Hadronic Transitions in Bottomonia and QCD

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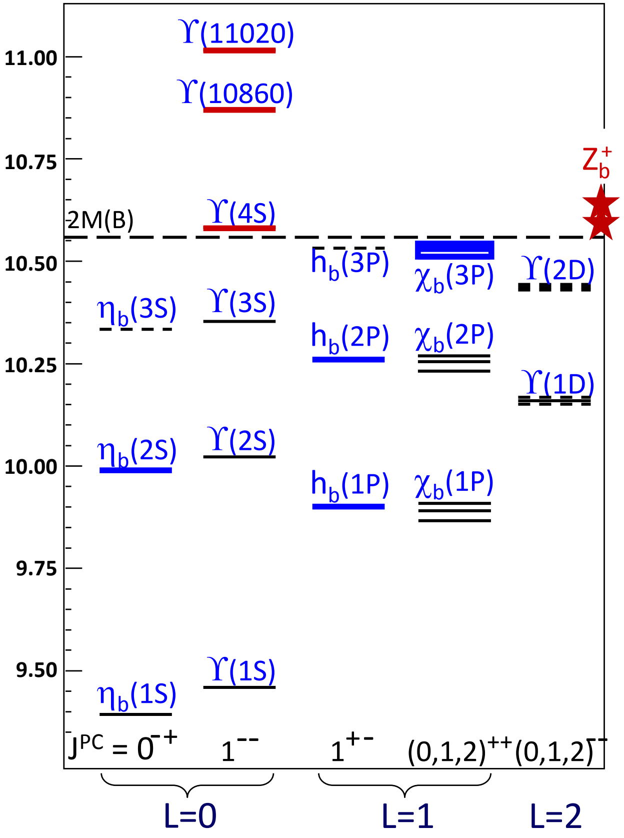
Outline

1. Transitions in bottomonia at Belle
2. Conclusions
3. Prospects for BelleII

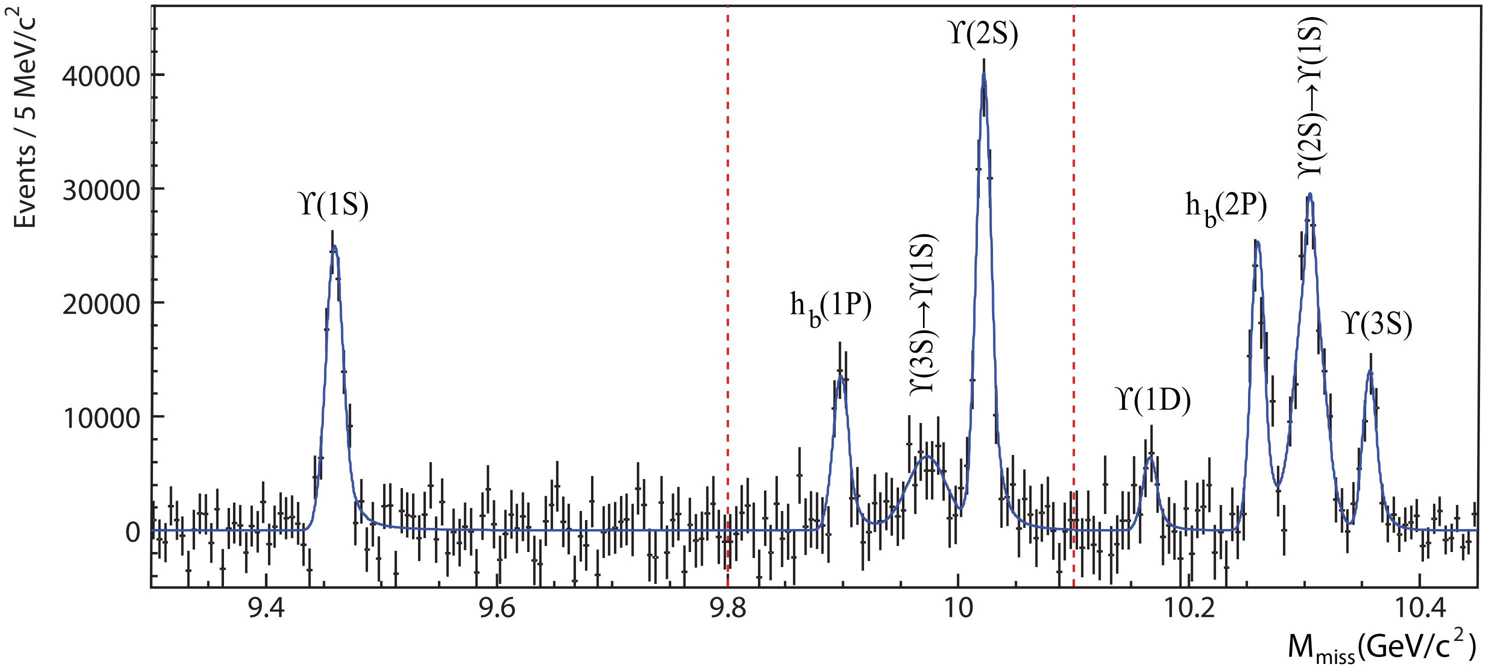
General

- Spectroscopy of heavy quarkonia provides crucial information for understanding strong interactions since QCD calculations become possible: heavy-quark spin symmetry (HQSS), multipole expansion etc.
- Measurements of hadronic transitions ($\pi^+\pi^-$, η, $\omega, \ldots$) btw. bottomonia yield important input for QCD
- η transitions are believed to be suppressed compared to $\pi^+\pi^-$ because of the spin flip
- $\pi^+\pi^-$ transitions and their peculiarities were studied by both BaBar and Belle, the contribution of Belle being particularly strong due to high statistics and versatile analyses like use of missing mass distributions
- Large integrated luminosity collected by Belle above the $\Upsilon(4S)$ opened unique possibilities resulting in exciting observations of $h_b(1P)$, $h_b(2P)$, $\eta_b(2S)$, $Z_b(10610)$ and $Z_b(10650)$

Bottomonium and Its Levels



Observation of $h_b(1P)$ and $h_b(2P)$ at Belle



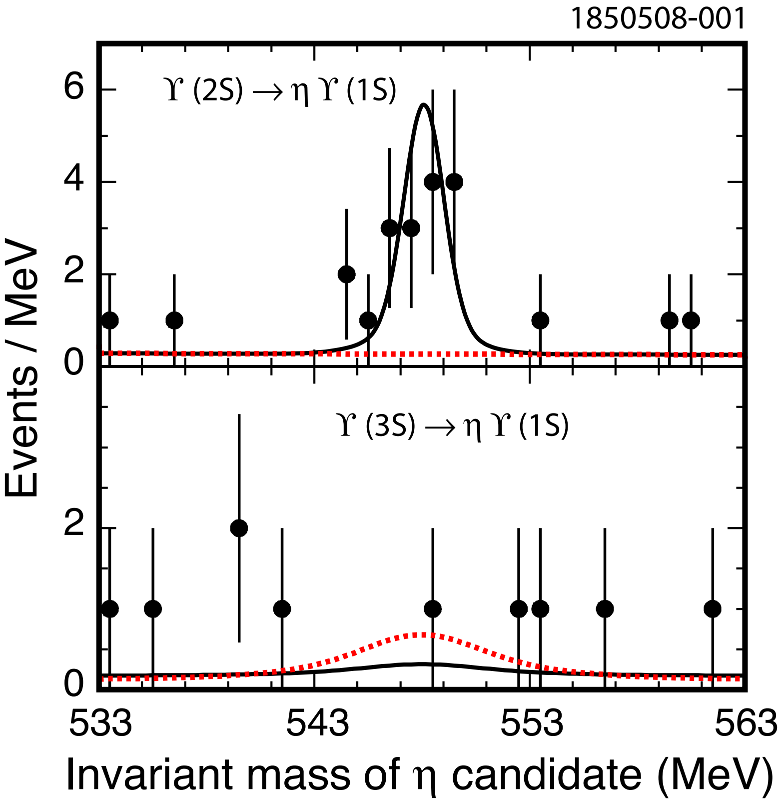
Belle used efficiently high-statistics data samples of the ϒ(10860) to study the $M_{\rm miss}(\pi\pi)$ spectrum in $e^+e^- \to h_b(nP)\pi^+\pi^-$ which shows a variety of states with different J^P

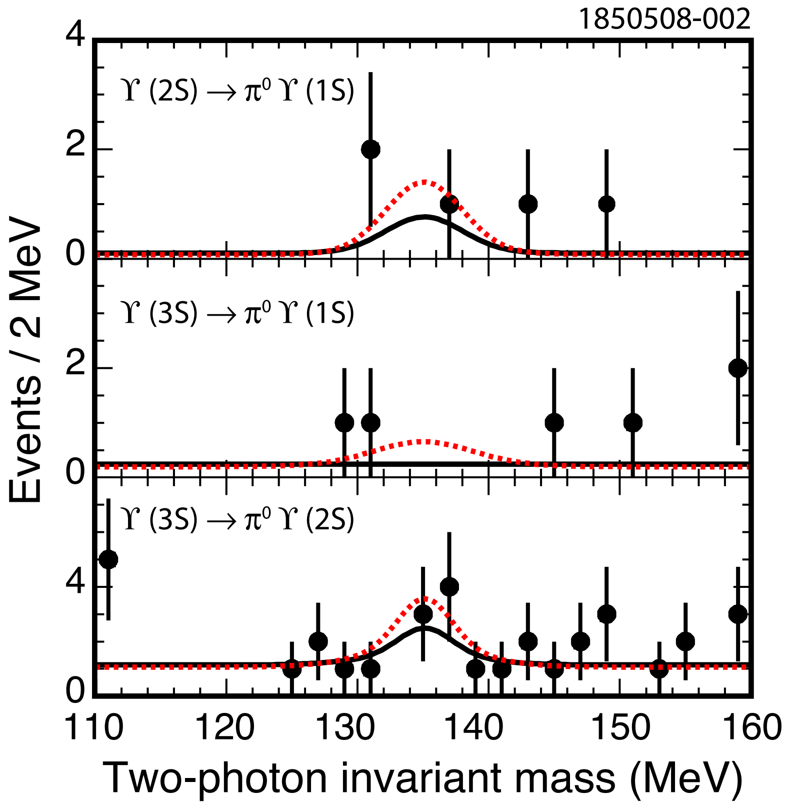
Also important for discovery of the $Z_b(10610)$ and $Z_b(10650)$

I. Adachi et al., Phys. Rev. Lett. 108, 032001 (2012)

Observation of $\Upsilon(2S) \to \eta\Upsilon(1S)$ at CLEO – I

CLEO used $9.32{\cdot}10^6$ $\Upsilon(2S)$ and $5.88{\cdot}10^6$ $\Upsilon(3S)$ to look for η and π^0 transitions





$\mathcal{B}(\Upsilon(2S) \to \eta\Upsilon(1S))\mathcal{B}(\Upsilon(1S) \to l^+l^-) = (1.06^{+0.35}_{-0.40}) \cdot 10^{-5}$, Other UL $\sim 10^{-5}$

Q. He et al., Phys. Rev. Lett. 101 (2008) 192001

Observation of $\Upsilon(2S) \to \eta\Upsilon(1S)$ at CLEO – II

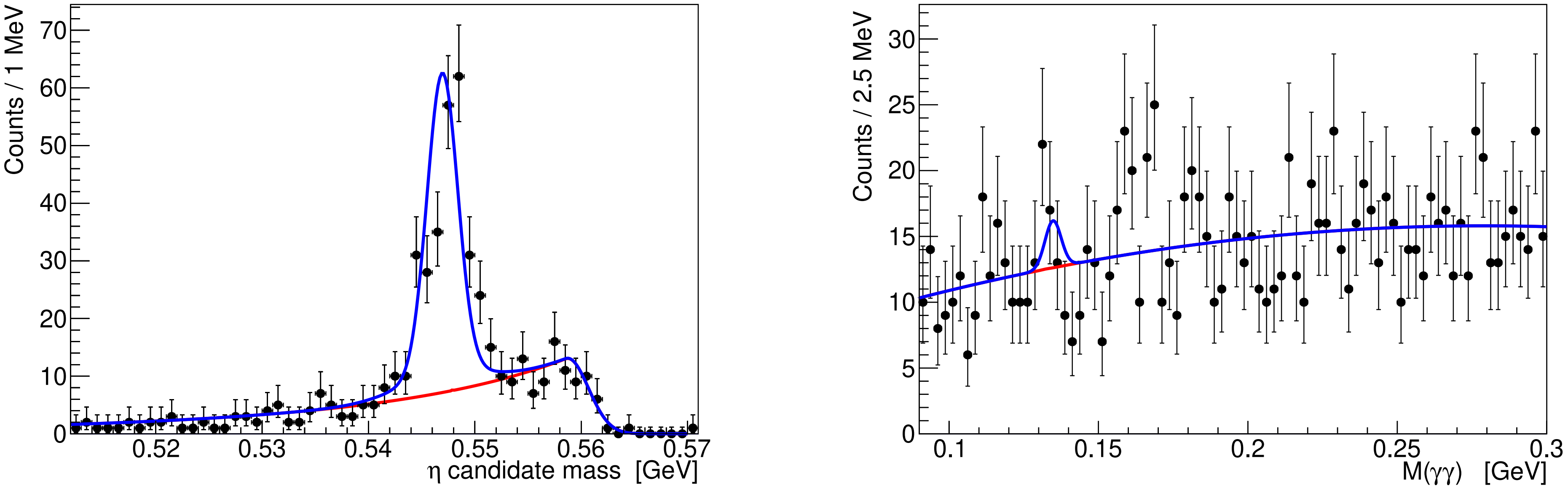
Decay mode	Events	$\mathcal{B} \cdot \mathcal{B}_l, 10^{-5}$
$\Upsilon(2S) \to \eta\Upsilon(1S)$	$13.9^{+4.5}_{-3.8}$	$1.06^{+0.35}_{-0.40}$
$\Upsilon(2S) \to \pi^0\Upsilon(1S)$	< 5.0	< 0.79
$\Upsilon(3S) \to \eta\Upsilon(1S)$	< 4.8	< 0.79
$\Upsilon(3S) \to \pi^0\Upsilon(1S)$	< 2.3	< 0.30
$\Upsilon(3S) \to \pi^0\Upsilon(2S)$	< 8.3	< 1.80

$\mathcal{B} = \mathcal{B}(\Upsilon(nS) \to (\eta/\pi^0)\Upsilon(mS)), \;\; \mathcal{B}_l = \mathcal{B}(\Upsilon(1,2S) \to l^+l^-)$

Q. He et al., Phys. Rev. Lett. 101 (2008) 192001

Study of the Hadronic Transitions $\Upsilon(2S) \to (\eta,\ \pi^0)\Upsilon(1S)$ at Belle

Belle used $158{\cdot}10^6$ $\Upsilon(2S)$ to study $\Upsilon(2S) \to \eta\Upsilon(1S)$ and $\Upsilon(2S) \to \pi^0\Upsilon(1S)$



$$\mathcal{B}(\Upsilon(2S) \to \eta\Upsilon(1S)) = (3.57 \pm 0.25 \pm 0.21) \cdot 10^{-4},$$

$$\mathcal{B}(\Upsilon(2S) \to \pi^0\Upsilon(1S)) < 4.1 \cdot 10^{-5}$$

U. Tamponi et al., Phys. Rev. D87 (2013) 011104

$\Upsilon(2S) \to (\pi^0/\eta)\Upsilon(1S)$ Transitions

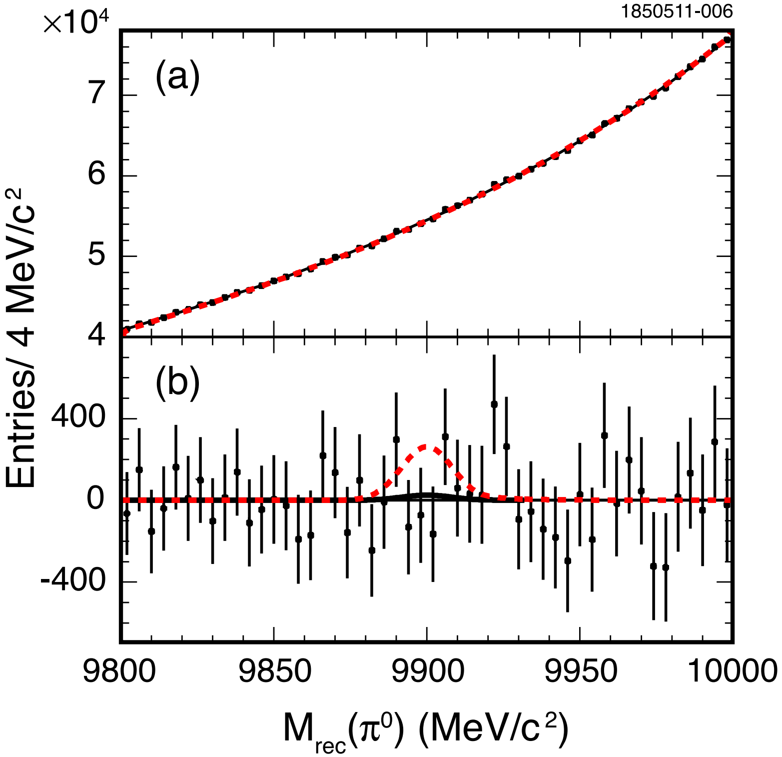
Decay	$\Upsilon(2S), 10^6$	Events	$\mathcal{B}, 10^{-5}$	Prediction	Group
$\pi^0\Upsilon(1S)$	9.3	-	< 18	6-8	CLEO, 2008
	158	-	< 4		Belle, 2013
$\eta\Upsilon(1S)$	9.3	14	$21^{+7}_{-6} \pm 3$	70-160	CLEO, 2008
	100	112	$23.9 \pm 3.1 \pm 1.4$		BaBar, 2011
	158	241	$35.5 \pm 3.2 \pm 0.5$		Belle, 2013

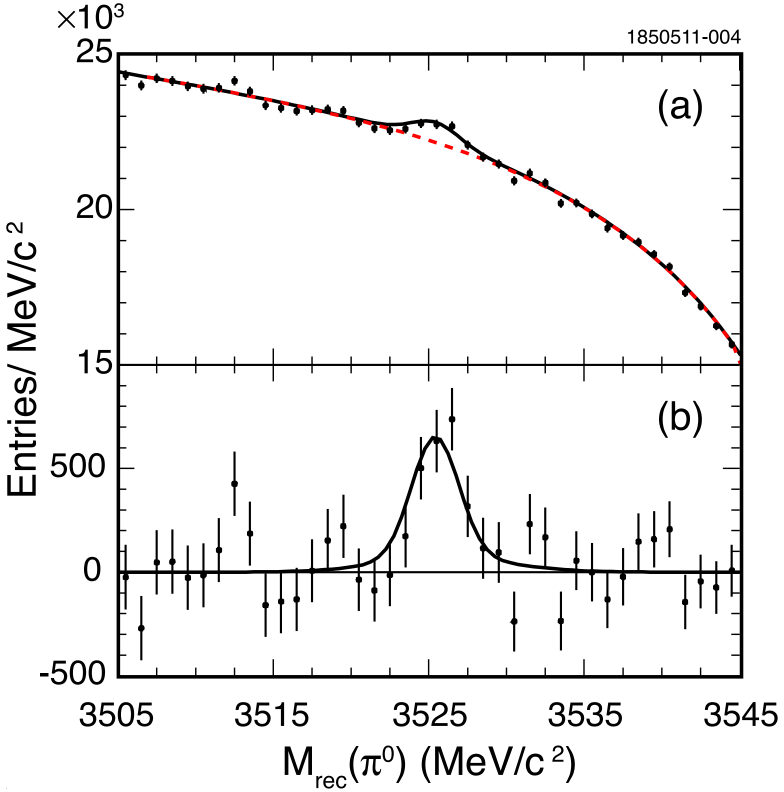
BaBar: J.P. Lees et al., Phys. Rev. D84 (2011) 092003

Belle: U.Tamponi et al., Phys. Rev. D87 (2013) 011104

Search for $\Upsilon(3S) \to \pi^0 h_b(1P)$ and $\psi(2S) h_c$ at CLEO

CLEO used $5.88 \cdot 10^6$ $\Upsilon(3S)$ and $25.9 \cdot 10^6$ $\psi(2S)$ to look for π^0 transitions to $h_{b(c)}(1P)$





$\mathcal{B}(\Upsilon(3S) \to \pi^0 h_b(1P)) < 1.2 \cdot 10^{-3}$ at 90%CL

J.Y. Ge et al., Phys. Rev. D84 (2011) 032008

π^0/η Transitions of $\Upsilon(3S)$

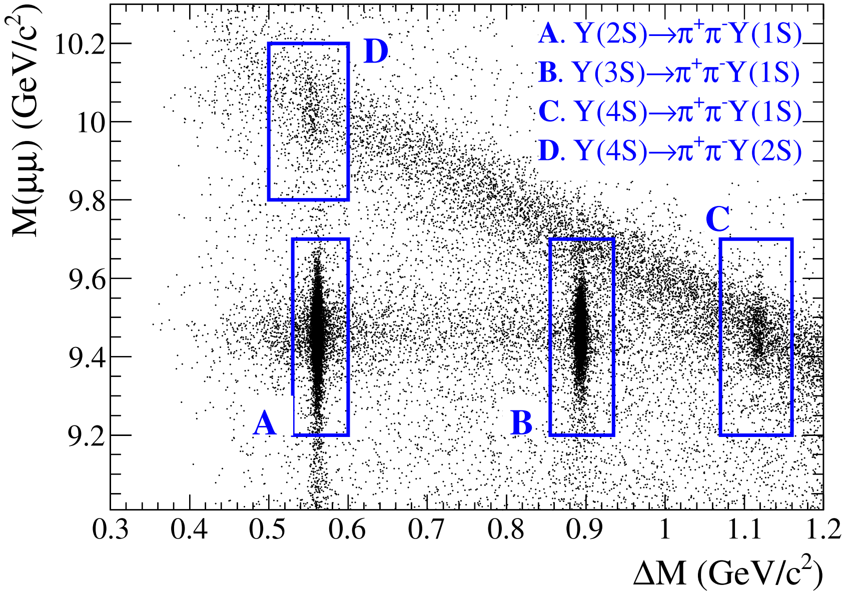
Decay	$\Upsilon(3S), 10^6$	$\mathcal{B}, 10^{-5}$	Prediction	Group
$\pi^0\Upsilon(1S)$	5.9	< 7		CLEO, 2008
$\pi^0\Upsilon(2S)$	5.9	< 51		CLEO, 2008
$\eta\Upsilon(1S)$	5.9	< 18	50-100	CLEO, 2008
	122	< 10		BaBar, 2011
$h_b\pi^0$	5.9	< 120		CLEO, 2011
$h_b\pi^0 \to \gamma\eta_b(1S)\pi^0$	122	$43 \pm 11 \pm 9$		BaBar, 2011

BaBar: J.P. Lees et al., Phys. Rev. D84 (2011) 091101

J.P. Lees et al., Phys. Rev. D84 (2011) 092003

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – I

From 538M $\Upsilon(4S)$ Belle studied $\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S,2S)$, $\Upsilon(4S) \to \eta\Upsilon(1S)$ and searched for inclusive $\Upsilon(1^3D_{1,2}) \to \eta\Upsilon(1S)$, $\eta \to \pi^+\pi^-\pi^0$, $\Upsilon(1S,2S) \to \mu^+\mu^-$

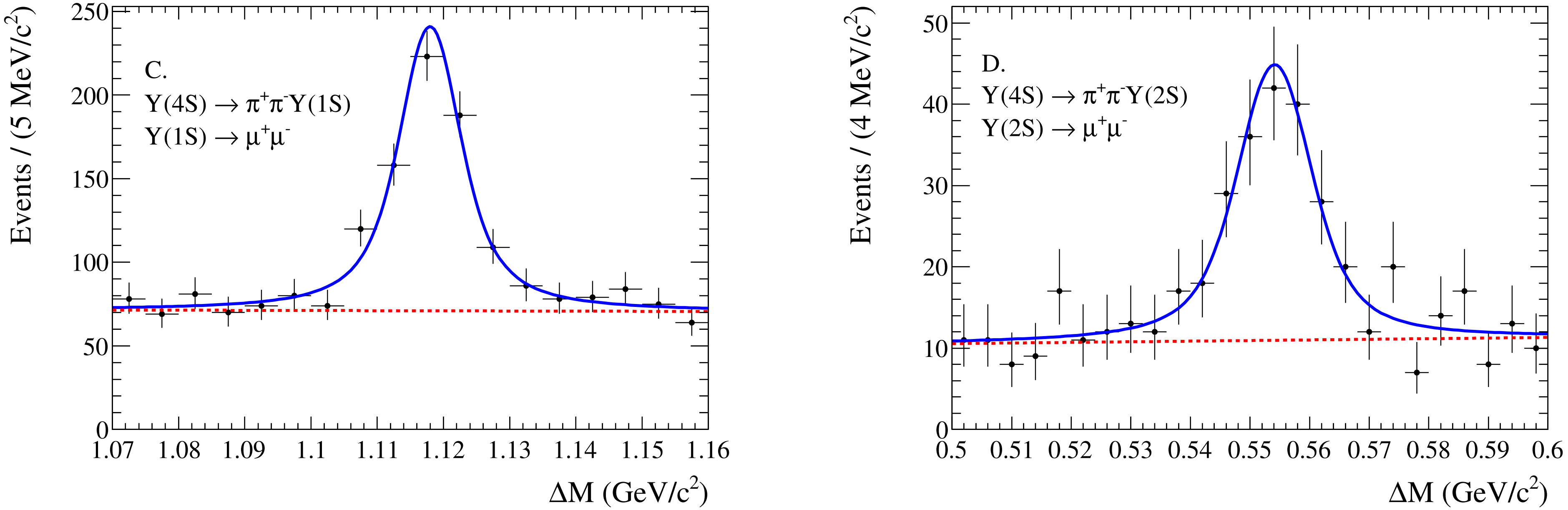


$\Delta M = M(\pi\pi\mu\mu) - M(\mu\mu)$,

Due to ISR: 9805±106 events of $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$

and 5222±77 events of $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$

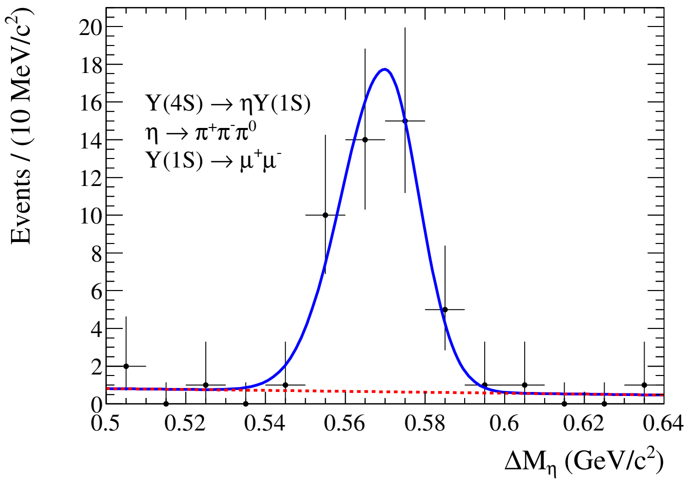
Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – II

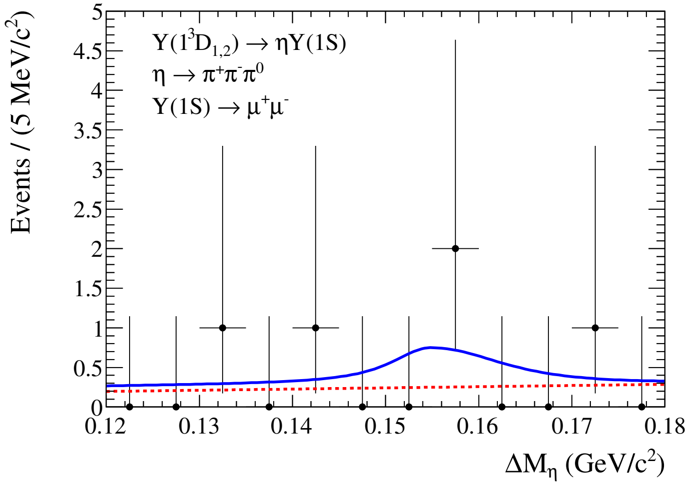


Decay	Events	$\mathcal{B}, 10^{-5}$	$\mathcal{B}_{\rm PDG}, 10^{-5}$
$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S)$	1095 ± 74	$8.2 \pm 0.5 \pm 0.4$	8.1 ± 0.6
$\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S)$	821 ± 107	$7.9 \pm 1.0 \pm 0.4$	8.6 ± 1.3

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – III





$$\Delta M_\eta = M(\pi\pi\gamma\gamma\mu\mu) - M(\mu\mu) - M(\pi\pi\gamma\gamma),$$

Via double-radiative transitions via $\chi_{bJ}(2P)$, $\Upsilon(1^3D_{1,2}) \to \eta\Upsilon(1S)$ produced

Decay	Events	$\mathcal{B}, 10^{-4}$	$\mathcal{B}_{\rm PDG}, 10^{-5}$
$\Upsilon(4S) \to \eta\Upsilon(1S)$	49 ± 7	$1.70 \pm 0.23 \pm 0.08$	1.96 ± 0.28
$\Upsilon(1^3D_{1,2}) \to \eta\Upsilon(1S)$	2.1 ± 3.0	< 0.23	–

η transitions are unexpectedly more probable than $\pi^+\pi^-$

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

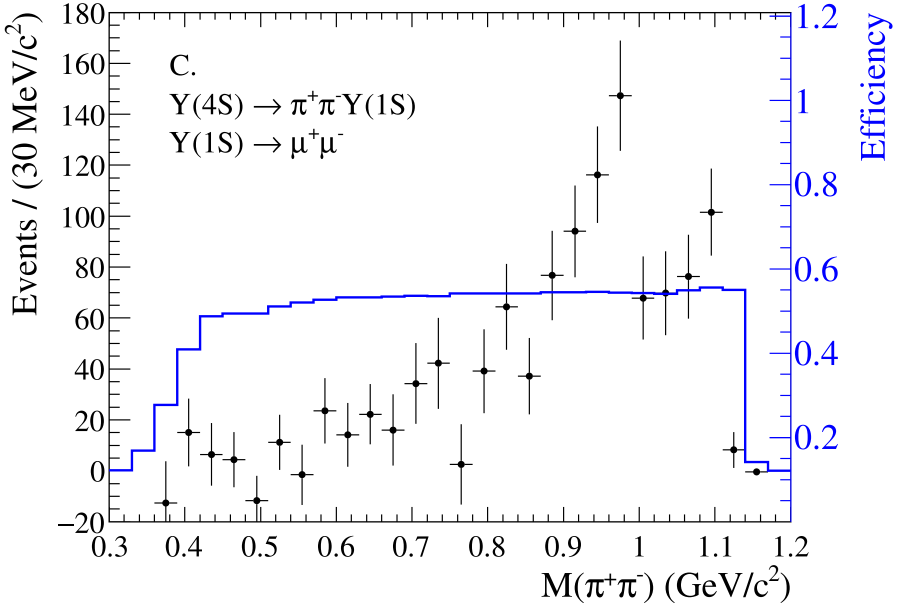
Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – IV

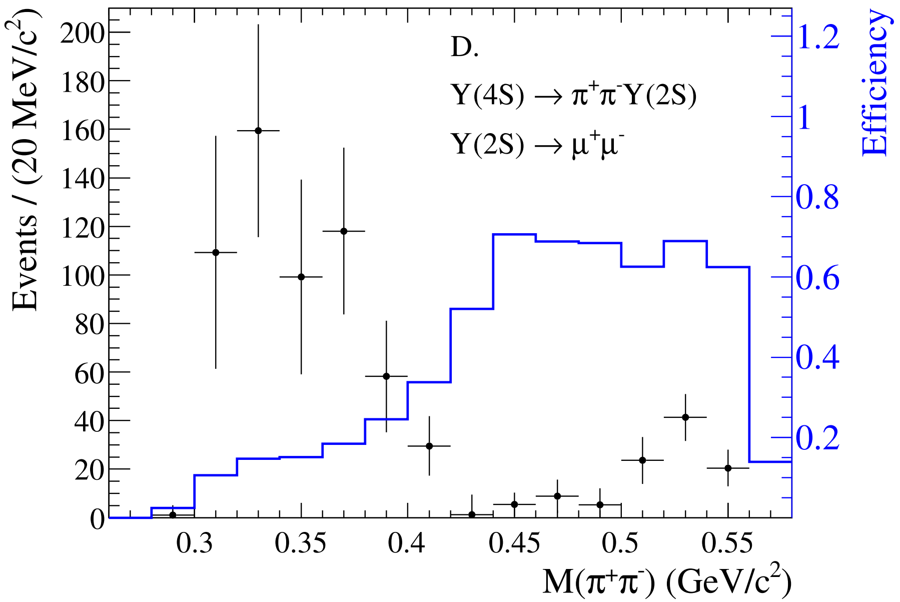
$$\mathcal{R} = \frac{\mathcal{B}(\Upsilon(4S) \to \eta\Upsilon(1S))}{\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))}$$

Quantity	Belle	PDG
$\mathcal{R}$	$2.07 \pm 0.30 \pm 0.11$	2.41 ± 0.42

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – V



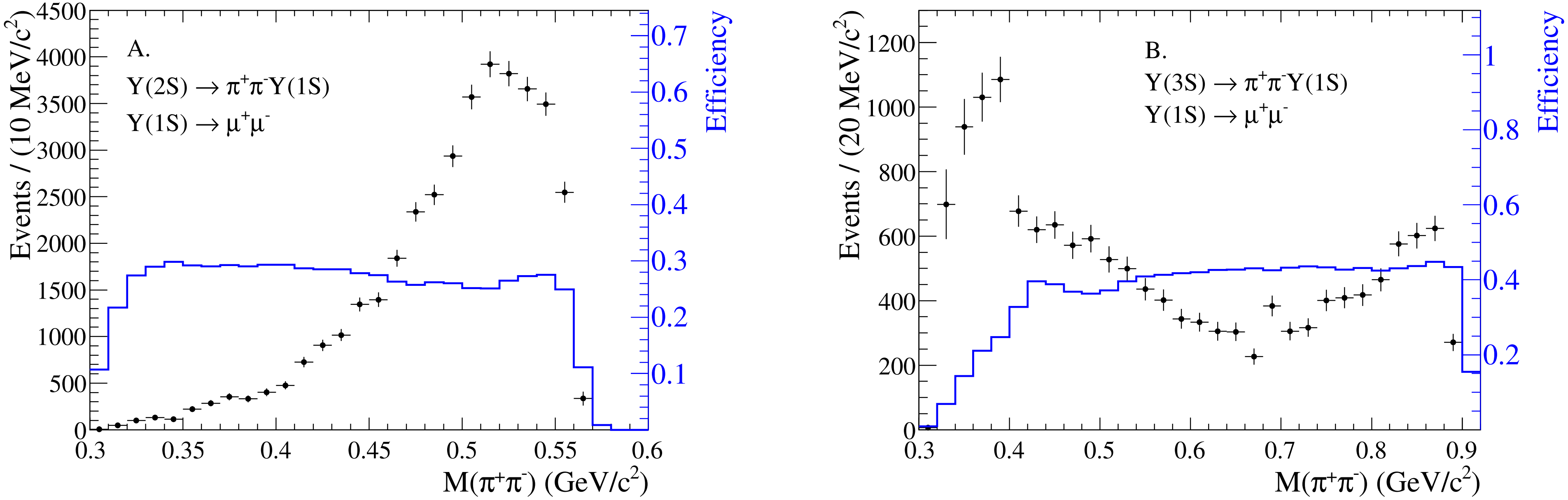


Striking difference of $M(\pi\pi)$ spectra:

Low masses suppressed for the decay to $\Upsilon(1S)$, a resonance at high mass?

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – VI

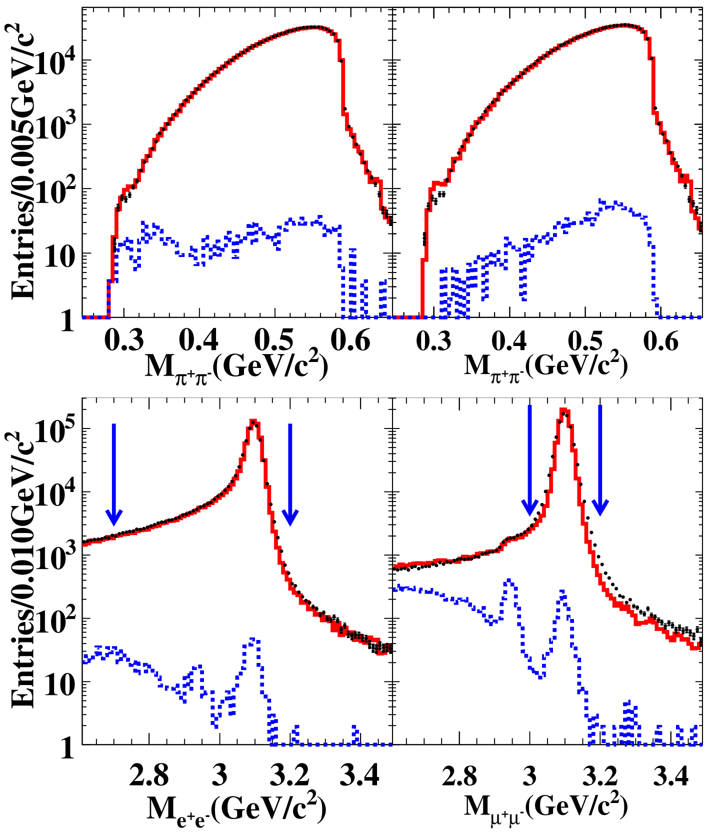


Once again a difference of $M(\pi\pi)$ spectra:

Low masses suppressed for the decay of $\Upsilon(2S)$ and bipolar picture for $\Upsilon(3S)$

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

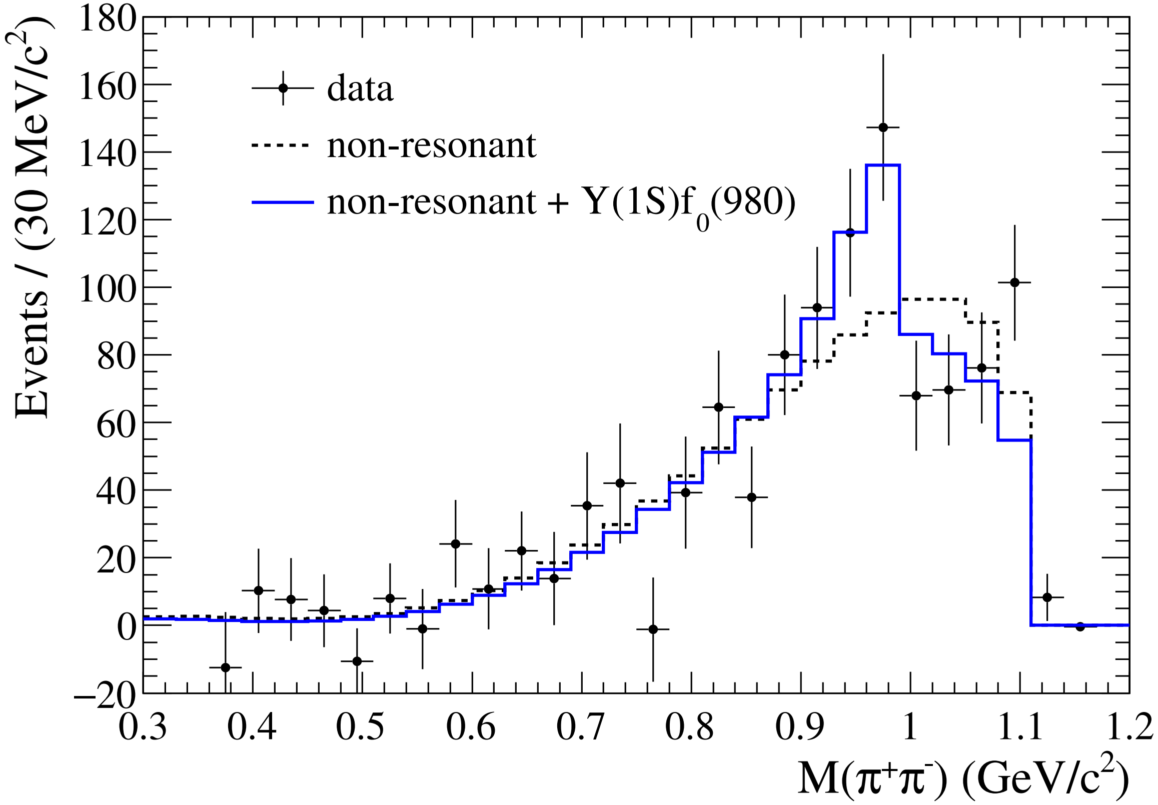
$M(\pi^+\pi^-)$ Distribution in $\psi(2S) \to J/\psi\pi^+\pi^-$



Suppression of low masses, Adler rule

M. Ablikim et al., Phys. Rev. D87 (2013) 072007

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{b})$ – VII

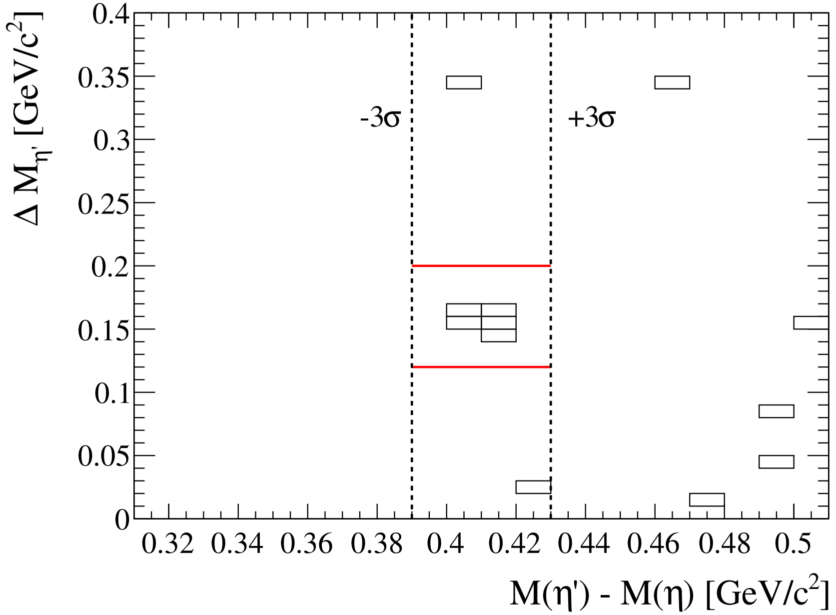


The model with the $f_0(980)$ is preferred with 2.8σ

E. Guido et al., Phys. Rev.D 96, 052005 (2017)

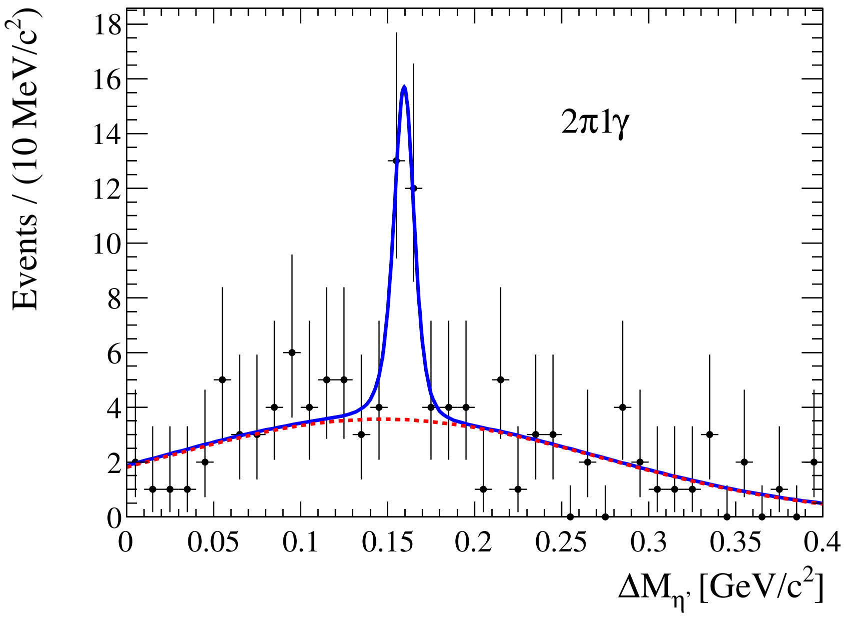
Observation of $\Upsilon(4S) \to \eta' \Upsilon(1S)$ – I

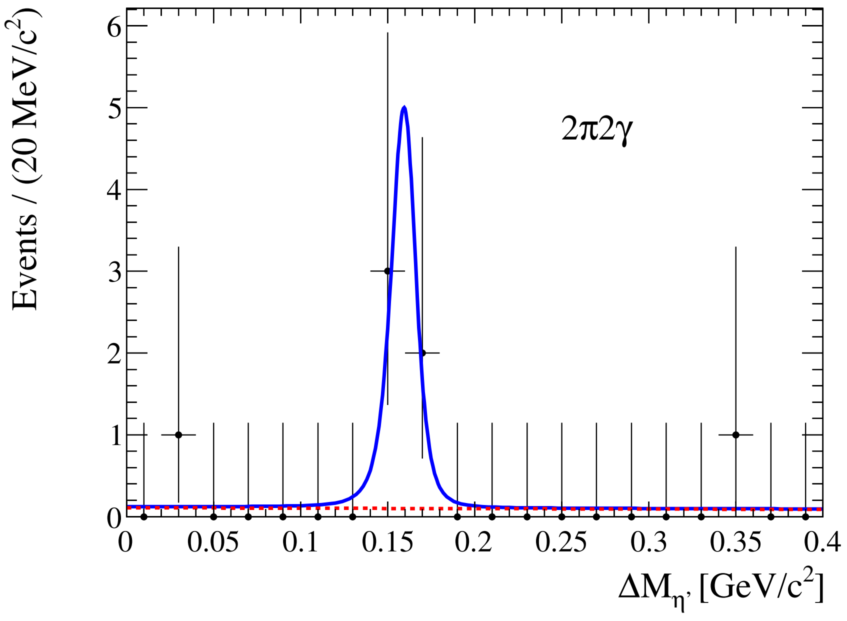
From 538M $\Upsilon(4S)$ Belle searched for $\Upsilon(4S) \to \eta'\Upsilon(1S)$,
$\eta' \to \eta\pi^+\pi^-(\rho^0\gamma)$, $\eta \to \gamma\gamma$, $\Upsilon(1S) \to \mu^+\mu^-$



$\Delta M_{\eta'} = M(\Upsilon(4S)) - M(\Upsilon(1S)) - M(\eta')$ identifies the signal,
$2\pi1\gamma:\ N_{\rm sig} = 22 \pm 7(4.2\sigma)$, $2\pi2\gamma:\ N_{\rm sig} = 5.0 \pm 2.3(4.1\sigma)$,
Systematic uncertainties: 7.6%($2\pi1\gamma$) and 3.5%($2\pi2\gamma$)
E. Guido et al., Phys. Rev. Lett. 121, 062001 (2018)

Observation of $\Upsilon(4S) \to \eta' \; \Upsilon(1S)$ – II





$$\mathcal{B}(\Upsilon(4S) \to \eta'\Upsilon(1S)) = (3.43 \pm 0.88 \pm 21) \cdot 10^{-5},$$

$$R_{\eta'/h} = \mathcal{B}(\Upsilon(4S) \to \eta'\Upsilon(1S))/\mathcal{B}(\Upsilon(4S) \to h\Upsilon(1S)),$$

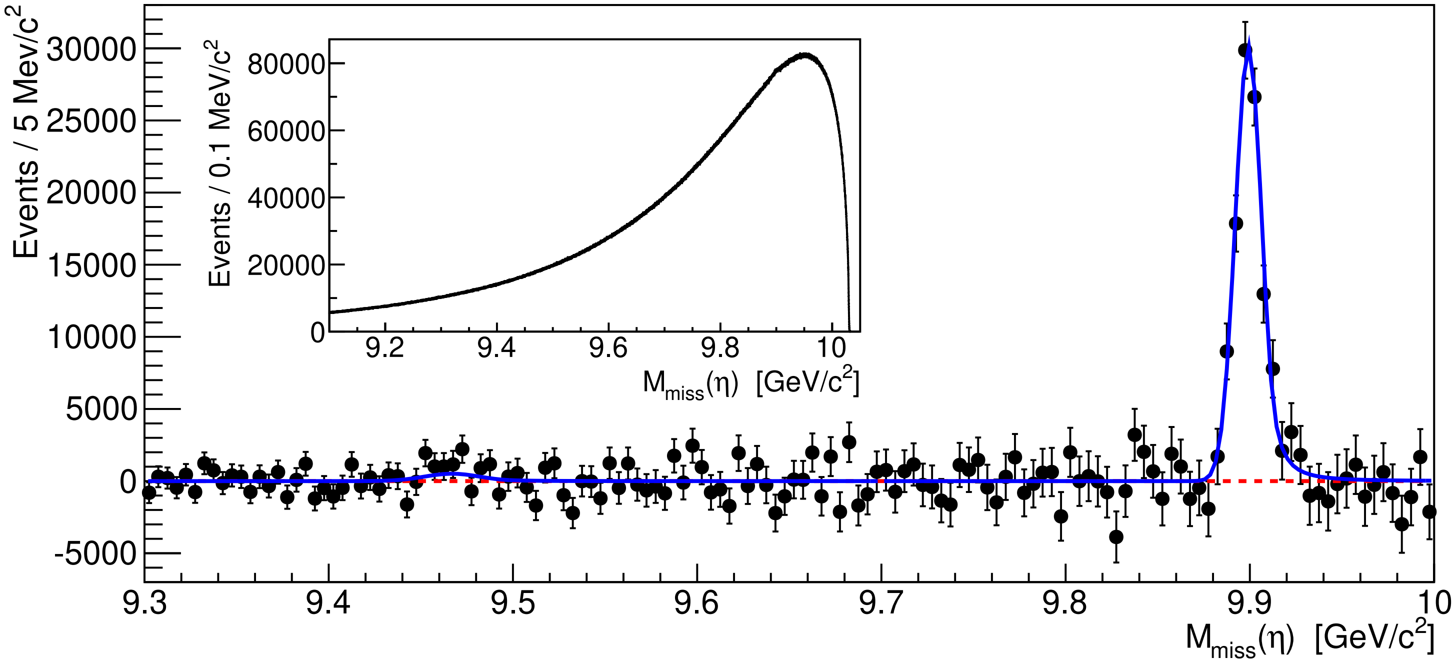
$R_{\eta'/\eta} = 0.20 \pm 0.06$, (0.2-0.6) predicted (rel.$u\bar{u} + d\bar{d}$),

$R_{\eta'/\pi^+\pi^-} = 0.42 \pm 0.11$, again no predicted suppression

E. Guido et al., Phys. Rev. Lett. 121, 062001 (2018)

Observation of the $\Upsilon(4S) \to \eta h_b(1P)$ Transition – I

From 771.6M $\Upsilon(4S)$ decays Belle studied $\Upsilon(4S) \to \eta h_b(1P)$ using the η missing mass, $M_{\text{miss}} = \sqrt{(P_{e^+e^-} - P_\eta)^2}$, $\eta \to \gamma\gamma$.

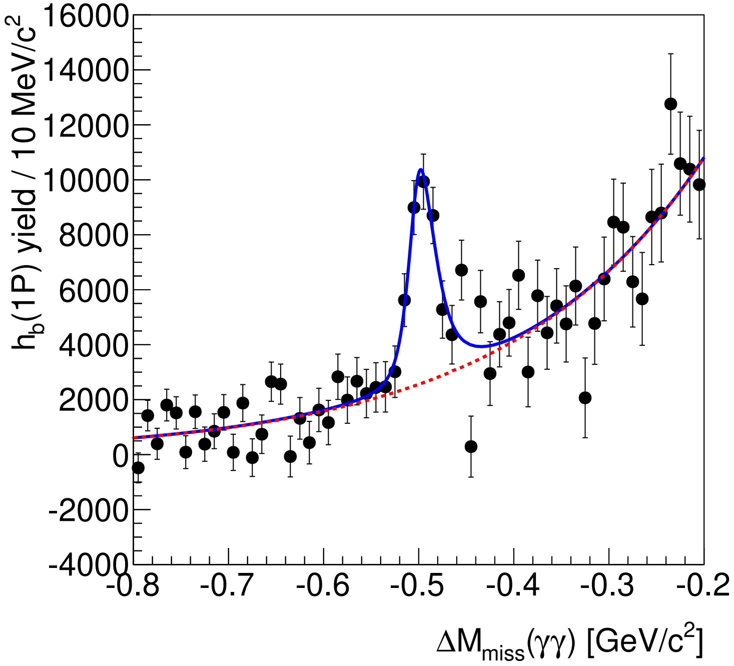


$N_{h_b(1P)} = 112469 \pm 5537$ (11σ significance)

U. Tamponi et al., Phys. Rev. Lett. 115, 142001 (2015)

Observation of the $\Upsilon(4S) \to \eta h_b(1P)$ Transition – II

Then $h_b(1P) \to \gamma\eta_b(1S)$ is searched via $\Delta M_{\rm miss} = M_{\rm miss}(\eta\gamma) - M_{\rm miss}(\eta)$



$N_{\eta_b(1S)} = 33116 \pm 4741$ (9σ significance)

U. Tamponi et al., Phys. Rev. Lett. 115, 142001 (2015)

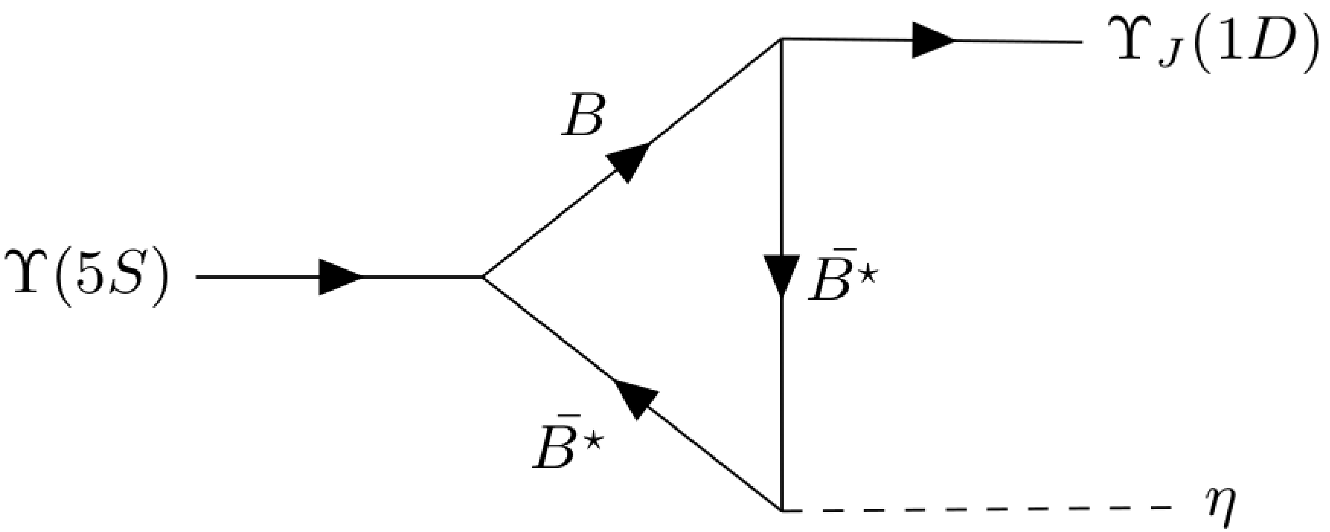
Observation of the $\Upsilon(4S) \to \eta h_b(1P)$ Transition – III

Observable	Value
$\mathcal{B}(\Upsilon(4S) \to \eta h_b(1P))$	$(2.18 \pm 0.11 \pm 0.18) \cdot 10^{-3}$
$\mathcal{B}(h_b(1P) \to \gamma \eta_b(1S))$	$(56 \pm 8 \pm 4)\%$
$M_{h_b(1P)}$	$(9899.3 \pm 0.4 \pm 1.0)$ MeV
$M_{\eta_b(1S)}$	$(9400.7 \pm 1.7 \pm 1.6)$ MeV
$\Gamma_{\eta_b(1S)}$	$(8^{+6}_{-5} \pm 5)$ MeV
$\Delta M_{\rm HF}(1P) = M^{\rm sa}_{\chi_{bJ}}(1P) - M_{h_b(1P)}$	$(+0.6 \pm 0.4 \pm 1.0)$ MeV
$\Delta M_{\rm HF}(1S) = M_{\Upsilon(1S)} - M_{\eta_b(1S)}$	$(59.6 \pm 1.7 \pm 1.6)$ MeV

U. Tamponi et al., Phys. Rev. Lett. 115, 142001 (2015)

$e^+e^- \to \eta\ (b\bar{b})$ Near $\Upsilon(5S)$ – I

From 121.4 fb^{-1} Belle studied $e^+e^- \to \eta\ (b\bar{b})$ near $\sqrt{s} = 10.860$ GeV,
$\eta \to \gamma\gamma$ only reconstructed, $M_{\text{miss}}(\eta)$ studied

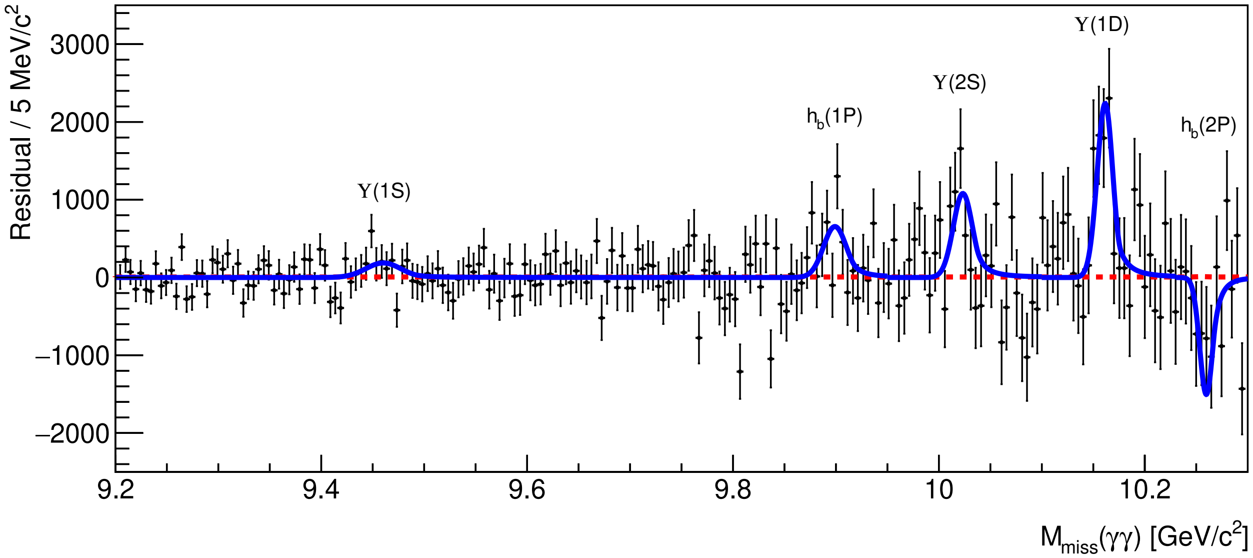


A possible way to observe $\Upsilon_J(1D)$ via triangular $B^{(*)}$ loops
U. Tamponi et al., Eur. Phys. J. C78, 633 (2018)

$e^+e^- \to \eta\ (b\bar{b})$ Near $\Upsilon(5S)$ – II

- B. Wang et al., Phys. Rev. D94 (2016) 094039, analyze $\Upsilon(5S) \to \eta\Upsilon_J(1D)$ in the rescattering model with triangular $B^{(*)}$ loops
- They calculate $\mathcal{B} \sim 10^{-3}$
- $f_1 = \mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_1(1D))/\mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_2(1D)) = 0.68$
- $f_3 = \mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_3(1D))/\mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_2(1D)) = 0.13$
- Triplet members are predicted at a comparable level

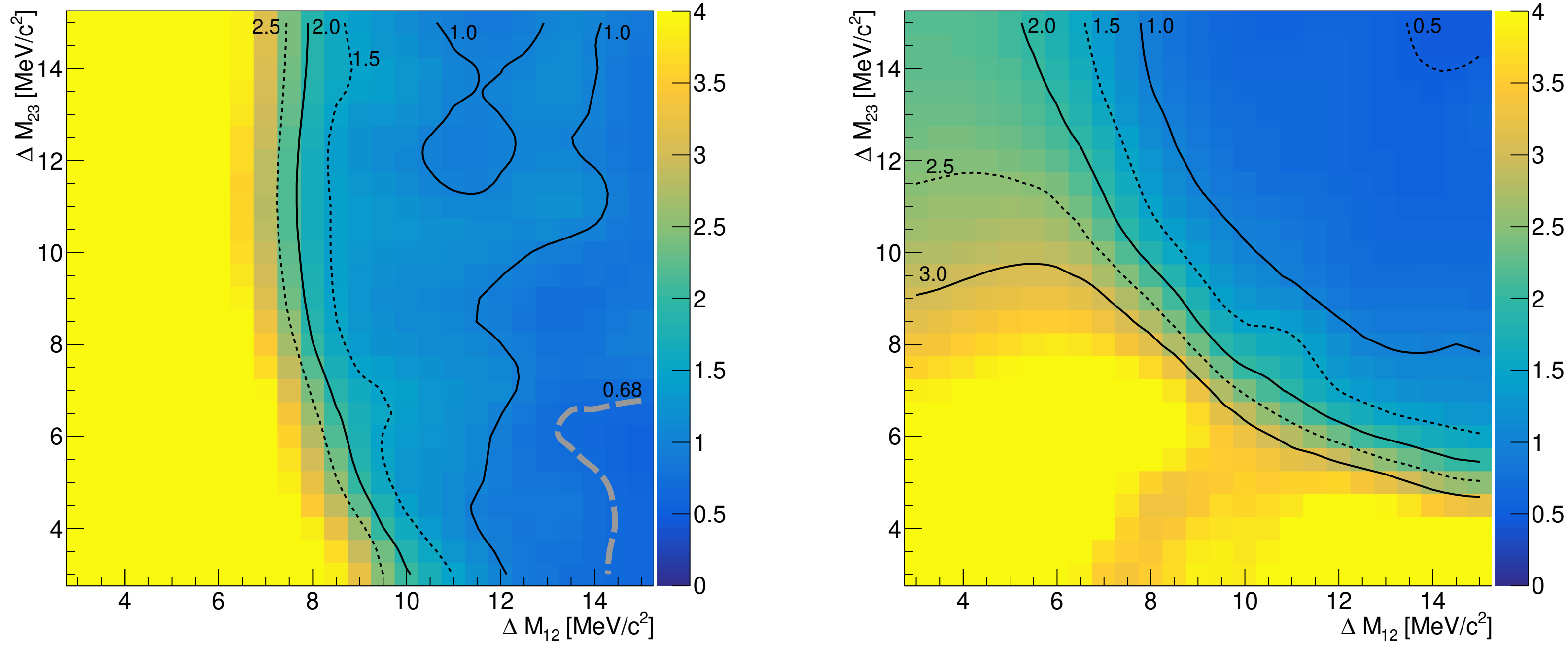
$e^+e^- \to \eta\ (b\bar{b})$ Near $\Upsilon(5S)$ – III



Process	Σ	$N, 10^3$	Process	Σ	$N, 10^3$
$\eta\Upsilon(1S)$	1.5σ	1.7 ± 1.0	$\eta\Upsilon(2S)$	3.3σ	5.6 ± 1.6
$\eta\ h_b(1P)$	2.7σ	3.9 ± 1.5	$\eta\Upsilon(1D)$	5.3σ	9.3 ± 1.8

U. Tamponi et al., Eur. Phys. J. C78, 633 (2018)

$e^+e^- \to \eta\ (b\bar{b})$ Near $\Upsilon(5S)$ – IV



$f_{1,3} = \mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_{1,3}(1D))/\mathcal{B}(\Upsilon(5S) \to \eta\Upsilon_2(1D))$ are compatible with 0

$$\mathcal{B}[\Upsilon(5S) \to \eta\Upsilon_J(1D)] = (4.82 \pm 0.92 \pm 0.67) \cdot 10^{-3}$$

U. Tamponi et al., Eur. Phys. J. C78, 633 (2018)

$e^+e^- \to \eta\ (b\bar{b})$ Near $\Upsilon(5S)$ – V

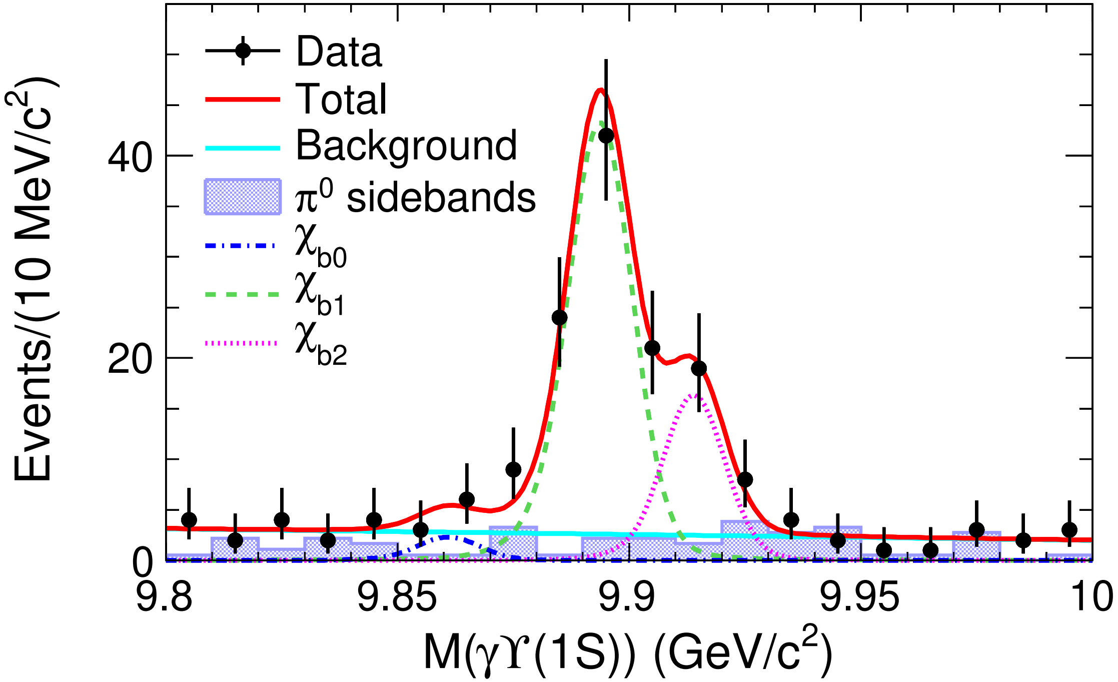
Decay	$\mathcal{B}, 10^{-3}$
$\eta\Upsilon(1S)$	< 1.4
$\eta h_b(1P)$	< 2.2
$\eta\Upsilon(2S)$	$3.00 \pm 0.88 \pm 0.50$
$\eta\Upsilon_J(1D)$	$4.82 \pm 0.91 \pm 0.62$
$\eta h_b(2P)$	< 1.9

Observation of $\Upsilon(10860) \to \Upsilon(1S, 2S)\eta$ Decays

- Belle used 121.4 fb^{-1} near the peak of $\Upsilon(10860)$ to study its decays to $\Upsilon(1S, 2S)\eta$, $\Upsilon(1S, 2S) \to \mu^+\mu^-$, $\eta \to \pi^+\pi^-\pi^0$
- An additional channel $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$ is also used
- $\mathcal{B}(\Upsilon(10860) \to \Upsilon(1S)\eta) \sim 9.7 \cdot 10^{-4}$, $\mathcal{B}(\Upsilon(10860) \to \Upsilon(2S)\eta) \sim 5.1 \cdot 10^{-3}$
- $\mathcal{B}(\Upsilon(10860) \to \Upsilon(1S)\eta') < 1.8 \cdot 10^{-4}$, $\eta' \to \eta\pi^+\pi^-$
- No strong suppression of the decays with $\eta(\eta')$

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – I

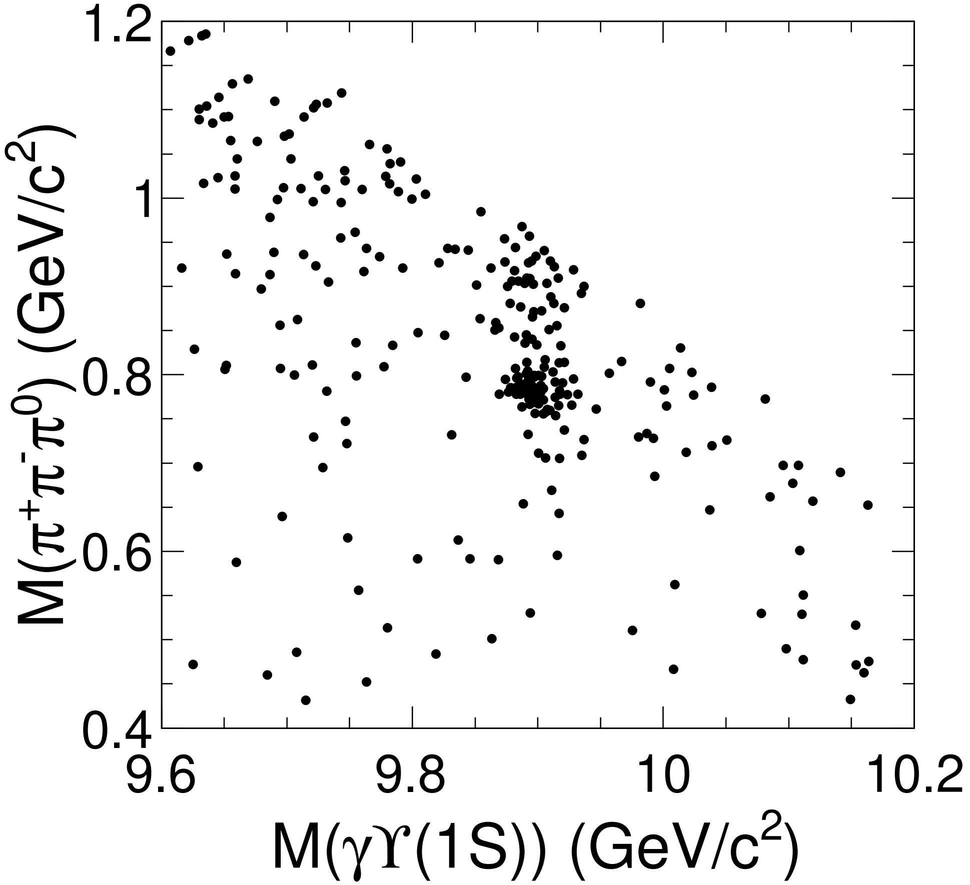
Belle used 118 fb^{-1} at 10.867 GeV to study $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ},\ \chi_{bJ} \to \gamma\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$ and search for $X_b \to \omega\Upsilon(1S)$, analogue of $\chi_{c1}(3872)$



The $\gamma\Upsilon(1S)$ spectrum shows clear signals of the $\chi_{b1}3\pi$ and $\chi_{b2}3\pi$

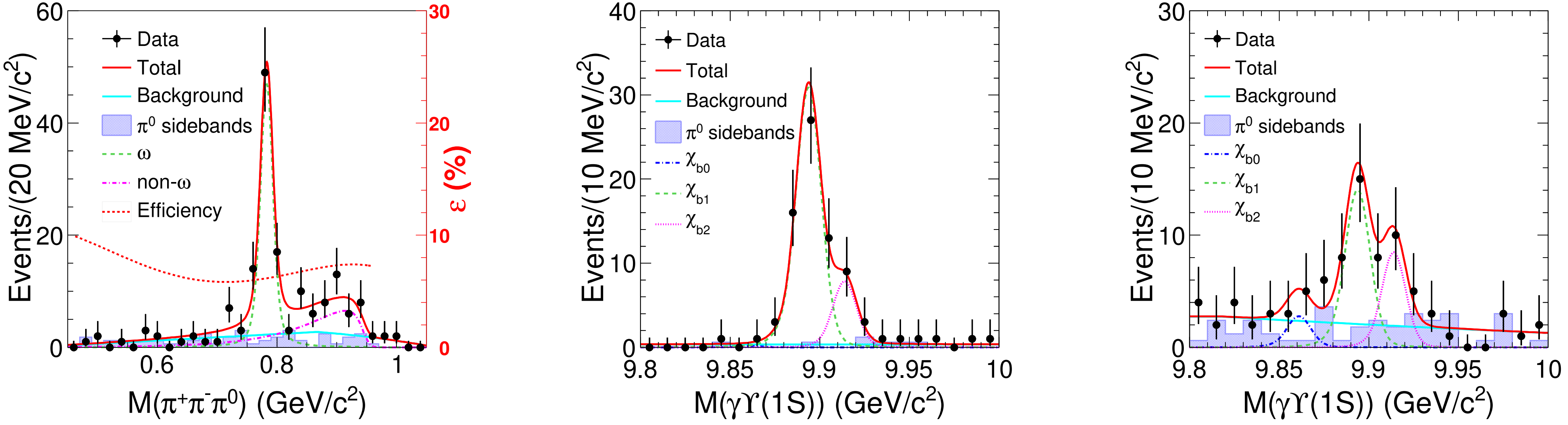
X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – II



X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – III



b/ The $M(3\pi)$ projection shows clear signals of ω and non-ω,

c/ and d/ show the $\gamma\Upsilon(1S)$ projection in the ω and non-ω

X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

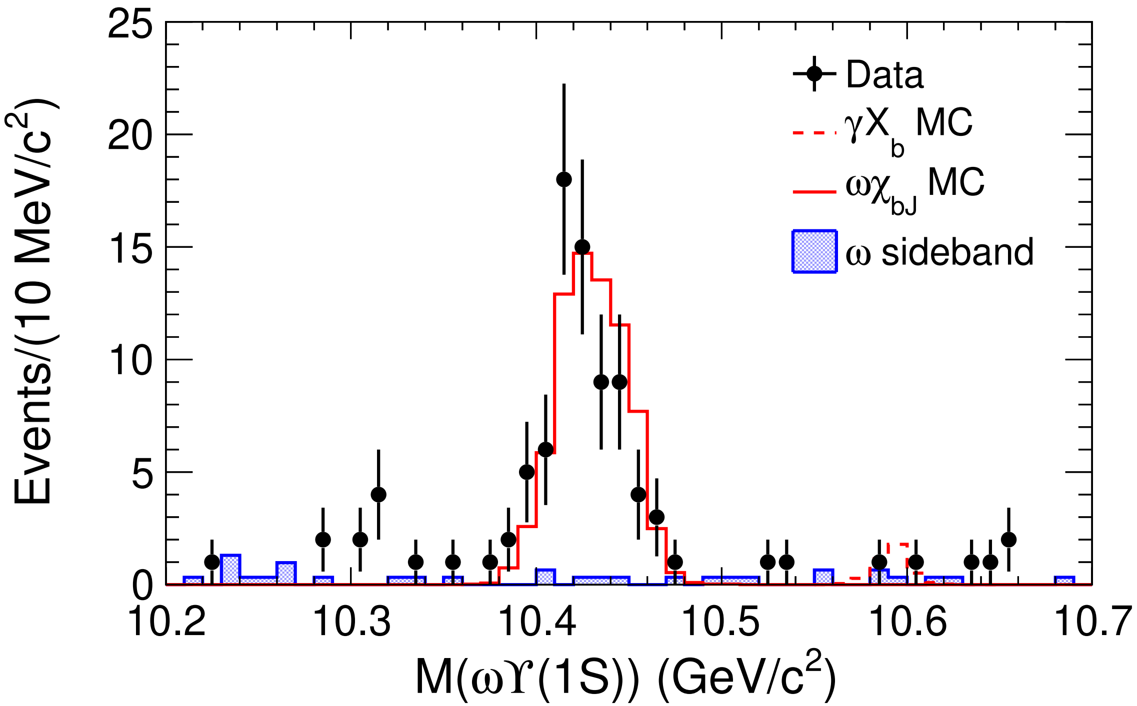
Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – IV

Mode	Yield	Σ (σ)	$\mathcal{B}, 10^{-3}$
$3\pi\chi_{b0}$	< 13.6	1.0	< 6.3
$3\pi\chi_{b1}$	80.1 ± 9.9	12	$1.85 \pm 0.23 \pm 0.23$
$3\pi\chi_{b2}$	28.6 ± 6.5	5.9	$1.17 \pm 0.27 \pm 0.14$
$\omega\chi_{b0}$	< 7.5	0.5	< 3.9
$\omega\chi_{b1}$	59.9 ± 8.3	12	$1.57 \pm 0.22 \pm 0.21$
$\omega\chi_{b2}$	12.9 ± 4.8	3.5	$0.60 \pm 0.23 \pm 0.15$
$(3\pi)_{\mathrm{non}-\omega\chi_{b0}}$	< 10.7	0.4	< 4.8
$(3\pi)_{\mathrm{non}-\omega\chi_{b1}}$	23.6 ± 6.4	4.9	$0.52 \pm 0.15 \pm 0.11$
$(3\pi)_{\mathrm{non}-\omega\chi_{b2}}$	15.6 ± 5.4	3.1	$0.61 \pm 0.22 \pm 0.28$

X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – V

Belle searches for X_b in $e^+e^- \to \gamma X_b,\ X_b \to \omega\Upsilon(1S)$



The peak in $M(\omega\Upsilon(1S))$ comes from $e^+e^- \to \omega\chi_{bJ},\ \chi_{bJ} \to \gamma\Upsilon(1S)$

$\mathcal{B}(\Upsilon(10860) \to \gamma X_b)\mathcal{B}(X_b \to \omega\Upsilon(1S)) < (2.6 - 3.8) \cdot 10^{-5}$ btw. 10.55 and 10.65 GeV

X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

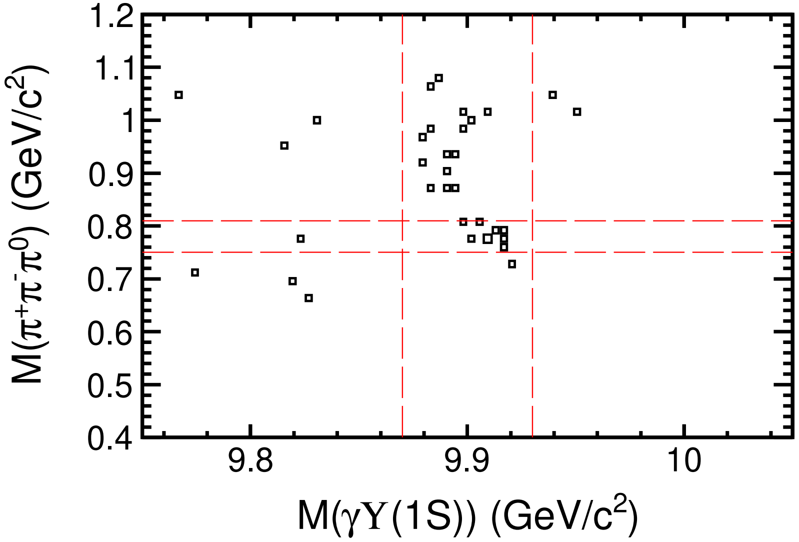
Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ – VI

- Clear $\pi^+\pi^-\pi^0\chi_{b1}$ and $\pi^+\pi^-\pi^0\chi_{b2}$ seen, no significant signal of $\pi^+\pi^-\pi^0\chi_{b0}$
- The $\omega\chi_{b1}$ signal amd indication for $\omega\chi_{b2}$ found, no $\omega\chi_{b0}$
- The measured $\mathcal{B}$ for $3\pi\chi_{b1,2}$ are large and of the same order as for $\pi^+\pi^-\Upsilon(nS)$
- $\mathcal{B}(\omega\chi_{b2})/\mathcal{B}(\omega\chi_{b1}) = 0.38 \pm 0.16 \pm 0.09$ while HQSS gives 1.57
- No $X_b \to \omega\Upsilon(1S)$ found in $\Upsilon(10860) \to \gamma X_b$

X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ and Search for $e^+e^- \to \phi\chi_{bJ}$ – I

Belle searches for $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$, $\phi\chi_{bJ}$ with 141 fb^{-1} in [10.77-11.05] GeV,
$\chi_{bJ} \to \gamma\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$, $\omega \to \pi^+\pi^-\pi^0$, $\phi \to K^+K^-$

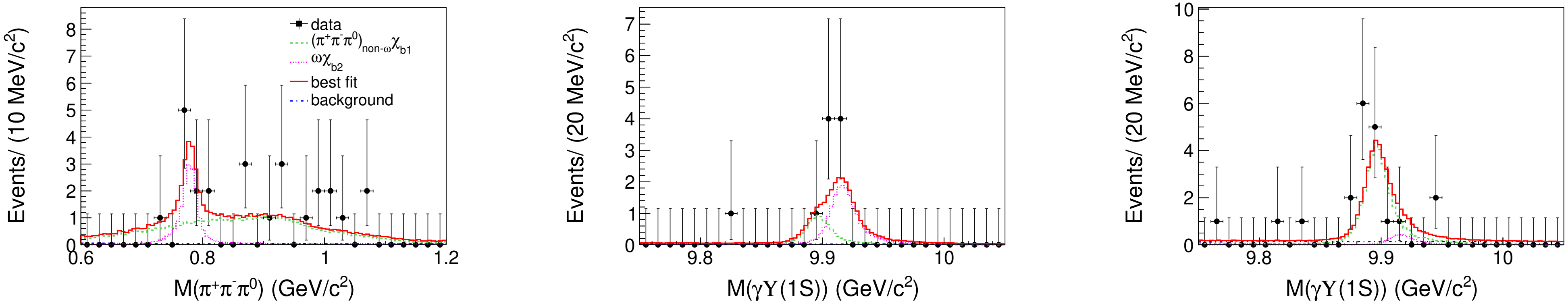


The scatter plot clealy shows clusters at $\omega\chi_{bJ}$ and above

The 2D fit yields 7.8 ± 3.2 (4.0σ) $\omega\chi_{b2}$ and 19.6 ± 5.3 (6.1σ) non-$\omega\chi_{b1}$

J.H. Yin et al., Phys. Rev. D98, 091102 (2018)

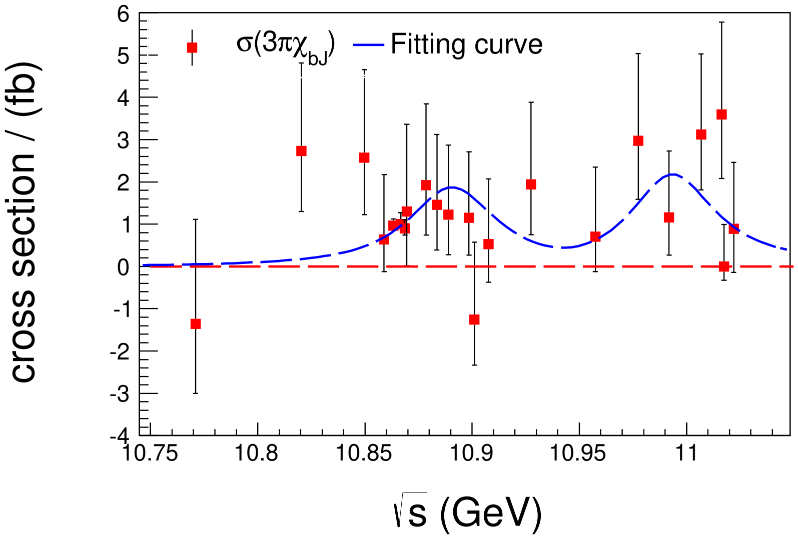
Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ and Search for $e^+e^- \to \phi\chi_{bJ}$ – II



1D projections: clear ω and non-ω, non-$\omega\chi_{b1}$, $\omega\chi_{b2}$

J.H. Yin et al., Phys. Rev. D98, 091102 (2018)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ and Search for $e^+e^- \to \phi\chi_{bJ}$ – III



Assuming the $3\pi\chi_{bJ}$ signal comes from the $\Upsilon(5S)$ and $\Upsilon(6S)$,

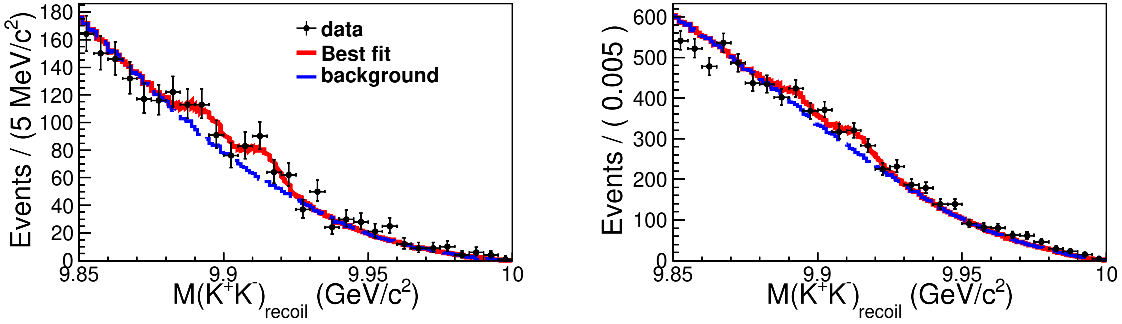
$$\mathcal{B}(\Upsilon(5S) \to e^+e^-)\mathcal{B}(\Upsilon(5S) \to 3\pi\chi_{bJ}) = (15.3 \pm 3.7) \cdot 10^{-9},$$

$$\mathcal{B}(\Upsilon(6S) \to e^+e^-)\mathcal{B}(\Upsilon(6S) \to 3\pi\chi_{bJ}) = (18.3 \pm 9.0) \cdot 10^{-9}$$

Low data samples preclude from any conclusions

J.H. Yin et al., Phys. Rev. D98, 091102 (2018)

Observation of $e^+e^- \to \pi^+\pi^-\pi^0\chi_{bJ}$ and Search for $e^+e^- \to \phi\chi_{bJ}$ – IV



Two types of events: $M(\gamma K^+K^-)_{\rm recoil}$ around $M(\Upsilon(1S))$ and non-$\Upsilon(1S)$

Then in $M(K^+K^-)_{\rm recoil}$ no signals of $\phi\chi_{b1}$ (2.6σ) and $\phi\chi_{b2}$ (2.1σ) seen

$\sigma(\phi\chi_{b1}) < 1.4$ pb, $\sigma(\phi\chi_{b2}) < 1.2$ pb at 90% CL or $\mathcal{B} \sim 10^{-3}$

J.H. Yin et al., Phys. Rev. D98, 091102 (2018)

Conclusions

- In addition to $\pi^+\pi^-$ transitions, CLEO and later Belle/BaBar studied other possible hadronic transitions - π^0, η, η', ω, $\ldots$
- Not all possibilities studied, some results suffer from low statistics
- η transitions show a puzzling pattern depending on $\sqrt{s}$
- Agreement with theory poor, still far from fair QCD description
- A strong interaction of quarks and gluons will benefit from much stronger than today interaction between theory and experiment

Prospects for BelleII

- 50-fold increase of the number of $\Upsilon(4S)$ together with improved resolution will allow extensive studies of its decays as well as of the $\Upsilon(1S, 2S, 3S)$ via ISR in addition to their separate scans
- It is extremely important to invest into the higher-energy region, moving if possible to 11.5 GeV to study the $\Upsilon(10860)$ and $\Upsilon(11020)$ and search for higher-mass states
- Of paramount importance is the precise measurement of R_b making possible measurements of various $\mathcal{B}$ and understanding full pattern of $\Upsilon(10860)$ and $\Upsilon(11020)$ decays
- Relatively rare hadronic transitions (η, η', ω) will be measured due to both high luminosity and better resolution improving signal-to-background ratio
- It is important to have a bridge btw. charmonia and bottomonia

News from PDG

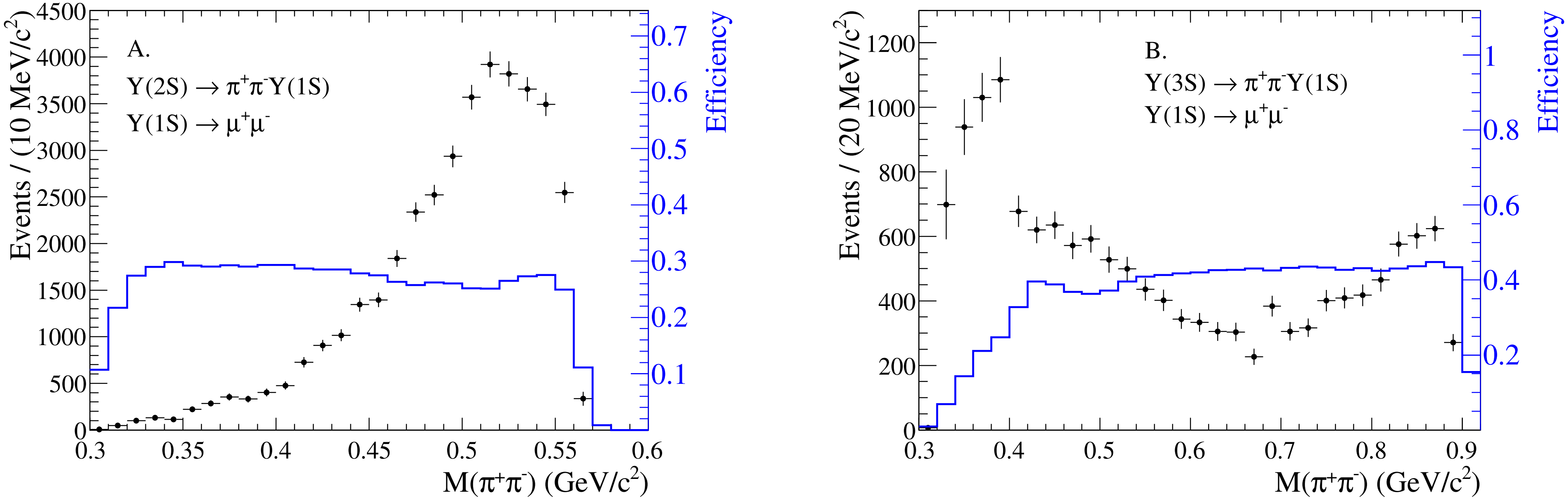
RPP 2018, New Edition of PDG

M. Tanabashi et al., Phys. Rev. D 98, 030001 (2018)

It uses the new naming scheme of hadrons

Backup Slides

Study of η and $\pi^+\pi^-$ Transitions in $\Upsilon(4S)$ Decays to Lower $(b\bar{B})$ – III



E. Guido et al., Phys. Rev.D 96, 052005 (2017)