ϒ(5S) (including Bs decays), ϒ(2S) and ϒ(1S) Results at B Factories

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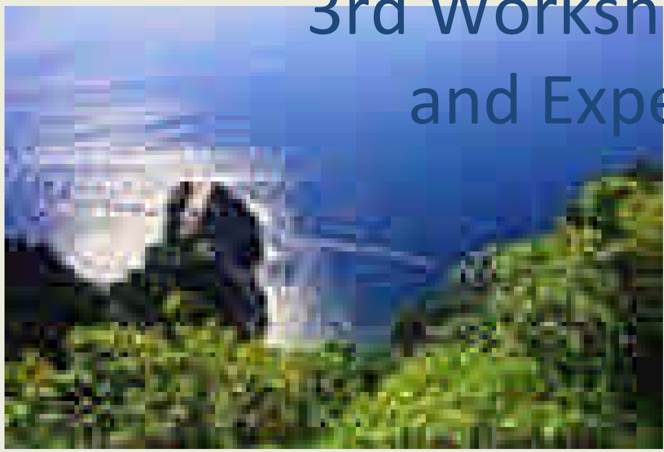


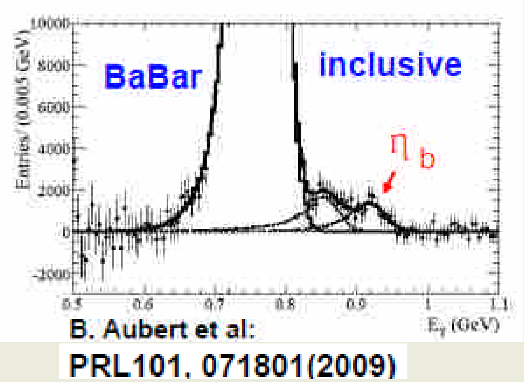
Introduction

- Successful B factories for 10 years:
  - CP violation and CKM, rare B decays, tau physics, $\gamma\gamma$ physics
  - Charm mixing and decays, charmonium
  - Discovering XYZ particles, studying Bs decays …
- B_S physics: complementary to LHCb

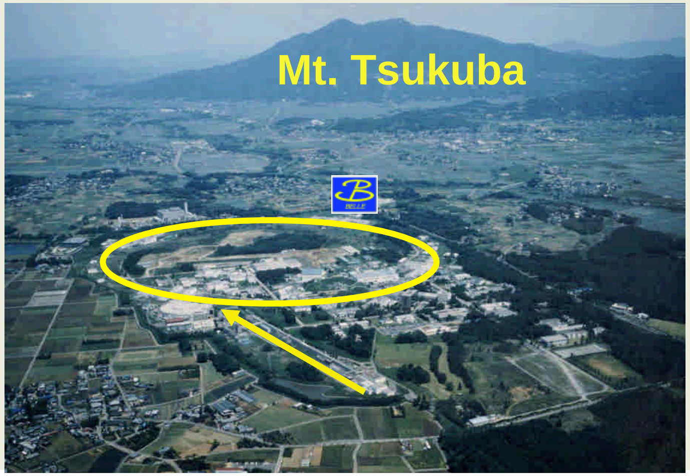
  Direct measurement, detecting π^0, η … , missing particles …

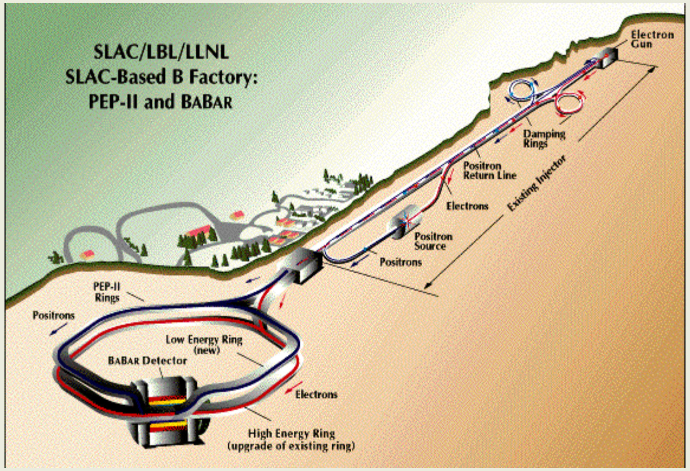
- Pay more attention to bottomonium

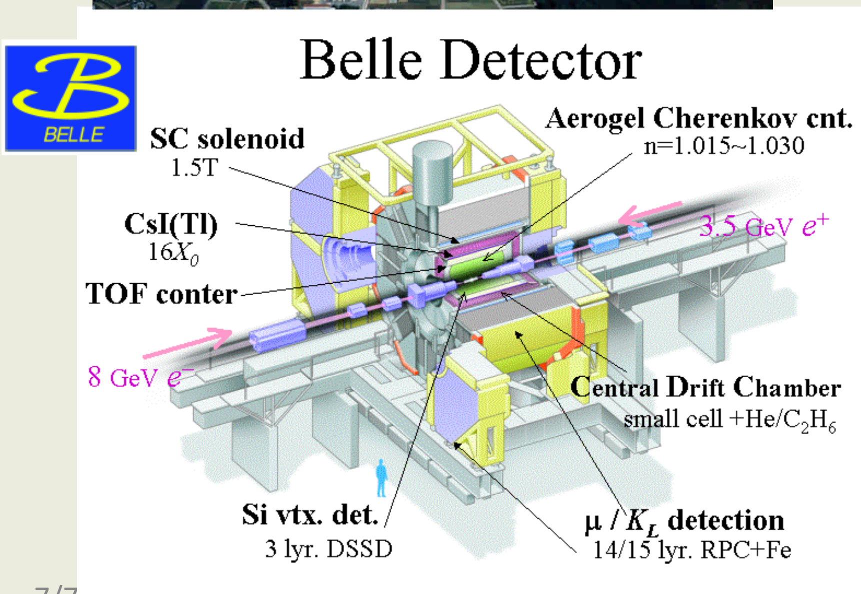
  spectroscopy, new physics …

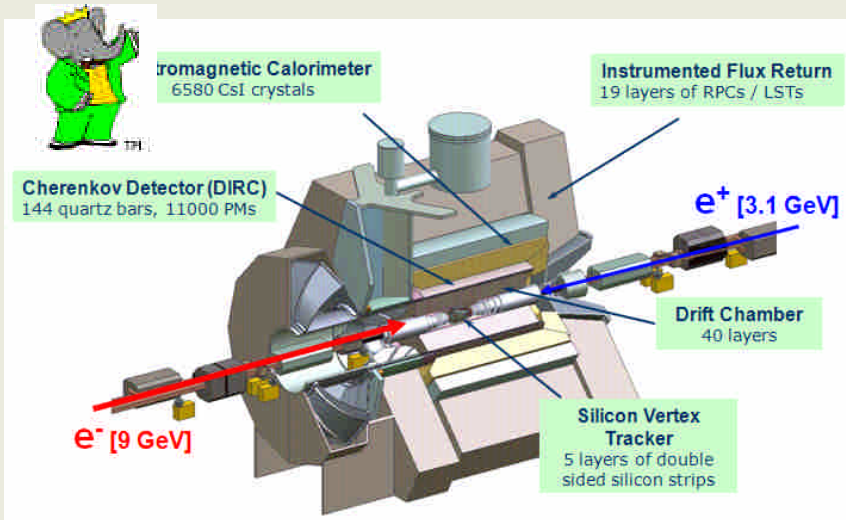


The Duel of B Factories

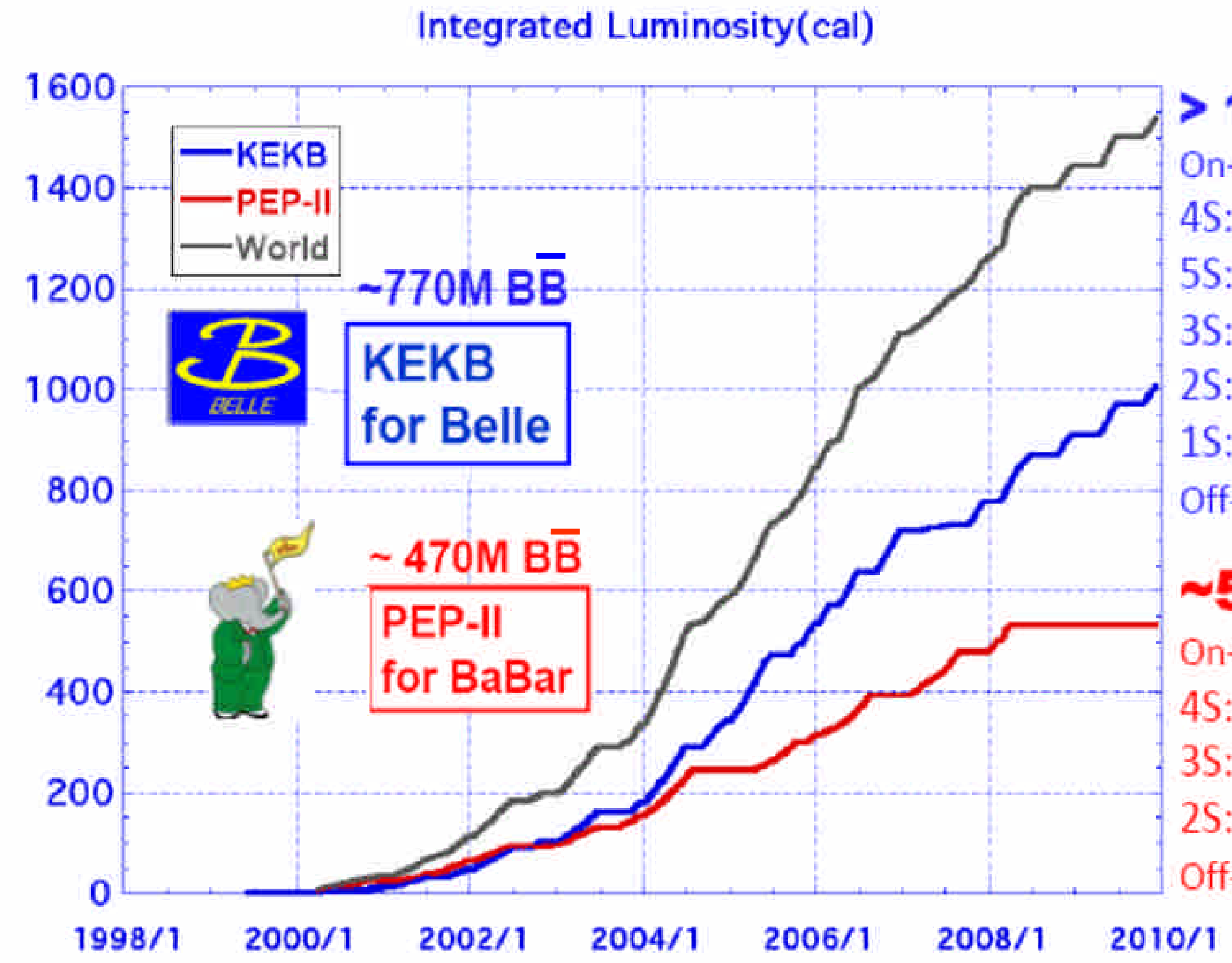








Successful Operation



> 1.0 ab^{-1}

On-resonance samples:

4S: 711 fb^{-1}

5S: 121 fb^{-1}

3S: 3.0 fb^{-1}

2S: 24 fb^{-1}

1S: 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

~553 fb^{-1}

On-resonance samples:

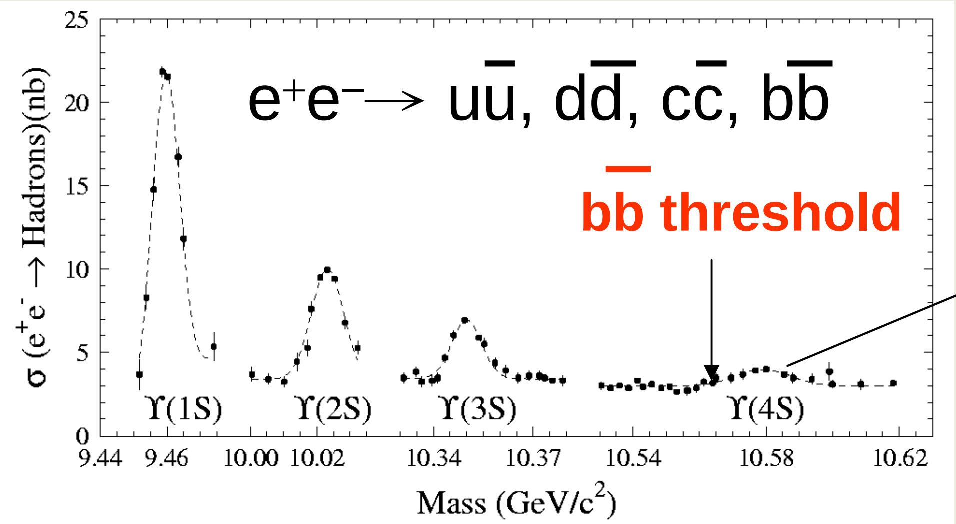
4S: 433 fb^{-1}

3S: 30 fb^{-1}

2S: 14 fb^{-1}

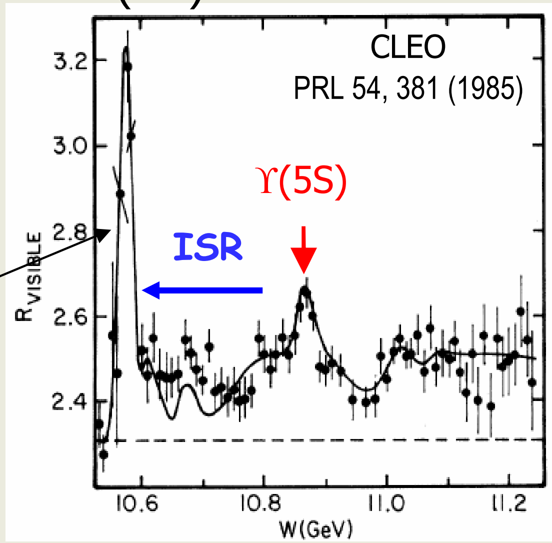
Off-resonance: 54 fb^{-1}

e^+e^- Hadronic cross-section



70 pb^{-1}

Υ(4S)



- Υ**(4S)** $\to B\bar{B}$, $B = B^+$ **or** B^0
- Υ**(5S)** $\to B^{(*)}B^{(*)}$, $B^{(*)}B^{(*)}\pi$, $BB\pi\pi$, $B_s^{(*)}B_s^{(*)}$, Υ**(1S)** $\pi\pi$ …

$M = 10.865 \pm 0.008$ GeV/c^2

$\Gamma = 110 \pm 13$ MeV $\Rightarrow$ Υ**(10860)**

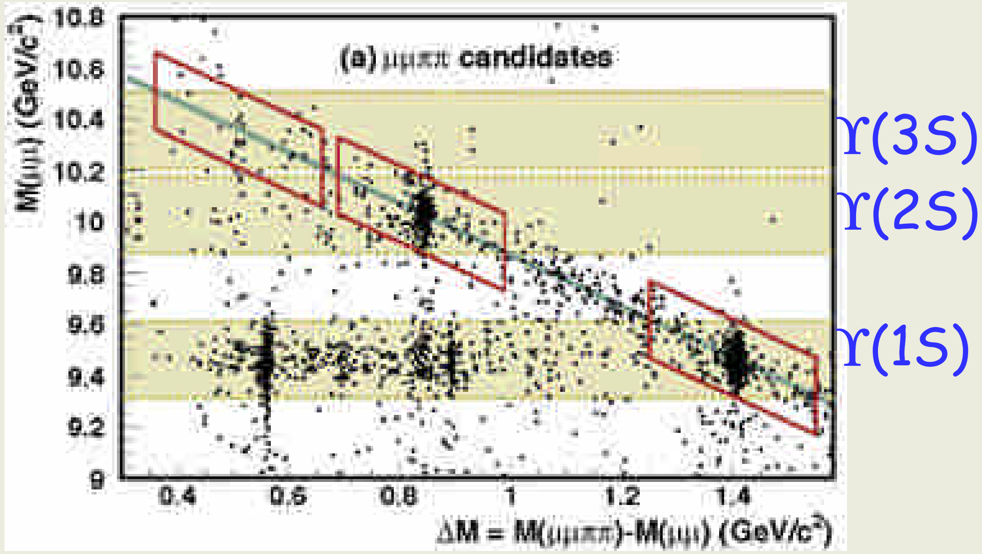
Is this really Υ**(5S)**?

Need measurements.

Observation of $\Upsilon(5S) \to \Upsilon(NS)\pi\pi$

- Took Data at 10867 MeV
- total 21.6 fb^{-1} in 2006
- Search for $\mu^+\mu^-\pi^+\pi^-$ events
- Observe unexpectedly large $\Upsilon(5S) \to \Upsilon(NS)\pi\pi$ signals

K.-F. Chen et al. (Belle colla.)
PRL 100, 112001 (2008)



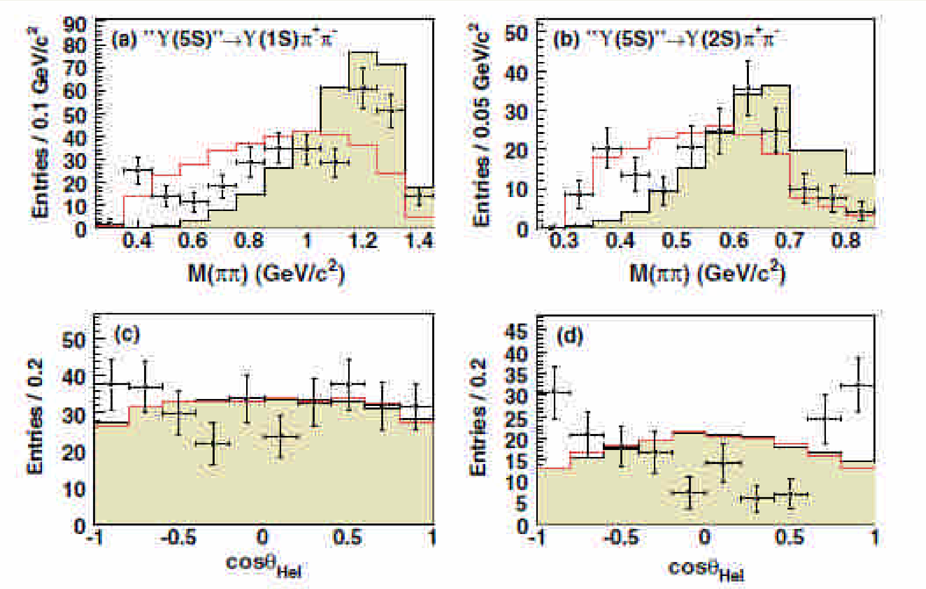
Process	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

Width, Mass and Angular Distributions

Anomalously large partial width at $\Upsilon(10860)$

Process	Γ_{total}	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2



- Histogram: phase space
- Shaded area: model from $\psi' \to J/\psi\ \pi\pi$; good for $\Upsilon(4S)$
- Rescattering Mechanism: Υ**(5S)** $\to B'B'\pi\pi \to \Upsilon$**(1S)** $\pi\pi$ Yu. Simonov, JETP Lett. 87, 121
- Other states: Yb near Υ**(5S)** W.-S. Hou, PRD 74, 017504

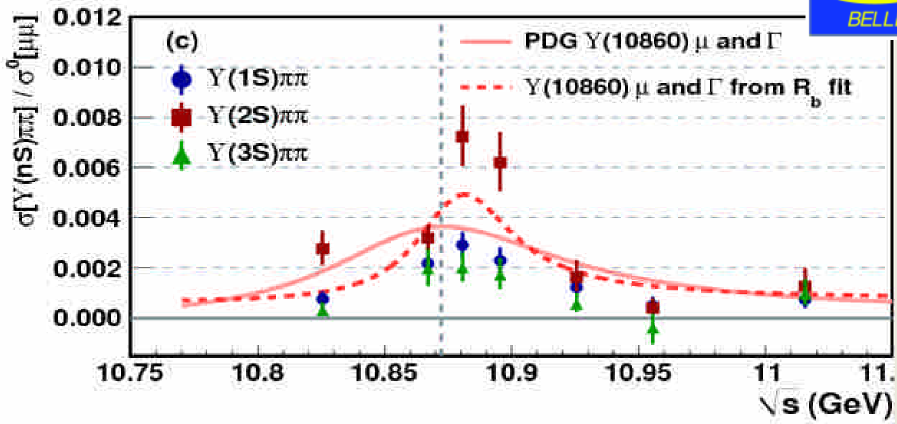
Energy Scans

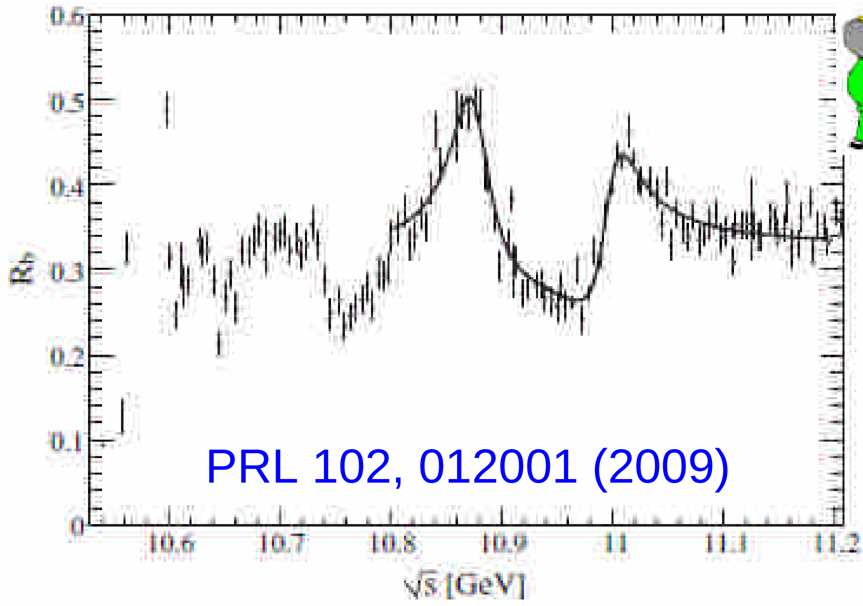
arXiv:0808.2445

- scan by Both Belle and BaBar
  - Belle: Υ(NS) $\pi\pi$ scan
  - BaBar: $R_b = \sigma(b\bar{b})/\sigma(\mu^+\mu^-)$
- Scan results:

	Mass (MeV/c^2)	Γ (MeV/c^2)
Belle ($\Upsilon(NS\pi\pi)$)	$10888.4^{+3.0}_{-2.9}$	$30.7^{+8.7}_{-7.7}$
Belle (R_b)	10879 ± 3	46^{+9}_{-7}
BaBar (R_b)	10876 ± 2	43 ± 4
PDG2008	10865 ± 8	110 ± 13

- Compared to Υ(10860) in PDG
  - mass is higher, width is narrower
- 3.2σ deviation on peak and width between Belle's Υ(NS) $\pi\pi$ and BaBar's R_b

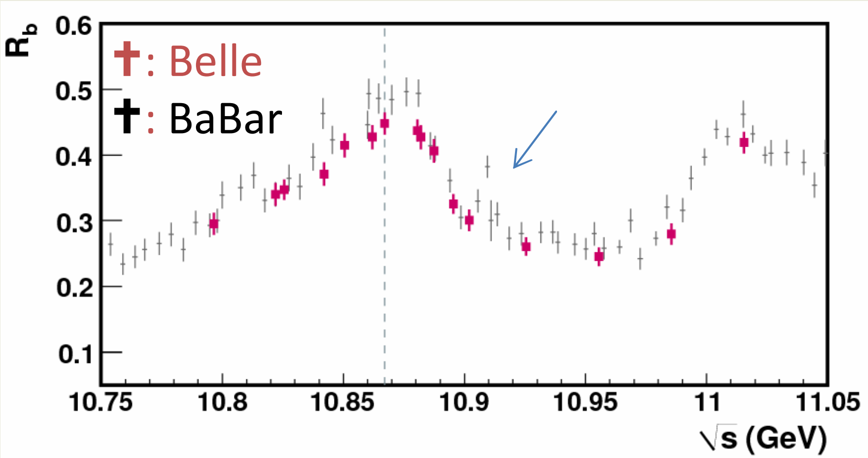


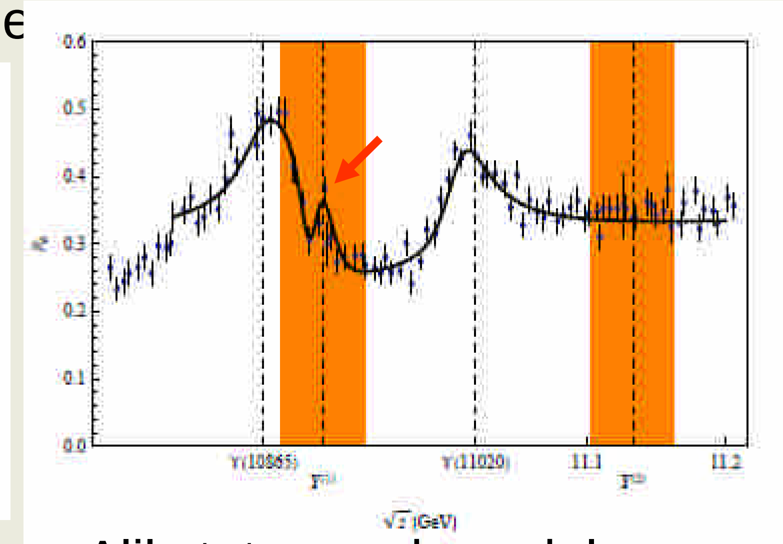


PRL 102, 012001 (2009)

What we want to know

Consistent R_b spectrum, but not scale





- Is there a peak at 10910 MeV/c²?
- Same shapes for R_b and Υ(NS)$\pi\pi$?
- Consistent R_b values for two exp.?

⇒ 2nd Belle energy scan (5,6/2010)

- Fine scan btw. 10.75 and 11.05 GeV
- More on Υ(5S), Υ(6S) and btw 4S&5S

- Ali's tetraquark model
  - Explain the BaBar R_b spectrum. PLB 684, 28-39 (2010)
  - Explain Belle's M($\pi\pi$) and angular distribution for $\Upsilon(5S) \to \Upsilon(NS)\ \pi\pi$ evts PRL 104, 162001 (2010)

Hadronic fractions

$f_{\not B} \geq (2.8 \pm 0.3)\%$
[K.F. Chen et al. (Belle) PRL 100, 112001 (08)]

Υ X

u,d,s,c continuum

b continuum

hadronic events at Υ(5S)

Υ(5S) events

bb events

$f(B^{+/0}) = (73.7 \pm 6.0)\%$
[A. Drutskoy et al. (Belle) arXiv:1003.5885]

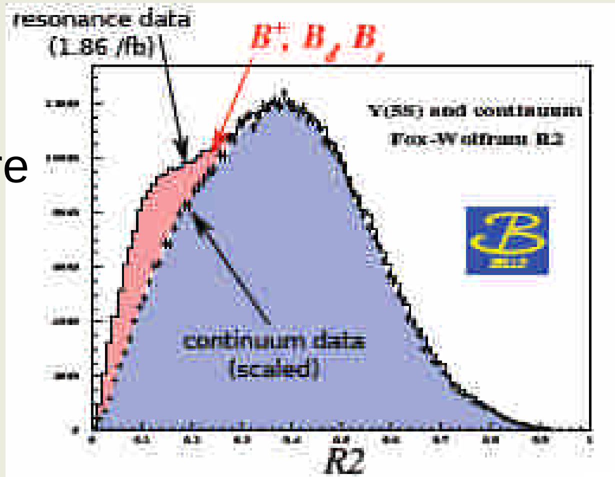
B^0, B^+ events

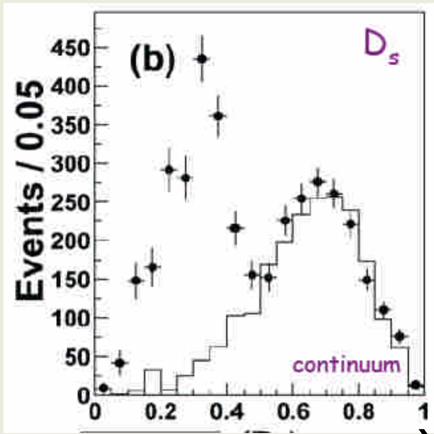
B_s events

$\sigma(b\bar{b}) = (302 \pm 14)$ pb
G.S. Huang et al. (CLEO) PRD 75, 012002 (07)
A. Drutskoy et al. (Belle) PRL 98, 052001 (07)

$f_s = (19.3 \pm 2.9)\,\%$
HFAG [PDG 2008]

Measure $\sigma(b\bar{b})$





X(D_s)

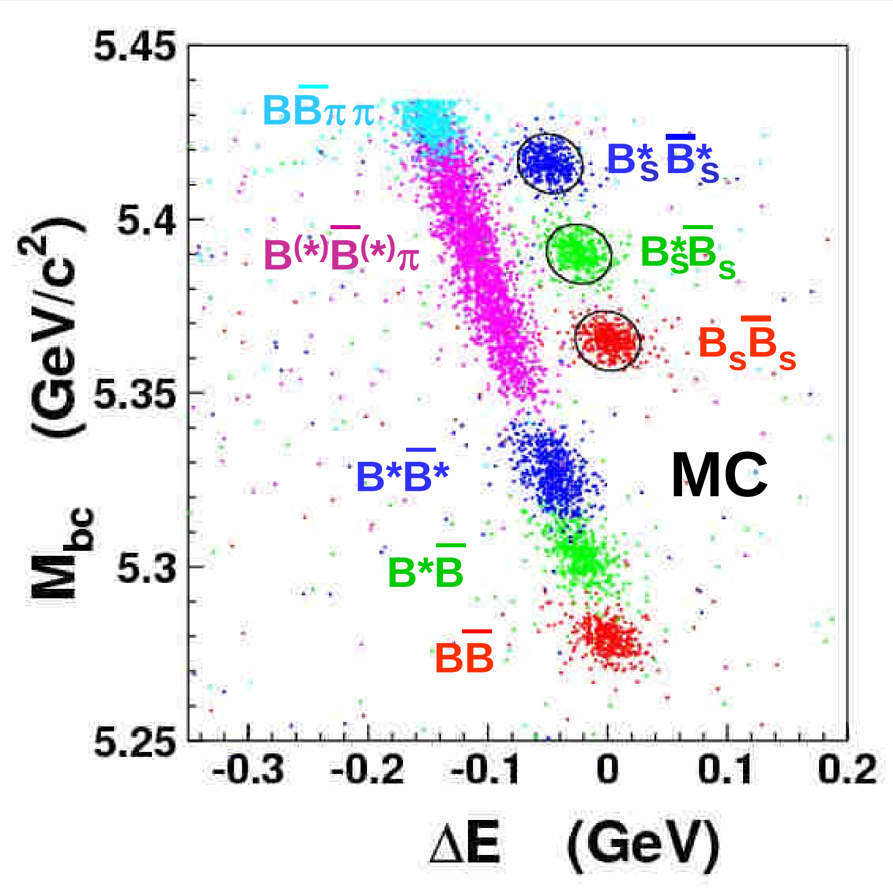
$$X(D_s) = P_{Ds} / \sqrt{E^2_{beam} - M^2_{Ds}}$$

fs is the dominant source of systematic errors for many Bs measurements

$$R_2 = \frac{\sum_{i,j} |p_i||p_j| P_2(\cos\theta)}{\sum_{i,j} |p_i||p_j| P_0(\cos\theta)}$$

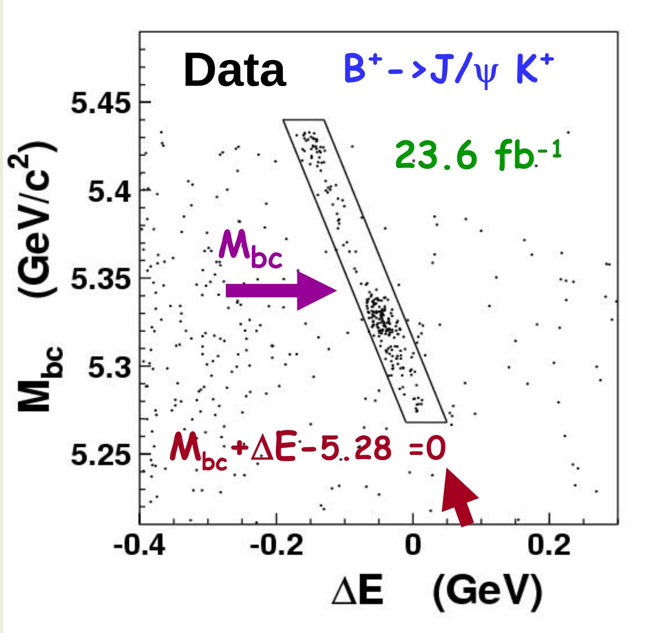
$$\frac{1}{2}\overbrace{\mathcal{B}(\Upsilon(5S) \to D_s X)}^{\Upsilon(5S)\text{ data}} = f_s \times \overbrace{\mathcal{B}(B_s \to D_s X)}^{\text{THEORY estimate}} + (1 - f_s) \times \frac{1}{2}\overbrace{\mathcal{B}(\Upsilon(4S) \to D_s X)}^{\Upsilon(4S)\text{ data}}$$

Fully Reconstructed B events at $\Upsilon(5S)$



$$e^+e^- \to \Upsilon(5S) \to B^{(*)}B^{(*)}(\pi)(\pi)$$

$$B^* \to B\,\gamma$$



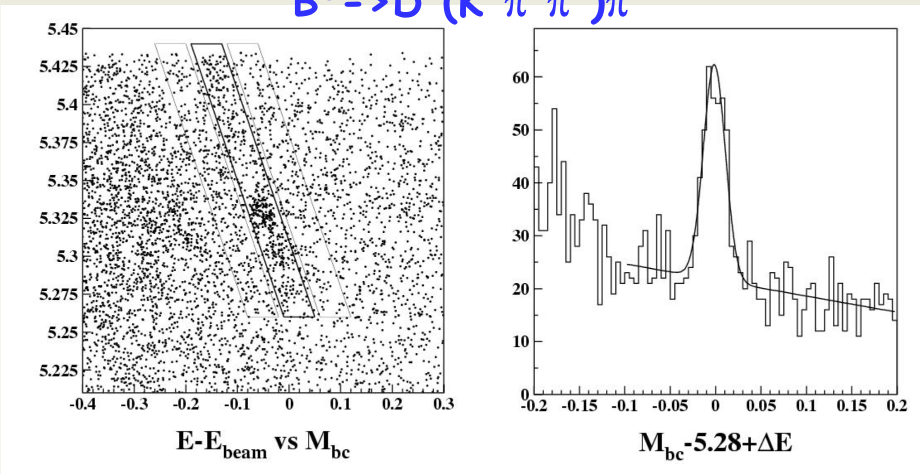
Only one B meson is reconstructed

$$M_{bc} = \sqrt{E^{*2}_{beam} - P^{*2}_B}\ ;\ \Delta E = E^*_B - E^*_{beam}$$

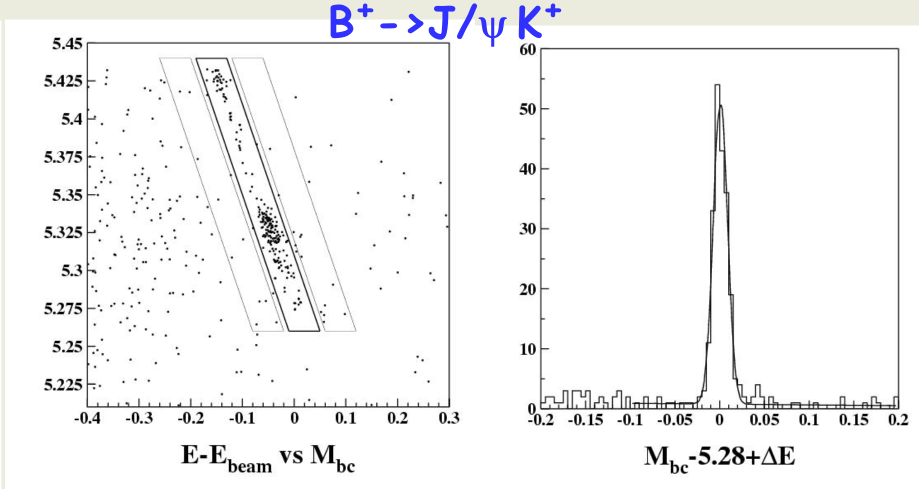
Υ(5S) to B Meson

PRD81, 112003(2010)

$B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$



$B^+ \to J/\psi K^+$



- Identify B meson in 5 decay modes **$f(X)=N(X)/N(b\bar{b})$**

Decay mode	Yield	Efficiency, %	$f(B^{+/0})$, %
$B^+ \to J/\psi K^+$	221^{+16}_{-15}	3.41	$89.0^{+6.3}_{-6.1} \pm 8.0$
$B^0 \to J/\psi K^{*0}$	105 ± 11	1.30	$85.3^{+9.2}_{-8.8} \pm 8.8$
$B^+ \to \bar{D}^0(K\pi)\pi^+$	215 ± 21	0.97	$64.0 \pm 6.2 \pm 4.9$
$B^+ \to \bar{D}^0(K3\pi)\pi^+$	275 ± 32	1.17	$68.3^{+8.0}_{-8.1} \pm 6.4$
$B^0 \to D^-\pi^+$	247 ± 25	1.80	$72.9 \pm 7.4 \pm 6.4$

$f(B^+) = (72.1 ^{+3.9}_{-3.8} \pm 5.0)\%$

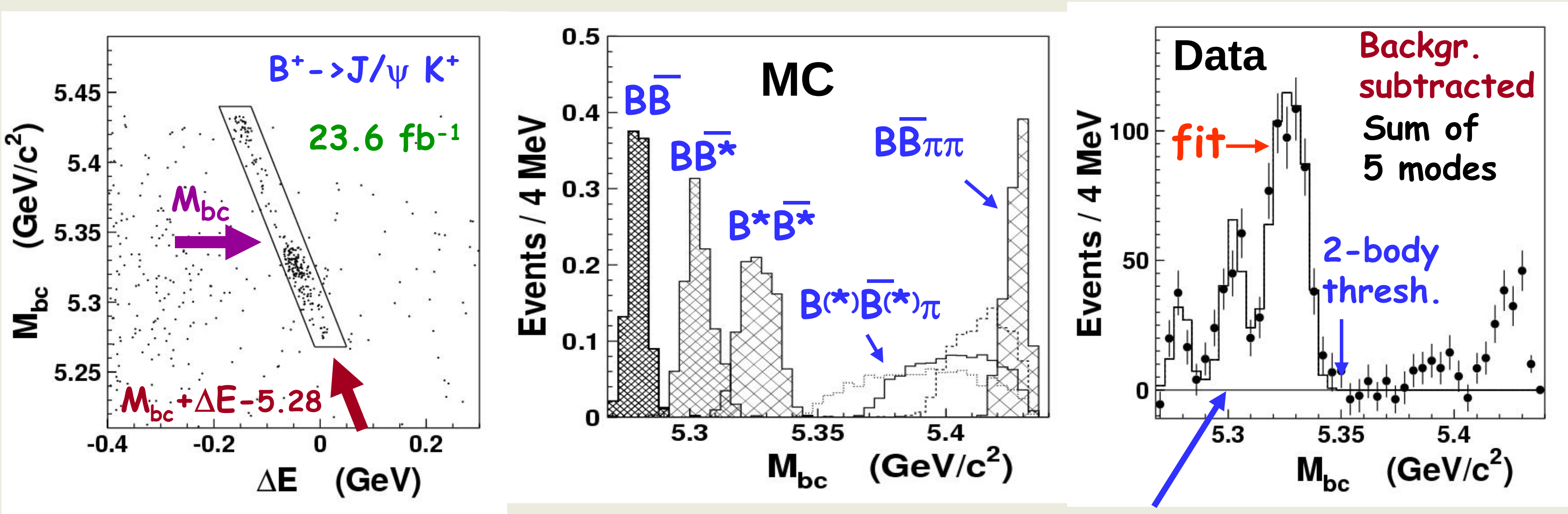
$f(B^0) = (77.0 ^{+5.8}_{-5.6} \pm 6.1)\%$

$f(B) = (73.7 \pm 3.2 \pm 5.1)\%$

$(58.9 \pm 10.0 \pm 9.2)\%$ (CLEO 2006)

$\Rightarrow f(B_s) = (19.5 \pm ^{3.0}_{2.2})\%$ (PDG, Belle+CLEO).

Two-Body Decays



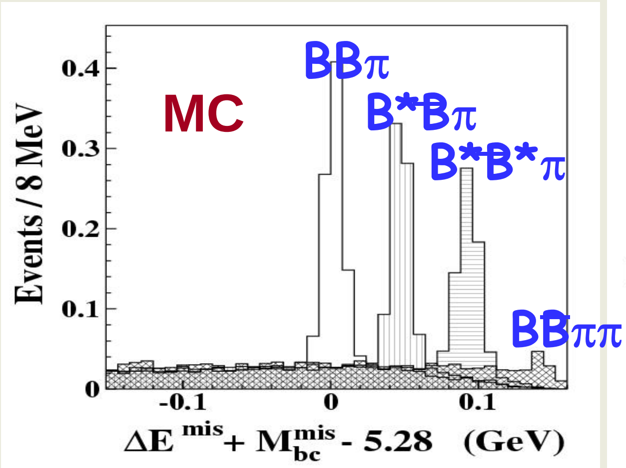
Channel	Fraction, %
$B\bar{B}$	$5.5^{+1.0}_{-0.9} \pm 0.4$
$B\bar{B}^* + B^*\bar{B}$	$13.7 \pm 1.3 \pm 1.1$
$B^*\bar{B}^*$	$37.5^{+2.1}_{-1.9} \pm 3.0$
Large M_{bc}	$17.5^{+1.8}_{-1.6} \pm 1.3$

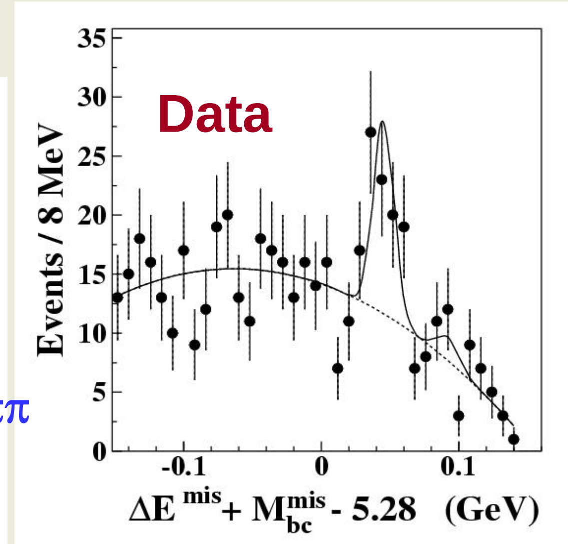
Simultaneous fit of 5 B modes in M_{bc}< 5.35 GeV/c^2 region

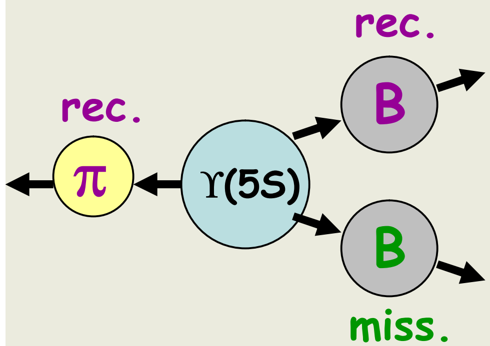
Theory: channel B*B* is dominant, 30-69%
⇒ need to modify the theory

M_{bc}>5.35 GeV/c: $17.5\pm^{1.8}\pm 1.3$ % => non 2-body channels, why so large?

Three-Body Decays







- fully reconstruct B & $\pi^{\pm}$
- Obtain E^{miss} and P^{miss}

Channel	Yield (π^+), events	Fraction over large M_{bc} %	Fraction per $b\bar{b}$ event %
$B\bar{B}\pi$	$0.2^{+7.2}_{-6.9}$	$0.2^{+6.8}_{-6.5}$	$0.0 \pm 1.2 \pm 0.3$
$B\bar{B}^*\pi + B^*\bar{B}\pi$	$38.3^{+10.5}_{-9.8}$	$41.6^{+12.1}_{-11.4}$	$7.3^{+2.3}_{-2.1} \pm 0.8$
$B^*\bar{B}^*\pi$	$4.8^{+6.4}_{-5.9}$	$5.9^{+7.8}_{-7.2}$	$1.0^{+1.4}_{-1.3} \pm 0.4$
Residual		$52.3^{+15.9}_{-15.0}$	$9.2^{+3.0}_{-2.8} \pm 1.0$
Large M_{bc}		100	$17.5^{+1.8}_{-1.6} \pm 1.3$

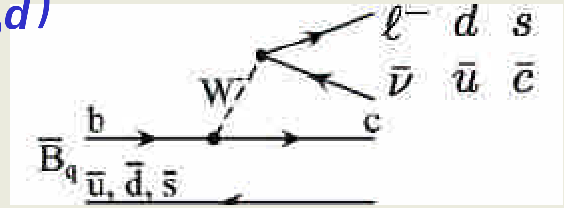
Theory, 3-body fractions:
~0.3% : L.Lellouch et al Nucl Phys B405:55,1993
~0.03% :Yu.Simonov et al hep-ph:0805.4518

Residual is too large for BBππ.
ISR ~4% to ϒ(4S) and ~6% to above ϒ(4S)

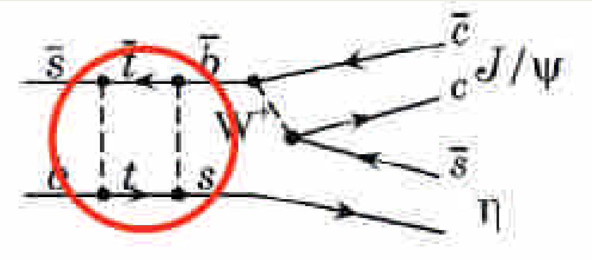
B_s Physics

B_s Decay Results

- $B_s \to D_s^{*-}\pi^+, D_s^{(*)-}\rho^+$ PRL 104, 231801 (2010)
  - Dominated by spectator process (like $B_{u,d}$)
    test of HQET, factorization …
  - Large statistics to study B_s properties
    mass, width, angular distributions …



- CP eigenstates ($D_s^{(*)+}D_s^{(*)-}$, $J/\psi\eta^{(\prime)}$, $J/\psi f_0(980)$, K^+K^-)
  - window for non-SM CP violations
    β_s, $\Delta\Gamma_s / \Gamma_s$
  - Rare decays ($B \to KK$)
    CKM angle ϕ_3/γ, NP in penguin loop



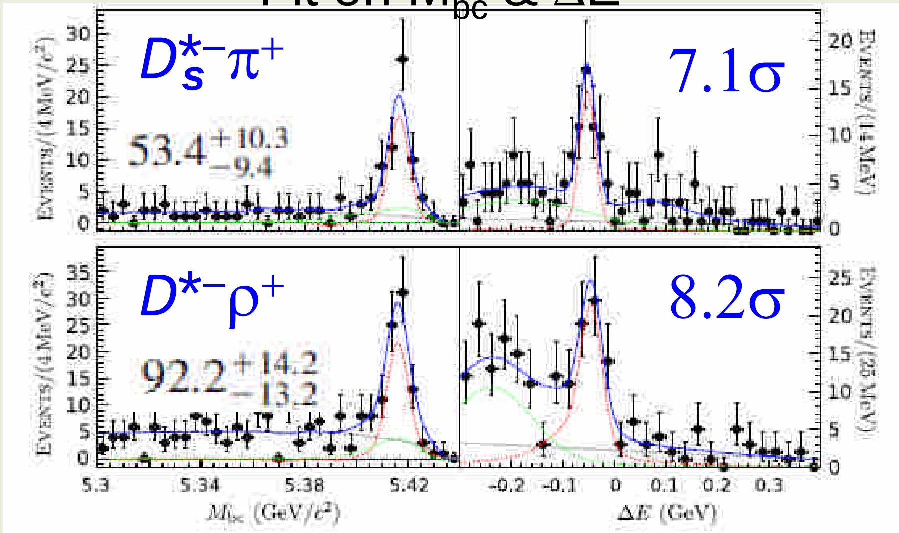
arg($V_{tb}^{*2}V_{ts}^2$) = 0 for B_s

Observation of $B_s \rightarrow D_s^{*-}\pi^+$, $D_s^{*-}\rho^+$

- reconstruct $D_s^{*-} \rightarrow D_s^- \gamma$

  $D^- \rightarrow \phi\pi^-, K^{*0}K^-, K_s^0 K^-$

Fit on M_{bc} & ΔE



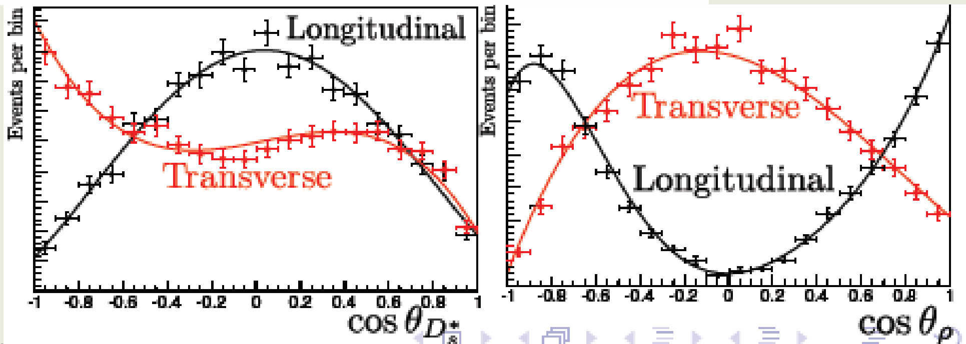
Mode	$\mathcal{B}$ (10^{-3})	HQET (10^{-3})
$B_s^0 \to D_s^{*-}\pi^+$	$2.4^{+0.5}_{-0.4} \pm 0.3 \pm 0.4$	2.8
$B_s^0 \to D_s^-\rho^+$	$8.5^{+1.3}_{-1.2} \pm 1.1 \pm 1.3$	7.5
$B_s^0 \to D_s^{*-}\rho^+$	$11.9^{+2.2}_{-2.0} \pm 1.7 \pm 1.8$	8.9

- $D_s^{*-}\rho^+$: scalar to vector vector

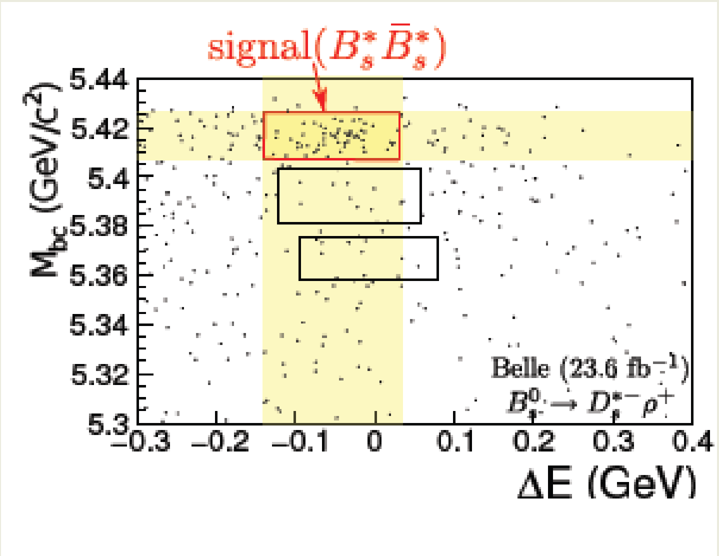
$$\frac{d^2\Gamma}{d\cos\theta_{D_s^*}\, d\cos\theta_\rho} \propto 4 f_L \sin^2\theta_{D_s^*} \cos^2\theta_\rho + (1 - f_L)\left(1 + \cos^2\theta_{D_s^*}\right)\sin^2\theta_\rho$$

Efficiency, M_{bc} & ΔE PDFs all depend on f_L

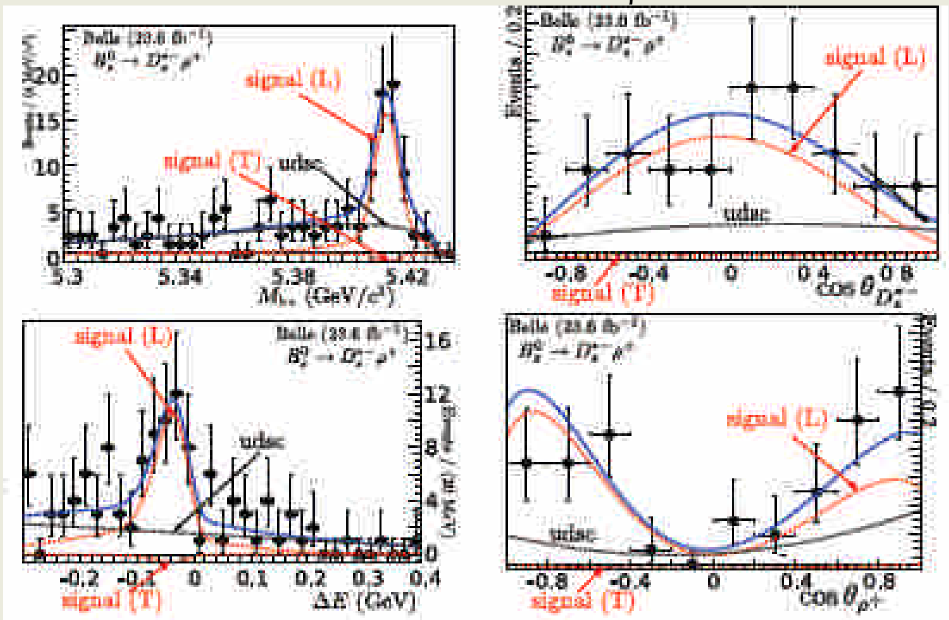
MC study



Observation of $B \to D_s^{*-}\rho^+$



4D fit on M_{bc}, ΔE, $\cos\theta_\rho$, $\cos\theta_{D^*}$



- $N(B_s^* \bar{B}_s^*) = 77.8^{+14.5}_{-13.4}(\text{stat.}) \pm 3.3(\text{fit})$ events (7.4σ significance)

$$\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+) = \left(11.8^{+2.2}_{-2.0}(\text{stat.}) \pm 1.7(\text{syst.}) \pm 1.8(f_s)\right) \times 10^{-3}$$

$f_L = 1.05^{+0.08}_{-0.10}{}^{+0.03}_{-0.04}$ or $f_L \in [0.93, 1.00]$ at 68% C.L.

$B_s \longrightarrow D_s^{(*)+} D_s^{(*)-}$

- Cabibbo favored and CP eigen state.
- Dominates $\Delta\Gamma_s^{CP}$ [Aleksan et al., Z. Phys., C54, 653 (1992)]

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \frac{2 \times \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}{1 - \mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right)}$$

, assuming no CPV

- Measure $\mathcal{B}(B \longrightarrow D^{(*)+}_s D^{(*)-}_s)$ with D decay into six states:

  $D_s^+ \to \phi\pi^+$, $K_s K^+$, $\phi\rho^+$, $\bar{K}^{*0}K^+$, $K_s K^{*+}$ and $\bar{K}^{*0}K^{*+}$

- Identify $D_s^{*+} \to D_s^+ \gamma$ with $E\gamma > 50$ & $|M_{D_s^*} - M_{D_s}| < 120$ MeV
- One candidate per event based on χ^2 of M(D) and M(D*)
- Suppress continuum events using Fox-Wolfram moments

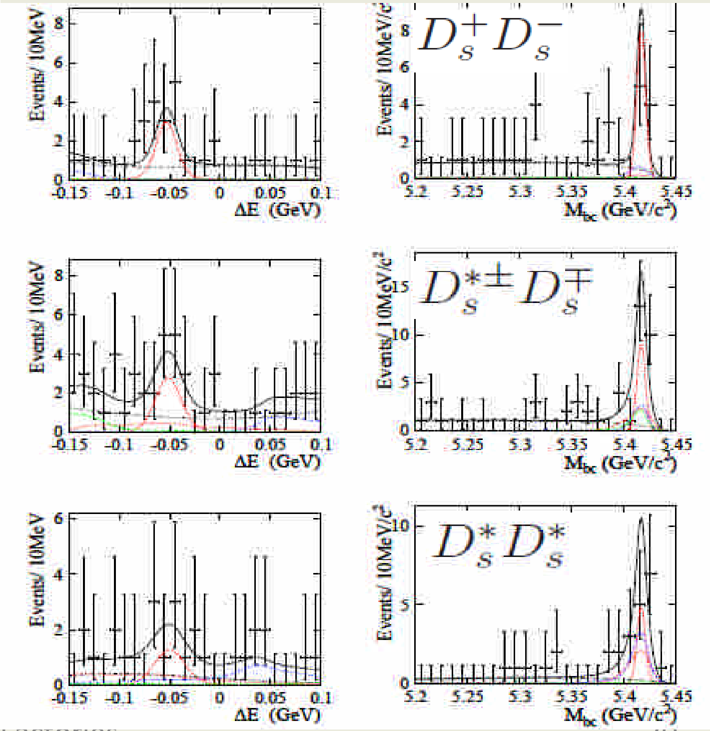
Extract of $B_s \to D_s^{(*)+} D_s^{(*)-}$

Mode	Y (events)	ϵ $(\times 10^{-4})$	$\mathcal{B}$ (%)	S
$D_s^+ D_s^-$	$8.5^{+3.2}_{-2.6}$	3.31	$1.03^{+0.39+0.15}_{-0.32-0.13} \pm 0.21$	6.2
$D_s^{*\pm} D_s^{\mp}$	$9.2^{+2.8}_{-2.4}$	1.35	$2.75^{+0.83}_{-0.71} \pm 0.40 \pm 0.56$	6.6
$D_s^* D_s^*$	$4.9^{+1.9}_{-1.7}$	0.643	$3.08^{+1.22}_{-1.04} \pm 0.56 \pm 0.63$	3.2
sum	$22.6^{+4.7}_{-3.9}$		$6.85^{+1.53+1.26}_{-1.30-1.25} \pm 1.41$	

consistent with CDF

first observation

first evidence



- Simultaneously fit three samples and consider their cross-feed

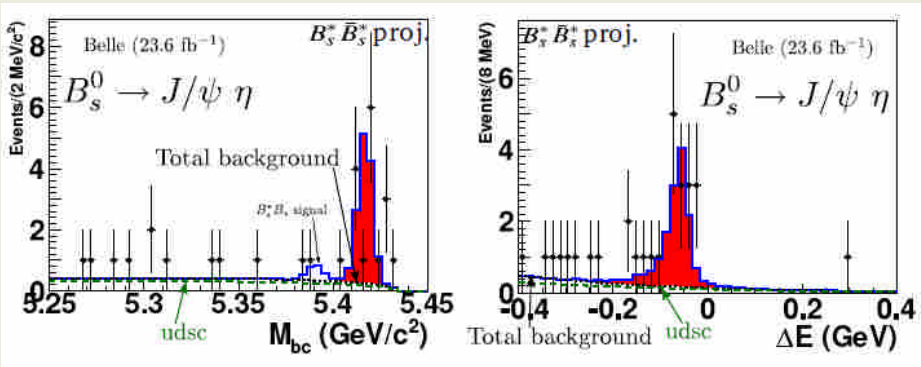
$$\Rightarrow \frac{\Delta\Gamma_s}{\Gamma_s} = (14.7^{+3.6+4.4}_{-3.0-4.3} \pm 0.4)\%$$

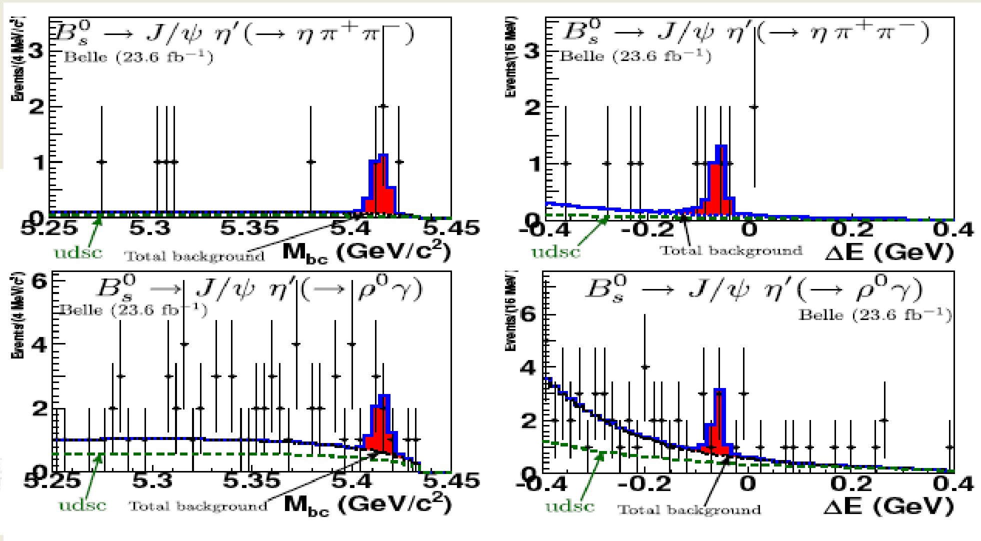
CDF: $(12 \pm 10)\%$ [PRL 100, 121803]

D0: $(7.2 \pm 3.0)\%$ [PRL 102, 091801]

B_s Decays to J/ψ η(')

- $\eta \to \gamma\gamma$; $\eta \to \pi^+\pi^-\pi^0$
- $\eta' \to \eta\pi^+\pi^-$; $\eta' \to \rho^0\gamma$





- First observation of $B_s \to J/\psi\ \eta$

  yield = 14.9± 4.1; sig. = 7.3σ

- First evidence of $B_s \to J/\psi\ \eta'$

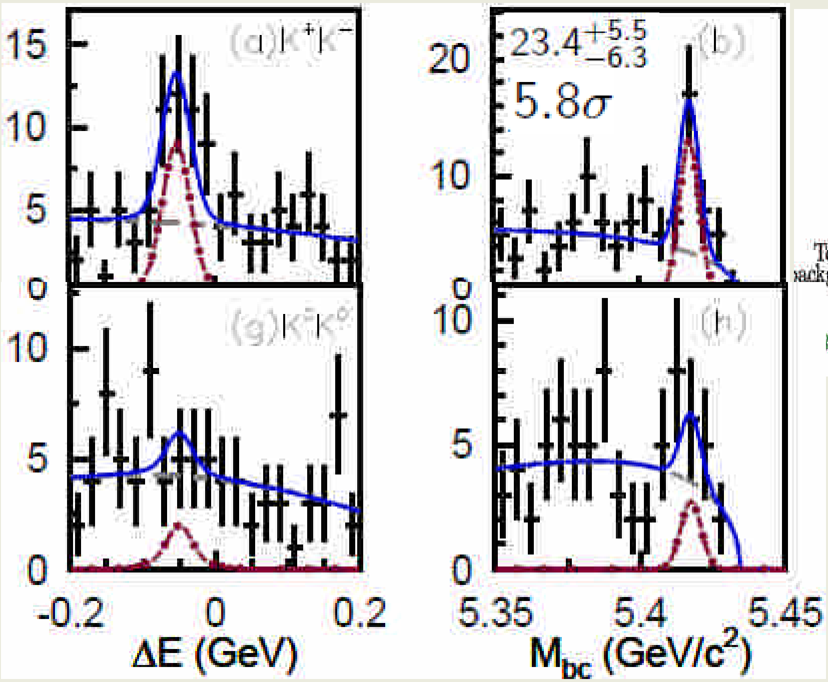
  yield = 10.7± 4.6; sig. = 3.8σ

$\mathcal{B} = (2.32 \pm 0.87\ ^{+0.32}_{-0.28} \pm 0.42(fs)) \text{x}10^{-4}$

$\mathcal{B} = (3.1 \pm 1.2\ ^{+0.5}_{-0.6}\ \pm 0.4(fs)) \text{x}10^{-4}$

B_s Decays to KK, J/ψ f_0

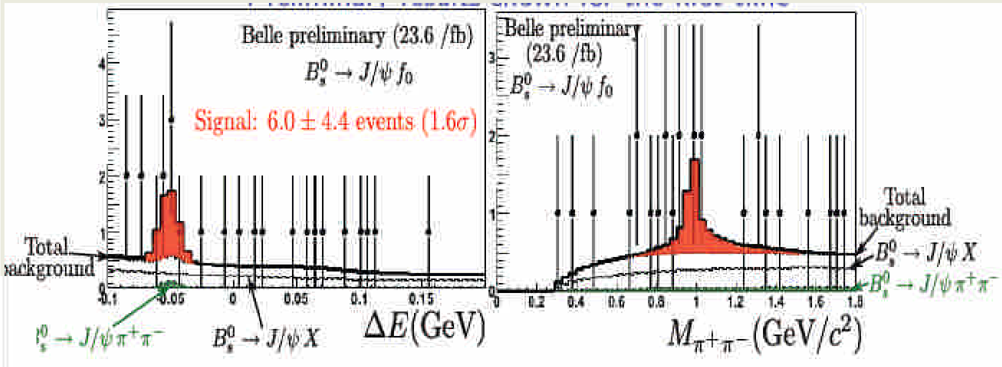
$B_s \to$ KK



$$\mathcal{B}(B_s^0 \to K^+K^-) = \left(3.8^{+1.0}_{-0.9} \pm 0.5 \pm 0.5(f_s)\right) \times 10^{-5}$$

$$\mathcal{B}(B_s^0 \to K^0\bar{K}^0) < 6.6 \times 10^{-5}$$

$B_s \to J/\psi f_0$, $f_0 \to \pi^+\pi^-$



$$R_{f/\phi} = \frac{\mathcal{B}(B_s^0 \to J/\psi f_0)\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi \phi)\mathcal{B}(\phi \to K^+K^-)};$$

$$\mathcal{B}(B_s^0 \to J/\psi f_0) \times \mathcal{B}(f_0 \to \pi^+\pi^-) < 1.63 \times 10^{-4} \text{ (at 90\% C.L.)}$$

Υ(1S) and Υ(2S)

$\Upsilon(1S)$ Radiative Decays

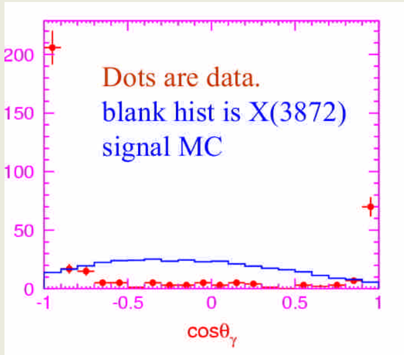
102 M $\Upsilon(1S)$

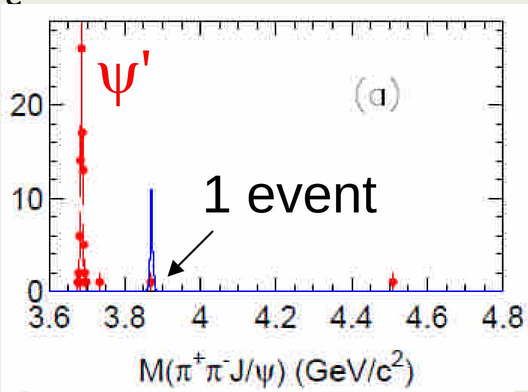
- Search for charmonium-like states in radiative $\Upsilon(1S)$ decays

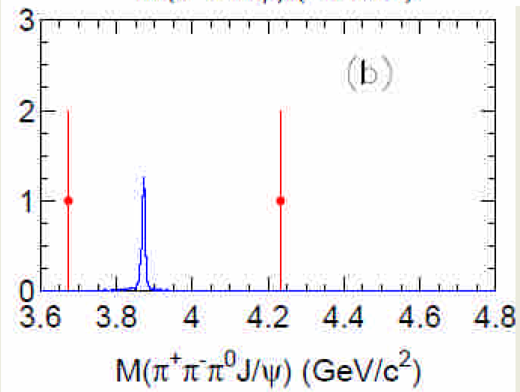
  X(3872) , X(3915), Y(4140), X(4350), X_{cJ}, η_c ...

- Search for C parity even state
- X(3872) $\rightarrow J/\psi\ \pi^+\pi^-(\pi^0)$
  - $J/\psi \rightarrow e^+e^-$, $\mu^+\mu^-$; E_γ>3.5 GeV
  - Recoil mass of $J/\psi\ \pi^+\pi^-(\pi^0)$ Consistent with γ
  - to suppress ISR

    $\Rightarrow |\cos\theta_\gamma|<0.9$

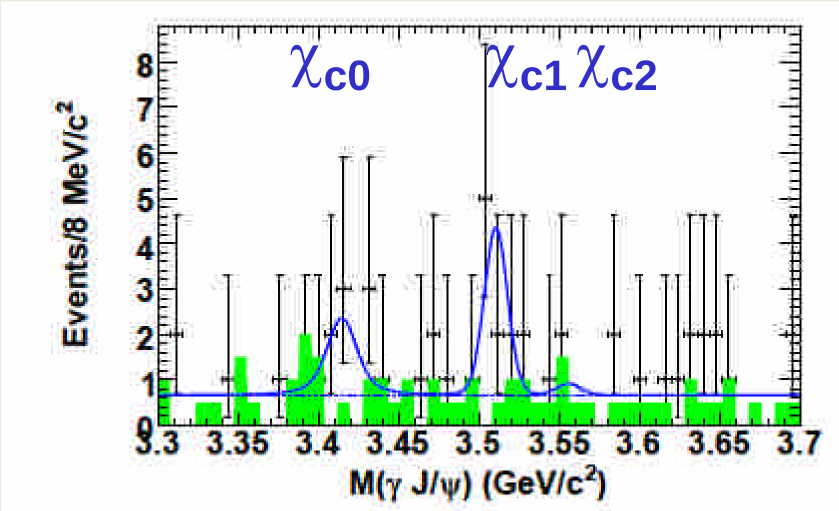




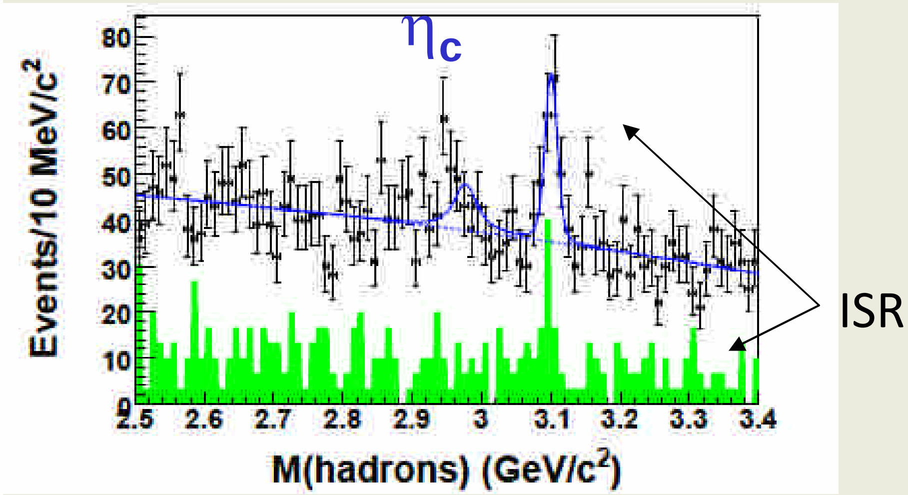


Υ(1S) Radiative Decays Cont.

Histogram: J/ψ sideband bkg



Histogram: off peak data



- $\chi_{cJ} \rightarrow \gamma J/\psi$
- $\eta_c \rightarrow K^0_S K^+\pi^- + c.c.$
  - $\rightarrow K^+K^-\pi^+\pi^-$
  - $\rightarrow 2K^+K^-$
  - $\rightarrow 2\pi^+\pi^-$
  - $\rightarrow 3\pi^+\pi^-$

$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c0}) < 5.0 \times 10^{-4},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c1}) < 1.5 \times 10^{-5},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma\chi_{c2}) < 1.2 \times 10^{-5},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma\eta_c) < 6.4 \times 10^{-5},$$

Upper limits at 90% C.L.

Limits on product of branching fractions for X & Y

$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) < 2.2 \times 10^{-6},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^-\pi^0 J/\psi) < 3.4 \times 10^{-6},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma X(3915)) \times \mathcal{B}(X(3915) \to \omega J/\psi) < 3.4 \times 10^{-6},$$
$$\mathcal{B}(\Upsilon(1S) \to \gamma Y(4140)) < 2.6 \times 10^{-6},$$

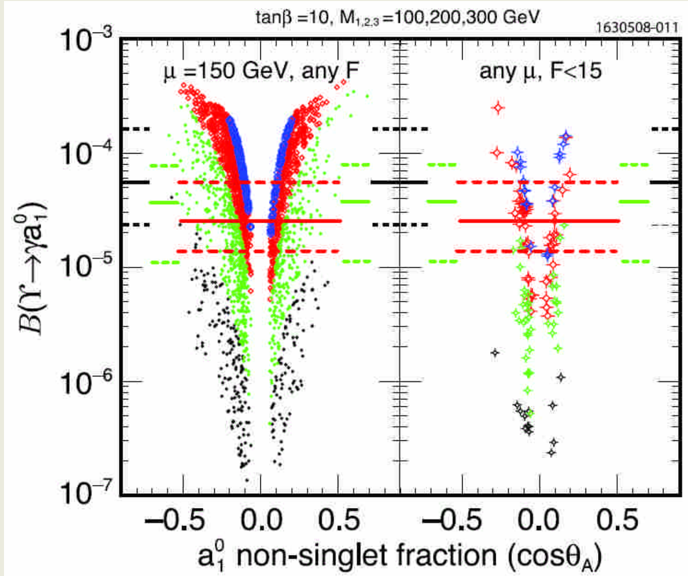
Search for Light Higgs

- NMSSM introduces single CP-odd light Higgs (PRD73, 111701(R), 2006)
  - $A^0 = (\cos\theta_A)\, a_{MSSM} + (\sin\theta_A)\, a_{singlet}$
  - $\mathcal{B}$ can be as high as 10^{-4}
  - direct search by B factory if $M(A^0) < 2m_b$
- HyperCP observed 3 $\Sigma \to p\mu^+\mu^-$ events

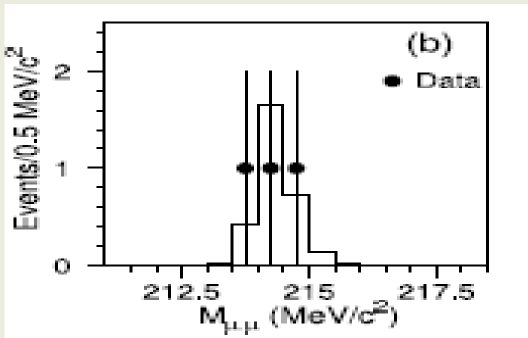
  Interpreted as light scalar to two muons
- First search by CLEO: $\Upsilon(1S) \to \gamma A^0$
- BaBar search for $\Upsilon(2S/3S) \to \gamma A^0$

  $A^0 \to \mu^+\mu^-$, $A^0 \to \tau^+\tau^-$, $A^0 \to$ invisible **3 PRLs!**

  $\Upsilon(3S)$ only

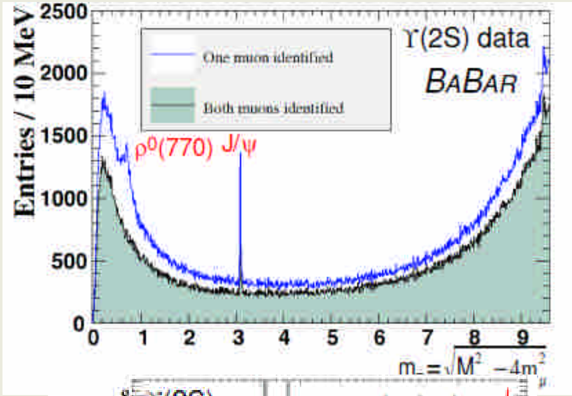


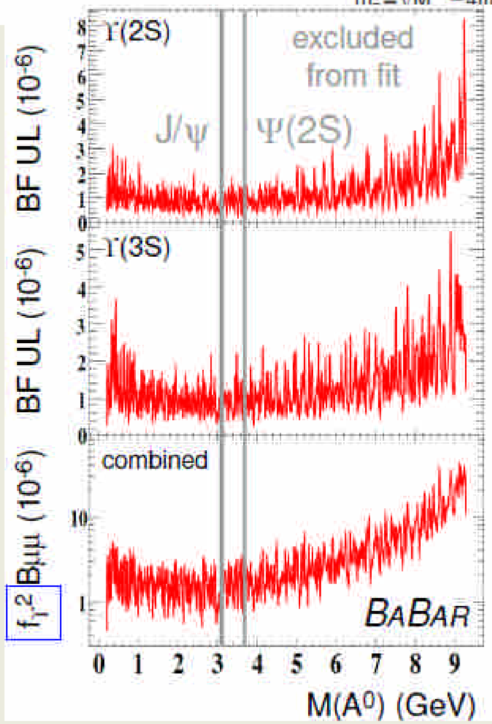
HyperCP



Search for $A^0 \to \mu^+\mu^-$

- 1 γ + balanced h^+h^-
- $E\gamma > 0.2$ GeV; one h is identified as μ
- Kinematic fit on $\gamma\mu^+\mu^-$ by constraining $\mu\mu$ vertex and Υ energy
- Search for peak in m_R by performing ~2000 ML fits from 0.212 to 9.3 GeV/c^2



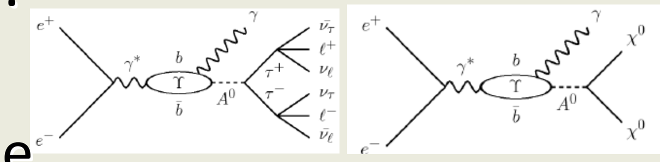


- **No signal at 214 MeV (HyperCP)**
- **$BF(\eta_b \to \mu^+\mu^-) < 0.9\%$ @ 90% CL**
  - **$BF_{TOT}(\Upsilon(2S)) < (0.26\text{-}8.3)\times10^{-6}$**
  - **$BF_{TOT}(\Upsilon(3S)) < (0.27\text{-}5.5)\times10^{-6}$**

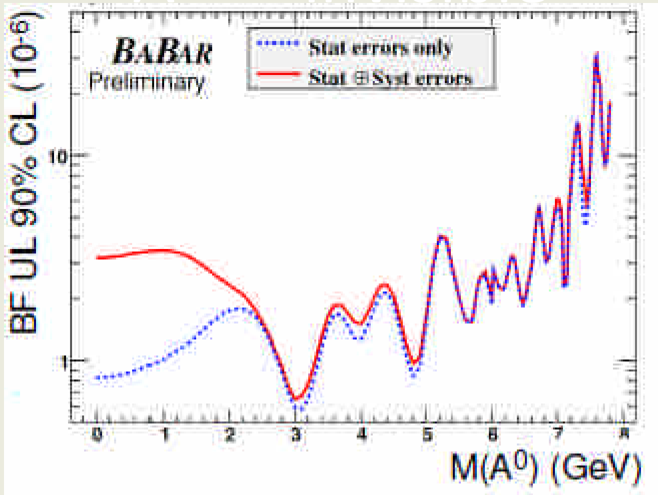
$$\frac{\mathcal{B}(\Upsilon(nS) \to \gamma A^0)}{\mathcal{B}(\Upsilon(nS) \to l^+l^-)} = \frac{f_\Upsilon^2}{2\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

Search for $A^0 \to \tau^+\tau^-$, invisible

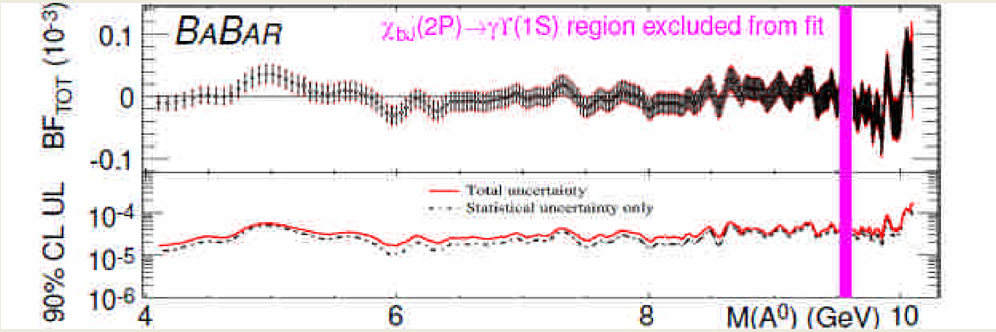
- Require only one photon with $E_\gamma > 0.1$ GeV.
  - Tag $\tau\tau$ using e^+e^-, $\mu^+\mu^-$ $e^\pm\mu^\mp$
  - No other particles for the invisible mode
- Search for E_γ peak



$A^0 \to$ invisible



$A^0 \to \tau^+\tau^-$



$BF(\Upsilon(3S)\to\gamma A^0) \times BF(A^0 \to\tau^+\tau^-) < (1.5\text{-}16) \times 10^{-5}$

BABAR PRL 103, 181801 2009

$BF_{TOT} < (0.7\text{-}31) \times 10^{-6}$

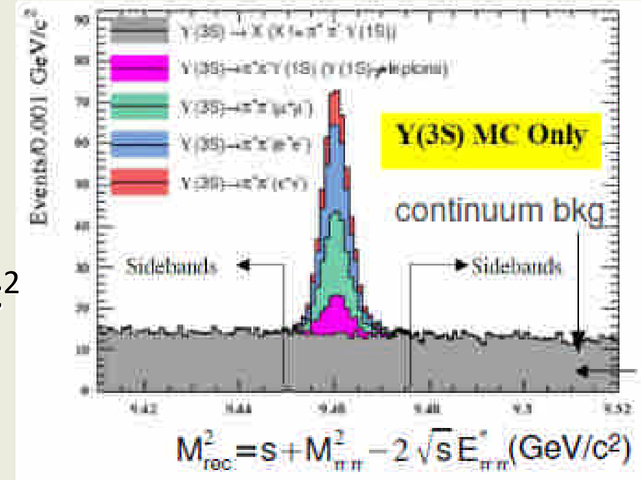
arXiv:0808.0017 [hep-ex]

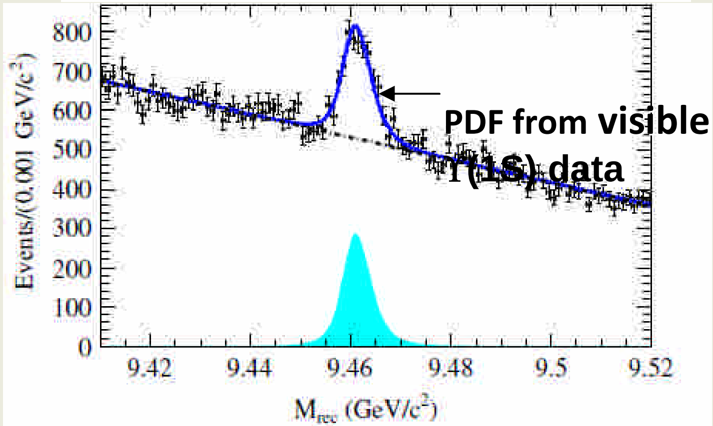
Search for light Dark Matter

$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-, \Upsilon(1S) \to \chi\chi$

- Require only two charged particles with recoiled mass btw 9.4 and 9.52 GeV/c^2
- Use multivariate method to reduce non-peaking background
- Peaking background comes from $\Upsilon(1S)$ daughters outside the acceptance
- Estimate Peaking bkg yield from MC and validate using ($\pi\pi$ +1,2 tracks) data

Fit yield: 2326 ± 105
Bkg pred: 2444 ± 123
Signal: -118 ± 105 ± 24





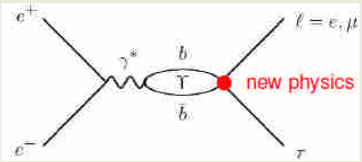
$BF(\Upsilon(1S) \to invisible) = (-1.6 \pm 1.4(stat) \pm 1.6(syst)) \times 10^{-4} < 3.0 \times 10^{-4}$ at 90% CL

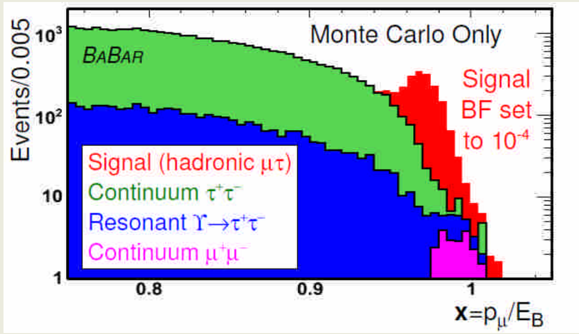
BaBar PRL 103, 251801 (2009) ~10× improvement over prior UL

Belle PRL98, 132001 (2007)

Other New Physics Search

- Search for lepton flavor violation
- Test for Lepton Universality





Prime leptons are monogenetic

	$\mathcal{B}$ (10^{-6})	UL (10^{-6})
$\mathcal{B}(\Upsilon(2S) \to e^\pm\tau^\mp)$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	<3.2
$\mathcal{B}(\Upsilon(2S) \to \mu^\pm\tau^\mp)$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	<3.3
$\mathcal{B}(\Upsilon(3S) \to e^\pm\tau^\mp)$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	<4.2
$\mathcal{B}(\Upsilon(3S) \to \mu^\pm\tau^\mp)$	$-0.8^{+1.5+1.4}_{-1.5-1.3}$	<3.1

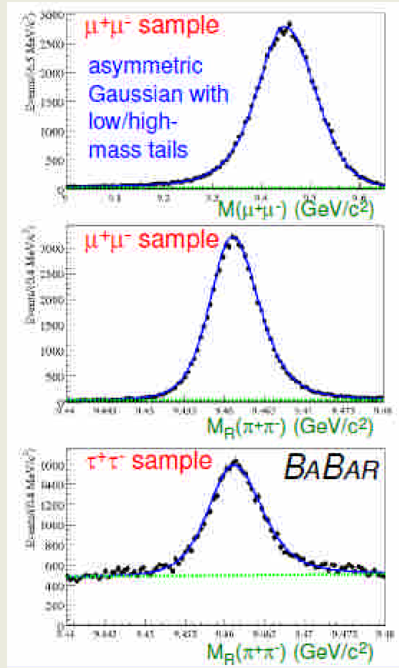
BABAR PRL 104, 151802 2010

$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$,
$\Upsilon(1S) \to ll$, $l = \mu, \tau$

– $\Upsilon(1S) \to \mu^+\mu^-$
 $M(\mu\mu)$ vs $M_R(\pi\pi)$

– $\Upsilon(1S) \to \tau^+\tau^-$
 $M_R(\pi\pi)$ only

No deviation of two branching fractions



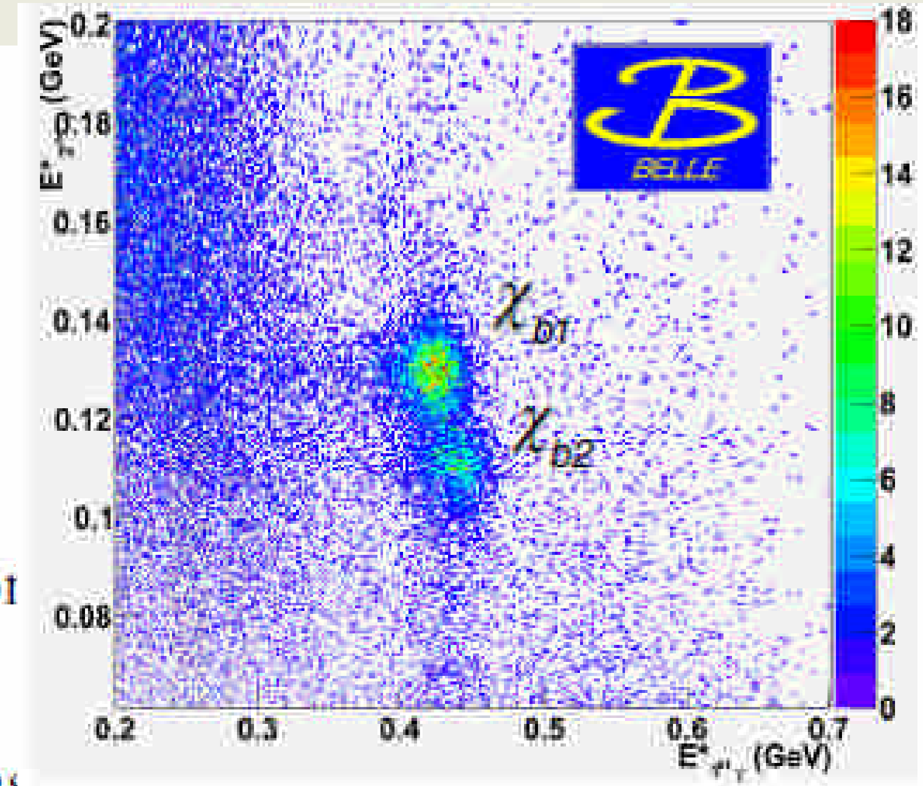
$R_{\tau\mu}(\Upsilon(1S)) = 1.005 \pm 0.013(\text{stat}) \pm 0.022(\text{syst})$

PRL 104,191801 2010

Υ(1S,2S) analysis under way

Preliminary

- $\Upsilon(2S) \rightarrow \gamma + \eta_b$
- $\chi_{b0} \rightarrow \gamma + \Upsilon(1S)$
- $\Upsilon(2S) \rightarrow \eta + \Upsilon(1S)$
- $\chi_{bJ} \rightarrow$ double charmonium
- $\Upsilon(2S) \rightarrow \gamma + A_0$
- $\Upsilon(1S)$ lepton universality from $\Upsilon(2S) \rightarrow \Upsilon(1S) + \pi^+\pi^-$
- $\Upsilon(1S) \rightarrow$ inclusive di-baryons



$Y(2S) \rightarrow \gamma\gamma\, Y(1S) \rightarrow \gamma\gamma\, \mu^+\mu^-$

Summary

- Data taken in other Υ(nS) resonances provide opportunities to understand physics and search for new phenomena.

- Υ(5S): 1. Scan results and large Υ(nS) $\pi\pi$ decay rates
  2. 2-body and 3-body B meson production
  3. Bs physics: DG/G, BF for various decay modes

- Υ(1-3S): 1. Decays to charmonium and charmonium-like stats
  2. NP searches: Search for light Higgs, light dark matter test for lepton flavor violations, test for lepton Univ.
  $\Rightarrow$ All have the best limits.

- Looking forward to next generation B factory.

BackUp

Anomalous Large Partial Width

Process	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

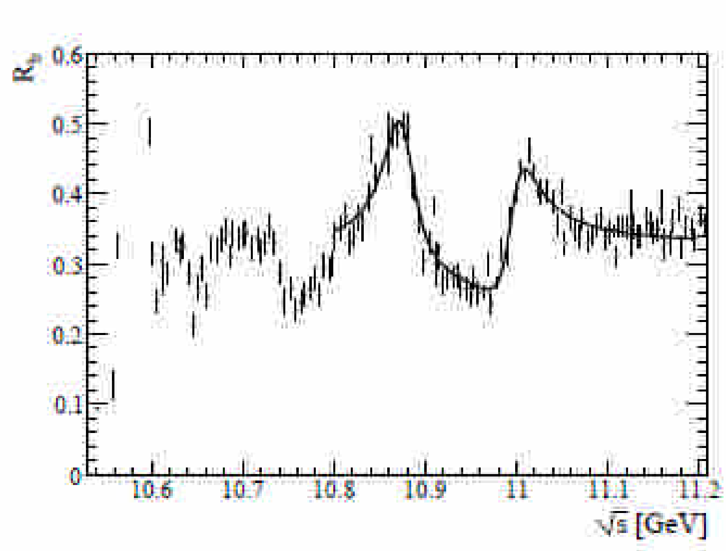
Process	Γ_{total}	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2

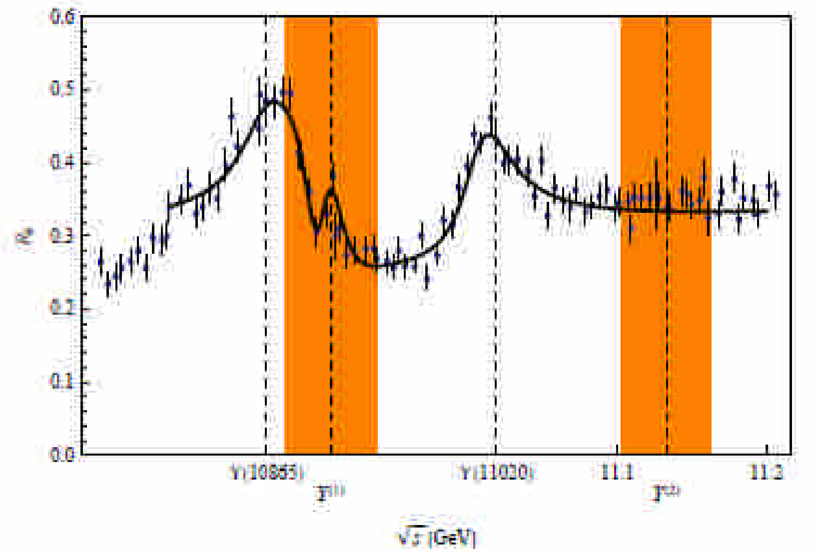
- Rescattering Mechanism: Υ**(5S)** $\to$B'B'$\pi\pi\to$ Υ**(1S)** $\pi\pi$
- More than one state: Yb near Υ**(5S)**

Ali's Tetraquark Interpretation

$\Upsilon(5S)$ and $\Upsilon(6S)$



$\Upsilon(5S)$, $\Upsilon(6S)$, $Y^{(1)}$ and $Y^{(2)}$



There are two mass states

in $Y^{(1)}$ since q = u, d

Phys.Lett.B684:28-39,2010

	$M[MeV]$	$\Gamma[MeV]$	φ [rad.]
$\Upsilon(5S)$	10864 ± 5	46 ± 8	1.3 ± 0.3
$\Upsilon(6S)$	11007 ± 0.3	40 ± 2	0.88 ± 0.06
$Y_{[b,l]}$	$10900 - \Delta M/2 \pm 2$	28 ± 2	4.4 ± 0.2
$Y_{[b,h]}$	$10900 + \Delta M/2 \pm 2$	28 ± 2	1.9 ± 0.2