$\Upsilon(nS)$ spectroscopy at Belle

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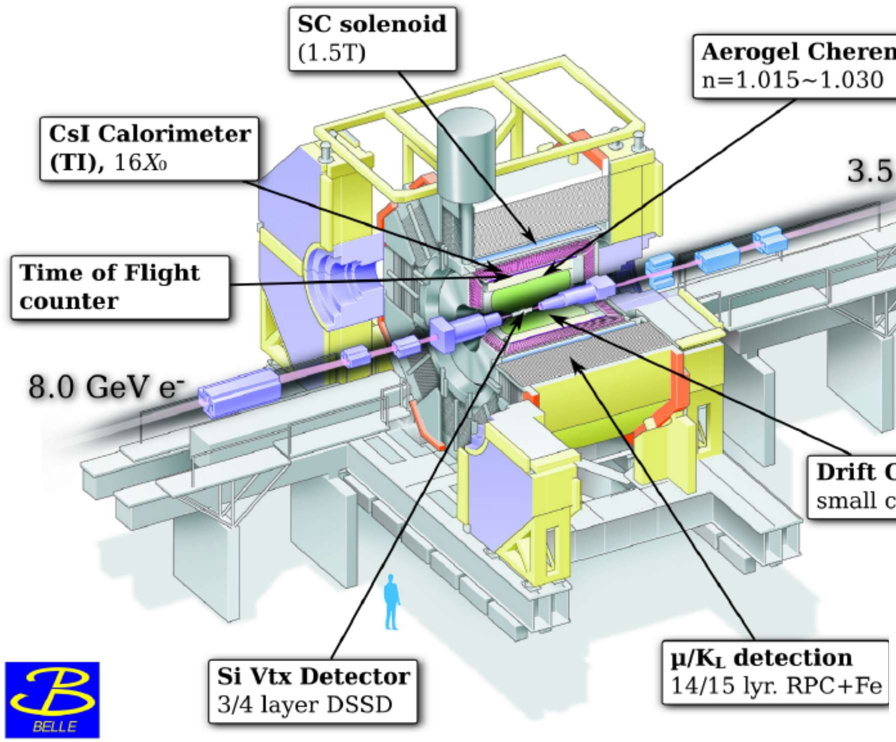
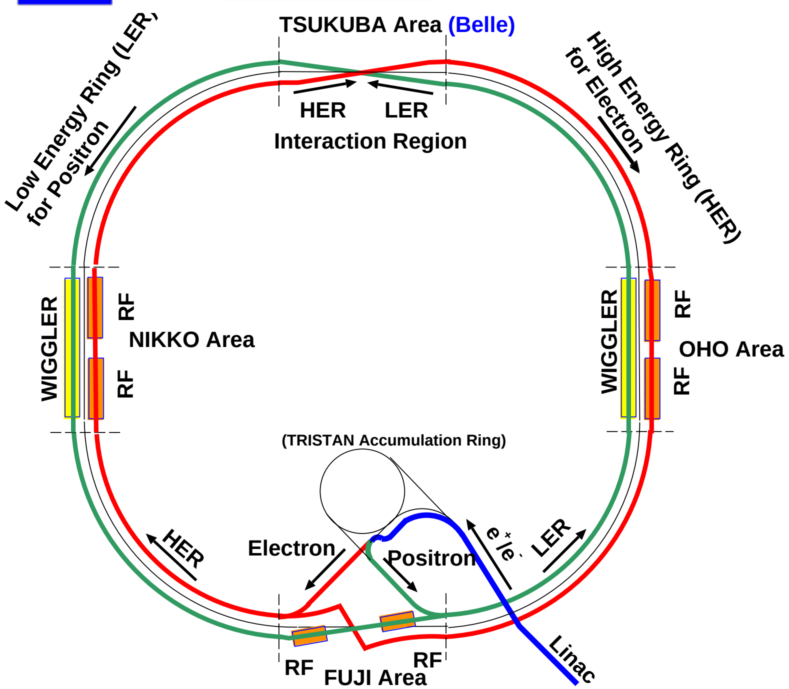
- Introduction
- Search for $\Upsilon(2S) \to X_{bb}(9975)\gamma$
- Search for $\Upsilon(1,2S) \to$ hyperon anti-hyperon + hadrons
- $\Upsilon(5S) \to \Upsilon(1D)\pi^+\pi^-$
- Summary

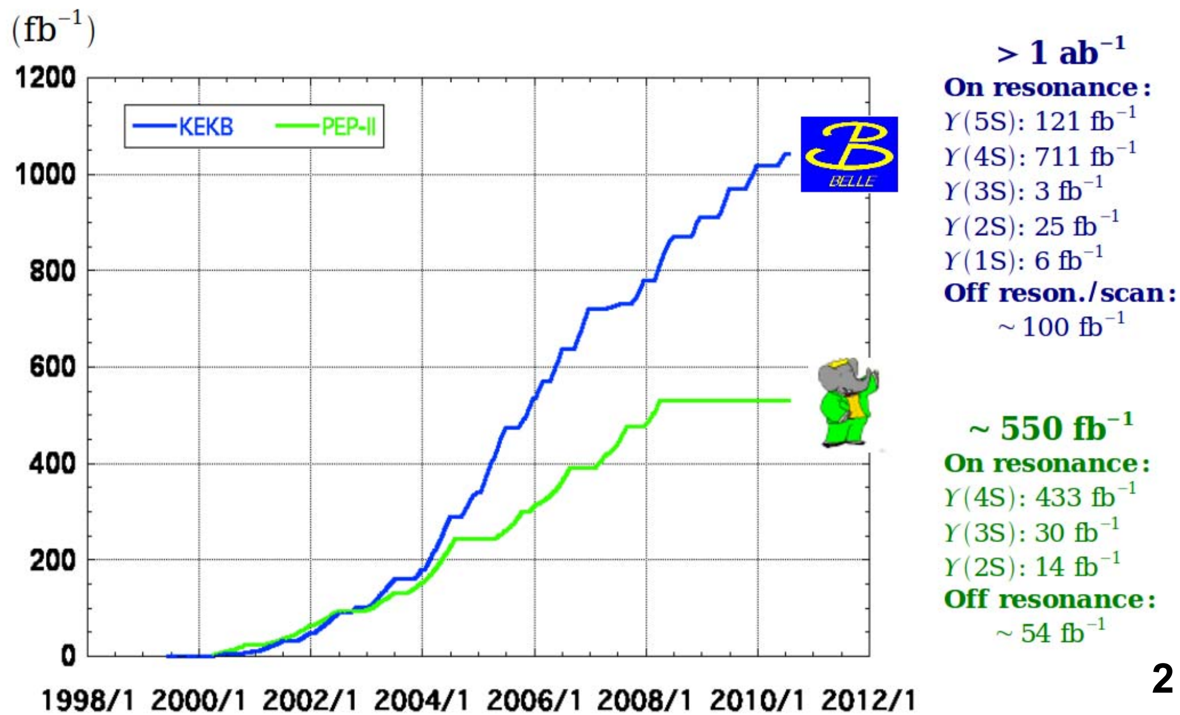
EPS HEP 2013

KEKB and Belle





Integrated luminosity of B factories



$\eta_b(2S)$ claim based on CLEO III data

Observation of the $\eta_b(2S)$ Meson in $\Upsilon(2S) \to \gamma\eta_b(2S)$, $\eta_b(2S) \to$ Hadrons and Confirmation of the $\eta_b(1S)$ Meson

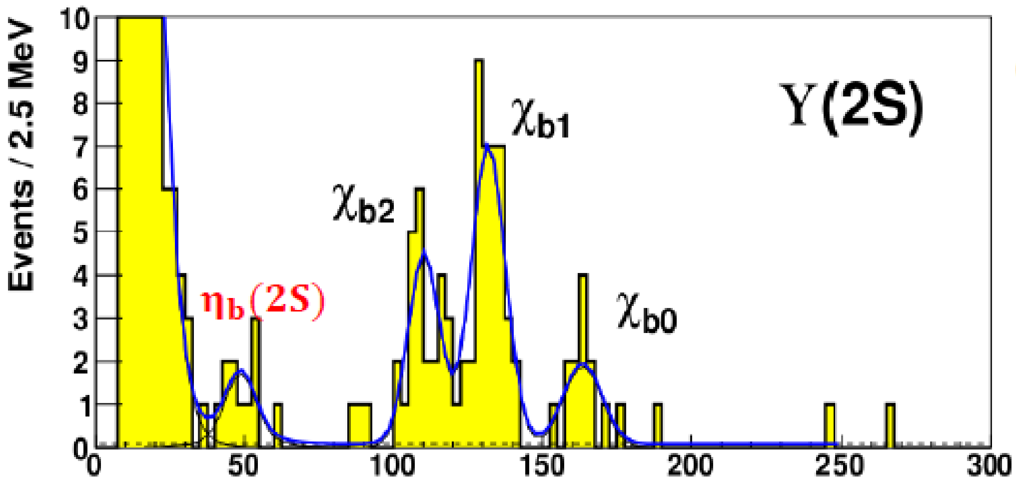
PRL 109, 082001 (2012)

S. Dobbs, Z. Metreveli, A. Tomaradze, T. Xiao, and Kamal K. Seth

Northwestern University, Evanston, Illinois 60208, USA

(Received 18 April 2012; published 24 August 2012)

The data for 9.3 million $\Upsilon(2S)$ and 20.9 million $\Upsilon(1S)$ taken with the CLEO III detector have been used to study the radiative population of states identified by their decay into 26 different exclusive hadronic final states. In the $\Upsilon(2S)$ decays, an enhancement is observed at a $\sim5\sigma$ level at a mass of $9974.6 \pm 2.3(\text{stat}) \pm 2.1(\text{syst})$ MeV. It is attributed to $\eta_b(2S)$ and corresponds to the $\Upsilon(2S)$ hyperfine splitting of $48.7 \pm 2.3(\text{stat}) \pm 2.1(\text{syst})$ MeV. In the $\Upsilon(1S)$ decays, the identification of $\eta_b(1S)$ is confirmed at a $\sim3\sigma$ level with $M[\eta_b(1S)]$ in agreement with its known value.



$\Delta M = M[\Upsilon(2S)] - M[(b\bar{b})]$

The measurement is carried out in 26 exclusive decays of the $\eta_b(2S)$ into charged hadrons.

$$\mathcal{B}_1 \times \mathcal{B}_2 \equiv \mathcal{B}_1[\Upsilon(nS) \to \gamma\eta_b(nS)] \times \sum_{i=1}^{26} \mathcal{B}_{2i}[\eta_b(nS) \to h_i].$$

$$\mathcal{B}_1 \times \mathcal{B}_2(\eta_b(2S)) = (46.2 \pm^{+29.7}_{-14.2} \pm 10.6) \times 10^{-6}$$

Reminder: Our ΔM_{HF} (2S) = $24.3^{+4.0}_{-4.5}$ MeV/c²

S. Dobbs's $\eta_b(2S)$ signal is not consistent with theory as well as our measurement

$\Upsilon(2S) \to \gamma b\bar{b}$

- Study is performed using the 25 fb^{-1} data (157.8×10^6 $\Upsilon(2S)$ events) .

- **~17 times more data than CLEO-c's $\Upsilon(2S)$ sample**

- We study $\Upsilon(2S) \to \gamma\ (b\bar{b})$; where $(b\bar{b})$ decays hadronically (same 26 exclusive hadronic final states as mentioned in S. Dobbs et. al.)

X_i : $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$, $4(\pi^+\pi^-)$, $5(\pi^+\pi^-)$, $K^+K^-\pi^+\pi^-$, $K^+K^-2(\pi^+\pi^-)$, $K^+K^-3(\pi^+\pi^-)$, $K^+K^-4(\pi^+\pi^-)$, $2(K^+K^-)$, $2(K^+K^-)\pi^+\pi^-$, $2(K^+K^-)2(\pi^+\pi^-)$, $2(K^+K^-)3(\pi^+\pi^-)$, $p\bar{p}\pi^+\pi^-$, $p\bar{p}2(\pi^+\pi^-)$, $p\bar{p}3(\pi^+\pi^-)$, $p\bar{p}4(\pi^+\pi^-)$, $p\bar{p}K^+K^-\pi^+\pi^-$, $p\bar{p}K^+K^-2(\pi^+\pi^-)$, $p\bar{p}K^+K^-3(\pi^+\pi^-)$, $K^0_SK^\pm\pi^\mp$, $K^0_SK^\pm\pi^\mp\pi^+\pi^-$, $K^0_SK^\pm\pi^\mp2(\pi^+\pi^-)$, $K^0_SK^\pm\pi^\mp3(\pi^+\pi^-)$, $2K^0_S\pi^+\pi^-$, $2K^0_S2(\pi^+\pi^-)$, $2K^0_S3(\pi^+\pi^-)$.

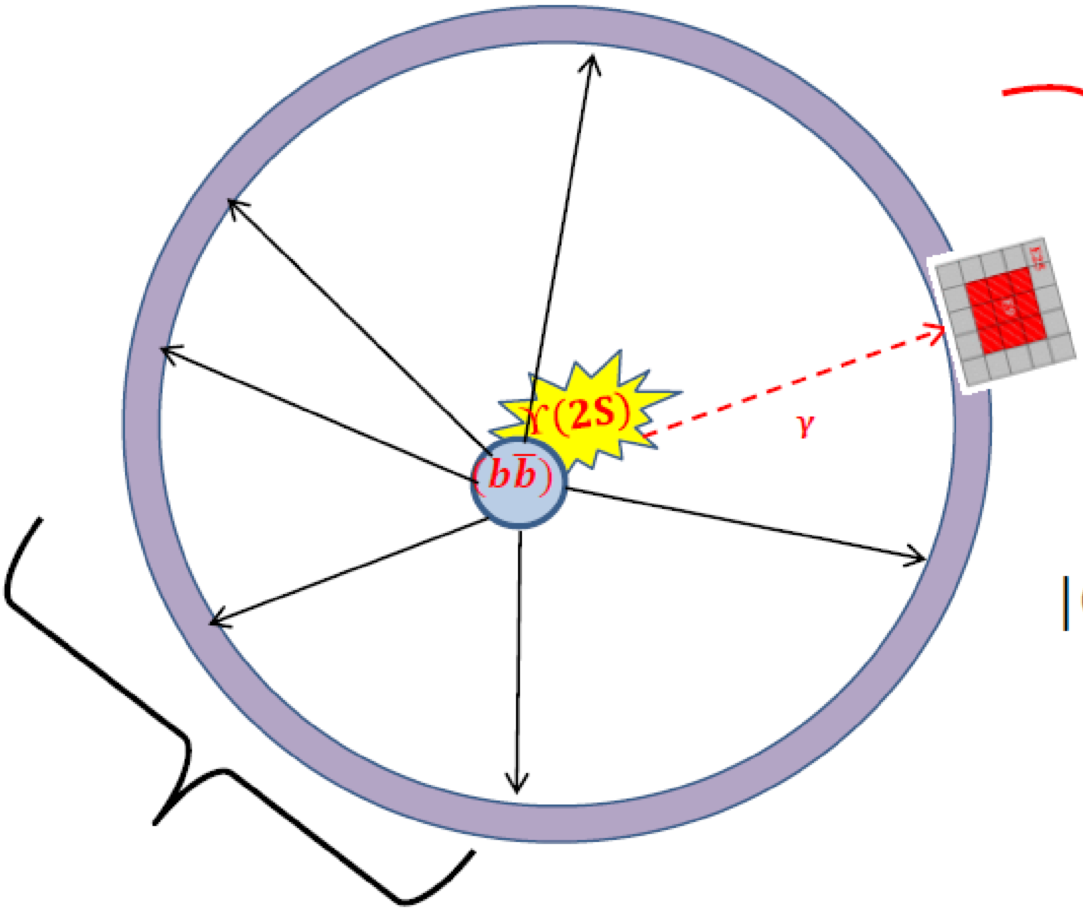
- Following decay channels are good control samples

$$\Upsilon(2S) \to \gamma\, \chi_{bJ} \quad (J = 0, 1, 2)$$

and χ_{bJ} can decay to the hadronic modes (comprising charged pions, kaons, protons and K_s mesons)

- Off-resonance $\Upsilon(4S)$ data [89.5 fb^{-1} ~4 times larger than our $\Upsilon(2S)$ data] used for background shape study.

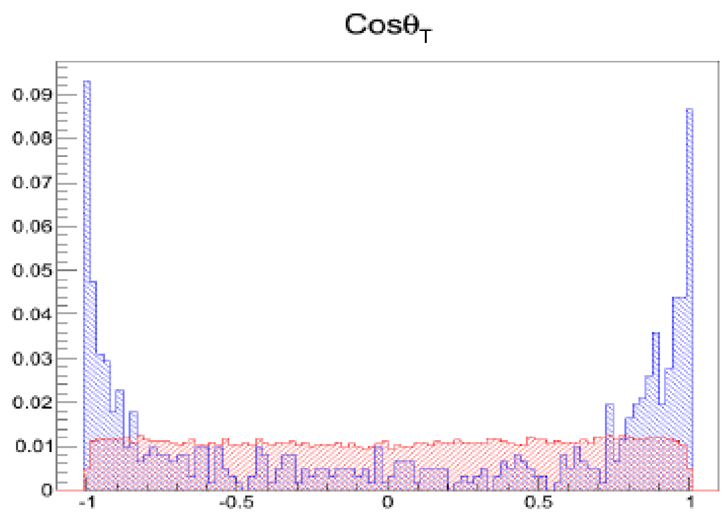
$\Upsilon(2S) \rightarrow \gamma b\bar{b}$ selection



γ - selection

- Isolated cluster
- Energy of gamma > 22 MeV
- E9/E25 > 0.85
- Exclude endcaps

$|Cos\theta_T| < 0.8$: Continuum - Suppression

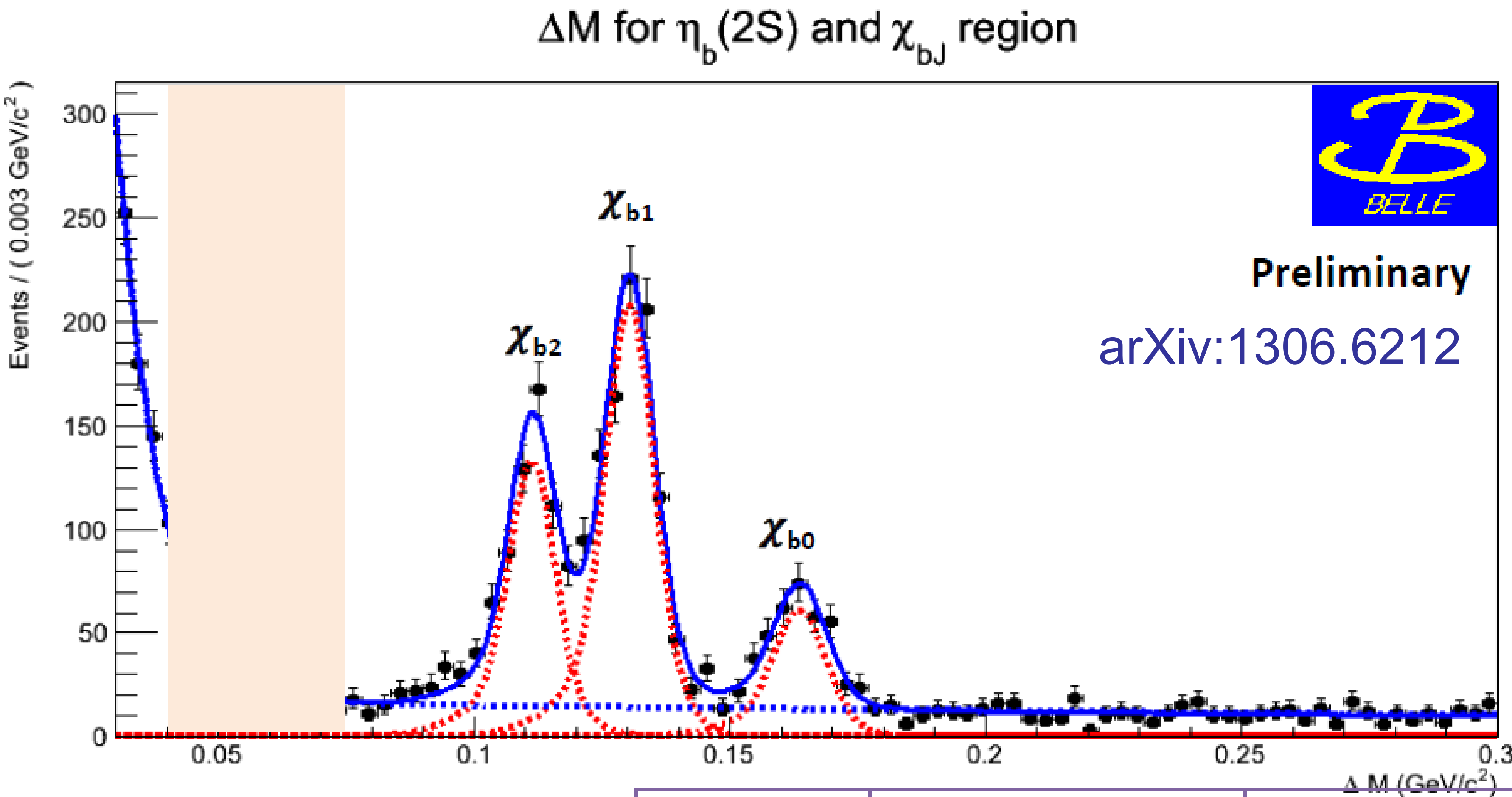


$(b\bar{b})$ reconstruction:

- Impact parameter cuts
- Number of charged tracks
- Particle identification (pion, kaon, proton)

Simple and Straightforward !!

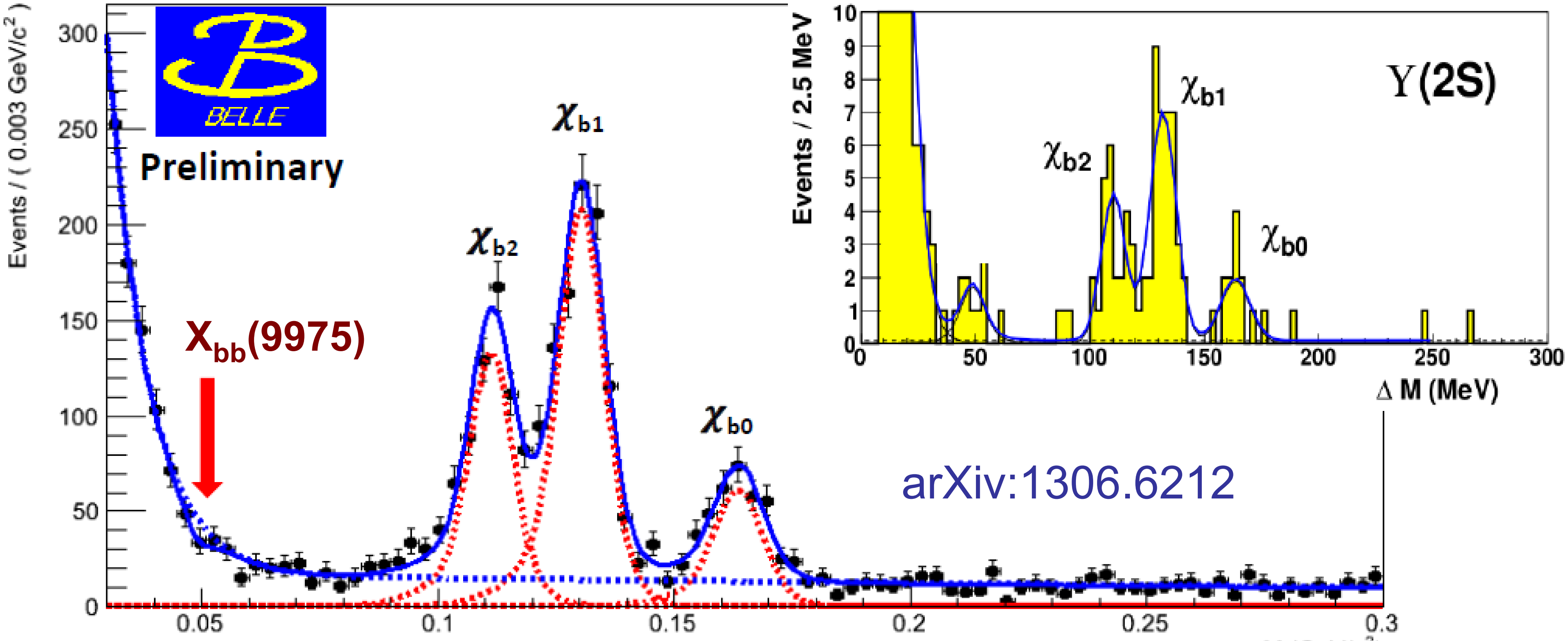
$\Upsilon(2S) \to \gamma b\bar{b}$ signal



Large statistics available in our sample for χ_{bJ} (300-950 candidates) allows to determine precisely the χ_{bJ} masses. (with an accuracy competitive with PDG 2012).

	Mass (MeV/c^2)	Mass PDG (MeV/c^2)
$\chi_{b0}(1P)$	9859.63±0.49	9859.42±0.42±0.31
$\chi_{b1}(1P)$	9892.83±0.23	9892.78±0.26±0.31
$\chi_{b2}(1P)$	9912.00±0.34	9912.21±0.26±0.31

No signal around ΔM=49 MeV



$B(\Upsilon(2S)\rightarrow\eta_b(1S)\gamma)\ B(\eta_b(1S)\rightarrow hadrons) < 3.7\ 10^{-6}$

$B(\Upsilon(2S)\rightarrow X_{bb}(9975)\gamma)\ B(X_{bb}(9975)\rightarrow hadrons) < 4.9\ 10^{-6}$

Reminder: $(46.2^{+29.7}_{-14.3} \pm 10.6)\ 10^{-6}$ S. Dobbs et al.

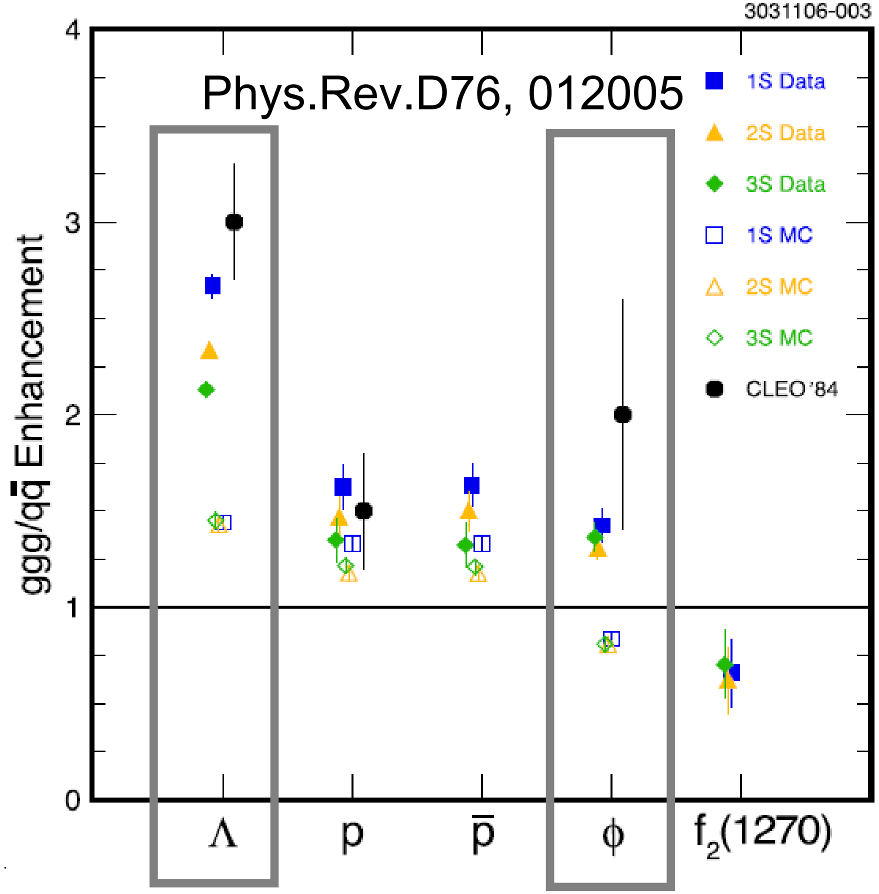
- Belle disconfirms the $\eta_b(2S)$ candidate found by Dobbs et al at 9975 MeV.
- The real $\eta_b(2S)$ is the one found by Belle in inclusive mode via radiative decays from $h_b(1,2S)$: PRL 109, 232002 (2012).
- No sensitivity at Belle to $\eta_b(2S)$ around ΔM=24 MeV.

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

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

BF(Υ(1S) $\rightarrow \Lambda$ + X) ~ 10%

BF(Υ(1S) $\rightarrow \Lambda\Lambda$ + X) ~ 3%



CLEO studied the enhancement for baryon **B**:

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

The MC fragmentation model fails only in describing Λ and ϕ enhancement

First study of exclusive decay channels;

Y(nS) $\rightarrow$ $\Lambda\Lambda$ **+** combination of K^+K^-, $\pi^+\pi^-$, **pp** and π^0

$\rightarrow$ Max 9 bodies, Max one π^0 $\rightarrow$ 48 channels

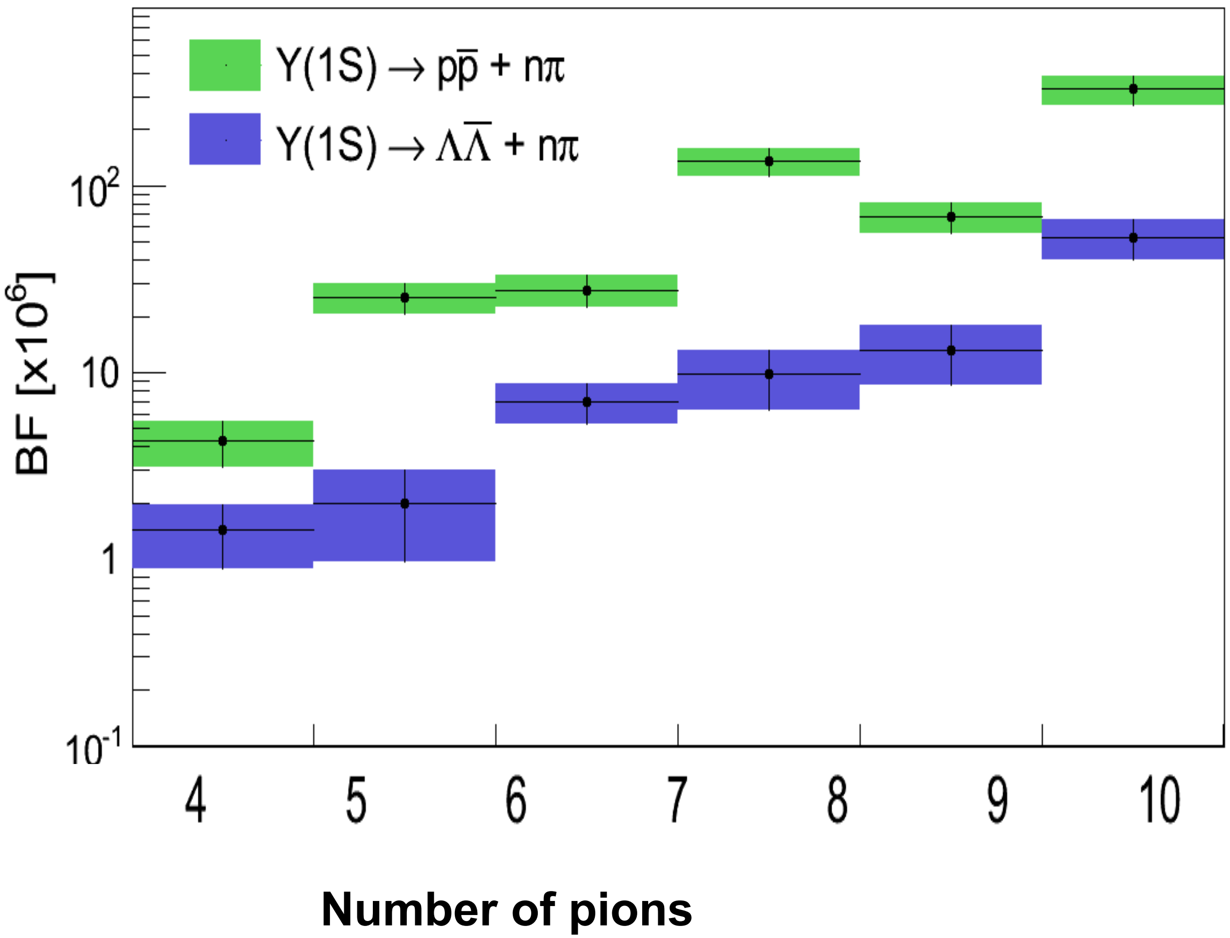
- Full event reconstruction
- Kinematic Fit of displaced vertexes
- Feedback suppression (p_t < 50 MeV)

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

Bottomonia and B mesons baryonic decays share two common features:

→ **Near threshold enhancement**

→ **Multiplicity hyerarchy**

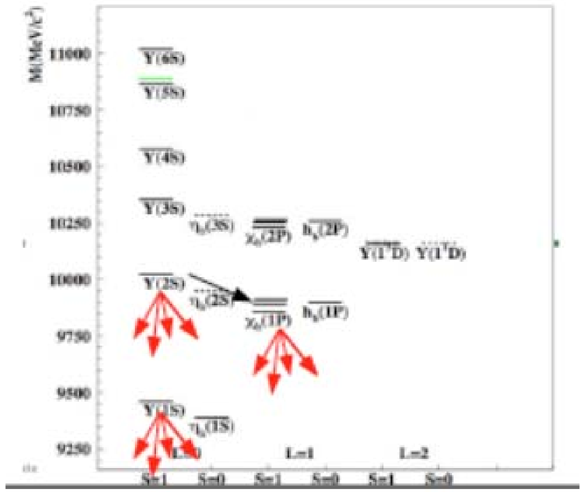


Dobbs et al (arXiv:1205.5070) analyzed CLEO data and measured BR

Final states with > 9 bodies seems to be favoured

→ but reconstruction efficiency decreases constantly

Results bb→hyperon anti-hyperon+ X



Evidence/observation in :
- 15 Y(1S) decays channels
- 7 Y(2S) decays channels

No evidence of χ_b decay in any channel

Channel	$\mathcal{B}[\Upsilon(1S)\to X]$ $[\times 10^{-6}]$	$\mathcal{B}[\Upsilon(2S)\to X]$ $[\times 10^{-6}]$	Q
$\Lambda\bar{\Lambda}+\pi^+\pi^-$	$1.43\pm0.48\pm0.23$		
$\Lambda\bar{\Lambda}+K^+K^-$	$1.29\pm0.51\pm0.20$	$1.27\pm0.47\pm0.20$	$0.98\pm0.53\pm0.11$
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)$	$6.99\pm1.28\pm1.11$	$3.81\pm0.97\pm0.61$	$0.55\pm0.17\pm0.06$
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-$	$11.83\pm2.01\pm1.87$		
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}$	$2.99\pm0.86\pm0.47$		
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)$	$13.14\pm2.36\pm2.10$	$4.72\pm1.64\pm0.75$	$0.36\pm0.14\pm0.04$
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-$	$18.99\pm3.60\pm3.04$		
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}$	$6.03\pm1.67\pm0.96$		
$\Lambda\bar{\Lambda}+\pi^+\pi^-2(K^+K^-)$		$2.93\pm1.49\pm0.47$	
$\Lambda\bar{\Lambda}+\pi^+\pi^-\ \pi^0$	$2.00\pm0.97\pm0.34$		
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)\ \pi^0$	$13.86\pm3.96\pm2.35$	$9.76\pm3.06\pm1.66$	$0.70\pm0.30\pm0.08$
$\Lambda\bar{\Lambda}+\pi^+\pi^-K^+K^-\ \pi^0$	$18.26\pm4.68\pm3.11$		
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}\ \pi^0$	$5.85\pm2.35\pm0.99$		
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)\ \pi^0$	$52.83\pm8.93\pm9.07$	$23.35\pm5.97\pm4.02$	$0.44\pm0.14\pm0.05$
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-\ \pi^0$	$31.78\pm9.35\pm5.54$	$30.70\pm8.60\pm5.36$	$0.97\pm0.39\pm0.12$
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}\ \pi^0$	$15.95\pm5.81\pm2.76$		

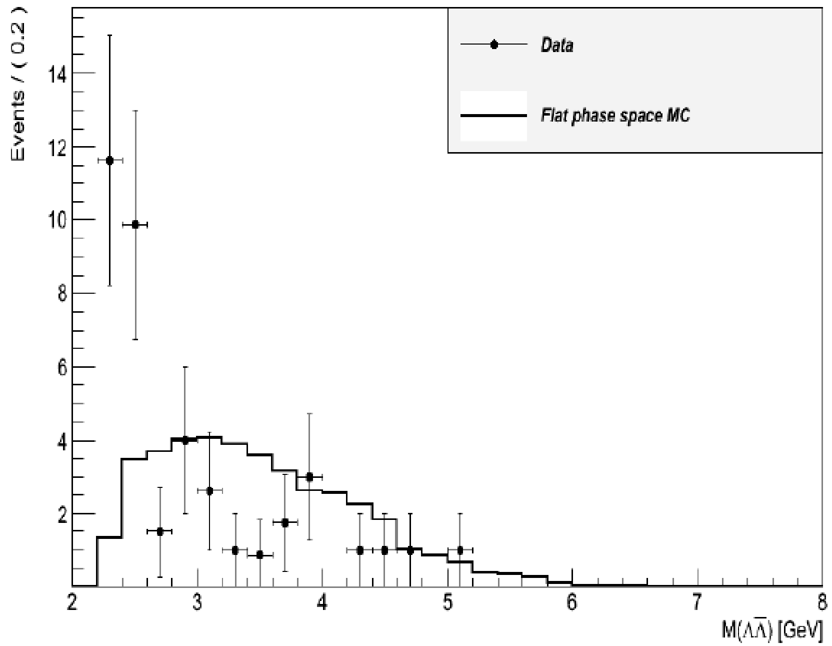
preliminary

Study of hyperon anti-hyperon mass

Significance of near-thresold enhancement (with Kolmogorov test)

	Υ(1S)	Υ(2S)	continuum
$\Lambda\bar{\Lambda}+\pi^+\pi^-$	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		2.3
$\Lambda\bar{\Lambda}+\pi^+\pi^-p\bar{p}\ \pi^0$	<0.1		
$\Lambda\bar{\Lambda}+3(\pi^+\pi^-)\ \pi^0$	1.38	0.25	2.1
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)K^+K^-\ \pi^0$	1.28	<0.1	1.2
$\Lambda\bar{\Lambda}+2(\pi^+\pi^-)p\bar{p}\ \pi^0$	<0.1		

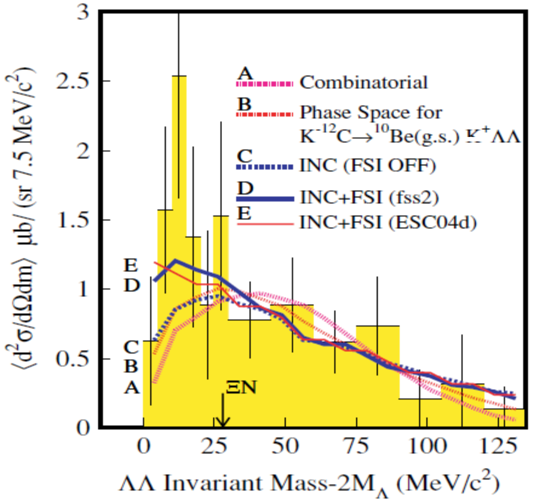
preliminary



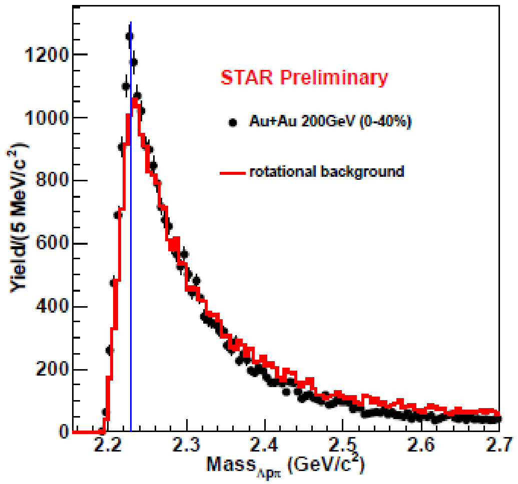
Search for H^0 dibaryon

arXiv:1302.4028

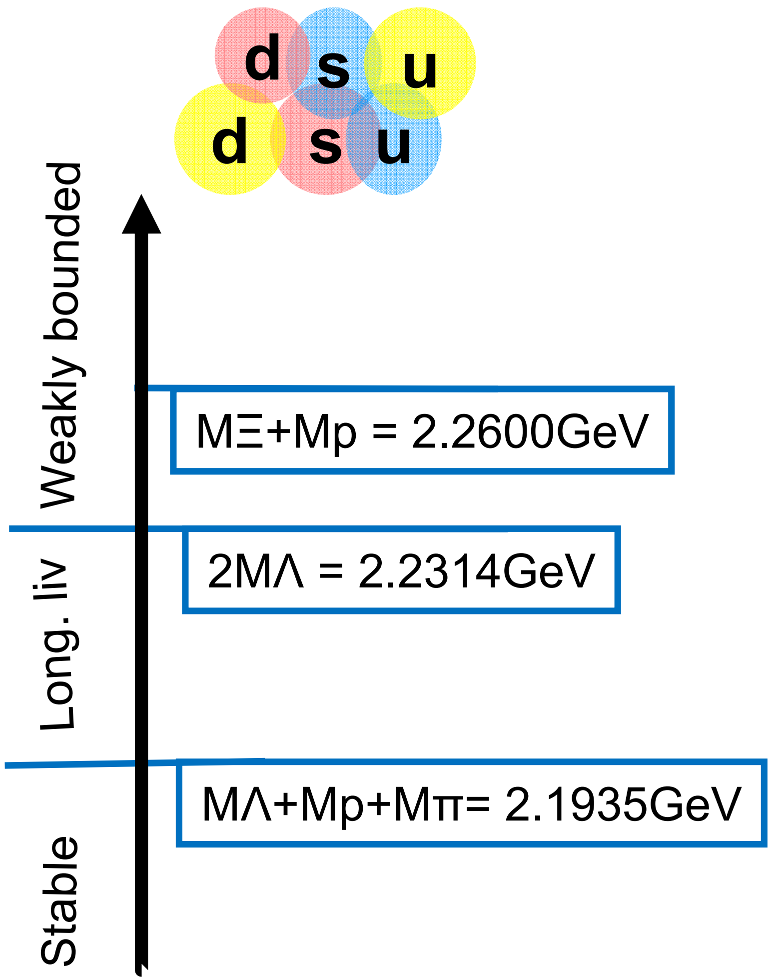
Exotic state (Jaffe, 1977)
→ completely antisymmetric arrangement of uuddss



KEK-PS
E522(2007)



RHIC-STAR
(2011)



Υ(nS) can produce **bound baryon-baryon states**
high yield of low momentum Λ .
Near threshold enhancement in some channels
→ **can the H^0 be produced also?**

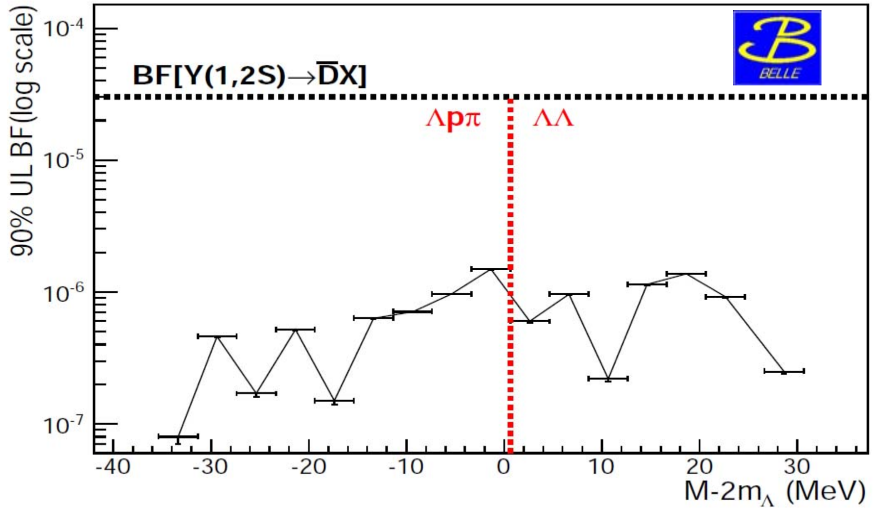
Search for H^0 dibaryon

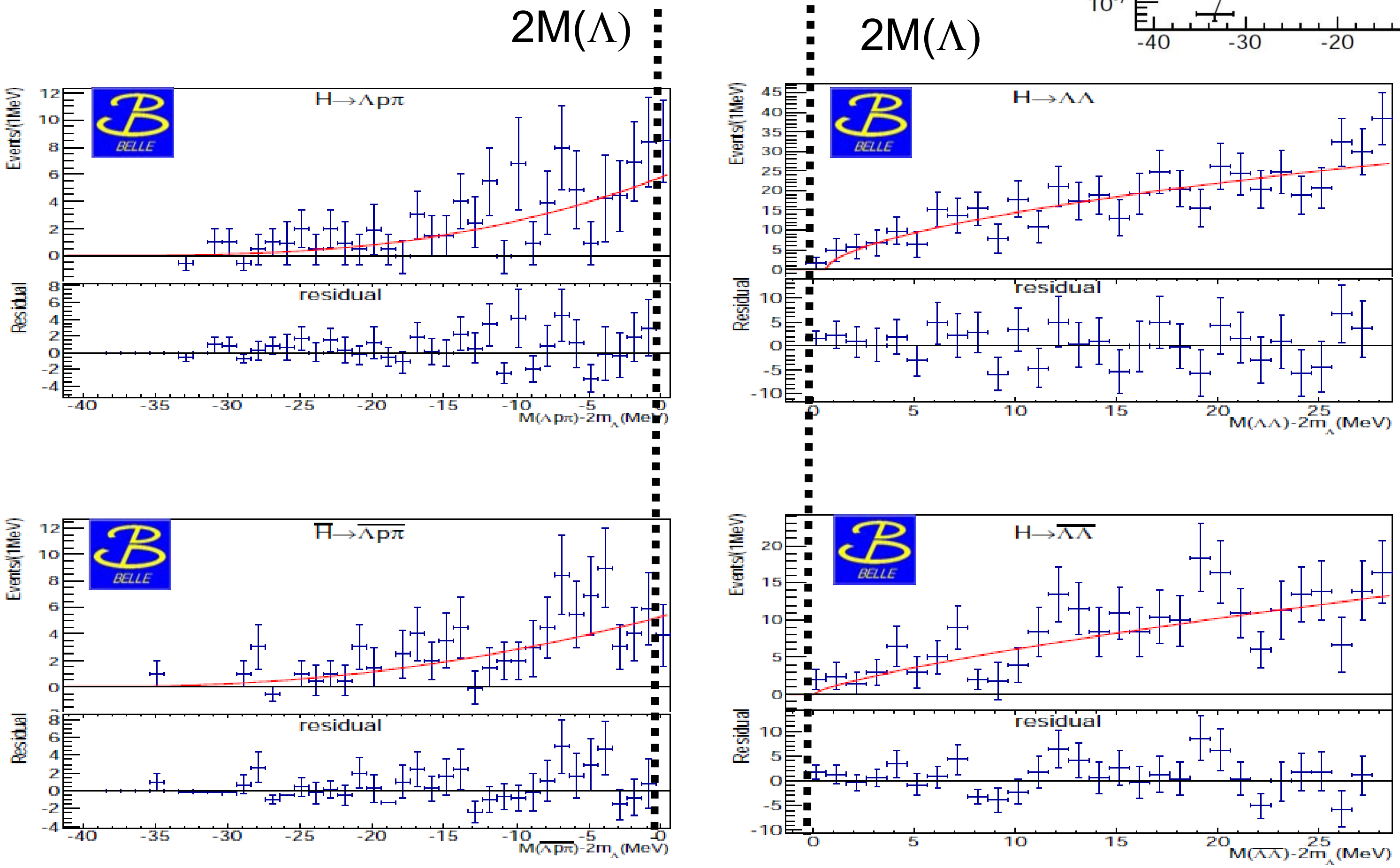
arXiv:1302.4028

Analysis strategy:

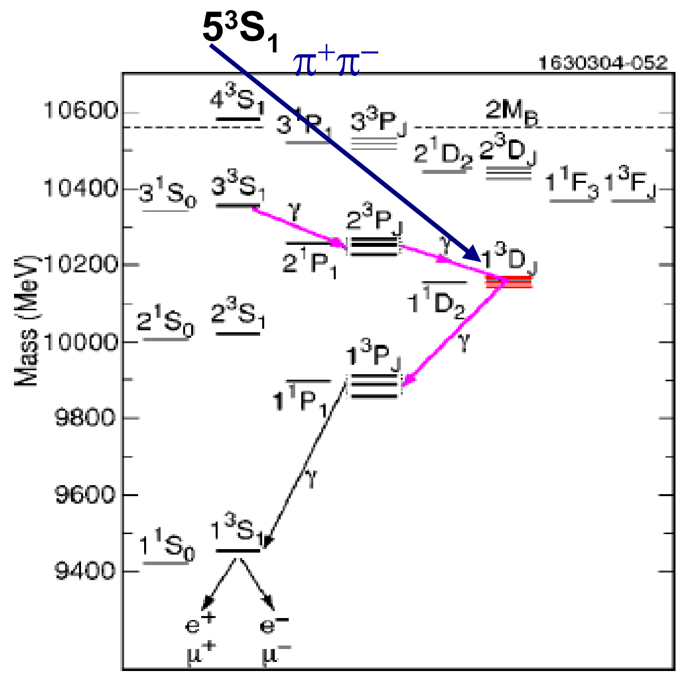
→ Inclusive reconstruction in Y(1S) and Y(2S) sample

→ Decays with **H** → ΛΛ, **H** → Λpπ$^-$





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



• First and only one *L*=2 state found in radiative decay chain CLEO(2004):

$\Upsilon(3S)\rightarrow\chi_b(2P)\gamma\rightarrow\Upsilon(1D)\gamma\gamma\rightarrow\chi_b(1P)\gamma\gamma\gamma\rightarrow\Upsilon(1S)\gamma\gamma\gamma\gamma$

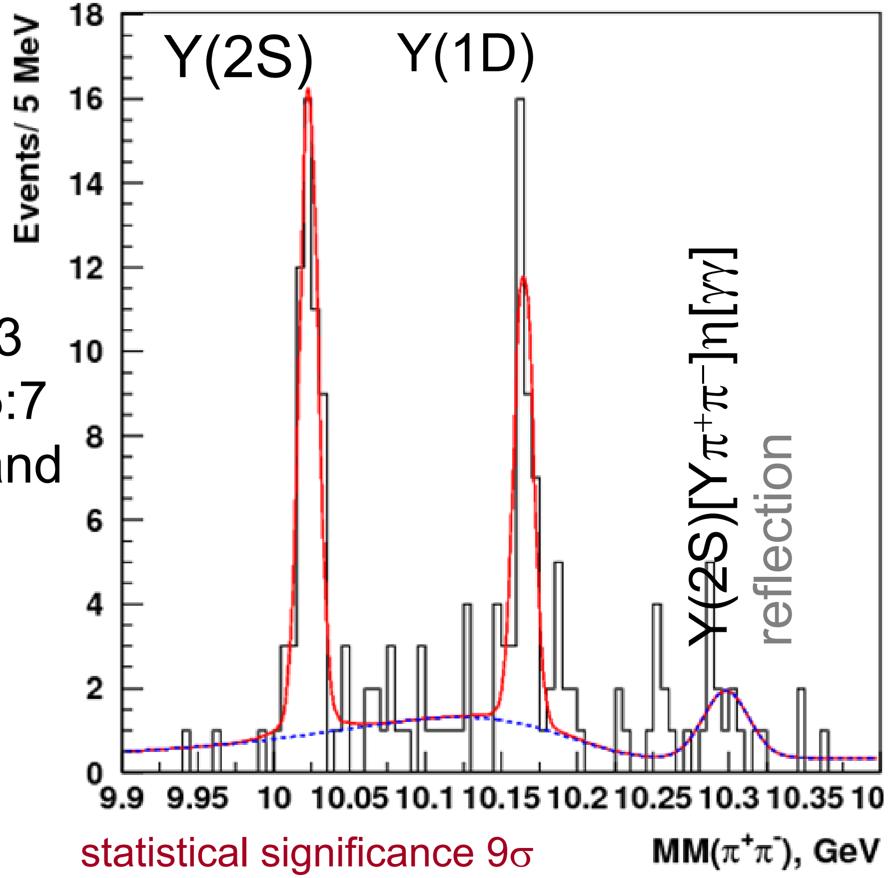
• Belle measured a new production chain

$\Upsilon(5S)\rightarrow\Upsilon(1D)\pi^+\pi^-\rightarrow\chi_b(1P)\gamma\pi^+\pi^-\rightarrow\Upsilon(1S)\gamma\gamma\pi^+\pi^-$

$M_{Y(1D)}$=10164.7 ± 1.4 ± 1.0 MeV/c^2
CLEO: 10161.1 ± 0.6 ± 1.6 MeV/c^2
BaBar: 10164.5 ± 0.5 ± 0.8 MeV/c^2

$M_{Y(2S)}$=10023.2 ± 1.0 MeV/c^2 PDG: 10023.6±0.3

• Three Υ(1D) states are predicted L=2, S=1: J=1,2,3
• We assume production of Υ_J(1D) ~ (2J+1), i.e. 3:5:7
• Using BF($Y_J(1D)\rightarrow\chi_{bi}\gamma$) from PRD 38, 279 (1998) and PDG for BF($\chi_{bi}\rightarrow Y(1S)\gamma$); we obtain N($Y_J$(1D)) 10%:49%:41%.
• We fit mass distribution with two Gaussian peaks.



statistical significance 9σ

Splitting between J=2 & J=3, ΔM <10 MeV 90% CL
Potential model expectations: 4-11 MeV

Summary

- $\Upsilon(2S) \rightarrow \gamma\, b\bar{b}$

  No signal found similar to Dobbs et.al.

  $B(\Upsilon(2S)\rightarrow X_{bb}(9975)\gamma)\, B(X_{bb}(9975)\rightarrow hadrons)<4.9\ 10^{-6}$

  $B(\Upsilon(2S)\rightarrow \eta_b(1S)\gamma)\, B(\eta_b(1S)\rightarrow hadrons)<3.7\ 10^{-6}$

- $\Upsilon(1,2S) \rightarrow$ hyperon anti-hyperon + hadrons

  First observation of these type decays.

  Threshold enchantment in baryon anti-baryon invariant mass.

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

  $M_{Y1D}=10164.7 \pm 1.4 \pm 1.0$ MeV/c^2

  splitting between J=2 and J=3, $\Delta M < 10$ MeV @ 90% CL

Back up

$\Upsilon(2S) \rightarrow \gamma b\underline{b}$ selection

- More variables exploited to suppress backgrounds :
  - **ΔE**

    $E^{*}_{\Upsilon(2S)} - E_{CM}$

    should peak around 0.

    [ΔE > -0.04 GeV & ΔE < 0.05 GeV]
  - **$P^*_{\Upsilon(2S)}$**

    momentum of the Υ(2S) candidate in the center-of-mass.

    should peak around 0.

    [$P^*_{\Upsilon(2S)} < 0.03$ GeV/c]
  - **$\theta_{\gamma(bb)}$**

    Angle between γ candidate and $(b\bar{b})$ in the CM Frame.

    should peak around 180^0.

    [$\theta_{\gamma(bb)} > 150^0$]
- Cut values obtained from optimization (assuming S. Dobbs et. al. B. F.)
- Multiple Candidates found at this stage is 8-10% .
- Energy-Momentum constrained kinematic fit (4C)is used to improve the resolution as well as for the best candidate selection.

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.

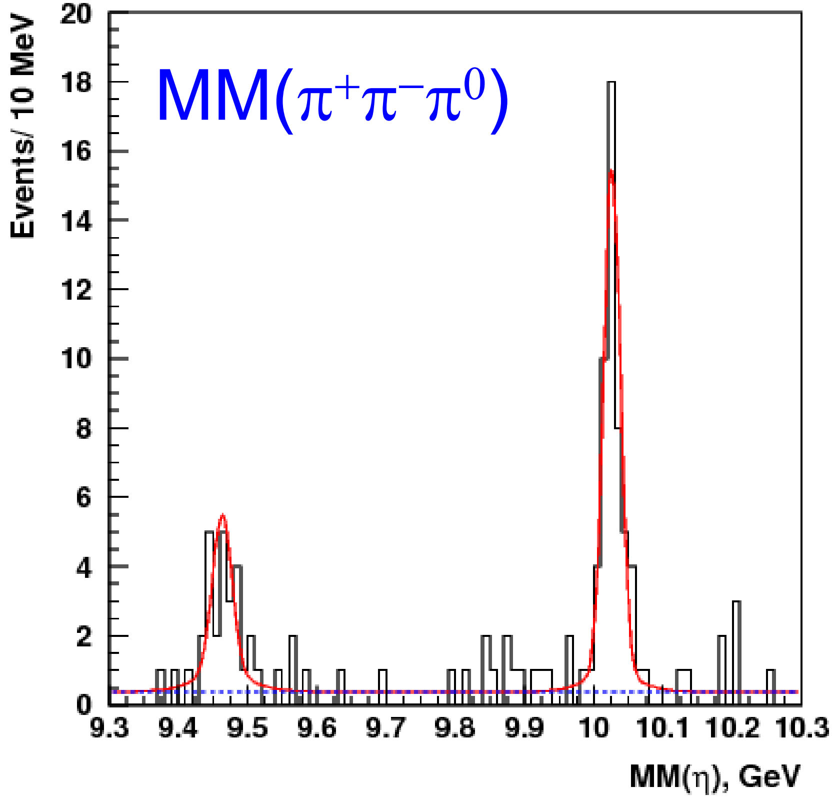
- The measured widths for Υ(4S) and Υ(2S) to Υ(1S)η differ from model predictions:

  - $\Upsilon(2S) \rightarrow \Upsilon(1S)\eta$ is about ½ than expected

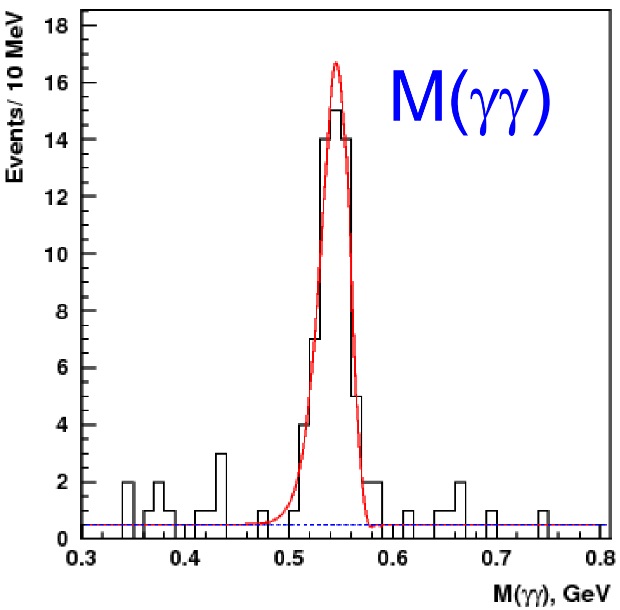
  - $\Upsilon(4S) \rightarrow \Upsilon(1S)\eta$ is 2.5 larger than $\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ (orders of magnitude large than theory)

- New information on this process is crucial.

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



- Three modes:
  - $\Upsilon(1,2S)[\mu^+\mu^-]\ \eta[\pi^+\pi^-\pi^0]$
  - $\Upsilon(2S)[\Upsilon(1S)\pi^+\pi^-]\ \eta[\gamma\gamma]$
  - $\Upsilon(1S)[\mu^+\mu^-]\ \eta'[\eta\pi^+\pi^-]$



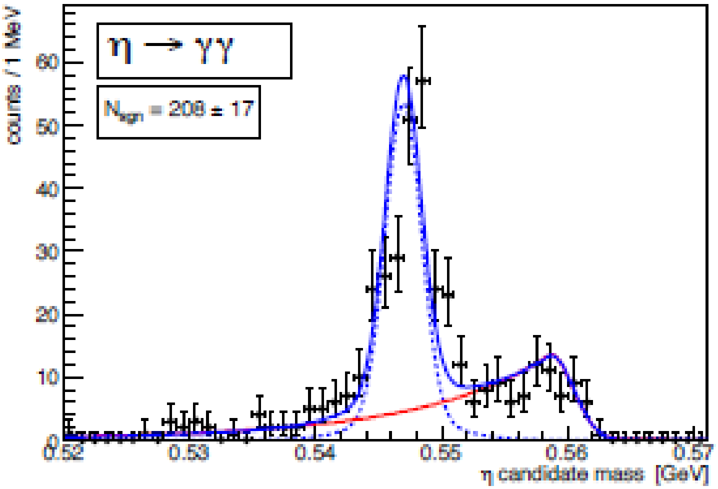
$B[\Upsilon(5S)\rightarrow\Upsilon(1S)\eta] = (7.3\pm1.6\pm0.8)\ 10^{-4}$

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

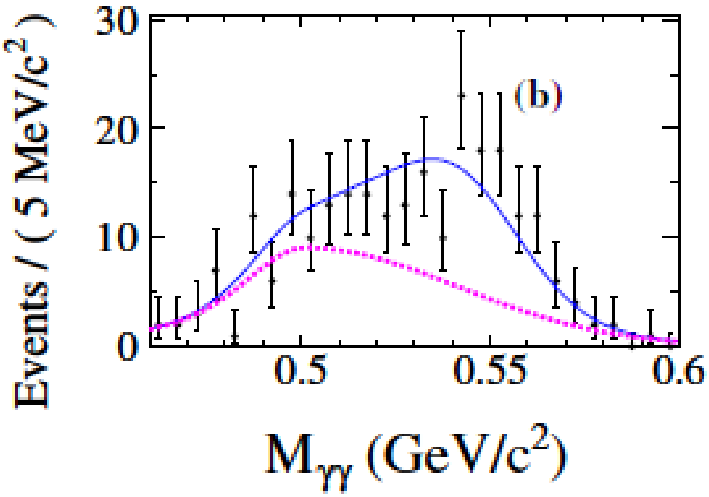
$B[\Upsilon(5S)\rightarrow\Upsilon(1S)\eta'] < 1.2\ 10^{-4}$

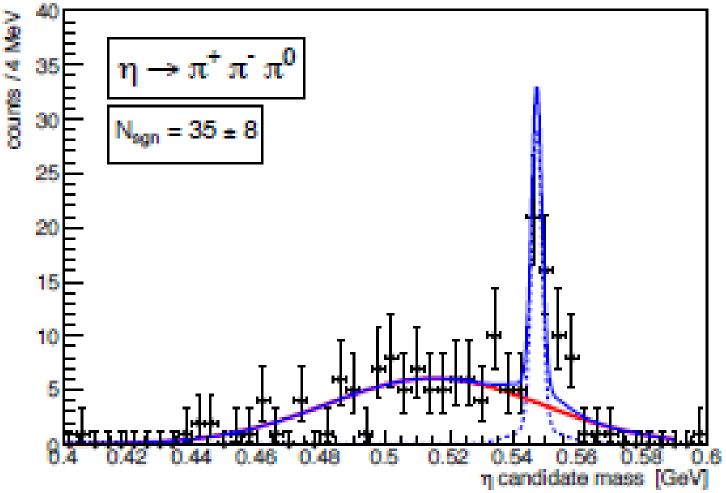
preliminary

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

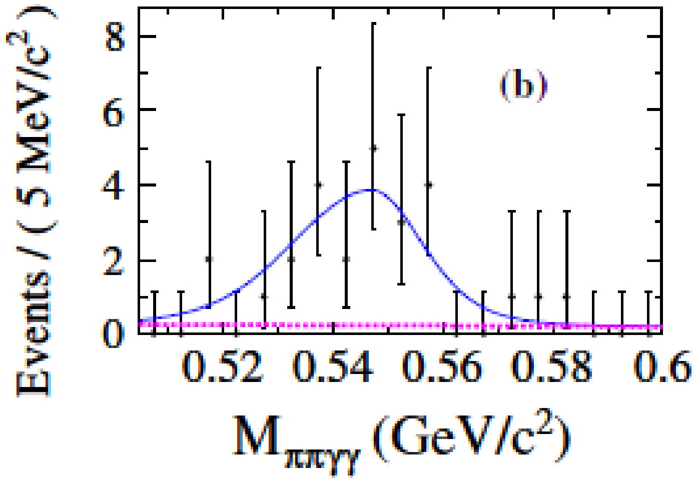


$\eta\rightarrow\gamma\gamma$





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



Phys.Rev.D 84 092003

B[Y(2S)→Y(1S)η]=$(3.28 \pm 0.37 \pm 0.35)\ 10^{-4}$

B[Y(2S)→Y(1S)π^0]< $4.3\ 10^{-5}$

B[Y(2S)→Y(1S)η]=$(2.39 \pm 0.31 \pm 0.14)\ 10^{-4}$

PRD 87, 011104(R) (2013)

B[Y(3S)→Y(1S)η]< $1.0\ 10^{-4}$

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

Decay chain

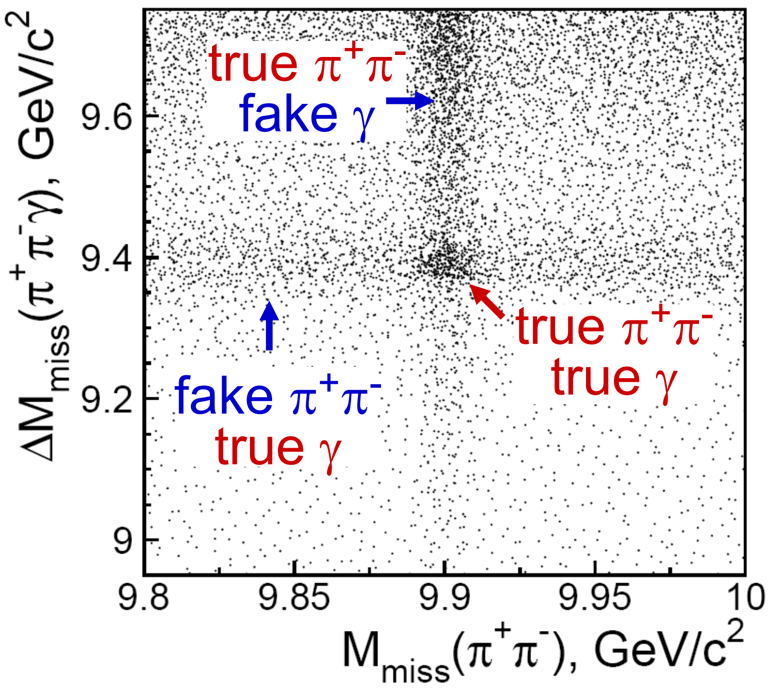
$\Upsilon(5S) \to Z_b^+ \pi^-$
$\hookrightarrow h_b(nP)\,\pi^+$
$\hookrightarrow \eta_b(mS)\,\gamma$

reconstruct

Use missing mass to identify signals

MC simulation

$M(\eta_b) \Rightarrow$



$\Uparrow$ $M(h_b)$

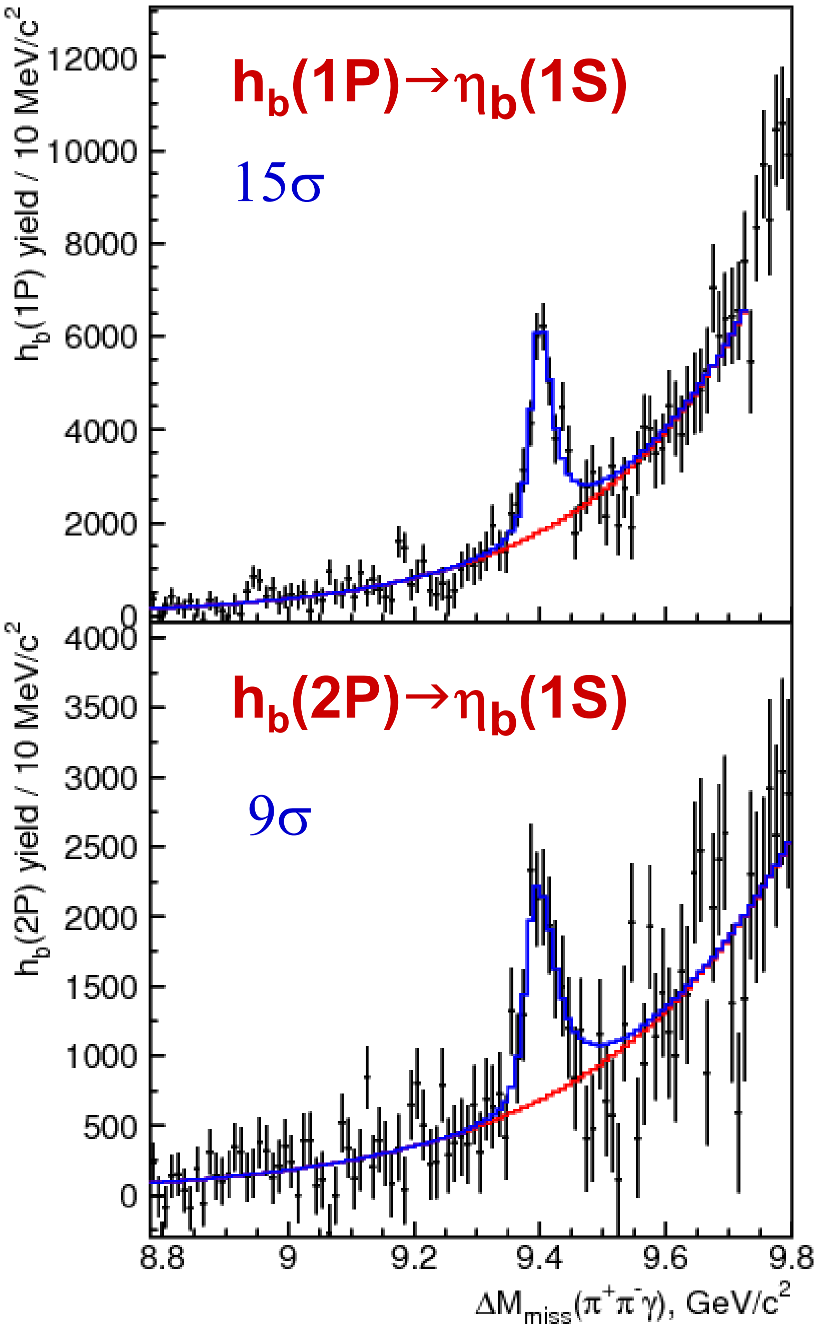
$\Delta M_{miss}(\pi^+\pi^-\gamma) \equiv$
$M_{miss}(\pi^+\pi^-\gamma) - M_{miss}(\pi^+\pi^-) + M[h_b]$

Approach:

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

$\Rightarrow$ $h_b(1P)$ yield vs. $\Delta M_{miss}(\pi^+\pi^-\gamma)$
$\Rightarrow$ search for $\eta_b(1S)$ signal

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



$$M[\eta_b(1S)] = 9402.4 \pm 1.5 \pm 1.8\ \mathrm{MeV}/c^2$$

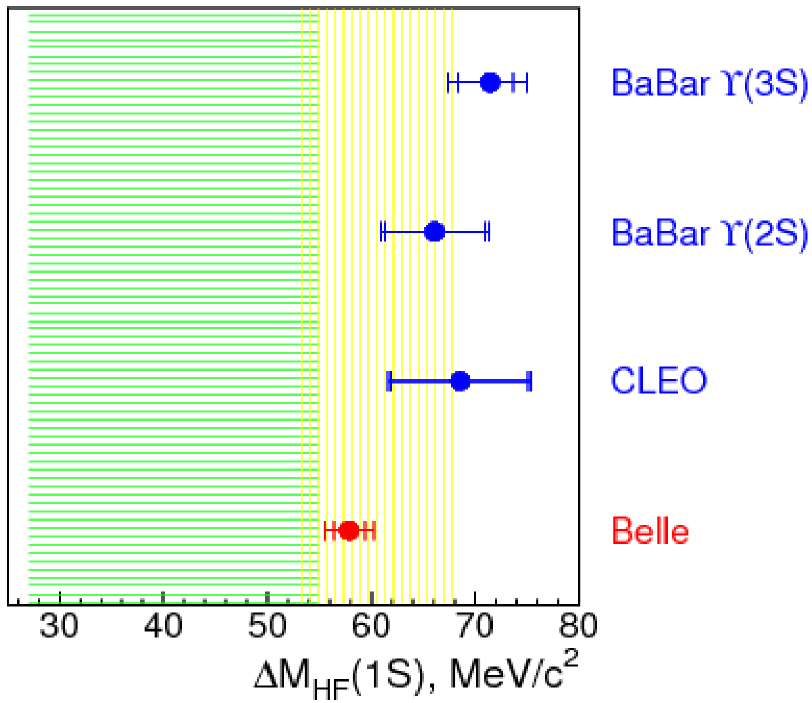
$$\Gamma[\eta_b(1S)] = 10.8^{+4.0+4.5}_{-3.7-2.0}\ \mathrm{MeV}$$

potential models : Γ = 5 – 20 MeV

$$B[h_b(1P)\to\eta_b(1S)\gamma] = (49.2 \pm 5.7\ ^{+5.6}_{-3.3})\ \%$$

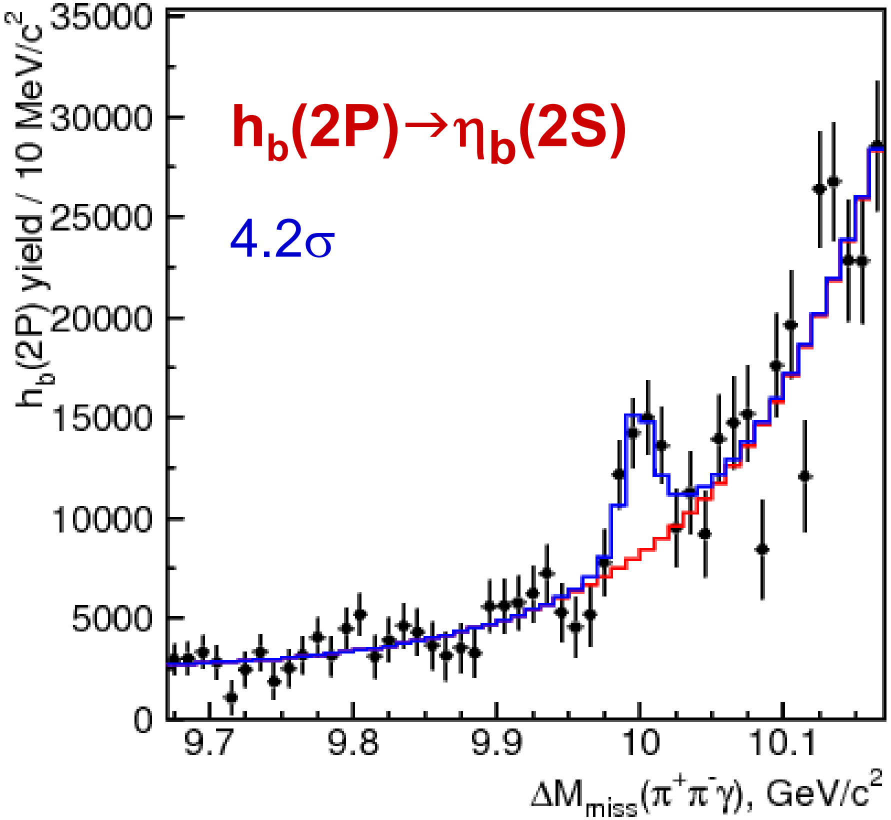
Godfrey & Rosner : BF = 41%

$$\Delta M_{HF}[\eta_b(1S)] = 57.9 \pm 2.3\ \mathrm{MeV}/c^2$$



PRL 109, 232002 (2012)

Evidence of $h_b \to \eta_b(2S)\,\gamma$



$$M\,[\eta_b(2S)] = 9999.0 \pm 3.5^{+2.8}_{-1.9}\ \ \mathrm{MeV}/c^2$$

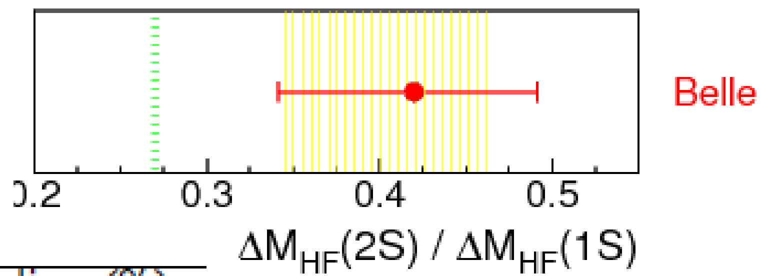
$$\Gamma[\eta_b(2S)] = 10.8^{+4.0+4.5}_{-3.7-2.0}\ \ \mathrm{MeV}$$

$$B[h_b(2P)\to\eta_b(2S)\gamma] = (47.5 \pm 10.5\ ^{+6.8}_{-7.7})\ \%$$

$$\Delta M_{HF}\,[\eta_b(2S)] = 24.3^{+4.0}_{-4.5}\ \mathrm{MeV}/c^2$$

ΔM_{HF} = 23.5 ±4.7 MeV

Lattice Meinel PRD82,114502(2010)



PRL 109, 232002 (2012)

Branching Fraction	Belle value (%)	Expectation (%)
$h_b(1P)\to\gamma\eta_b(1S)$	$49.2 \pm 5.7^{+5.6}_{-3.3}$	41
$h_b(2P)\to\gamma\eta_b(1S)$	$22.3 \pm 3.8^{+3.1}_{-3.3}$	13
$h_b(2P)\to\gamma\eta_b(2S)$	$47.5 \pm 10.5^{+6.8}_{-7.7}$	19

Υ(1,2S) → light hadrons

$$Q_\psi = \frac{\mathcal{B}_{\psi(2S)\to \mathrm{hadrons}}}{\mathcal{B}_{J/\psi\to \mathrm{hadrons}}} = \frac{\mathcal{B}_{\psi(2S)\to e^+e^-}}{\mathcal{B}_{J/\psi\to e^+e^-}} \approx 12\%$$

12% rule in charmonium: violated in some VT and VP final states (ρπ puzle)

$$Q_\Upsilon = \frac{\mathcal{B}_{\Upsilon(2S)\to \mathrm{hadrons}}}{\mathcal{B}_{\Upsilon(1S)\to \mathrm{hadrons}}} = \frac{\mathcal{B}_{\Upsilon(2S)\to e^+e^-}}{\mathcal{B}_{\Upsilon(1S)\to e^+e^-}} = 0.77 \pm 0.07$$

From pertrubtive QCD, to be tested

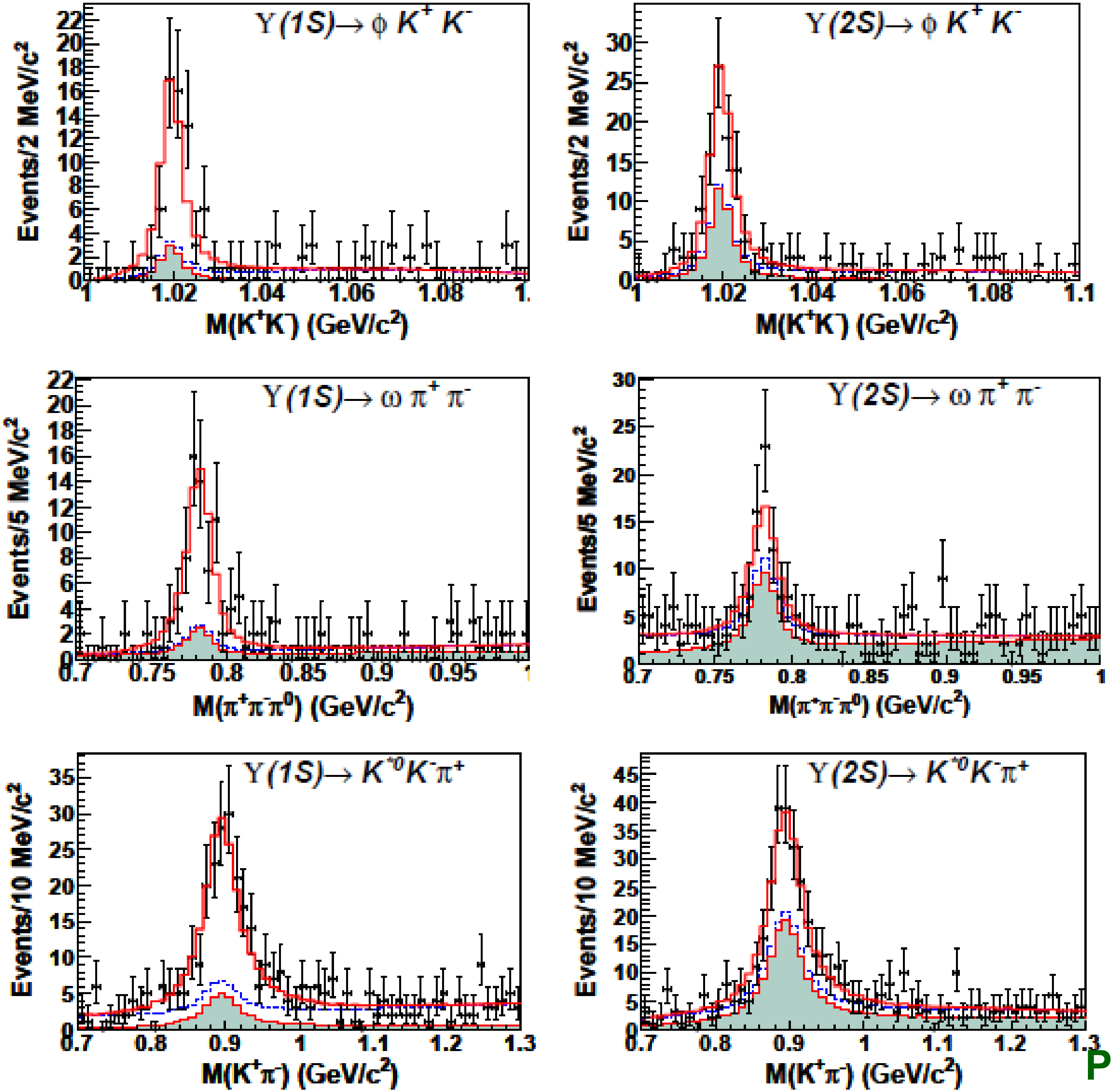
Full reconstruction of 10 decay channels (5 with observation):

3-body decays, 2-body Vector-Tensor & Axial-Pseudoscalar

Channel	Υ(1S)					Υ(2S)						
	N^{sig}	$N^{\mathrm{UP}}_{\mathrm{sig}}$	Σ	$\mathcal{B}$	$\mathcal{B}^{\mathrm{UP}}$	N^{sig}	$N^{\mathrm{UP}}_{\mathrm{sig}}$	Σ	$\mathcal{B}$	$\mathcal{B}^{\mathrm{UP}}$	Q_Υ	Q^{UP}_Υ
ϕK^+K^-	56.3 ± 9.0		8.6	$2.36 \pm 0.38 \pm 0.29$		69 ± 36		6.5	$1.86 \pm 0.96 \pm 0.21$		$0.79 \pm 0.54 \pm 0.13$	
$\omega\pi^+\pi^-$	63.6 ± 9.5		8.5	$4.46 \pm 0.67 \pm 0.72$		29 ± 12	51	2.5	$1.32 \pm 0.54 \pm 0.45$	2.58	$0.30 \pm 0.13 \pm 0.11$	0.55
$K^{*0}K^-\pi^+$	173 ± 20		11	$4.42 \pm 0.50 \pm 0.58$		135 ± 23		6.4	$2.32 \pm 0.40 \pm 0.54$		$0.52 \pm 0.11 \pm 0.14$	
$\phi f_2'$	6.9 ± 3.9	15	2.1	$0.64 \pm 0.37 \pm 0.14$	1.63	8.3 ± 6.0	18	1.6	$0.50 \pm 0.36 \pm 0.19$	1.33	$0.77 \pm 0.70 \pm 0.33$	2.54
ωf_2	5.2 ± 4.0	13	1.5	$0.57 \pm 0.44 \pm 0.13$	1.79	-0.4 ± 3.3	6.1		$-0.03 \pm 0.24 \pm 0.01$	0.57	$-0.06 \pm 0.42 \pm 0.02$	1.22
ρa_2	29 ± 11	49	2.7	$1.15 \pm 0.47 \pm 0.18$	2.24	10 ± 11	30	0.9	$0.27 \pm 0.28 \pm 0.14$	0.88	$0.23 \pm 0.26 \pm 0.12$	0.82
$K^{*0}\bar{K}_2^{*0}$	42.2 ± 9.5		5.4	$3.02 \pm 0.68 \pm 0.34$		32 ± 11		3.3	$1.53 \pm 0.52 \pm 0.19$		$0.50 \pm 0.21 \pm 0.07$	
$K_1(1270)^+K^-$	3.7 ± 4.9	13	0.8	$0.54 \pm 0.72 \pm 0.21$	2.41	11.0 ± 4.4	26	1.2	$1.06 \pm 0.42 \pm 0.32$	3.22	$1.96 \pm 2.71 \pm 0.84$	4.73
$K_1(1400)^+K^-$	23.8 ± 8.2		3.3	$1.02 \pm 0.35 \pm 0.22$		9.2 ± 8.2	24	0.5	$0.26 \pm 0.23 \pm 0.09$	0.83	$0.26 \pm 0.25 \pm 0.10$	0.77
$b_1(1235)^+\pi^-$	14.4 ± 6.9	28	2.4	$0.47 \pm 0.22 \pm 0.13$	1.25	1.2 ± 3.5	13	0.2	$0.02 \pm 0.07 \pm 0.01$	0.40	$0.05 \pm 0.16 \pm 0.03$	0.35

PRD 86, 031102(R) (2012)

Υ(1,2S) → light hadrons



$Q_Υ = 0.79 \pm 0.54 \pm 0.13$

consistent

$Q_Υ = 0.30 \pm 0.13 \pm 0.11$

2.6σ under pQCD value

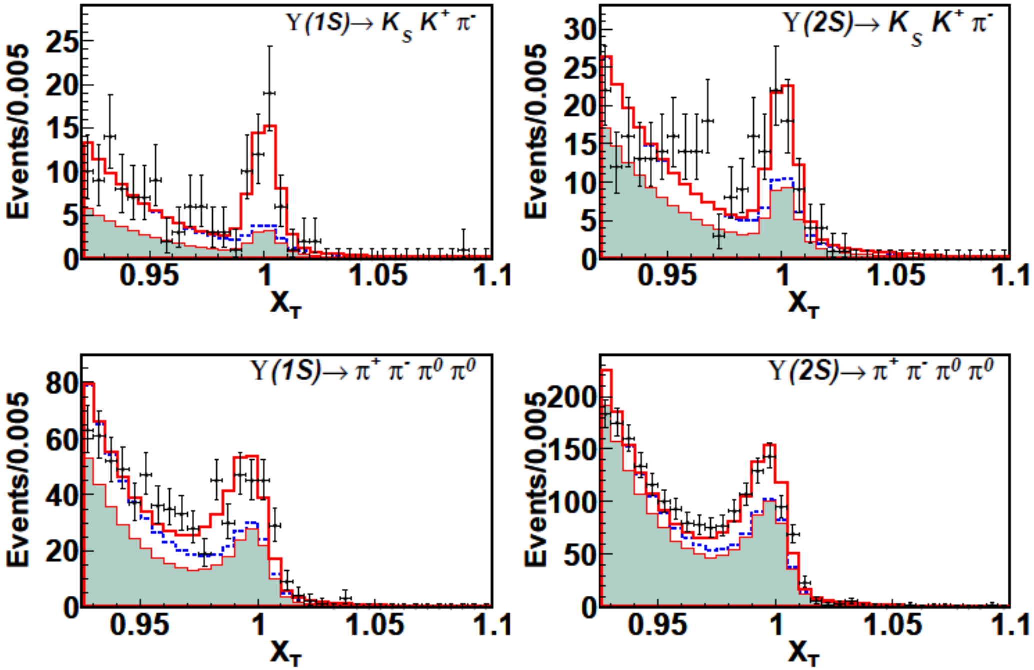
$Q_Υ = 0.52 \pm 0.11 \pm 0.14$

consistent

PRD 86, 031102(R) (2012)

$\Upsilon(1,2S) \rightarrow$ light hadrons

Y(1,2S) decays to $K_S K^+ \pi^-$, $\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^0$ and 2-body VP (K^*K, $\omega\pi^0$, $\rho\pi$)



Channel	$\Upsilon(1S)$						$\Upsilon(2S)$							
	$N_{\rm sig}$	$N_{\rm sig}^{\rm UL}$	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{\rm UL}$	$N^{\rm sig}$	$N_{\rm sig}^{\rm UL}$	ϵ	Σ	$\mathcal{B}$	$\mathcal{B}^{\rm UL}$	Q_Υ	$Q_\Upsilon^{\rm UL}$
$K_S^0 K^+ \pi^-$	37.2 ± 7.6	—	22.96	6.2	$1.59 \pm 0.33 \pm 0.18$	—	39.5 ± 10.3	—	21.88	4.0	$1.14 \pm 0.30 \pm 0.13$	—	$0.72 \pm 0.24 \pm 0.09$	—
$\pi^+\pi^-\pi^0\pi^0$	143.2 ± 22.4	—	11.20	7.1	$12.8 \pm 2.01 \pm 2.27$	—	260.7 ± 37.2	—	12.98	7.4	$13.0 \pm 1.86 \pm 2.08$	—	$1.01 \pm 0.22 \pm 0.23$	—
$\pi^+\pi^-\pi^0$	25.5 ± 8.6	—	11.86	3.4	$2.14 \pm 0.72 \pm 0.34$	—	-2.1 ± 9.5	15	13.19	—	$-0.10 \pm 0.46 \pm 0.02$	0.80	$-0.05 \pm 0.21 \pm 0.02$	0.42
$K^*(892)^0 \bar{K}^0$	16.1 ± 4.7	—	16.23	4.4	$2.92 \pm 0.85 \pm 0.37$	—	14.7 ± 6.0	30	15.59	2.7	$1.79 \pm 0.73 \pm 0.30$	4.22	$0.61 \pm 0.31 \pm 0.12$	1.20
$K^*(892)^- K^+$	2.0 ± 1.9	6.3	18.92	1.3	$0.31 \pm 0.30 \pm 0.04$	1.11	5.7 ± 3.4	13	18.77	2.0	$0.58 \pm 0.35 \pm 0.09$	1.45	$1.87 \pm 2.12 \pm 0.33$	5.52
$\omega\pi^0$	2.5 ± 2.1	6.8	2.11	1.6	$1.32 \pm 1.11 \pm 0.14$	3.90	0.1 ± 2.2	4.6	2.32	0.1	$0.03 \pm 0.68 \pm 0.01$	1.63	$0.02 \pm 0.50 \pm 0.01$	1.68
$\rho\pi$	11.3 ± 5.9	22	6.41	2.2	$1.75 \pm 0.91 \pm 0.28$	3.68	-1.4 ± 8.6	14	8.66	—	$-0.11 \pm 0.64 \pm 0.03$	1.16	$-0.06 \pm 0.38 \pm 0.02$	0.94

arXiv:1305.5887

$\Upsilon(1,2S) \rightarrow$ hyperon anti-hyperon + hadrons

Aim:

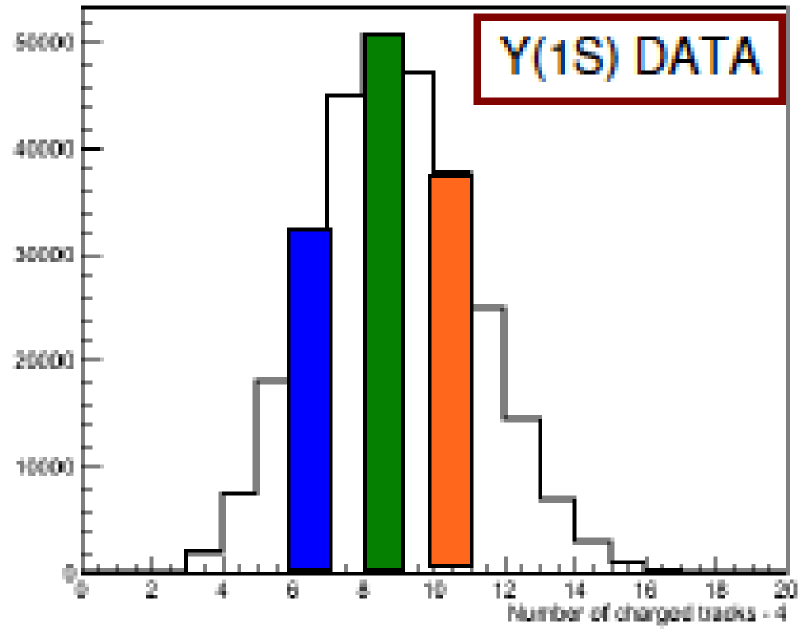
Search for $\Lambda\bar{\Lambda}$ + long living particles

Caveat: Conservation of Charge, B and S

→ $p\bar{p}$, K^+K^-, $\pi^+\pi^-$ pairs only

→ the distribution of # of charged tracks per event suggests to investigate the states with

- → **4 + 2 tracks (3 channels)**
- → **4 + 4 tracks (6 channels)**
- → **4 + 6 tracks (10 channels)**



Samples for the analisys:

- Y(1,2S) full sample (~5.7/fb @1S, ~24/fb @2S)
- Individual signal MC samples (50k evts. each)
- 10 M evts of Generic Y(1S) → Λ+X MC
- Continuum sample from data under Y(4S) collected in exp > 31: 74/fb

Theoretical predictions:

- No theoretical paper available
- Prediction can be made with Pythia
  → 115 M of generic Y(1S) decay