Bottomonium states on B factories

Pavel Krokovny

Budker Institute of Nuclear Physics,
Novosibirsk, Russia

- Introduction
- Di-pion bottomonia transitions
  - $h_b\ \pi^+\pi^-$ } Observation of Z_b
  - $Y\ \pi^+\pi^-$ }
- Observation of $h_b \to \eta_b\ \gamma$
- Bottomonia transitions via η meson
- Summary

Introduction

- Anomalous production of $\Upsilon\pi^+\pi^-$ and $h_b\pi^+\pi^-$ in $\Upsilon(5S)$ decays:

PRL100,112001(2008)

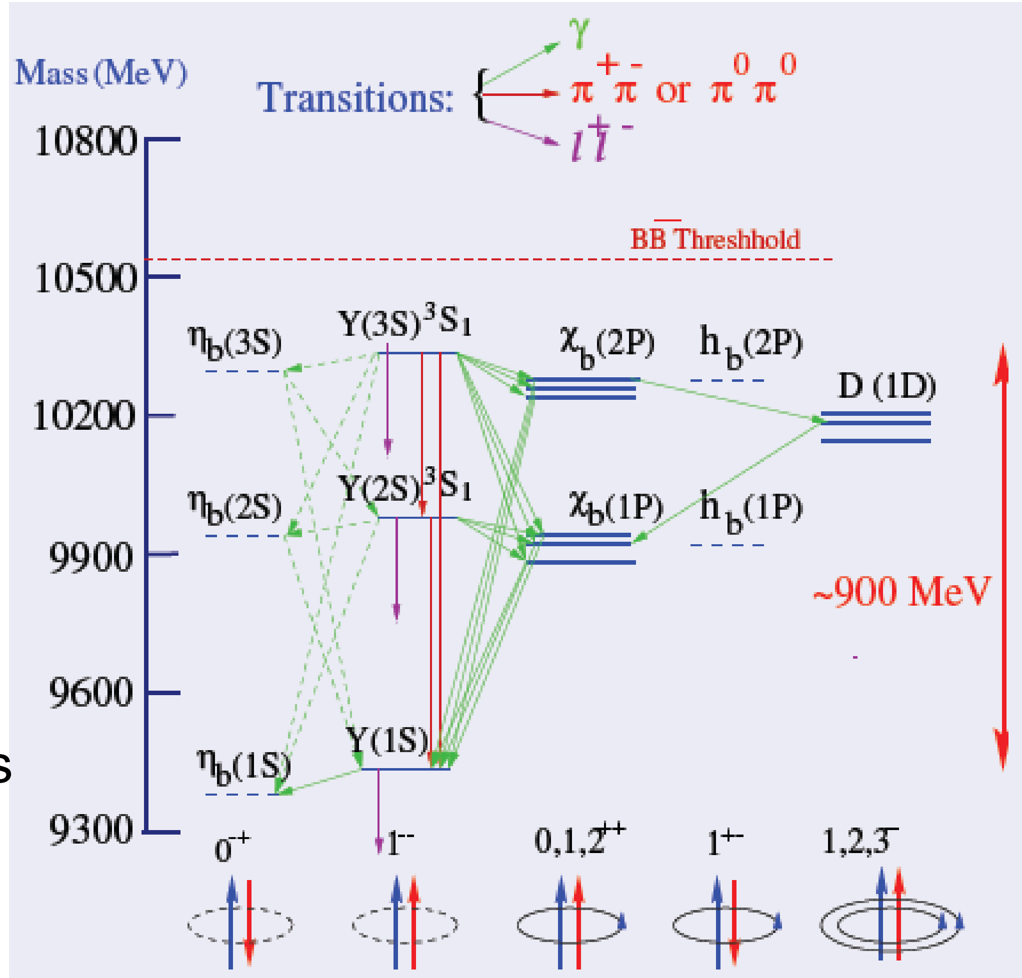
	Γ(MeV)
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019

10^2

and observation of $e^+e^- \to h_c\,\pi^+\pi^-$ by CLEO motivated to search for the resonant structures in Y(5S) decays

- Large h_b sample and high Br(h_b) $\to \eta_b\gamma$ allows to study η_b properties

- Bottomonia transitions via η meson can be used to test the quark structure of Y states

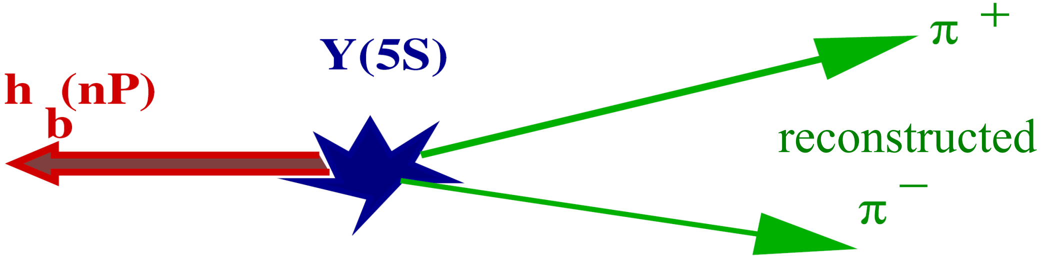


Belle
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(2S)$: 24 fb^{-1}

BaBar
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}

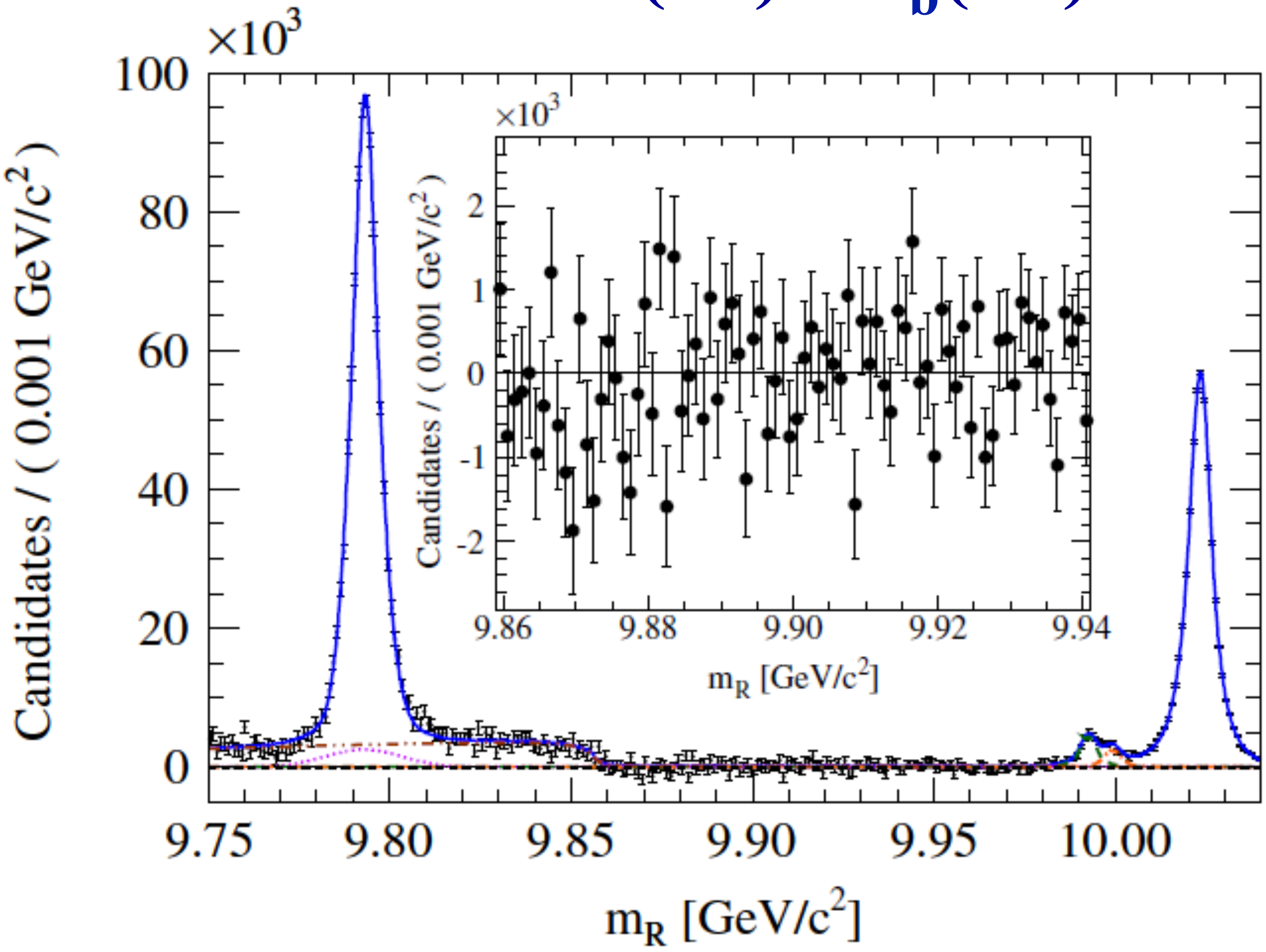
Di-pion Bottomonia transitions

- Reasonable branching fractions, high reconstruction efficiencies
- Full reconstruction: $\Upsilon(5S) \to \Upsilon(nS)[\mu^+\mu^-]\pi^+\pi^-$
  - High signal purity
  - Study of resonant structure
  - Angular analysis
- Inclusive analysis using $\pi^+\pi^-$: $\Upsilon(5S) \to h_b(nP)\pi^+\pi^-$
  - No good channel for h_b reconstruction
  - Using "missing mass" to $\pi^+\pi^-$ system to extract signal:



"Missing mass" $M(h_b) = \sqrt{(E_{c.m.} - E^*_{\pi+\pi-})^2 - p^{*2}_{\pi+\pi-}} \equiv M_{miss}(\pi^+\pi^-)$

Search for Υ(3S)→h_b(1P)π+π−

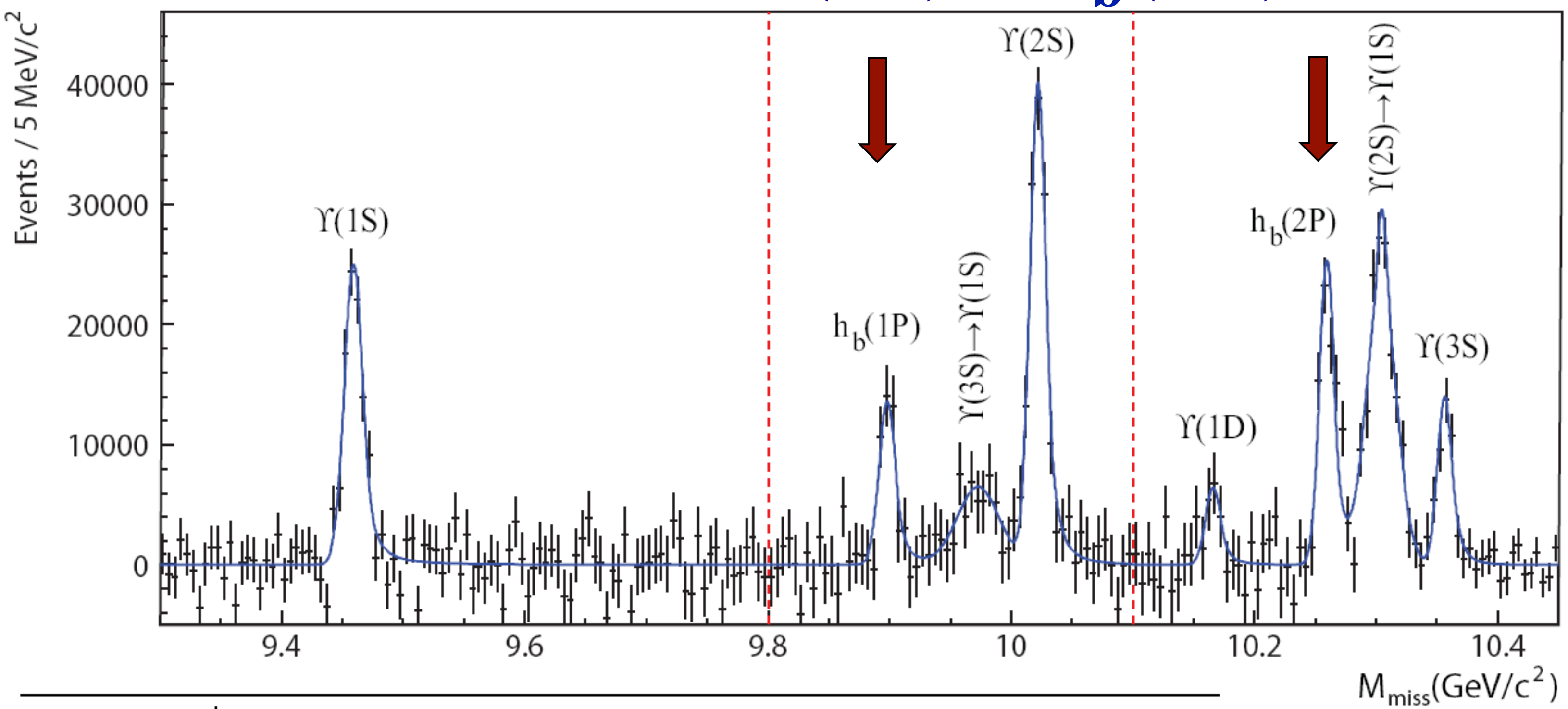


B[Υ(3S)→Υ(2S) $\pi^+\pi^-$] = (3.00 ± 0.02 ± 0.14) %

B[Υ(3S)→h_b(1P)$\pi^+\pi^-$] < 1.2 10^{-4}

Phys.Rev.D 84 011104(R)

Observation of $\Upsilon(5S) \to h_b(nP)\pi^+\pi^-$



	Yield, 10^3	Mass, MeV/c^2	Significance
$\Upsilon(1S)$	$105.0 \pm 5.8 \pm 3.0$	$9459.4 \pm 0.5 \pm 1.0$	$18.1\,\sigma$
$h_b(1P)$	$50.0 \pm 7.8^{+4.5}_{-9.1}$	$9898.2^{+1.1+1.0}_{-1.0-1.1}$	$6.1\,\sigma$
$3S \to 1S$	55 ± 19	9973.01	$2.9\,\sigma$
$\Upsilon(2S)$	$143.8 \pm 8.7 \pm 6.8$	$10022.2 \pm 0.4 \pm 1.0$	$17.1\,\sigma$
$\Upsilon(1D)$	22.4 ± 7.8	10166.1 ± 2.6	$2.4\,\sigma$
$h_b(2P)$	$84.0 \pm 6.8^{+23.}_{-10.}$	$10259.8 \pm 0.6^{+1.4}_{-1.0}$	$12.3\,\sigma$
$2S \to 1S$	$151.3 \pm 9.7^{+9.0}_{-20.}$	$10304.6 \pm 0.6 \pm 1.0$	$15.7\,\sigma$
$\Upsilon(3S)$	$45.5 \pm 5.2 \pm 5.1$	$10356.7 \pm 0.9 \pm 1.1$	$8.5\,\sigma$

Phys.Rev.Lett. 108, 032001 (2012)

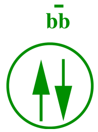
Hyperfine splitting

Deviations from Center of Gravity of χ_{bJ} masses

$\Delta M_{HF} = M\chi_{b0} + 3\ M\chi_{b1} + 5\ M\chi_{b2})/9$

$h_b(1P)$	$(1.7 \pm 1.5)\ \mathrm{MeV}/c^2$	consistent with zero, as expected
$h_b(2P)$	$(0.5\ ^{+1.6}_{-1.2})\ \mathrm{MeV}/c^2$	

Ratio of production rates



spin-flip

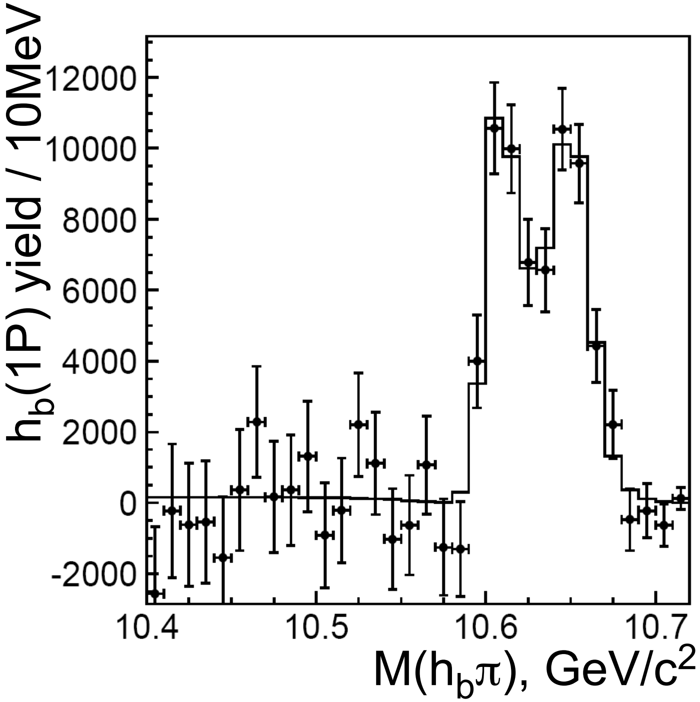
$$\frac{\Gamma[\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-]}{\Gamma[\Upsilon(5S) \to \Upsilon(2S)\,\pi^+\pi^-]} = \begin{cases} 0.45 \pm 0.08^{+0.07}_{-0.12} & \text{for } h_b(1P) \\ 0.77 \pm 0.08^{+0.22}_{-0.17} & \text{for } h_b(2P) \end{cases}$$

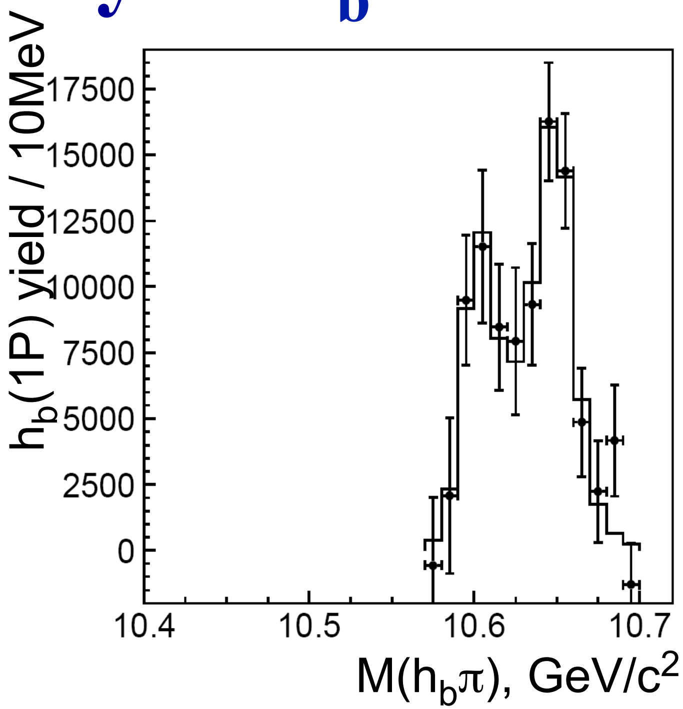
no spin-flip

Process with spin-flip of heavy quark is not suppressed

$\Rightarrow$ Mechanism of $\Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-$ decay violates Heavy Quark Spin Symmetry

Discovery of Z_b



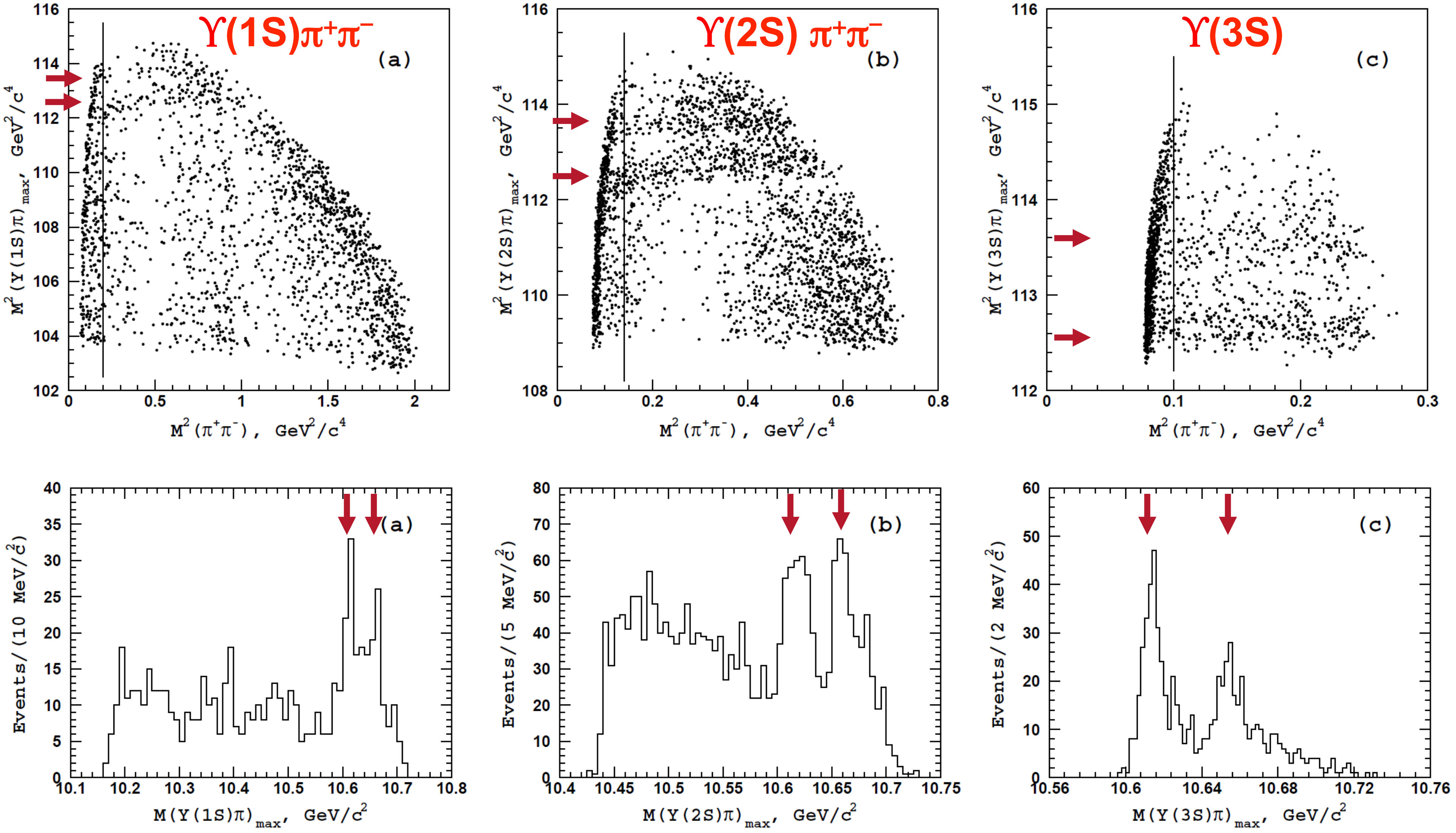


fit $M_{miss}(\pi^+\pi^-)$ in $M(h_b\pi)$ bins

$h_b(1P)\pi^+\pi^-$		$h_b(2P)\pi^+\pi^-$
$M_1 = 10605 \pm 2^{+3}_{-1}$ MeV/c^2	consistent	10599^{+6+5}_{-3-4} MeV/c^2
$\Gamma_1 = 11.4^{+4.5+2.1}_{-3.9-1.2}$ MeV		13^{+10+9}_{-8-7} MeV
$M_2 = 10654 \pm 3^{+1}_{-2}$ MeV/c^2		10651^{+2+3}_{-3-2} MeV/c^2
$\Gamma_2 = 20.9^{+5.4+2.1}_{-4.7-5.7}$ MeV		$19 \pm 7^{+11}_{-7}$ MeV
$a = 1.39 \pm 0.37^{+0.05}_{-0.15}$		$1.6^{+0.6+0.4}_{-0.4-0.6}$
$\varphi = 187^{+44+3}_{-57-12}$ degrees		$181^{+65+74}_{-105-109}$ degrees
non-res.~0		non-res. set to zero

arXiv:1110.2251, accepted by PRL

Discovery of Z_b



arXiv:1110.2251, accepted by PRL

Summary of Z_b parameters

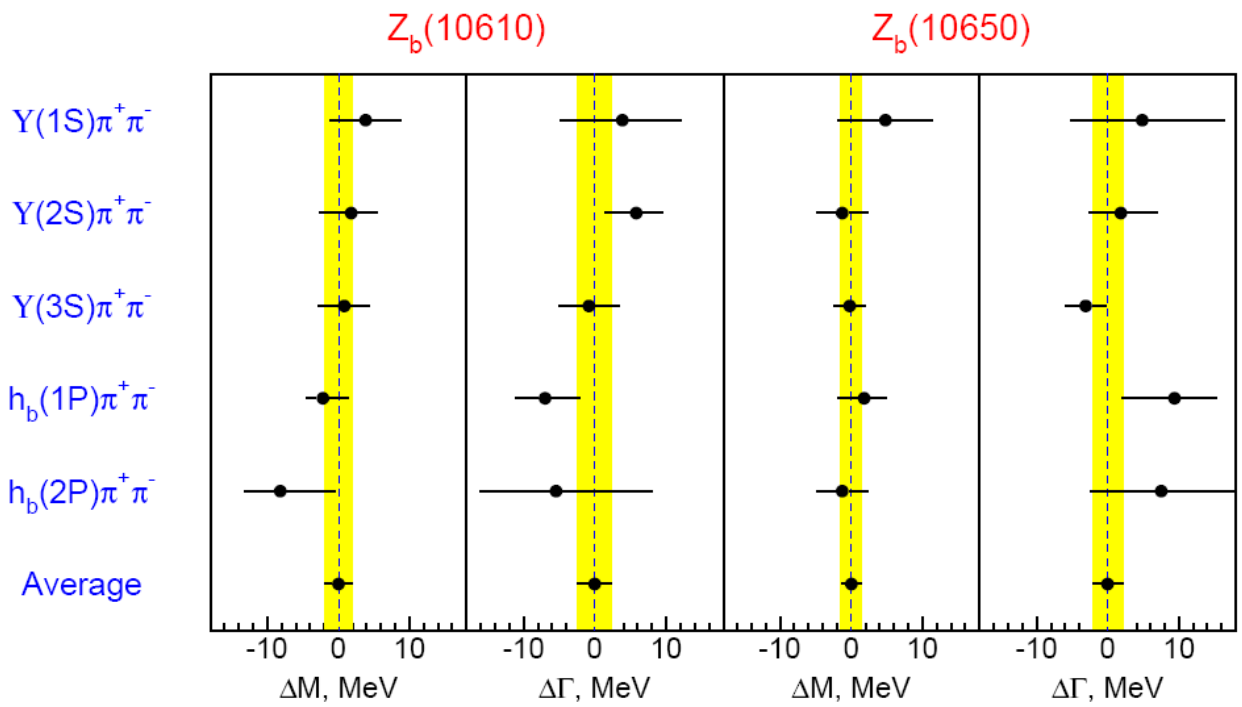
Average over 5 channels

$\langle M_1 \rangle = 10607.2 \pm 2.0$ MeV

$\langle \Gamma_1 \rangle = 18.4 \pm 2.4$ MeV

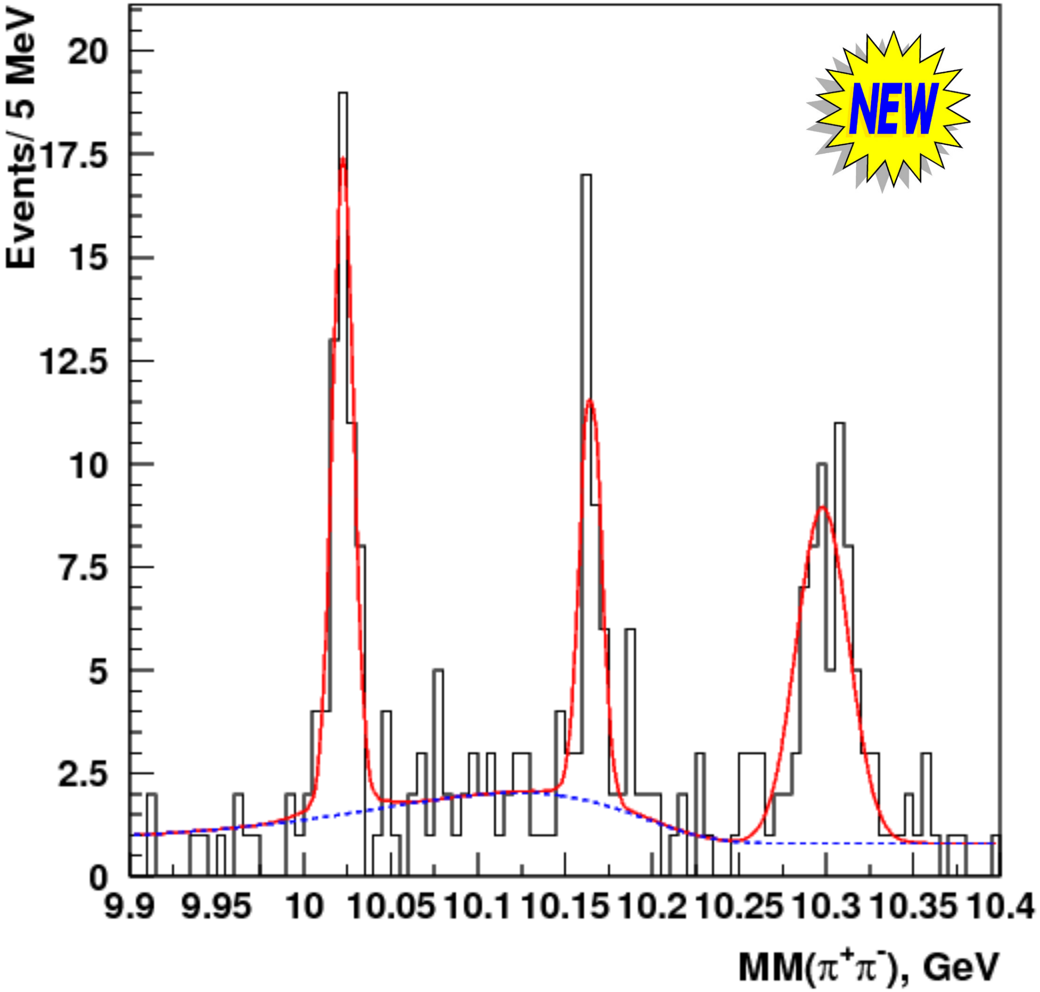
$\langle M_2 \rangle = 10652.2 \pm 1.5$ MeV

$\langle \Gamma_2 \rangle = 11.5 \pm 2.2$ MeV



Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$h_b(1P)\pi^+\pi^-$	$h_b(2P)\pi^+\pi^-$
$M[Z_b(10610)]$, MeV/c^2	$10611 \pm 4 \pm 3$	$10609 \pm 2 \pm 3$	$10608 \pm 2 \pm 3$	$10605 \pm 2^{+3}_{-1}$	10599^{+6+5}_{-3-4}
$\Gamma[Z_b(10610)]$, MeV	$22.3 \pm 7.7^{+3.0}_{-4.0}$	$24.2 \pm 3.1^{+2.0}_{-3.0}$	$17.6 \pm 3.0 \pm 3.0$	$11.4\,^{+4.5+2.1}_{-3.9-1.2}$	$13\,^{+10+9}_{-8-7}$
$M[Z_b(10650)]$, MeV/c^2	$10657 \pm 6 \pm 3$	$10651 \pm 2 \pm 3$	$10652 \pm 1 \pm 2$	$10654 \pm 3\,^{+1}_{-2}$	10651^{+2+3}_{-3-2}
$\Gamma[Z_b(10650)]$, MeV	$16.3 \pm 9.8^{+6.0}_{-2.0}$	$13.3 \pm 3.3^{+4.0}_{-3.0}$	$8.4 \pm 2.0 \pm 2.0$	$20.9\,^{+5.4+2.1}_{-4.7-5.7}$	$19 \pm 7\,^{+11}_{-7}$
Rel. normalization	$0.57 \pm 0.21^{+0.19}_{-0.04}$	$0.86 \pm 0.11^{+0.04}_{-0.10}$	$0.96 \pm 0.14^{+0.08}_{-0.05}$	$1.39 \pm 0.37^{+0.05}_{-0.15}$	$1.6^{+0.6+0.4}_{-0.4-0.6}$
Rel. phase, degrees	$58 \pm 43^{+4}_{-9}$	$-13 \pm 13^{+17}_{-8}$	$-9 \pm 19^{+11}_{-26}$	187^{+44+3}_{-57-12}	$181^{+65+74}_{-105-109}$

Observation of Υ(5S)→Υ(1D)$\pi^+\pi^-$



Υ(1S)[$\mu^+\mu^-$]$\pi^+\pi^-\gamma\gamma$ final state

After χ_b(1P)→Υγ selection

Three peaks in MM($\pi^+\pi^-$):

- Υ(2S) $\pi^+\pi^-$
- Υ(1D) $\pi^+\pi^-$
- Υ(2S)[Υ$\pi^+\pi^-$]η[γγ] reflection

An evidence of Υ(1D) was seen in inclusive analysis of MM($\pi^+\pi^-$) spectra

preliminary

B[Υ(5S)→Υ(2S)$\pi^+\pi^-$] = (7.5±1.1±0.8) 10^{-3} (cross check)

B[Υ(5S)→Υ(1D)$\pi^+\pi^-$] B[Υ(1D)→χ_b(1P)γ→Υ(1S)γγ] = (2.0±0.4±0.3) 10^{-4}

statistical significance 9σ

Introduction to η_b

Expected decays of h_b

Godfrey & Rosner, PRD66 014012 (2002)

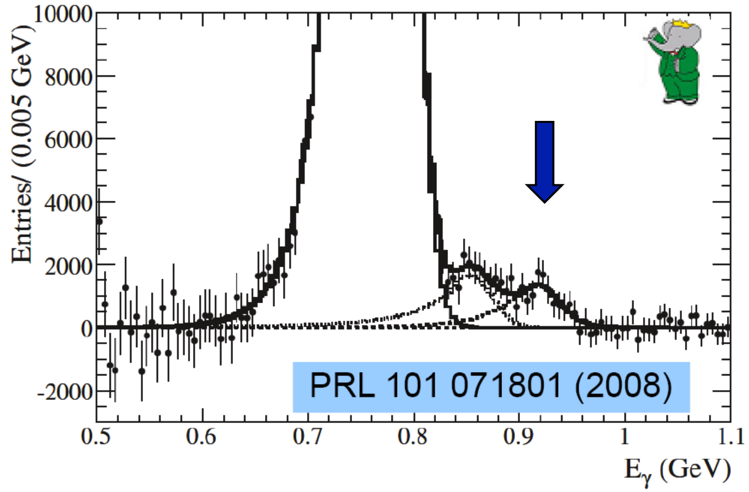
$h_b(1P) \to ggg$ (57%), $\eta_b(1S)\gamma$ (41%), γgg (2%)

$h_b(2P) \to ggg$ (63%), $\eta_b(1S)\gamma$ (13%), $\eta_b(2S)\gamma$ (19%), γgg (2%)

Large $h_b(mP)$ samples give opportunity to study $\eta_b(nS)$ states.

Experimental status of η_b

$\Upsilon(3S) \to \eta_b(1S)\,\gamma$



$M[\eta_b(1S)] = 9390.9 \pm 2.8$ MeV BaBar & CLEO

$M[\Upsilon(1S)] - M[\eta_b(1S)] = 69.3 \pm 2.8$ MeV

pNRQCD: 41 ± 14 MeV

Kniehl et al., PRL92,242001(2004)

Lattice: 60 ± 8 MeV

Meinel, PRD82,114502(2010)

Width of $\eta_b(1S)$: no information

Search for decay $h_b \rightarrow \eta_b \gamma$

Decay chain

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

$\hookrightarrow h_b(nP)\, \pi^+$

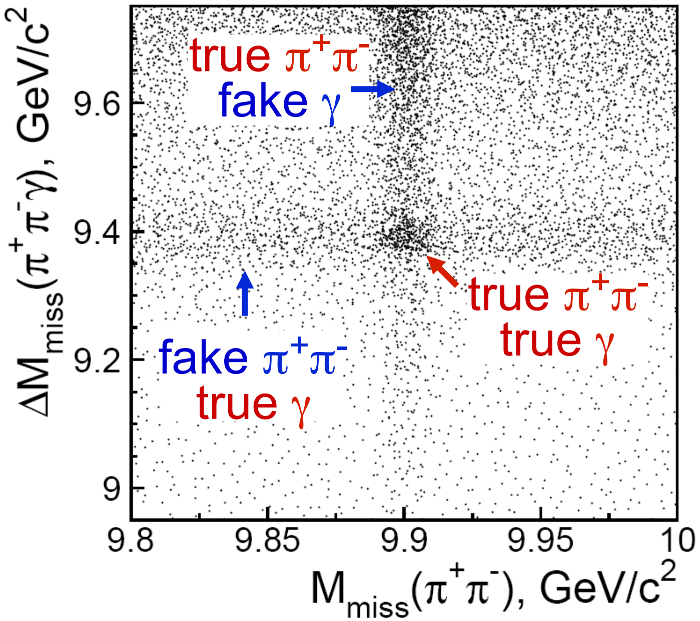
$\hookrightarrow \eta_b(mS)\, \gamma$

reconstruct

Use missing mass to identify signals

MC simulation

$M(\eta_b)$ ⇨



⇧ $M(h_b)$

$\Delta M_{miss}(\pi^+\pi^-\gamma) \equiv$
$M_{miss}(\pi^+\pi^-\gamma) - M_{miss}(\pi^+\pi^-) + M[h_b]$

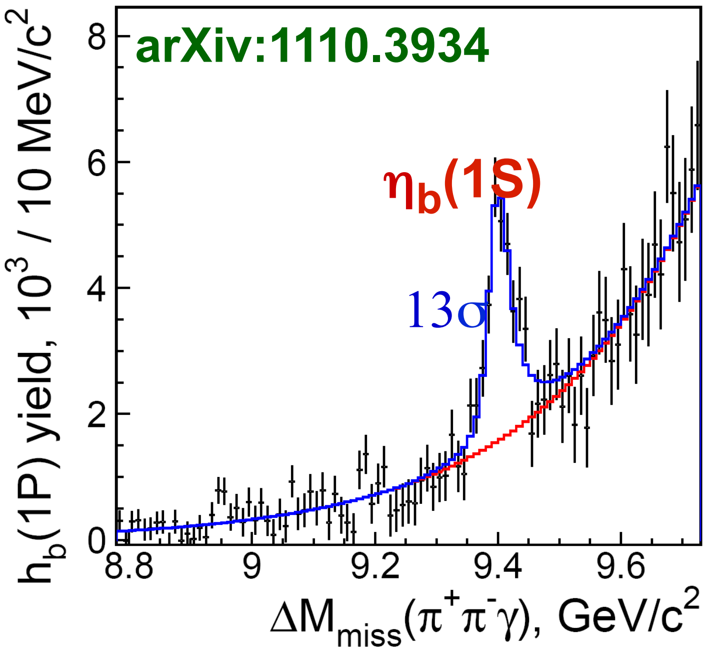
Approach:

fit $M_{miss}(\pi^+\pi^-)$ spectra in $\Delta M_{miss}(\pi^+\pi^-\gamma)$ bins

⇒ $h_b(1P)$ yield vs. $\Delta M_{miss}(\pi^+\pi^-\gamma)$

⇒ search for $\eta_b(1S)$ signal

Observation of $h_b \rightarrow \eta_b(1S)\,\gamma$



$M\,[\eta_b(1S)] = 9401.0 \pm 1.9\,^{+2.4}_{-1.4}$ MeV/c^2

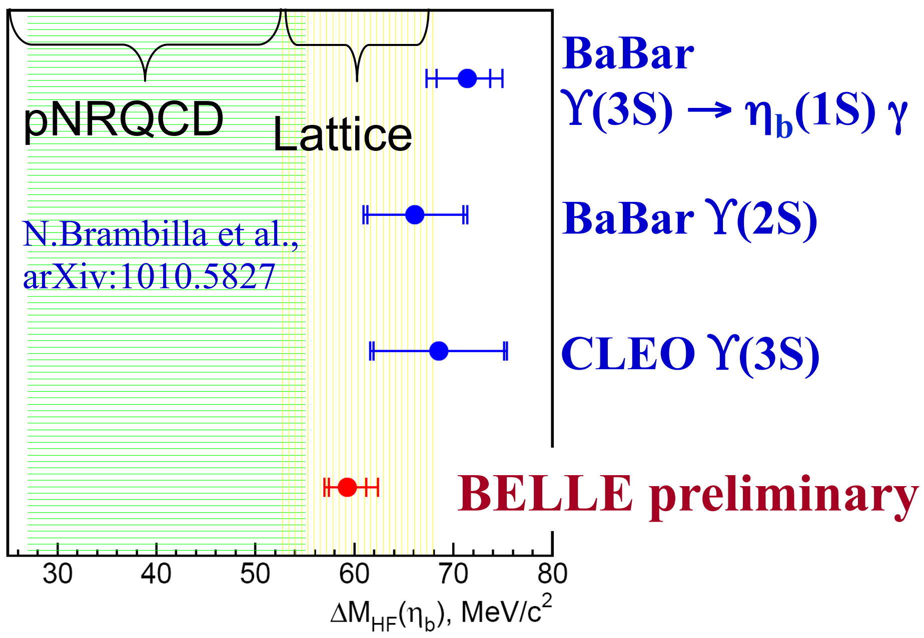
$\Delta M_{HF}\,[\eta_b(1S)] = 59.3 \pm 1.9\,^{+2.4}_{-1.4}$ MeV/c^2

$\Gamma[\eta_b(1S)] = 12.3\,^{+5.5}_{-4.6}\,^{+11.5}_{-3.4}$ MeV

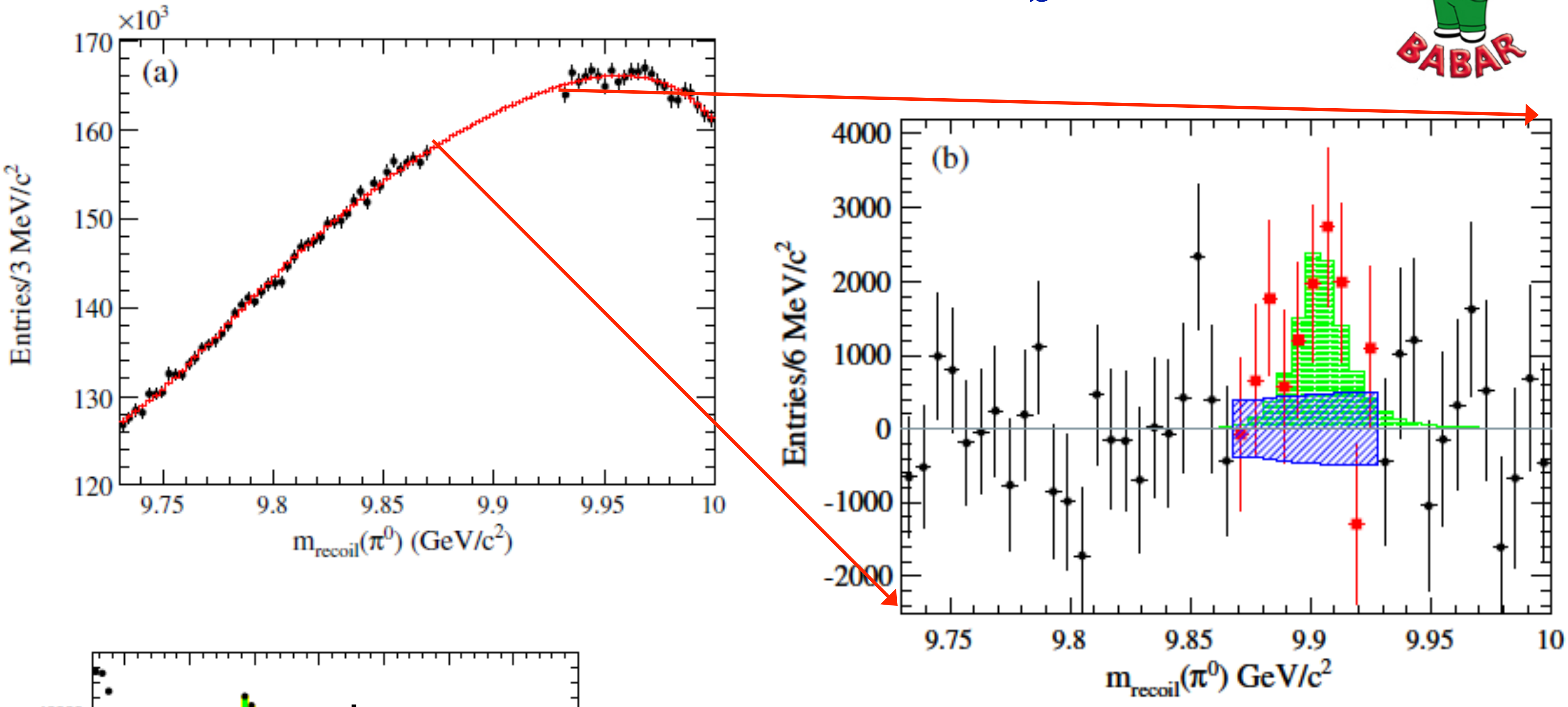
potential models : Γ = 5 – 20 MeV

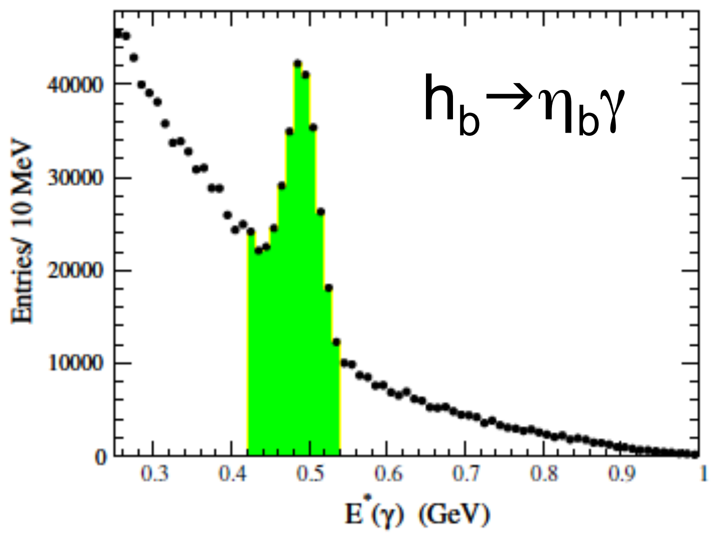
$B[h_b(1P) \rightarrow \eta_b(1S)\gamma] = (49.8 \pm 6.8\,^{+10.9}_{-5.2})$ %

Godfrey & Rosner : BF = 41%



Evidence for $\Upsilon(3S)\rightarrow h_b\pi^0$





$B[\Upsilon(3S)\rightarrow h_b(1P)\pi^0] = (4.3 \pm 1.1 \pm 0.9)\ 10^{-4}$

3.1σ significance

Phys.Rev.D 84 091101(R)

Bottomonia transitions via η meson

• Measurement of bottomonia transitions via η meson is important to test its quark structure.

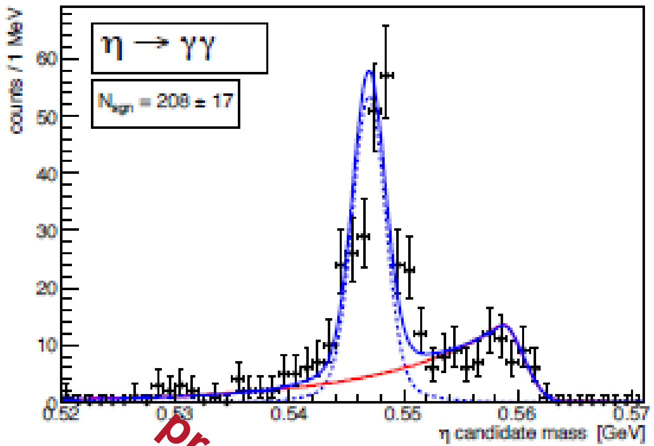
• QCD multipole expansion model Kuang Front.Phys.China 1, 19 (2006) predicts suppression transitions between bottomonia via η meson with respect to di-pion.

• The measured widths for Υ(4S) and Υ(2S) to Υ(1S)η are differ from model predictions:

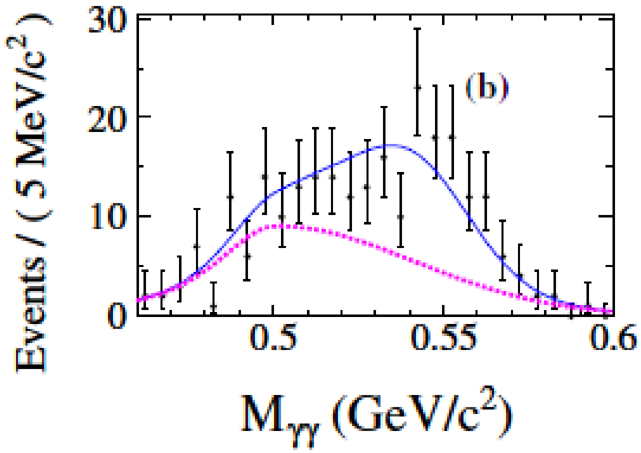
  - Υ(2S)→Υ(1S)η is about ½ than expected
  - Υ(4S)→Υ(1S)η is 2.5 larger than Υ(4S) →Υ(1S)$\pi^+\pi^-$ (orders of magnitude large than theory)

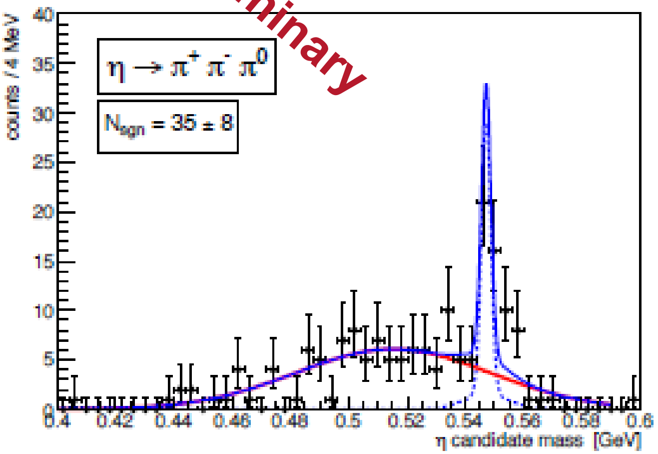
• Therefore a new information on this process is crucial.

$\Upsilon(2S)\rightarrow\Upsilon(1S)\eta$

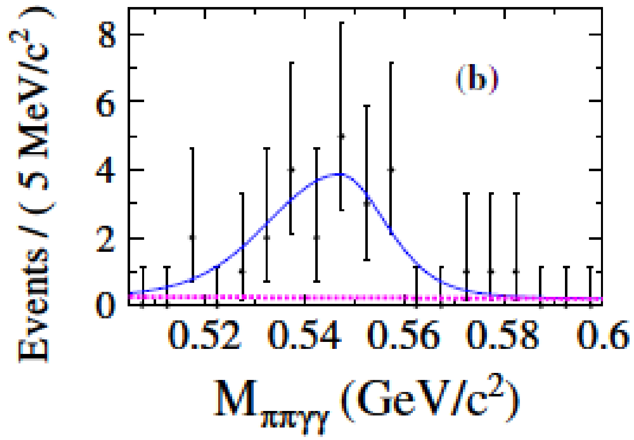


$\eta\rightarrow\gamma\gamma$





$\eta\rightarrow\pi^+\pi^-\pi^0$

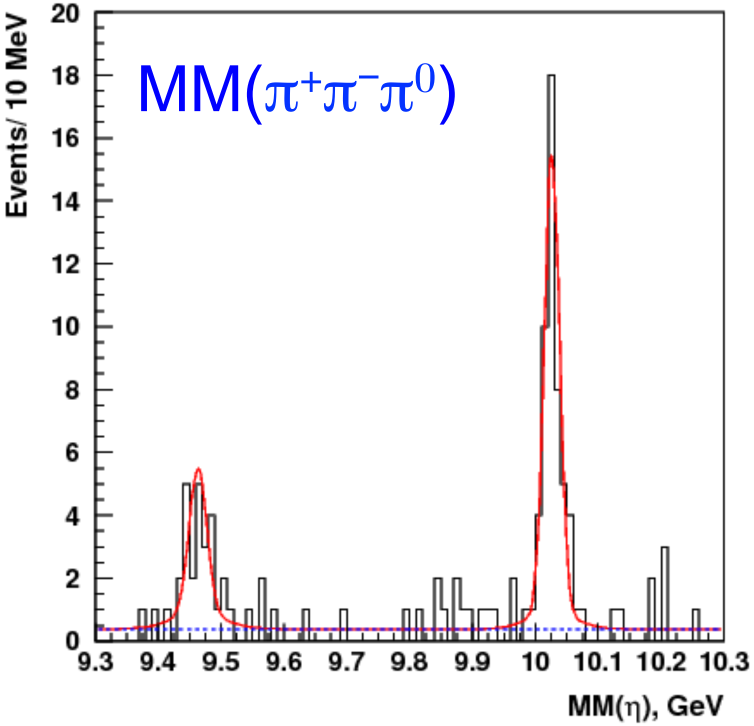


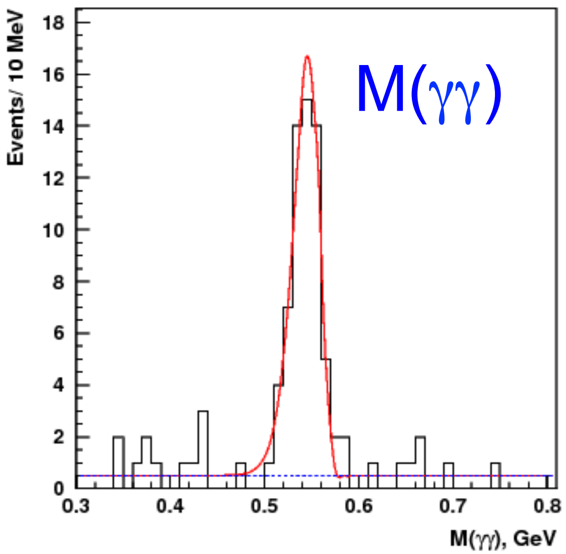
Phys.Rev.D 84 092003

$B[\Upsilon(2S)\rightarrow\Upsilon(1S)\eta]=(3.28 \pm 0.37 \pm 0.35)\ 10^{-4}$
$B[\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^0] < 4.3\ 10^{-5}$

$B[\Upsilon(2S)\rightarrow\Upsilon(1S)\eta]=(2.39 \pm 0.31 \pm 0.14)\ 10^{-4}$
$B[\Upsilon(3S)\rightarrow\Upsilon(1S)\eta] < 1.0\ 10^{-4}$

Observation of Y(5S)→Y(1,2S)η





- Three modes:
  - Y(1,2S)[$\mu^+\mu^-$] η[$\pi^+\pi^-\pi^0$]
  - Y(2S)[Y(1S)$\pi^+\pi^-$] η[γγ]
  - Y(1S)[$\mu^+\mu^-$] η' [η$\pi^+\pi^-$]

B[Y(5S)→Y(1S)η] = (7.3±1.6±0.8) 10^{-4}

B[Y(5S)→Y(2S)η] = (38 ± 4 ± 5) 10^{-4}

B[Y(5S)→Y(1S)η'] < 1.2 10^{-4}

preliminary

NEW

Summary

- Observation of **h_b(1P)** and **h_b(2P)**

  Hyperfine splitting consistent with zero, as expected. Anomalous production rates

- Observation of two charged bottomonium-like resonances in 5 final states

  Υ(1S)π^+, Υ(2S)π^+, Υ(3S)π^+, h_b(1P)π^+, h_b(2P)π^+

  $Z_b(10610)$ $M = 10607.2 \pm 2.0$ MeV, $\Gamma = 18.4 \pm 2.4$ MeV $Z_b(10610)$ $M = 10652.2 \pm 1.5$ MeV, $\Gamma = 11.5 \pm 2.2$ MeV

  Masses are close to BB* and B*B* thresholds
  Angular analyses favour $J^P = 1^+$

- Observation of **h_b(1P)$\rightarrow\eta_b$(1S)γ**

  The most precise measurement, decreases tension with theory

- Observation of **Υ(5S)$\rightarrow\Upsilon$(1D)$\pi^+\pi^-$**
- Observation of **Υ(5S)$\rightarrow\Upsilon$(1,2S)η**

NEW

preliminary

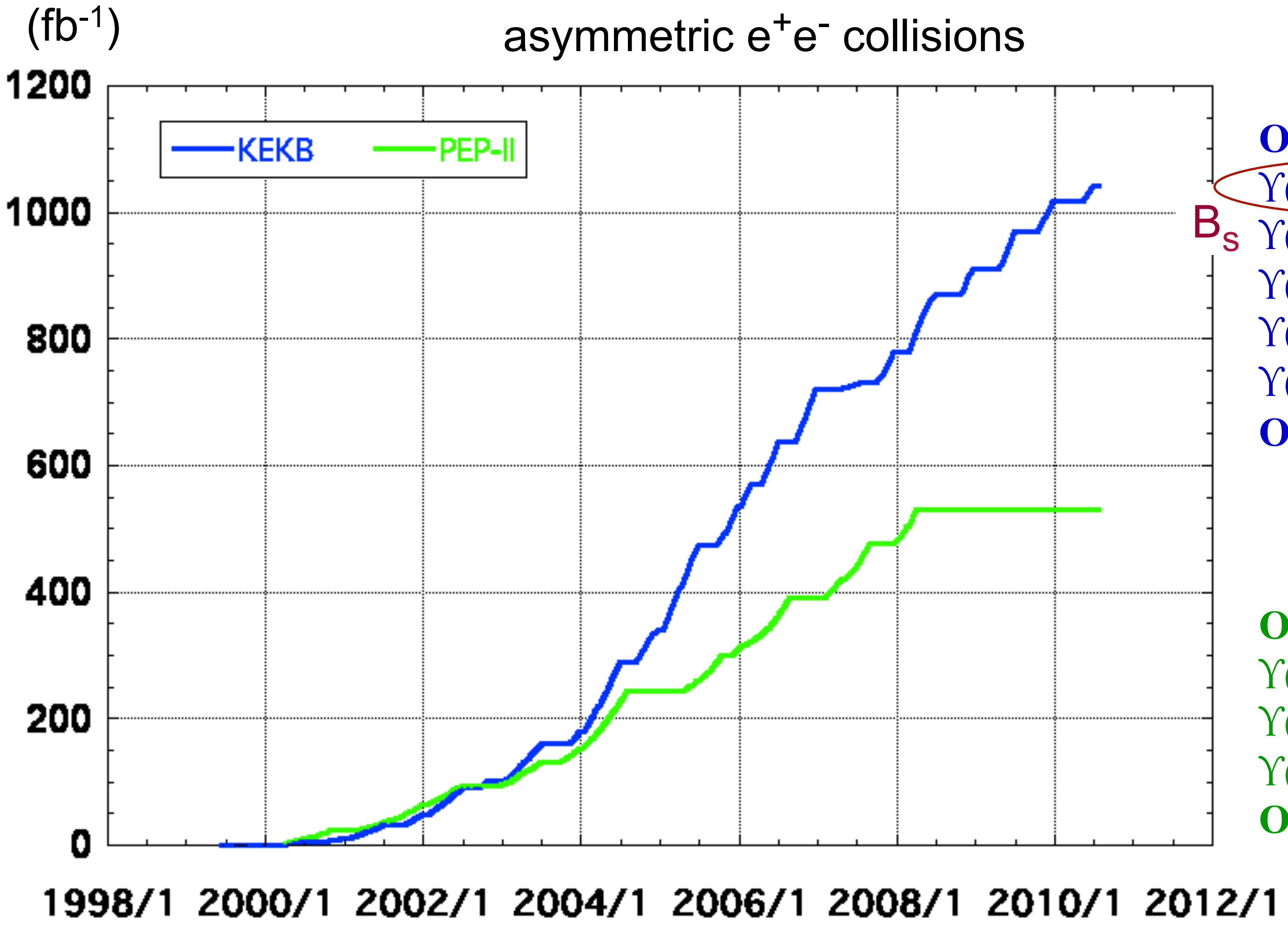
B[Y(5S)→Y(1S)η] = (7.3±1.6±0.8) 10^{-4}

B[Y(5S)→Y(2S)η] = (38 ± 4 ± 5) 10^{-4}

Back up

Integrated Luminosity at B-factories

asymmetric e^+e^- collisions



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1} — B_s

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan :

~100 fb-1

530 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

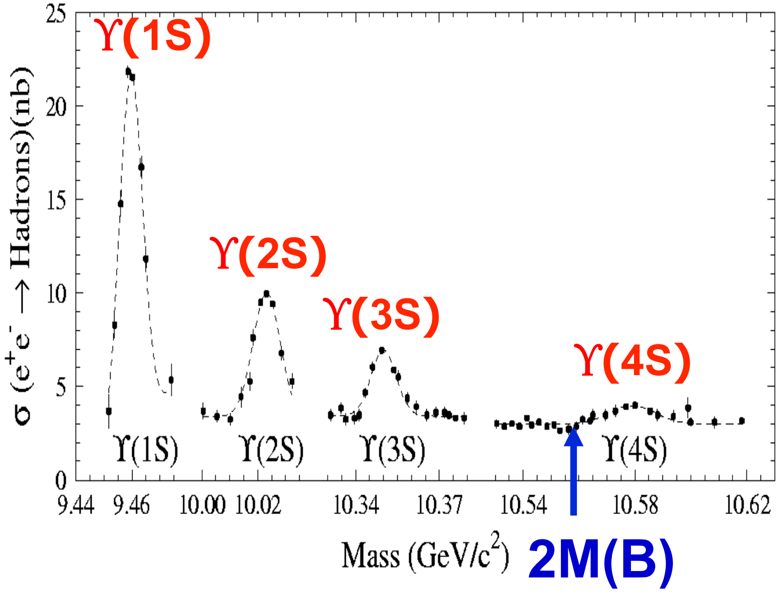
$\Upsilon(3S)$: 30 fb^{-1}

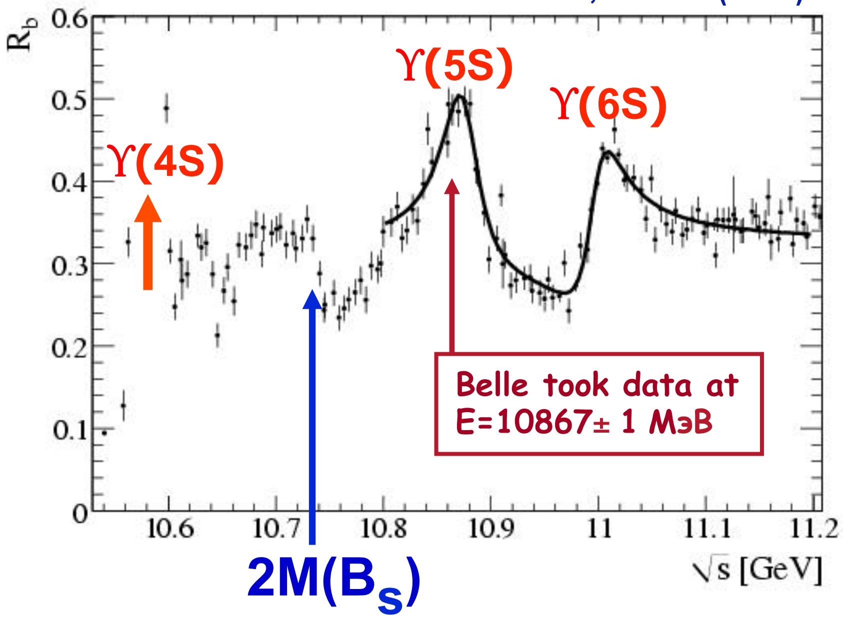
$\Upsilon(2S)$: 14 fb^{-1}

Off reson./scan :

~54 fb-1

e^+e^- hadronic cross-section





$e^+ e^- \to \Upsilon(4S) \to B\bar{B}$, where B is B^+ or B^0

$e^+ e^- \to b\bar{b}\ (\Upsilon(5S)) \to B^{(*)}\bar{B}^{(*)}$, $B^{(*)}\bar{B}^{(*)}\pi$, $B\bar{B}\pi\pi$, $B_s^{(*)}\bar{B}_s^{(*)}$, $\Upsilon(1S)\pi\pi$, ΥX …

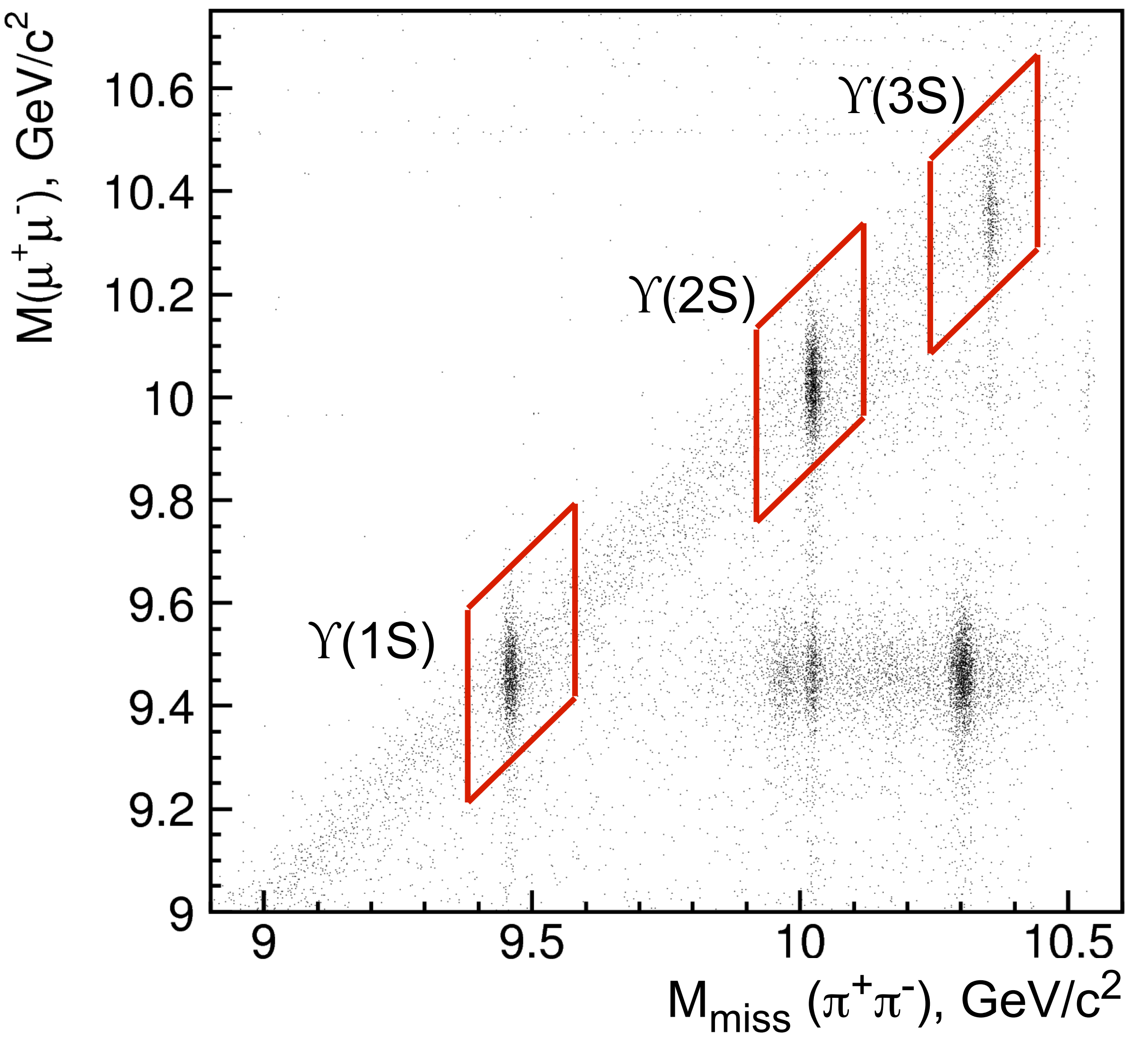
main motivation
for taking data at $\Upsilon(5S)$

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

$\quad\hookrightarrow \mu^+\mu^-$

(n = 1,2,3)

purity 92 – 94%



Fitting the Dalitz plots

Angular analysis favors $\mathbf{J^P=1^+}$

$\Upsilon(5S) \xrightarrow{\text{S-wave}} Z_b\pi,\ \ Z_b \xrightarrow{\text{S-wave}} \Upsilon(nS)\pi$ – no spin orientation change

Non-resonant heavy quark spin-flip amplitude is suppressed

Spins of Υ(5S) and Υ(nS) can be ignored

Signal amplitude parameterization:

$$\mathbf{S(s1,s2) = A(Z_{b1}) + A(Z_{b2}) + A(f_0(980)) + A(f_2(1275)) + A_{NR}}$$

$$\mathbf{A_{NR} = C_1 + C_2 \cdot m^2(\pi\pi)}$$

Parameterization of the non-resonant amplitude is discussed in

[1] M.B. Voloshin, Prog. Part. Nucl. Phys. 61:455, 2008.

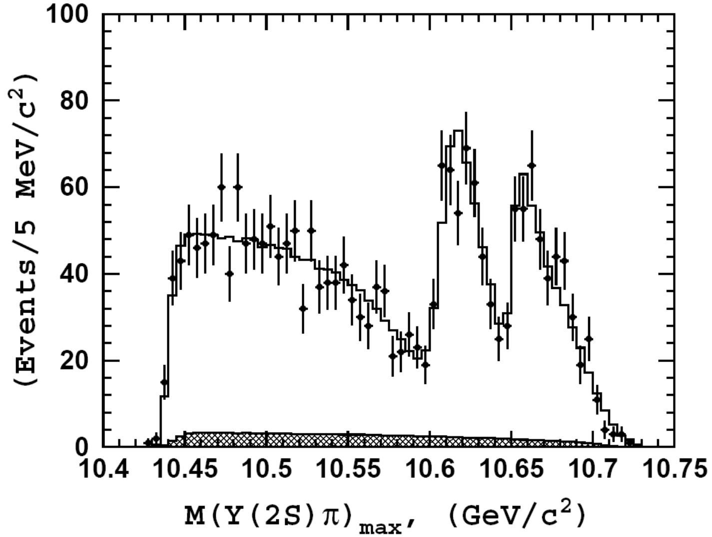
[2] M.B. Voloshin, Phys. Rev. D74:054022, 2006.

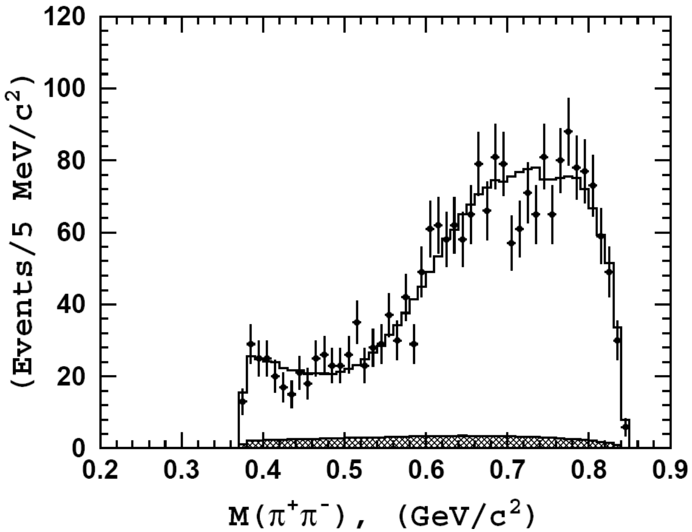
$\mathbf{A(Z_{b1}) + A(Z_{b2}) + A(f_2(1275))}$ – Breit-Wigner

$\mathbf{A(f_0(980))}$ – Flatte

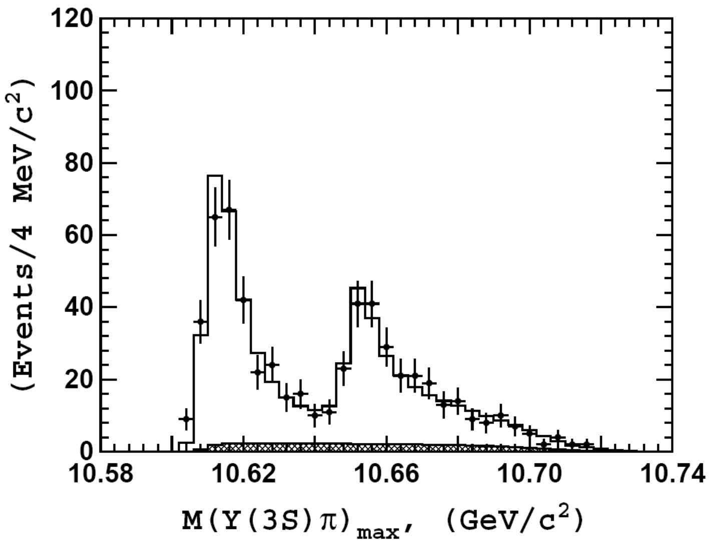
Fitting the Dalit plots

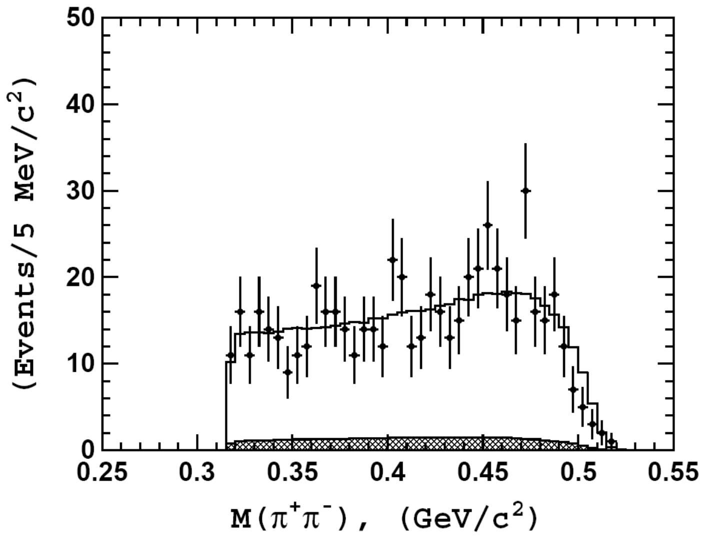
$M(\Upsilon\pi)_{max}$ $M(\pi^+\pi^-)$





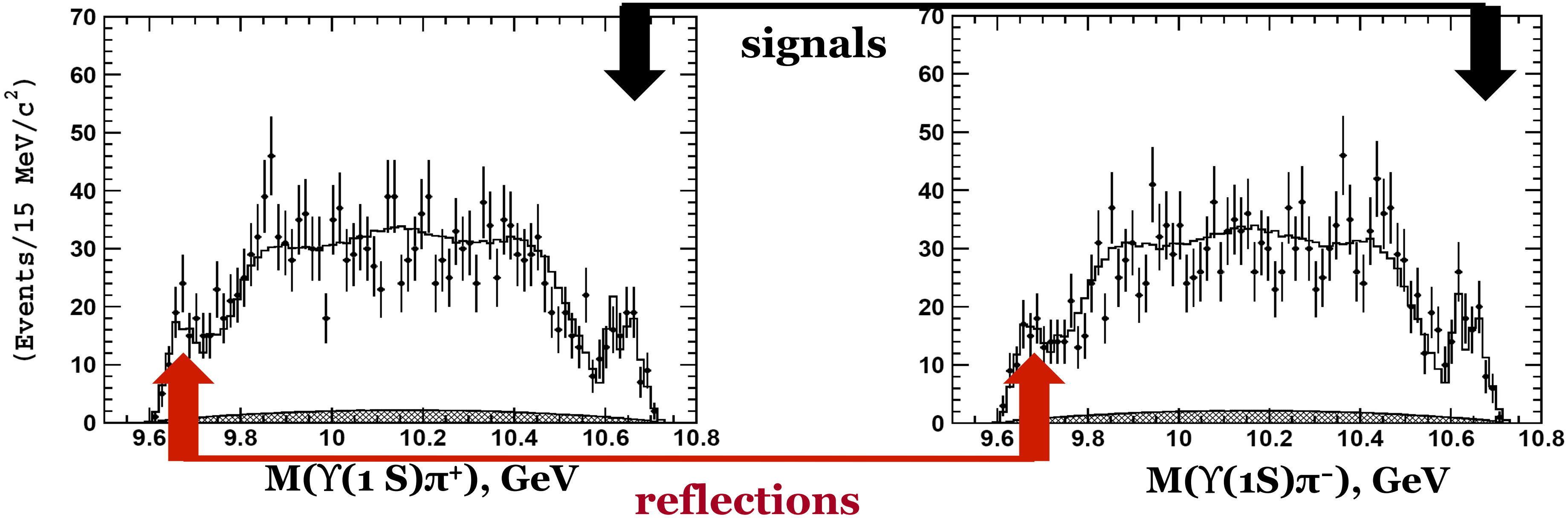
$\Upsilon(2S)\pi^+\pi^-$

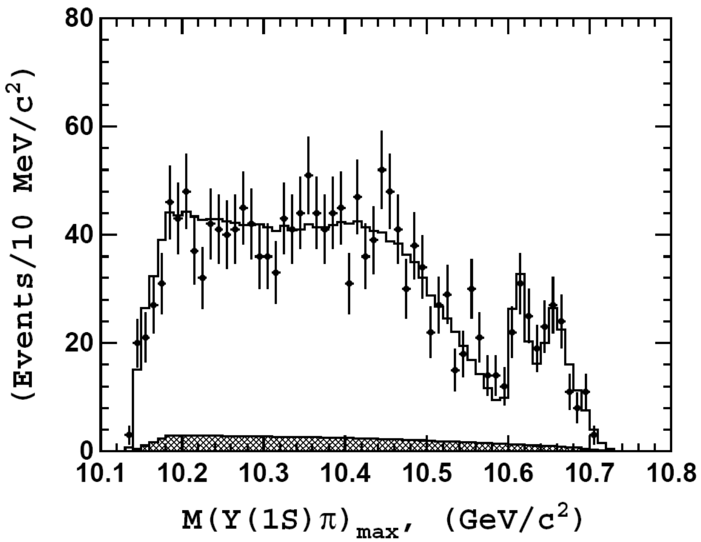


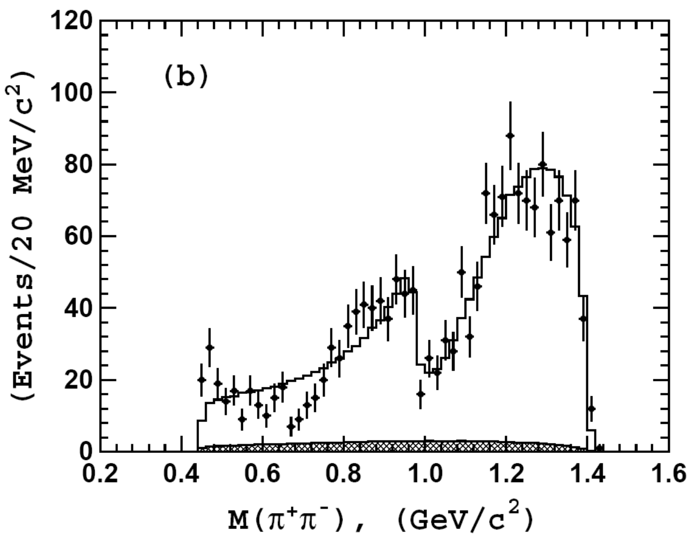


$\Upsilon(3S)\pi^+\pi^-$

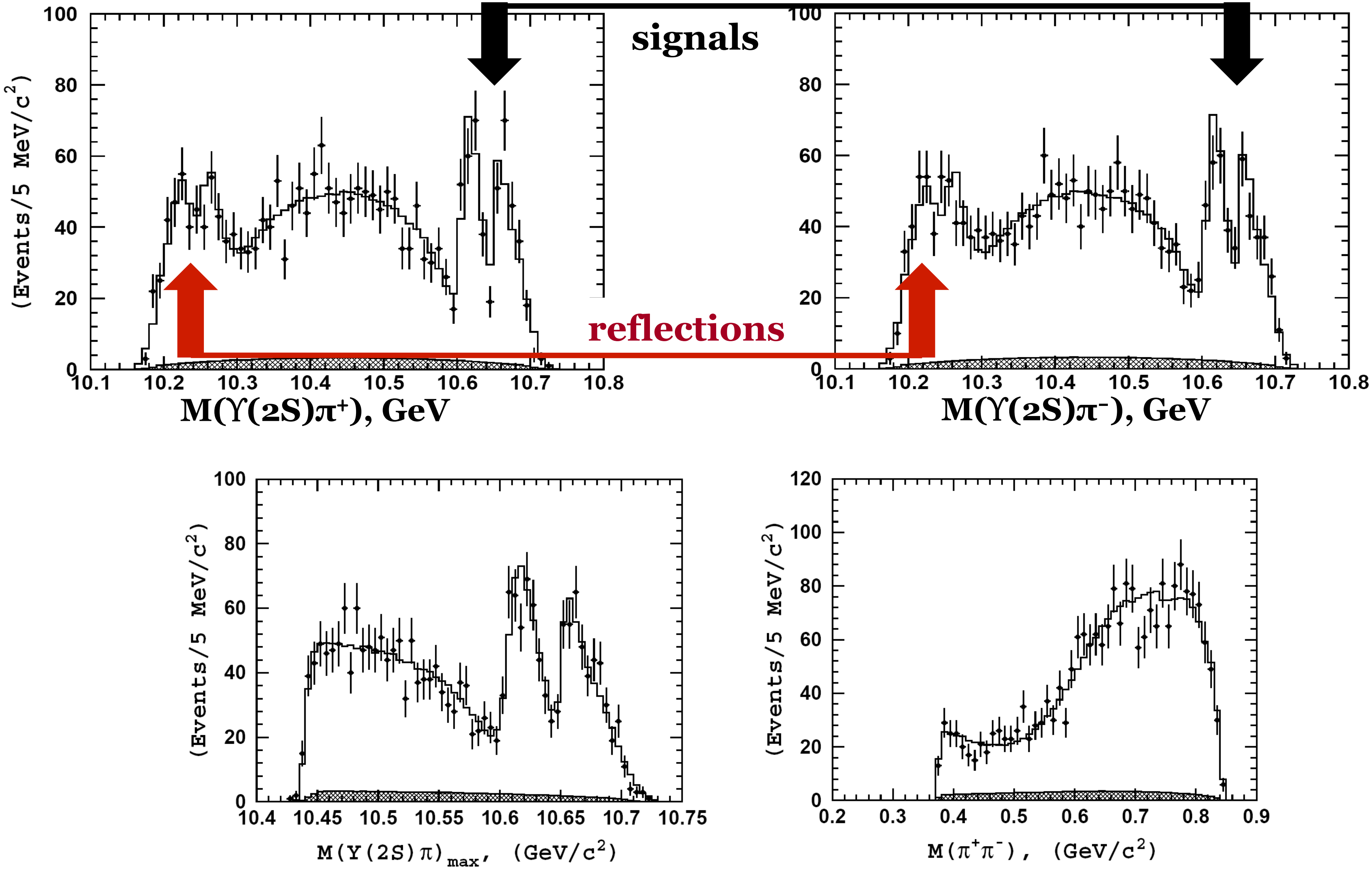
Results: $\Upsilon(1S)\pi^+\pi^-$



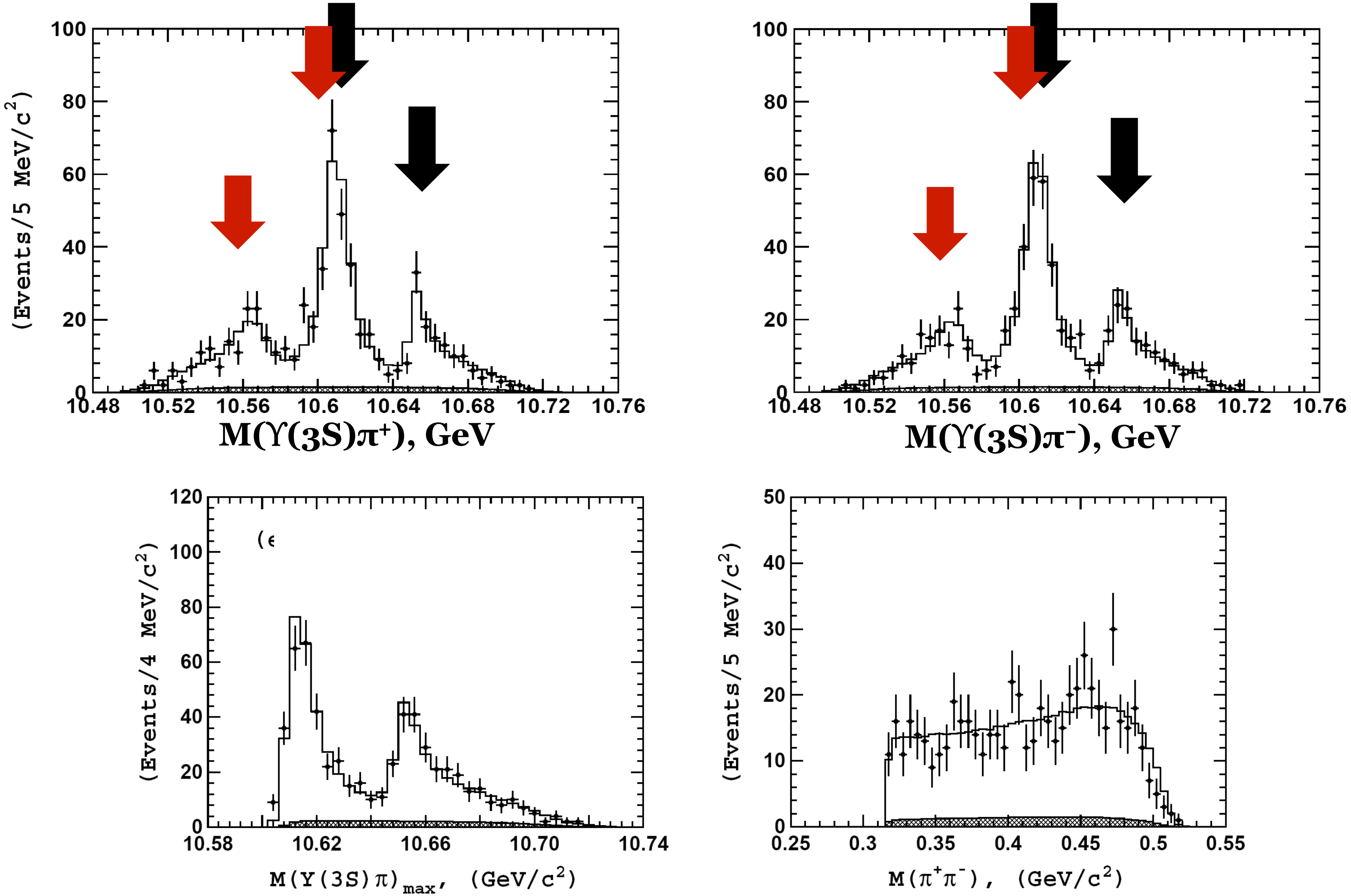




Results: $\Upsilon(2S)\pi^+\pi^-$



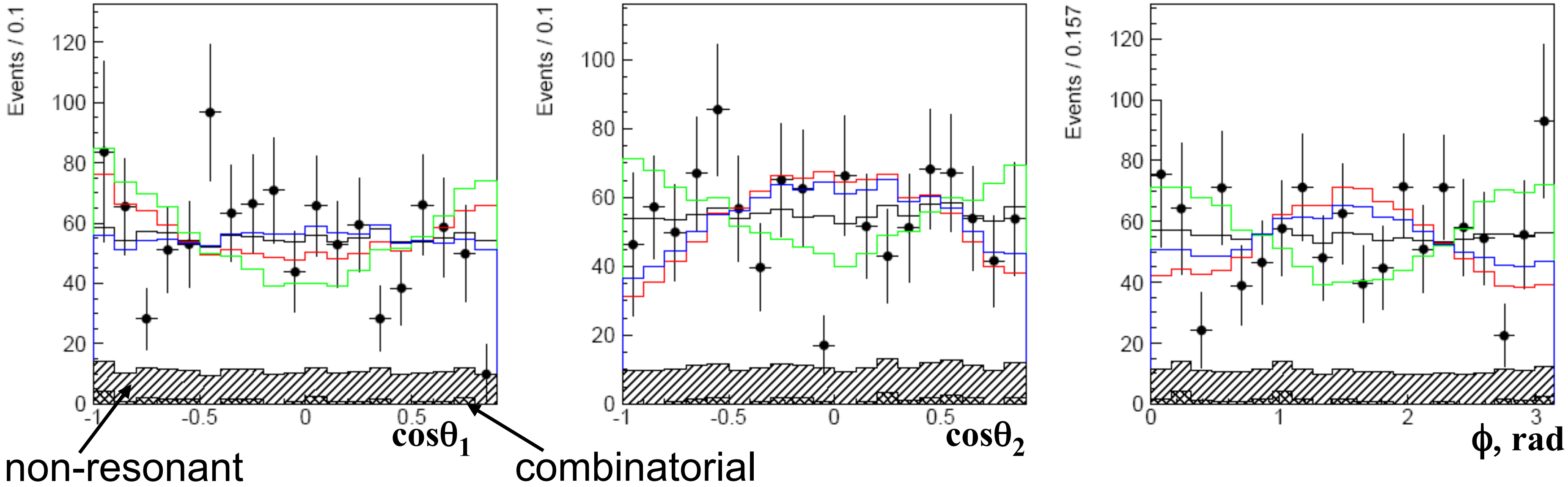
Results: $\Upsilon(3S)\pi^+\pi^-$



Angular analysis

Definition of angles $\theta_i = \angle(\pi_i, e^+)$, $\phi = \angle[\text{plane}(\pi_1, e^+), \text{plane}(\pi_1, \pi_2)]$

Example : $\Upsilon(5S) \to Z_b^+(10610)\,\pi^- \to [\Upsilon(2S)\pi^+]\,\pi^-$



Color coding: J^P= **1⁺** **1⁻** **2⁺** **2⁻** (0± is forbidden by parity conservation)

Angular distributions are consistent with $J^P=1^+$ for $Z_b(10610)$ & $Z_b(10650)$.
All other J^P are disfavored at typically 3σ level.

arXiv:1105.4583

Summary of angular analysis

All angular distributions are consistent with $J^P=1^+$ for $Z_b(10610)$ & $Z_b(10650)$.

All other J^P with $J\leq 2$ are disfavored at typically 3σ level.

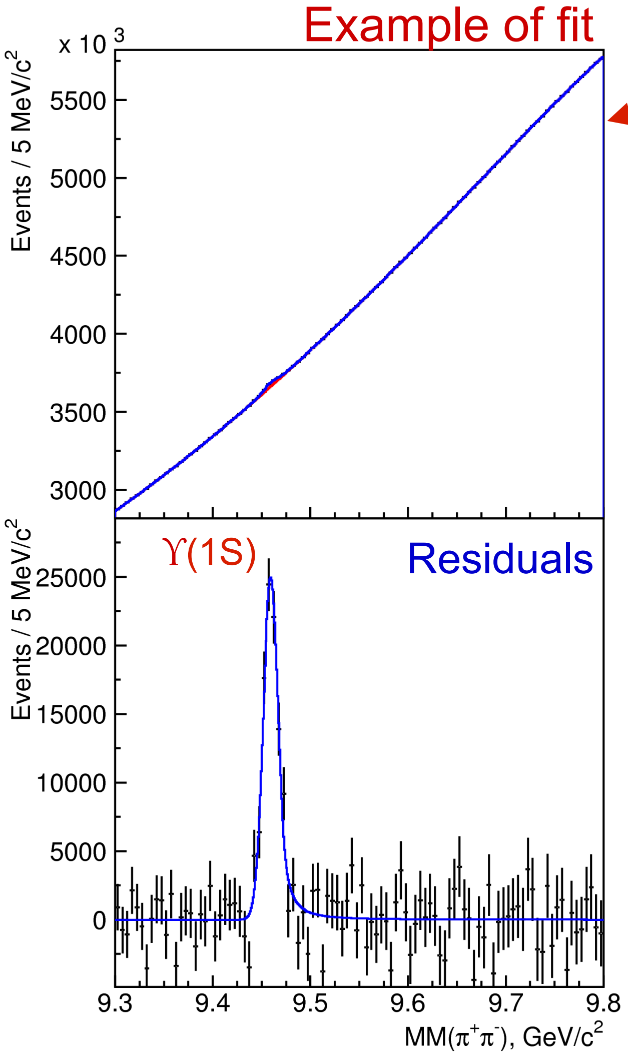
Probabilities at which different J^P hypotheses are disfavored compared to 1^+

J^P	$Z_b(10610)$			$Z_b(10650)$		
	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$h_b(1P)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$h_b(1P)\pi^+\pi^-$
1^-	$3.6\,\sigma$	$0.3\,\sigma$	$0.3\,\sigma$	$3.7\,\sigma$	$2.6\,\sigma$	$2.7\,\sigma$
2^+	$4.3\,\sigma$	$3.5\,\sigma$	$4.3\,\sigma$	$4.4\,\sigma$	$2.7\,\sigma$	$2.1\,\sigma$
2^-	$2.7\,\sigma$	$2.8\,\sigma$		$2.9\,\sigma$	$2.6\,\sigma$	

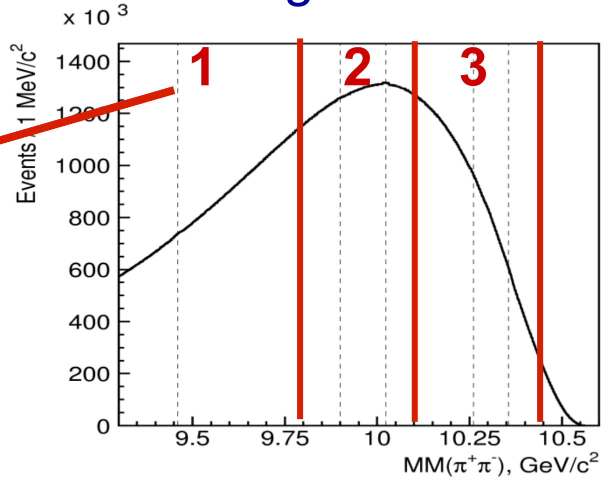
Preliminary:

procedure to deal with non-resonant contribution is approximate,
no mutual cross-feed of Z_b's

Description of fit to MM($\pi^+\pi^-$)



Three fit regions

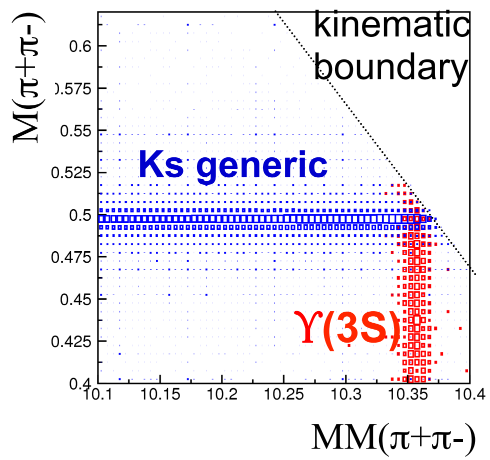


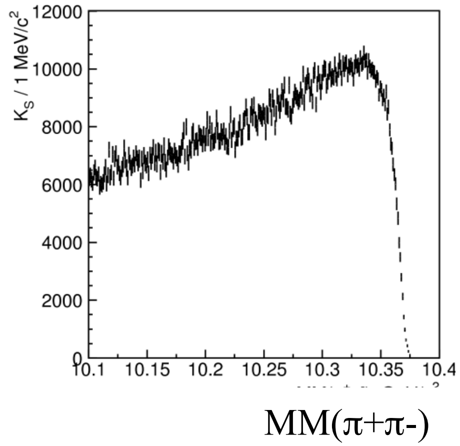
BG: Chebyshev polynomial, 6th or 7th order

Signal: shape is fixed from $\mu^+\mu^-\pi^+\pi^-$ data

"Residuals" – subtract polynomial from data points

K_S contribution: subtract bin-by-bin





Selection

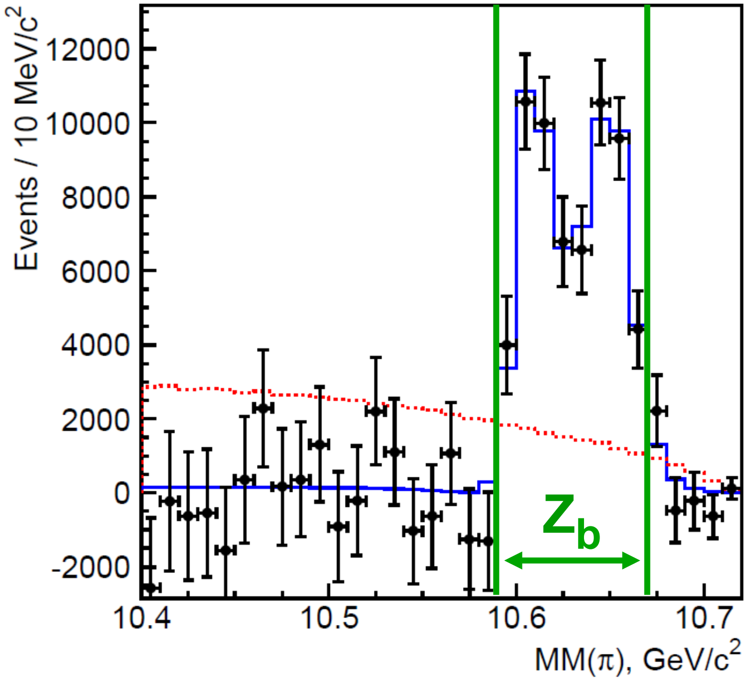
Decay chain $\Upsilon(5S) \to Z_b^+ \pi^-$
$\hookrightarrow h_b(nP)\, \pi^+$
$\hookrightarrow \eta_b(mS)\, \gamma$

reconstruct

R_2<0.3

Hadronic event selection; continuum suppression using event shape; π^0 veto.

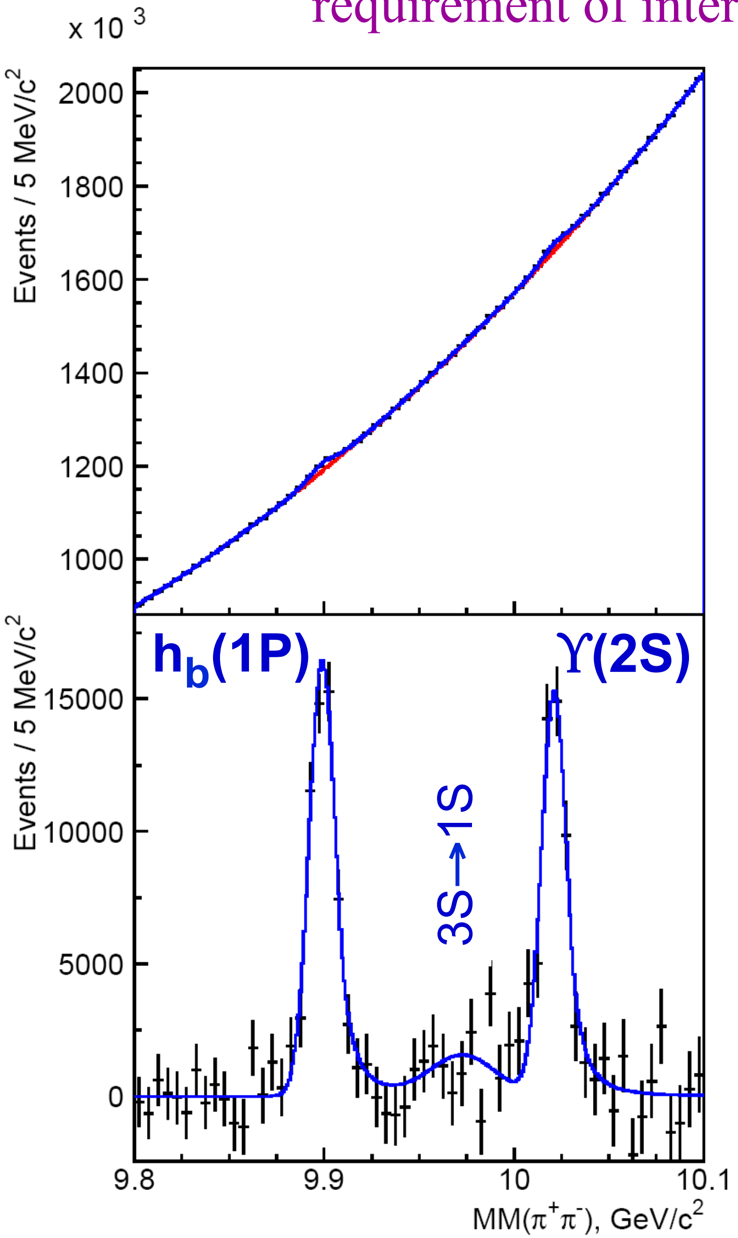
Require intermediate Z_b : **$10.59 < MM(\pi) < 10.67$ GeV**



bg. suppression ×5.2

$M_{miss}(\pi^+\pi^-)$ spectrum

requirement of intermediate Z_b



Update of M [h_b(1P)] :

$(9899.0 \pm 0.4 \pm 1.0)$ MeV/c^2

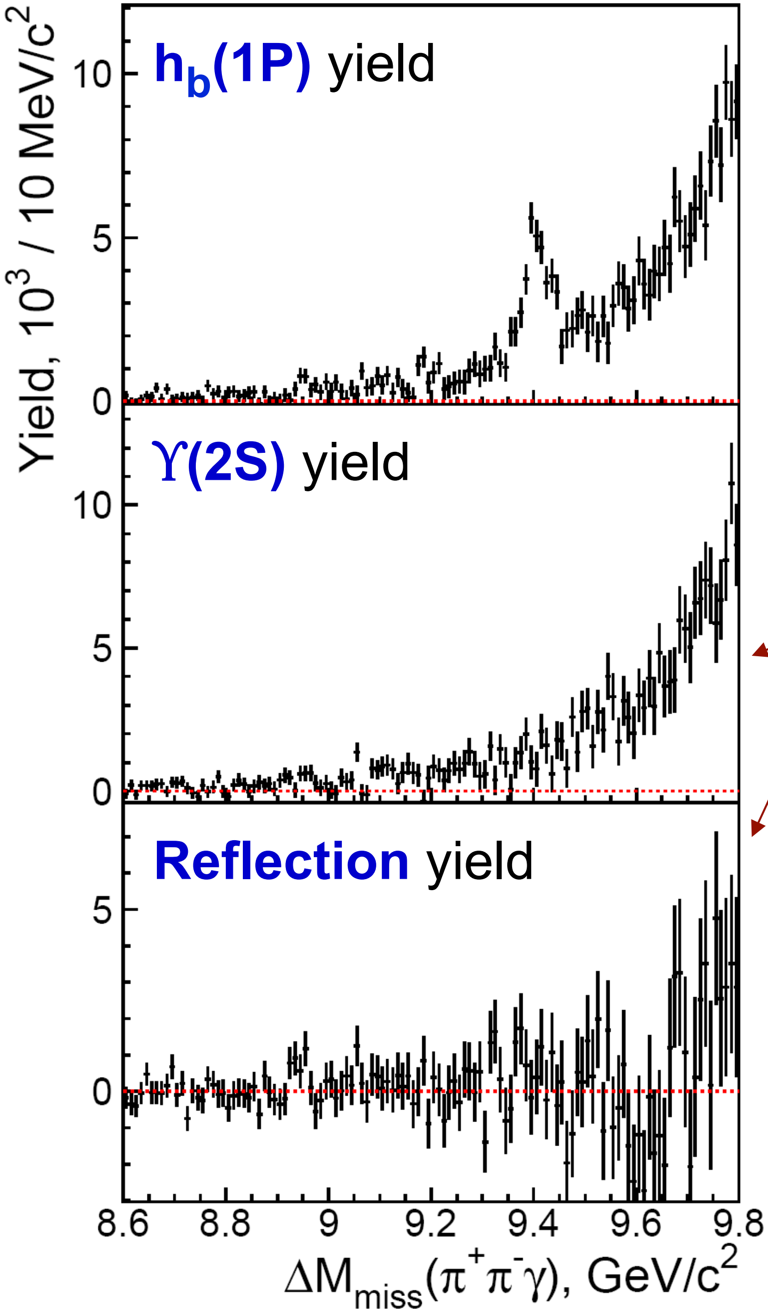
ΔM_{HF} [h_b(1P)] = (+0.8 ± 1.1)MeV/c^2

Previous Belle meas.: arXiv:1103.3411

$(9898.3 \pm 1.1^{+1.0}_{-1.1})$ MeV/c^2

ΔM_{HF} [h_b(1P)] = (+1.6 ± 1.5)MeV/c^2

Results of fits to $M_{miss}(\pi^+\pi^-)$ spectra



$\eta_b(1S)$

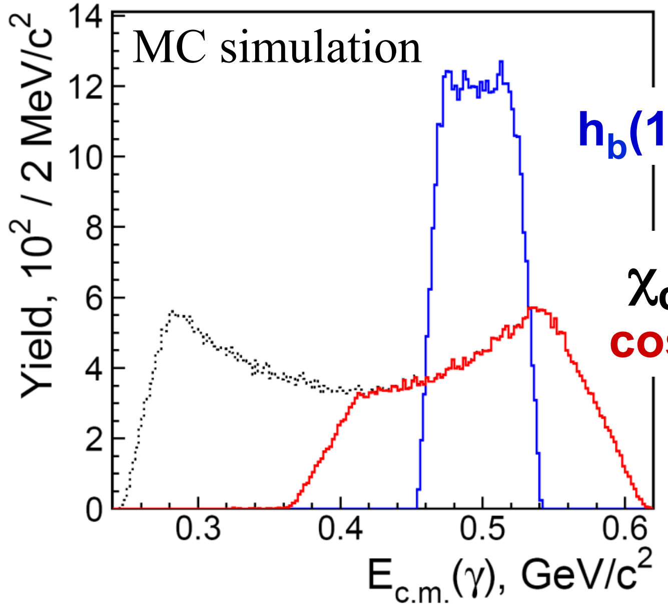
Peaking background?
MC simulation ⇒ none.

no significant structures

Calibration

Use decays $B^+ \to \chi_{c1} K^+ \to (J/\psi\ \gamma)\ K^+$

Photon energy spectrum



$h_b(1P) \to \eta_b(1S)\gamma$

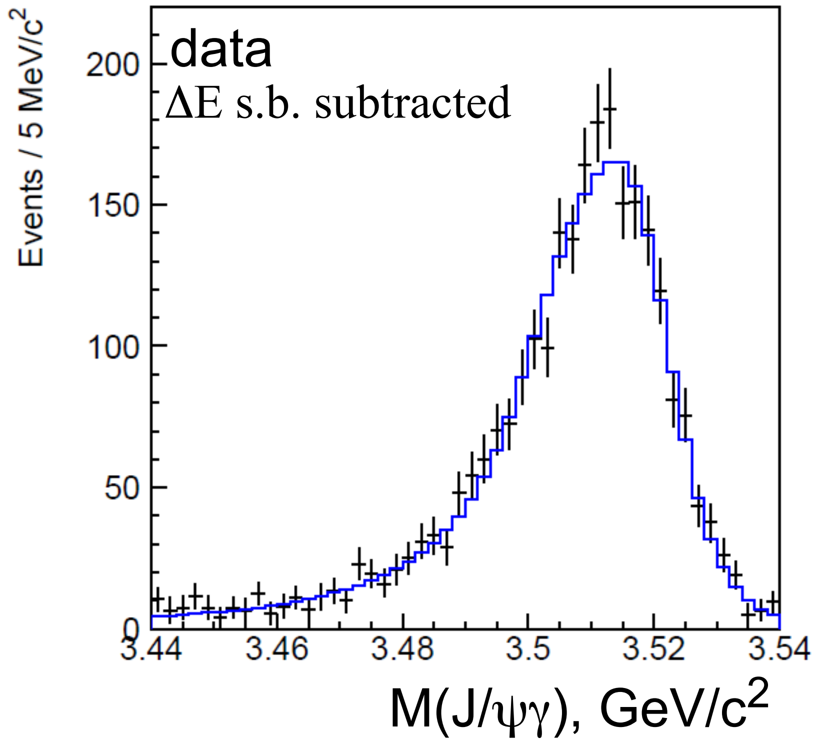
$\chi_{c1} \to J/\psi\gamma$

$\cos\theta_{Hel} > -0.2$

$\cos\theta_{Hel}(\chi_{c1}) > -0.2 \Rightarrow$ match γ energy of **signal** & **callibration** channels

Calibration (2)

Resolution: double-sided CrystalBall function with asymmetric core



⇒ Correction of MC

mass shift	$-0.7 \pm 0.3\ ^{+0.2}_{-0.4}$ MeV
fudge-factor for resolution	$1.15 \pm 0.06 \pm 0.06$

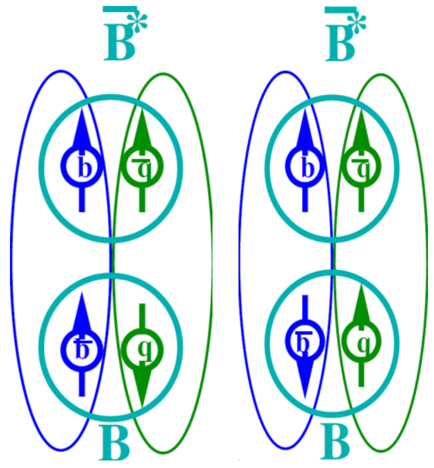
Heavy quark structure in Z_b

Bondar, Garmash, Milstein, Mizuk, Voloshin Phys.Rev.D 84 054010

Wave func. at large distance – B(*)B*

$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} - \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$

$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} + \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$



Explains

- Why $h_b\pi\pi$ is unsuppressed relative to $\Upsilon\pi\pi$
- Relative phase ~0 for Υ and ~180^0 for h_b
- Production rates of Z_b(10610) and Z_b(10650) are similar
- Widths   –”–

Predicts

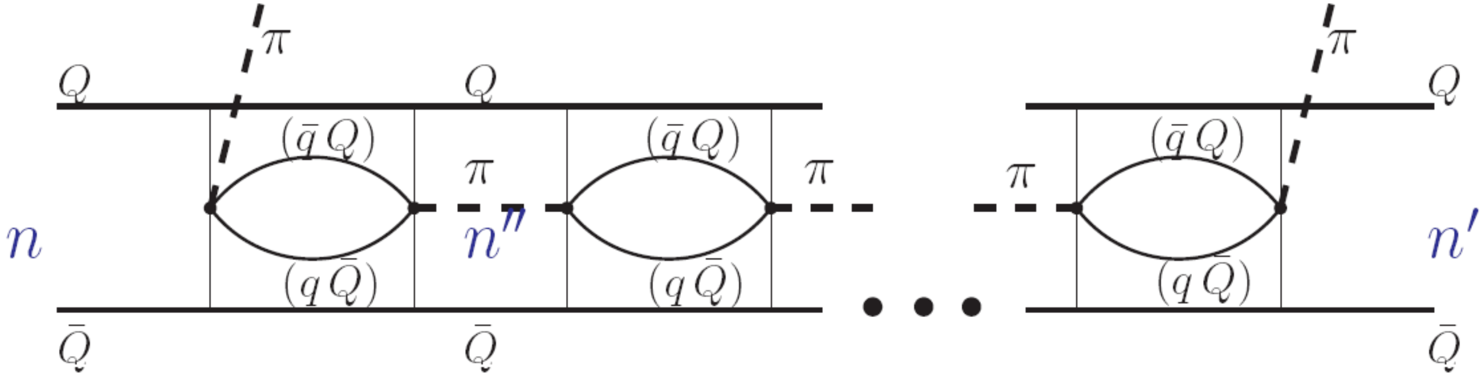
- Existence of other similar states

Other Possible Explanations

- Coupled channel resonances (I.V.Danilkin et al, arXiv:1106.1552)
- Cusp   (D.Bugg Europhys.Lett.96 (2011),arXiv:1105.5492)
- Tetraquark   (M.Karliner, H.Lipkin, arXiv:0802.0649)

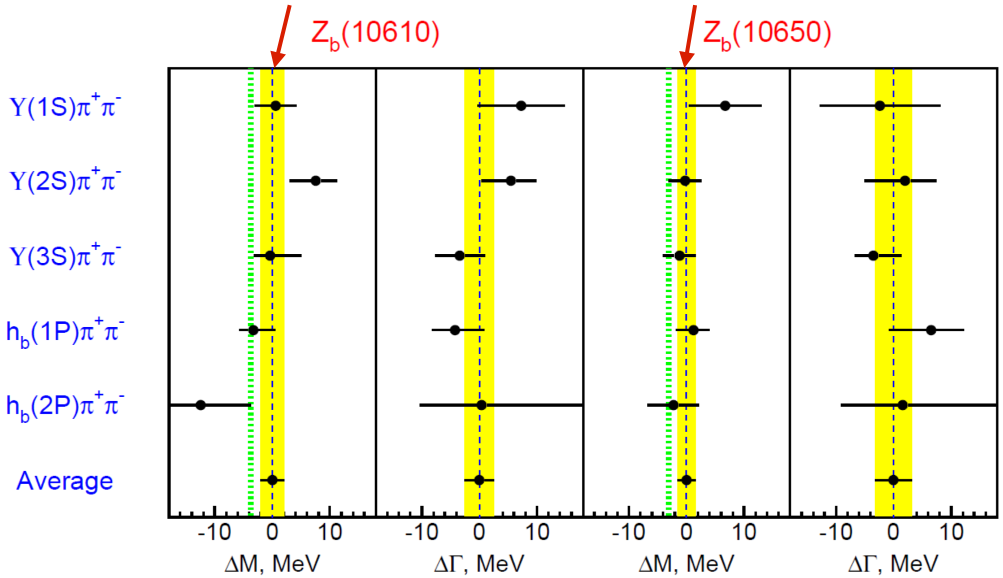
Coupled channel resonance?

I.V.Danilkin, V.D.Orlovsky, Yu.Simonov arXiv:1106.1552



No interaction between B(*)B* or ϒπ is needed to form resonance

No other resonances predicted

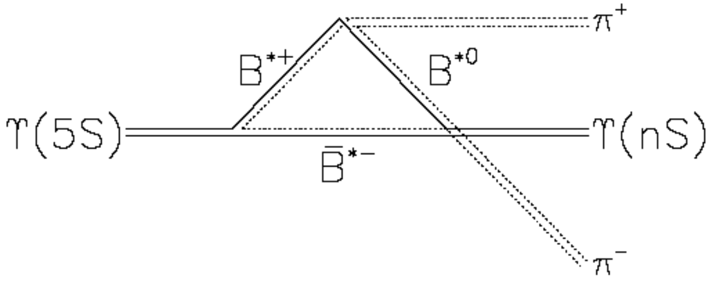


B(*)B* interaction switched on ⇒ individual mass in every channel?

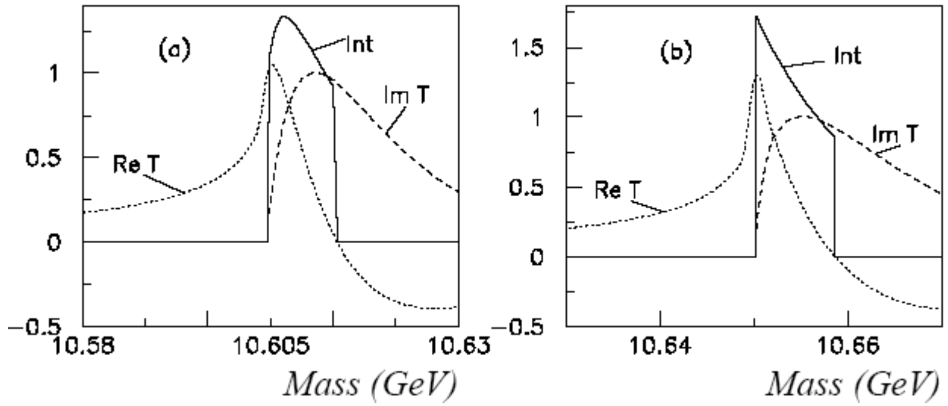
Cusp?

D.Bugg Europhys.Lett.96 (2011) (arXiv:1105.5492)

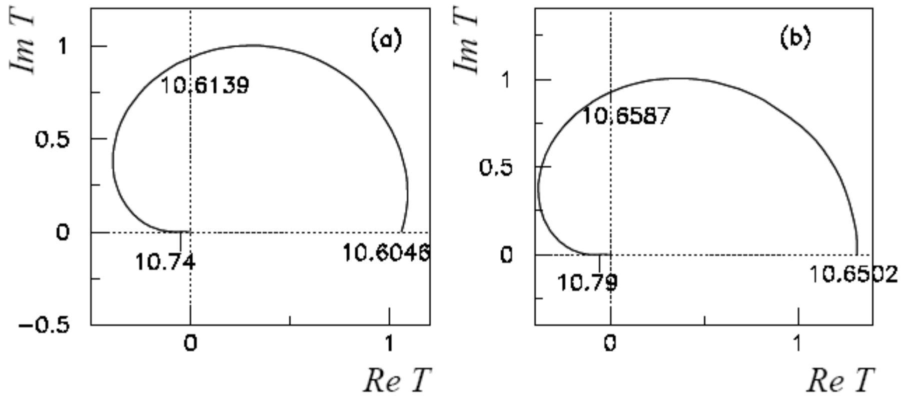
Amplitude



Line-shape



Not a resonance



Tetraquark?

M ~ 10.2 – 10.3 GeV	Ying Cui, Xiao-lin Chen, Wei-Zhen Deng, Shi-Lin Zhu, High Energy Phys.Nucl.Phys.31:7-13, 2007 (hep-ph/0607226)
M ~ 10.5 – 10.8 GeV	Tao Guo, Lu Cao, Ming-Zhen Zhou, Hong Chen, (1106.2284)
M ~ 9.4, 11 GeV	M.Karliner, H.Lipkin, (0802.0649)

Introduction

- Anomalous production of $\Upsilon\pi^+\pi^-$ and $h_b\pi^+\pi^-$ in $\Upsilon(5S)$ decays:

PRL100,112001(2008)	Γ(MeV)
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019

10^2

and observation of $e^+e^- \to h_c\,\pi^+\pi^-$ by CLEO motivated to search for the resonant structures in Y(5S) decays

- Large h_b sample and high Br(h_b) $\to \eta_b\gamma$ allows to study η_b properties

- Bottomonia transitions via η meson can be used to test the quark structure of Y states