Physics with first data taking

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II Italian BelleII collaboration Meeting
Napoli, 12/18/2014

First physics run

First physics run ~ 300/fb https://belle2.cc.kek.jp/~twiki/bin/viewauth/Physics/FirstPhysicsTaskForce

→ Some data at Υ(4S) are mandatory

→ ~ 200/fb can be taken at different energies

→ Vertexing may not be optimal

Topic	Sub-topics	Contributors
Bottomonium(like) below 4S	Υ(1S), Υ(2S), Υ(3S)	B. Fulsom, R. Mussa
Bottomonium(like) above 4S	Υ(6S), E_CM scan, b-quark mass	R. Mizuk, T. Pedlar
Charmonium(like)	(not so compelling prospects for $\int \mathcal{L} < 1\ ab^{-1}$)	C. H. Li
Dark sectors & Light Higgs		C. Hearty, I. Jaegle, G. Inguglia, S. Vahsen
Production and fragmentation		A. Rostomyan
Electroweak	Rho-parameter, contact interactions	T. Ferber
Tau		C. Schwanda
Trigger considerations		P. Urquijo, C. H. Li
Summary and Recommendations		

Missing states

$\Upsilon(1^3D_{1,3})$, $\Upsilon(2D_J)$, $\eta_b(3S)$...

Interesting states

$\eta_b(1S,2S)$, $h_b(1P,2P)$, $\Upsilon(1^3D_2)$

Experiment	$\Upsilon(3S)$	$\Upsilon(2S)$	$\Upsilon(1S)$
CLEO	$1.2 fb^{-1} \sim 5M$	$1.2 fb^{-1} \sim 10M$	$1.2 fb^{-1} \sim 21M$
BaBar	$30 fb^{-1} \sim 122M$	$14 fb^{-1} \sim 99M$	-
Belle	$3 fb^{-1} \sim 12M$	$25 fb^{-1} \sim 158M$	$6 fb^{-1} \sim 102M$

Options

→ **Υ(5,6S) scan**

→ **Υ(3S) data**

→ **Υ(1,2D) scan**

→ **Exploratory run at Υ(6S)**

WORK IN PROGRESS

50/ab Υ(4S) data sample potential

→ **~10 Millions $h_b(1P)$ tagged with $\eta \to \gamma\gamma$**

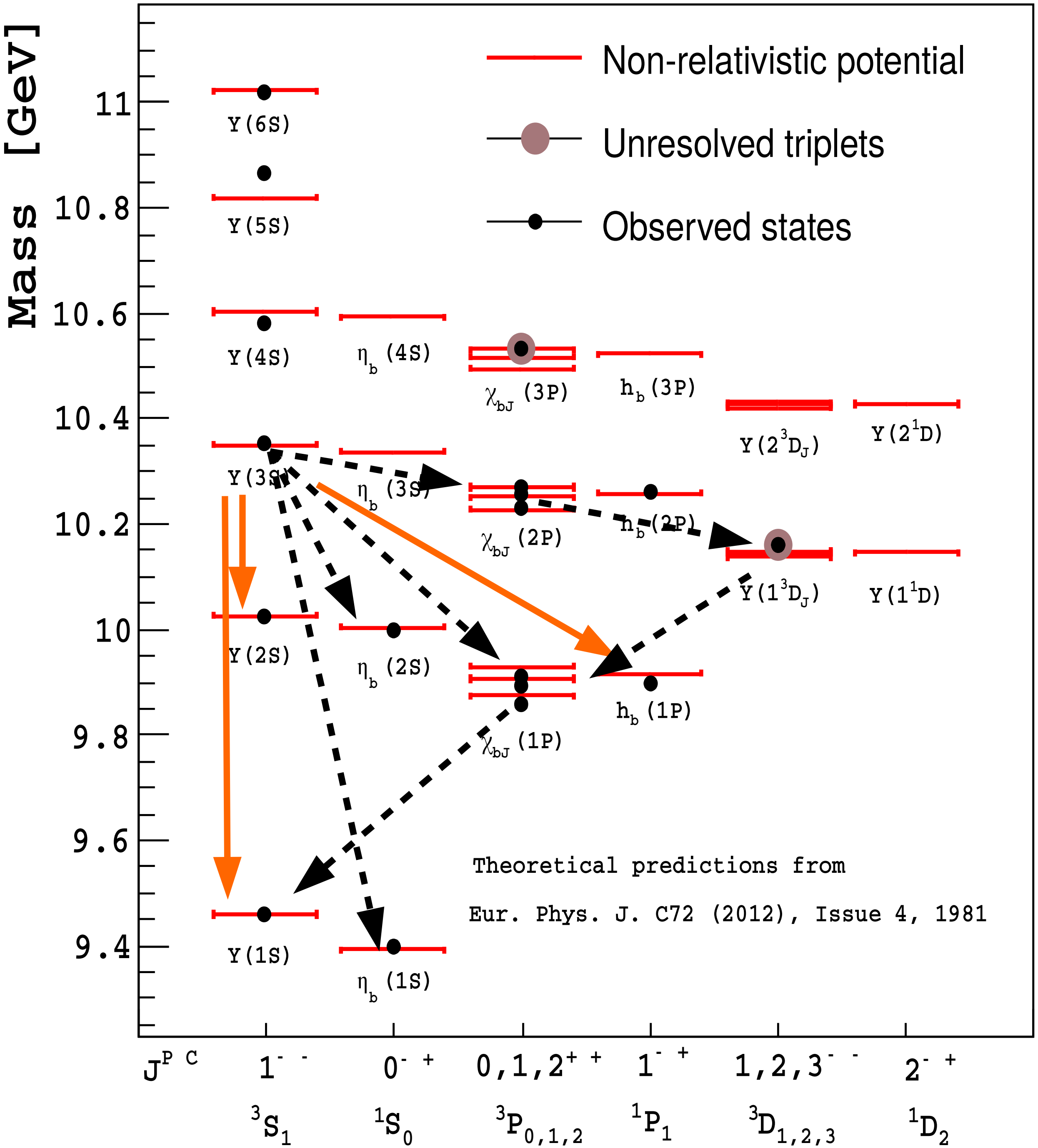
→ **~3.5 Millions $\eta_b(1S)$ tagged with $\eta \to \gamma\gamma$**

→ high precision 1S hiperfine splitting

→ precise determination of $\eta_b(1S)$ width

→ **$h_b(1P)$ and $\eta_b(1S)$ decays and transitions**

Y(3S) opportunities



Why 3S

→ Access to the Y(1D) states

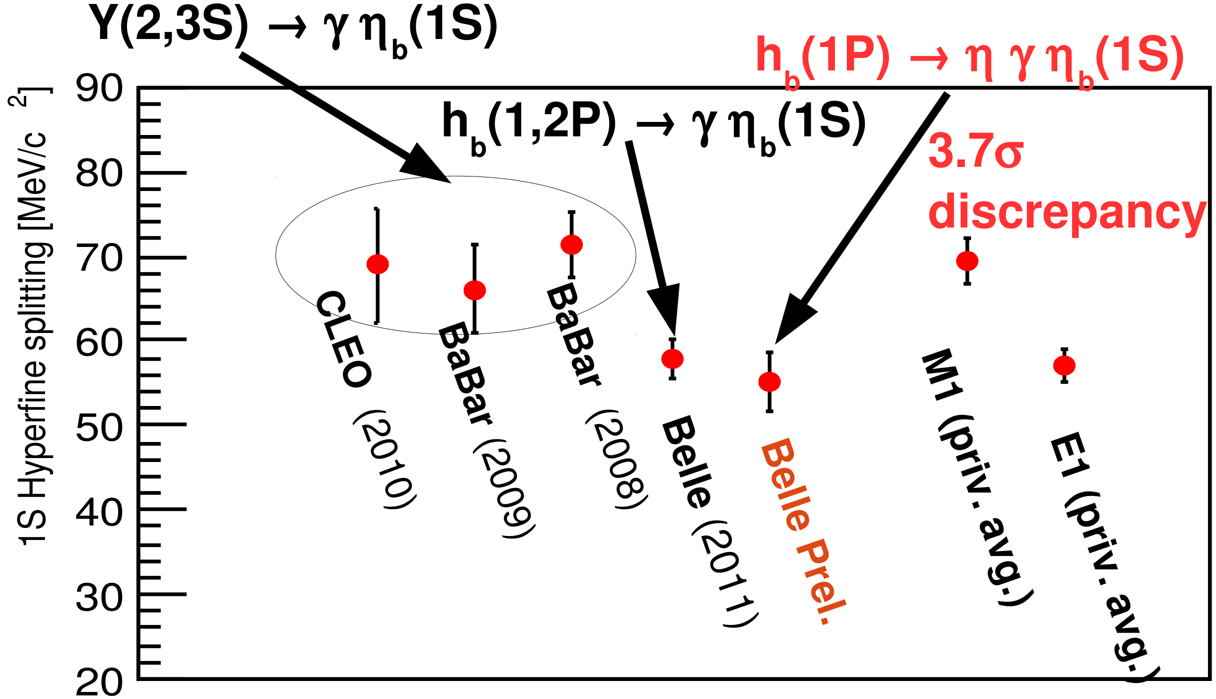
→ Access to χ_b(2P)

→ Hindered transitions to both η_b(1S) and η_b(2S)

→ $\pi\pi$ tagging for Y(1,2S) → Y(1S) → invisible

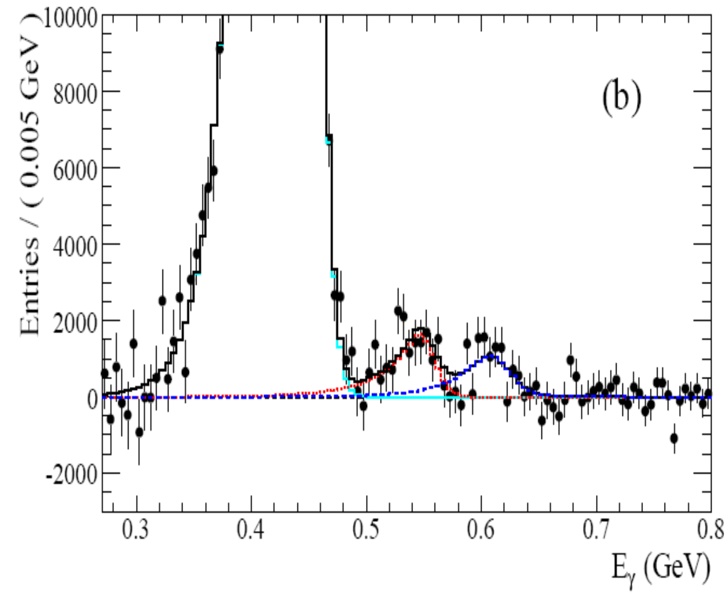
→ single meson transitions to h_b(1P)

η_b(1,2S) from Y(3S)

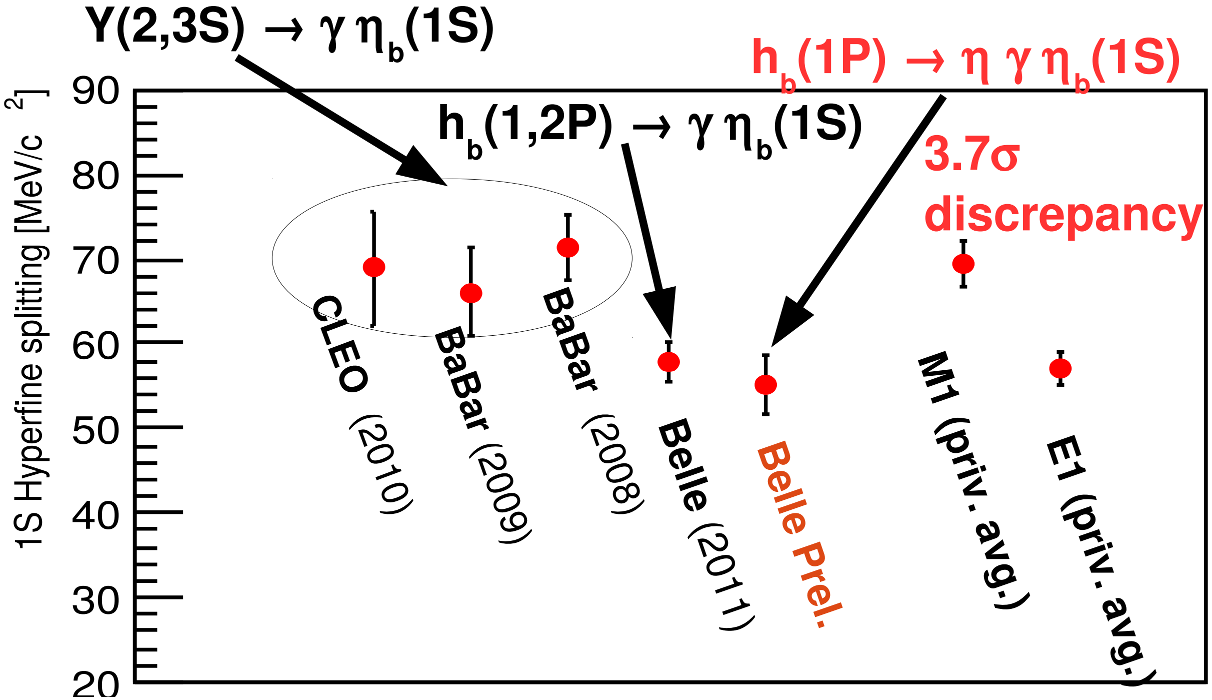


$M(\eta_b)_{M1} - M(\eta_b)_{E1} = -12 \pm 3$ MeV

BaBar Y(3S)



η_b(1,2S) from Υ(3S)



$M(\eta_b)_{M1} - M(\eta_b)_{E1}$ = -12 ± 3 MeV

$M(\eta_c)_{M1} - M(\eta_c)_{E1}$ = -7.7 ± 1.4 MeV

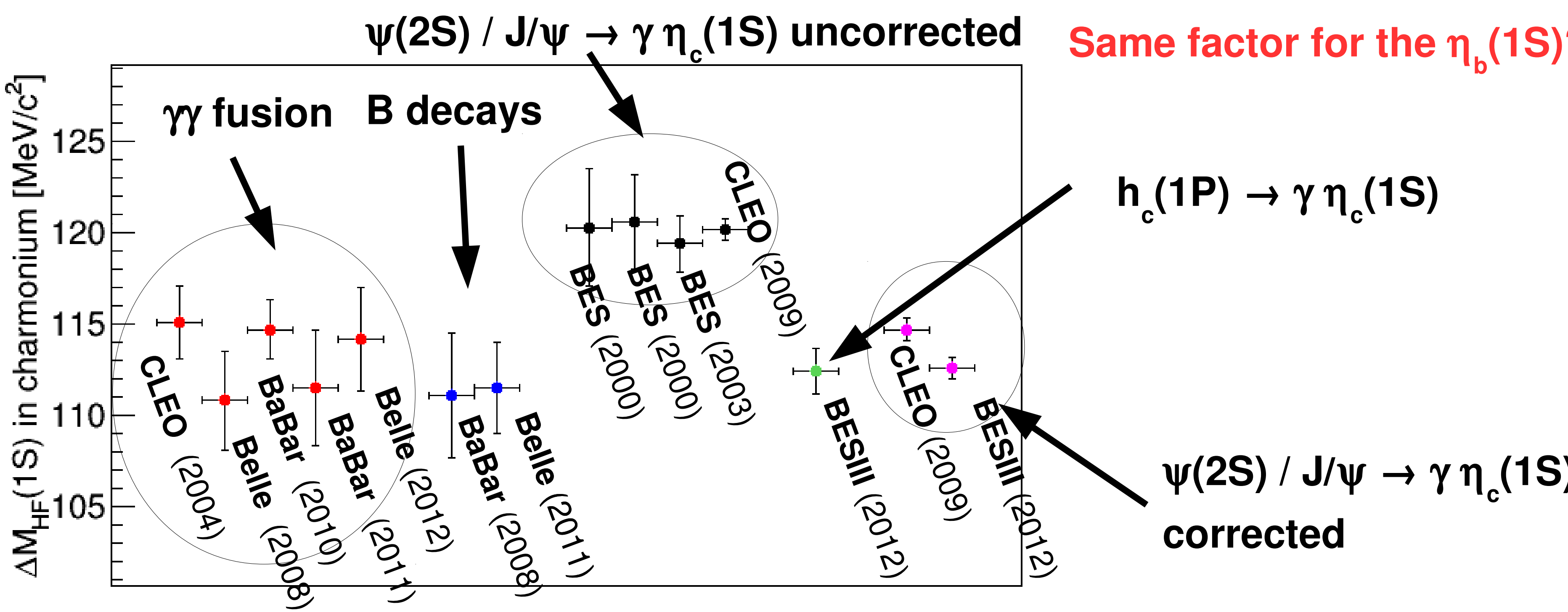
M(η_c)line shape factor:

$$E_\gamma^3 \exp\left(E_\gamma^{-2}/(8\beta^2)\right)$$

β = 65 ± 2.5 MeV

PRL 102 (2009) 011801,
Erratum-ibid. 106 (2011) 159903

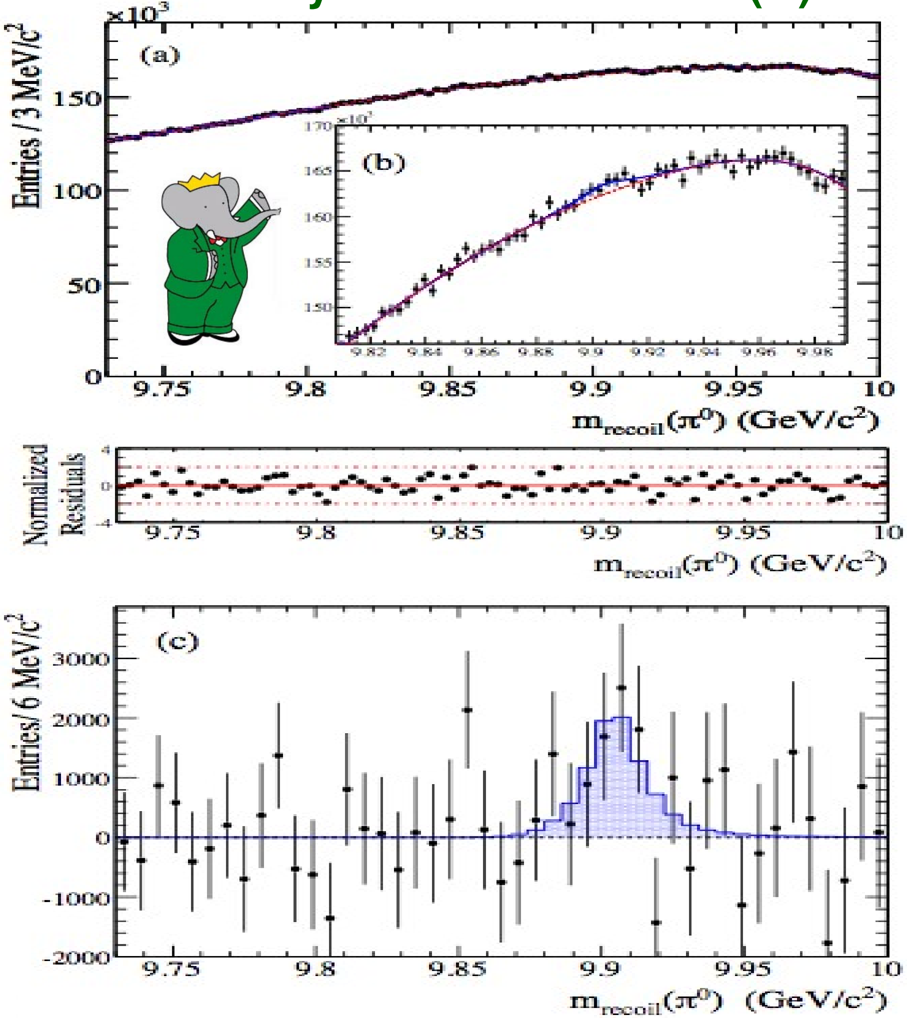
Same factor for the η_b(1S)?



Y(3S): hadronic transitions

Challenging pattern for all the Y(3S) hadronic transitions

Phys.Rev.D 84 091101(R)



π⁰ recoil mass (GeV/c²)

$$\frac{B[Y(2S)\to\eta Y(1S)]}{B[Y(2S)\to\pi\pi Y(1S)]}=(1.64\pm0.25)\times10^{-3}$$ **OK**

$$\frac{B[Y(3S)\to\eta Y(1S)]}{B[Y(3S)\to\pi\pi Y(1S)]}<2.2\times10^{-3}$$ **3 σ below theory**

Isospin violating

$$\frac{B[Y(3S)\to\pi^0 h_b(1P)]}{B[Y(3S)\to\eta Y(1S)]}>10$$

Isospin preserving

Heavy quark spin symmetry breaking effects already at Y(3S)?

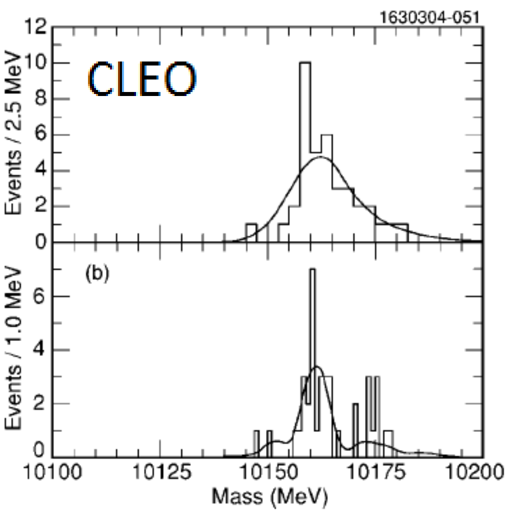
Y(3S): study of Y(1D) triplet

From Brian Fulsom's talk at B2TIP

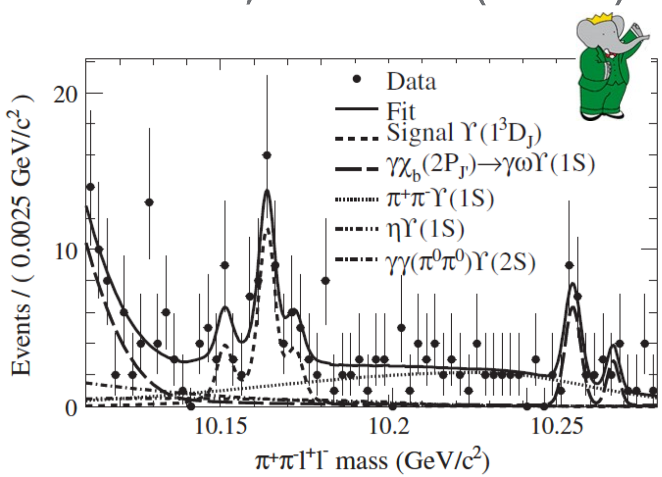
- **$Y(1^3D_2)$**
  - Discovered by CLEO: $Y(3S) \to \gamma\chi_{bJ}(2P) \to \gamma Y(1D) \to \gamma\chi_{bJ}(1P) \to \gamma Y(1S)$
  - Seen by BaBar: $Y(3S) \to \gamma\chi_{bJ}(2P) \to \gamma Y(1D) \to \pi^+\pi^- Y(1S)$
  - Preliminary results from Belle: $Y(5S) \to \pi^+\pi^- Y(1D)$, $Y(5S) \to \eta\, Y(1D)$

- **J=1 and J=3 states have yet to be seen/resolved**
- **Hadronic transtion patter is not yet clear**

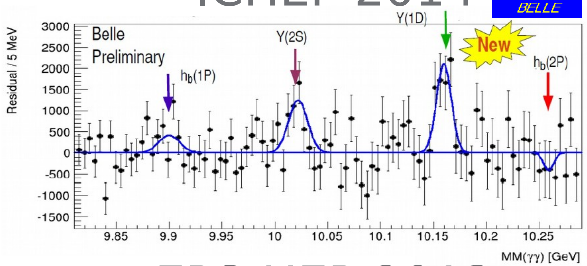
PRD 70, 032001 (2004)



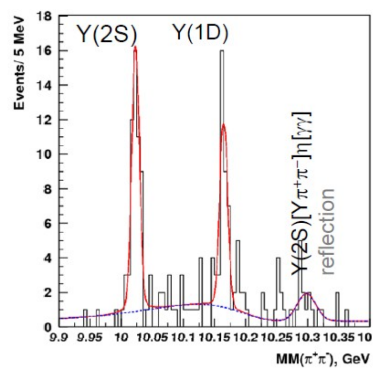
PRD 82, 111102 (2010)



ICHEP 2014



EPS-HEP 2013



Y(3S): study of Y(1D) triplet

Some $Y(m^3D_{1,3})$ Possibilities

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- Y(3S) options ($Y(1^3D_J)$ only)
  - 4γ cascade: $Y(3S) \rightarrow \gamma\gamma Y(1D) \rightarrow \gamma\gamma Y(1S)$
    - BF($Y(3S) \rightarrow \gamma\gamma Y(1D_{1,2,3}) \rightarrow \gamma\gamma Y(1S)$): (1.6, 11, 3.0) x 10^{-4} — Kwong/Rosner, PRD 38, 279 (1988)
    - Difficult due to overlapping photon energies
  - $\gamma\gamma\pi\pi$ transition: $Y(3S) \rightarrow \gamma\gamma Y(1D_{1,3}) \rightarrow \pi^+\pi^- Y(1S)$
    - Scaling from BaBar (2.0σ, 1.7σ) requires ~7-9x larger dataset
  - 3γ inclusive: $Y(3S) \rightarrow \gamma\gamma Y(1D) \rightarrow \gamma\chi_b(1P)$
    - $Y(1^3D_1) \rightarrow \gamma\chi_{b0}(1P)$ has E_γ^*~288 MeV, highest Y(1D) transition by ~20 MeV
    - Might see it in inclusive photon spectrum like CLEO $Y(3S) \rightarrow \gamma\chi_{b0}(1P)$
- Other options — CLEO, PRL 94, 032001 (2005)
  - Existing Belle/BaBar data
    - Y(4S) decays via $\gamma\chi_b(3P)$?
    - $Y(5S) \rightarrow \eta Y(1D)$, $\pi^+\pi^- Y(1D)$: peaks not separated, 2D not seen
    - Cross section for direct ISR production of $Y(1,2^3D_1)$ states: 0.06, 0.36 fb
      Benayoun et al., Mod. Phys. Lett. A 14, 2605 (1999)

Y(1D) direct scan

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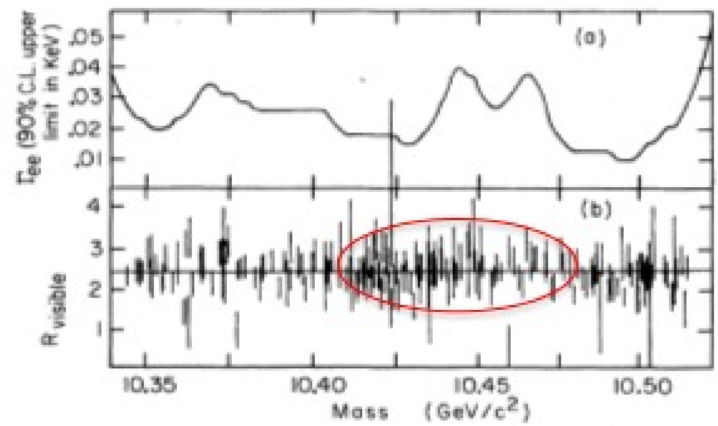
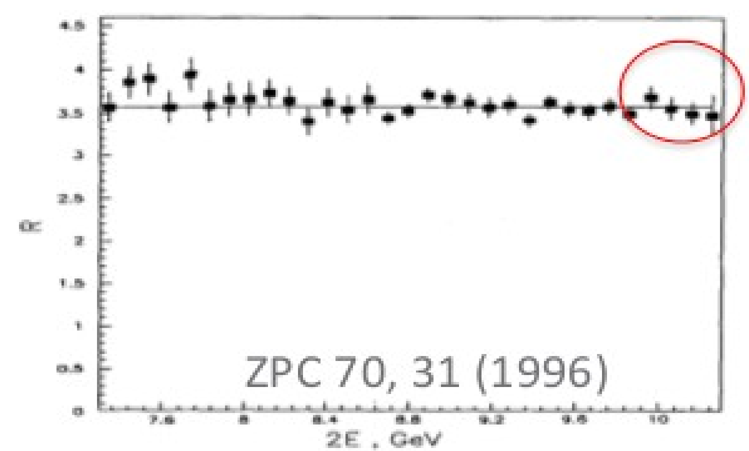
Direct Scan for $\Upsilon(m^3D_1)$?

- J=1 can be produced directly in e^+e^-
  - Γ_{ee}: (0.6 – 1.5, 1.1 – 2.7) eV
  - $\Upsilon(1^3D_1)$: 10150 – 10155 MeV
  - $\Upsilon(2^3D_J)$: 10430 – 10445 MeV
- Previous $\Upsilon(2^3D_1)$ search by CUSB (5 pb^{-1})
  - Experimental limit: Γ_{ee}<40eV
  - No evidence/publication from CLEO
- Previous $\Upsilon(1^3D_1)$ search by MD-1
  - VEPP-4 scan data from 1984-85
  - ~0.2 pb^{-1} per point (?)
- Unique early opportunity for Belle-2?



PRL 48, 906 (1982)



ZPC 70, 31 (1996)

Y(1D) direct scan

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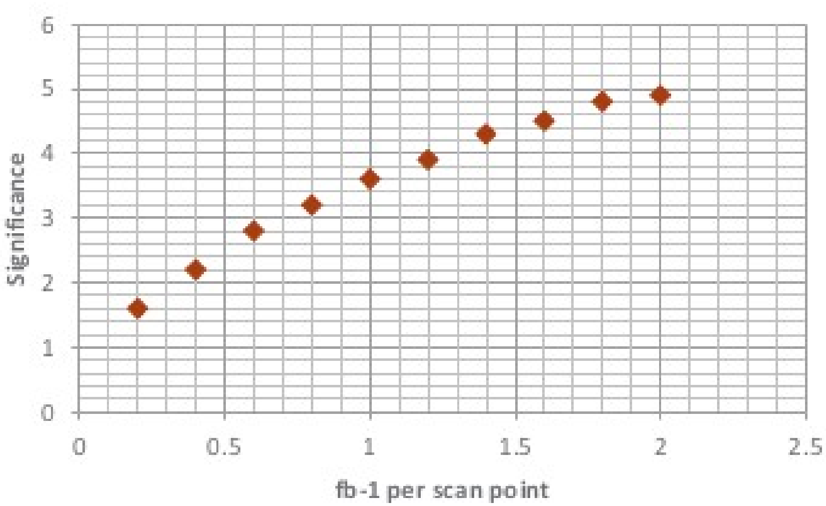
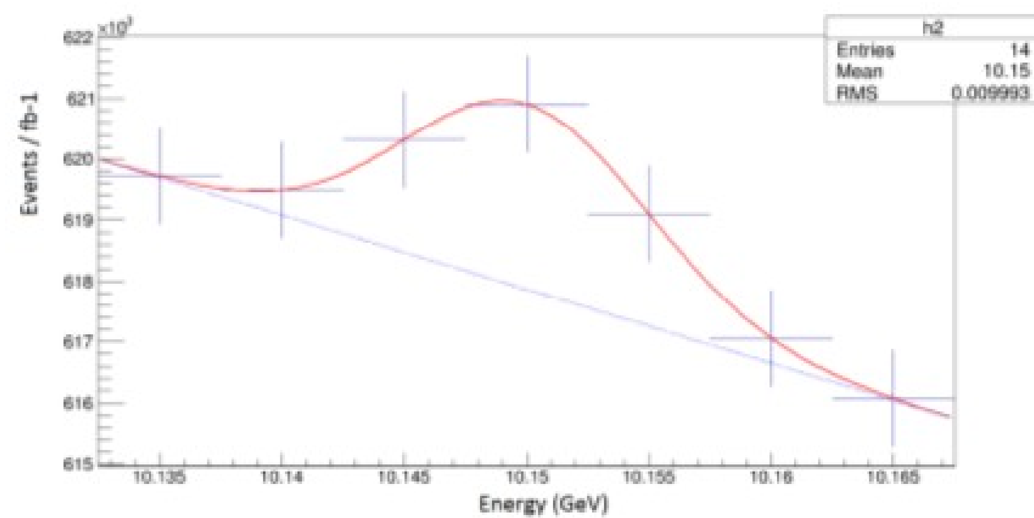
Scan example and significance $\Upsilon(1^3D_1)$

- 7 points in 5MeV steps centred on m=10.150 GeV
  - ~$1fb^{-1}$ per scan point appears to needed for 3σ, >$2fb^{-1}$ for 5σ
  - Mass uncertainty ~1.4 MeV (statistical)
  - At L = $2x10^{-34}$ $cm^{-2}s^{-1}$, would (realistically) take a minimum of 1 week





Y(6S) exploratory run

Motivation for taking data at $\Upsilon(6S)$

From Roman Mizuk's talk at first B2TIP

Z_b and Z_b' are produced in roughly equal proportion at $\Upsilon(5S)$

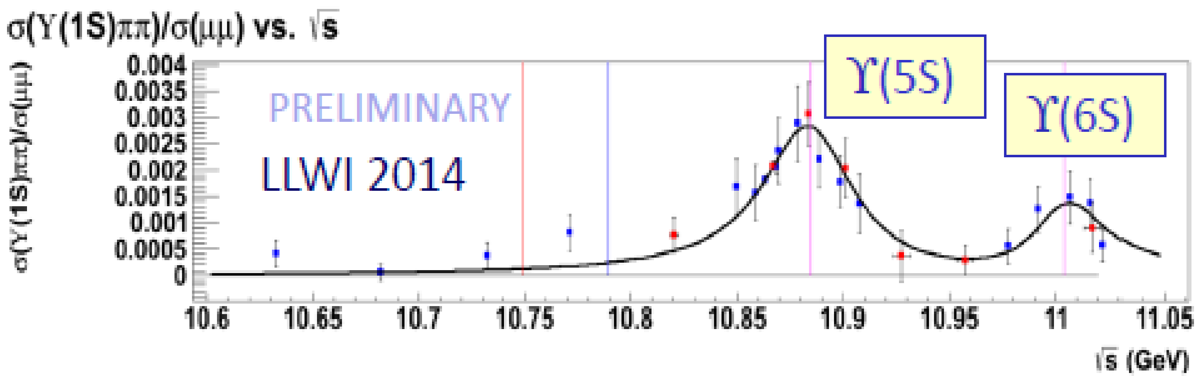
$\Rightarrow$ information on $\Upsilon(5S)$ wave-function.

Alternative?

Z_c is produced in Y(4260) decays, while Z_c' is not [only one peak in $M(J/\psi\pi)$].

Explained by model in which Y(4260) is a DD_1 molecule.

D_1 = narrow P-wave state



@ $\Upsilon(6S)$:
anomalous transitions exist.
In which proportion Z_b's are produced?

Belle data at $\Upsilon(6S)$ – $6fb^{-1}$ – inconclusive. Need similar to $\Upsilon(5S)$ sample of $\sim 100fb^{-1}$.

for start-up

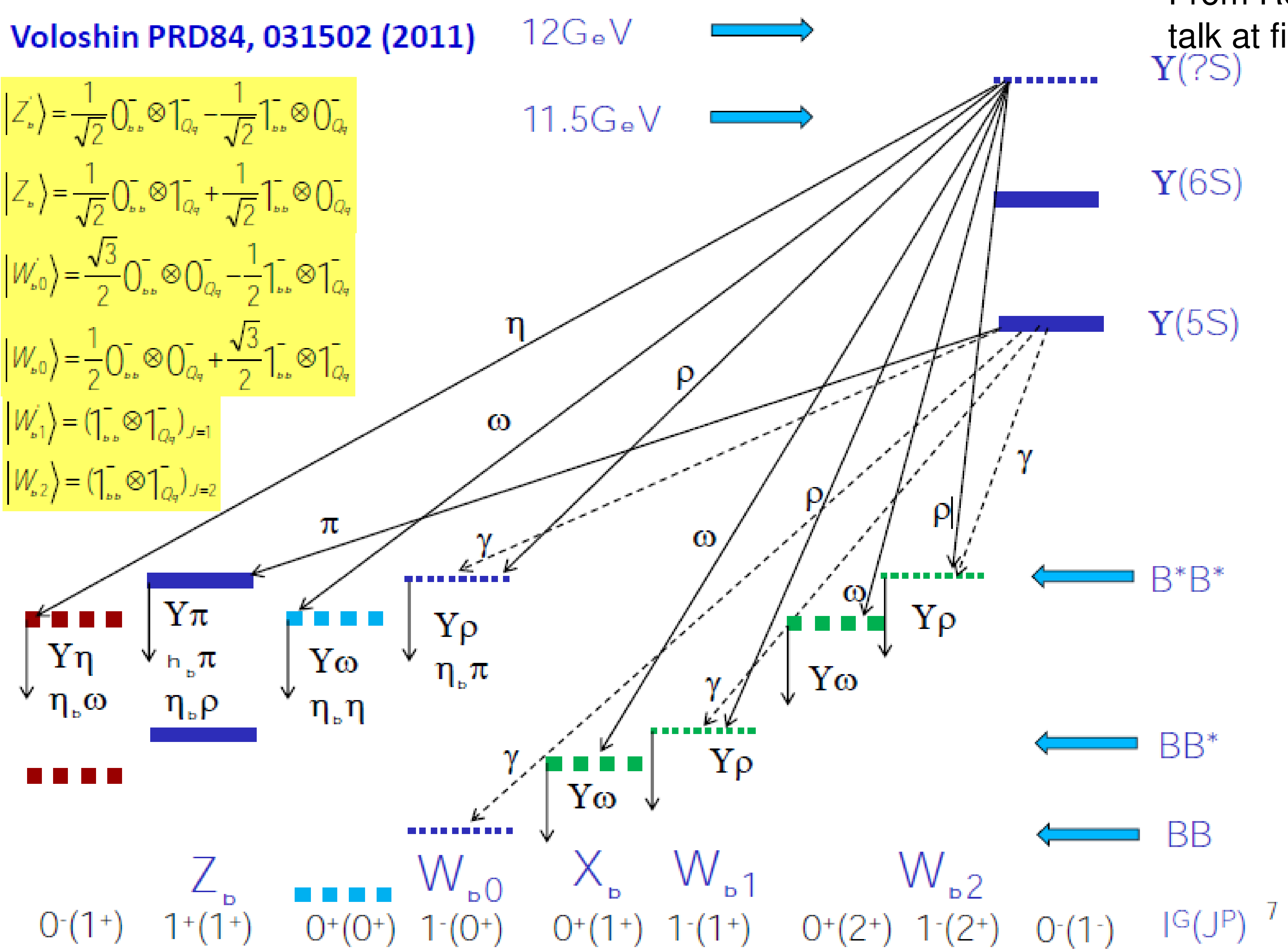
Other studies at $\Upsilon(6S)$: hadronic transitions to lower bottomonia, their spectroscopy.

BESIII observed $Y(4260) \to X(3872)\gamma$. $\Rightarrow$ Search for $\Upsilon(6S) \to X_b\,\gamma$.

NB : signal purity in $\Upsilon(6S) \to B^{(*)}B^*(\pi)$ due to kaon ID? $\Rightarrow$ Need to be simulated.

Y(6S) exploratory run

From Roman Mizuk's talk at first B2TIP



Υ(6S) early scan

From Roman Mizuk's talk at first B2TIP

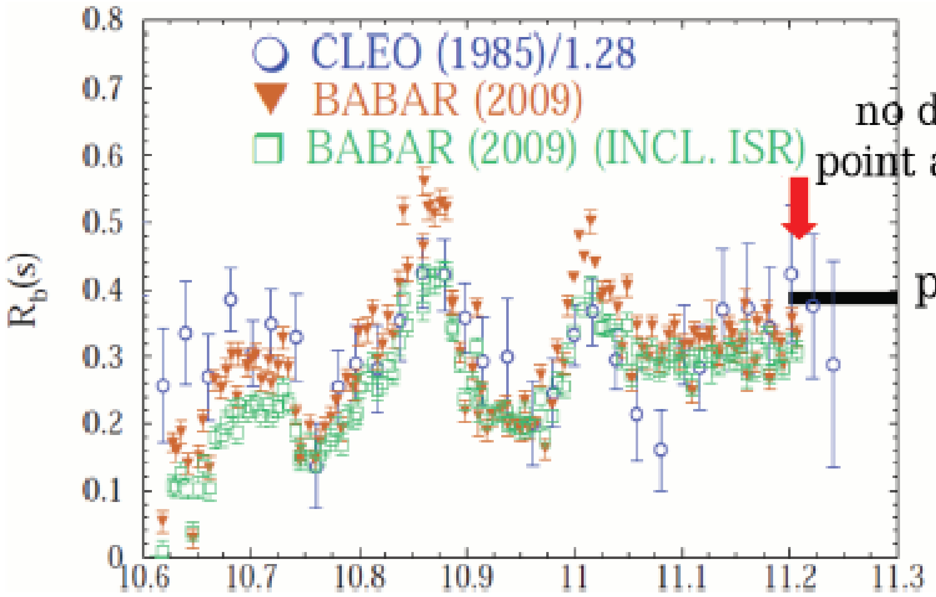
Motivation for energy scan

For comprehensive studies of molecules desired c.m. energy range is up to 12.0GeV.

Present limit is 11.25GeV. For further increase upgrade of injection system is needed.

Possible data taking scenario (E_{max}=12.0GeV):
Scan with 10MeV step 10fb^{-1} per point (~1.3ab^{-1} total), take 500fb^{-1} at Υ(5S), Υ(6S),..

Start-up:
Scan 10.95-11.25GeV region with 10MeV step ≥1fb^{-1} per point, ~50 fb^{-1} total.



Plans for scan data:

Measure m_b
Measure σ [Υ/$h_b\pi\pi$]... , search for peaks
Decompose R_b into $B\bar{B}$, $B\bar{B}^*$,..
signal purity due to PID

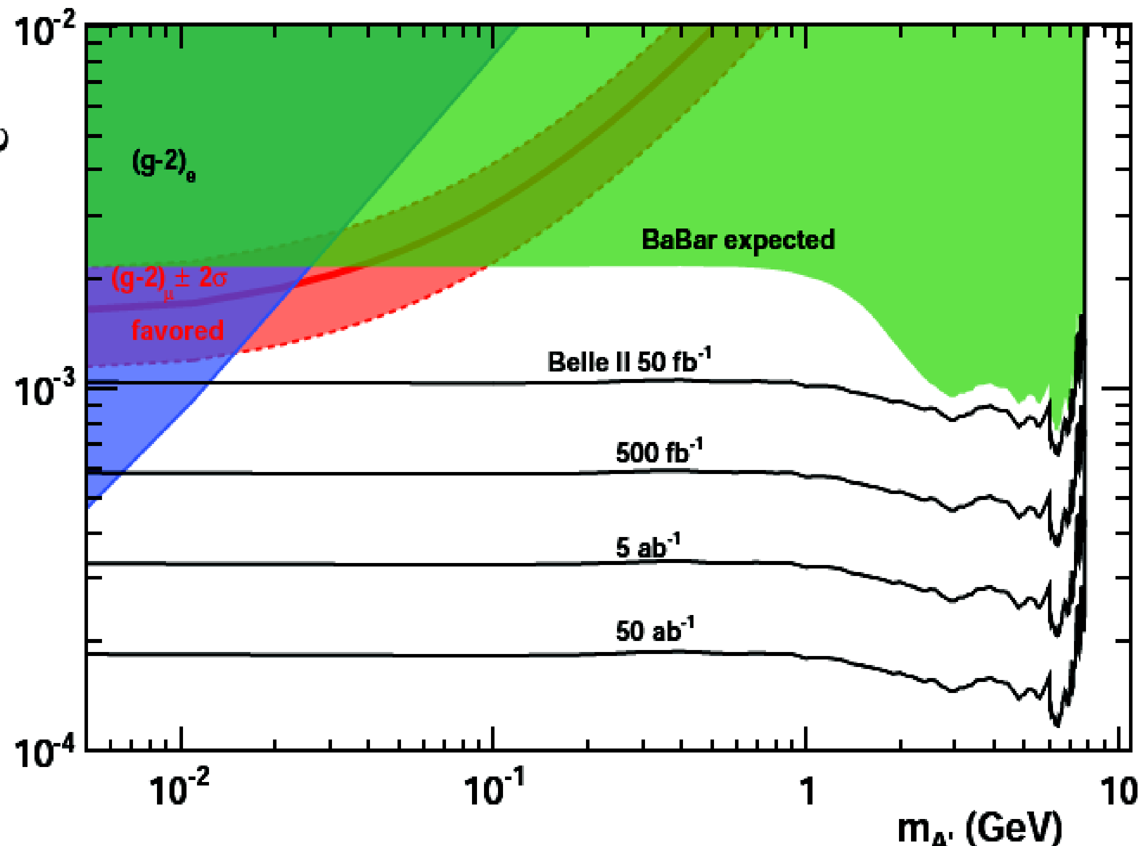
8

Invisible final states

Gianluca Inguglia, Igal Jaegle, Christopher Hearty

Not really dependent on beam energy
Not limited to early physics period

Exploit the **low luminosity** early physics period to implement single particle and missing energy triggers
→ 3 tracks trigger for Y(1S) → invisible in Y(3S) dataset
→ Single photon trigger fro dark photon searches



From Gianluca's talk

MC generators for early physics

MC generators validation groups
→ validation
→ tuning

Topic		Contact/Coordination
EvtGen	Charm & Charmonium	Roy Briere (tbc.)
	Hadronic B Decay and Direct CP Violation	tba. (was Lucien Cremaldi)
	Radiative and Electroweak Penguin	tba. (was Todd Pedlar)
	Semileptonic and Missing Energy	Romulus Godang (confirmed)
	Time Dependent CP Violation	Vladimir Savinov (tbc.)
	Upsilon(nS)	Umberto Tamponi, Todd Pedlar (confirmed)
	Continuum	Hulya Atmacan (confirmed)
KKMC		Kiyosi Hayasaka (tbc.)
PHOKHARA		Torben Ferber (confirmed)
Large Angle Bhabha		Chris Hearty (tbc)
eell		David Joffe (tbc.)
eeqq		Torben Ferber (confirmed)
MadGraph		Igal Jaegle, Torben Ferber or Gianluca Inguglia (tbc)
PYTHIA tuning Joint group of all qqbar final state contacts		Hulya Atmacan, Umberto Tamponi (for Y(nS), Torben Ferber (for QED/NP)

Early physics needs this

Υ(nS) MC generators

	New Analysis ?	Theoretical work needed?	EvtGen methods to be written?	Timescale	Priority	Contact person	
Fix DECAY.DEC	No	No	No	Short	HIGH	U. Tamponi	~Done
PYTHIA tuning	Yes	No	No	Long	HIGH	U. Tamponi	Ongoing
ππ transitions Υ(5S)	No	No	Yes	Medium	HIGH	R. Mizuk	
Soft ISR	suggested	No	Maybe	Short - Medium	**MEDIUM**	?	
ππ transitions Υ(4S)	Yes	No (?)	No (?)	Medium - Long	LOW (?)	?	
ππ transitions among Υ(nS)	suggested	No	**Maybe**	Medium	LOW	?	
Υ(nS) → γ ηb	Yes	Yes	Yes	Long	LOW	?	

Summary

First physics program should be

- → Complementary to Υ(4S) and Υ(5S)
- → Not demanding in terms of vertexing
- → Fruitful even with L ~ 300/fb

Υ(3S) run

- → conventional bottomonium measurements
- → invisible Υ(1S) decays
- → compatible with Υ(1,2D) scan

Υ(6S) exploratory run

- → maybe very interesting
- → should we do it with limited vertexing and/or limited PID (?)
- → Should we push KEKB at its highest energy from the beginning?

Backup

Hadronic transitions: Υ(4,5S)

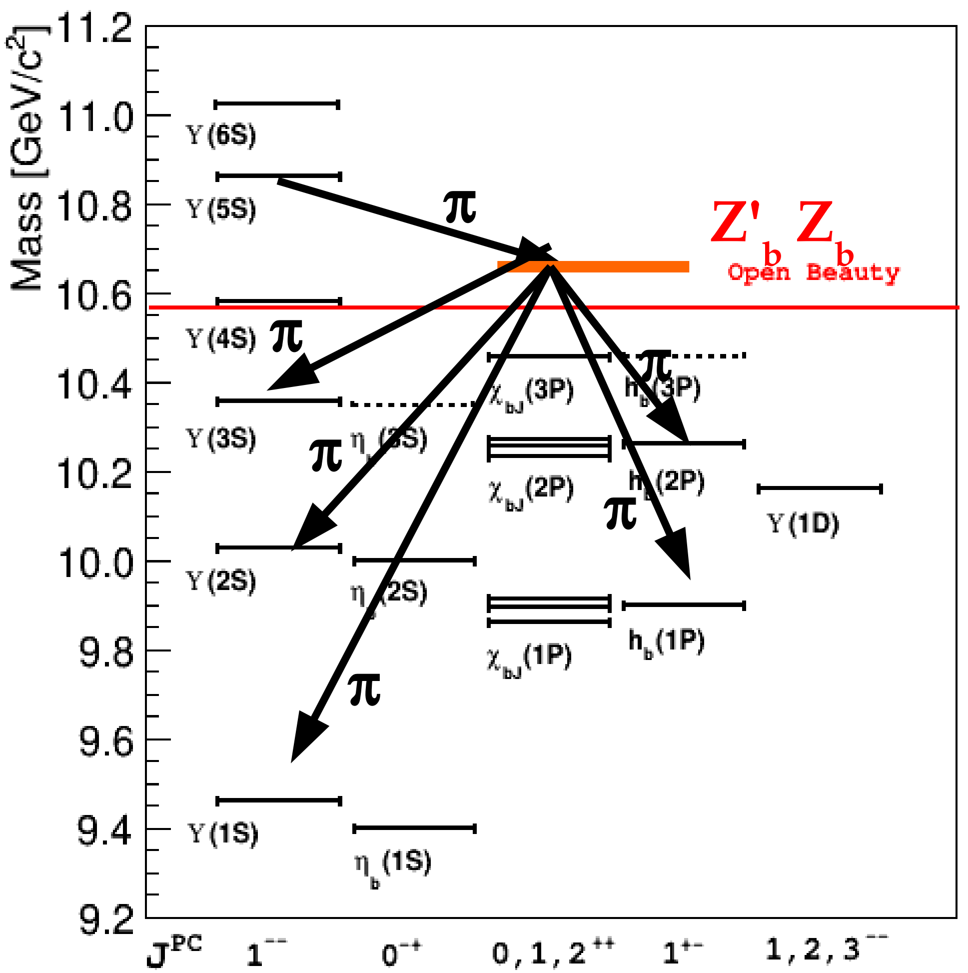
b quark spin flip

no b quark spin flip

Spin-flip prediction

$$\frac{\Gamma[Y(nS)\to\eta Y(mS)]}{\Gamma[Y(nS)\to\pi\pi Y(mS)]}\ll 1$$

$$\frac{\Gamma[Y(nS)\to\pi\pi h_b(mP)]}{\Gamma[Y(nS)\to\pi\pi Y(mS)]}\ll 1$$



Experiment

$$\frac{\Gamma[Y(5S)\to\pi\pi h_b(2P)]}{\Gamma[Y(5S)\to\pi\pi Y(2S)]}=0.77\pm0.08^{+0.22}_{-0.17}$$

$$\frac{\Gamma[Y(5S)\to\pi\pi h_b(1P)]}{\Gamma[Y(5S)\to\pi\pi Y(2S)]}=0.46\pm0.08^{+0.07}_{-0.12}$$

PRL108, 122001

No suppression

$$\frac{\Gamma[Y(5S)\to\eta Y(1S)]}{\Gamma[Y(5S)\to\pi\pi Y(1S)]}=0.16$$

$$\frac{\Gamma[Y(5S)\to\eta Y(2S)]}{\Gamma[Y(5S)\to\pi\pi Y(2S)]}=0.48$$

Belle preliminary

No suppression

$$\frac{\Gamma[Y(4S)\to\eta Y(1S)]}{\Gamma[Y(4S)\to\pi\pi Y(1S)]}=2.41\pm0.40\pm0.20$$

Spin flipping-enhanced transition

PRD 78, 112002

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

BF[Y(5S) → η Y(2S)] = (2.1 ± 0.7 ± 0.3) x 10^{-3}

BF[Y(5S) → η Y(1D)] = (2.8 ± 0.7 ± 0.4) x 10^{-3}

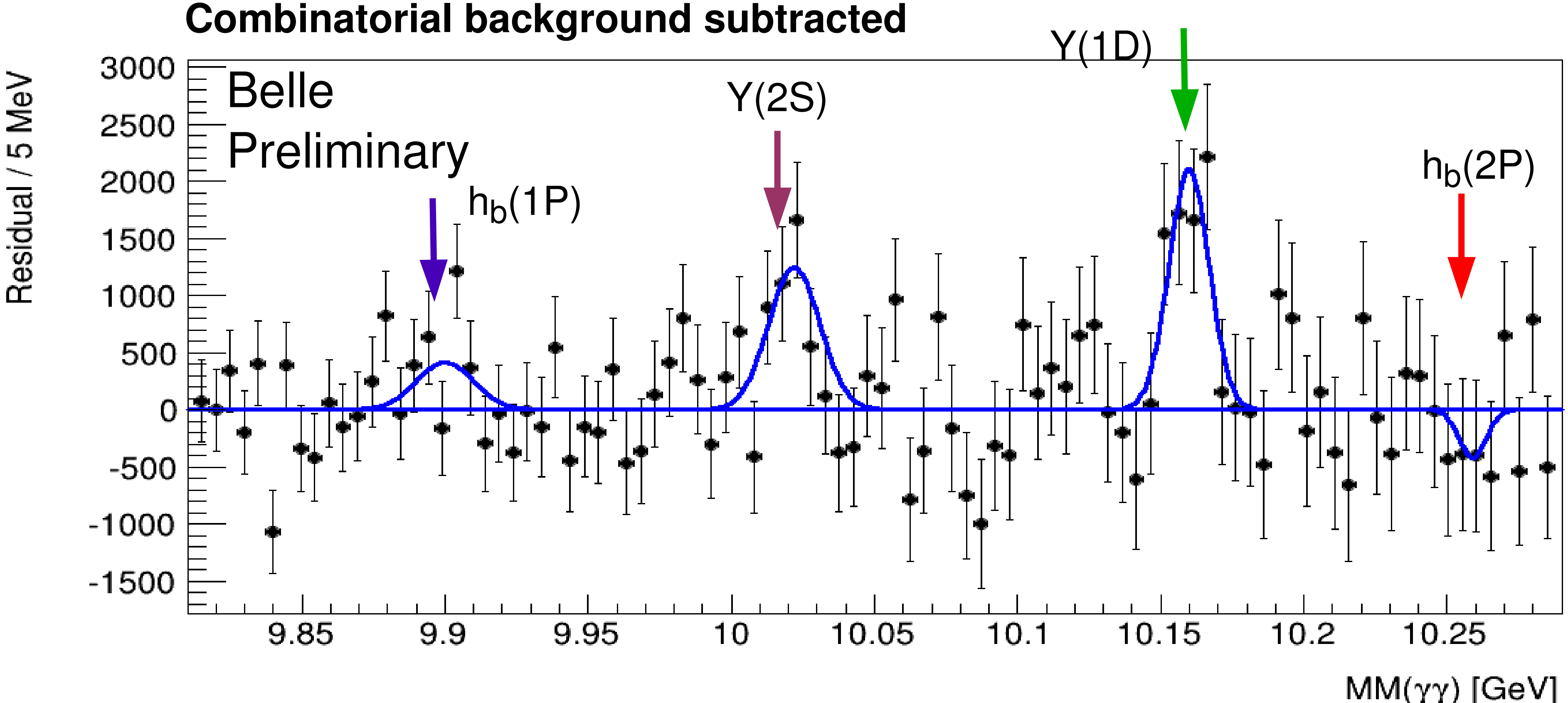
BF[Y(5S) → η hb(1P)] = < 3.3 x 10^{-3} (90% CL)

BF[Y(5S) → η hb(2P)] = < 3.7 x 10^{-3} (90% CL)

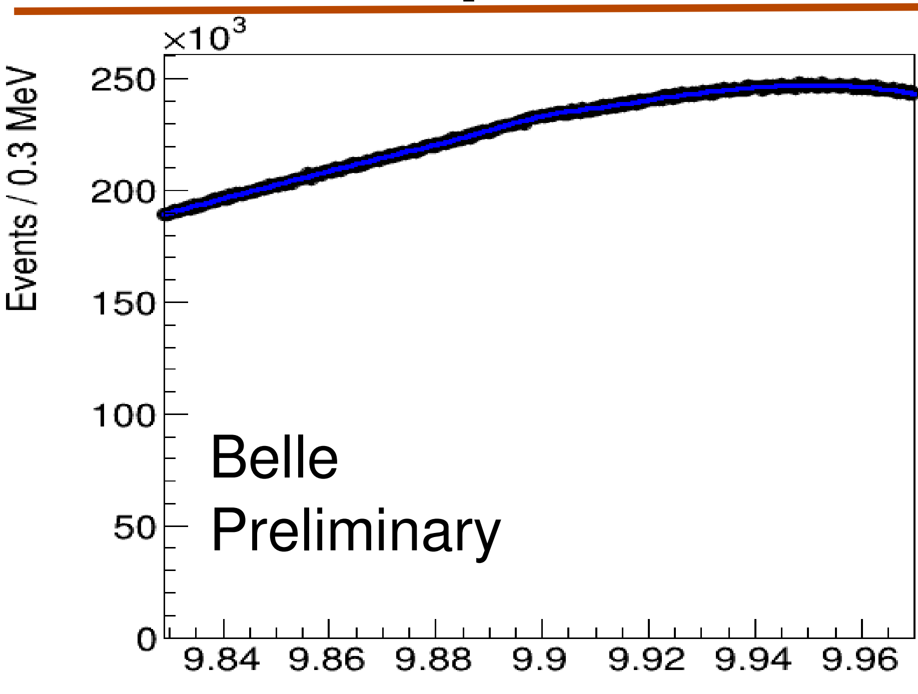
$$\frac{\Gamma[Y(5S) \to \eta h_b(1P)]}{\Gamma[Y(5S) \to \pi\pi h_b(1P)]} < 0.94$$

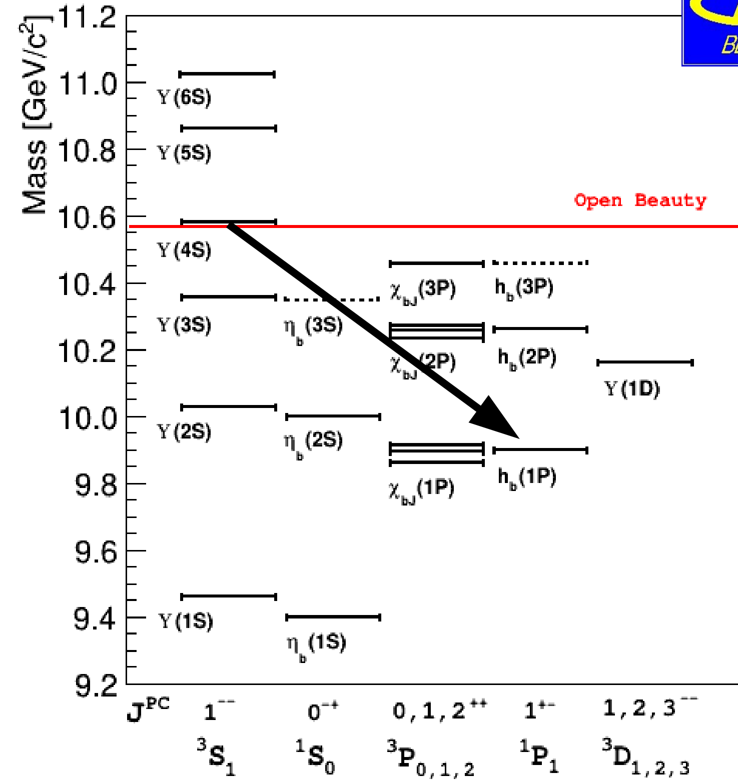
$$\frac{\Gamma[Y(5S) \to \eta h_b(2P)]}{\Gamma[Y(5S) \to \pi\pi h_b(2P)]} < 0.62$$

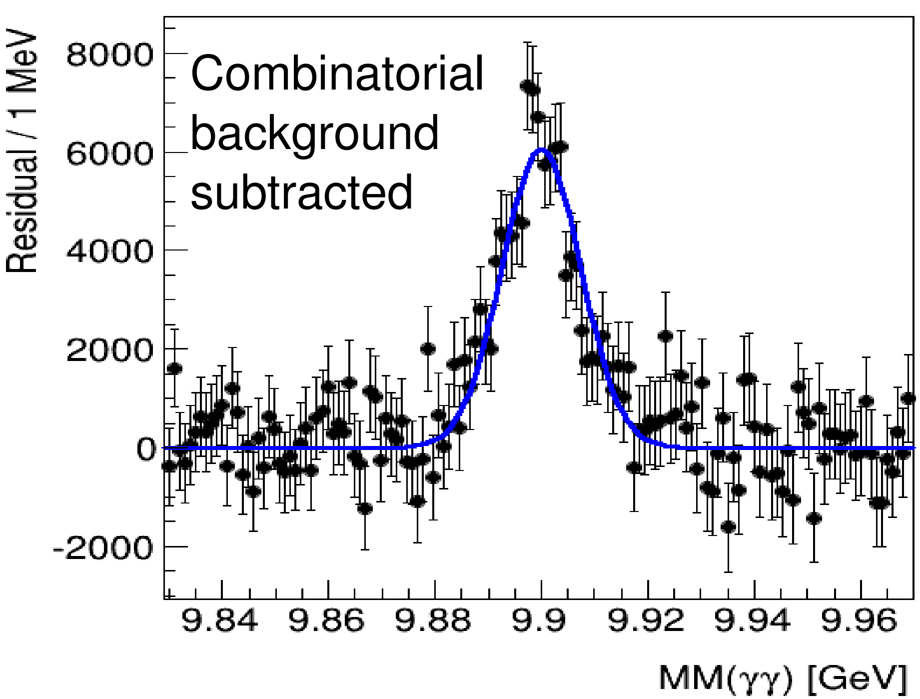
Combinatorial background subtracted



$\Upsilon(4S) \rightarrow \eta\, b\bar{b}$







First **single meson**, $^3S \rightarrow {}^1P$ transition observed with > 5 σ

BF[Υ(4S)→η hb(1P)] = (1.83 ± 0.16 ± 0.17)x10^{-3}

$\Gamma_{\eta\Upsilon(1S)}$ = 4 KeV

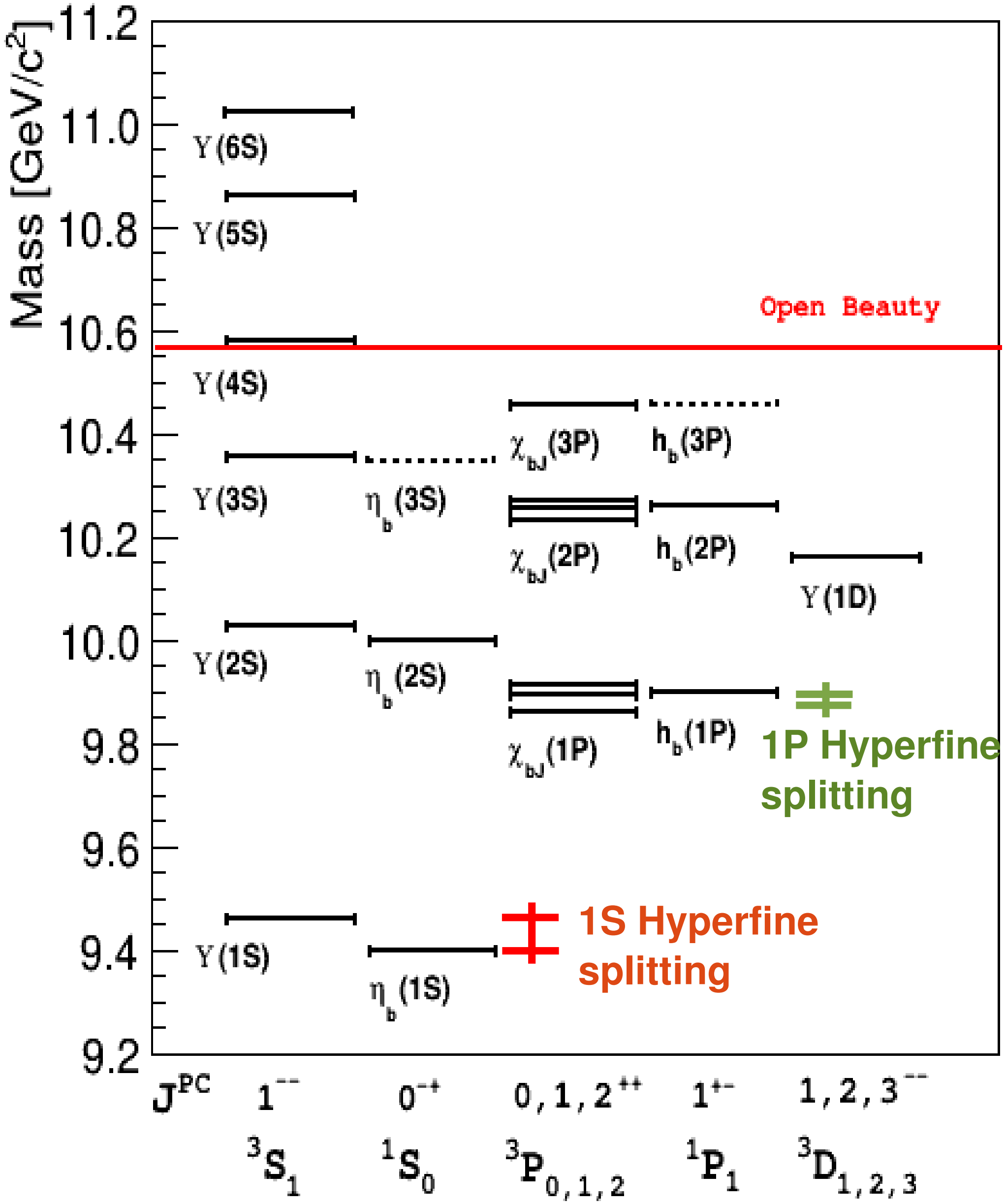
$\Gamma_{\pi\pi\Upsilon(1S)}$ = 1.7 KeV

$\Gamma_{\eta hb(1P)}$ = 37 KeV

One order of magnitude larger than any other Υ(4S) transition

Probing the spin structure

Hyperfine splitting = M(triplet) – M(singlet)



Spin interaction term:

$$V_{SS} = \frac{16\pi\alpha_s}{9m^2} \cdot \delta(\vec{r})$$

$$\Delta M_{HF} \propto |\psi(0)|^2$$

P wave → Odd ψ(r) → |ψ(0)|^2 = 0

$\Delta M_{HF}(1P) = +0.8 \pm 1.1$ MeV/c^2

$\Delta M_{HF}(2P) = +0.5 \pm 1.2$ MeV/c^2

S wave → Even ψ(r) → |ψ(0)|^2 ≠0

pNRQCD: 41± 14 MeV/c^2

Kniehl et al., PRL92,242001(2004)

Lattice: 60 ± 8 MeV/c^2

Meinel, PRD82,114502(2010)

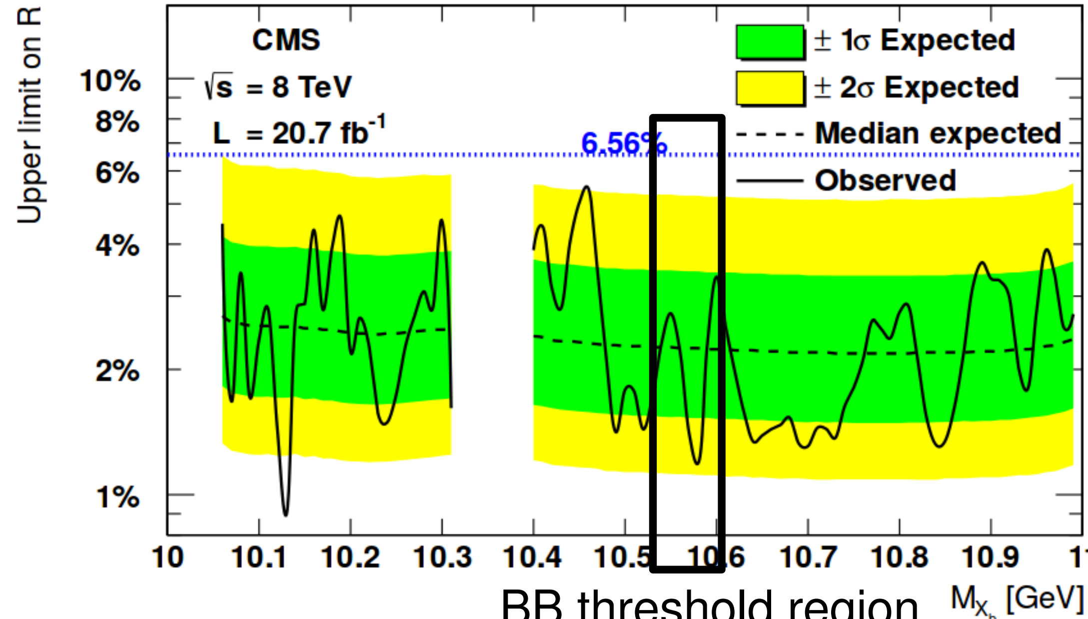
PDG '12 : 69.3 ± 2.8 MeV/c^2

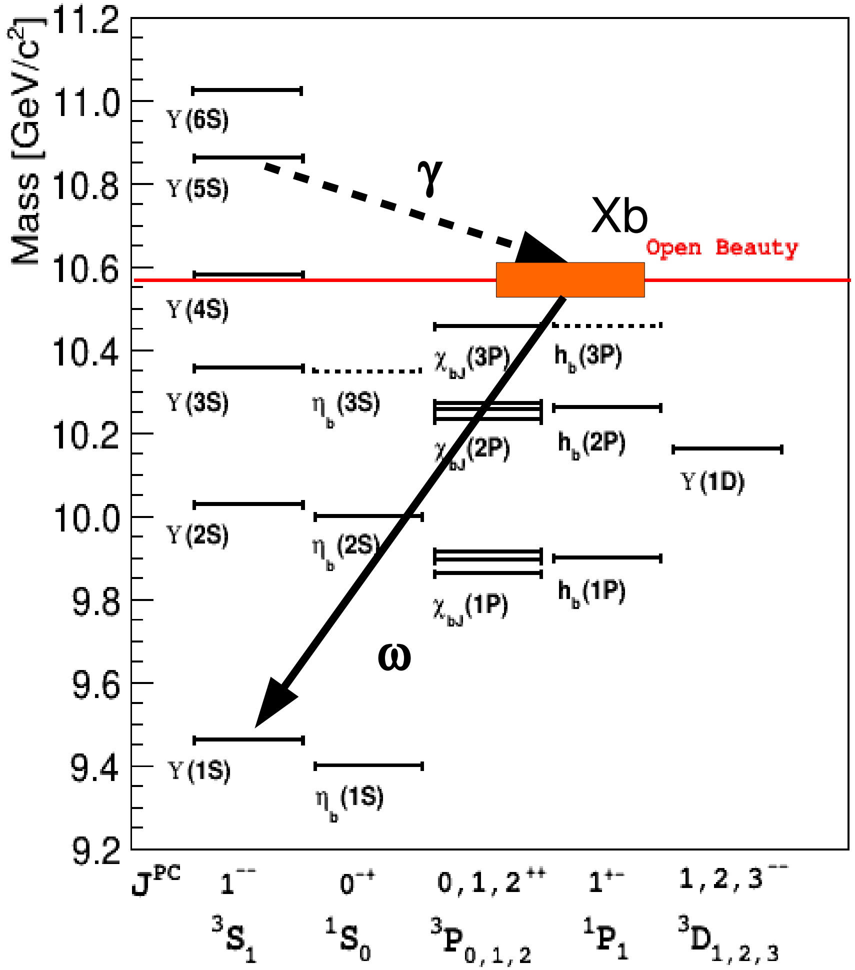
Exotics in Υ(5S) decays

Bottomonium equivalent of X(3872)

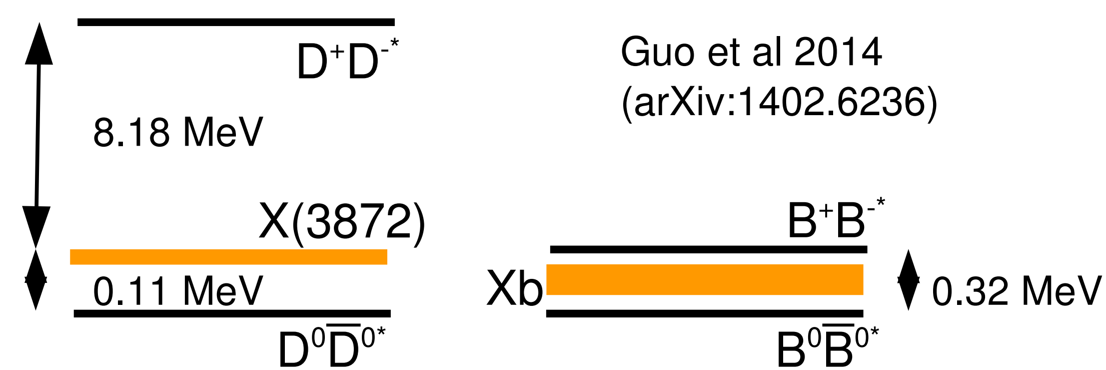
CMS: inclusive search for PLB 727 (2013) 57
Xb → ππ Υ(1S) in pp collisions

Belle: exclusive Υ(5S) decay
Υ(5S) → γ Xb → γ ω Υ(1S) arXiv:1408.0504





X(3872) is closer to $D^0\bar{D}^{0*}$ than to D^+D^{-*}
sizable isospin violation X(3872) → ππ J/ψ



Xb → ω Υ(1S)	Isospin preserving
Xb → ππ Υ(1S)	Isospin violating

Exotics in Υ(5S) decays

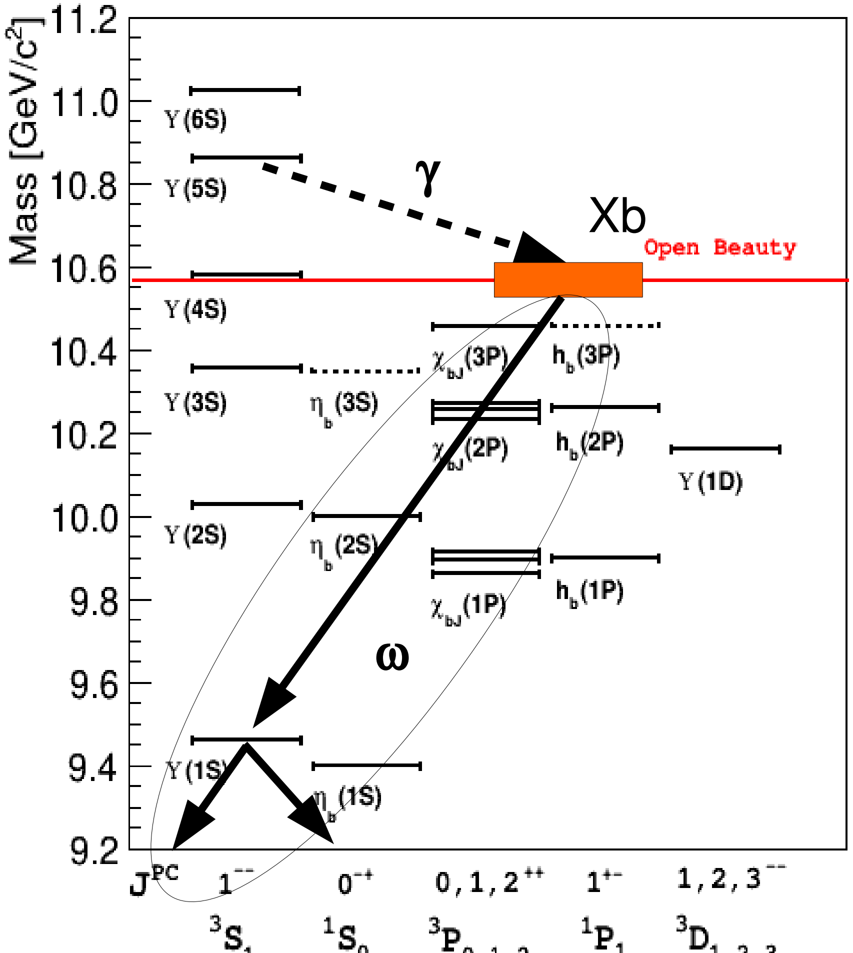
arXiv:1408.0504

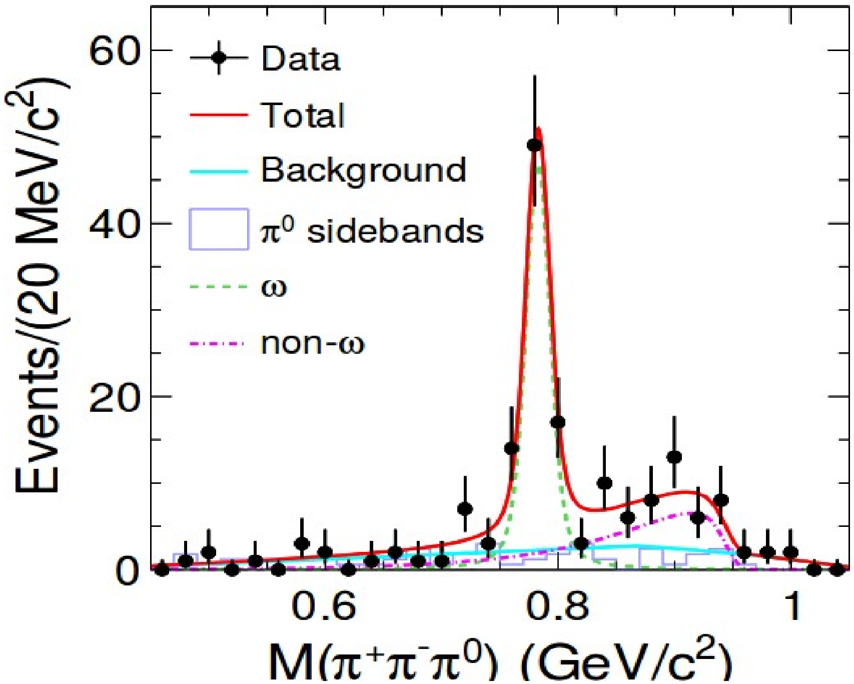
$\Upsilon(5S) \rightarrow \gamma\, X_b \rightarrow \gamma\, \omega\, \Upsilon(1S)$

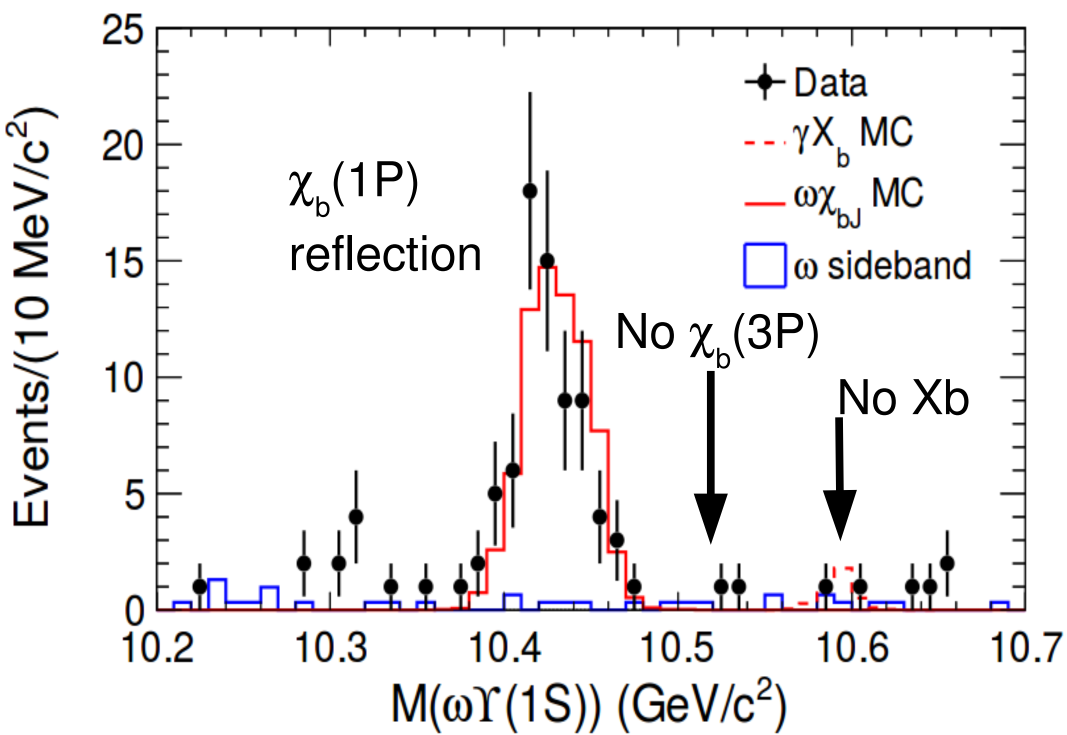
$\Upsilon(5S) \rightarrow \gamma\;\; \pi^+\pi^-\pi^0$ $\mu^+\mu^-$ (e^+e^-)

Υ(1S)

5C kinematic fit







$\Upsilon(5S) \rightarrow \omega\, \chi_b(1P)$

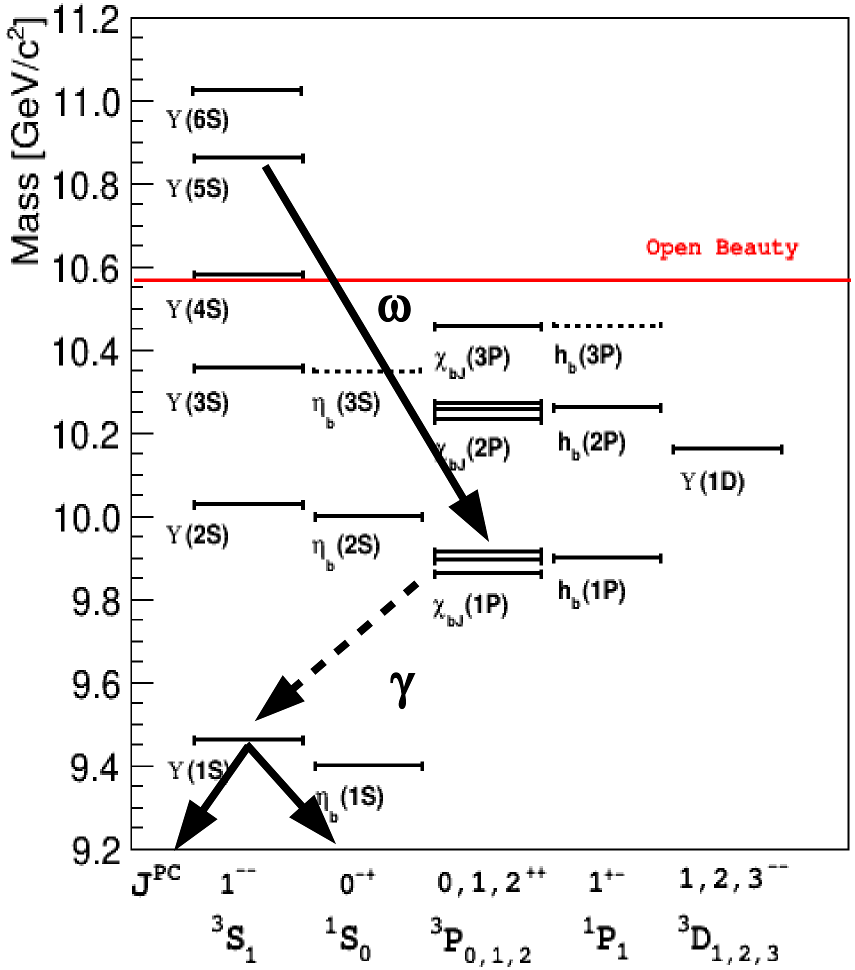
arXiv:1408.0504

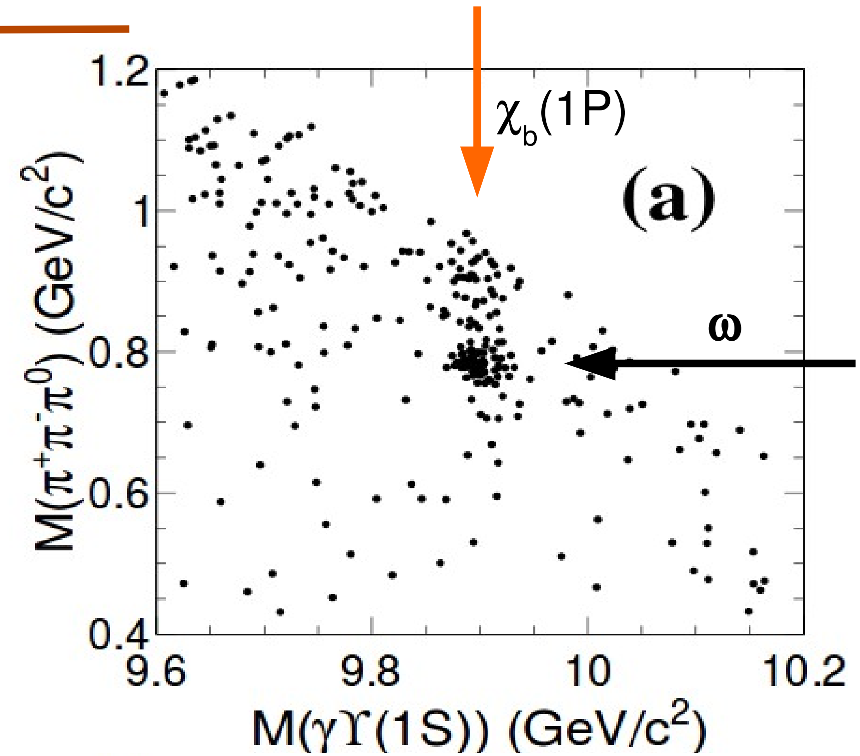
$B[\Upsilon(5S) \rightarrow \omega\, \chi_{b0}(1P)] < 3.9 \times 10^{-3}$

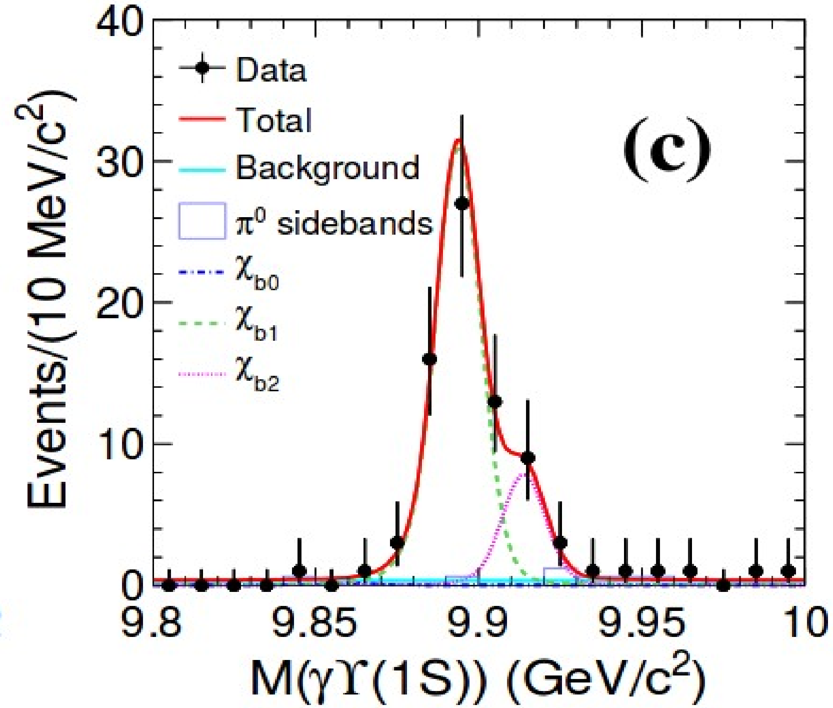
$B[\Upsilon(5S) \rightarrow \omega\, \chi_{b1}(1P)] = 1.57 \pm 0.22 \pm 0.21 \times 10^{-3}$

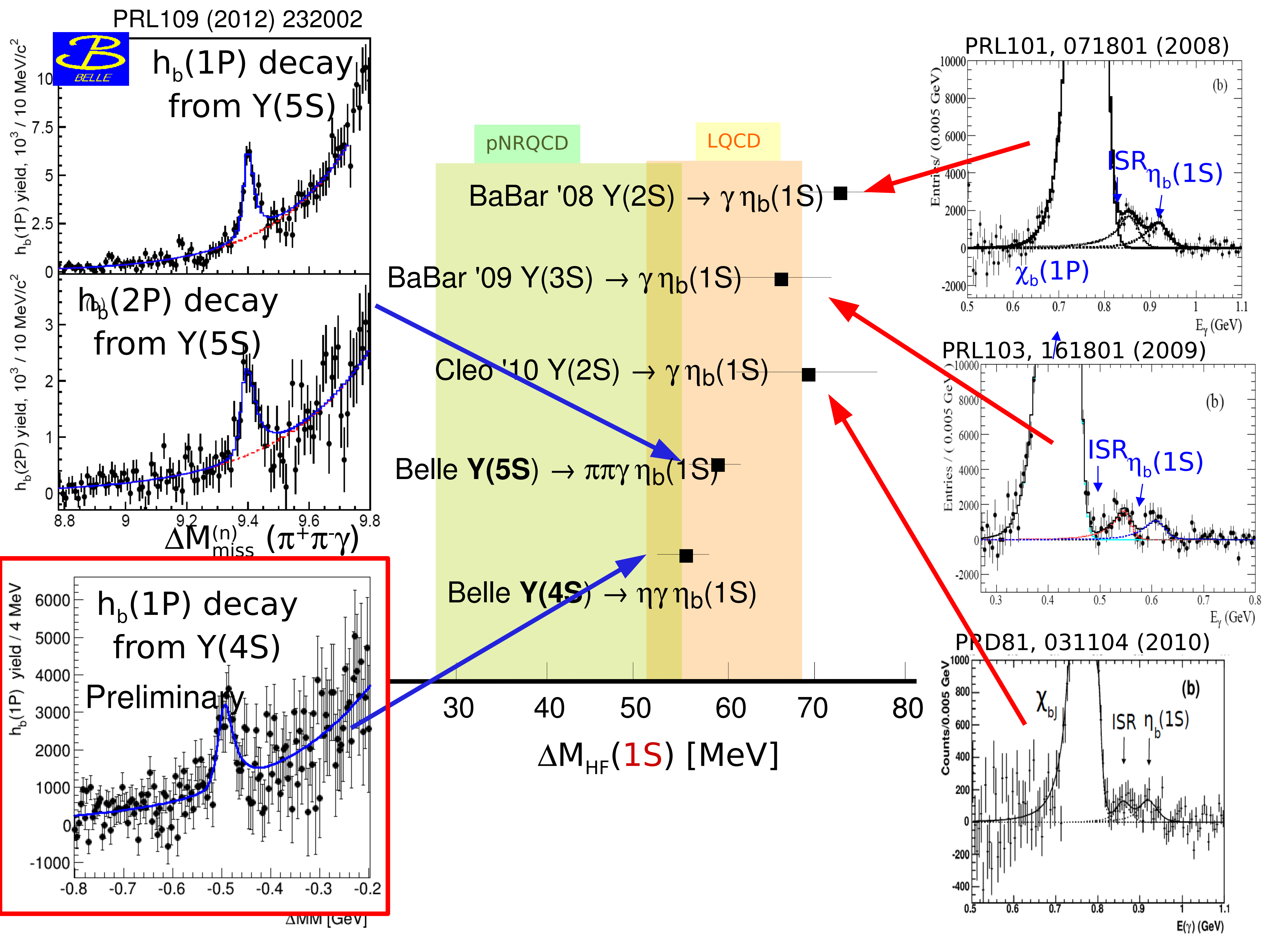
$B[\Upsilon(5S) \rightarrow \omega\, \chi_{b2}(1P)] = 0.60 \pm 0.23 \pm 0.15 \times 10^{-3}$

$B[\Upsilon(5S) \rightarrow \gamma X_b \rightarrow \gamma\omega\, \Upsilon(1S)] < 2.6 - 3.8 \times 10^{-5}$





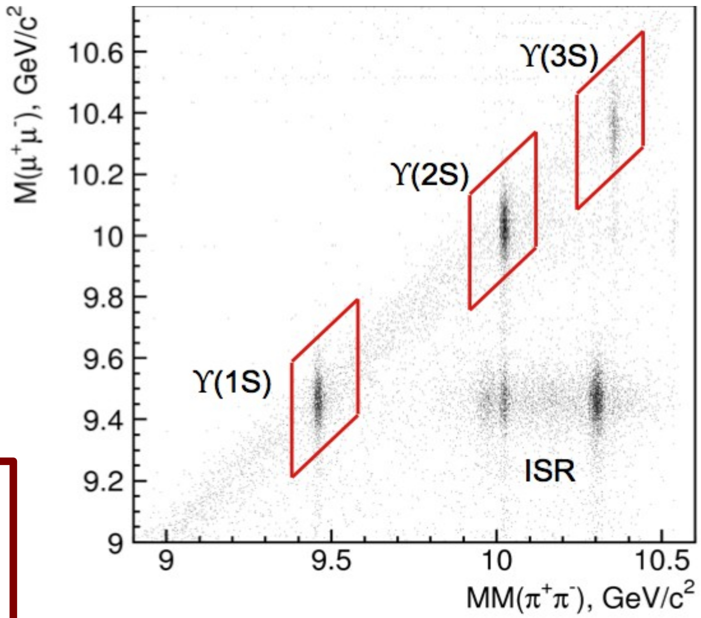


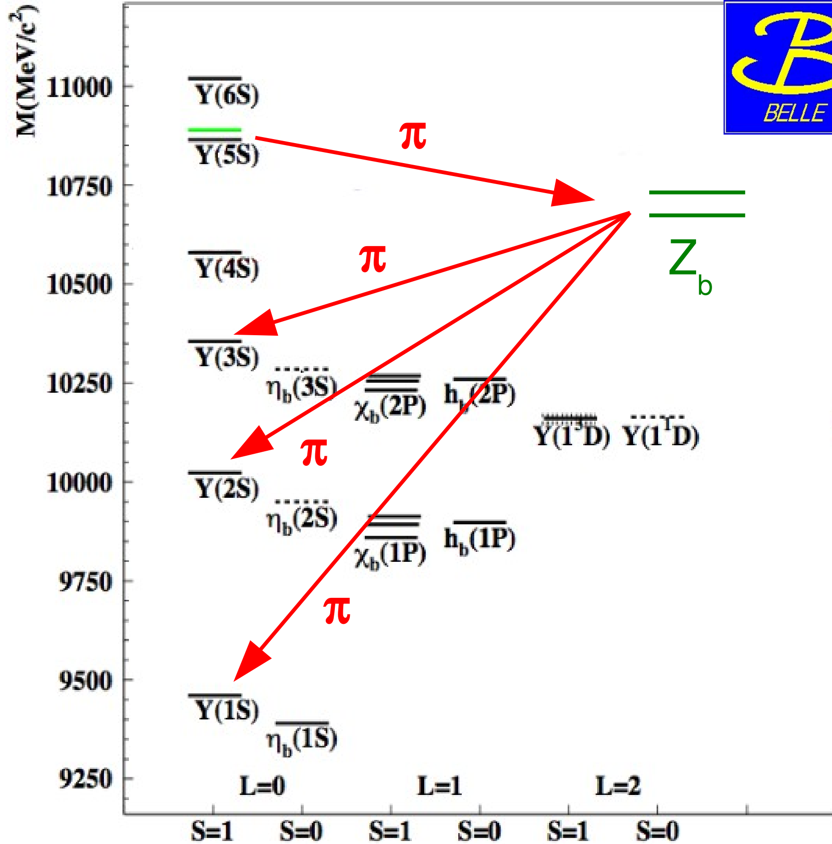


PRL109 (2012) 232002
BELLE
$h_b(1P)$ decay from Y(5S)
$h_b(2P)$ decay from Y(5S)
$\Delta M^{(n)}_{miss}(\pi^+\pi^-\gamma)$
$h_b(1P)$ decay from Y(4S)
Preliminary
pNRQCD
LQCD
BaBar '08 Y(2S) → $\gamma\eta_b(1S)$
BaBar '09 Y(3S) → $\gamma\eta_b(1S)$
Cleo '10 Y(2S) → $\gamma\eta_b(1S)$
Belle **Y(5S)** → $\pi\pi\gamma\eta_b(1S)$
Belle **Y(4S)** → $\eta\gamma\eta_b(1S)$
$\Delta M_{HF}(1S)$ [MeV]
PRL101, 071801 (2008)
PRL103, 161801 (2009)
PRD81, 031104 (2010)
ISR
$\eta_b(1S)$
$\chi_b(1P)$
χ_{bJ}

Z_b in Y(nS) final states

PRL108,122001

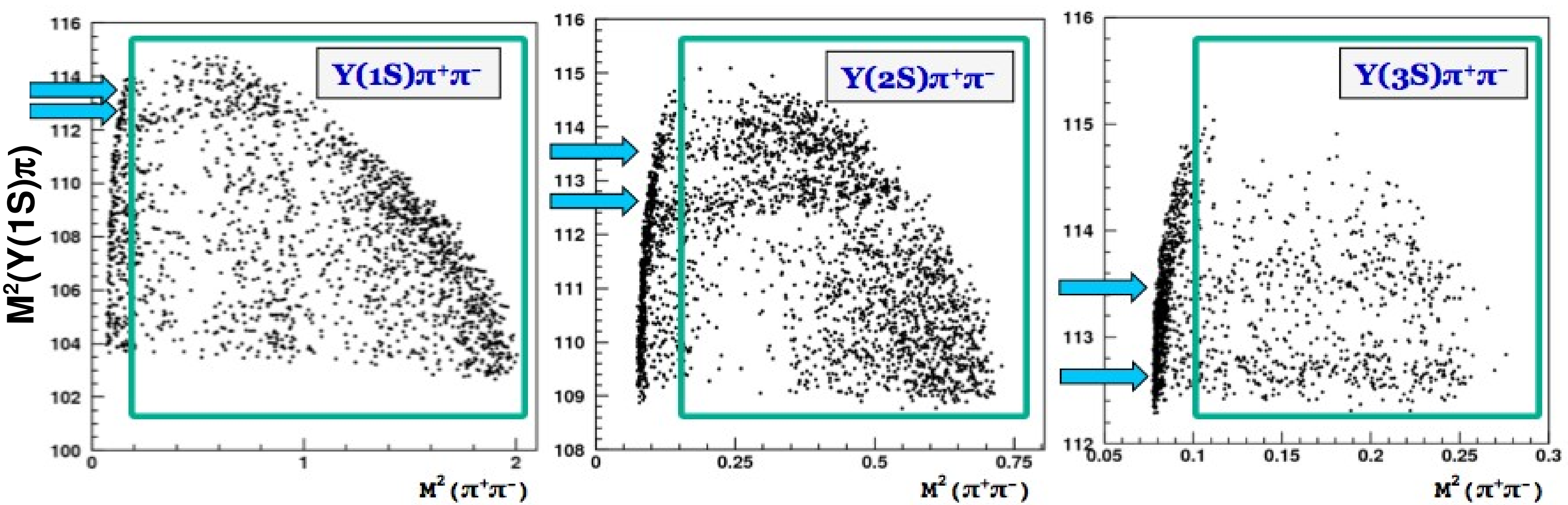




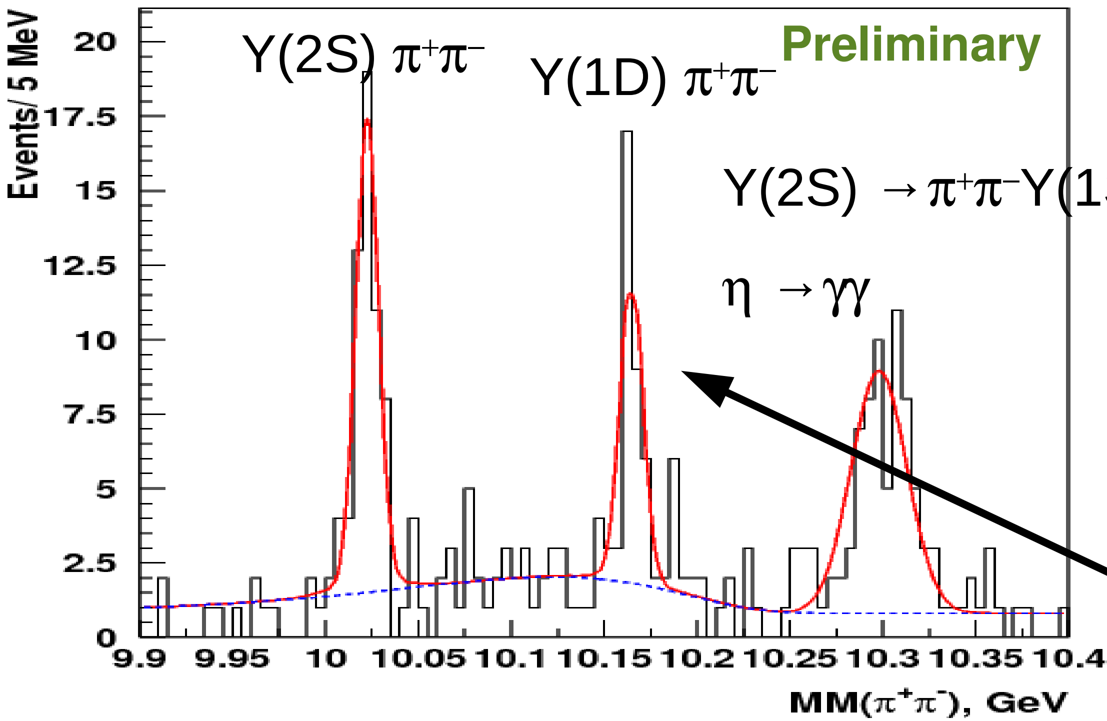
Y(nS) → $\mu^+\mu^-$

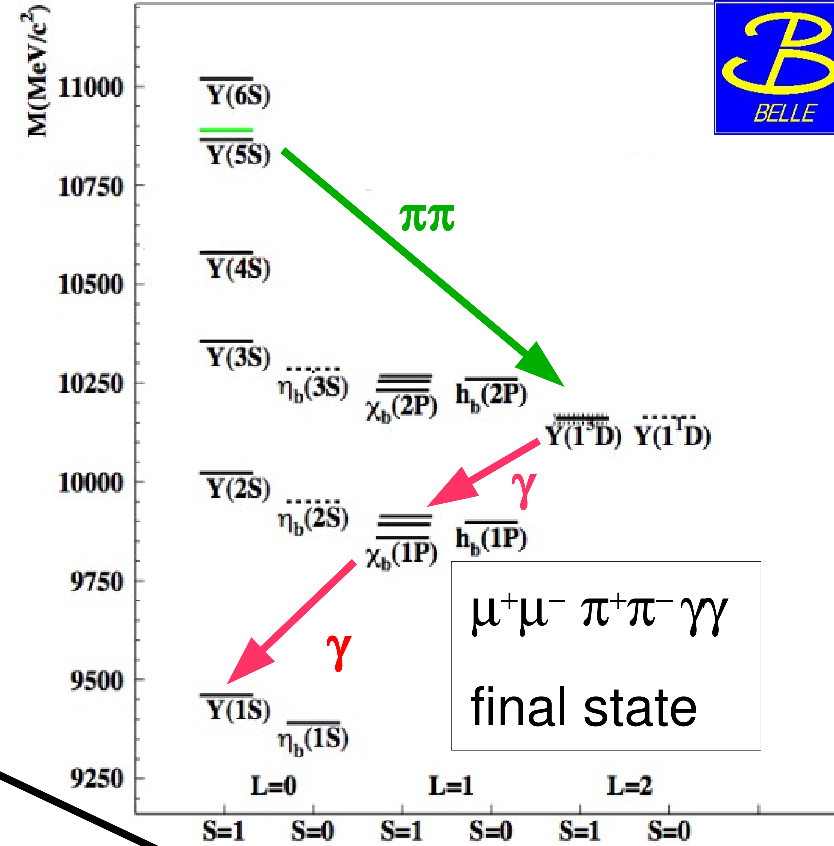
- Clean final state
- Pure Y(nS) sample
- $\pi^+\pi^-$ recoil tag

3 other observation of Z_b's !



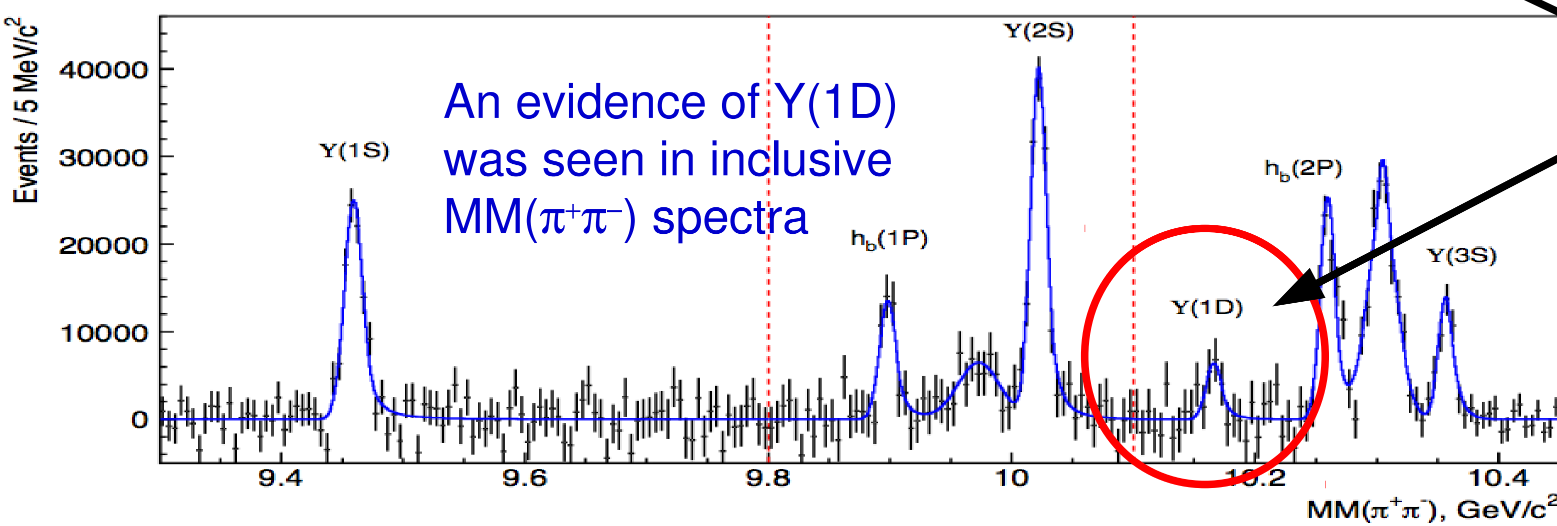
$\Upsilon(5S) \to \Upsilon(1D)\pi^+\pi^-$





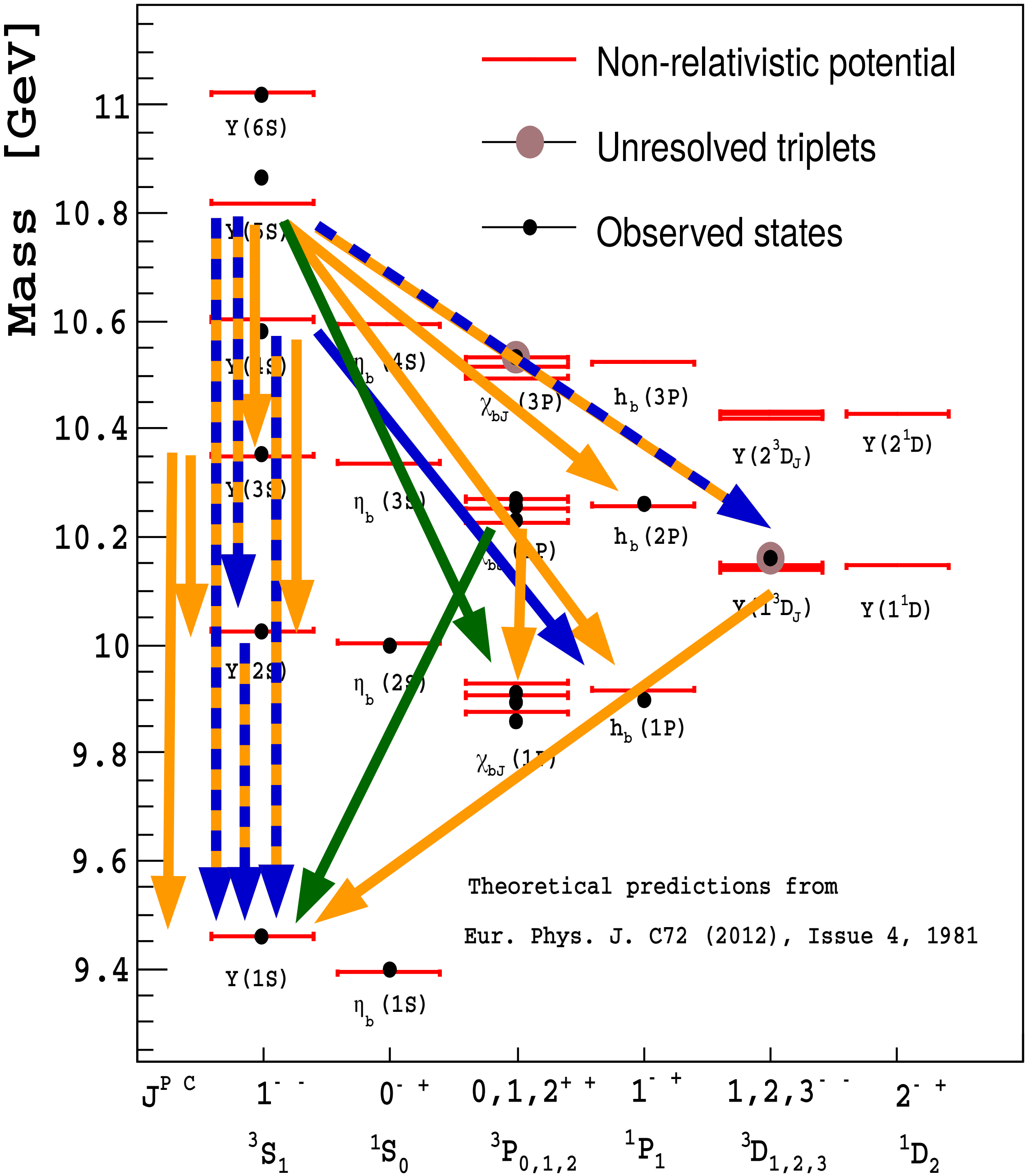
Significance 9 σ

Significance 2.9σ



$B[\Upsilon(5S)\to\Upsilon(1D)\pi^+\pi^-]\ B[\Upsilon(1D)\to\chi_b(1P)\gamma \to \Upsilon(1S)\gamma\gamma] = (2.0\pm0.4\pm0.3)\ 10^{-4}$

Missing hadronic transitions



What we have measured:

Υ(5S) → η/ππ Υ(1S)
Υ(5S) → η/ππ Υ(2S)
Υ(5S) → ππ Υ(3S)
Υ(5S) → ππ hb(1P)
Υ(5S) → ππ hb(2P)
Υ(5S) → η/ππ Υ(^{3}1D)
Υ(5S) → ω χ_b(1P)

Υ(4S) → η/ππ Υ(1S)
Υ(4S) → ππ Υ(2S)
Υ(4S) → η hb(1P)

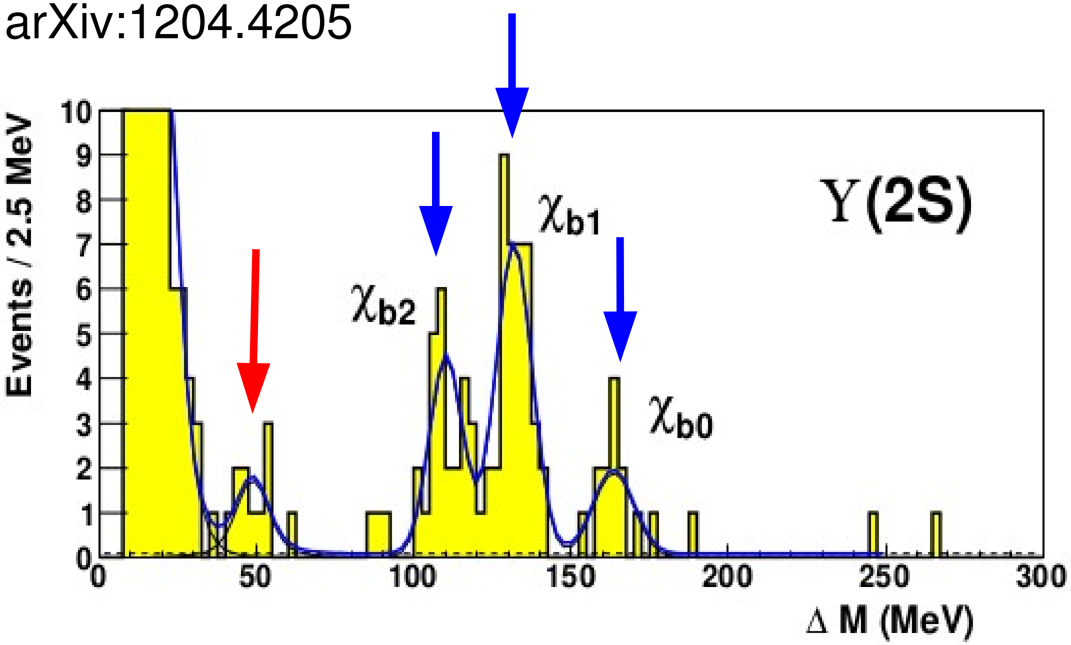
χ_b(2P) → ππ χ_b(1P)
χ_b(2P) → ω Υ(1S)

Υ(2S) → η/ππ Υ(1S)
Υ(3S) → ππ Υ(1S)
Υ(3S) → ππ Υ(2S)
Υ(1D) → ππ Υ(1S)

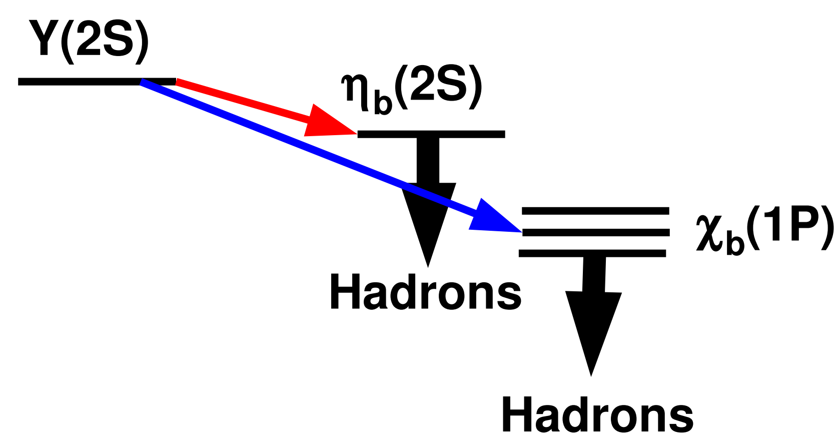
Only Triplet → Triplet/Singlet

$\eta_b(2S)$ claim

arXiv:1204.4205



Dobbs et. Al analyzed the data from CLEO-III searching for **Υ(2S)-> γ ($b\bar{b}$)** with exlcusive reconstruction of ($b\bar{b}$) → X in **26 different hadronic modes**



Belle: **$\Delta M_{HF}(2S) = 23.4^{+4.0}_{-4.5}$ MeV**

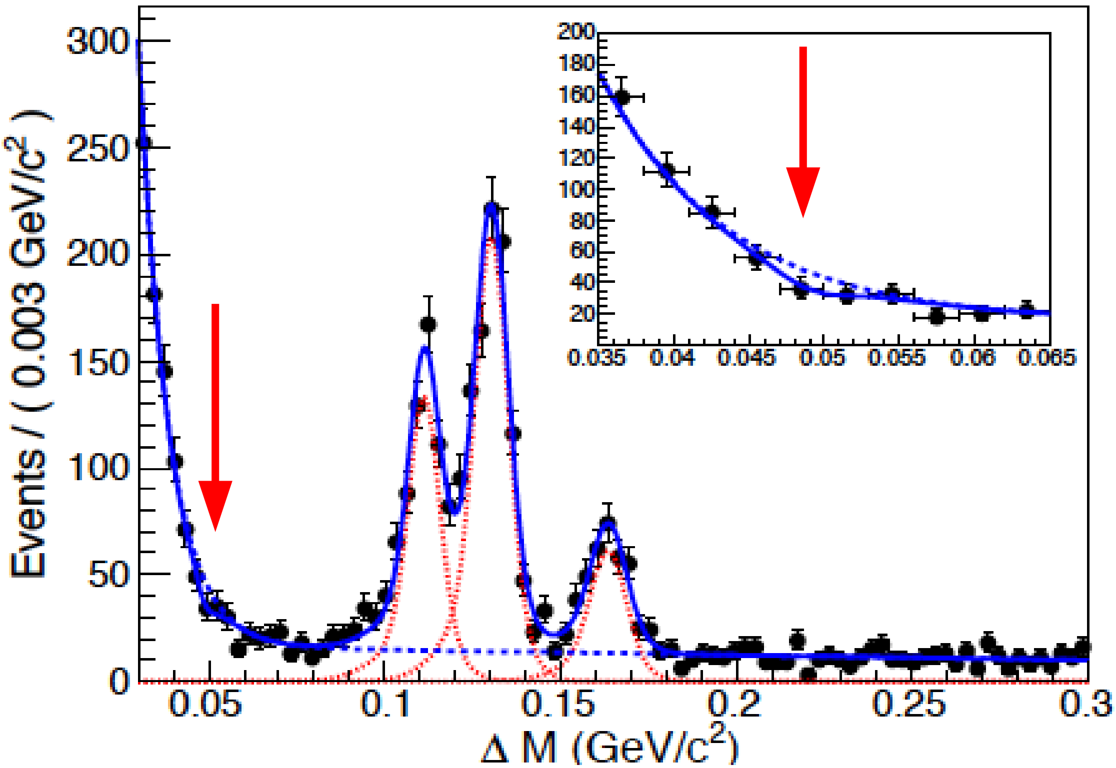
Dobbs et al.: **$\Delta M_{HF}(2S) = 48.7$ MeV**

	N	$\Delta M_{\rm hf}$ (MeV)	M (MeV)	$\chi^2/d.o.f.$	signif. (σ)	$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^6$
$\eta_b(2S)$	$11.4^{+4.3}_{-3.5}$	$48.7 \pm 2.3 \pm 2.1$	$9974.6 \pm 2.3 \pm 2.1$	$91.8/103$	4.9	$46.2^{+29.7}_{-14.2} \pm 10.6$
$\eta_b(1S)$	$10.3^{+4.9}_{-4.1}$	$67.1 \pm 3.4 \pm 2.3$	$9393.2 \pm 3.4 \pm 2.3$	$114.6/107$	3.1	$30.1^{+33.5}_{-7.4} \pm 7.5$

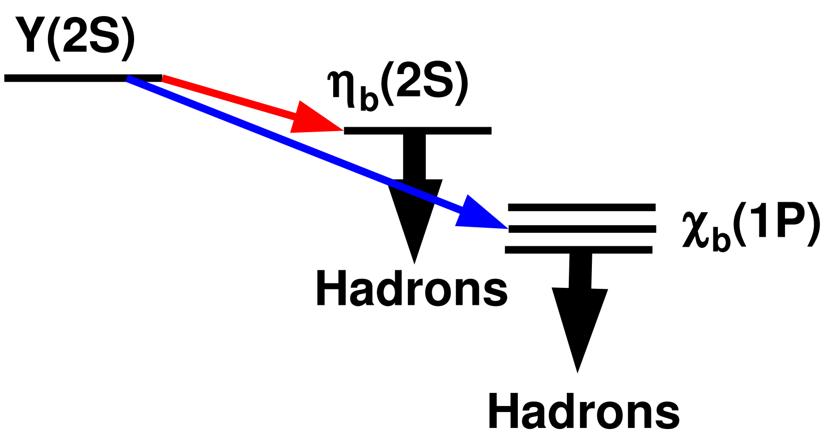
BF[Υ(2S) → $\gamma\eta_b$(2S)] x BF[$\gamma\eta_b$(2S) → hadrons] = **$(46.2^{+29.2}_{-14.2} \pm 10.6) \times 10^{-6}$**

Exclusive $\eta_b(2S)$ at Belle

arXiv:1306.6212



Identical reconstruction modes



25 fb^{-1} at Υ(2S) energy
(158 M Υ(2S) decays, **16x CLEO)**

87 fb^{-1} below Υ(4S) energy
for the study of the contiuum background study

η_b(2S) claim by Dobbs et Al. is disconfirmed by Belle.

BF[Υ(2S) → $\gamma\eta_b$(2S)] x BF[$\gamma\eta_b$(2S) → had] < 4.9 x 10^{-6}

~ one order of magnitude below the claim by Dobbs et at