Recent bottomonium results from Belle

Umberto Tamponi
tamponi@to.infn.it

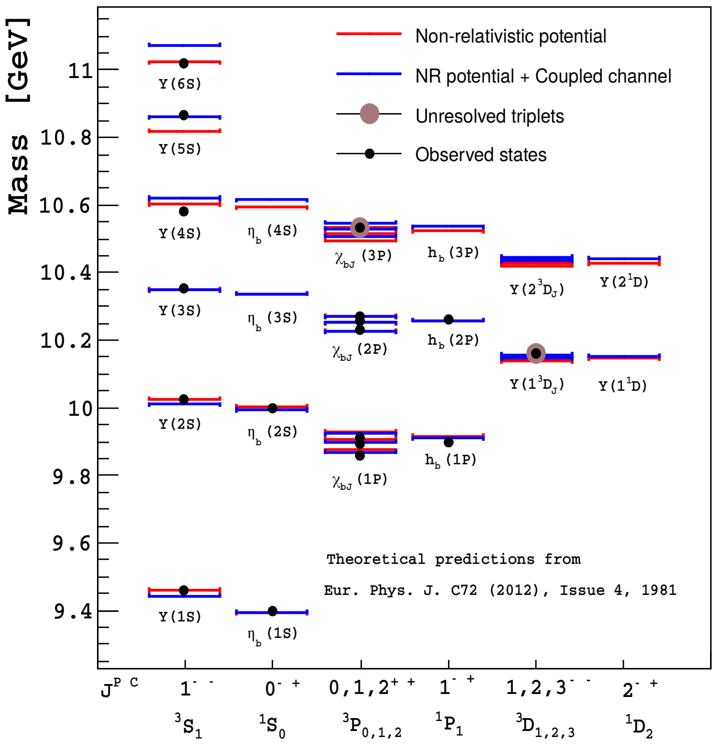
INFN, Sezione di Torino
University of Torino

Quark Confinement and the Hadron Spectrum XI
St. Petersburg, 09/09/2014

Outline

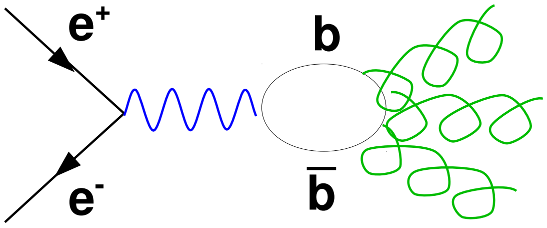
Spectrum and transitions

$\Upsilon(5S) \to \eta\, b\bar{b}$
$\Upsilon(4S) \to \eta\, h_b(1P)$ **first observation**
$\eta_b(1S)$ mass and 1S hyperfine splitting
$\Upsilon(5S) \to \omega\, \chi_b(1P)$ **first observation**
Search for $X_b \to \omega\, \Upsilon(1S)$



Annihilations

$\Upsilon(1,2S) \to (c\bar{c})(c\bar{c})$ **first evidence**
Search for H^0 dibaryon

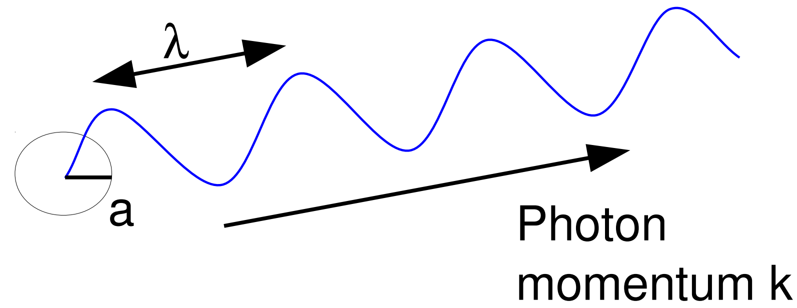


Hadronic transitions: lower states

Kuang, Front.Phys.China 1, 19 (2006)

QED multipole expansion term:

$a/\lambda \sim ak < 1$

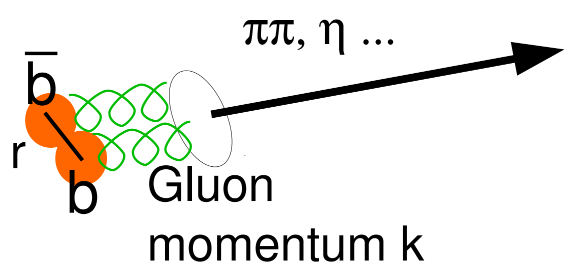


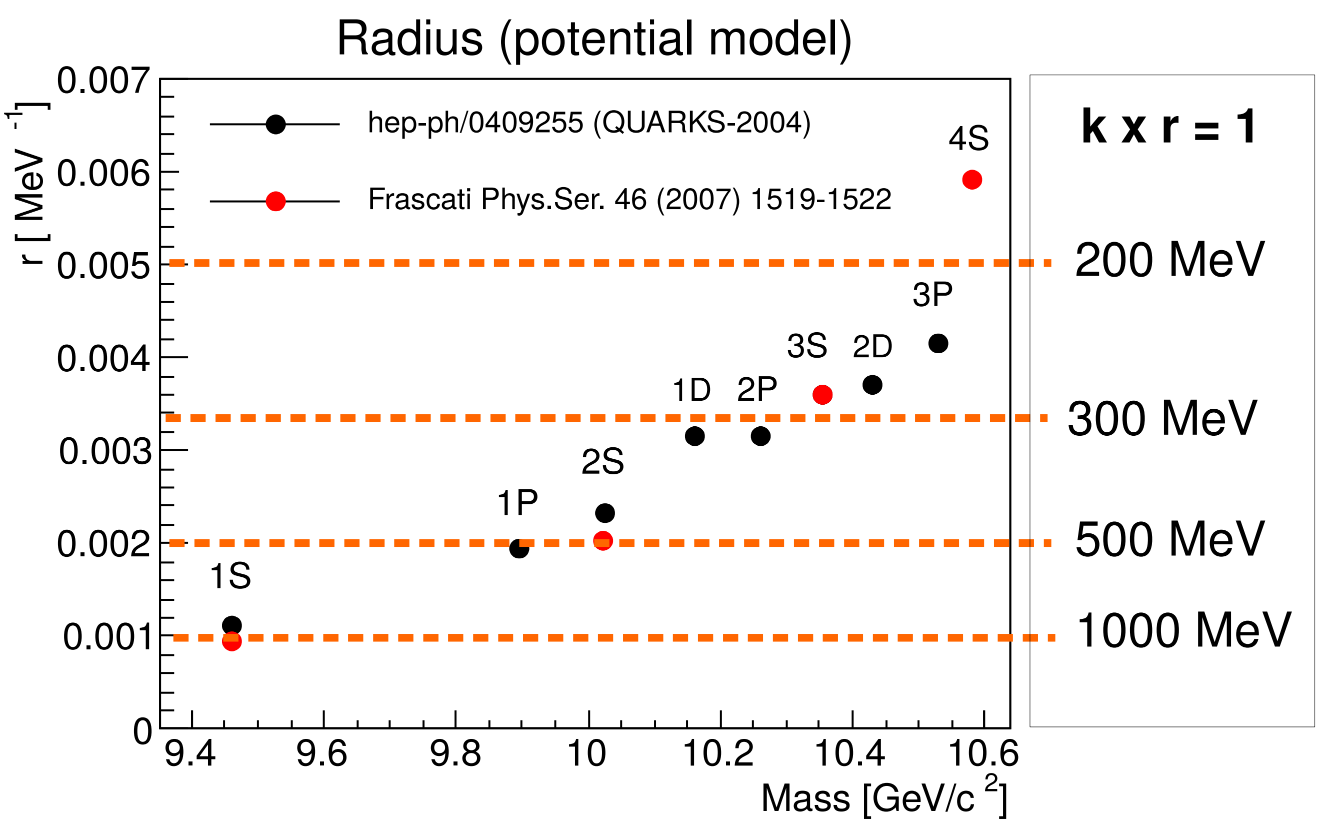
In quarkonia:

r ~ 0.1 fm

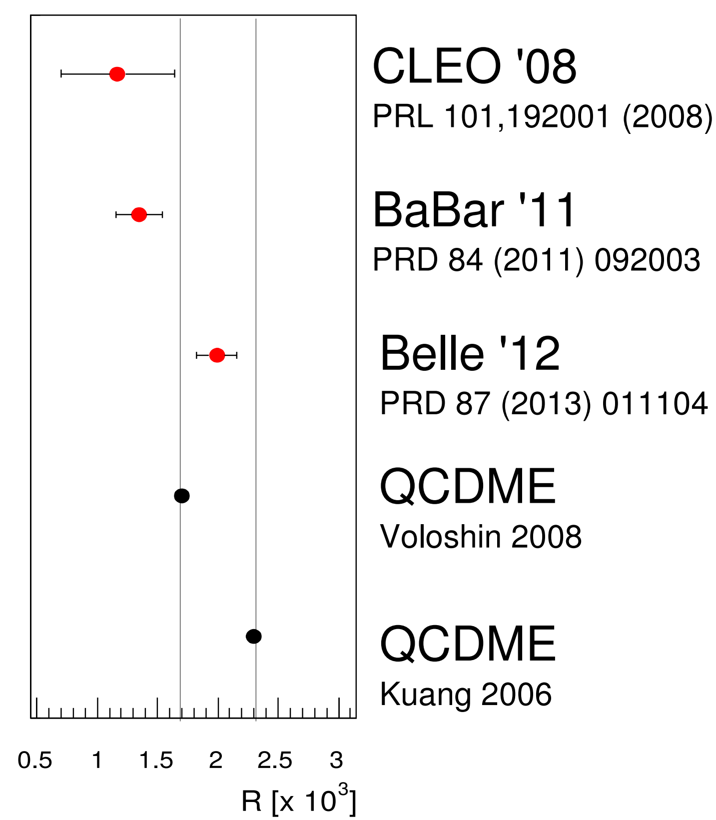
k ~ 100 MeV

rk < 1





$$\frac{B[Y(2S)\to\eta Y(1S)]}{B[Y(2S)\to\pi\pi Y(1S)]}$$



Hadronic transitions: Υ(5S)

BELLE

Spin-flip prediction

b quark spin flip

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

no b quark spin flip

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

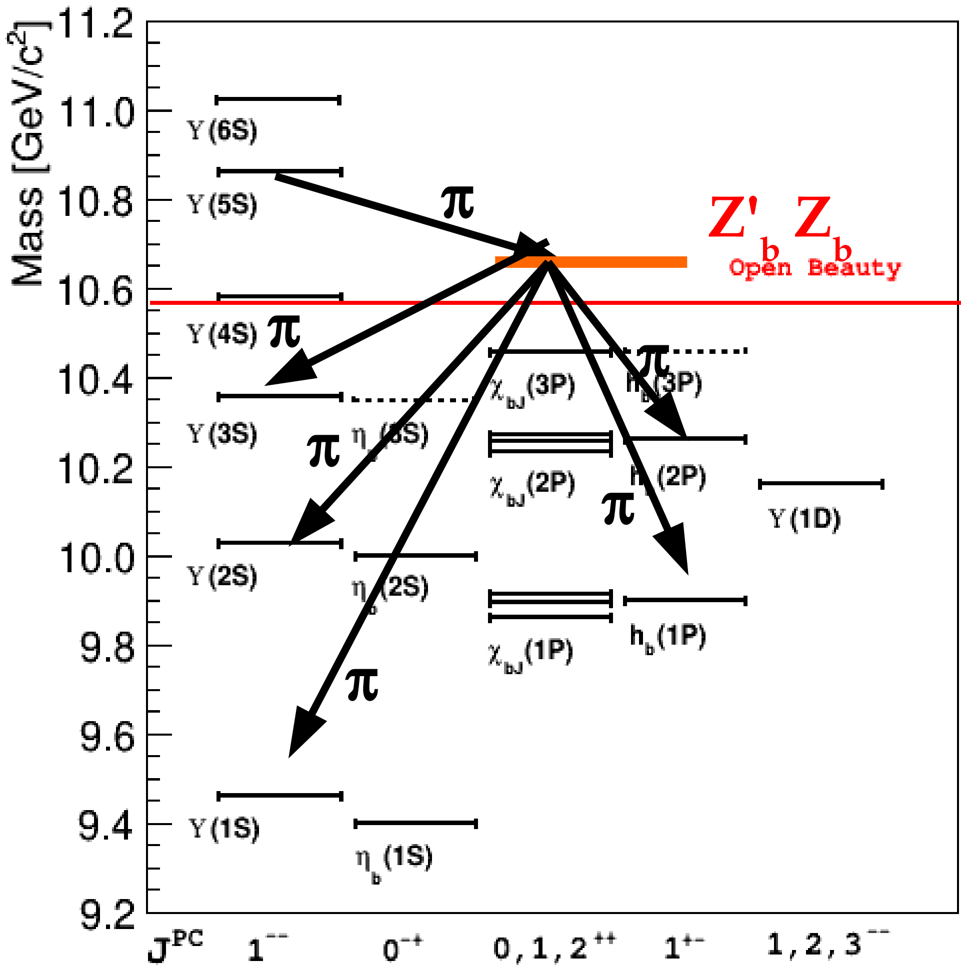
Experiment

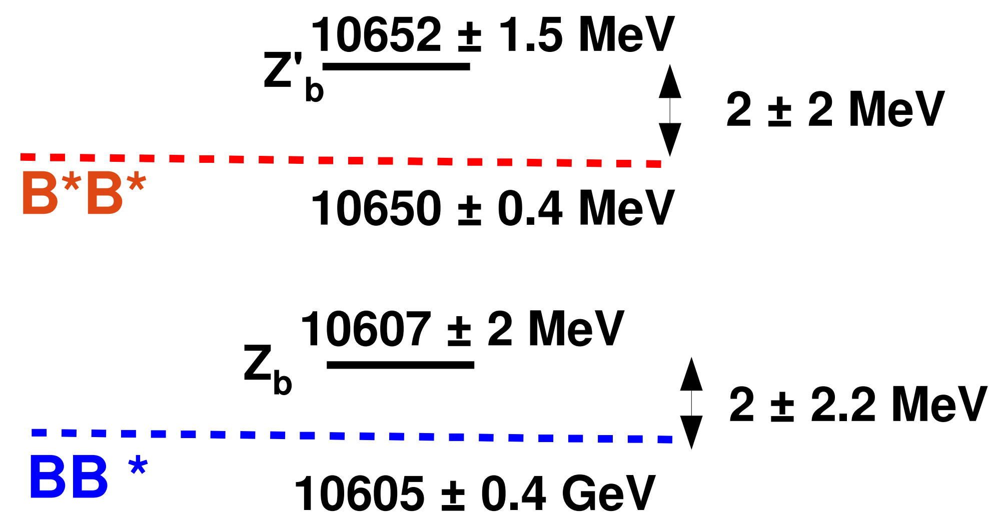
$$\frac{\Gamma[\Upsilon(5S)\to\pi\pi\,h_b(2P)]}{\Gamma[\Upsilon(5S)\to\pi\pi\,\Upsilon(2S)]}=0.77\pm0.08^{+0.22}_{-0.17}$$

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

PRL108, 122001

No suppression





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

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

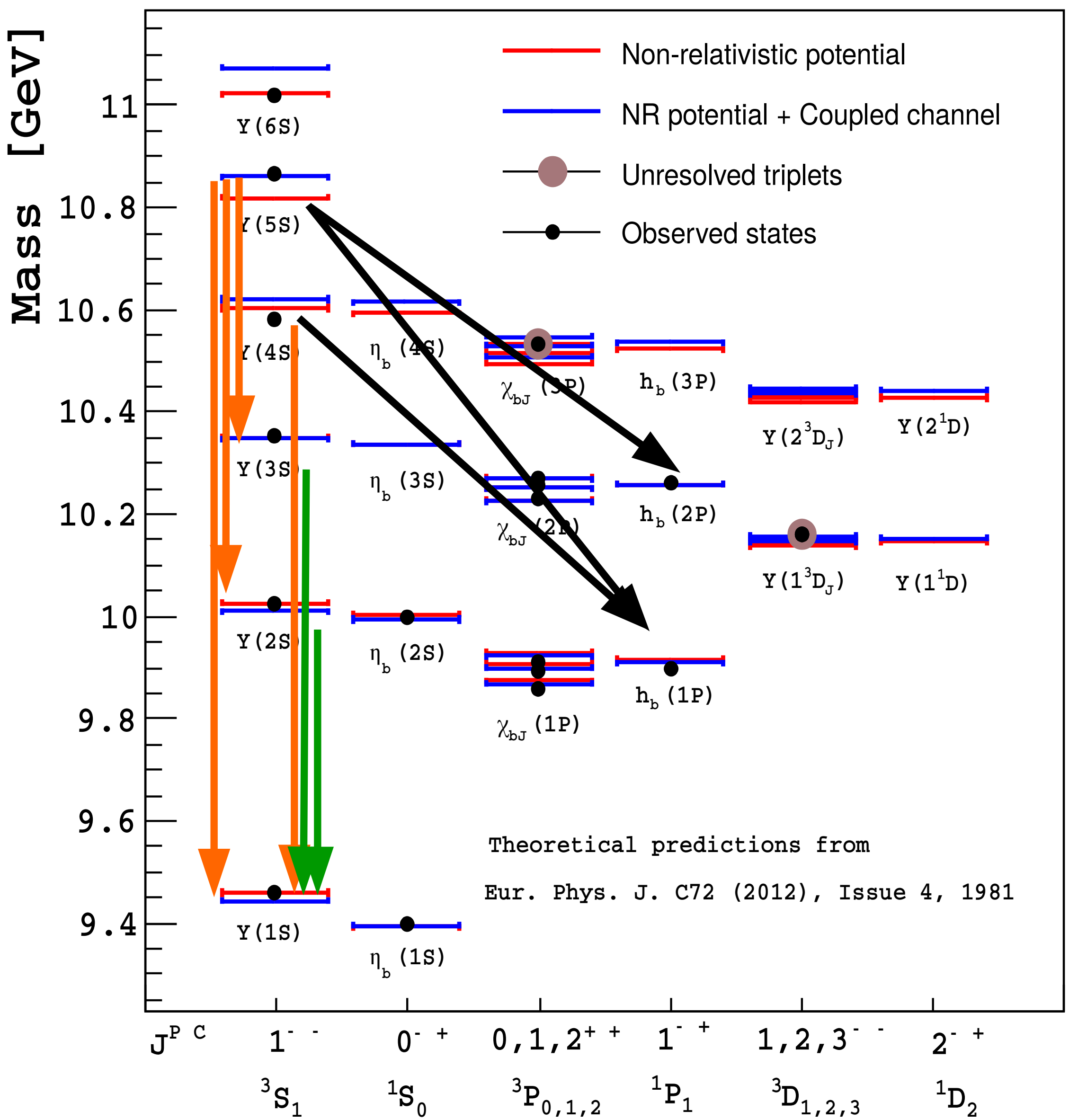
Belle preliminary

No suppression

Hadronic transitions: Υ(4S)

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

Spin flipping-enhanced transition PRD 78, 112002



- Spin-flipping suppressed
- Spin-flipping non suppressed
- Missing information

Light quark dynamics is not negligible **in both transitions and spectra**

Light quark dynamics dominates over spin symmetry effects

Υ(4S) → ηh_b(1P)

Predicted as large as 10^{-3}

Guo, PRL 105 (2010) 162001

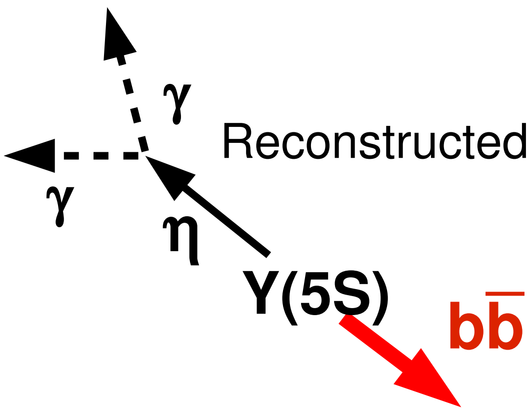
Υ(5S) → ηh_b(1P)

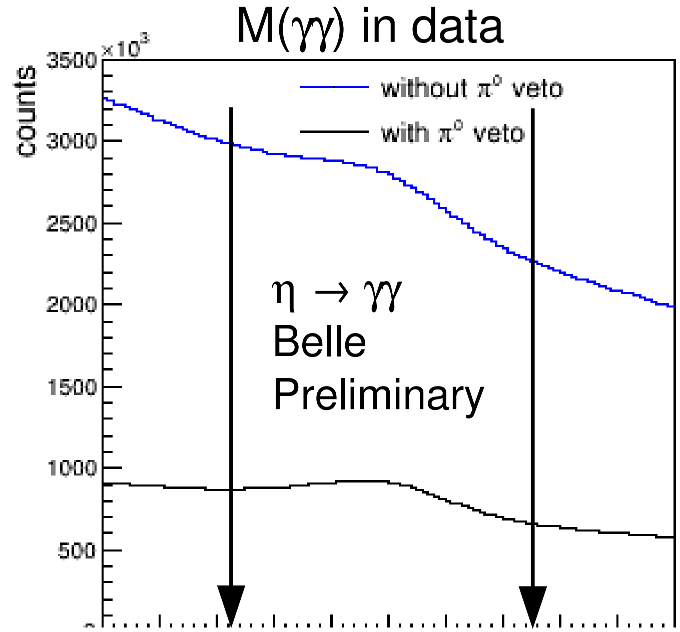
Υ(5S) → ηh_b(2P)

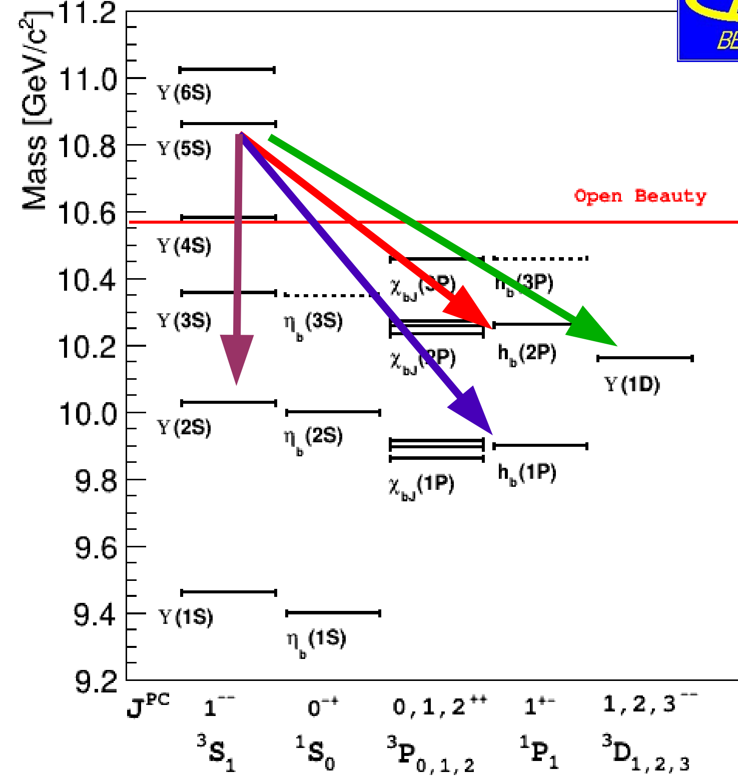
No predictions

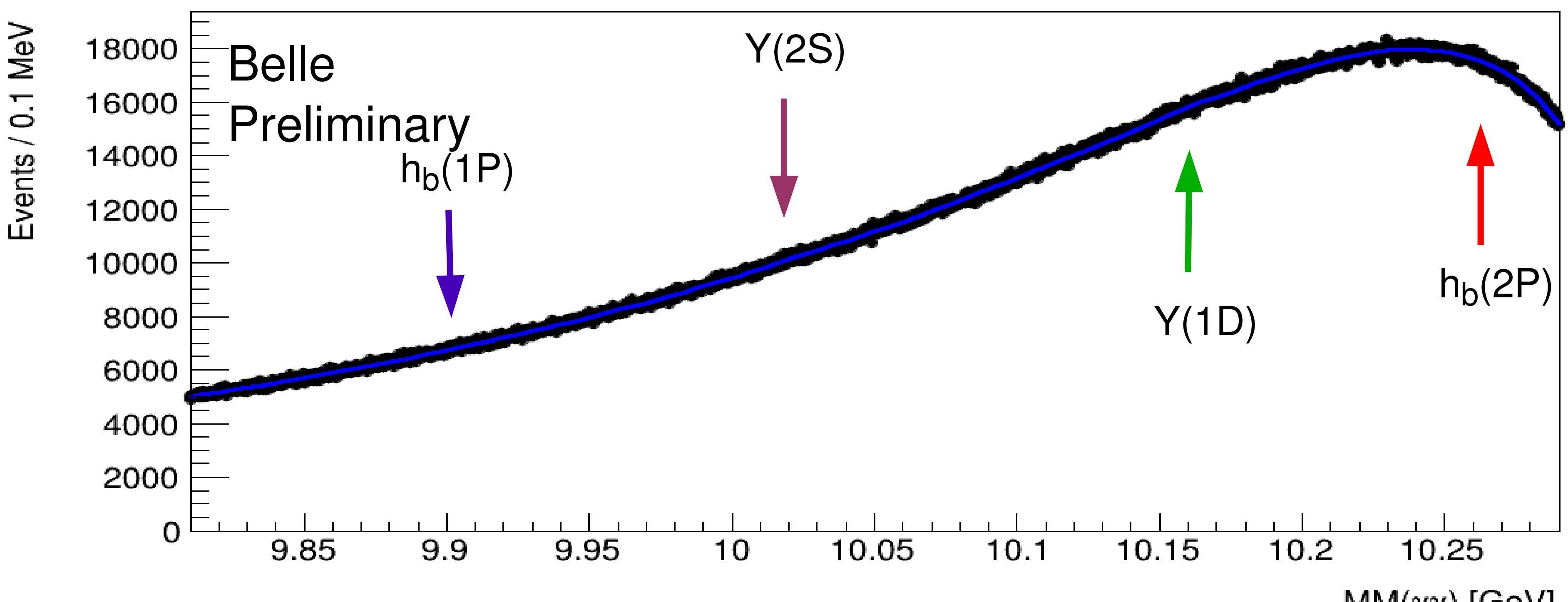
Υ(5S) → η $b\bar{b}$

121 fb^{-1} of e^+e^- collisions at Υ(5S) energy









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

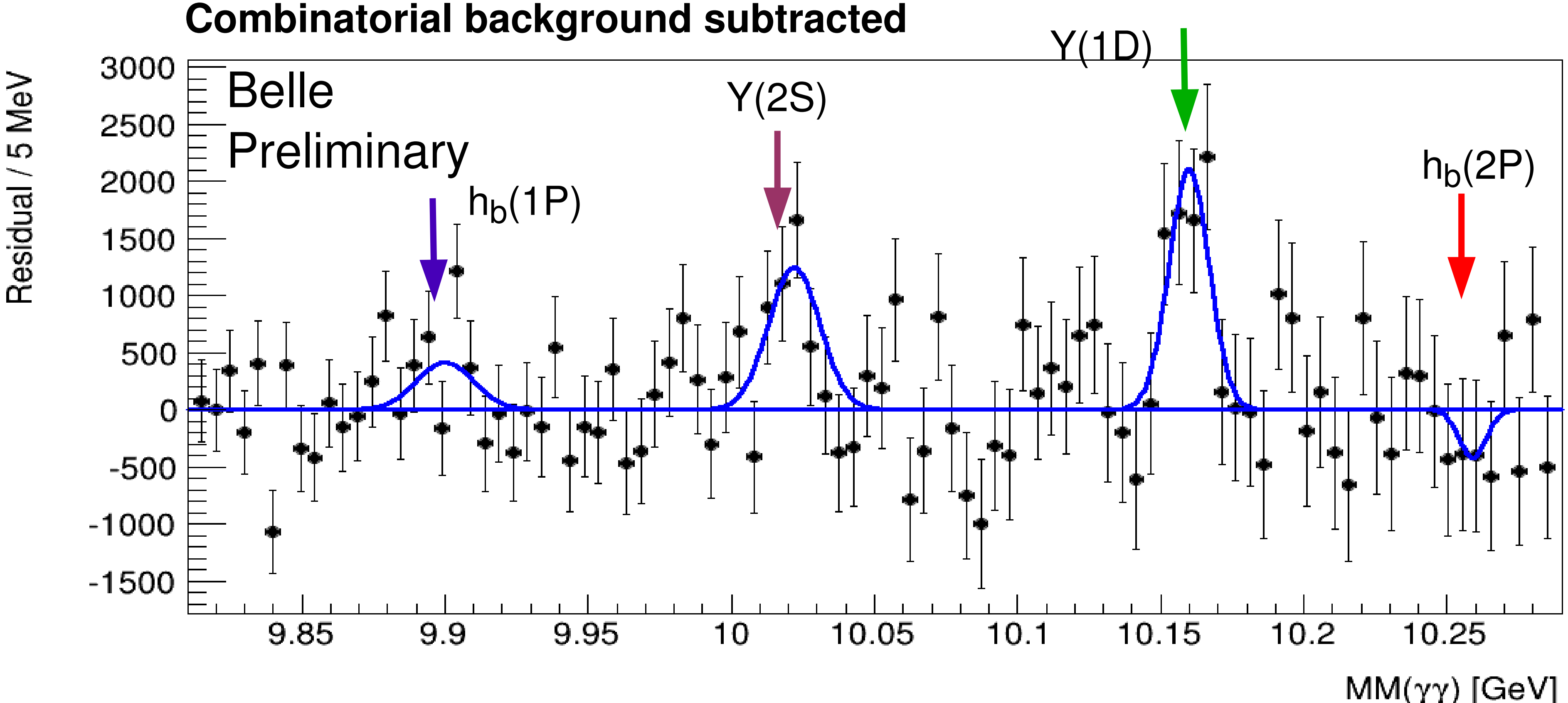
BF[Υ(5S) → η Υ(2S)] = (2.1 ± 0.7 ± 0.3) x 10^{-3}
BF[Υ(5S) → η Υ(1D)] = (2.8 ± 0.7 ± 0.4) x 10^{-3}

BF[Υ(5S) → η hb(1P)] = < 3.3 x 10^{-3} (90% CL)
BF[Υ(5S) → η hb(2P)] = < 3.7 x 10^{-3} (90% CL)

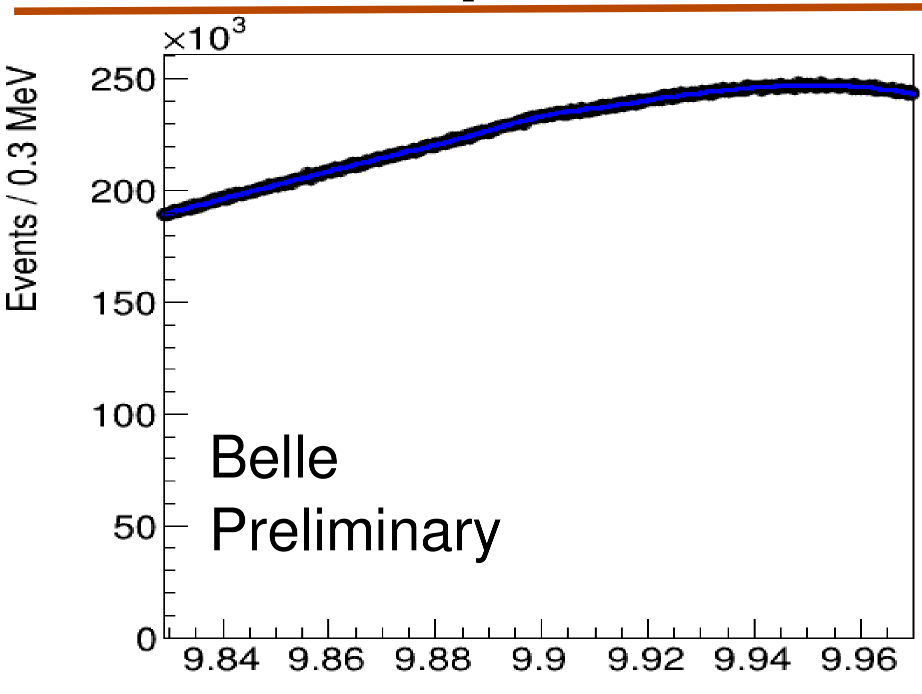
$$\frac{\Gamma[\Upsilon(5S)\to\eta h_b(1P)]}{\Gamma[\Upsilon(5S)\to\pi\pi h_b(1P)]}<0.94$$

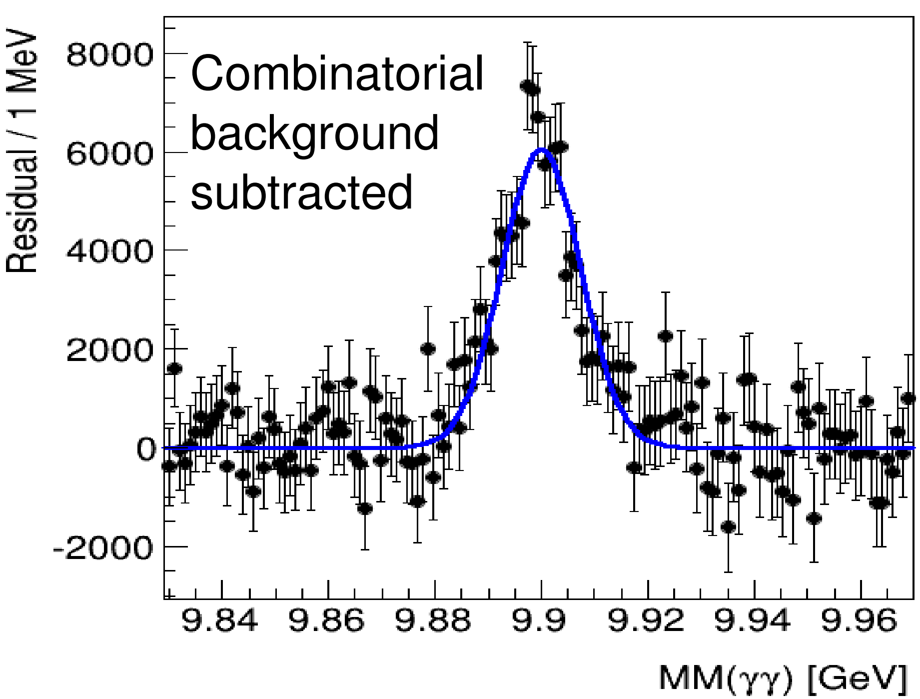
$$\frac{\Gamma[\Upsilon(5S)\to\eta h_b(2P)]}{\Gamma[\Upsilon(5S)\to\pi\pi h_b(2P)]}<0.62$$

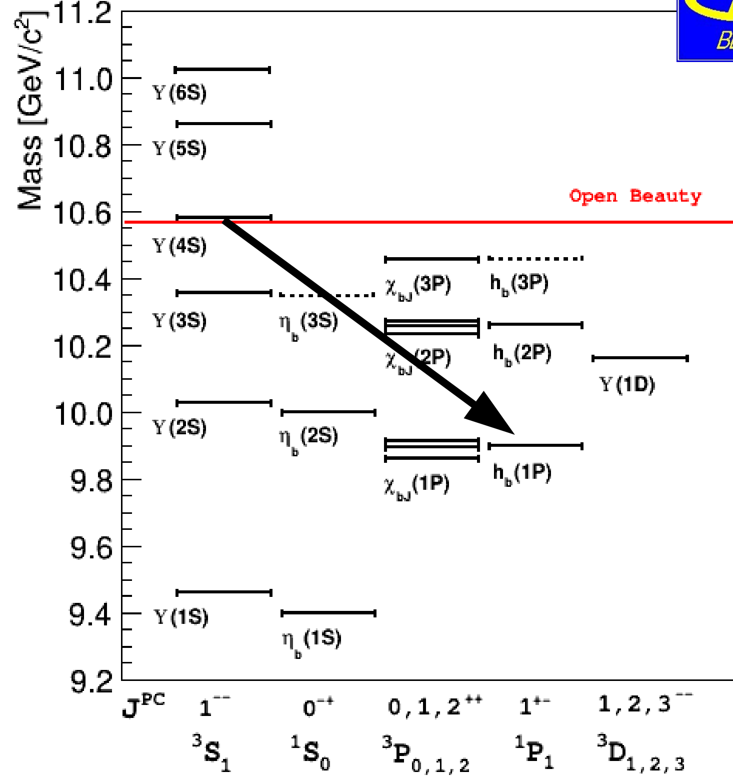
Combinatorial background subtracted



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







First **single meson**, $^3S \to {}^1P$ 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

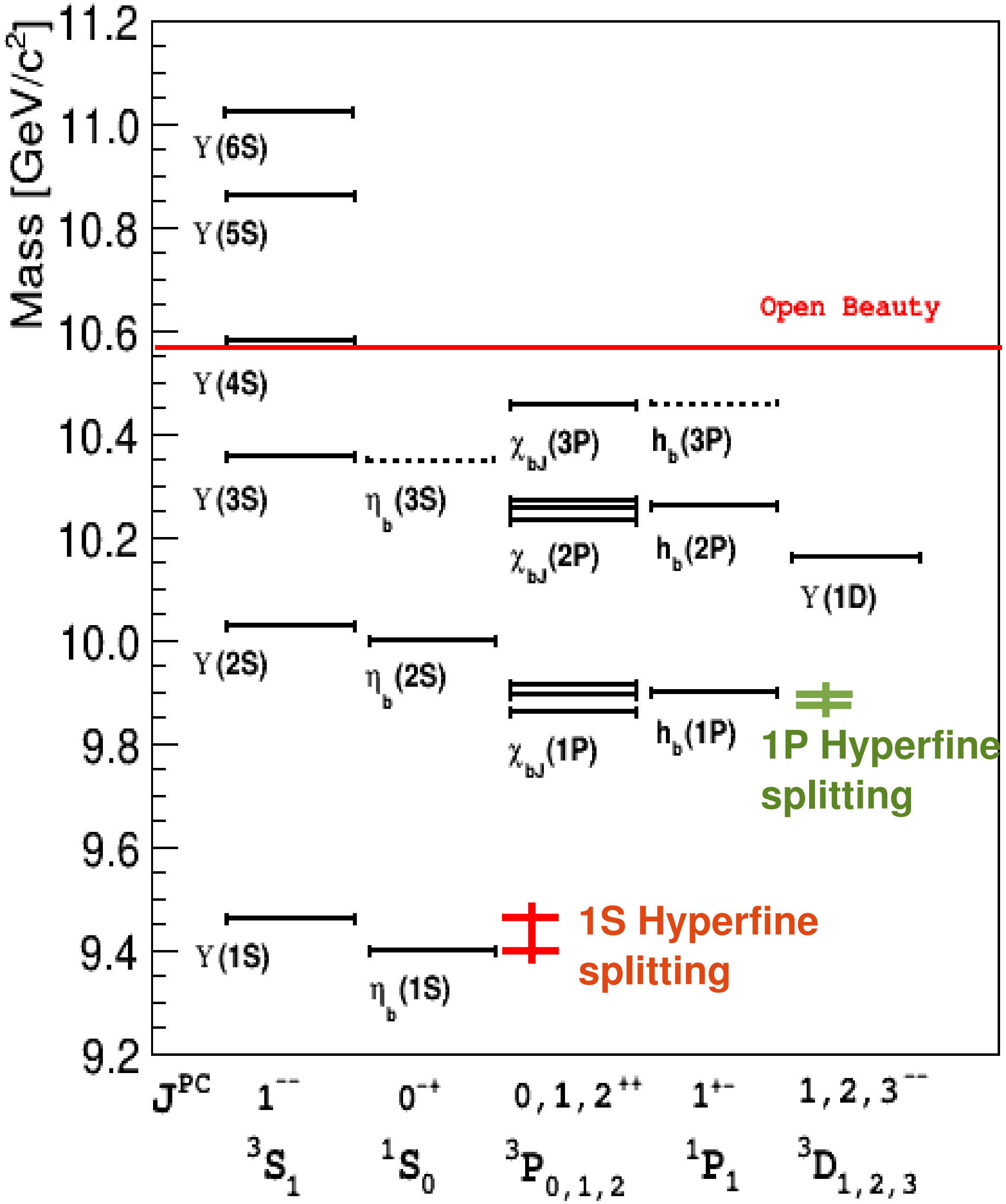
$\Gamma_{\pi\pi\Upsilon(1S)}$ = 1.7 KeV

$\Gamma_{\eta hb(1P)}$ = 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) → $|\psi(0)|^2 = 0$

$\Delta M_{HF}(1P) = +0.8 \pm 1.1$ MeV/c²

$\Delta M_{HF}(2P) = +0.5 \pm 1.2$ MeV/c²

S wave → Even ψ(r) → $|\psi(0)|^2 \neq 0$

pNRQCD: 41 ± 14 MeV/c²

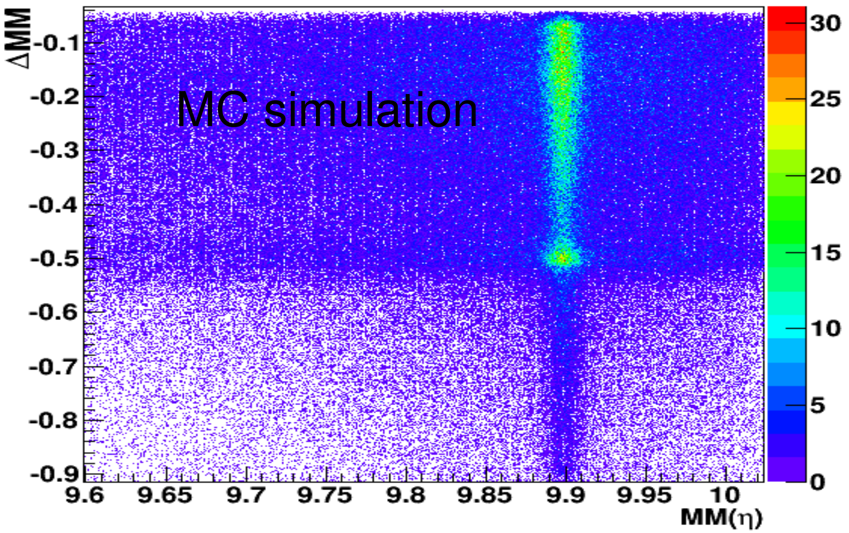
Kniehl et al., PRL92,242001(2004)

Lattice: 60 ± 8 MeV/c²

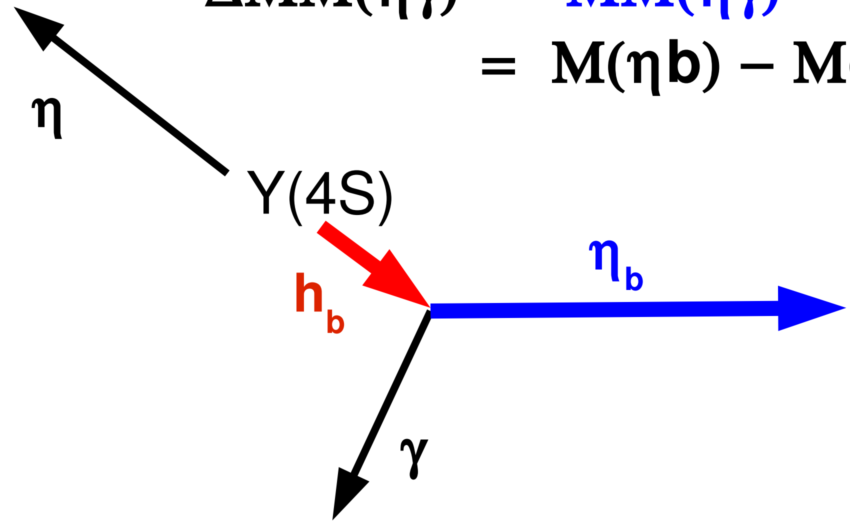
Meinel, PRD82,114502(2010)

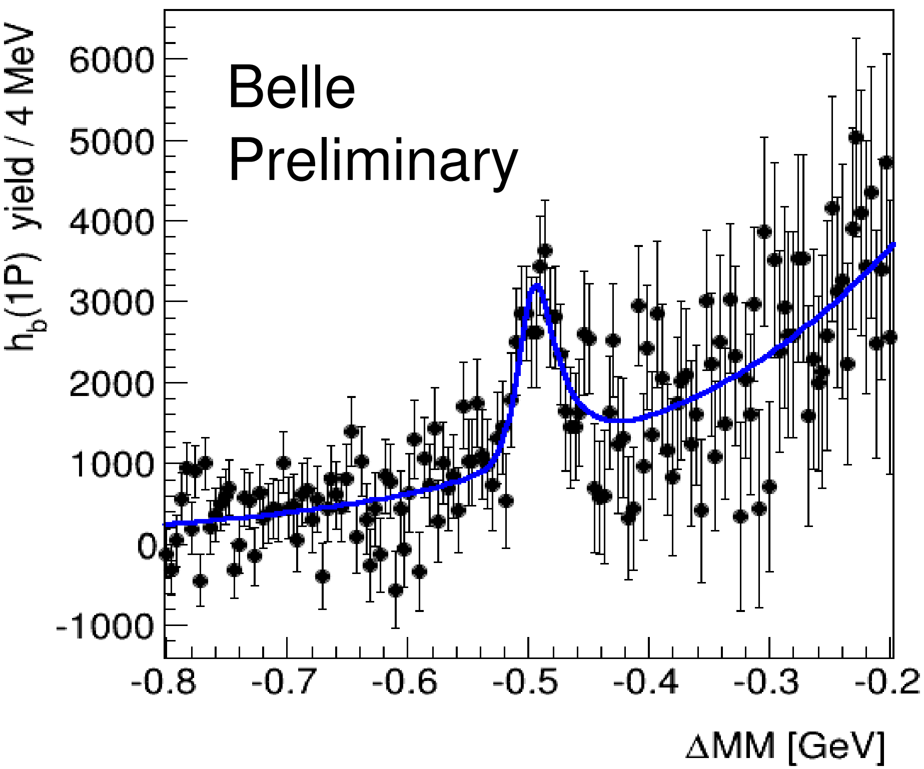
PDG ’12 : 69.3 ± 2.8 MeV/c²

Detecting spin singlets



$$\Delta MM(\eta\gamma) = MM(\eta\gamma) - MM(\eta)$$
$$= M(\eta b) - M(hb)$$





M[ηb(1S)] = (9405.3 ± 1.3 ± 3.0) MeV

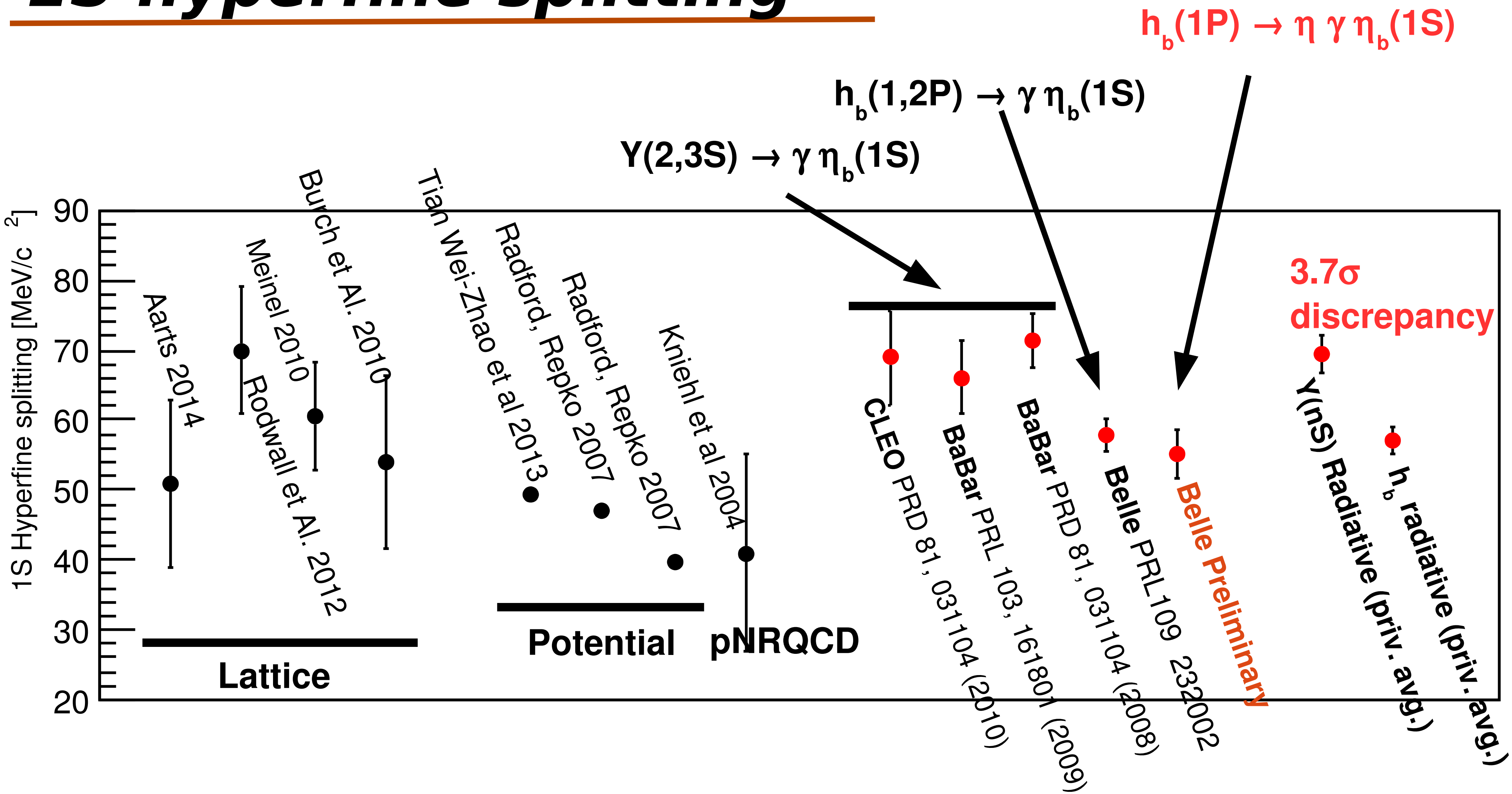
Γ[ηb(1S)] = $(11^{+8}_{-6} \pm 3)$ MeV

BF[hb(1P) → γ ηb(1S)] = $(52^{+11}_{-10} \pm 4)$ %

$\Delta M_{HF}(\eta_b) = M(\eta_b) - M(\Upsilon(1S)) =$
(55.0 ± 1.3 ± 3.2) MeV

Assuming Y(1S) mass = 9460.3 MeV

1S hyperfine splitting

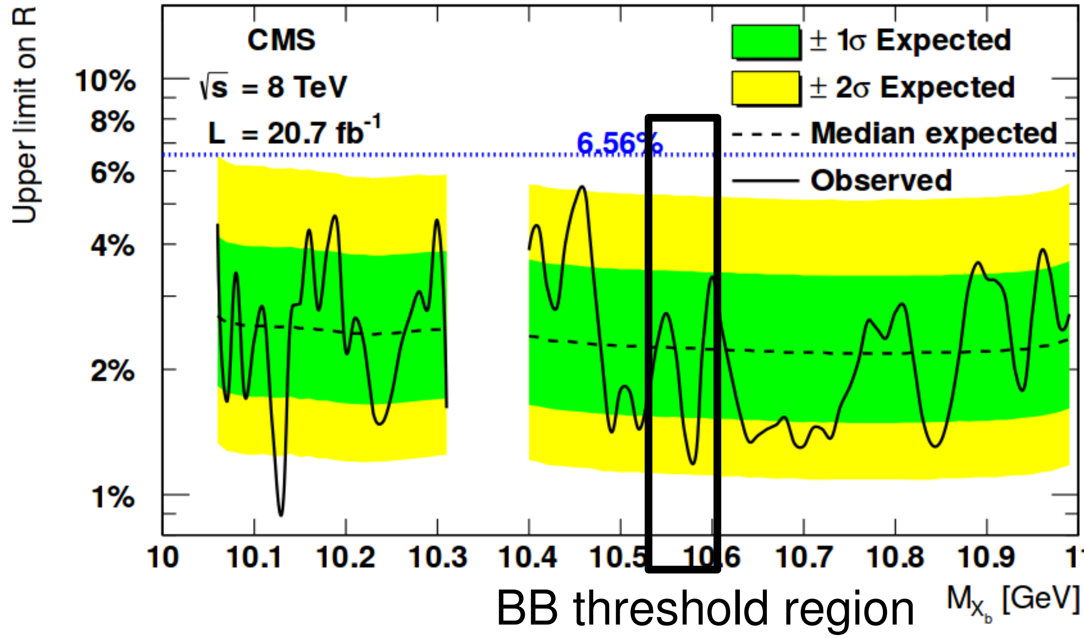


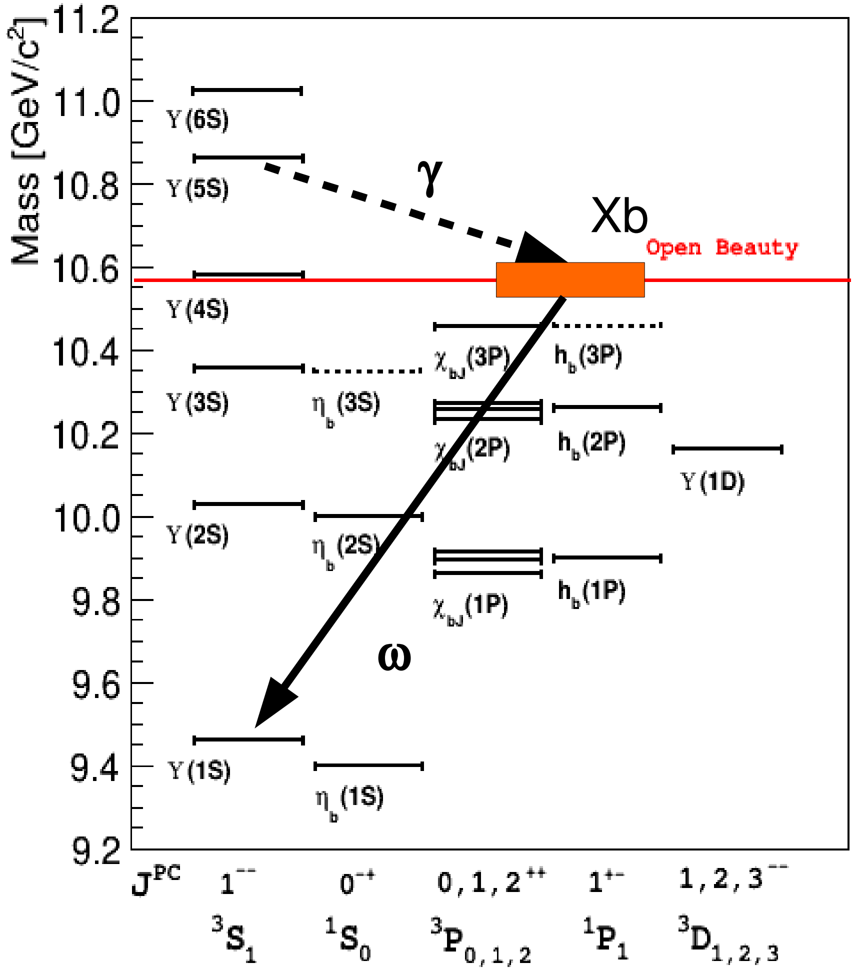
Exotics in Υ(5S) decays

Bottomonium equivalent of X(3872)

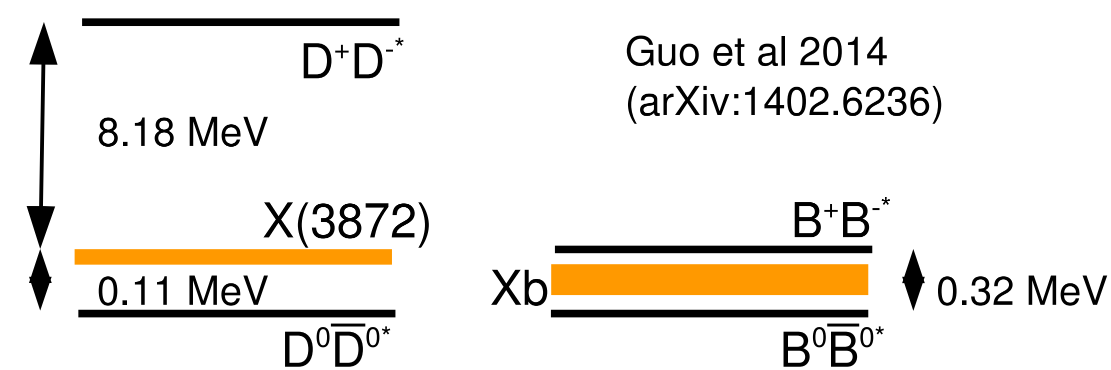
CMS: inclusive search for PLB 727 (2013) 57
Xb → ππ Υ(1S) in pp collisions

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

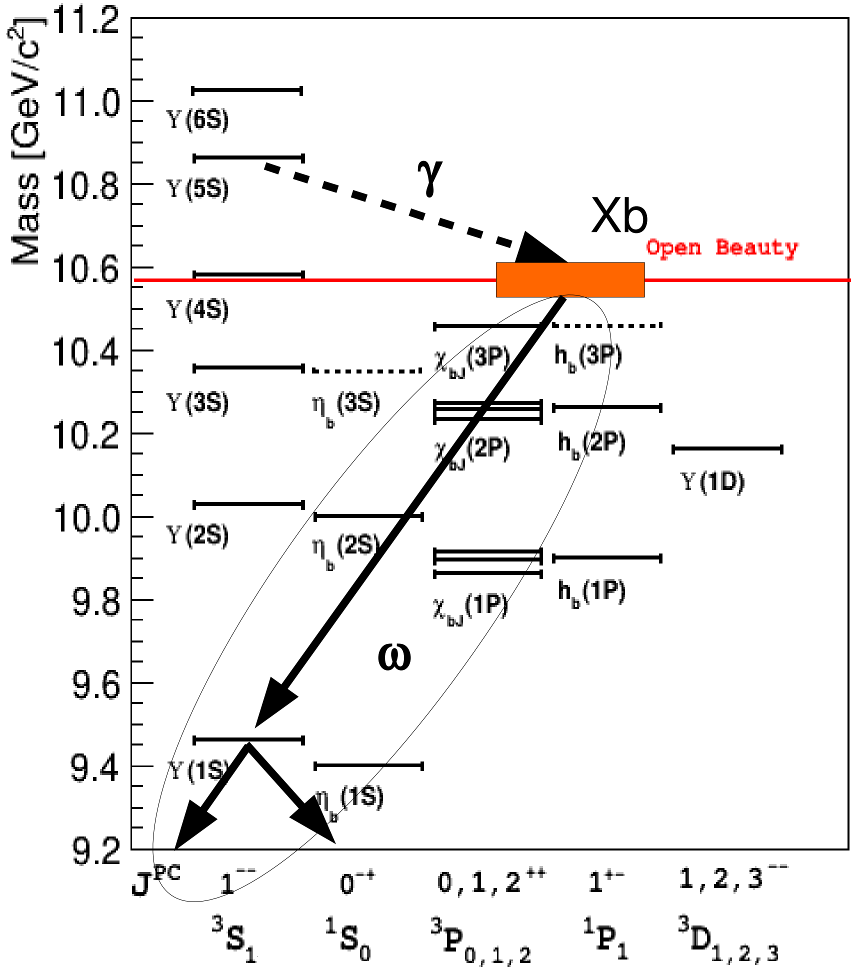
arXiv:1408.0504

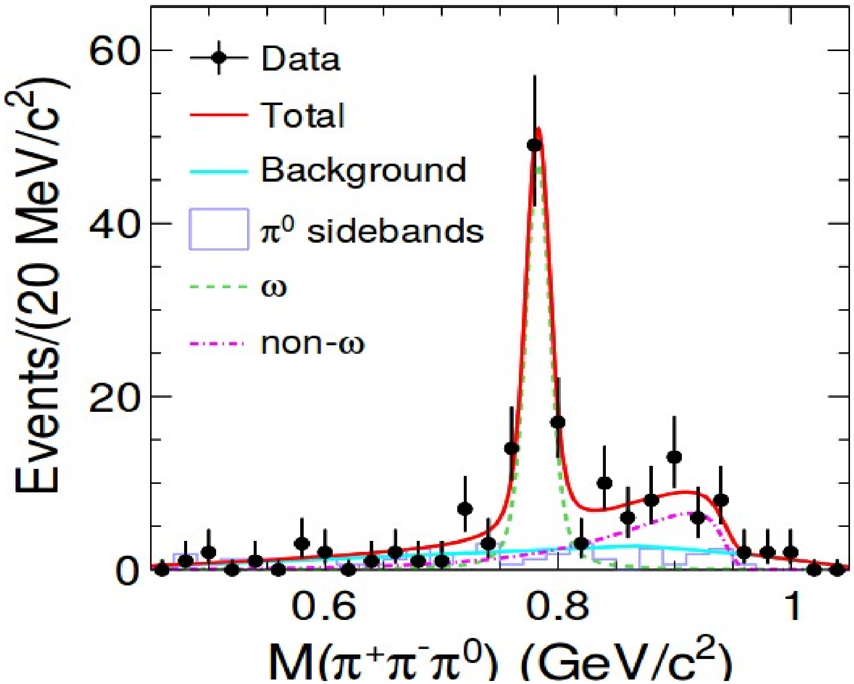
Υ(5S) → γ Xb → γ ω Υ(1S)

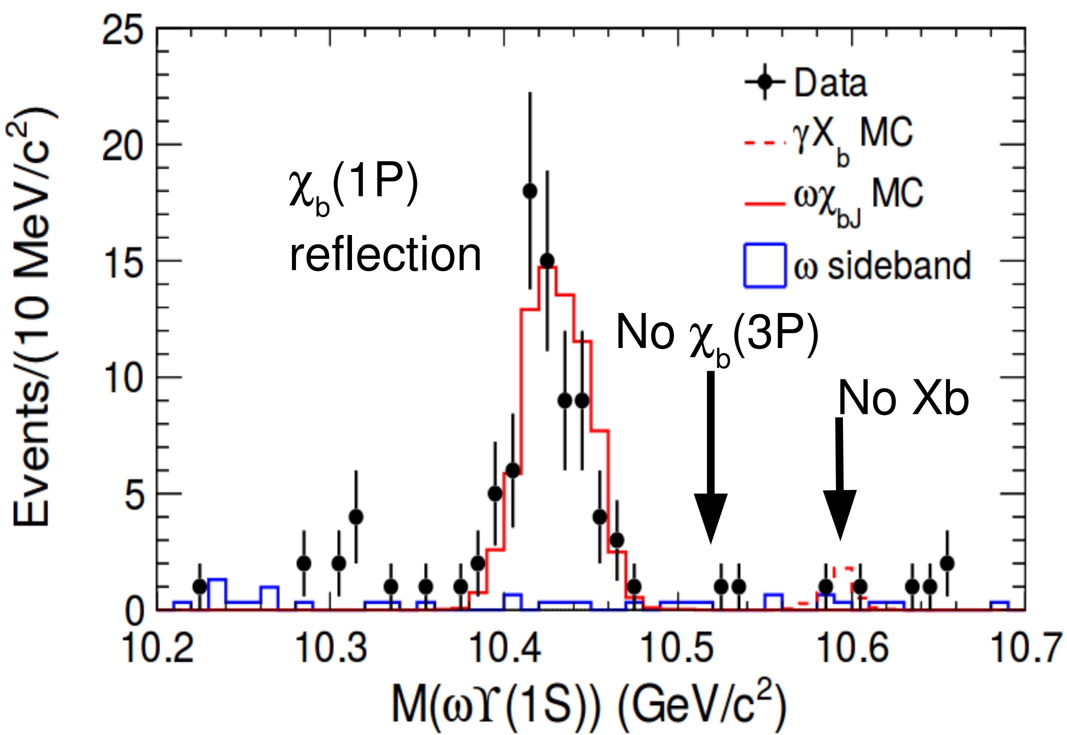
Υ(5S) → γ π⁺π⁻π⁰ μ⁺μ⁻ (e⁺e⁻)

Υ(1S)

5C kinematic fit







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

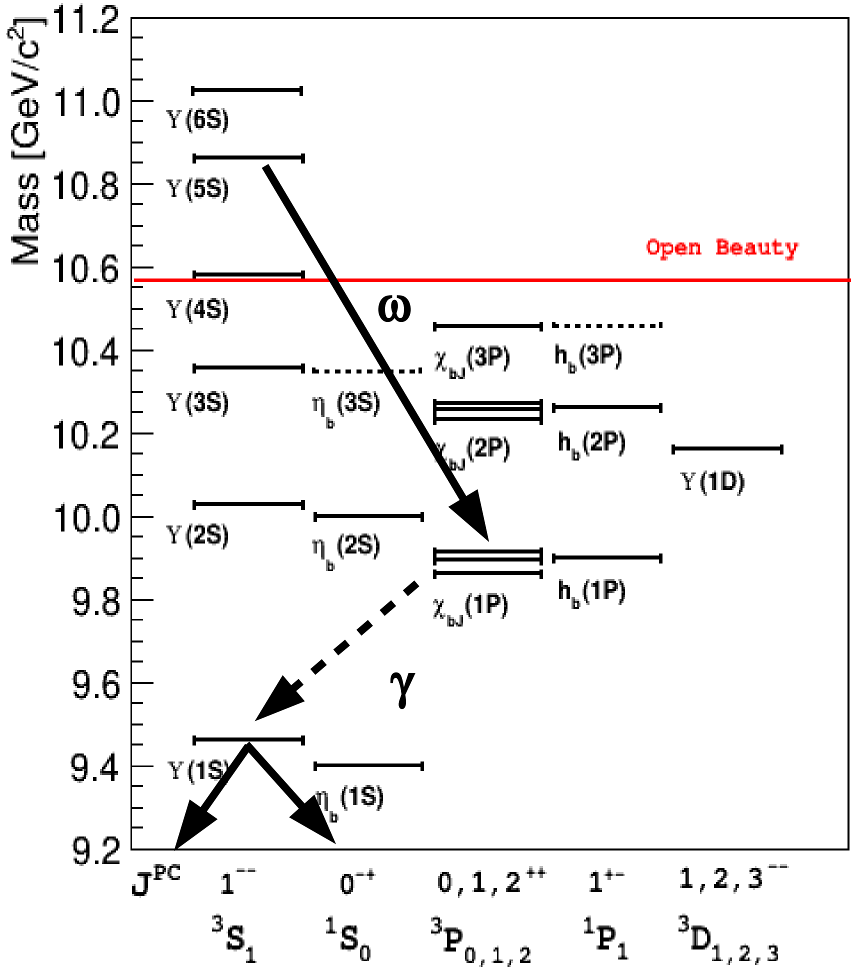
arXiv:1408.0504

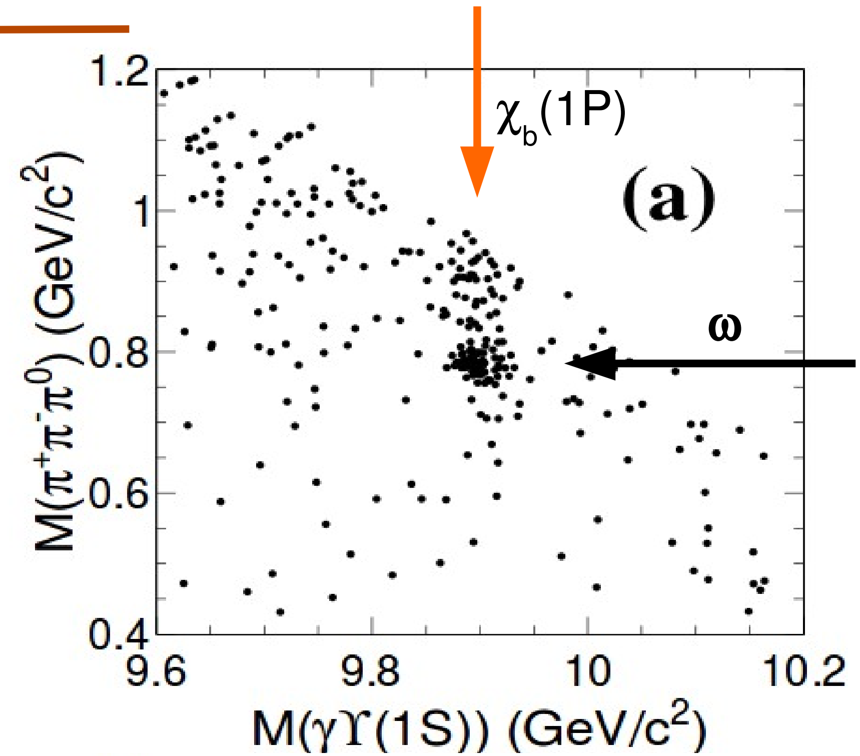
$B[\Upsilon(5S) \rightarrow \omega\, \chi_{b0}(1P)] < 3.9 \times 10^{-3}$

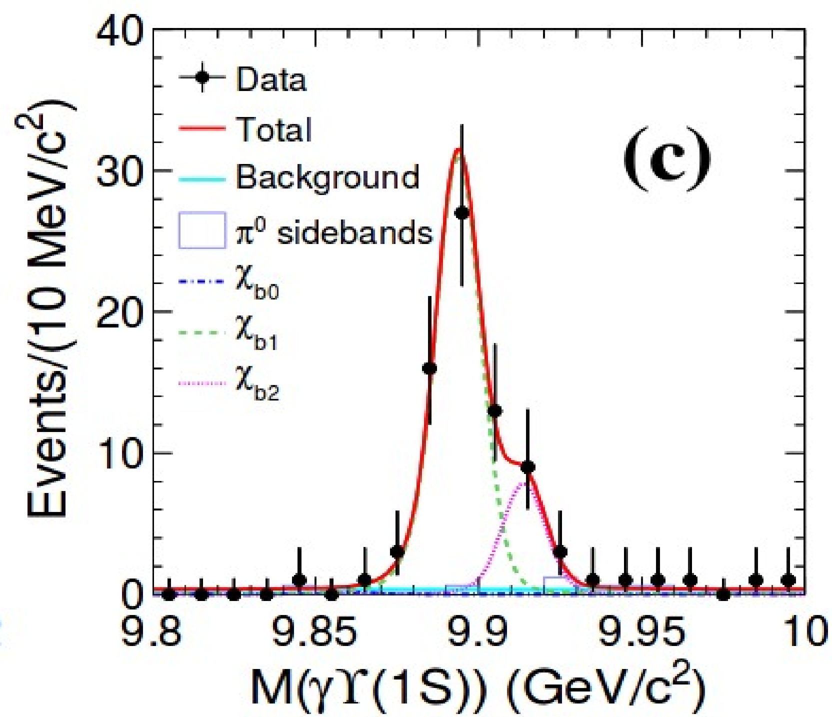
$B[\Upsilon(5S) \rightarrow \omega\, \chi_{b1}(1P)] = 1.57 \pm 0.22 \pm 0.21 \times 10^{-3}$

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

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







Part II

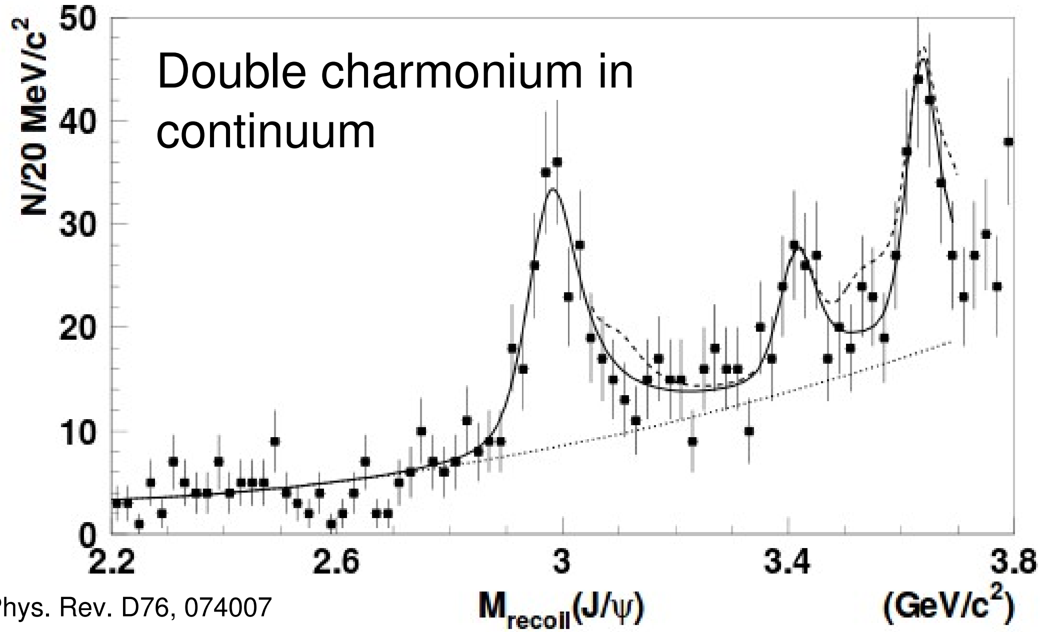
Bottomonium annihilations

Υ(1,2S) → double charmonium

$e^+e^- \to \gamma^* \to$ double charmonium

PRL 89, 142001
PRD 70, 071102
PRD 72, 031101

~10 x theory



Phys. Rev. D76, 074007

$\chi_{bJ}(1P) \to$ double charmonium

PRD 85, 071102(R) U.L Only

Matching

Light Cone formalism PRD 80, 094008

NRQCD PRD 84,094031

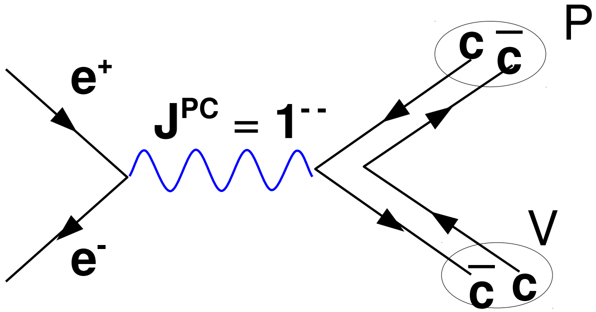
Not matching

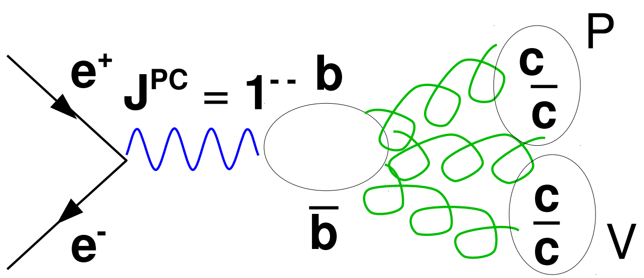
Potential QCD PRD 72, 094018

Υ(1,2S) → double charmonium

Perturbative QCD PRD 76, 074007

NRQCD PRD 87, 094004



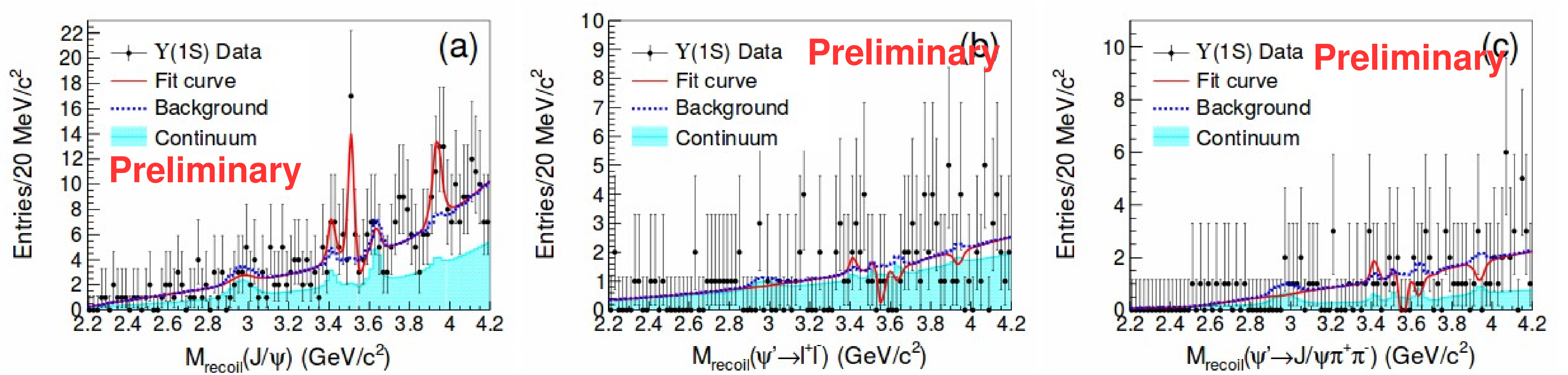


Quantum numbers
V → VP

Reconstruct V in l^+l^- or $\pi\pi l^+l^-$

Identify P with missing mass

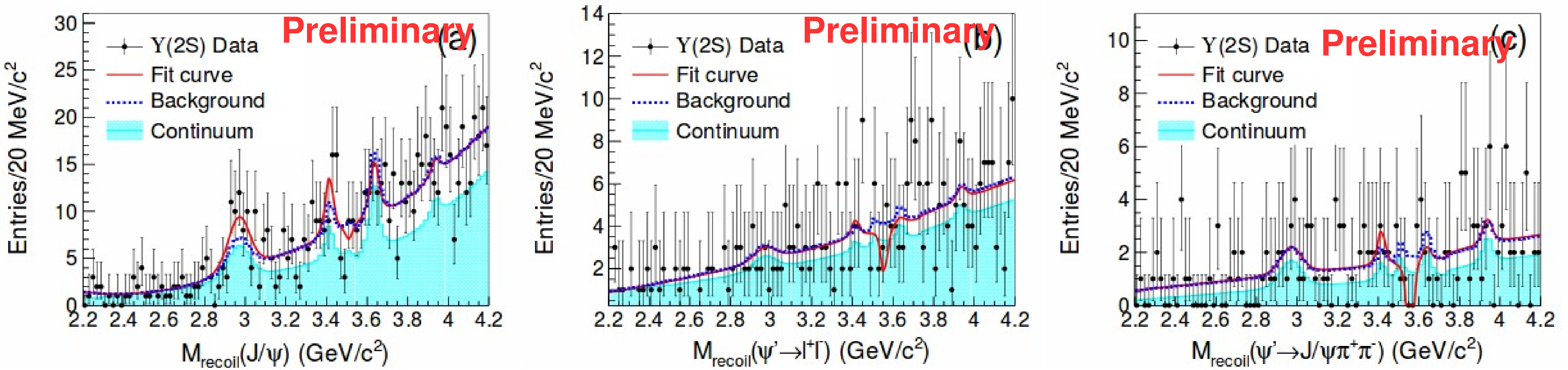
Υ(1S) → double charmonium



Channels	N_{fit}	$N_{\rm up}$	$\varepsilon(\%)$	$\sigma_{syst}(\%)$	$\Sigma\ (\sigma)$	$\mathcal{B}_R(\times10^{-6})$	$\mathcal{B}_{\rm th}(\times10^{-6})$
$\Upsilon(1S) \to J/\psi + \eta_c$	-5.0 ± 6.3	8.1	3.72	9.3	–	< 2.2	$3.9^{+5.6}_{-2.3}$
$\Upsilon(1S) \to J/\psi + \chi_{c0}$	6.0 ± 5.6	14.5	4.23	6.1	1.3	< 3.4	1.3
$\Upsilon(1S) \to J/\psi + \chi_{c1}$	19.9 ± 6.2	–	4.89	5.6	4.6	$3.98 \pm 1.24 \pm 0.22$	4.9
$\Upsilon(1S) \to J/\psi + \chi_{c2}$	-3.2 ± 4.0	6.4	4.55	5.1	–	< 1.4	0.20
$\Upsilon(1S) \to J/\psi + \eta_c(2S)$	-2.1 ± 6.0	9.4	4.32	6.3	–	< 2.2	$2.0^{+3.4}_{-1.4}$
$\Upsilon(1S) \to J/\psi + X(3940)$	19.0 ± 8.7	31.1	5.64	7.1	2.8	< 5.4	–
$\Upsilon(1S) \to \psi' + \eta_c$	-5.0 ± 3.9	5.7	1.58	12.6	–	< 3.6	$1.7^{+2.4}_{-1.0}$
$\Upsilon(1S) \to \psi' + \chi_{c0}$	2.1 ± 4.1	10.6	1.60	20.0	0.6	< 6.5	–
$\Upsilon(1S) \to \psi' + \chi_{c1}$	0.2 ± 3.6	7.7	1.68	20.4	0.1	< 4.5	–
$\Upsilon(1S) \to \psi' + \chi_{c2}$	-6.7 ± 2.3	3.4	1.63	7.6	–	< 2.1	–
$\Upsilon(1S) \to \psi' + \eta_c(2S)$	-5.7 ± 3.3	5.4	1.68	22.6	–	< 3.2	$0.8^{+1.4}_{-0.6}$
$\Upsilon(1S) \to \psi' + X(3940)$	-5.9 ± 4.0	6.6	1.90	8.0	–	< 2.9	–

First evidence

Υ(2S) → double charmonium



Channels	N_{fit}	$N_{\rm up}$	$\varepsilon(\%)$	$\sigma_{syst}(\%)$	$\Sigma\ (\sigma)$	$\mathcal{B}_R(\times 10^{-6})$	$\mathcal{B}_{\rm th}(\times 10^{-6})$
$\Upsilon(2S) \to J/\psi + \eta_c$	16.3 ± 11.9	30.6	3.61	8.9	1.9	< 5.4	$2.6^{+3.7}_{-1.6}$
$\Upsilon(2S) \to J/\psi + \chi_{c0}$	7.8 ± 9.5	22.1	4.16	18.5	1.1	< 3.4	1.1
$\Upsilon(2S) \to J/\psi + \chi_{c1}$	-4.4 ± 6.6	8.6	4.72	14.3	–	< 1.2	4.1
$\Upsilon(2S) \to J/\psi + \chi_{c2}$	2.1 ± 7.4	13.4	4.43	13.4	0.4	< 2.0	0.17
$\Upsilon(2S) \to J/\psi + \eta_c(2S)$	-3.8 ± 10.8	16.7	4.23	24.6	–	< 2.5	$1.3^{+2.1}_{-0.9}$
$\Upsilon(2S) \to J/\psi + X(3940)$	0.7 ± 12.1	17.6	5.61	12.7	0.1	< 2.0	–
$\Upsilon(2S) \to \psi' + \eta_c$	-0.4 ± 7.9	12.4	1.56	8.2	–	< 5.1	$1.1^{+1.6}_{-0.7}$
$\Upsilon(2S) \to \psi' + \chi_{c0}$	2.6 ± 5.7	11.9	1.63	7.1	0.6	< 4.7	–
$\Upsilon(2S) \to \psi' + \chi_{c1}$	-2.8 ± 4.2	6.4	1.67	6.8	–	< 2.5	–
$\Upsilon(2S) \to \psi' + \chi_{c2}$	-13.3 ± 4.8	4.9	1.66	6.9	–	< 1.9	–
$\Upsilon(2S) \to \psi' + \eta_c(2S)$	-3.0 ± 5.9	8.5	1.65	7.6	–	< 3.3	$0.5^{+0.9}_{-0.4}$
$\Upsilon(2S) \to \psi' + X(3940)$	-0.3 ± 7.1	11.7	1.93	9.5	–	< 3.9	–

Baryons in Υ(1,2S)

Large baryon production in quarkonium

BF(Υ(1S) → Λ + X) ~ 10%

BF(Υ(1S) → $\Lambda\bar{\Lambda}$ + X) ~ 3%

Only exclusive study available:

X = combination of K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ and π^0

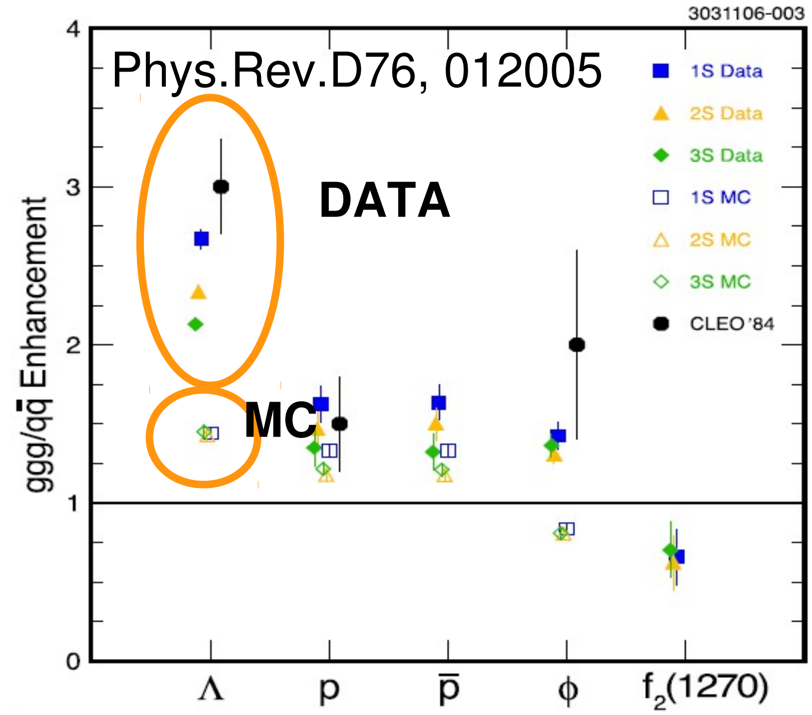
(max 6 charged + 1 neutral)

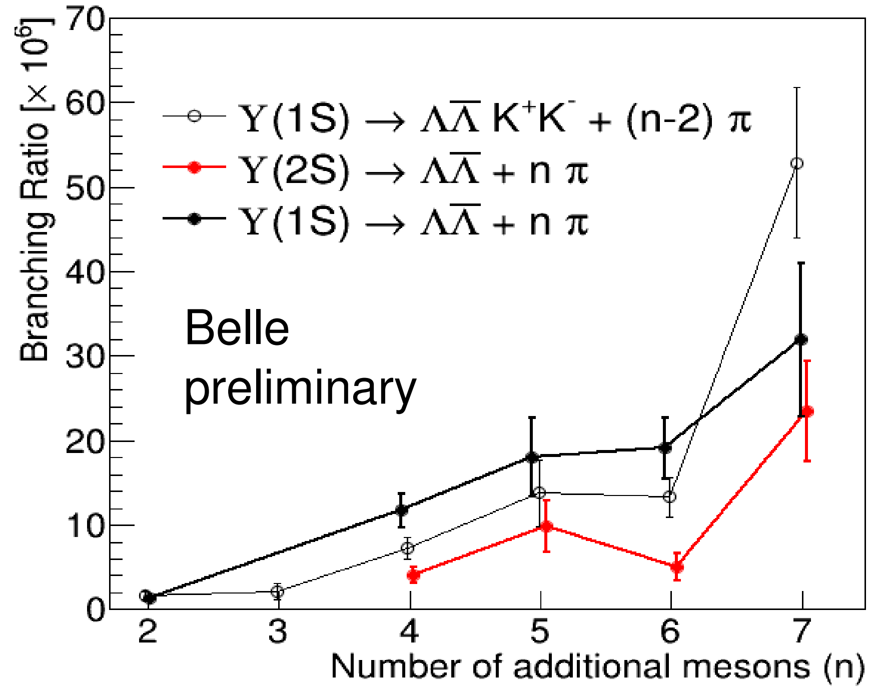
$\sum_X BF[\Upsilon(1S) \to X] \simeq 2 \times 10^{-4}$	Belle
$\sum_X BF[\Upsilon(2S) \to X] \simeq 0.7 \times 10^{-4}$	preliminary

Hyperons produced in high density environment with low momentum

→ interactions, rescattering and coalescence are possible

CLEO

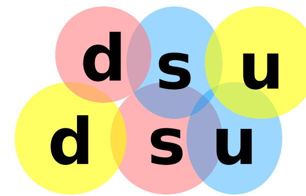




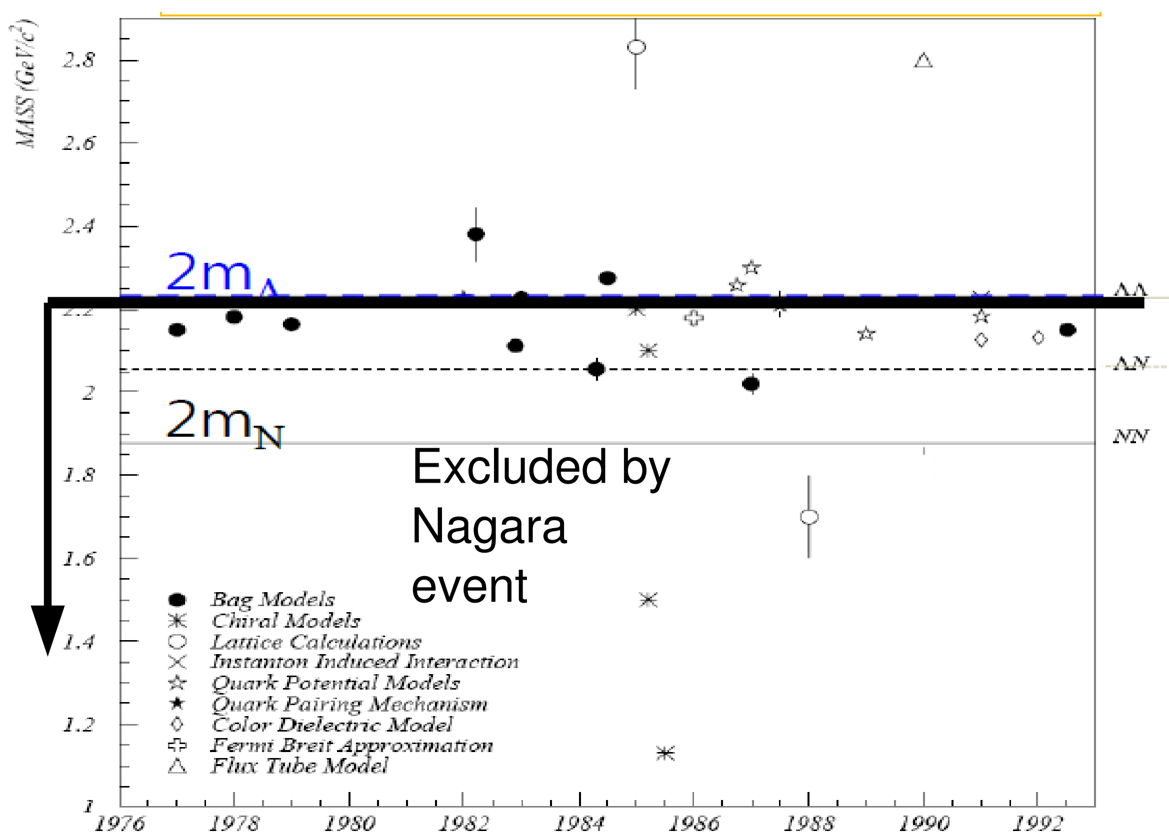
The H dibaryon

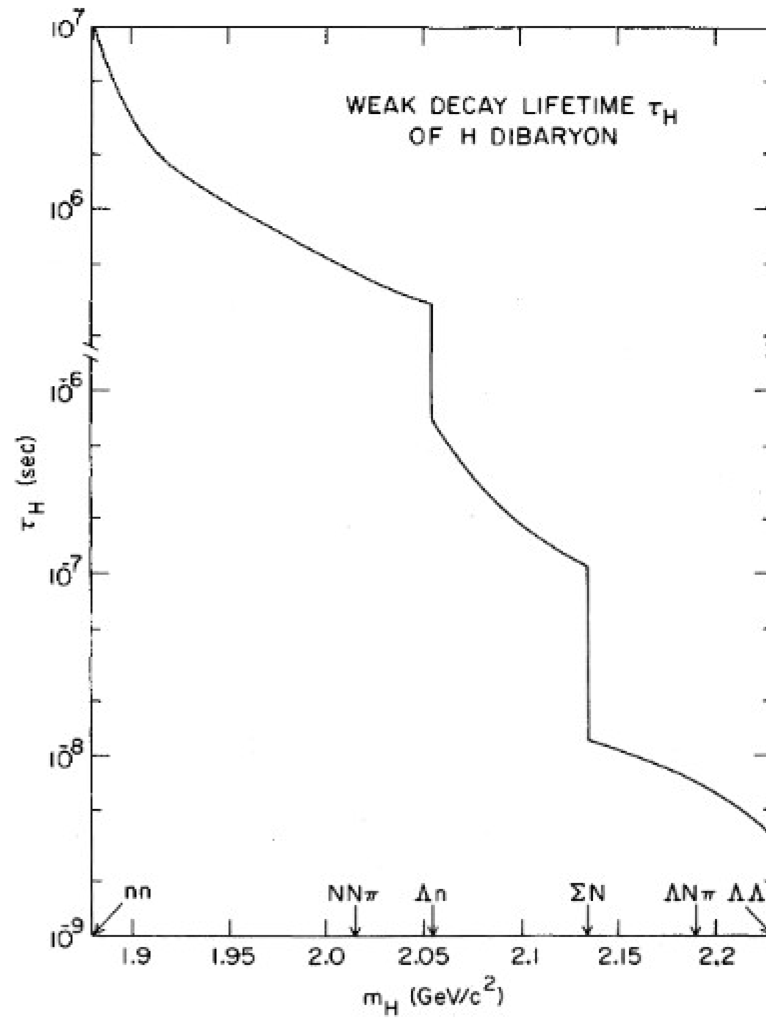
Exotic state (Jaffe, 1977)

→ completely antisymmetric arrangement of uuddss



H → ΛΛ, H → Ξ⁻p , H → Λpπ⁻





Search for H dibaryon

PRL 110, 222002 (2013)

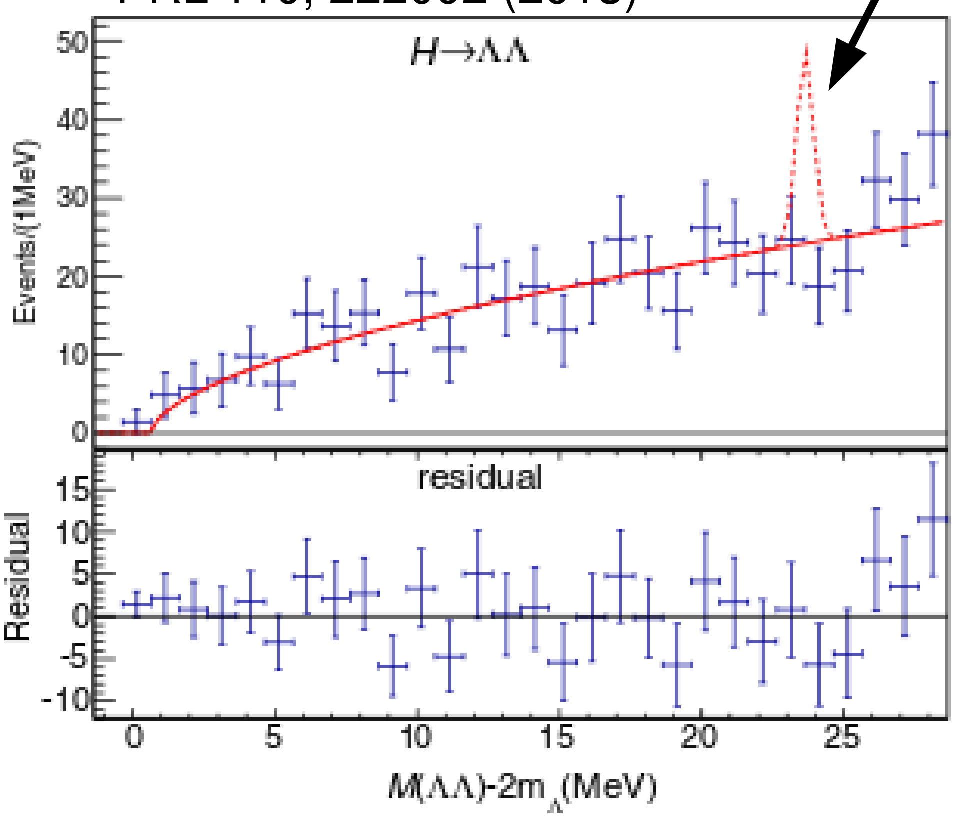
Analysis strategy:

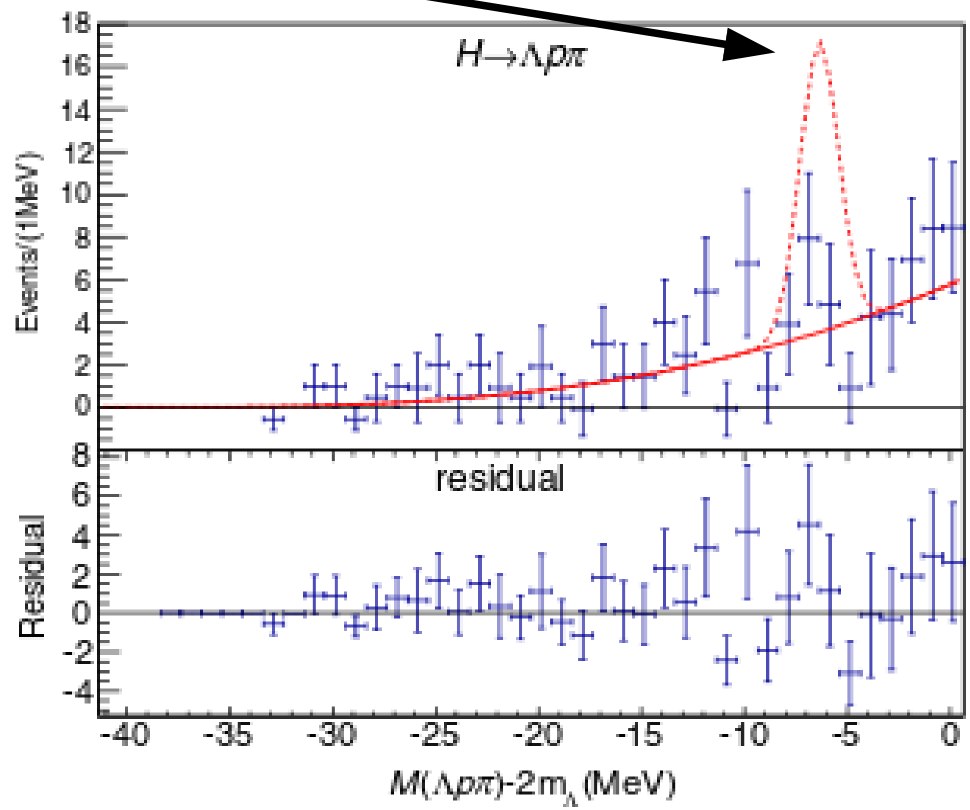
→ Inclusive reconstruction in Υ(1S) and Υ(2S) sample

→ Decays with **H → ΛΛ, H → Ξ⁻p , H → Λpπ⁻**

Assuming BF[Υ(1,2S) → H + X] = 5% BF[Υ(1,2S) → d + X]

PRL 110, 222002 (2013)



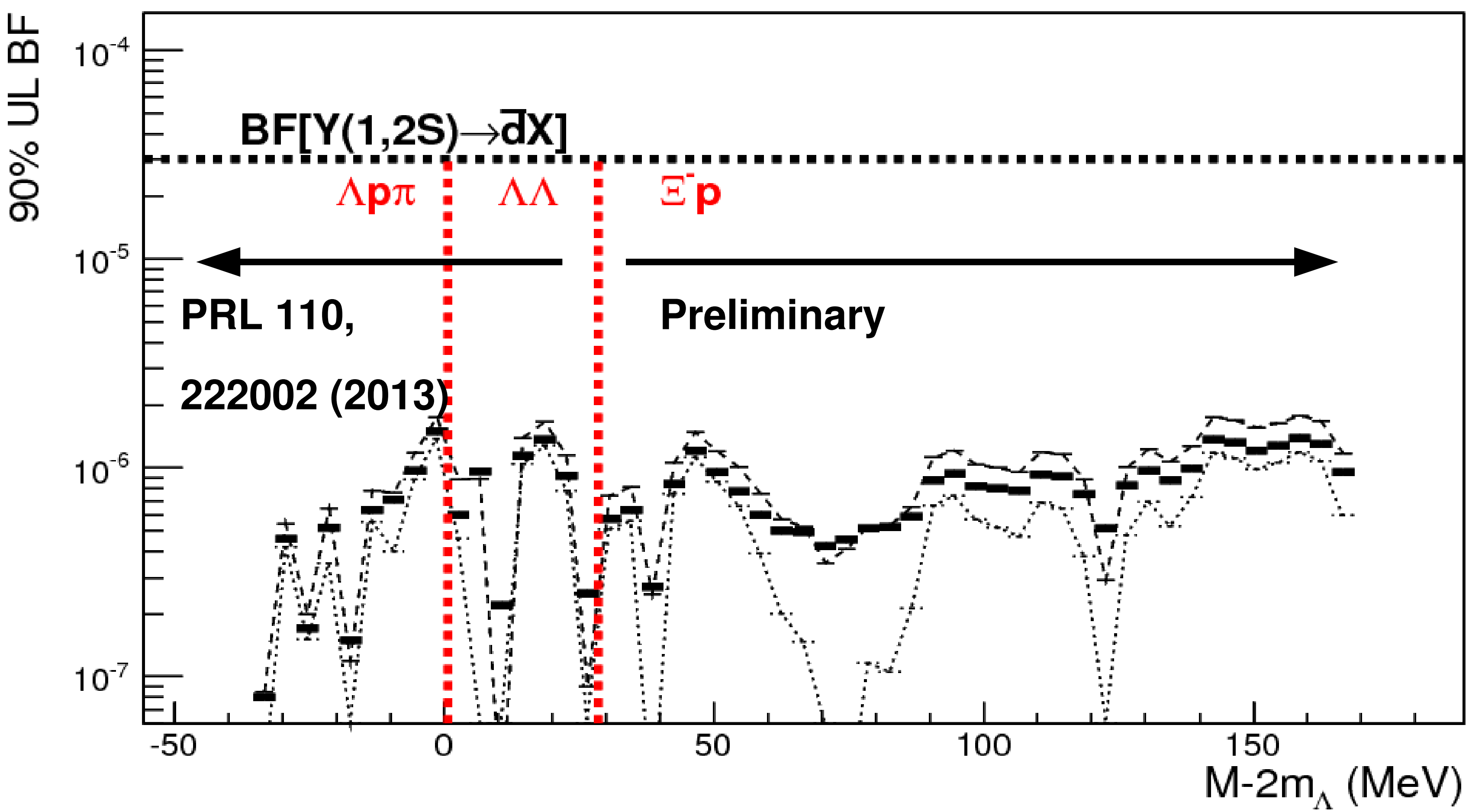


Search for H dibaryon

Analysis strategy:

→ Inclusive reconstruction in Y(1S) and Y(2S) sample

→ Decays with **H → ΛΛ, H → Ξ⁻p , H → Λpπ⁻**



Summary

First observation of $\Upsilon(4S) \to \eta\, h_b(1P)$ Preliminary

$\to$ First test of QCDME with $\eta\, h_b(1P)$ transitions

First study of $\Upsilon(5S) \to \eta\, h_b(1P)$ Preliminary

$\to$ No evidences, but upper limits allows to increase our knowledge of the spin flipping transitions pattern

Updated parameters of $\eta_b(1S)$ Preliminary

First evidence of double charmonium in $\Upsilon(nS)$ decays

$\to$ Agreement with th. predictions

First observation of $\Upsilon(5S) \to \omega\, \chi_{bJ}(1P)$

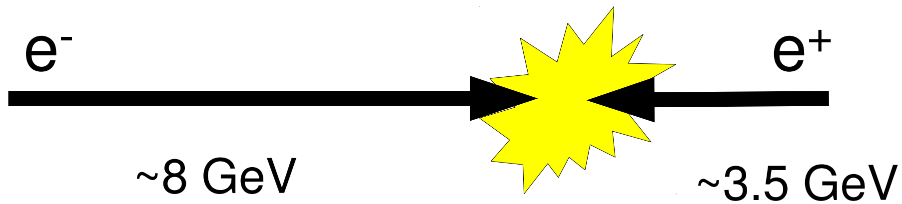
Stringent upper limits on H dibaryon production

Backup

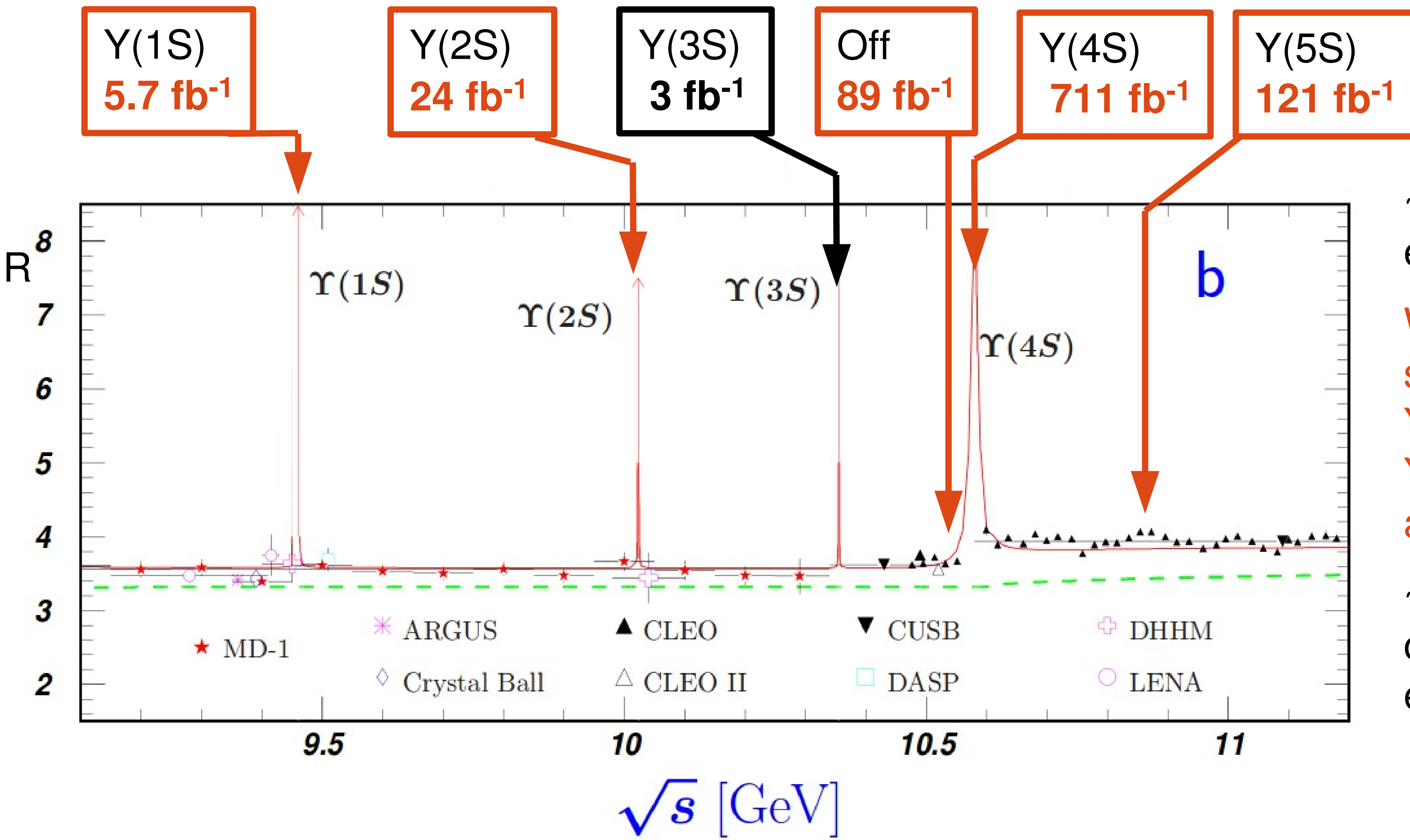
The Belle experiment

For a summary of Belle's resuts: arXiv:1212.5342v1

KEKB asymmetric collider



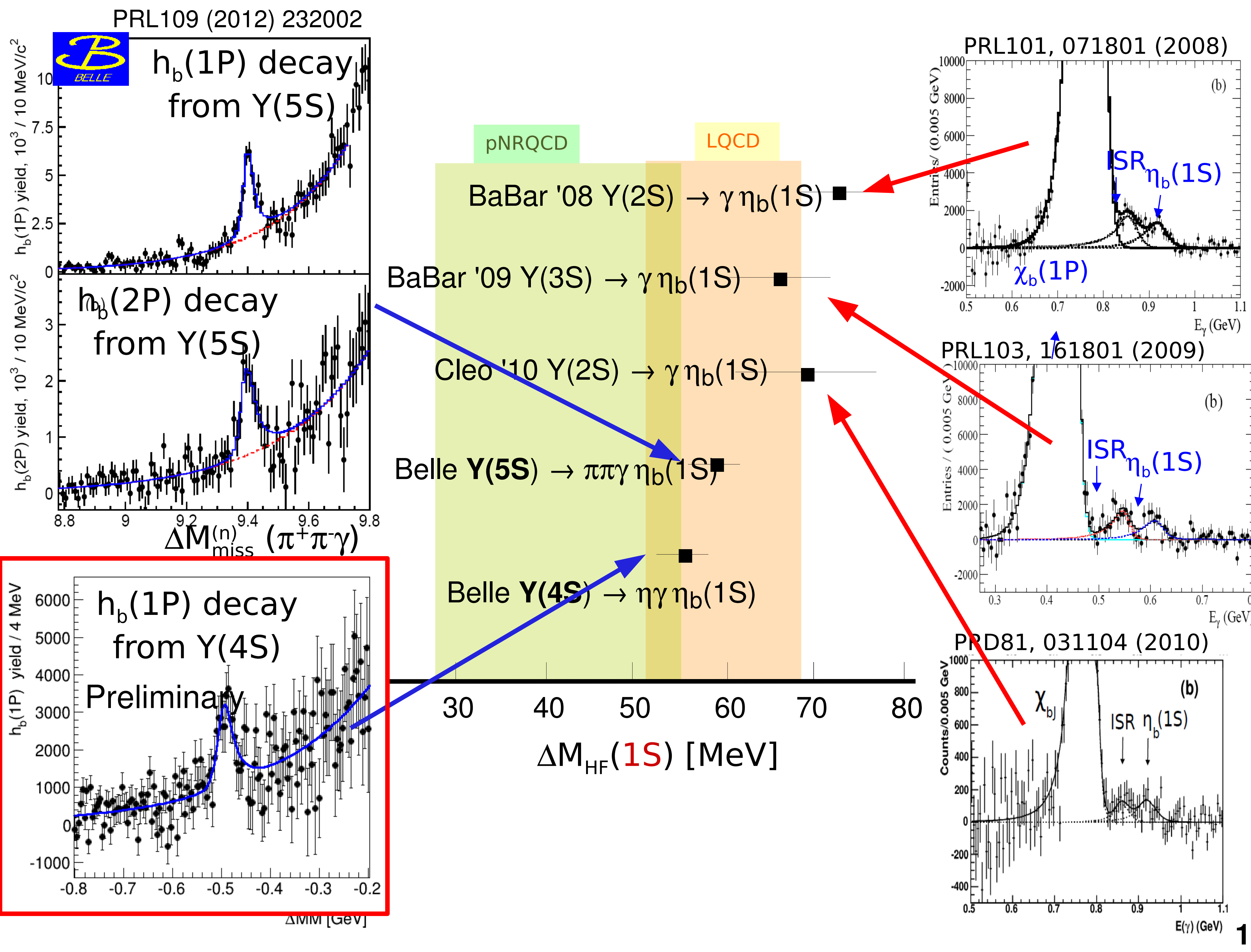
1^{--} quarkonium states produced at rest



~ 1 ab of e^+e^- events

World largest samples of Y(1S), Y(2S), Y(4S), Y(5S) and off-resonance

~ 770 M of of Y(4S) → BB events

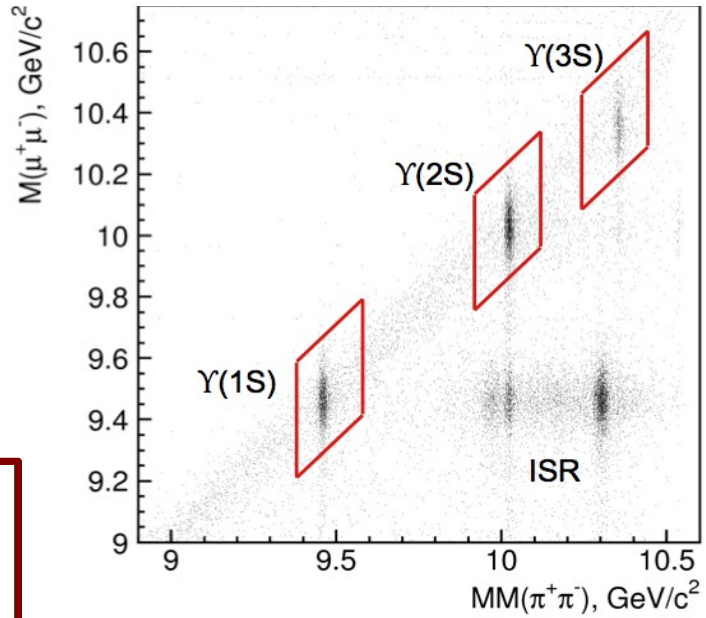


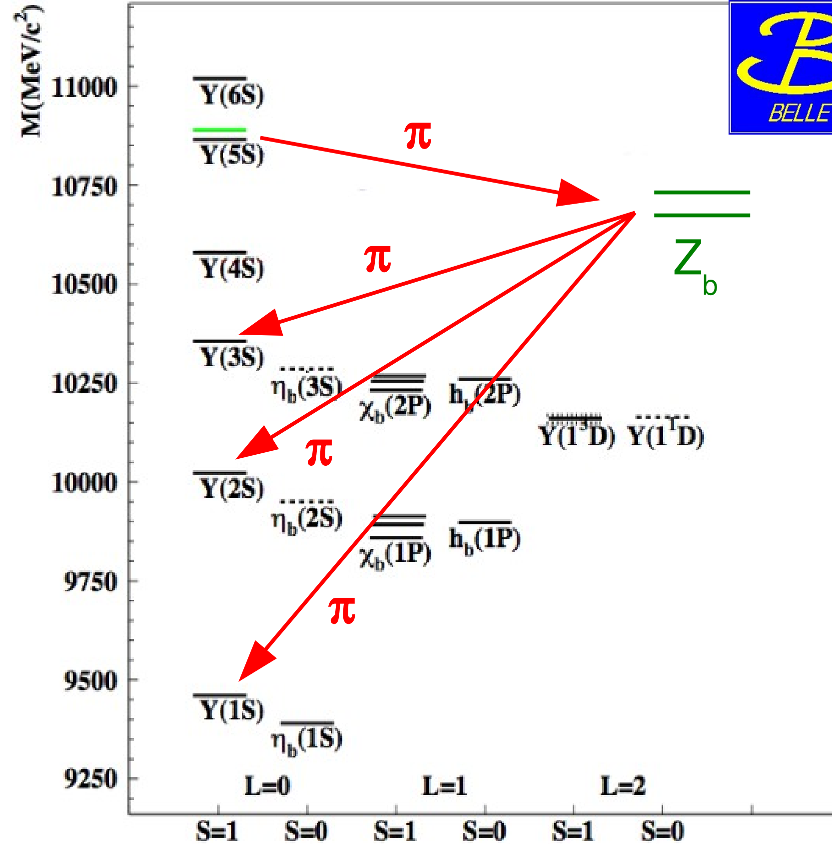
PRL109 (2012) 232002
BELLE
$h_b(1P)$ decay from Υ(5S)
$h_b(2P)$ decay from Υ(5S)
$h_b(1P)$ yield, 10^3 / 10 MeV/c^2
$h_b(2P)$ yield, 10^3 / 10 MeV/c^2
$\Delta M^{(n)}_{miss}$ $(\pi^+\pi^-\gamma)$
$h_b(1P)$ decay from Υ(4S)
Preliminary
$h_b(1P)$ yield / 4 MeV
ΔMM [GeV]
pNRQCD
LQCD
BaBar '08 Υ(2S) → $\gamma\,\eta_b(1S)$
BaBar '09 Υ(3S) → $\gamma\,\eta_b(1S)$
Cleo '10 Υ(2S) → $\gamma\,\eta_b(1S)$
Belle **Υ(5S)** → $\pi\pi\gamma\,\eta_b(1S)$
Belle **Υ(4S)** → $\eta\gamma\,\eta_b(1S)$
30 40 50 60 70 80
$\Delta M_{HF}(1S)$ [MeV]
PRL101, 071801 (2008)
ISR $\eta_b(1S)$
$\chi_b(1P)$
Entries/ (0.005 GeV)
E_γ (GeV)
PRL103, 161801 (2009)
ISR $\eta_b(1S)$
Entries / (0.005 GeV)
E_γ (GeV)
PRD81, 031104 (2010)
χ_{bJ}
ISR $\eta_b(1S)$
Counts/0.005 GeV
E(γ) (GeV)

Z_b in Υ(nS) final states

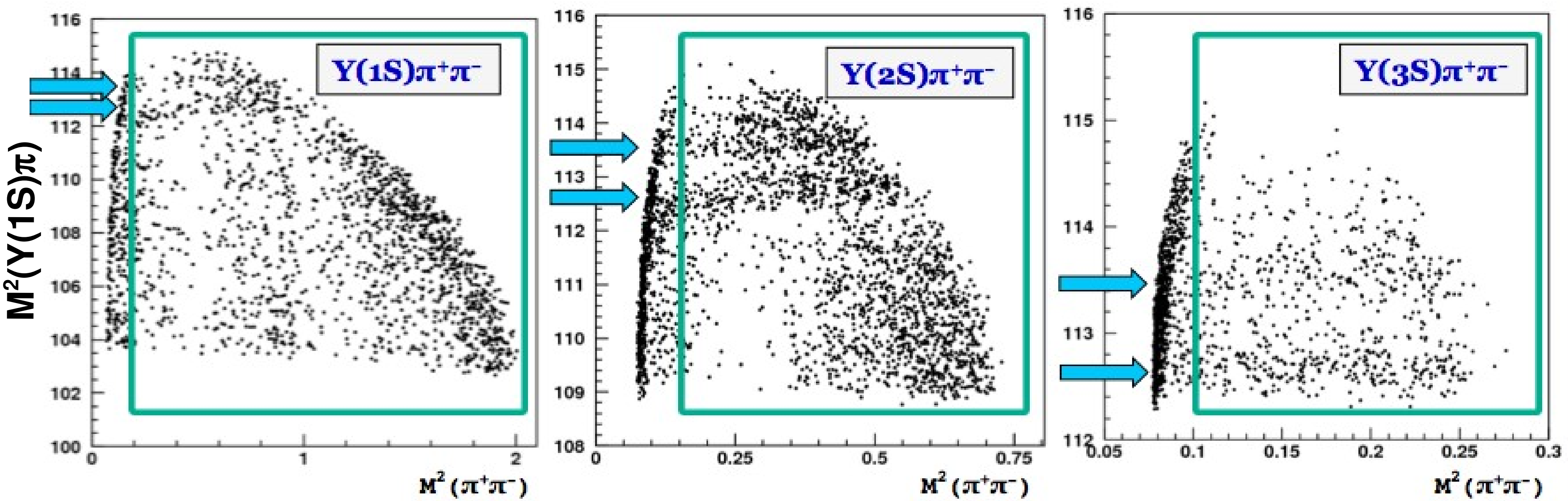
PRL108,122001

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



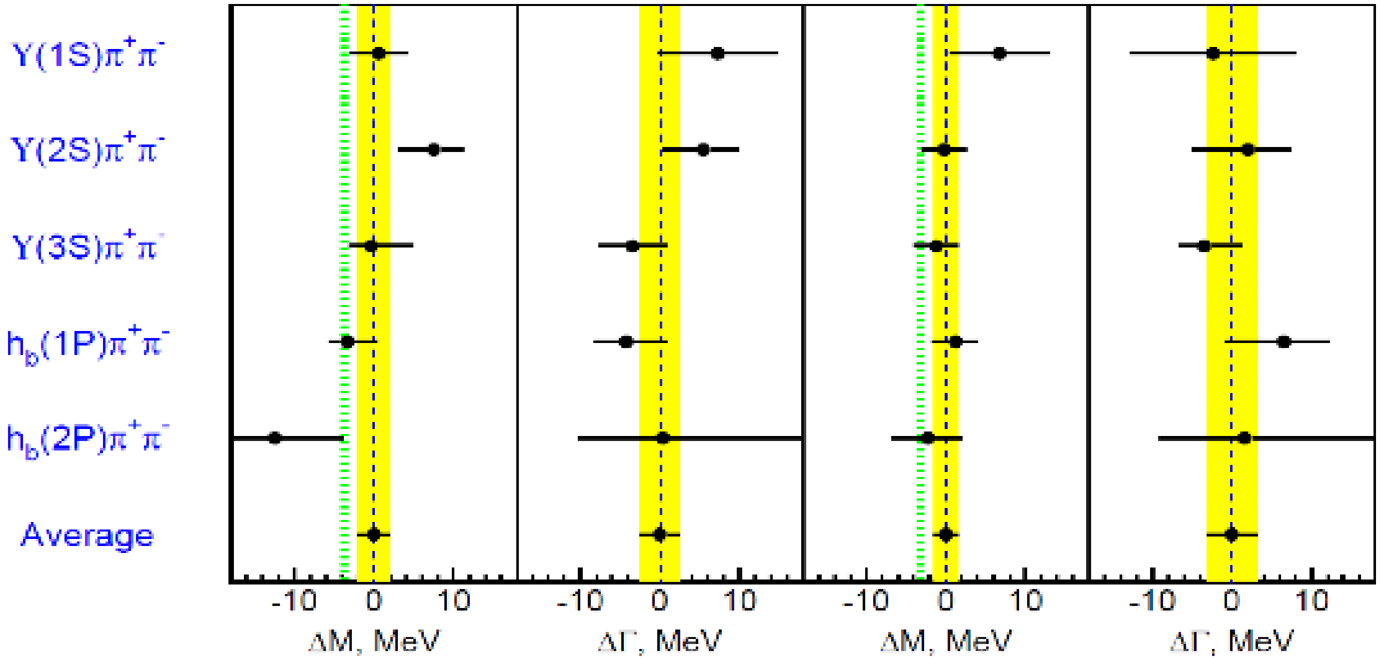


3 other observation of Z_b's !



Z_b Summary

PRL108,122001



Mass and Γ measured in 5 different final states agree

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

Z_b(10610)
M = 10608 pm 2.0 MeV
Γ = 15.6 pm 2.5 MeV
Z_b(10650)
M = 10653 pm 1.5 MeV
Γ = 14.4 pm 3.2 MeV

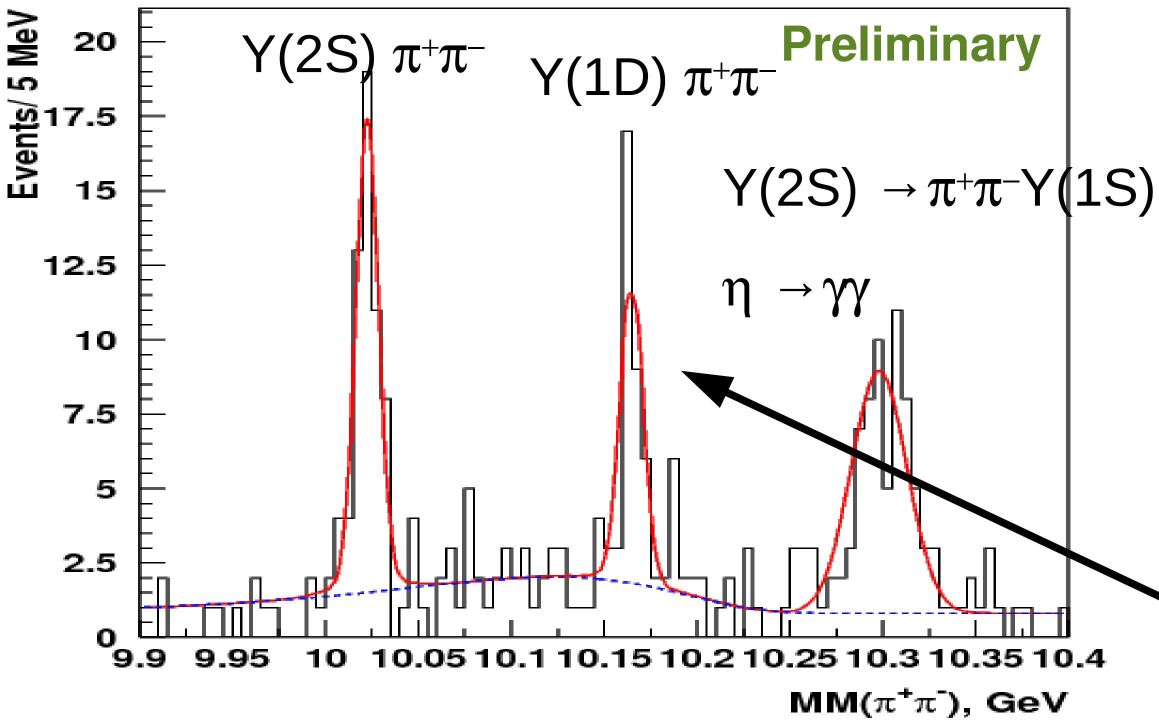
The Di Pion transitions from the Υ(5S) proceed via the intermediate charged state Z_b

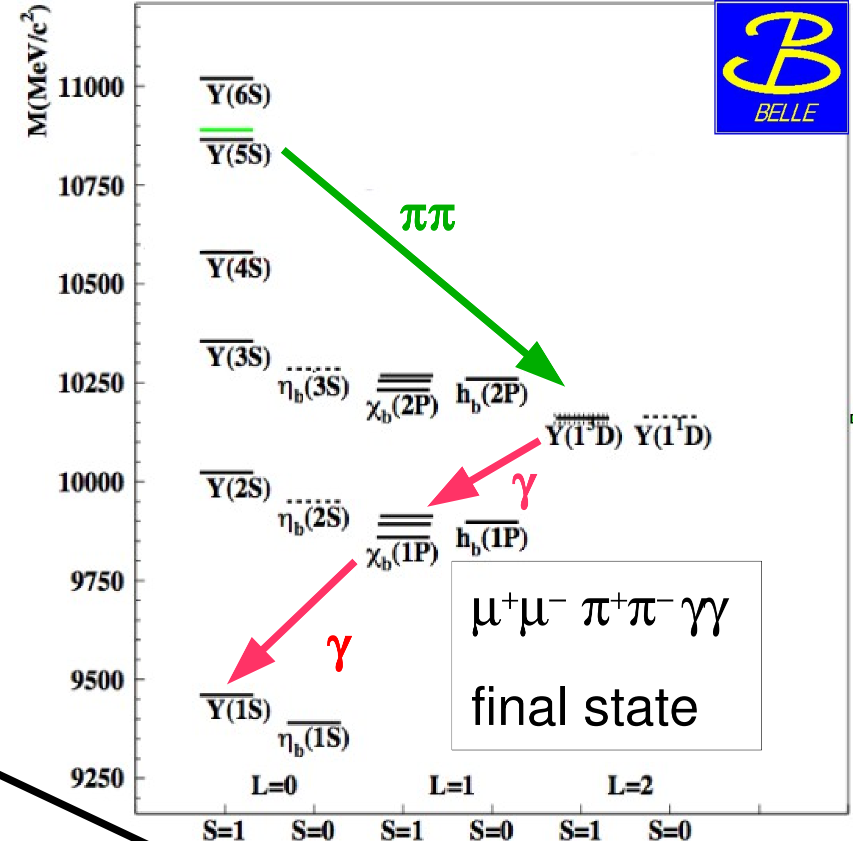
The transition does not imply spin flip

Masses are close to B*B and B*B* theresholds
Molecules?

The Υ(5S) is an unexpected source of h_b

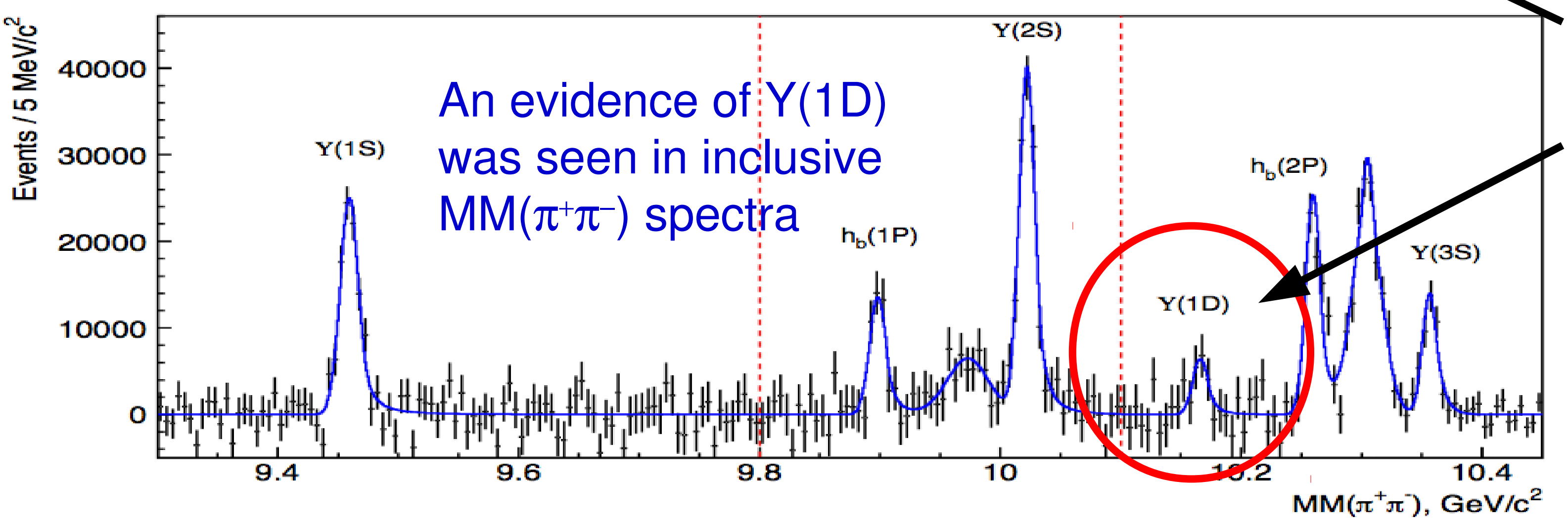
Υ(5S)→Υ(1D)$\pi^+\pi^-$





Significance 9 σ

Significance 2.9σ



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

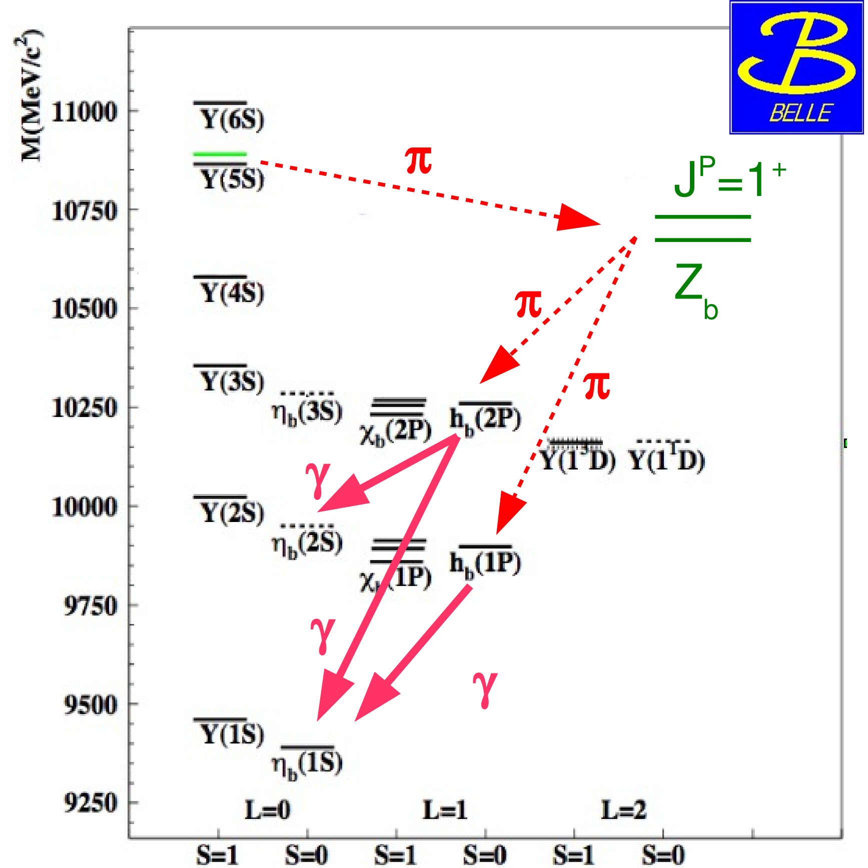
h_b (1P,2P)→ $\gamma\,\eta_b$ (1S,2S)

PRL109 (2012) 232002

h_b(1,2P) is predicted to have large BF for radiative decays to η_b

BF[$h_b(1P) \to \gamma\,\eta_b(1S)$] = **41%**
BF[$h_b(2P) \to \gamma\,\eta_b(1S)$] = **63%**
BF[$h_b(2P) \to \gamma\,\eta_b(2S)$] = **13%**

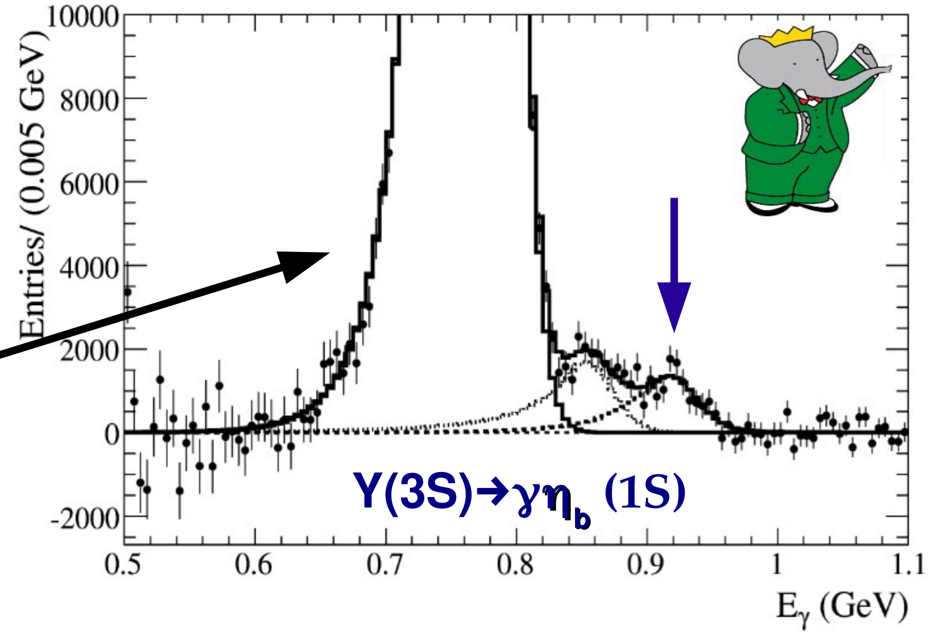
O(**10**^{4}) larger than in the Y(nS) system



Clean experimental signature with the h_b(1,2P) and Z_b tagging

Means

Less background than in the inclusive searches from Y(2,3S)



$\Upsilon(5S) \rightarrow \eta\, \Upsilon(1,2S)$

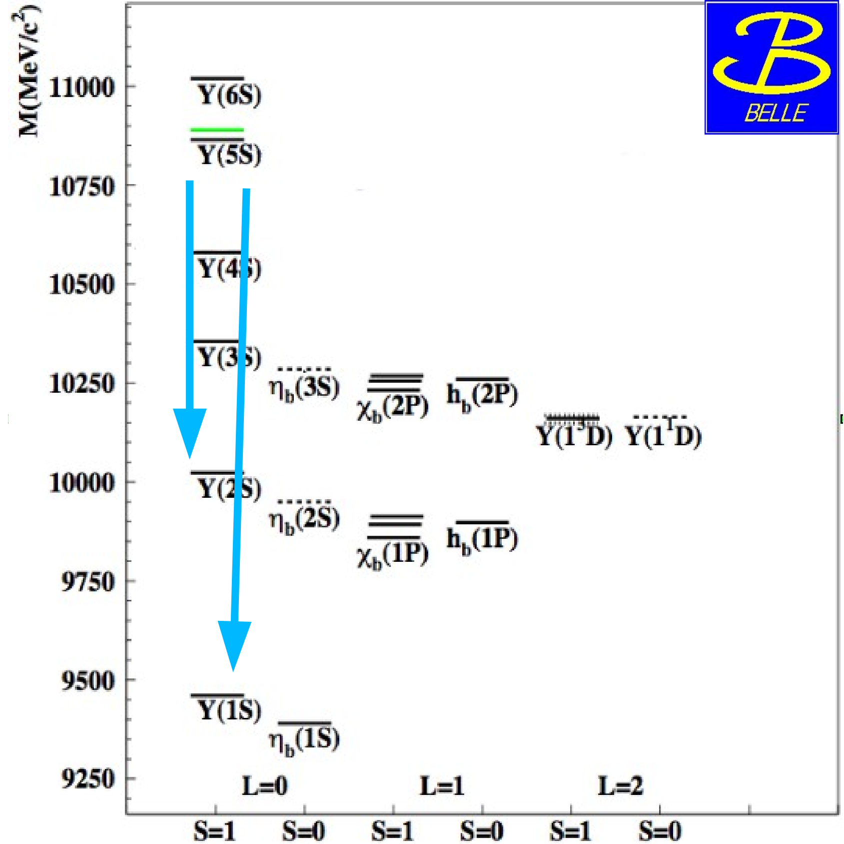
Exclusive reconstruction

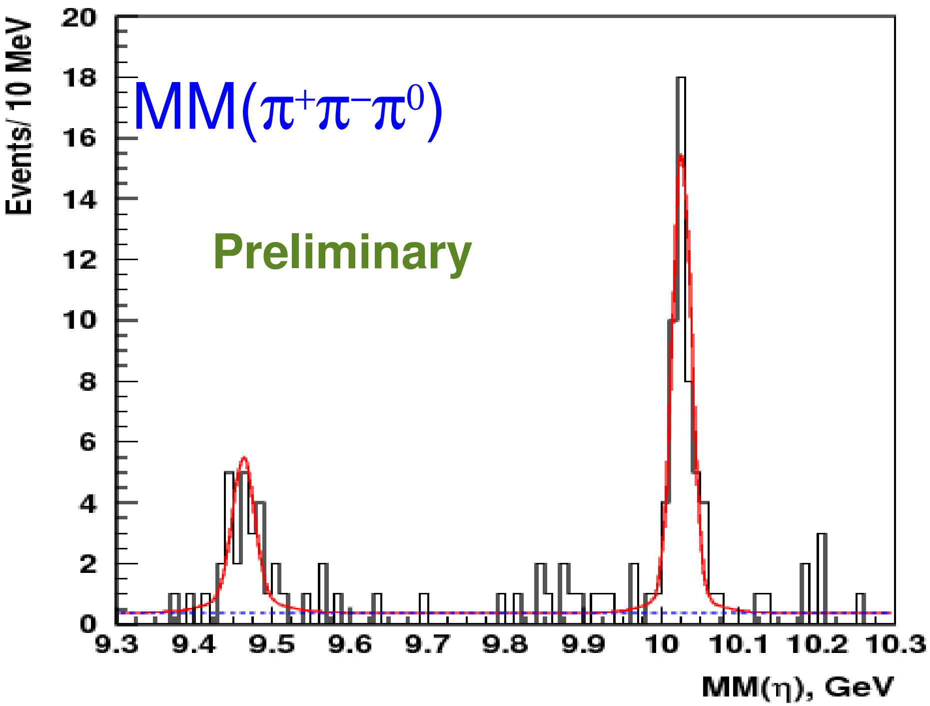
- $\Upsilon(1,2S) \rightarrow \mu^+\mu^- + \eta \rightarrow \pi^+\pi^-\pi^0$
- $\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^- + \eta \rightarrow \gamma\gamma$

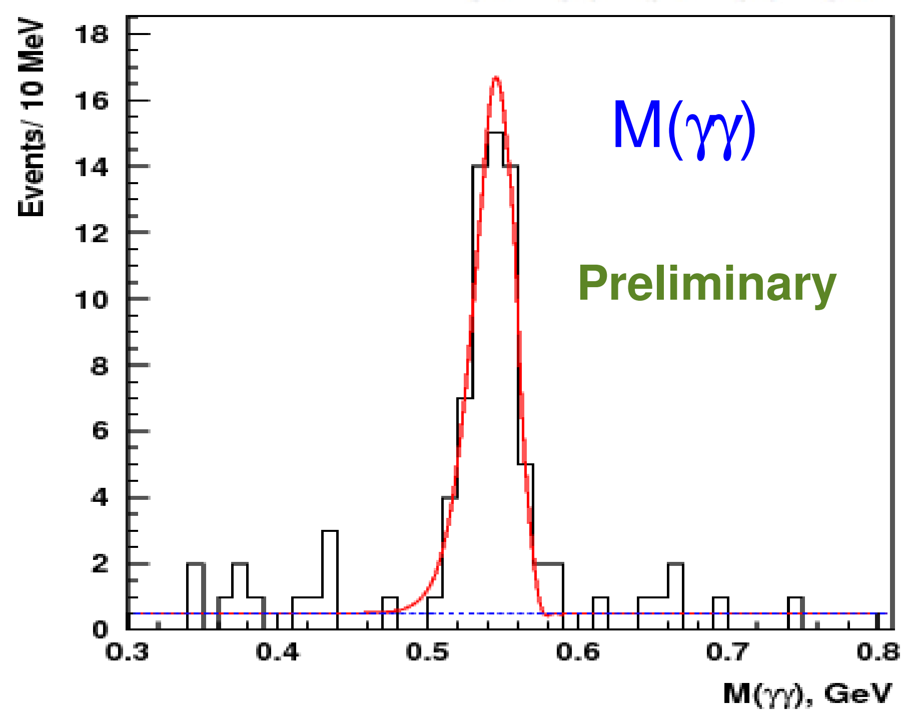
$B[\Upsilon(5S) \rightarrow \Upsilon(1S)\eta] = (7.3 \pm 1.6 \pm 0.8)\, 10^{-4}$

$B[\Upsilon(5S) \rightarrow \Upsilon(2S)\eta] = (38 \pm 4 \pm 5)\, 10^{-4}$

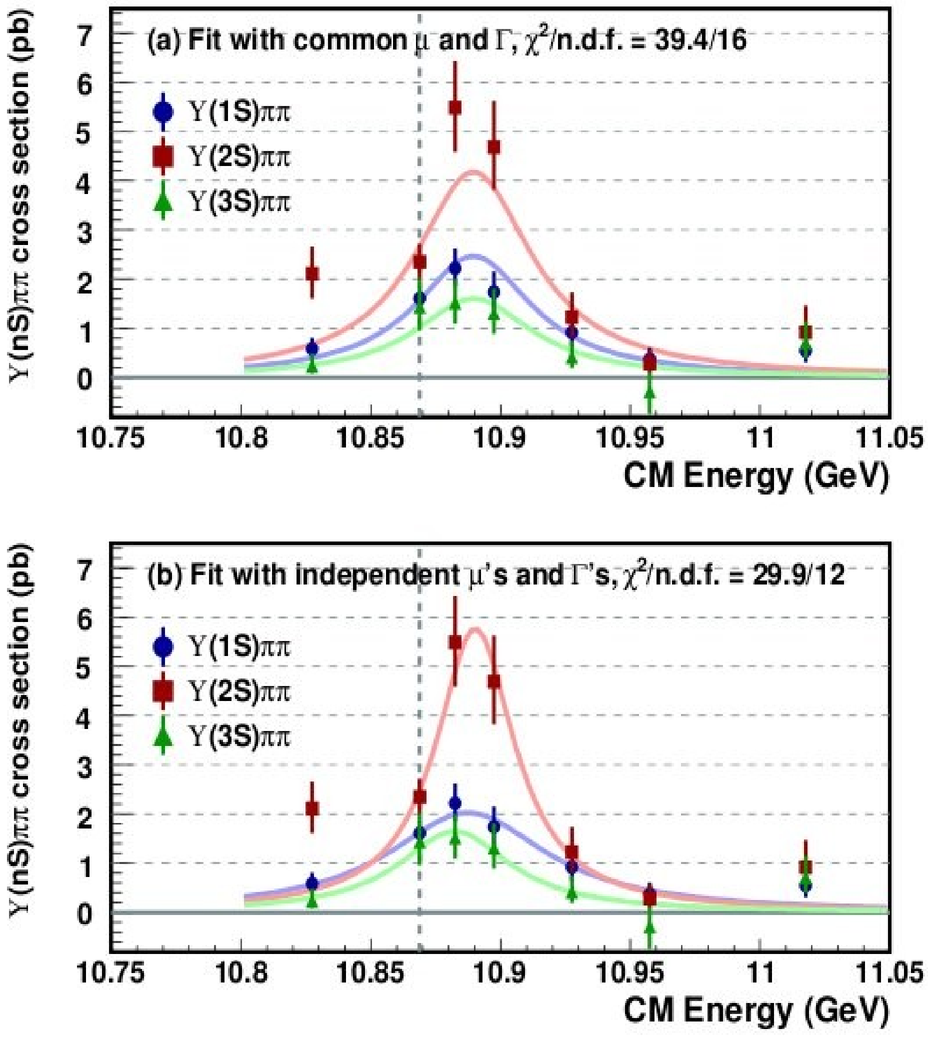
Preliminary

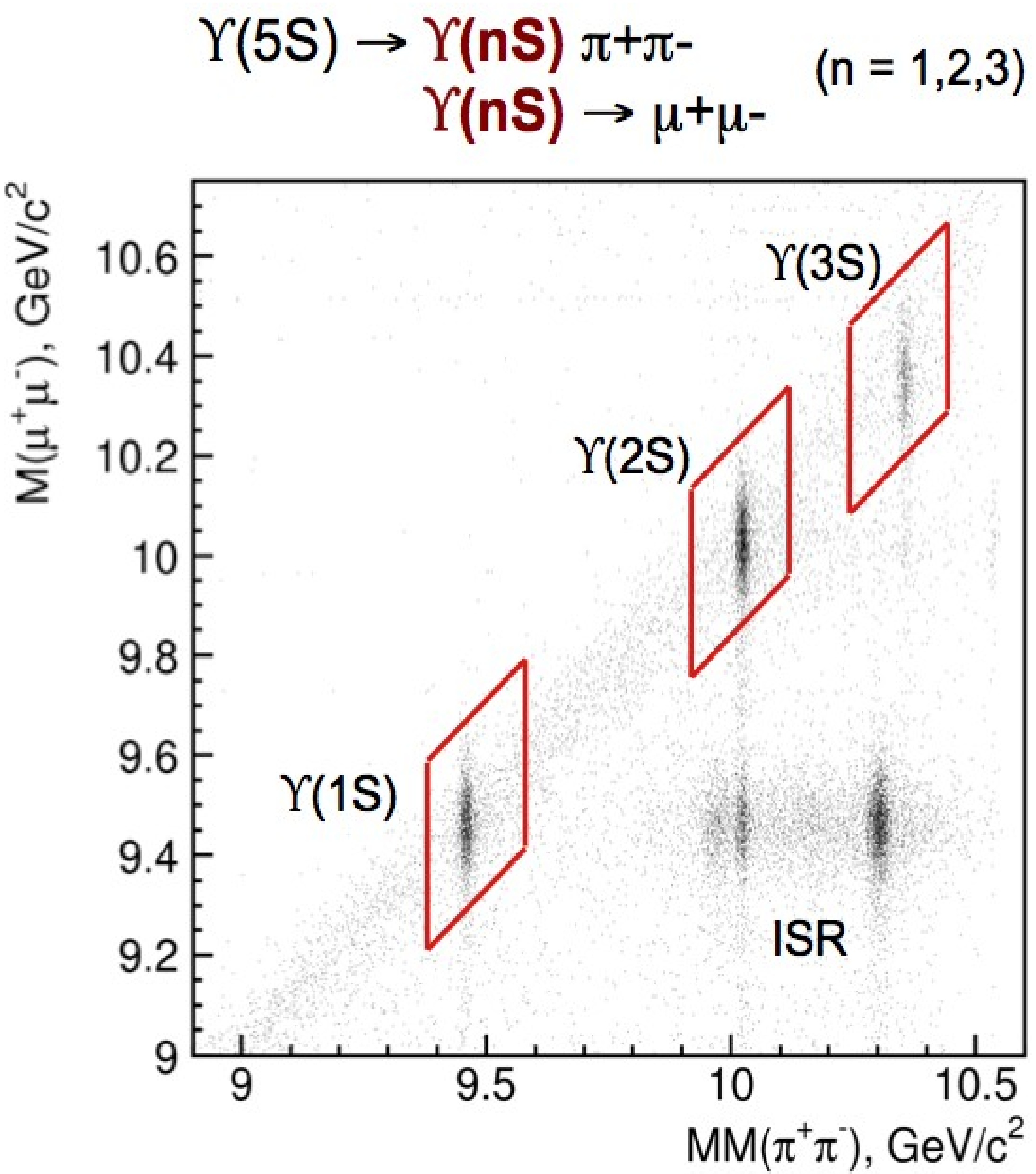






$\pi^+\pi^-$ transitions @ Υ(5S)





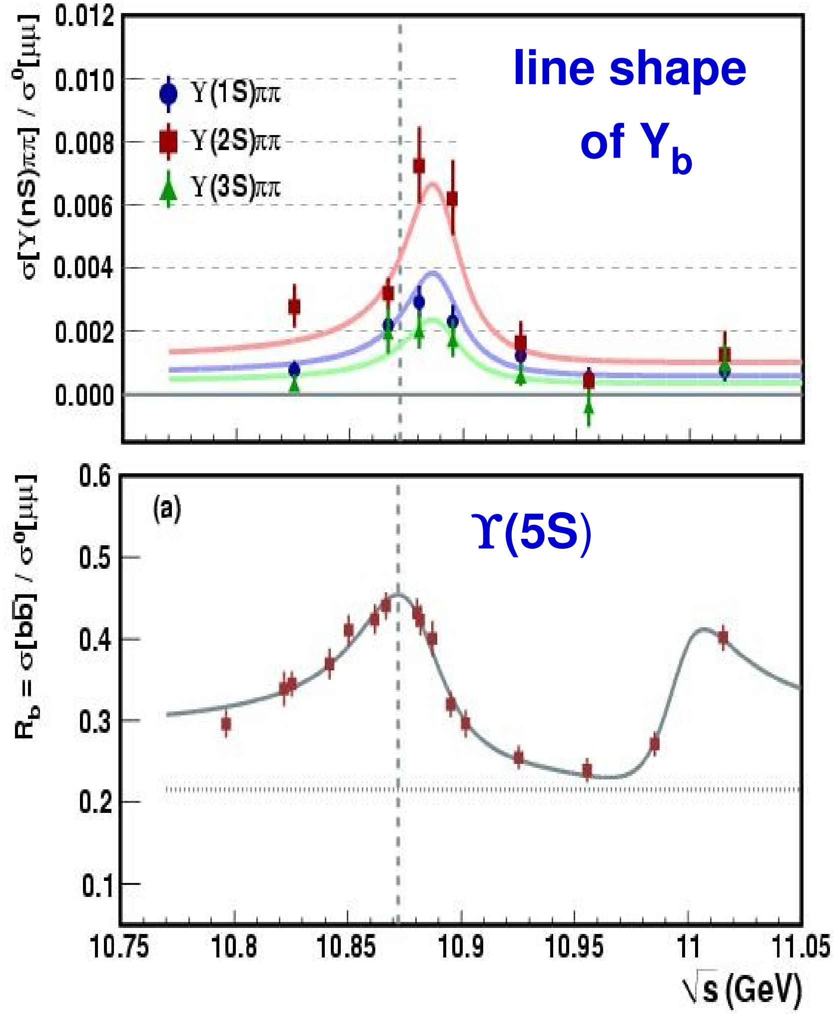
PRD82(2010),091106R

$\pi^+\pi^-$ transitions @ Υ(5S)

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

PRD82,091106R(2010)

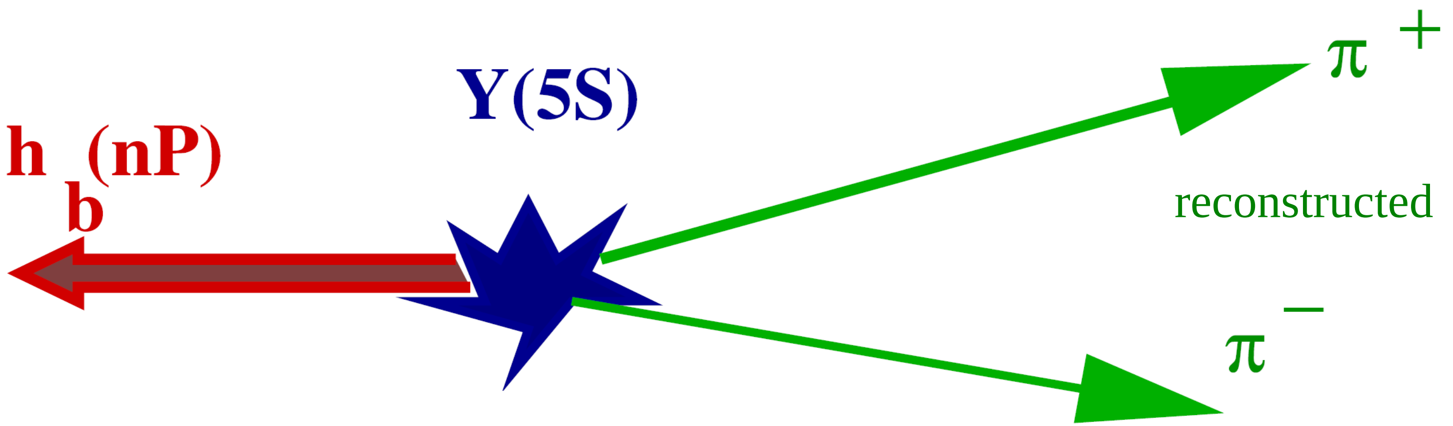


Simonov JETP Lett 87,147(2008)

Rescattering Y(5S) → BBππ → Y(nS)?

Missing Mass technique

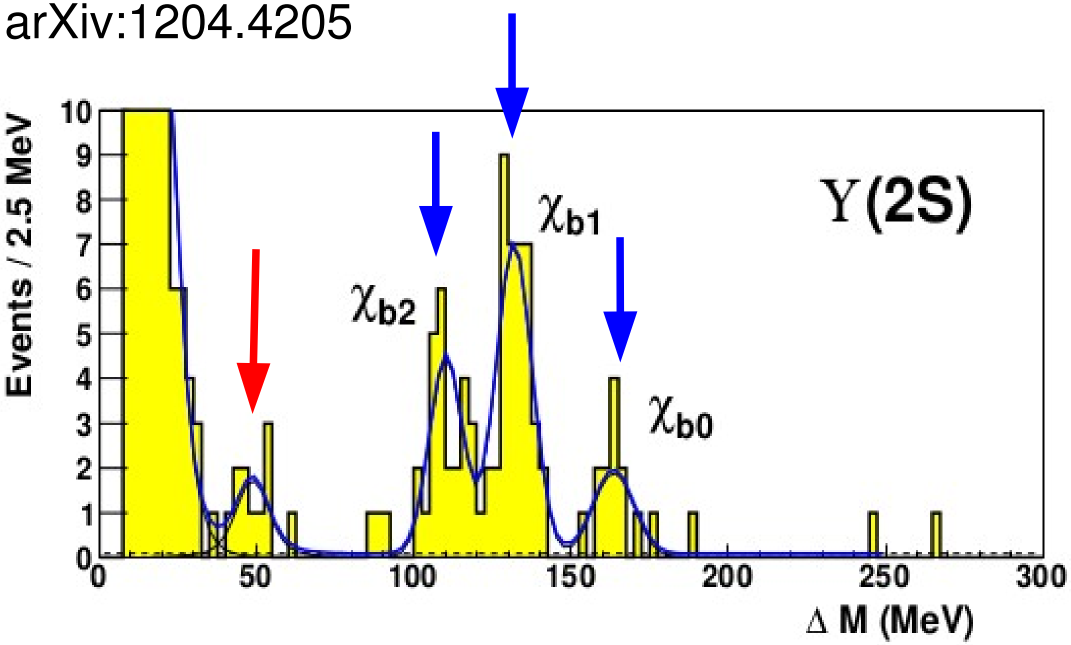
Y(5S) produced <u>at rest</u> in the colliding e⁺e⁻ frame



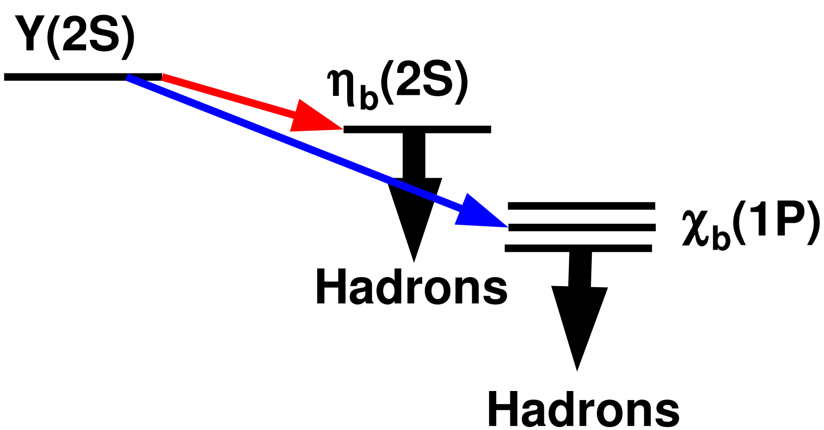
$$M(h_b) = \sqrt{(E_{c.m.} - E^*_{\pi+\pi-})^2 - p^2_{\pi+\pi-}} \equiv M_{miss}(\pi^+\pi^-)$$

η_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: **ΔM_{HF}(2S) = $23.4^{+4.0}_{-4.5}$ MeV**

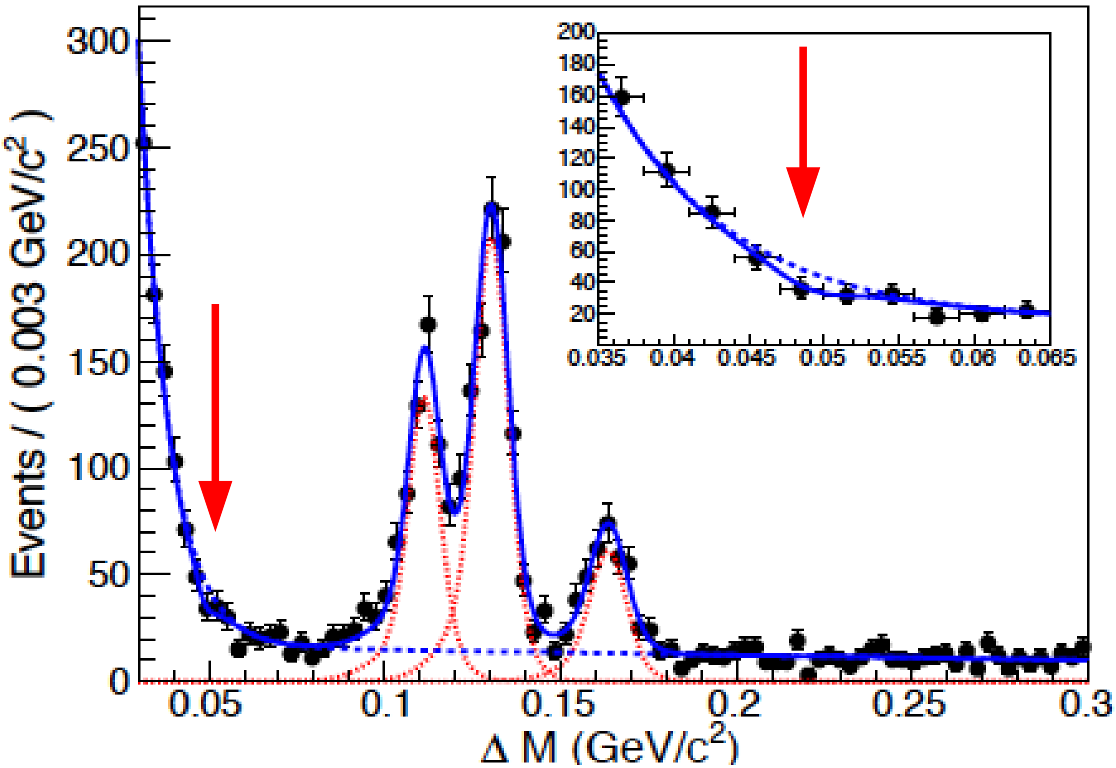
Dobbs et al.: **ΔM_{HF}(2S) = 48.7 MeV**

	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	$30.1^{+33.5}_{-7.4} \pm 7.5$

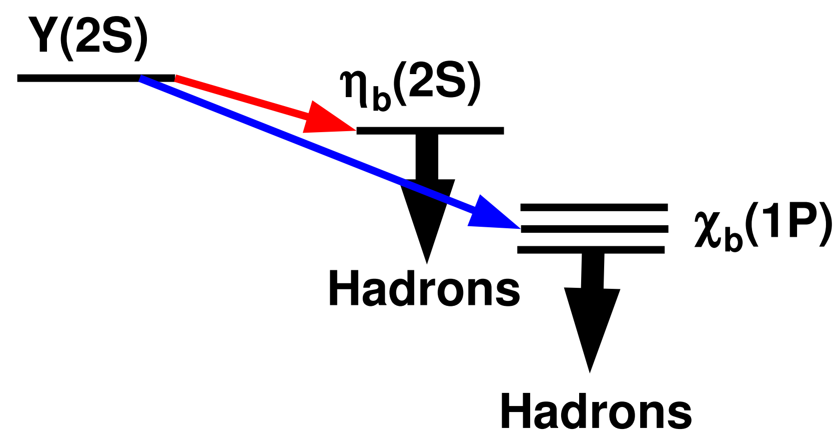
BF[Υ(2S) → $\gamma\eta_b$(2S)] x BF[$\gamma\eta_b$(2S) → hadrons] = **($46.2^{+29.2}_{-14.2}$ ±10.6) x 10^{-6}**

Exclusive $\eta_b(2S)$ at Belle

arXiv:1306.6212



Identical reconstruction modes



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

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

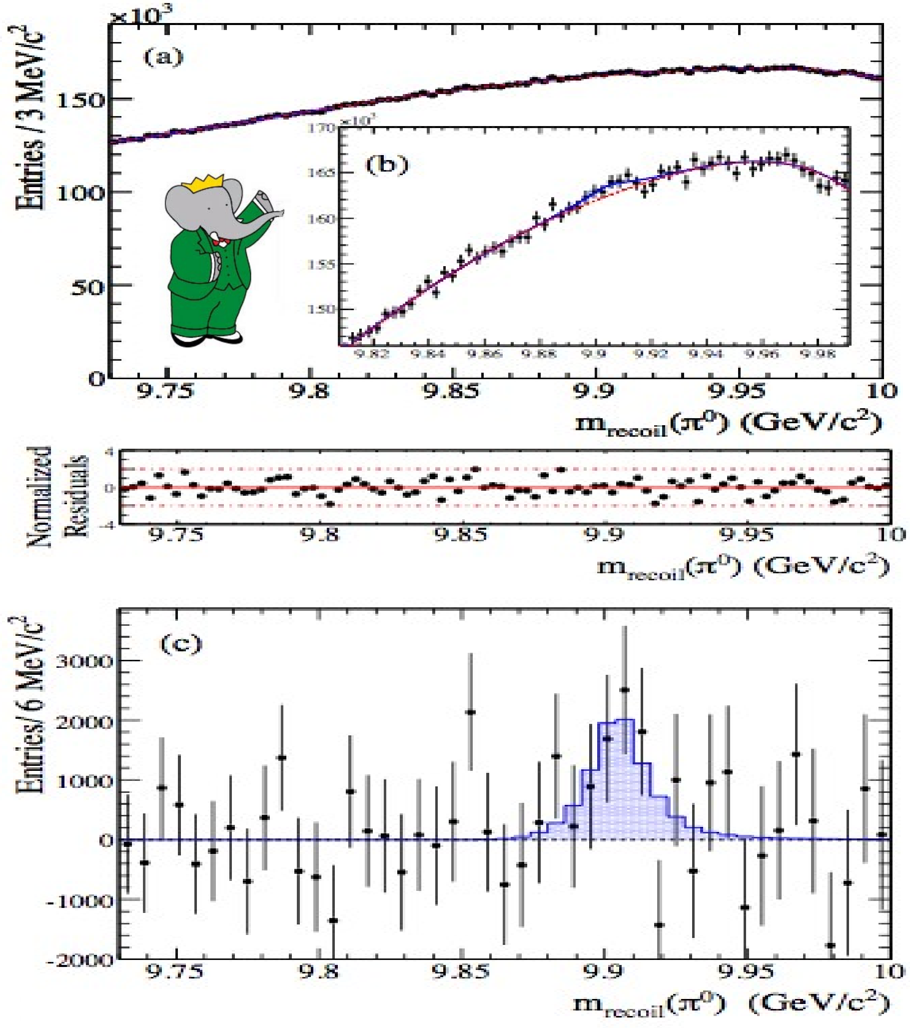
87 fb^{-1} below Y(4S) energy
for the study of the contiuum background study

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

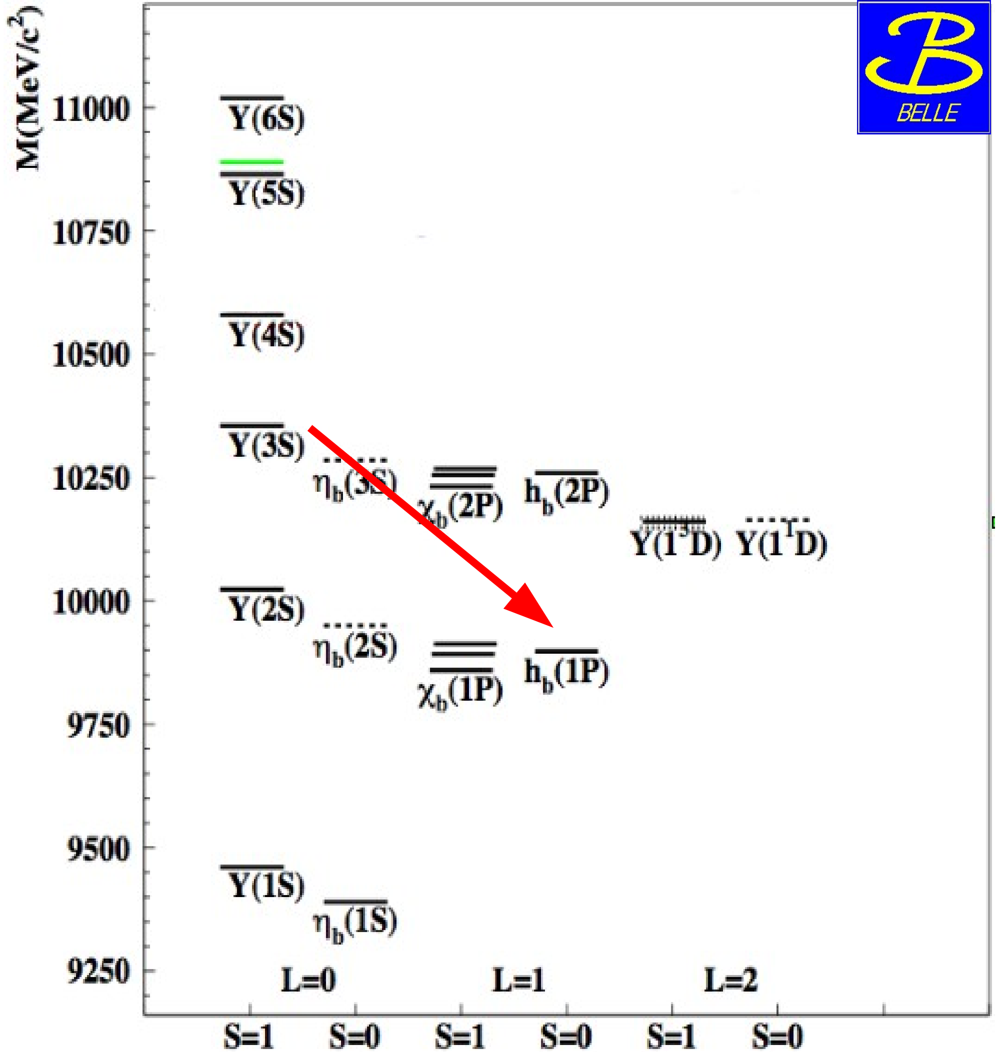
~ one order of magnitude below the claim by Dobbs et at

$h_b(1P)$ at BaBar

3 sigma evidence:
$e^+e^- \rightarrow \Upsilon(3S) \rightarrow \pi^0 h_b$



π^0 recoil mass (GeV/c^2)



Phys.Rev.D 84 091101(R)

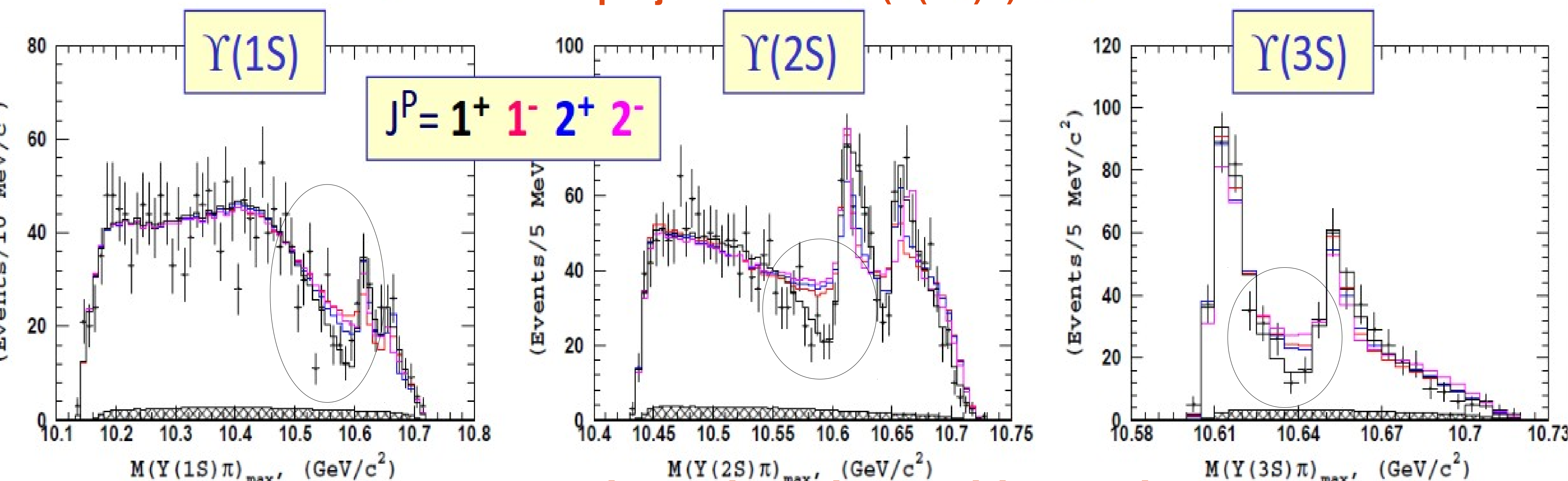
Spin-parity of the Z_b

New study of spin parity with a **6-D fit** that includes contributions from non-resonant S and D waves:

$$S(s1,s2) = A(Z_b) + A(Z'_b) + A(f_0(980)) + A(f_2(1275)) + A(NR) + A(\sigma)$$

- $A(Z_b)$, $A(Z'_b)$: Breit-Wigner
- $A(f_0(980))$: Flatte
- $A(f_2(1275))$: Breit-Wigner
- $A(NR)$: $c_1 + c_2 M^2(\pi\pi)$
- $A(\sigma)$: Breit-Wigner

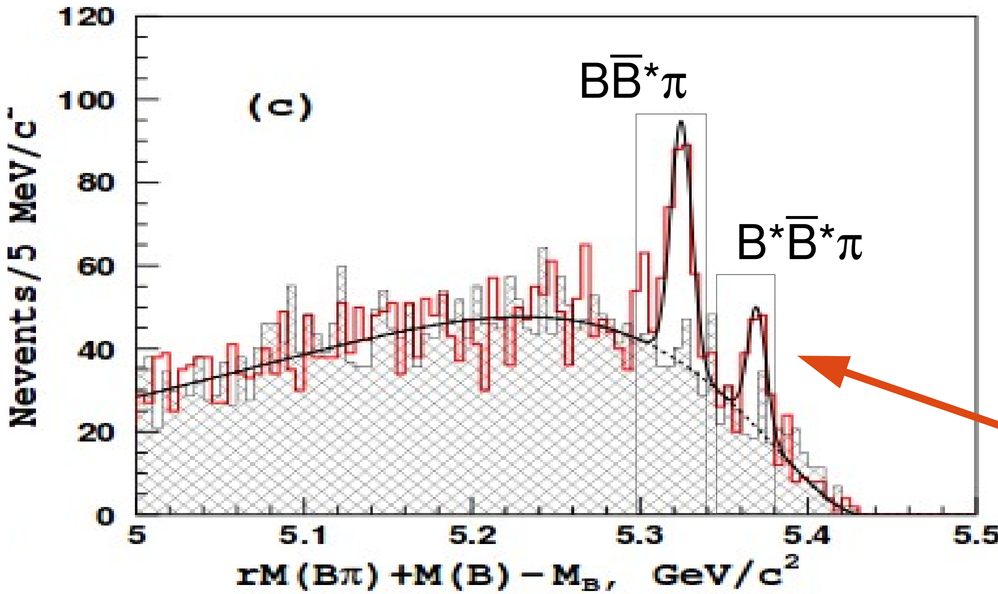
Fit projections in $M(\Upsilon(nS)\pi)$

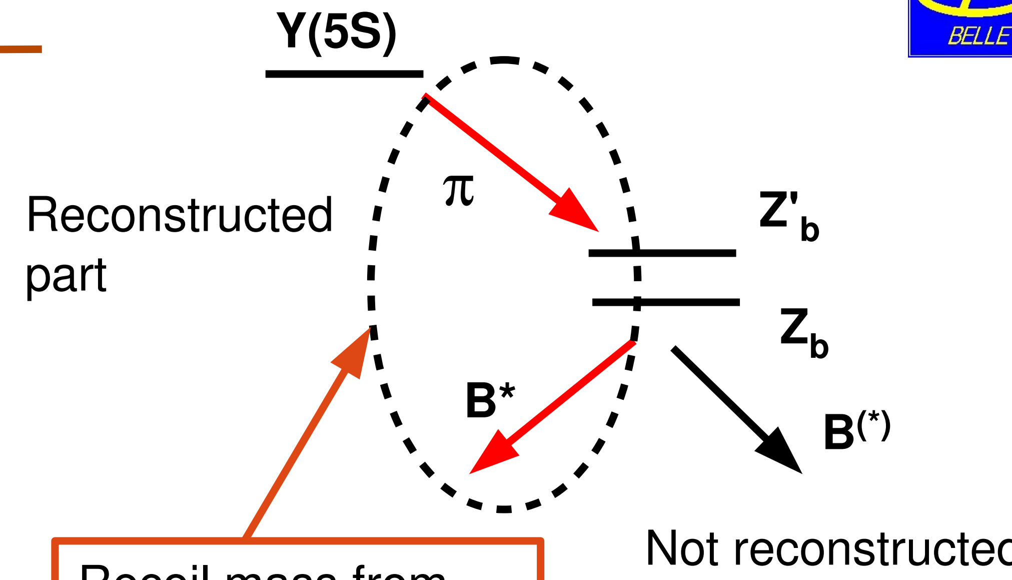


1^+ is assigned unambiguously

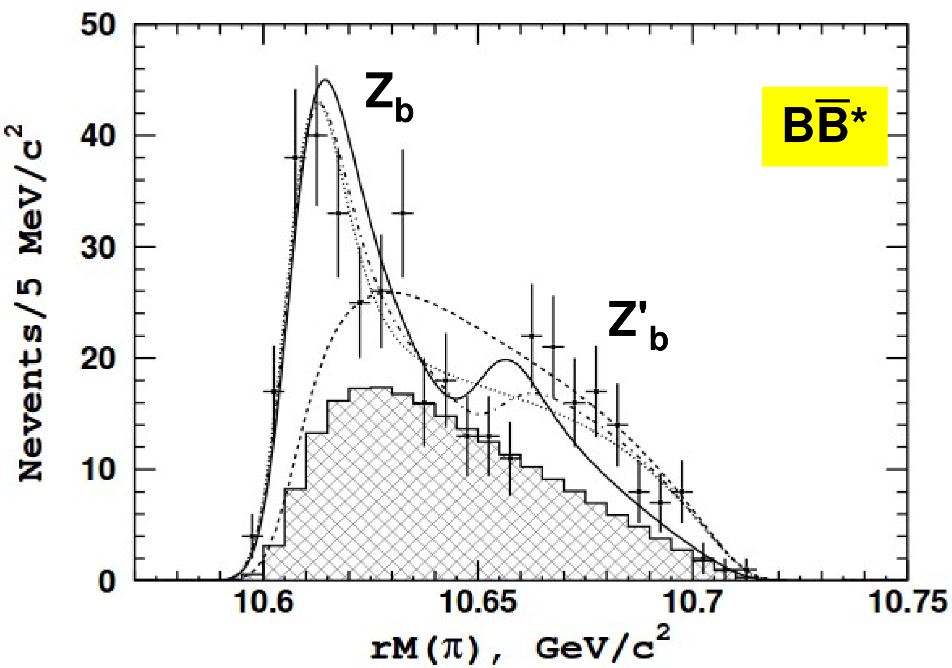
Z_b decay modes

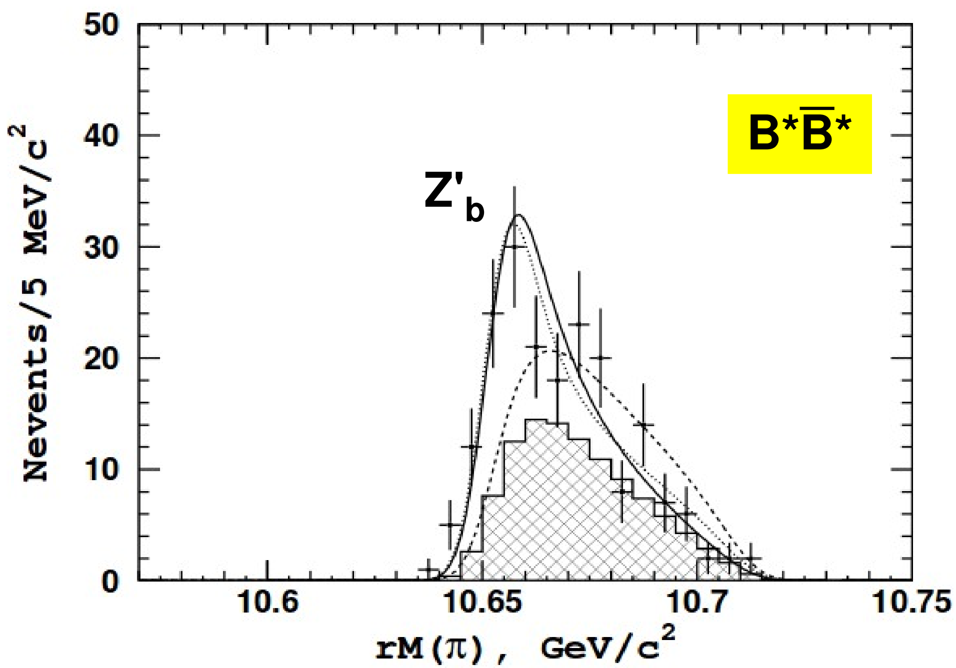
arXiv:1209.6450v2





Recoil mass from $B^*\pi$ system tags the other B



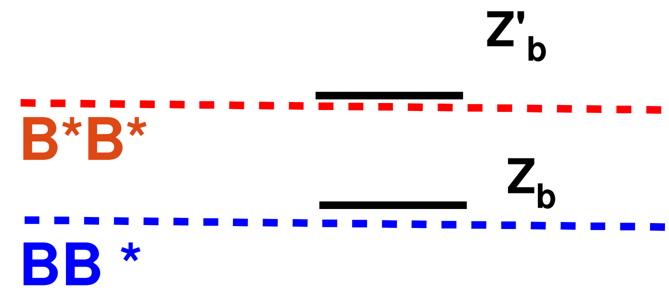


Recoil mass form single pion in selected events

Z_b decay modes

arXiv:1209.6450v2

Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ± 3.6	–
$B^{*+}\bar{B}^{*0}$	–	73.4 ± 7.0



From inclusive Y(5S) → $\pi^+\pi^-$ +X decays

Kinematically favoured but absent

Why Z_b(10650) should not decay in BB* ?

Molecular Model

Z_b ~ | BB *>

Z'_b ~ |B*B* >   with negligible |BB*> component

Proximity to open threshold ✓

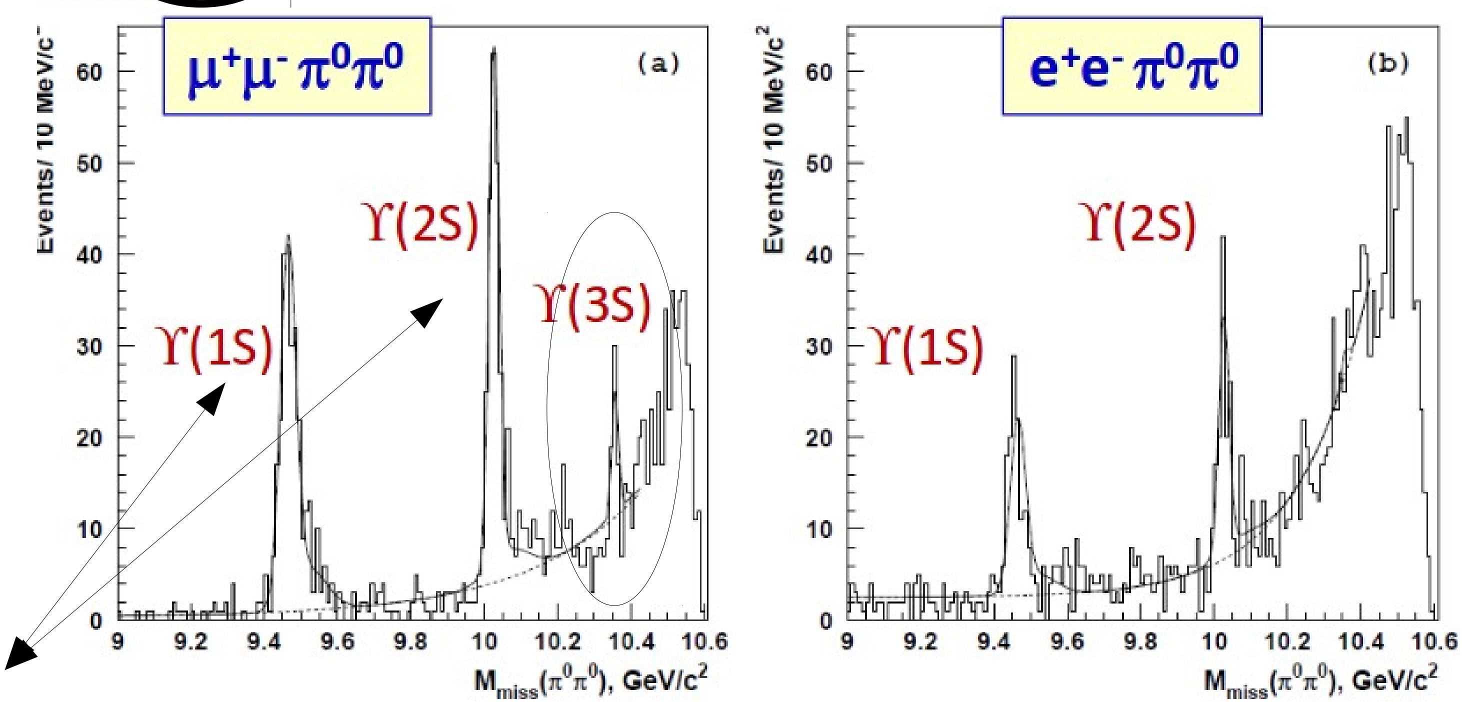
Γ(open flavour) >> Γ(narrow quarkonium) ✓

The Z_b are BB* and B*B* molecules with $J^P = 1^+$ (?)

Search for Z_b^0

arXiv:1318.2648

$\Upsilon(5S) \to \pi^0\pi^0 \Upsilon(nS) \longrightarrow e^+e^-, \mu^+\mu^-$



BF[$\Upsilon(5S) \to \pi^0\pi^0 \Upsilon(1S)$] = $(2.25 \pm 0.11 \pm 0.20) \times 10^{-3}$ BF[$\pi^+\pi^-$] = $(4.45 \pm 0.16 \pm 0.35) \times 10^{-3}$

BF[$\Upsilon(5S) \to \pi^0\pi^0 \Upsilon(2S)$] = $(3.79 \pm 0.24 \pm 0.49) \times 10^{-3}$ BF[$\pi^+\pi^-$] = $(7.97 \pm 0.31 \pm 0.96) \times 10^{-3}$

BF[$\Upsilon(5S) \to \pi^0\pi^0 \Upsilon(3S)$] = $(2.09 \pm 0.51 \pm 0.34) \times 10^{-3}$ BF[$\pi^+\pi^-$] = $(2.88 \pm 0.19 \pm 0.36) \times 10^{-3}$

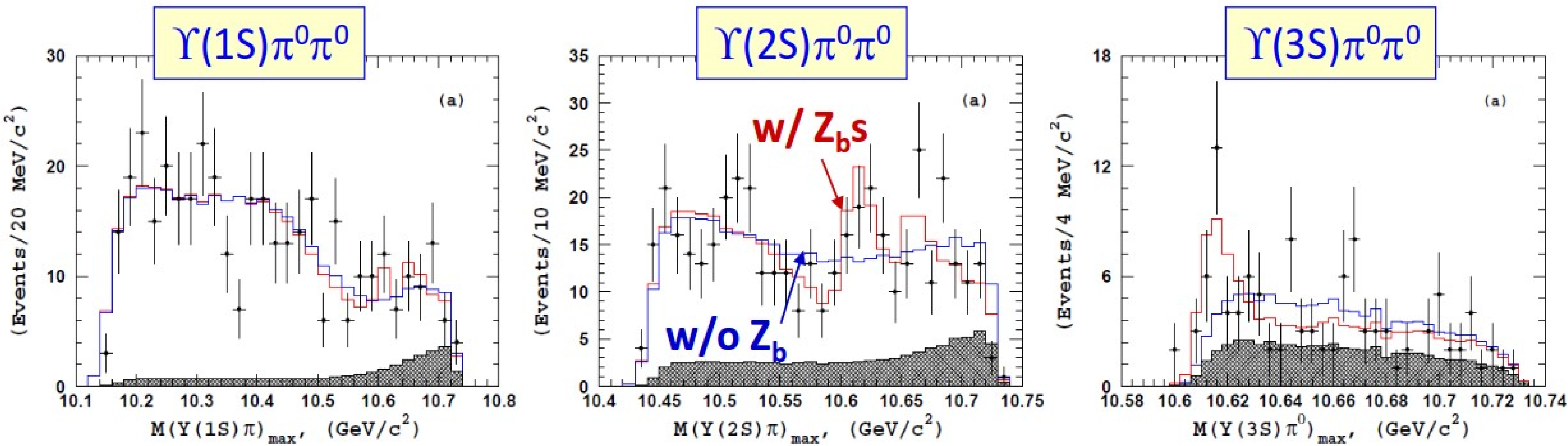
Isospin symmetry : BF[$\pi^+\pi^-$] = 2x BF[$\pi^0\pi^0$] OK

Search for Z_b^0

arXiv:1318.2648

Again multidimensional fit that includes contributions from non resonant S and D wave

$$S(s1,s2) = A(Z_b) + A(Z'_b) + A(f_0(980)) + A(f_2(1275)) + A(NR)$$



Significance is calculated from the Multi-dimensional fit

Z^0_b(10610): 6.5 σ [4.9σ from Y(2S) + 4.3σ from Y(3S)] Observed

Z^0_b(10650): not observed but not excluded either

$\Upsilon(1,2S) \rightarrow \Lambda + X$

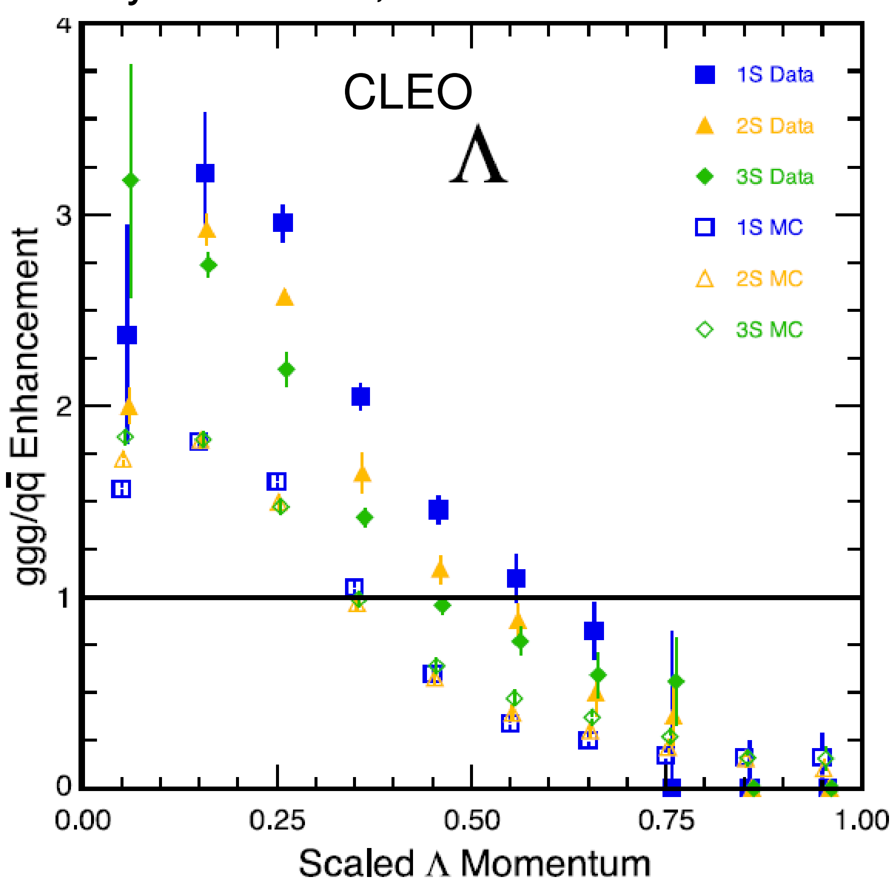
Hyperon production is **enhanced** in Υ decays with respect to the nearby continuum and is **large**.

BF(Υ(1S) → Λ + X) ~ 10%

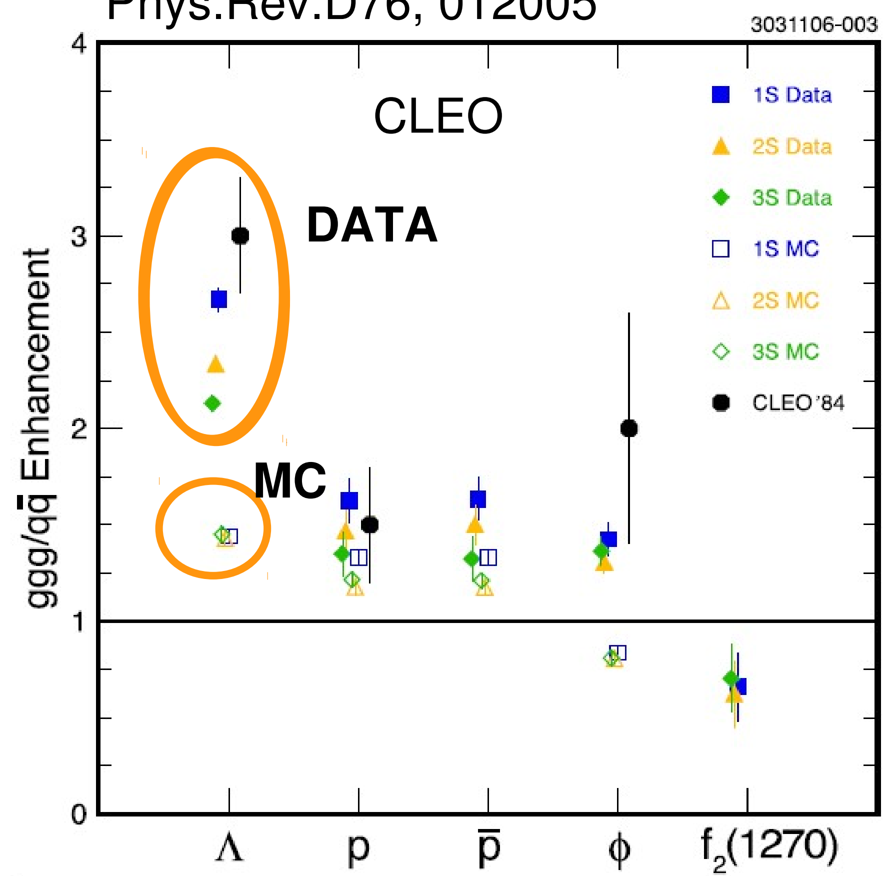
Enhancement for baryon $\mathcal{B}$:

$$\frac{\sigma[e^+e^- \rightarrow \Upsilon(nS) \rightarrow \mathcal{B} + X]}{\sigma[e^+e^- \rightarrow q\bar{q} \rightarrow \mathcal{B} + X]}$$

Phys.Rev.D76, 012005

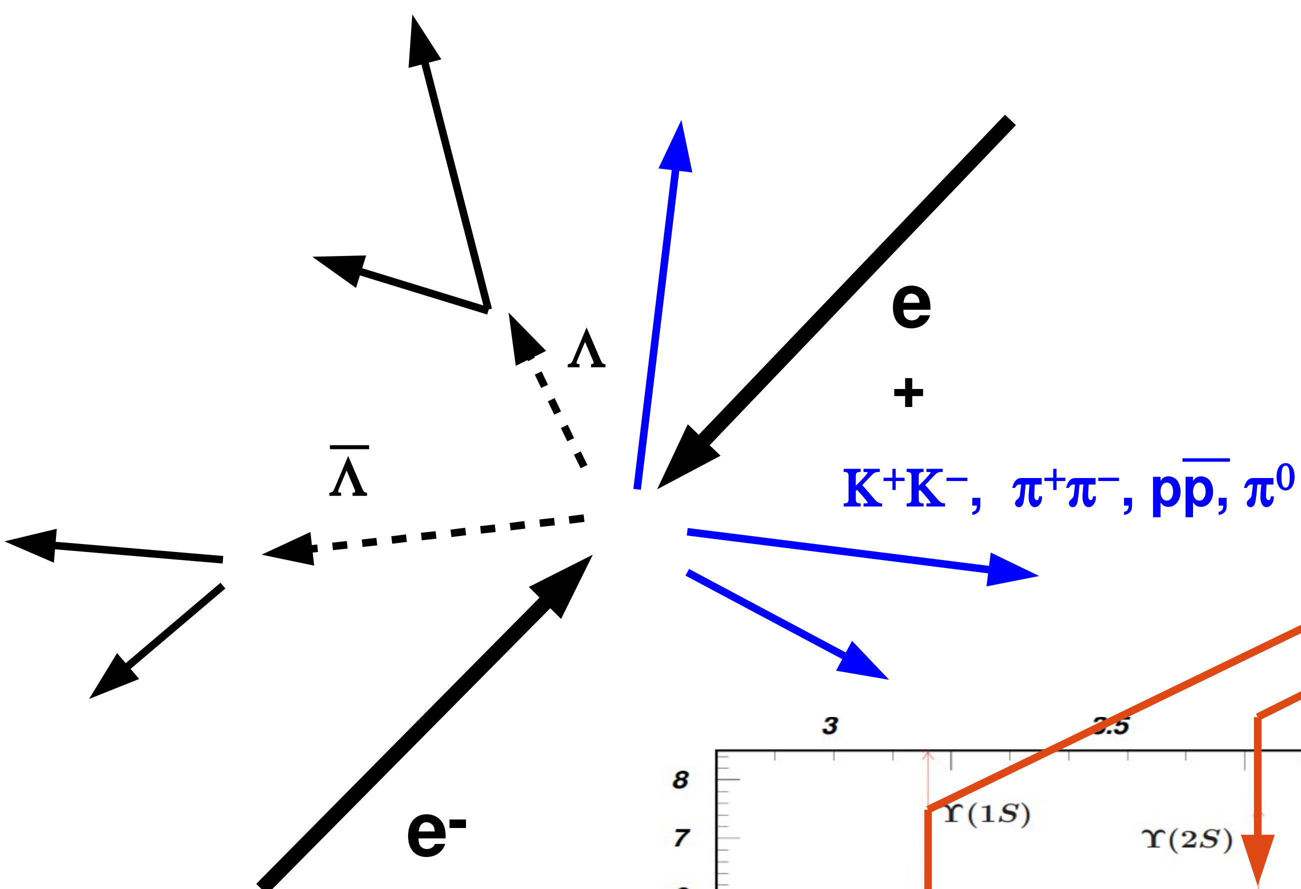


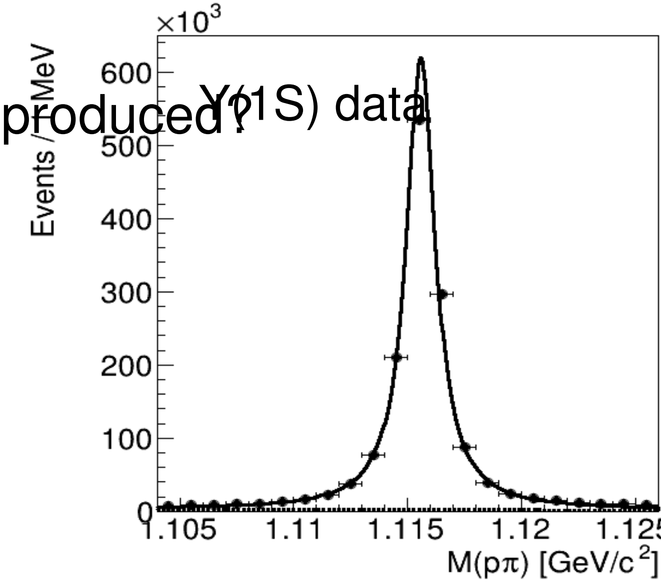
Phys.Rev.D76, 012005



Υ(1,2S)→ exclusive $\Lambda\bar{\Lambda}$ + X

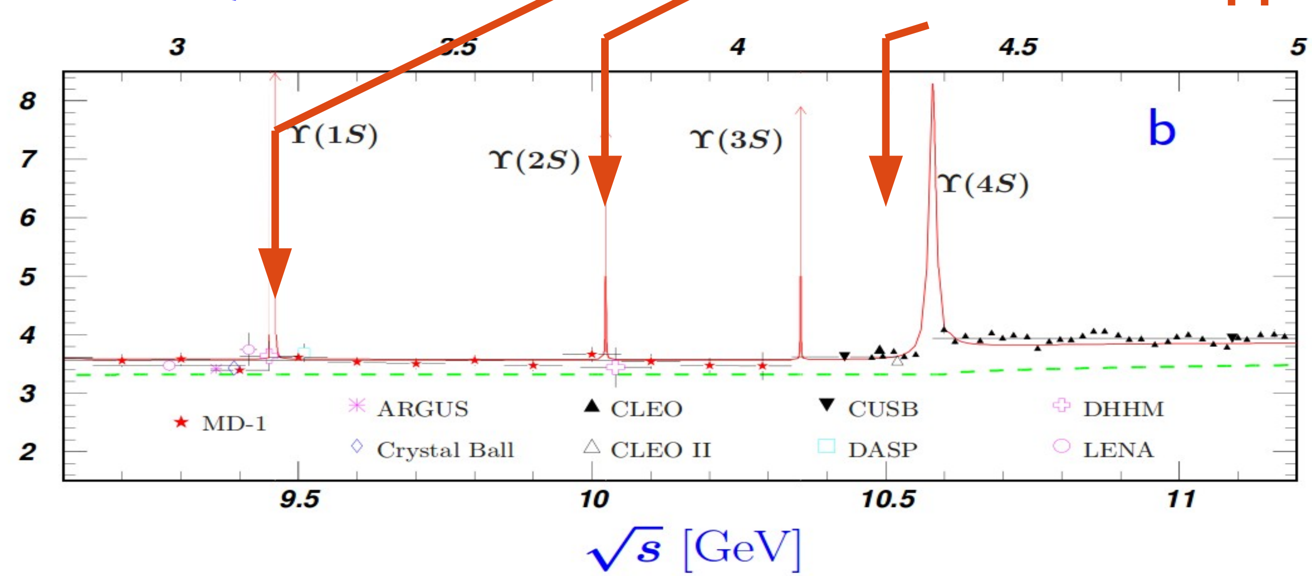
What is the enviroment in which these hyperons are produced?





Energies:

- Υ(1S)
- Υ(2S)
- Continuum $q\bar{q}$



$\Upsilon(1,2S) \rightarrow$ exclusive $\Lambda\bar{\Lambda}$ + X

X = combination of K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ and π^0

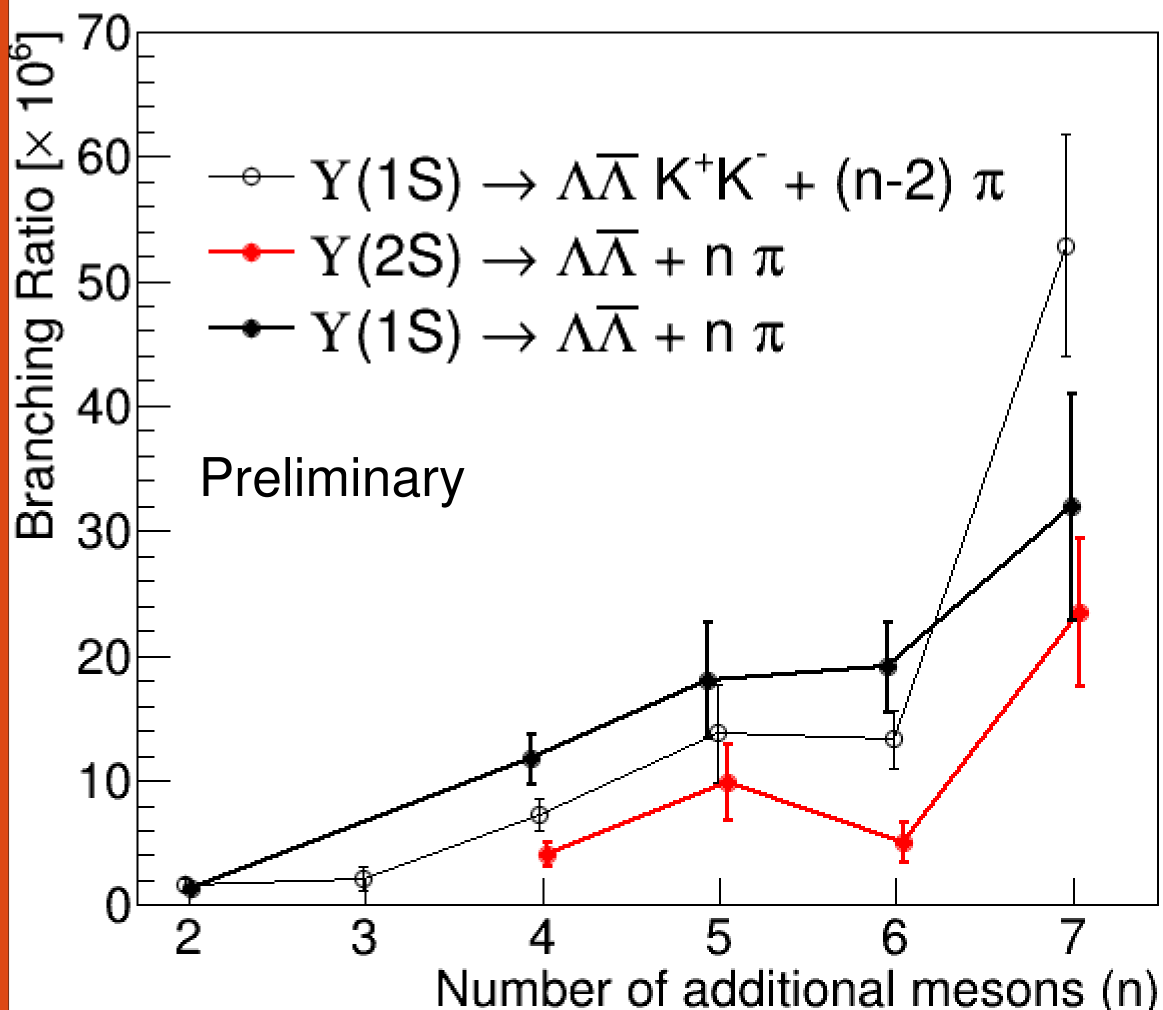
Max 9 bodies,

$\sum_X BF[\Upsilon(1S$

$\sum_X BF[\Upsilon(2S$

$2S(0)|^2$ = **0.77**

$1S(0)|^2$

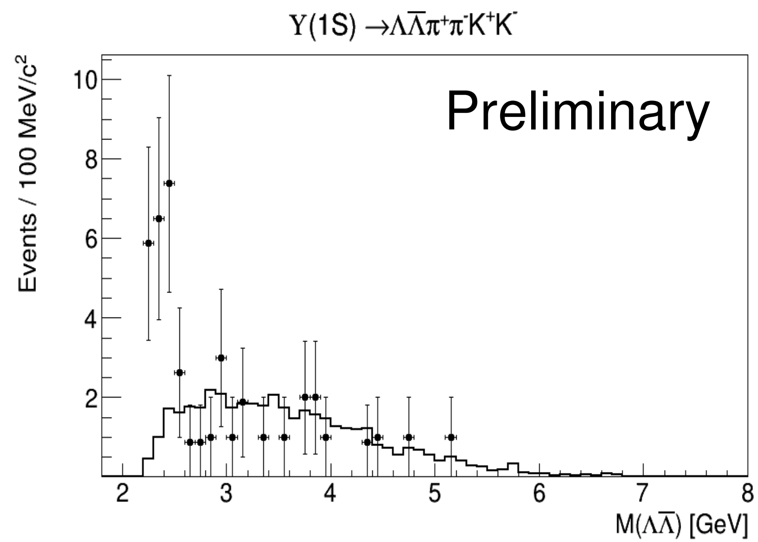


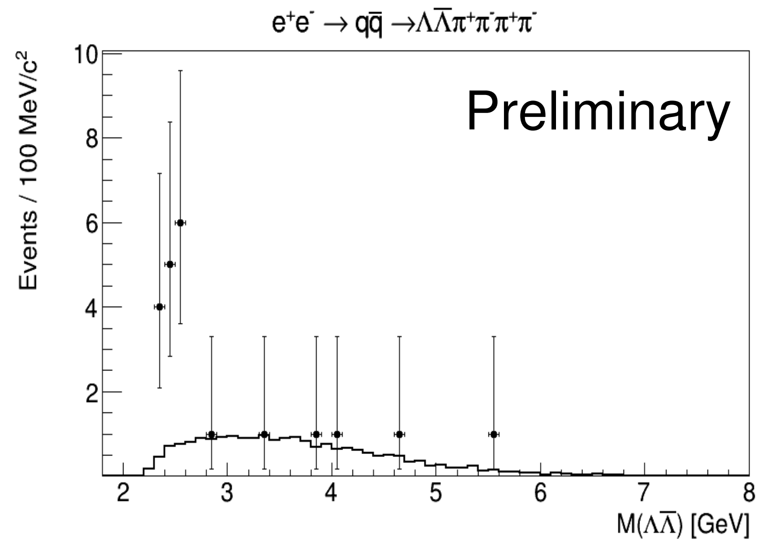
Channel			Q
$\Lambda\bar{\Lambda} + \pi^+\pi^-$			
$\Lambda\bar{\Lambda} + K^+K^-$			$\pm\ 0.53 \pm 0.11$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-$			$\pm\ 0.17 \pm 0.06$
$\Lambda\bar{\Lambda} + \pi^+\pi^- K$			
$\Lambda\bar{\Lambda} + \pi^+\pi^- p\bar{p}$			
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-$			$\pm\ 0.14 \pm 0.04$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-$			
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-$			
$\Lambda\bar{\Lambda} + \pi^+\pi^- 2($			
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi$			
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-$			$\pm\ 0.30 \pm 0.08$
$\Lambda\bar{\Lambda} + \pi^+\pi^- K$			
$\Lambda\bar{\Lambda} + \pi^+\pi^- p\bar{p}$			
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-$			$\pm\ 0.14 \pm 0.05$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78 \pm 9.35 \pm 5.54$	$30.70 \pm 8.60 \pm 5.36$	$0.97 \pm 0.39 \pm 0.12$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95 \pm 5.81 \pm 2.76$		

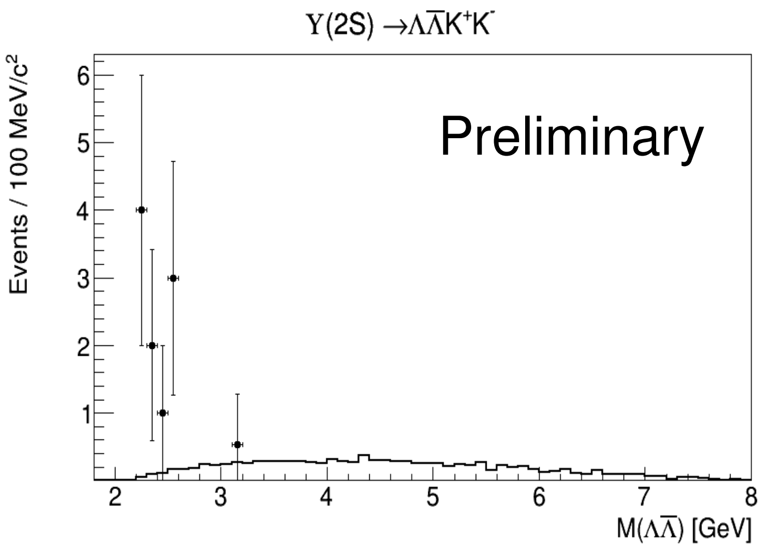
$\Upsilon(1,2S) \rightarrow$ exclusive $\Lambda\bar{\Lambda}$ + X

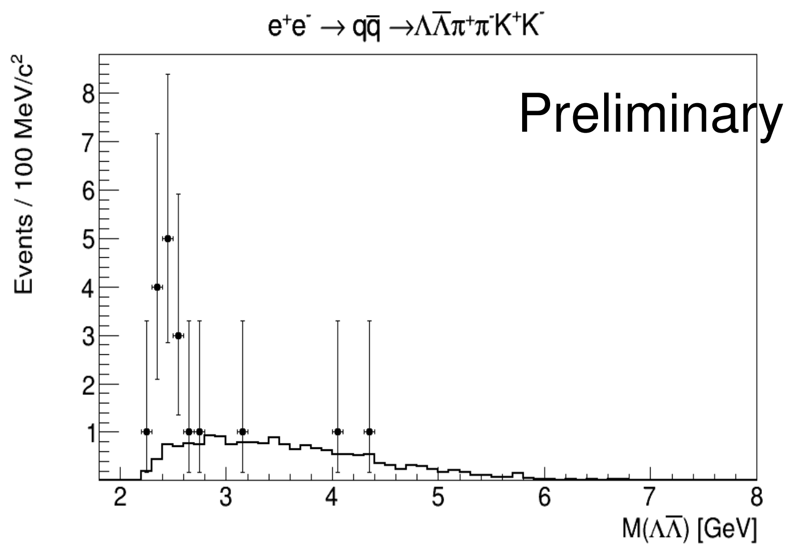
Dynamical interaction within the $\Lambda\bar{\Lambda}$ pair

→ Low threshold enhancement in M($\mathcal{B}\bar{\mathcal{B}}$) is a common feature in B meson baryonic decays









$\Upsilon(1,2S) \rightarrow$ exclusive $\Lambda\bar{\Lambda}$ + X

Preliminary

Dynamical interaction within the $\Lambda\bar{\Lambda}$ pair

→ Low threshold enhancement in M($\mathcal{B}\bar{\mathcal{B}}$) is a common feature in B meson baryonic decays

Significance of the deviation form phase space flat distribution

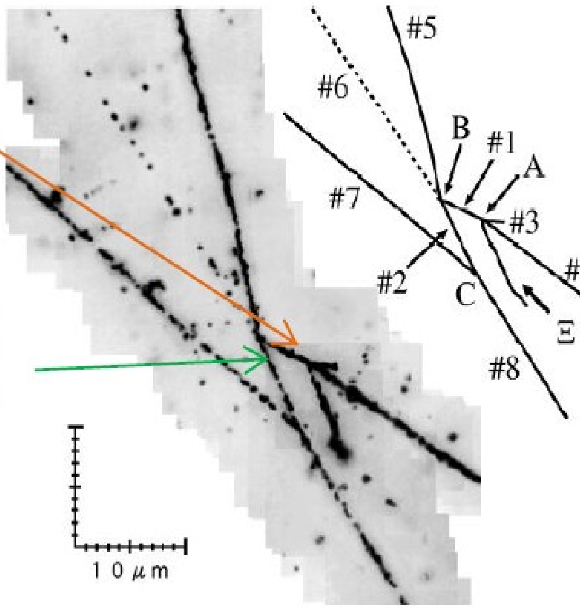
Final state X	$\Upsilon(1S) \to X$	$\Upsilon(2S) \to X$	$e^+e^- \to q\bar{q} \to X$
$\Lambda\bar{\Lambda} + \pi^+\pi^-$	2.16		1.83
$\Lambda\bar{\Lambda} + K^+K^-$	2.94	4.60	
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	2.96	3.07	4.23
$\Lambda\bar{\Lambda} + \pi^+\pi^- K^+K^-$	4.61		6.08
$\Lambda\bar{\Lambda} + \pi^+\pi^- p\bar{p}$	2.06		0.57
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)$	0.31	2.97	3.76
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	0.36		3.75
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	<0.1		0.83
$\Lambda\bar{\Lambda} + \pi^+\pi^- 2(K^+K^-)$	0.50	0.29	
$\Lambda\bar{\Lambda} + \pi^+\pi^- \ \pi^0$	1.95		2.36
$\Lambda\bar{\Lambda} + K^+K^- \ \pi^0$			1.51
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-) \ \pi^0$	<0.1	0.36	4.27
$\Lambda\bar{\Lambda} + \pi^+\pi^- K^+K^- \ \pi^0$	<0.1		2.33
$\Lambda\bar{\Lambda} + \pi^+\pi^- p\bar{p} \ \pi^0$	<0.1		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-) \ \pi^0$	1.38	0.25	2.10
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^- \ \pi^0$	1.28	<0.1	1.28
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p} \ \pi^0$	<0.1		

The Nagara event

Ξ^- beam on emulsion target (Phys. Rev. Lett. 87, 212502)

$\Xi^- + {}^{12}C \rightarrow {}_{\Lambda\Lambda}{}^{6}He(\#1) + t(\#4) + \alpha(\#3)$

${}_{\Lambda\Lambda}{}^{6}He(\#1) \rightarrow {}_{\Lambda}{}^{5}He(\#2) + p(\#5) + \pi(\#6)$



Event	Nuclide	$B_{\Lambda\Lambda}$ (MeV)	$\Delta B_{\Lambda\Lambda}$ (MeV)
1963	${}^{10}_{\Lambda\Lambda}Be$	17.7 ± 0.4	4.3 ± 0.4
1966	${}^{6}_{\Lambda\Lambda}He$	10.9 ± 0.5	4.7 ± 1.0
1991	${}^{13}_{\Lambda\Lambda}B$	27.5 ± 0.7	4.8 ± 0.7
NAGARA	${}^{6}_{\Lambda\Lambda}He$	7.13 ± 0.87	1.0 ± 0.2
MIKAGE	${}^{6}_{\Lambda\Lambda}He$	10.06 ± 1.72	3.82 ± 1.72
DEMACHIYANAGI	${}^{10}_{\Lambda\Lambda}Be$	11.90 ± 0.13	-1.52 ± 0.15
HIDA	${}^{11}_{\Lambda\Lambda}Be$	20.49 ± 1.15	2.27 ± 1.23
	${}^{12}_{\Lambda\Lambda}Be$	22.23 ± 1.15	–
E176	${}^{13}_{\Lambda\Lambda}Be$	23.3 ± 0.7	0.6 ± 0.8

ΛΛ binding energy = 7 MeV

M(H) > 2223.7 MeV (90% CL)

2M(Λ) = 2231.36 MeV

$\Upsilon(1,2S) \to$ exclusive $\Lambda\bar{\Lambda} + X$

BELLE

Preliminary

X = combination of K^+K^-, $\pi^+\pi^-$, $p\bar{p}$ and π^0
Max 9 bodies, Max one π^0 → 48 channels

First observation of Y(nS) exclusive decays with hyperons

$$\sum_X BF[Y(1S) \to X] \approx 2 \times 10^{-4}$$
$$\sum_X BF[Y(2S) \to X] \approx 0.7 \times 10^{-4}$$

BF ratio
(th. Prediction = 0.77)

Channel	$\mathcal{B}[\Upsilon(1S) \to X]$ $[\times 10^{-6}]$	$\mathcal{B}[\Upsilon(2S) \to X]$ $[\times 10^{-6}]$	Q
$\Lambda\bar{\Lambda} + \pi^+\pi^-$	$1.43 \pm 0.48 \pm 0.23$		
$\Lambda\bar{\Lambda} + K^+K^-$	$1.29 \pm 0.51 \pm 0.20$	$1.27 \pm 0.47 \pm 0.20$	$0.98 \pm 0.53 \pm 0.11$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)$	$6.99 \pm 1.28 \pm 1.11$	$3.81 \pm 0.97 \pm 0.61$	$0.55 \pm 0.17 \pm 0.06$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-$	$11.83 \pm 2.01 \pm 1.87$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}$	$2.99 \pm 0.86 \pm 0.47$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)$	$13.14 \pm 2.36 \pm 2.10$	$4.72 \pm 1.64 \pm 0.75$	$0.36 \pm 0.14 \pm 0.04$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-$	$18.99 \pm 3.60 \pm 3.04$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}$	$6.03 \pm 1.67 \pm 0.96$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-2(K^+K^-)$		$2.93 \pm 1.49 \pm 0.47$	
$\Lambda\bar{\Lambda} + \pi^+\pi^-\ \pi^0$	$2.00 \pm 0.97 \pm 0.34$		
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)\ \pi^0$	$13.86 \pm 3.96 \pm 2.35$	$9.76 \pm 3.06 \pm 1.66$	$0.70 \pm 0.30 \pm 0.08$
$\Lambda\bar{\Lambda} + \pi^+\pi^-K^+K^-\ \pi^0$	$18.26 \pm 4.68 \pm 3.11$		
$\Lambda\bar{\Lambda} + \pi^+\pi^-p\bar{p}\ \pi^0$	$5.85 \pm 2.35 \pm 0.99$		
$\Lambda\bar{\Lambda} + 3(\pi^+\pi^-)\ \pi^0$	$52.83 \pm 8.93 \pm 9.07$	$23.35 \pm 5.97 \pm 4.02$	$0.44 \pm 0.14 \pm 0.05$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78 \pm 9.35 \pm 5.54$	$30.70 \pm 8.60 \pm 5.36$	$0.97 \pm 0.39 \pm 0.12$
$\Lambda\bar{\Lambda} + 2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95 \pm 5.81 \pm 2.76$		