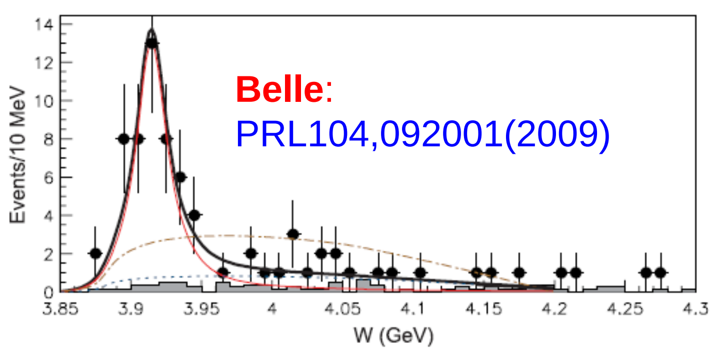
- Searches for charmonium-like states.

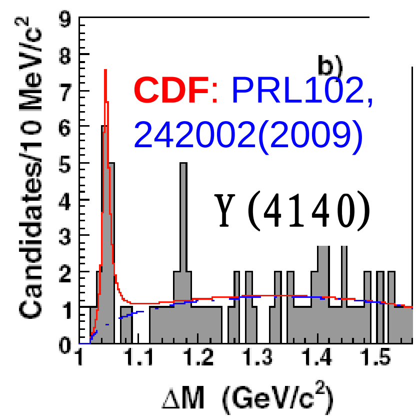
X(3872), X(3915), Y(4140), X(4350)…

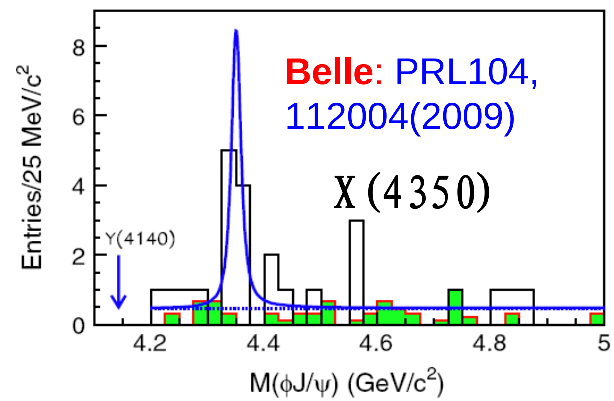
- Search for a C even parity state.



$\gamma\gamma \rightarrow \omega J/\psi$







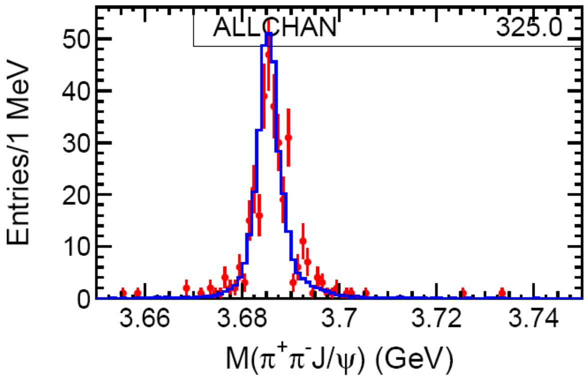
- Theory predictions for charmonium production.

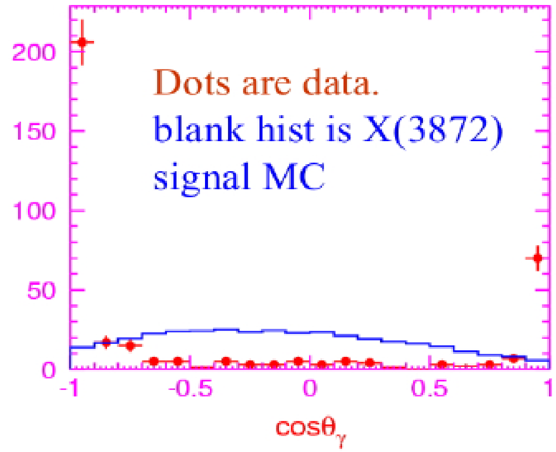
process	$\Upsilon \rightarrow \chi_{c2}\gamma$	$\Upsilon \rightarrow \chi_{c1}\gamma$	$\Upsilon \rightarrow \chi_{c0}\gamma$	$\Upsilon \rightarrow \eta_c\gamma$
BR_{QCD}	5.1×10^{-6}	4.5×10^{-6}	4.0×10^{-6}	2.9×10^{-5}
$BR_{QCD+QED}$	5.6×10^{-6}	9.8×10^{-6}	3.2×10^{-6}	4.9×10^{-5}

Y.J. Gao, Y.J. Zhang, K.T Chao:hep-ph/0701009v2

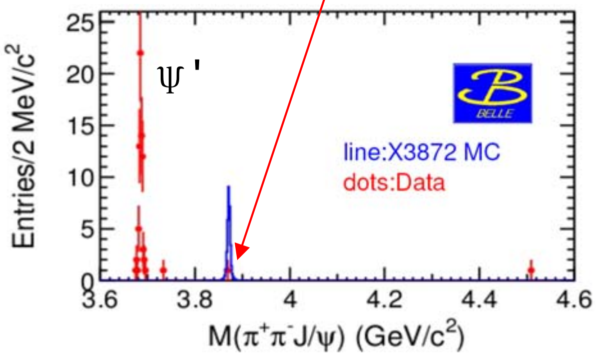
X(3872) in Υ(1S) radiative decay

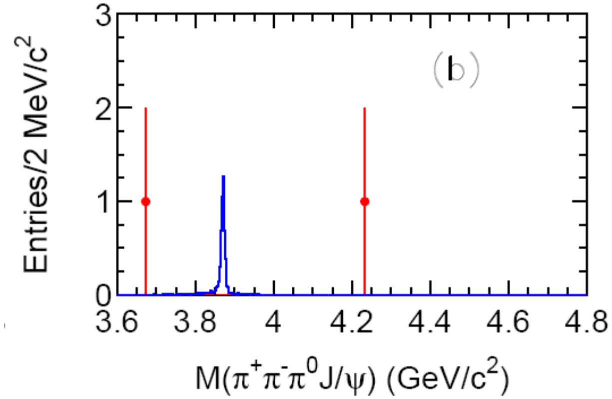
- E(γ) > 3.5 GeV.
- X(3872)→ $\pi^+\pi^-(\pi^0)$+J/ψ , J/ψ → e^+e^- or $\mu^+\mu^-$, π^0 → γ γ .
- ISR(e^+e^- → ψ ', Y(4260)): reference signal & dominant backgrounds!





One event!





We expect:

$\sigma_{ISR}(e^+e^- \rightarrow \gamma\psi')$=18.9 pb

No cuts on photon:

$\sigma_{ISR}(\psi')$ = 20.9 ±1.1 pb

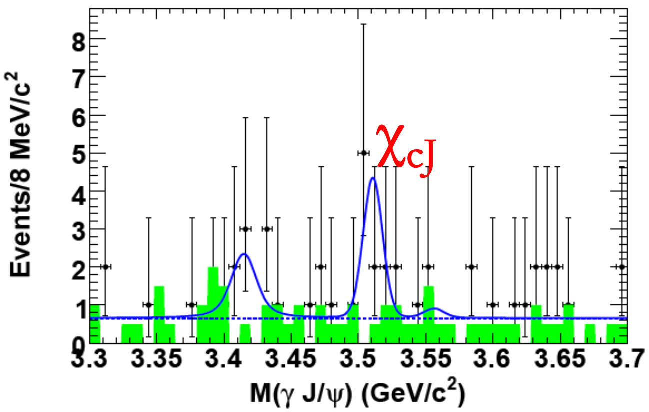
Photon tagged:|cosθ|<0.9

$\sigma_{ISR}(\psi')$ = 21.8 ±2.4 pb

MC simulation is reliable.

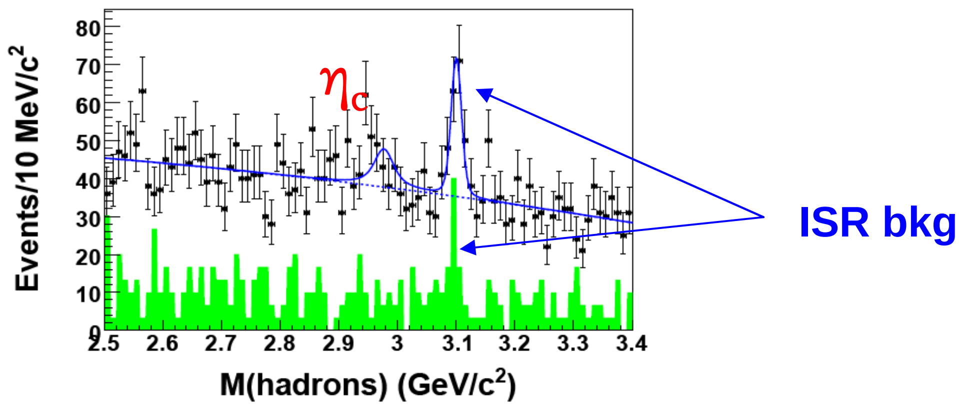
Hist – X(3872) MC(good resolution)

Υ (1S) radiative decays



Dots – signals

Hist – sideband bkg



Study channels:

χ_{cJ} → J/ψ + γ ,

η_c → 2(K⁺K⁻), K⁺K⁻ π⁺π⁻,

$K_sK^+\pi^-$ + c.c., 2(π⁺π⁻), 3(π⁺π⁻).

X(3915) → ω J/ψ,

Y(4140) → Φ J/ψ,

With J/ψ → e⁺ e⁻ or μ⁺μ⁻.

Upper Limits with 90% C.L. for all channels:

$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c0}) < 5.0 \times 10^{-4},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c1}) < 1.5 \times 10^{-5},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c2}) < 1.2 \times 10^{-5},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma\eta_c) < 6.4 \times 10^{-5},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) < 2.2 \times 10^{-6},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^-\pi^0 J/\psi) < 3.4 \times 10^{-6},$$

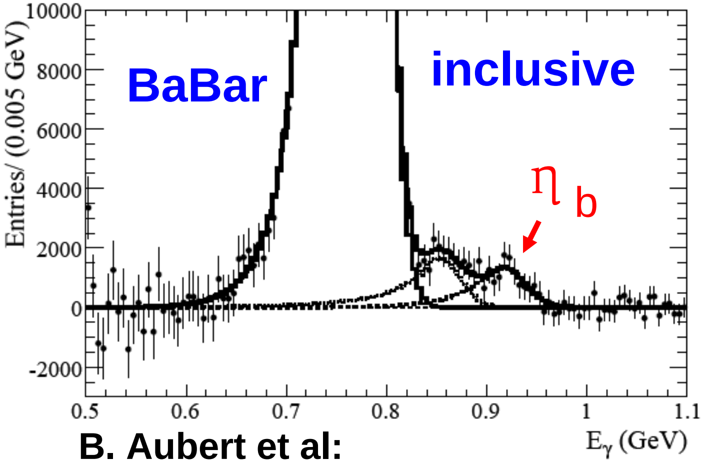
$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3915)) \times \mathcal{B}(X(3915) \to \omega J/\psi) < 3.4 \times 10^{-6},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma Y(4140)) < 2.6 \times 10^{-6},$$

The above upper limits do not contradict the calculation in K.T.Chao et al., hep-ph/0701009. No obvious C even parity excited state found.

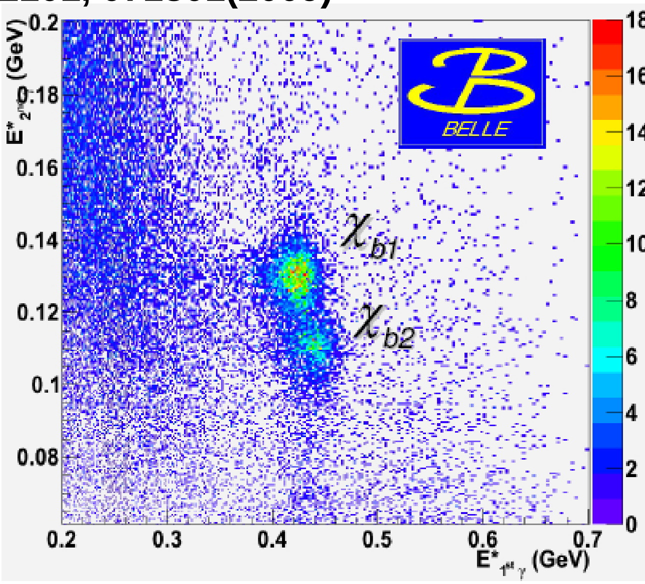
Υ (1,2S) analyses under way

- $\Upsilon(2S) \rightarrow \gamma + \eta_b$
- $\chi_{b0} \rightarrow \gamma + \Upsilon(1S)$
- $\Upsilon(2S) \rightarrow \eta + \Upsilon(1S)$
- $\chi_{bJ} \rightarrow$ double charmonium
- $\Upsilon(2S) \rightarrow \gamma + A_0$
- $\Upsilon(1S)$ lepton universality from $\Upsilon(2S) \rightarrow \Upsilon(1S) + \pi^+\pi^-$
- $\Upsilon(1S) \rightarrow$ inclusive di-baryons



B. Aubert et al:

PRL101, 071801(2009)



$\Upsilon(2S) \rightarrow \gamma\gamma\ \Upsilon(1S) \rightarrow \gamma\gamma\ \mu^+\mu^-$

Part II

Upsilon(5S) decays

- **Transition**
- **To B mesons**
- **Others?**

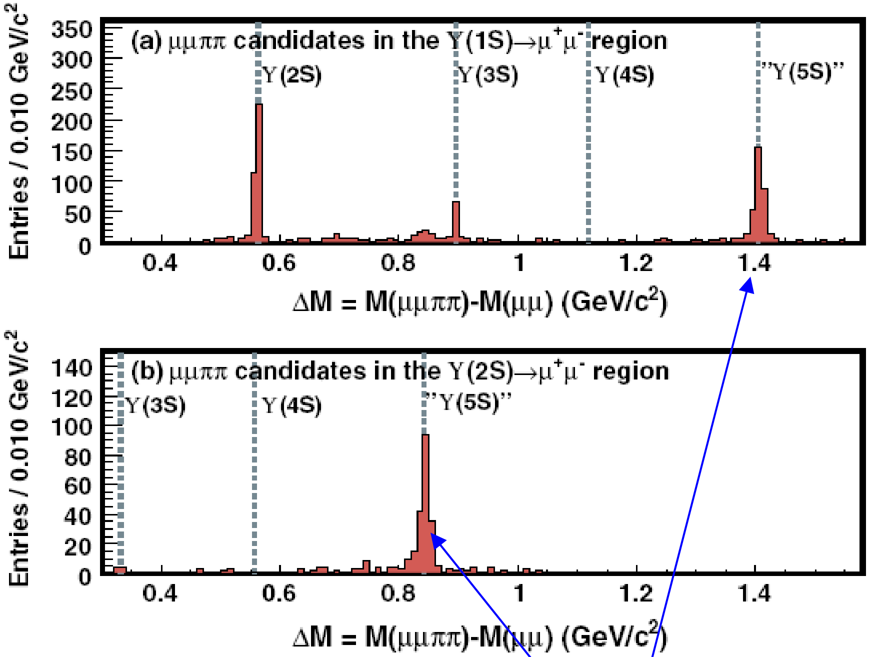
$\Upsilon(5S) \rightarrow \Upsilon(nS) + \pi^+\pi^-$

- $\pi^+\pi^-$ transition of Υ(5S) has much large partial width.
- A b-quark version of Y(4260) – Y_b? Or something not understood?

- The abnormal Br needs more study!
- Belle took more data after then.

120 fb^{-1}, including scan data.

21.7fb^{-1}@10.87 GeV



$$\Gamma(\Upsilon(5S) \rightarrow \Upsilon(2S)\pi^+\pi^-) = 0.85 \pm 0.07(\text{stat}) \pm 0.16(\text{syst})\ \text{MeV}$$

K.F. Chen: PRL100,112001(2008)

Process	Γ_{total}	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10\,860) \rightarrow \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

Abnormal enhancement

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

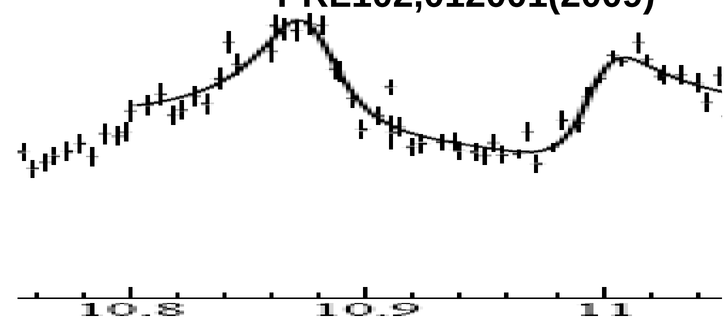
- The resonance parameters of Y(10860).

8.1 fb^{-1}, 9 scan points

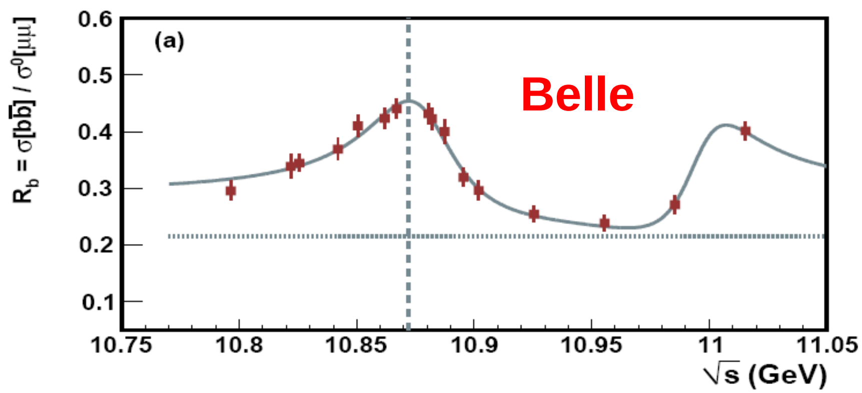
Fit with Breit-Wigner:
Mass = 10879 $\pm$3 MeV,
Width = 46 $^{+9}_{-7}$ MeV
(only stat. errors)

BaBar:

PRL102,012001(2009)



BaBar	$\Upsilon(10860)$	$\Upsilon(11020)$
mass (GeV)	10.876 ± 0.002	10.996 ± 0.002
width (MeV)	43 ± 4	37 ± 3
ϕ (rad)	2.11 ± 0.12	0.12 ± 0.07



PDG08:

Mass $m = 10.865 \pm 0.008$ GeV (S = 1.1)

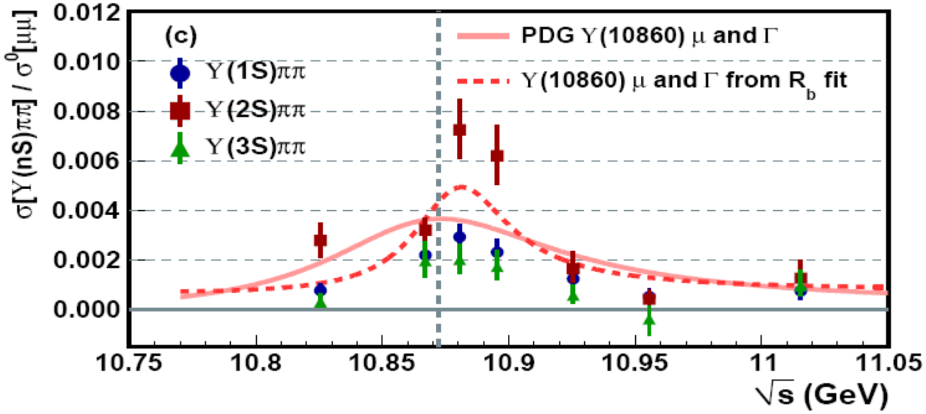
Full width $\Gamma = 110 \pm 13$ MeV

$\Gamma_{ee} = 0.31 \pm 0.07$ keV (S = 1.3)

K.F. Chen et al, hep-ex/0810.3829

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

- Measure $\Upsilon(nS)\pi^+\pi^-$ yield vs sqrt(s).



$\Upsilon(1S)\pi\pi$ σ at peak	$(2.78^{+0.42}_{-0.34} \pm 0.23)$ pb
$\Upsilon(2S)\pi\pi$ σ at peak	$(4.82^{+0.77}_{-0.62} \pm 0.66)$ pb
$\Upsilon(3S)\pi\pi$ σ at peak	$(1.71^{+0.35}_{-0.31} \pm 0.24)$ pb
μ	$(10888.4^{+2.7}_{-2.6} \pm 1.2)$ MeV$/c^2$
Γ	$(30.7^{+8.3}_{-7.0} \pm 3.1)$ MeV$/c^2$
ϕ	$(1.97 \pm 0.26 \pm 0.06)$ or $(-1.74 \pm 0.11 \pm 0.02)$ rad
R_0	$(1.98^{+0.72}_{-0.60} \pm 0.20)$ or $(0.87^{+0.29}_{-0.22} \pm 0.09)$ (GeV)$^{-2}$

$$\mu_{\Upsilon(nS)\pi\pi} - \mu_{10860} = 9 \pm 4 \ \mathrm{MeV}/c^2$$

$$\Gamma_{\Upsilon(nS)\pi\pi} - \Gamma_{10860} = -15^{+11}_{-12} \ \mathrm{MeV}/c^2$$

Different line shape:

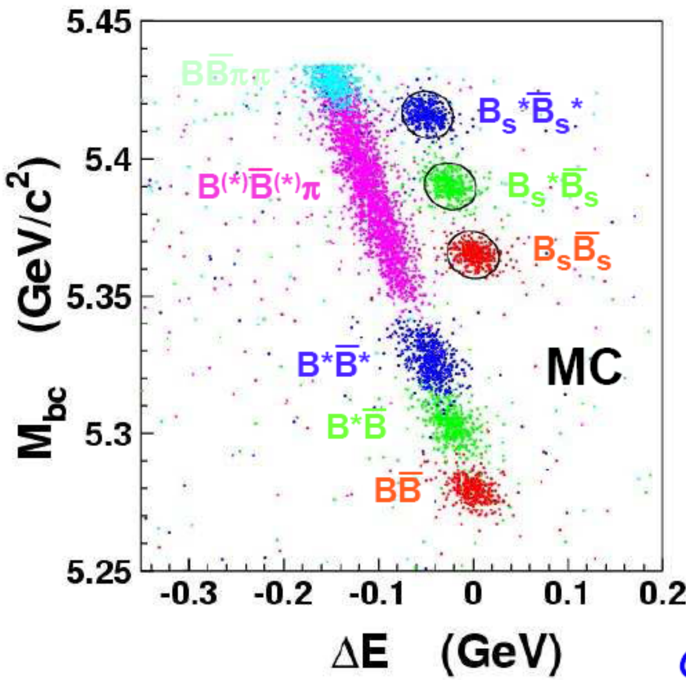
A Y_b state with small production cross section and large fraction to $\Upsilon(nS)\pi^+\pi^-$ is possible.

K.F. Chen et al, hep-ex/0810.3829

Υ (5S) → B mesons

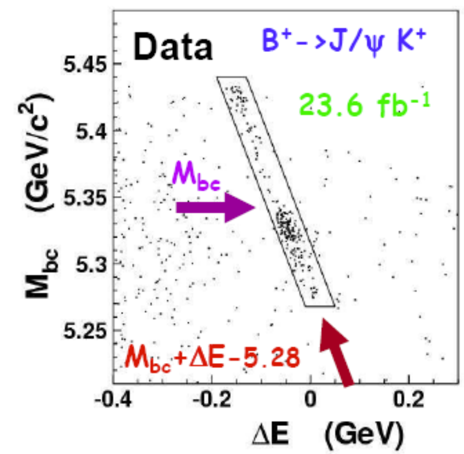
- Belle mesured B production rate, and 2-body and 3-body channels with B meson pairs.

2-body: BB, BB*, B*B*; 3-body: BBπ, BB* π, B*B* π



$e^+ e^-$ -> Υ(5S) -> B(*)B(*) (π)(π),

where B* -> B γ



Only one B meson is reconstructed

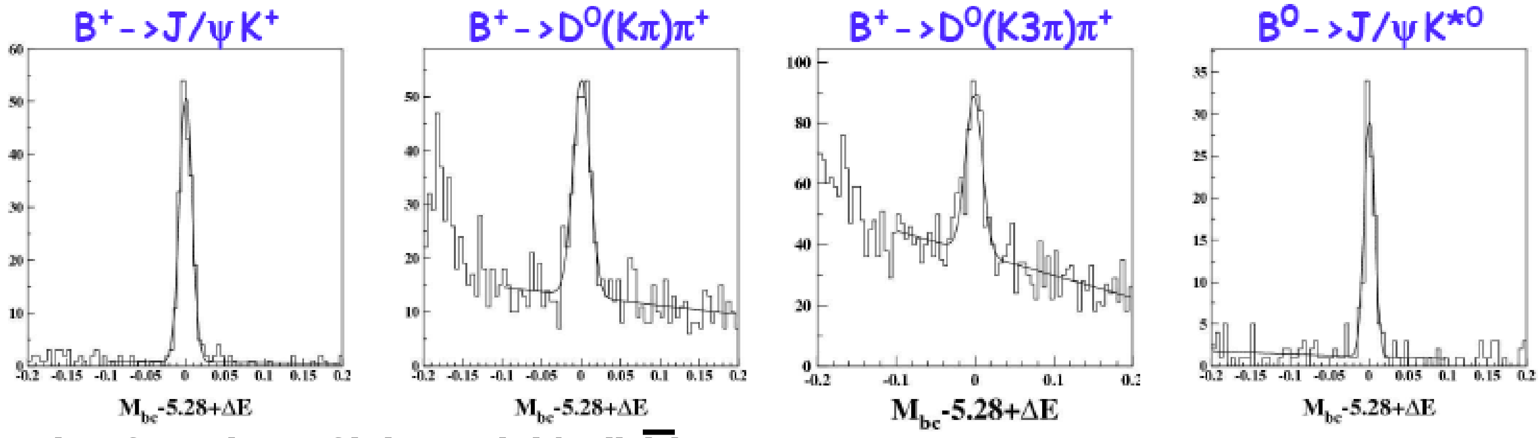
Two variables calculated: $M_{bc} = \sqrt{E^{*2}_{beam} - P^{*2}_{B}}$, $\Delta E = E^*_B - E^*_{beam}$

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

A. Drutskoy et al， PRD81, 112003(2010)

Υ (5S) → B mesons

5 modes of B decays

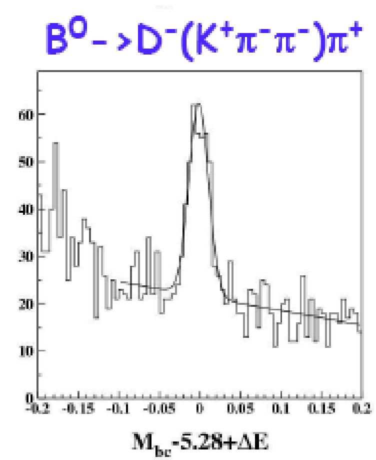


The fraction: f(x) = N(x)/N($b\bar{b}$)

The rate of a $b\bar{b}$ pair decay to x

Decay mode	Yield	Efficiency, %	$f(B^{+/0})$, %
$B^+ \to J/\psi K^+$	221^{+16}_{-15}	3.41	$89.0^{+6.3}_{-6.1} \pm 8.0$
$B^0 \to J/\psi K^{*0}$	105 ± 11	1.30	$85.3^{+9.2}_{-8.8} \pm 8.8$
$B^+ \to \bar{D}^0(K\pi)\pi^+$	215 ± 21	0.97	$64.0 \pm 6.2 \pm 4.9$
$B^+ \to \bar{D}^0(K3\pi)\pi^+$	275 ± 32	1.17	$68.3^{+8.0}_{-8.1} \pm 6.4$
$B^0 \to D^-\pi^+$	247 ± 25	1.80	$72.9 \pm 7.4 \pm 6.4$

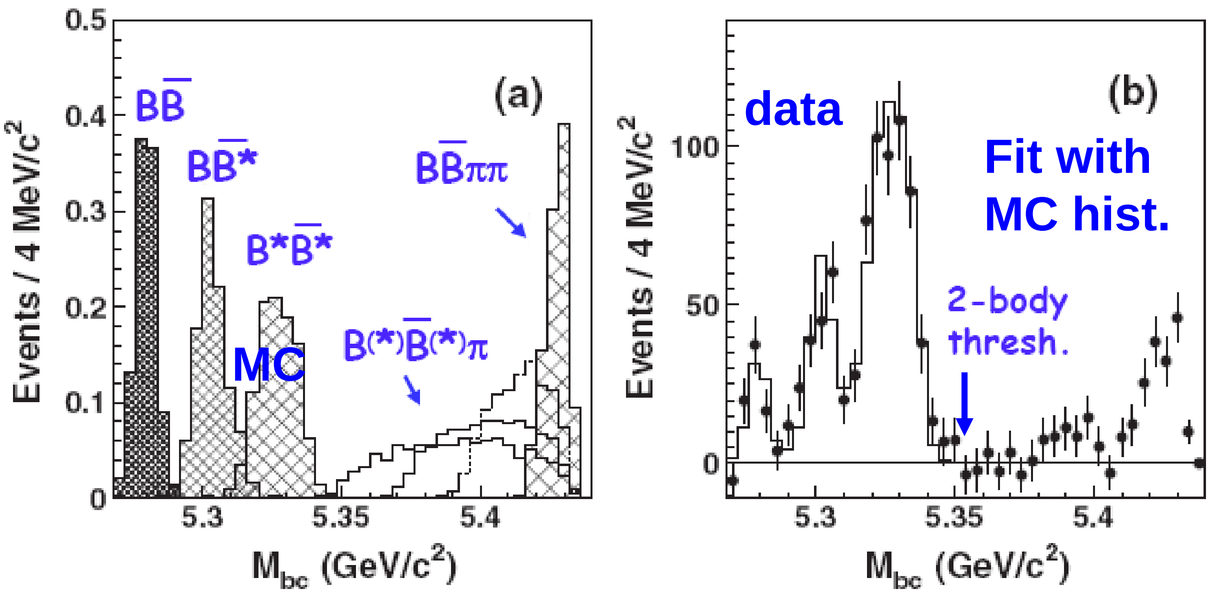
$f(B^+) = (72.1^{+3.9}_{-3.8} \pm 5.0)\%$ $\quad f(B^0) = (77.0^{+5.8}_{-5.6} \pm 6.1)\%$



f_s = (19.5 $^{+3.0}_{-2.2}$)% (PDG08) →

{1- f(B$^+$)/2 – f(B^0)/2 – f_s} ~ 5%, → other kinds decays.

2-body decays



Simultaneous fit with 5 B modes in M_{bc} < 5.35 GeV

Channel fractions per bb-pair:

Channel	Fraction, %
$B\bar{B}$	$5.5^{+1.0}_{-0.9} \pm 0.4$
$B\bar{B}^* + B^*\bar{B}$	$13.7 \pm 1.3 \pm 1.1$
$B^*\bar{B}^*$	$37.5^{+2.1}_{-1.9} \pm 3.0$
Large M_{bc}	$17.5^{+1.8}_{-1.6} \pm 1.3$

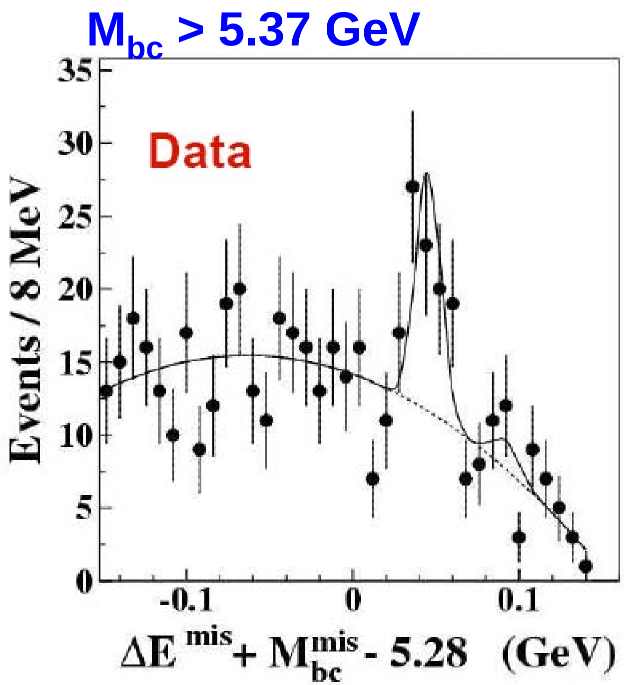
Theory: channel B*B* is dominant, 30-69%

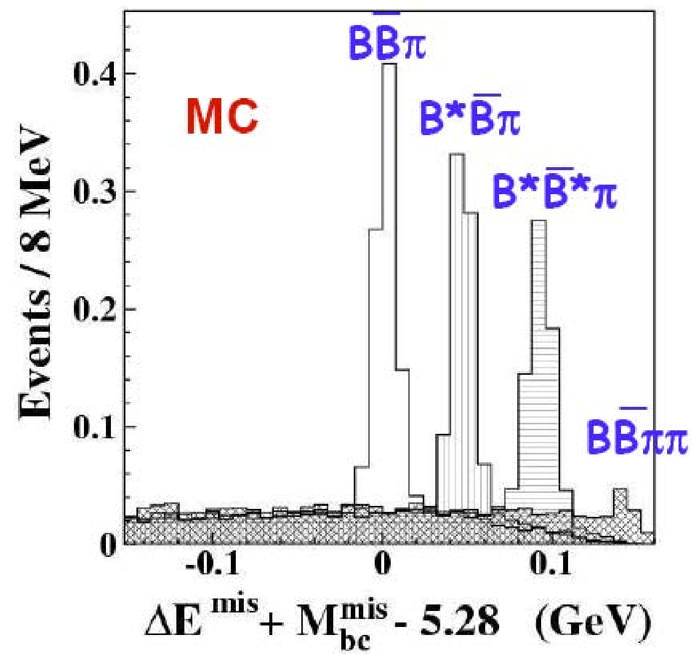
Results should be used to adjust theory.

No 2-body channels, the fraction is large.

A. Drutskoy et al， PRD81, 112003(2010)

3-body decays





Assuming CG coefficients:
Fr($\pi^{\pm}$)/Fr(π^0) = 2:1

Channel	Yield (π^+), events	Fraction over large M_{bc} %	Fraction per $b\bar{b}$ event %
$B\bar{B}\pi$	$0.2^{+7.2}_{-6.9}$	$0.2^{+6.8}_{-6.5}$	$0.0 \pm 1.2 \pm 0.3$
$B\bar{B}^*\pi + B^*\bar{B}\pi$	$38.3^{+10.5}_{-9.8}$	$41.6^{+12.1}_{-11.4}$	$7.3^{+2.3}_{-2.1} \pm 0.8$
$B^*\bar{B}^*\pi$	$4.8^{+6.4}_{-5.9}$	$5.9^{+7.8}_{-7.2}$	$1.0^{+1.4}_{-1.3} \pm 0.4$
Residual		$52.3^{+15.9}_{-15.0}$	$9.2^{+3.0}_{-2.8} \pm 1.0$
Large M_{bc}		100	$17.5^{+1.8}_{-1.6} \pm 1.3$

Large fraction of B*B π^+.

Residual is large, but could be explained by ISR(10%).

A. Drutskoy et al， PRD81, 112003(2010)

Summary

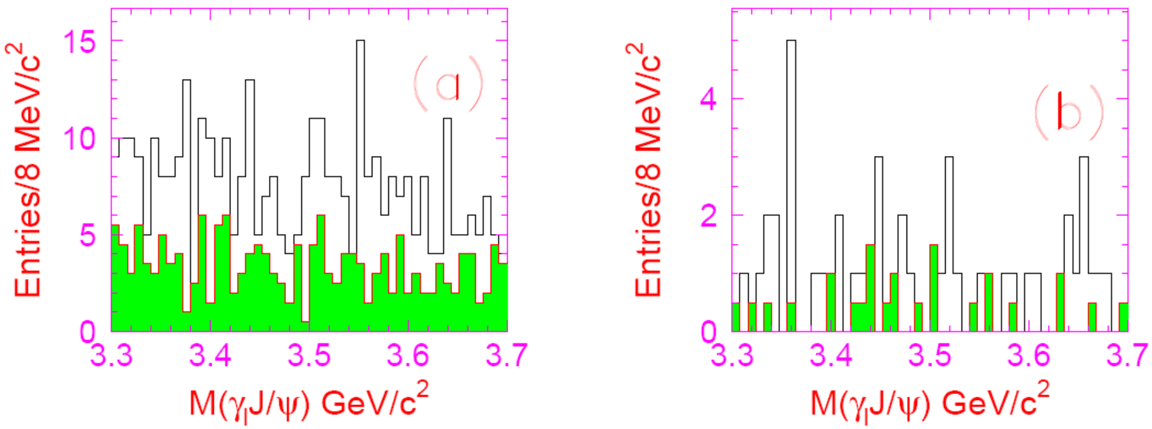
- Large data samples collected on Υ(1,2,5S) by Belle detector.

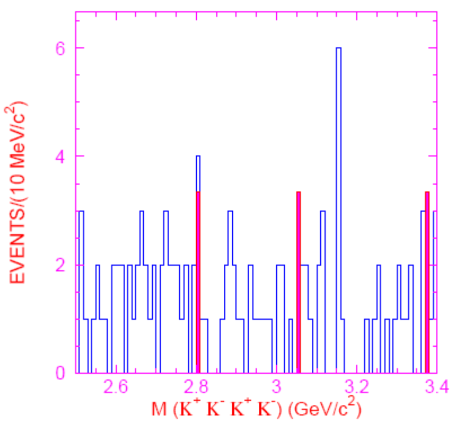
  100 M@Υ(1S), 170M@Υ(2S), 120fb^{-1}@Υ(5S)
- Exclusive radiative decays of Υ(1S) to charmonia and charmonium-like states are studied for the first time.
- $\pi^+\pi^-$ transition of Υ(5S) to Υ(nS) may indicate the existence of a Y_b state.
- Υ(5S) decays to final states including B meson have been studied systematicly.
- Analyses of Many decays of bottomonia are under way.
- **And, "What can we do for QCD?" Any idea with these samples are welcome!**

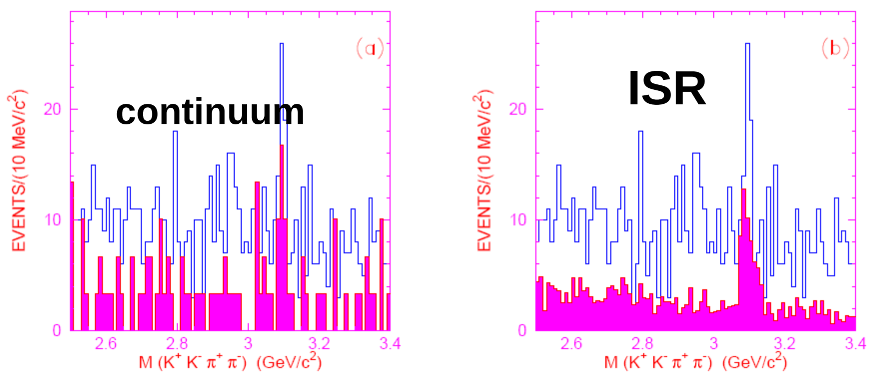
Thank you!

backup

Y(1S) radiative decays.

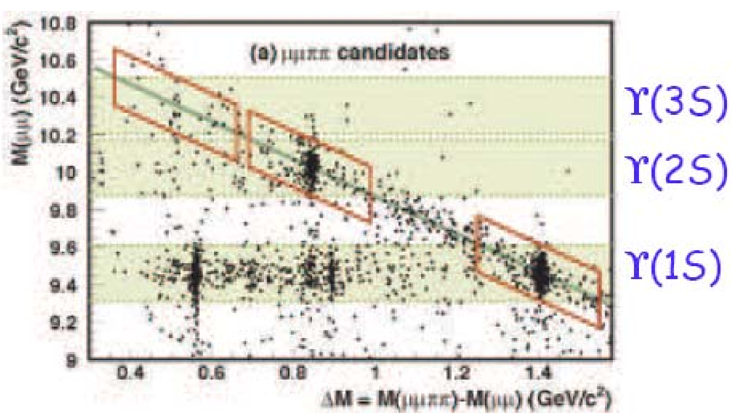






- $\Upsilon(5S) \rightarrow \Upsilon(nS) + \pi^+\pi^-$

		$e^+e^- \to \Upsilon(1S)\pi^+\pi^-$			$e^+e^- \to \Upsilon(2S)\pi^+\pi^-$			$e^+e^- \to \Upsilon(3S)\pi^+\pi^-$		
$\sqrt{s}$(GeV)	$\mathcal{L}$(fb^{-1})	N_s	Eff.(%)	σ(pb)	N_s	Eff.(%)	σ(pb)	N_s	Eff.(%)	σ(pb)
10.8255	1.73	$10.6^{+4.0}_{-3.3}$	43.8	$0.56^{+0.21}_{-0.18} \pm 0.06$	$24.0^{+5.6}_{-4.9}$	34.9	$2.05^{+0.48}_{-0.42} \pm 0.24$	$1.8^{+1.8}_{-1.1}$	20.5	$0.23^{+0.23}_{-0.14} \pm 0.03$
10.8805	1.89	$43.4^{+7.2}_{-6.5}$	43.1	$2.14^{+0.36}_{-0.32} \pm 0.15$	$68.8^{+9.0}_{-8.3}$	35.4	$5.31^{+0.69}_{-0.64} \pm 0.59$	$14.9^{+4.3}_{-3.7}$	24.5	$1.47^{+0.43}_{-0.37} \pm 0.18$
10.8955	1.46	$26.2^{+5.8}_{-5.1}$	43.2	$1.68^{+0.37}_{-0.33} \pm 0.13$	$45.4^{+7.4}_{-6.7}$	35.6	$4.53^{+0.74}_{-0.67} \pm 0.51$	$10.3^{+3.7}_{-3.1}$	25.7	$1.26^{+0.45}_{-0.38} \pm 0.15$
10.9255	1.18	$11.1^{+4.0}_{-3.3}$	42.6	$0.89^{+0.32}_{-0.27} \pm 0.08$	$9.7^{+3.8}_{-3.1}$	35.9	$1.19^{+0.47}_{-0.38} \pm 0.16$	$2.9^{+2.2}_{-1.5}$	27.5	$0.41^{+0.31}_{-0.21} \pm 0.05$
10.9555	0.99	$3.9^{+2.6}_{-1.9}$	42.5	$0.37^{+0.25}_{-0.18} \pm 0.04$	$2.0^{+2.0}_{-1.3}$	36.4	$0.29^{+0.29}_{-0.19} \pm 0.05$	$-1.8^{+2.5}_{-3.0}$	29.4	$-0.28^{+0.39}_{-0.47} \pm 0.03 < 0.20$
11.0155	0.88	$4.9^{+2.8}_{-2.1}$	42.0	$0.53^{+0.31}_{-0.23} \pm 0.05$	$5.5^{+3.1}_{-2.4}$	36.0	$0.90^{+0.51}_{-0.39} \pm 0.17$	$4.3^{+2.6}_{-1.9}$	32.7	$0.69^{+0.42}_{-0.30} \pm 0.08$
10.8670	21.74	325^{+20}_{-19}	37.4	$1.61 \pm 0.10 \pm 0.12$	186 ± 15	18.9	$2.35 \pm 0.19 \pm 0.32$	$10.5^{+4.0}_{-3.3}$	1.5	$1.44^{+0.55}_{-0.45} \pm 0.19$



Decomposition of 3- and 4-body channels