Bottomonium studies at Belle

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Representing

the Belle Collaboration

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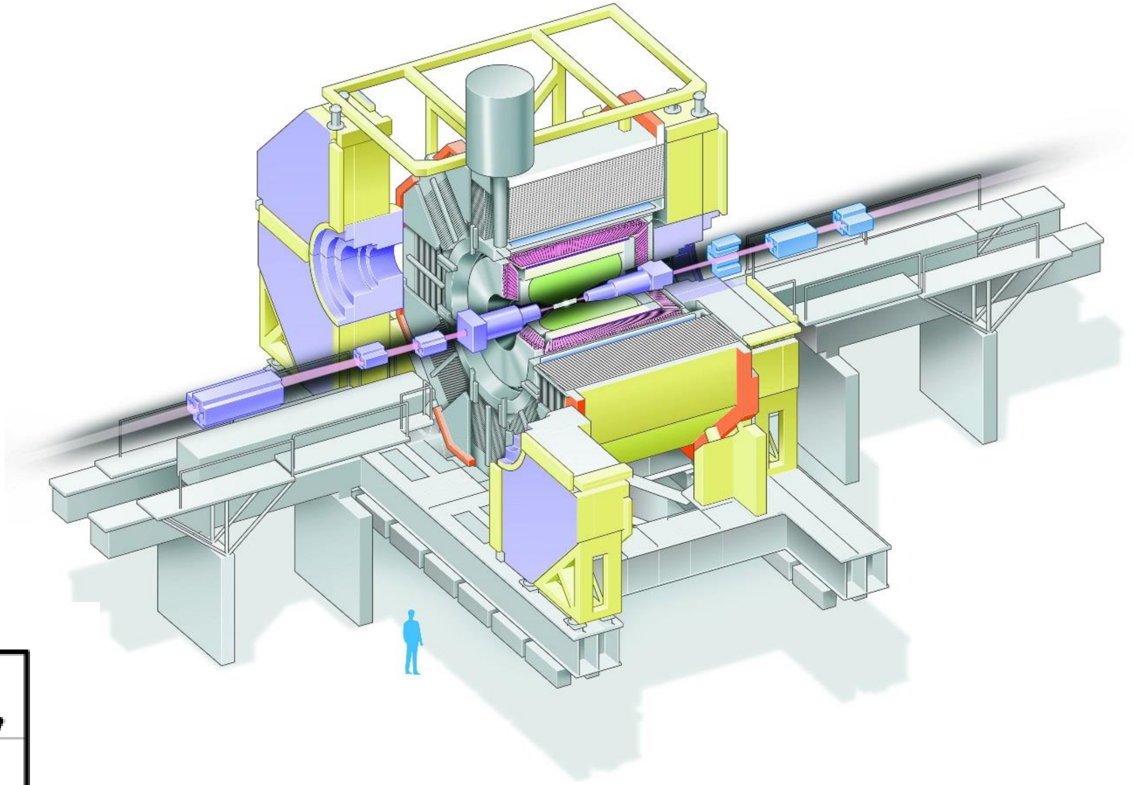
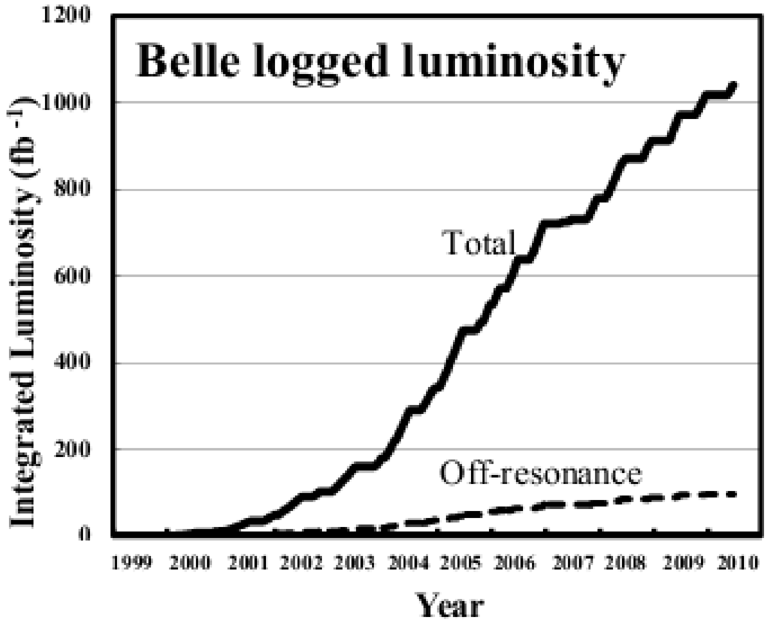
1. Bottomonium transitions at $\Upsilon(4S)$ and $\Upsilon(5S)$
2. Search for exotic state

The Belle experiment

Luminosity:
ϒ(5S) : 121 fb^{-1}
ϒ(4S) : 711 fb^{-1}
ϒ(3S) : 3 fb^{-1}
ϒ(2S) : 24 fb^{-1}
ϒ(1S) : 6 fb^{-1}
Off-resonance/ scan : 100 fb^{-1}





The total of Belle experiment luminosity is > 1ab^{-1}

Bottomonium transition I

Heavy quarkonia hadronic transition :

QCD multipole expansion (QCDME) model. [Y. P Kuang, Front Phys. China 1, 19 (2006)]

For $\Upsilon(5S)$ resonance peak:

- The anomalously large width :$e^+e^- \rightarrow \pi^+\pi^-\Upsilon(ns)$ [Belle PRL 100, 112001]

  and $e^+e^- \rightarrow \pi^+\pi^- h_b(ns)$ [PRL 108, 032001] .
- $Z_b(10610)^{\pm}$ and $Z_b(10650)^{\pm}$ [PRL 108, 122001].

- Search for **hadronic transition** : $\mathbf{\Upsilon(5S) \rightarrow \pi^+\pi^-\pi^0 \chi_{bJ}}$

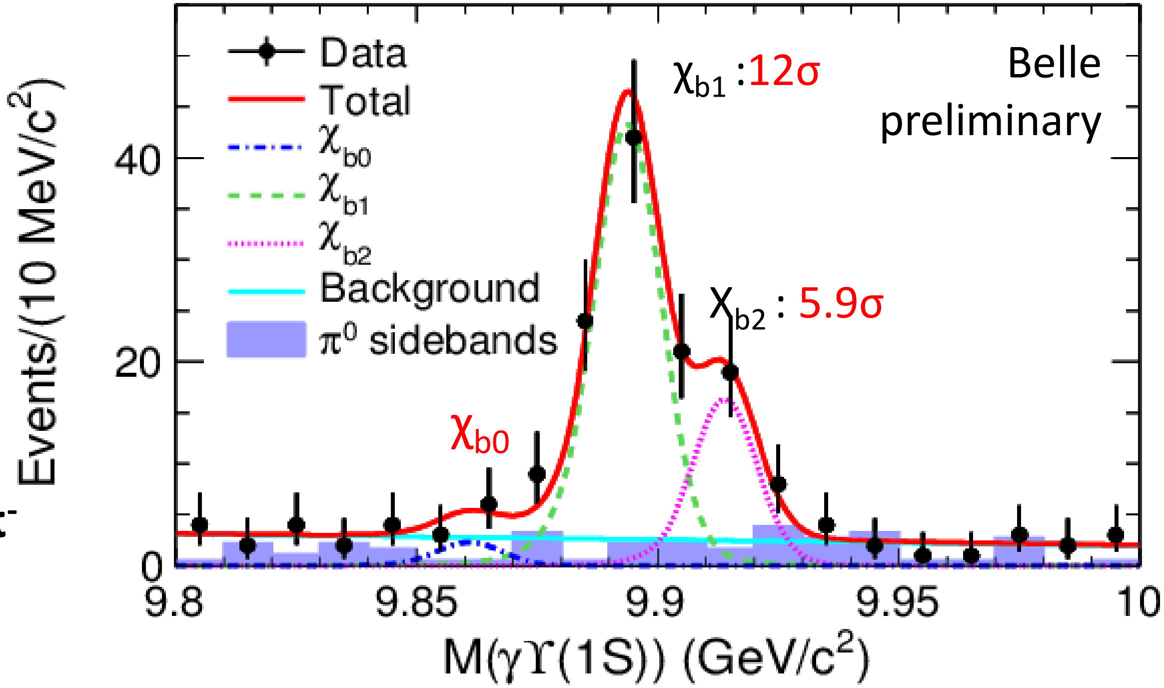
$e^+e^- \to \pi^+\pi^-\pi^0\, \chi_{bJ}$

preliminary

118 fb^{-1} $\Upsilon(5S)$ data sample

$\chi_{bJ} \to \gamma\Upsilon(1S)$

- **The same order as $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$.** [PRL 100, 112001].
- **Hadronic loop effect?** [arXiv:1406.6763]



Assuming all events decay from $\Upsilon(5S)$.

Born cross section:

$\sigma(e^+e^- \to \pi^0\pi^+\pi^-\chi_{b0}) < 3.4$ (pb) at 90% C.L.

$\sigma(e^+e^- \to \pi^0\pi^+\pi^-\chi_{b1}) = 0.98 \pm 0.12 \pm 0.12$ (pb)

$\sigma(e^+e^- \to \pi^0\pi^+\pi^-\chi_{b2}) = 0.62 \pm 0.14 \pm 0.08$ (pb)

Product BF :

$BF(\Upsilon(5S) \to \pi^0\pi^+\pi^-\chi_{b0}) < 6.9 \times 10^{-3}$ at 90% C.L.

$BF(\Upsilon(5S) \to \pi^0\pi^+\pi^-\chi_{b1}) = (2.02 \pm 0.25 \pm 0.25) \times 10^{-3}$

$BF(\Upsilon(5S) \to \pi^0\pi^+\pi^-\chi_{b2}) = (1.27 \pm 0.29 \pm 0.16) \times 10^{-3}$

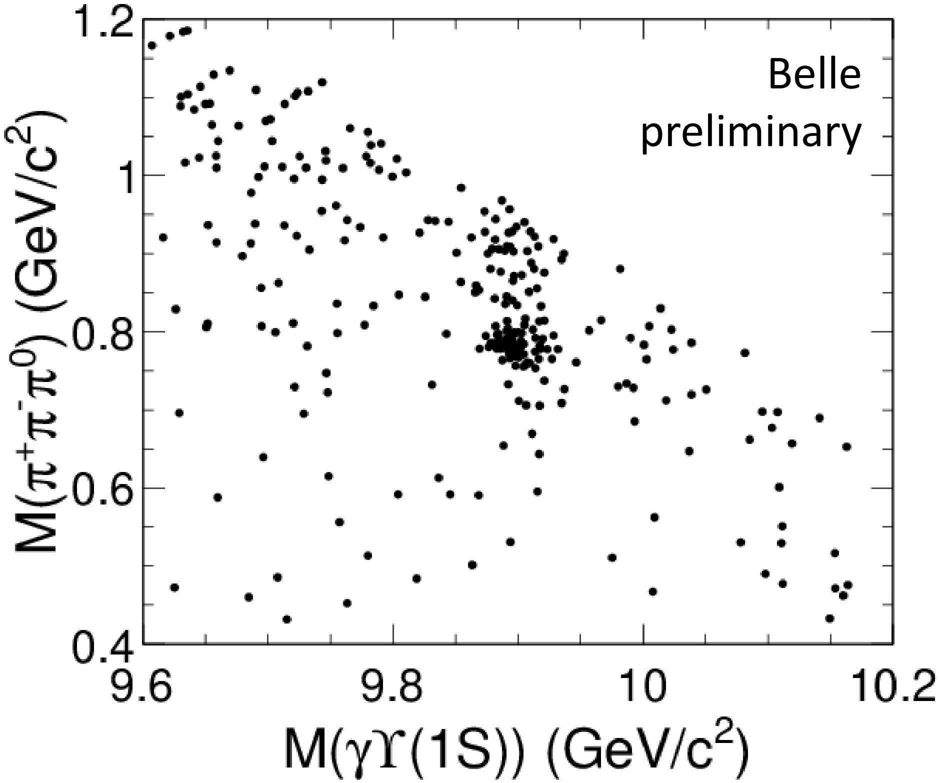
$e^+e^- \rightarrow \pi^+\pi^-\pi^0\chi_{bJ}$

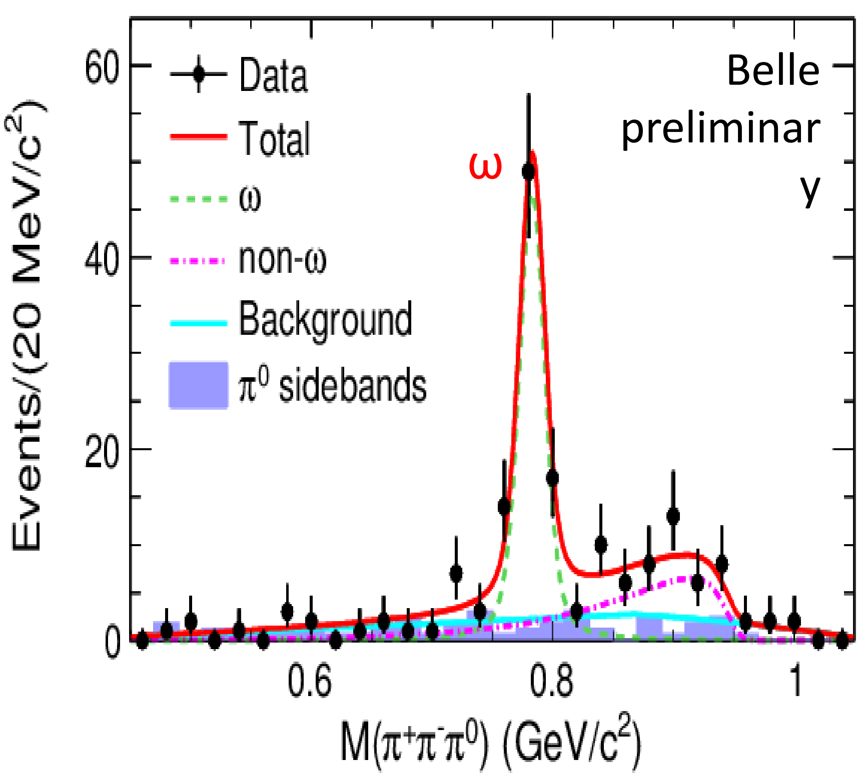
preliminary

$\pi^+\pi^-\pi^0$ invariant mass distribution:

- **ω signal**
- **An enhancement in higher M($\pi^+\pi^-\pi^0$)**

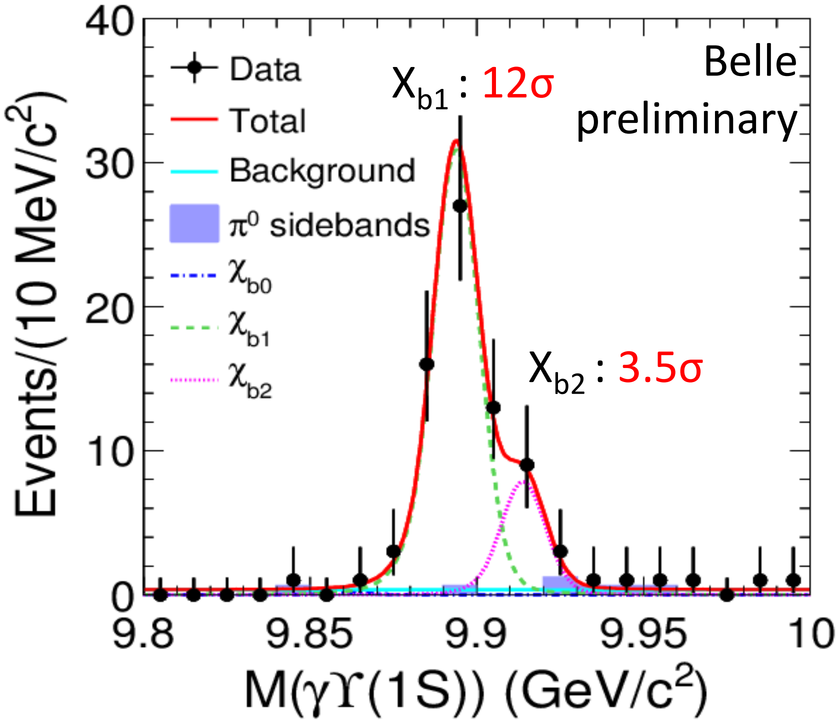
2D fit to scatter plot of M($\pi^+\pi^-\pi^0$) vs M(γϒ(1S)).



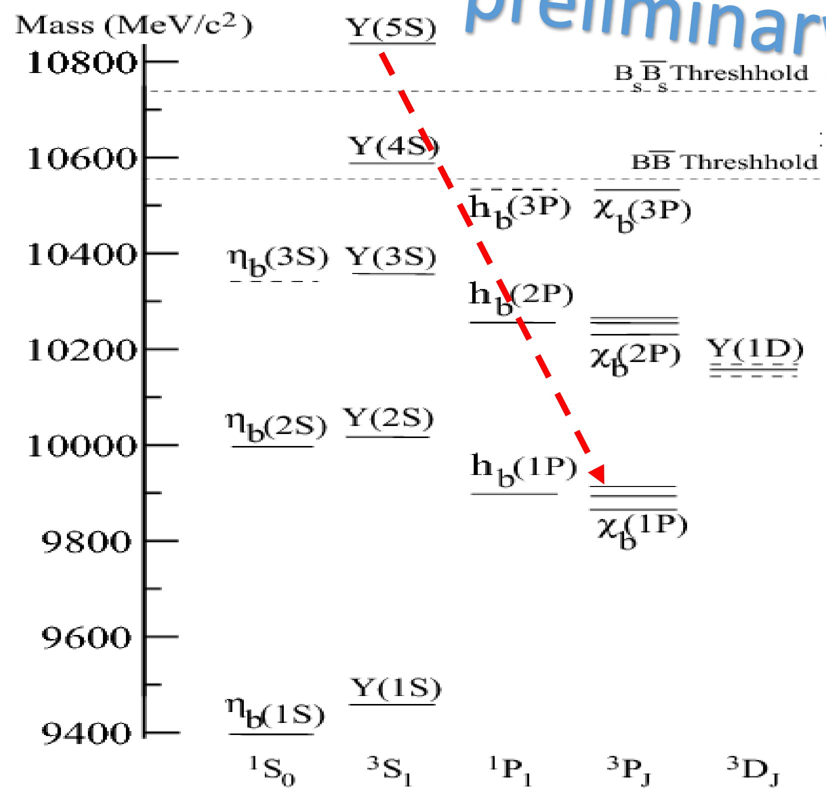


$e^+e^- \rightarrow \omega\chi_{bJ}$

ω signal region.



preliminary



The $\frac{Br(\Upsilon(5S)\rightarrow\omega\chi_{b2})}{Br(\Upsilon(5S)\rightarrow\omega\chi_{b1})}$ higher than **expectation from quark symmetry**. [PLB 346, 129 (1995)].

→ **a molecular component in** ϒ(5S) [arXiv: 1406.0082]

→ **S- and D- wave mixing** [arXiv:1406.6543]

Born cross section:

$\sigma(e^+e^-\rightarrow\omega\chi_{b0})$ < 1.9 (pb) at 90% C.L.

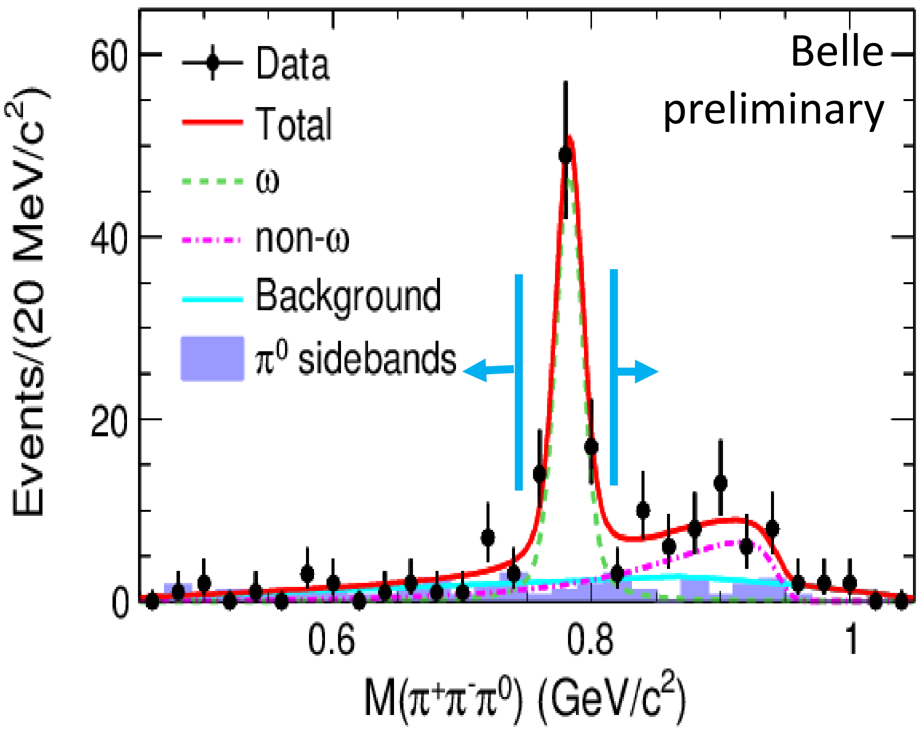
$\sigma(e^+e^-\rightarrow\omega\chi_{b1}) = 0.76\pm0.11\pm0.11$ (pb)

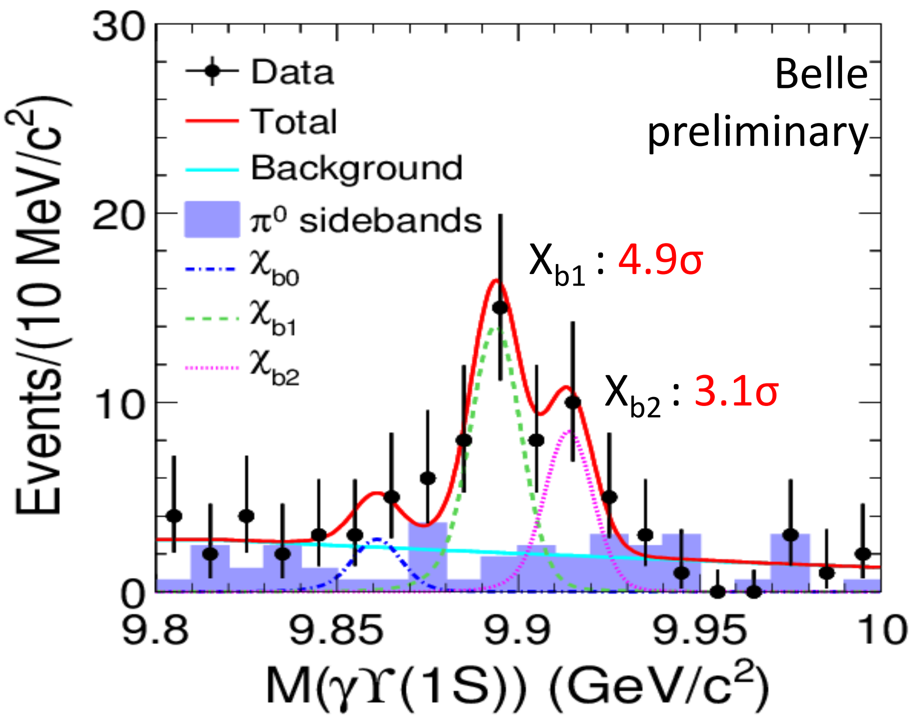
$\sigma(e^+e^-\rightarrow\omega\chi_{b2}) = 0.29\pm0.11\pm0.08$ (pb)

$e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{bJ}$

preliminary

- The χ_{bJ} candidates out of ω signal region.
- Possible cascade decay from $\Upsilon(5S) \to \pi Z_b \to \pi\rho\chi_{bJ}$ [arXiv:1406.0082]
- **The interpretation is currently limited.**





Born cross section:

$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b0}) < 2.3$ (pb) at 90% C.L.

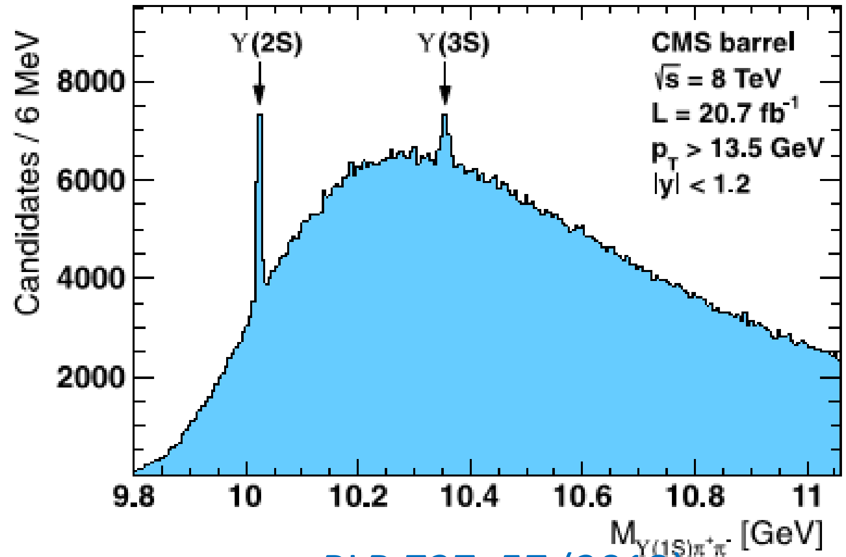
$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b1}) = 0.25 \pm 0.07 \pm 0.06$ (pb)

$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b2}) = 0.30 \pm 0.11 \pm 0.14$ (pb)

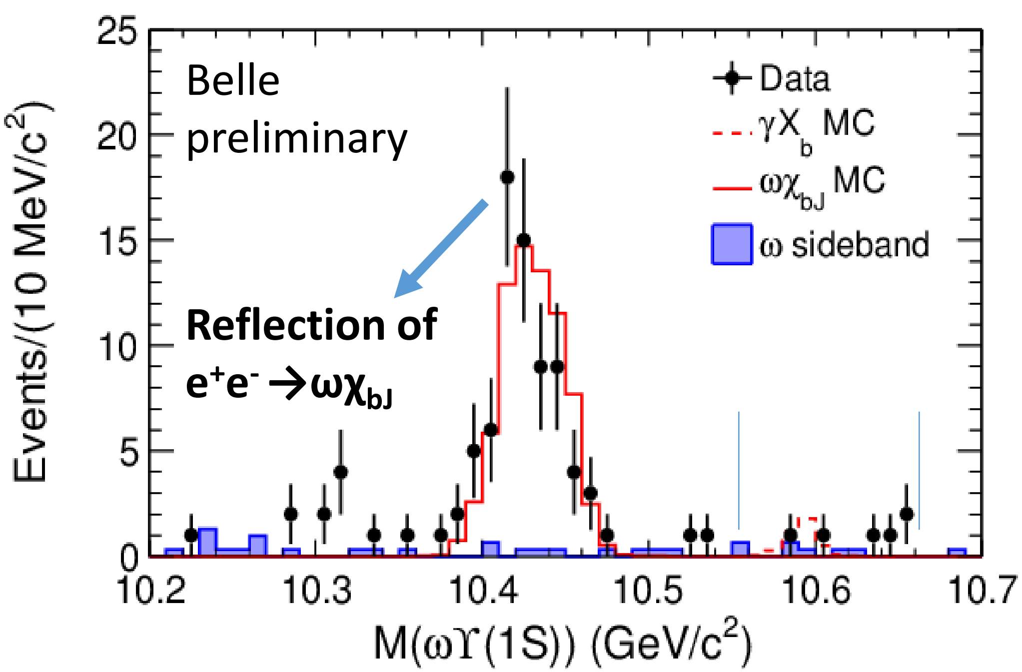
$e^+e^- \to \gamma X_b \to \gamma\omega\Upsilon(1S)$

preliminary

- **The X(3872) counterpart in the bottomonium sector X_b, NOT observed decay channel $\pi^+\pi^-\Upsilon(1S)$.**
- **As X_b is above $\omega\chi_{bJ}$ threshold, this Isospin-conserving process should be a more promising decay mode.** [PRD88, 054007].



PLB 727, 57 (2013) .



Assuming X_b is narrow, the product branching fraction :

$Br(\Upsilon(5S) \to \gamma X_b)$ $Br(X_b \to \omega\chi_{bJ})$ varies from **2.6×10^{-5} to 3.8×10^{-5} between 10.55 and 10.65 GeV/c^2**.

Bottomonium transition II

QCDME model. [Y. P Kuang, Front Phys. China 1, 19 (2006)]

Assuming **heavy quark spin symmetry is the dominant effect**

$\Upsilon(nS) \to \pi\pi\ \Upsilon(mS)$ **No Spin Flip Transition**

$\Upsilon(nS) \to \eta\ \Upsilon(mS)$ **Spin Flip Transition**

Suppression of spin flip in S→S transition

$$R^{SS}(\pi\pi, \eta) = \frac{BF(\Upsilon(nS) \to \eta\Upsilon(mS))}{BF(\Upsilon(nS) \to \pi\pi\Upsilon(mS))} << 1$$

Experimental status :

$\Upsilon(2S) \to \eta/\pi\pi\ \Upsilon(1S)$
$\Upsilon(3S) \to \eta/\pi\pi\ \Upsilon(1S)$ → $R^{SS}(\pi\pi, \eta)$ are consistent with some theory expectations. Foresee a larger width [PLB 673, 211 (2009)]

$\Upsilon(4S) \to \eta/\pi\pi\ \Upsilon(1S)$ → $R^{SS}(\pi\pi, \eta) = 2.41 \pm 0.40 \pm 0.12$. [PRD 78, 112002]

Suppression of spin flip in S→P transition

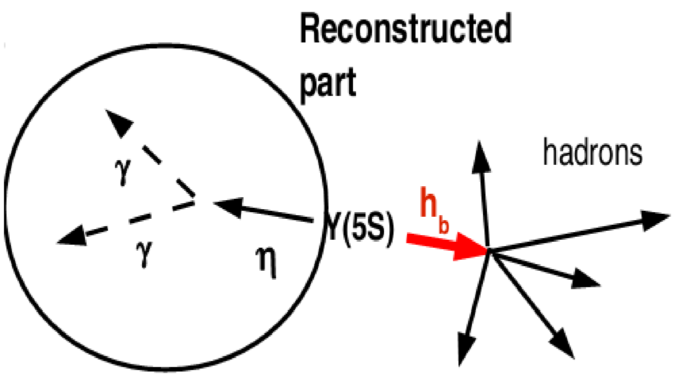
$$R^{SP}(\pi\pi, \eta) = \frac{BF(\Upsilon(nS) \to \eta h_b(mS))}{BF(\Upsilon(nS) \to \pi\pi h_b(mS))} >= 1$$

$\Upsilon(5S) \to \pi\pi\ h_b(mS)$: effect of Z_b intermediate states.

$R^{SP}(\pi\pi, \eta)$ experimental result?

$\Upsilon(5S) \rightarrow \eta\,(b\bar{b})$

hb(nP) has no known exclusive decays



- $BF(\Upsilon(5S) \rightarrow \eta\, h_b(1P)) < 3.3 \times 10^{-3}$ (90% CL)

  $\rightarrow R^{SP}(\pi\pi, \eta) < 0.94$

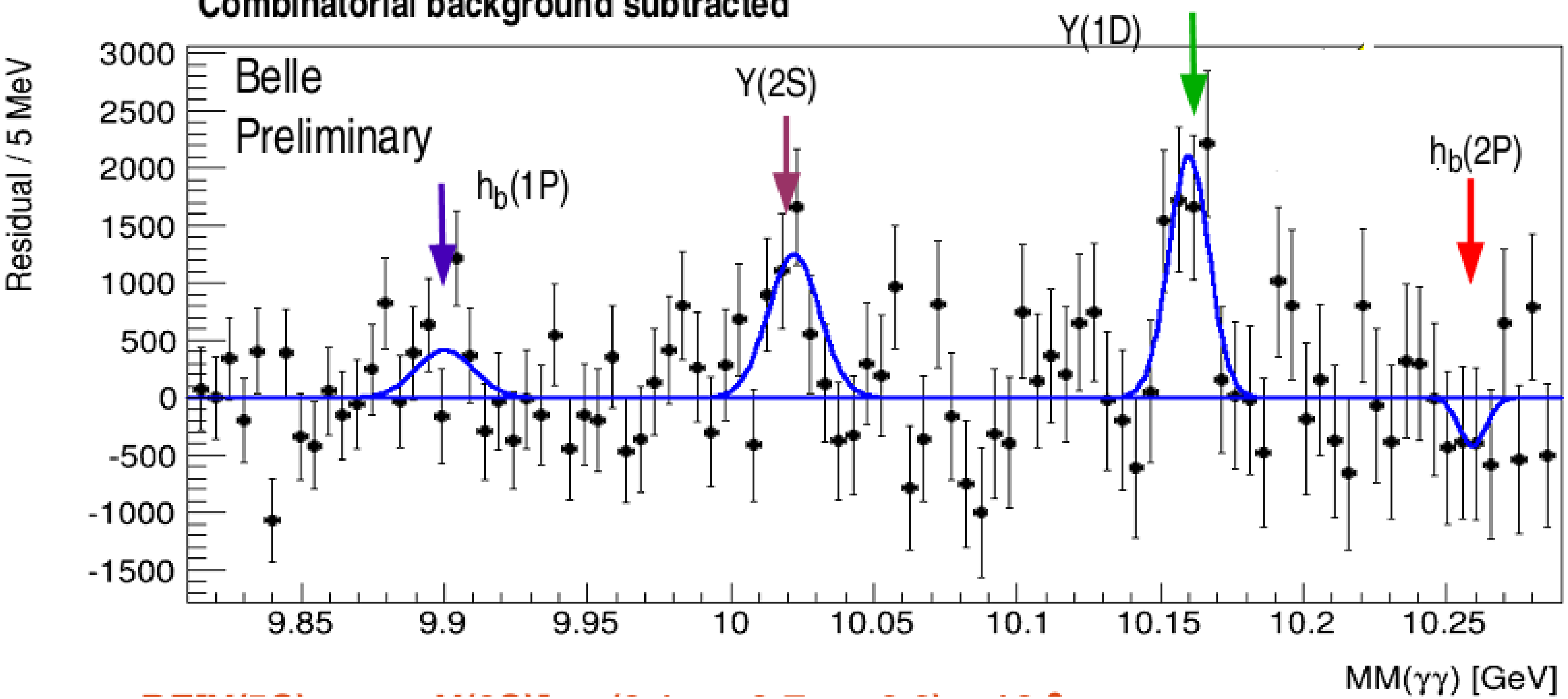
- $BF(\Upsilon(5S) \rightarrow \eta\, h_b(2P)) < 3.7 \times 10^{-3}$ (90% CL)

  $\rightarrow R^{SP}(\pi\pi, \eta) < 0.62$

- $BF(\Upsilon(5S) \rightarrow \eta\, \Upsilon(2S)) = (2.1 \pm 0.7 \pm 0.3) \times 10^{-3}$
- $BF(\Upsilon(5S) \rightarrow \eta\, \Upsilon(1D)) = (2.8 \pm 0.7 \pm 0.4) \times 10^{-3}$

First evidence of single meson transition to Υ(1D).

Combinatorial background subtracted

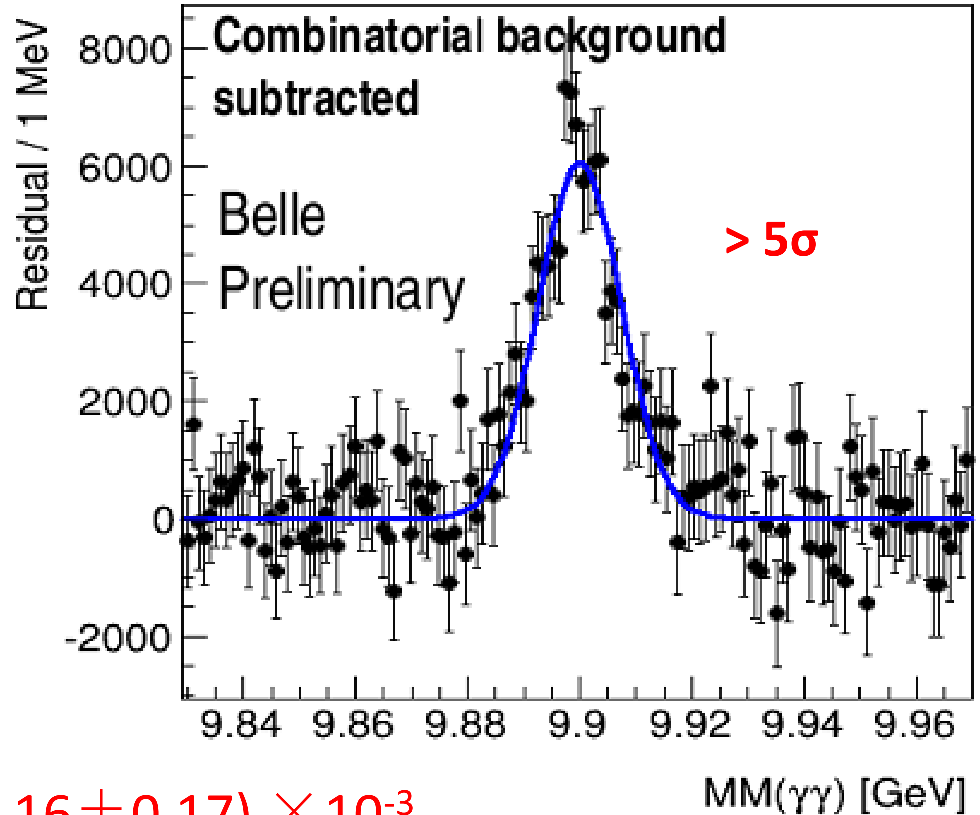


$\Upsilon(4S) \rightarrow \eta h_b(1P)$

preliminary

Theory [PRL105, 162001]

- BF ~ 10^{-3}
- Small Coupled-channel related term(~20%)



$BF(\Upsilon(4S)) \rightarrow \eta\, h_b(1P) = (1.83 \pm 0.16 \pm 0.17) \times 10^{-3}$

→ **R^{SP} (ππ, η) > 2.0**

Spin-flipping based prediction matched **if light quark contribution is small.**

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

→detecting spin singlet **$\eta_b(1S)$**

Detecting $\eta_b(1S)$

preliminary

pNRQCD: 41±14 MeV

Kniehl et al., PRL92,242001(2004)

Lattice: 60±8 MeV

Meinel, PRD82,114502(2010)

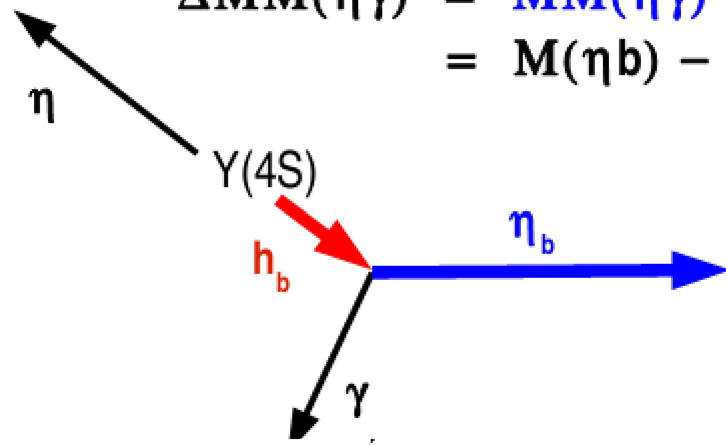
Belle 5S : $57.9 \pm 2.3 ^{+1.6}_{-1.2}$ MeV

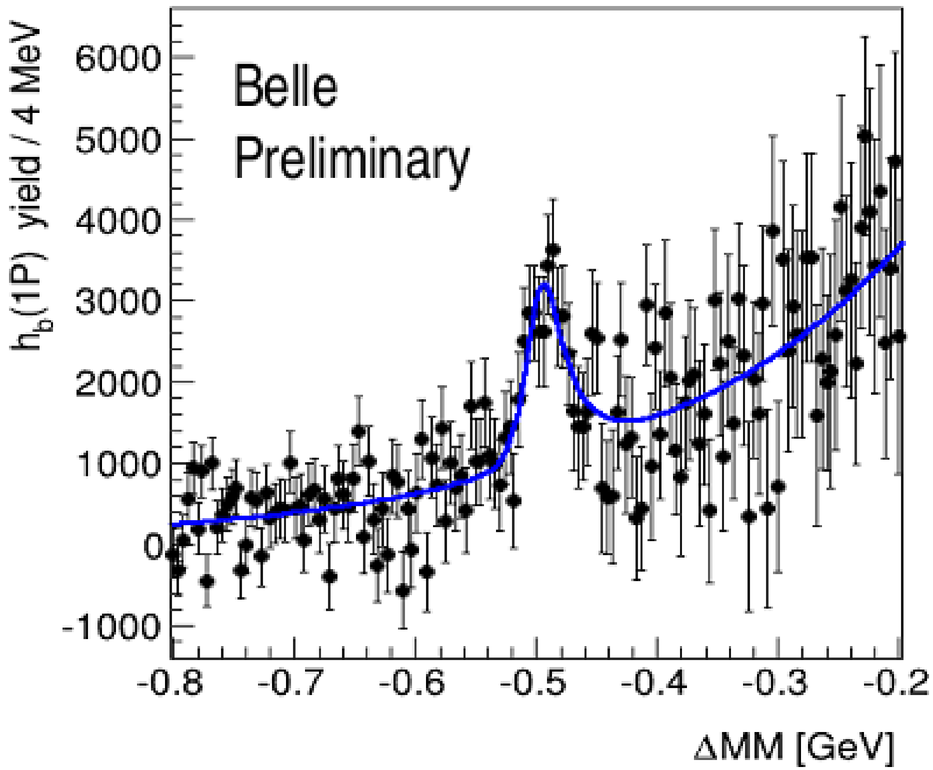
PRL109 (2012) 232002

PDG '12 : 69.3 ± 2.8 MeV

$\Delta MM(\eta\gamma) = MM(\eta\gamma) - MM(\eta)$

$= M(\eta b) - M(hb)$





$M[\eta b(1S)] = (9405.3 \pm 1.3 \pm 3.0)$ MeV

$\Gamma[\eta b(1S)] = (11 ^{+8}_{-6} \pm 3)$ MeV

$BF[hb(1P) \rightarrow \gamma\, \eta b(1S)] = (52^{+11}_{-10} \pm 4)\,\%$

$\Delta M_{HF}(\eta_b) = M(\eta_b) - M(Y(1S)) =$

$(55.0 \pm 1.3 \pm 3.2)$ MeV

Assuming Y(1S) mass = 9460.3 MeV

Summary

- First observation of $e^+e^- \to \pi^0\pi^+\pi^- \chi_{b1,2}$, clear ω and $(\pi^+\pi^-\pi^0)_{non-\omega}$ events in $\pi^0\pi^+\pi^-$ invariant mass distribution.
- Search for $X_b \to \omega\, \Upsilon(1S)$, no evidence.
- First observation of $\Upsilon(4S) \to \eta h_b(1p)$ and study of $\Upsilon(5S) \to \eta\, h_b\, (\Upsilon(2S), \Upsilon(1D))$.
- Updated $\eta_b(1S)$ resonance parameters.

Back up

$e^+e^- \to \pi^+\pi^-\pi^0 \chi_{bJ}$

Product branch fractions :

$BF(\Upsilon(5S) \to \omega\chi_{b0}) < 3.9 \times 10^{-3}$ at 90% C.L.

$BF(\Upsilon(5S) \to \omega\chi_{b1}) = (1.57 \pm 0.22 \pm 0.21) \times 10^{-3}$

$BF(\Upsilon(5S) \to \omega\chi_{b2}) = (0.60 \pm 0.23 \pm 0.15) \times 10^{-3}$

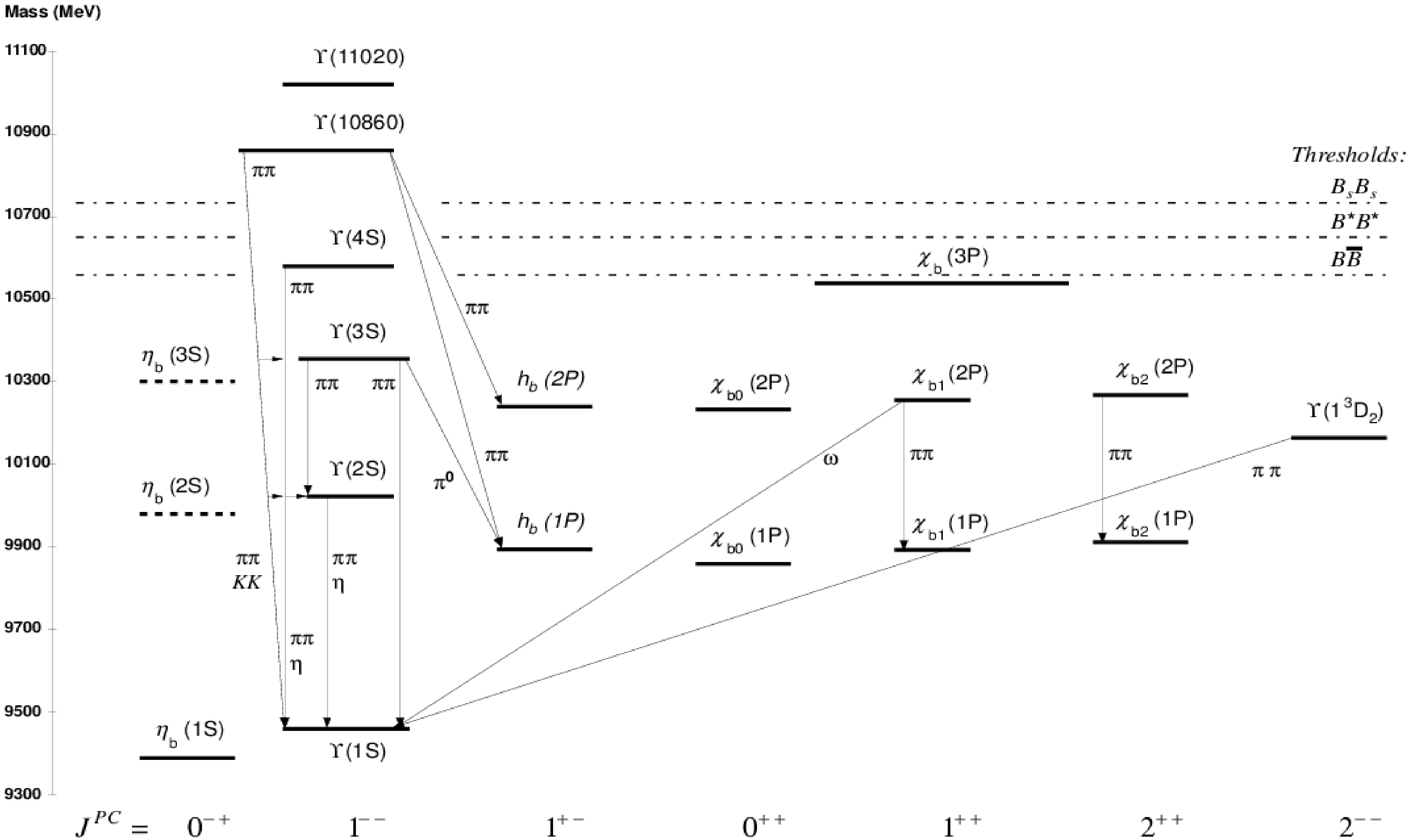
$BF(\Upsilon(5S) \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b0}) < 4.8 \times 10^{-3}$ at 90% C.L.

$BF(\Upsilon(5S) \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b1}) = (0.52 \pm 0.15 \pm 0.11) \times 10^{-3}$

$BF(\Upsilon(5S) \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b2}) = (0.61 \pm 0.22 \pm 0.28) \times 10^{-3}$

Assuming all events decay from $\Upsilon(5S)$.

Bottomonium spectroscopy



Umberto Tamponi talk at DIS 2014