Energy Scan above the $\Upsilon(4S)$: BaBar Measurements & Perspectives at SuperB

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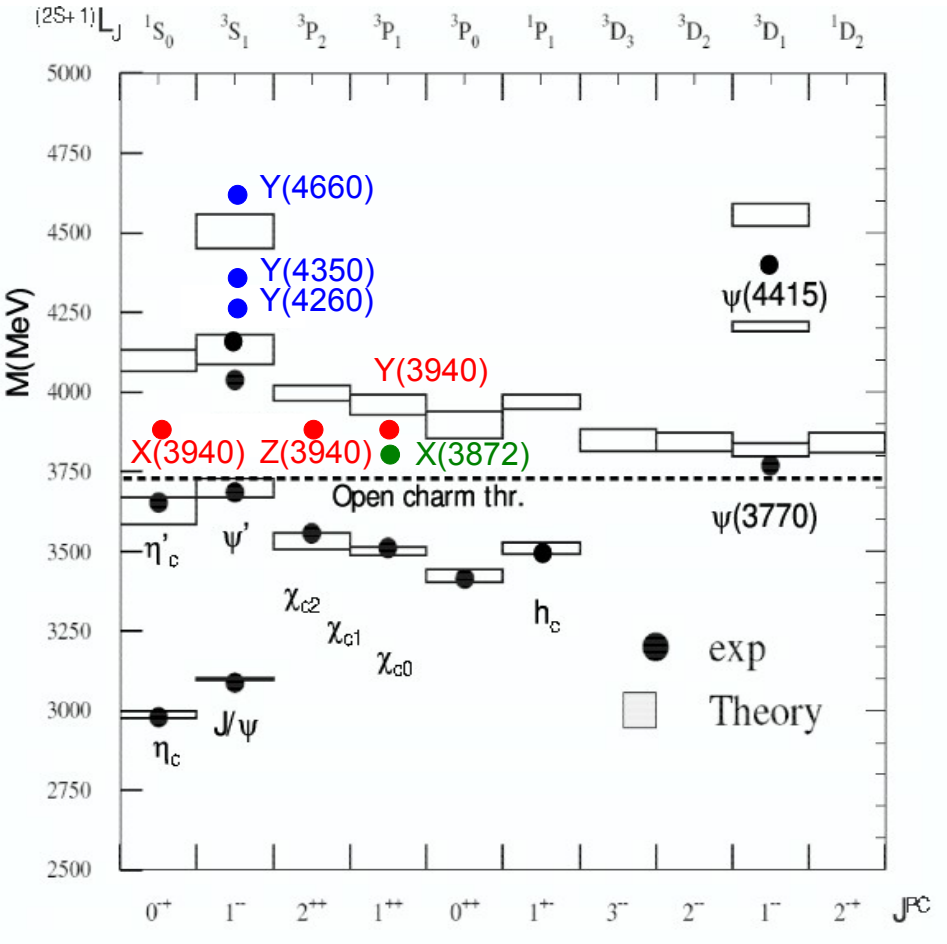
The New Charmonia

- New charmonium-like states discovered at the B-Factories;
- Do not fit in the standard picture:

✗ Masses far from predicted states;

✗ Widths too small;

✗ Unusual decay rates (e.g. large J/ψ π π rate for some of them).

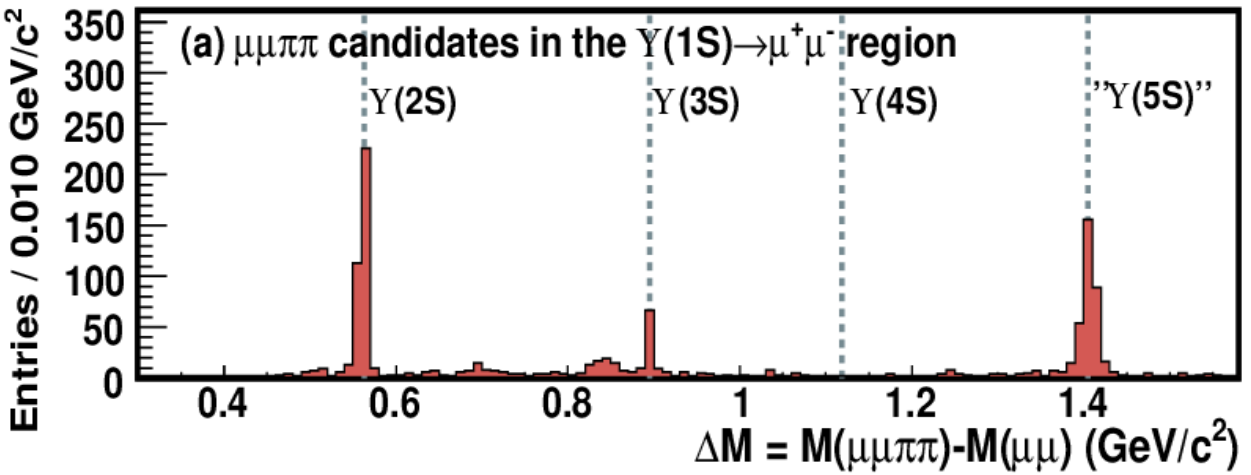


Exotic Bottomonium?

- New charmonium-like states could have bottomonium companions;
- Interest boosted by Belle's observation of an anomalously large $\Upsilon(1S)\pi\,\pi$ ISR production around the $\Upsilon(5S)$.

$$e^+e^- \to \gamma_{\rm ISR}\,\Upsilon(nS)$$
$$\hookrightarrow \Upsilon(1S)\pi^+\pi^-$$

Phys.Rev.Lett.100:112001,2008



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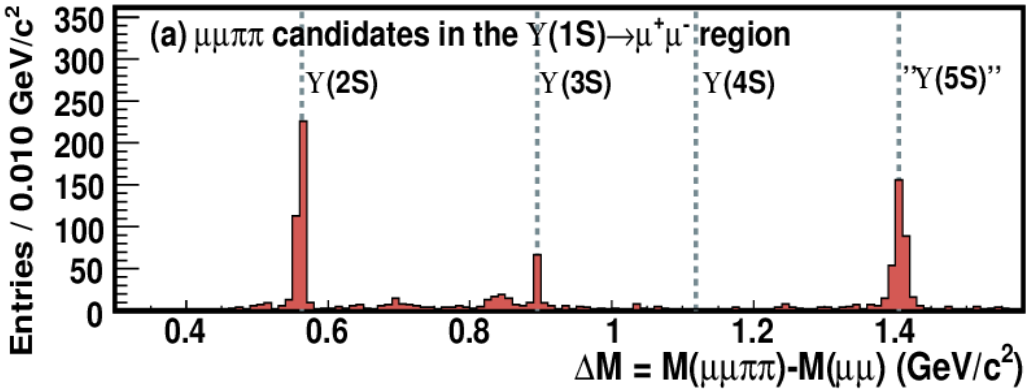

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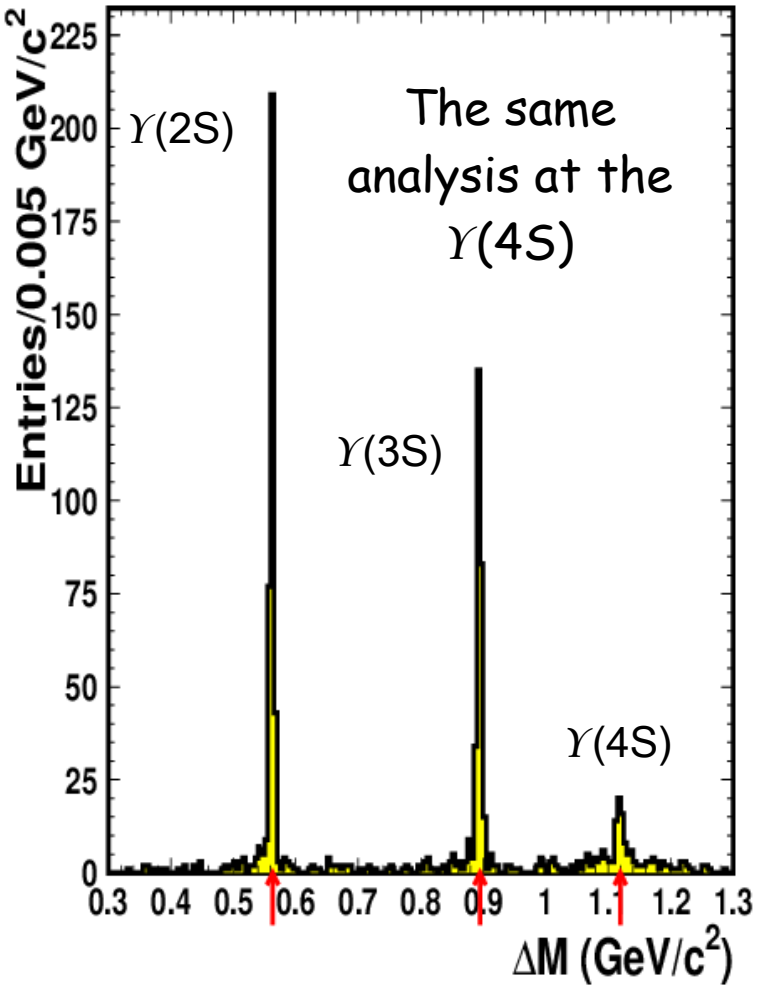


Phys.Rev.D 75 (2007) 071103

Exotic Bottomonium?

- Mass of new bottom resonances could be guessed just applying a shift to the new charmonium resonances:

$$m(\text{bottomonium}) = m(\text{charmonium}) + m(\Upsilon(1S)) - m(J/\psi)$$

Works fine for standard bottomonium!

$$Y(4260) \rightarrow Y_b(10620)\,???$$

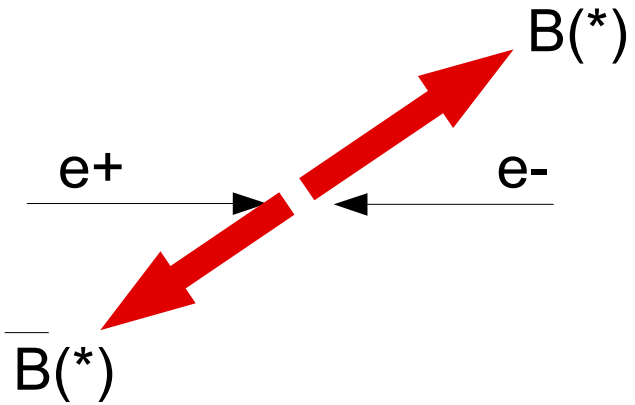
$$Y(4350) \rightarrow Y_b(10710)\,???$$

$$Y(4660) \rightarrow Y_b(11020)\,???$$

Energy Scan

- New bottomonium resonances can be searched for with an energy scan above the $\Upsilon(4S)$ resonance;
- *Inclusive approach:*
  - Search for unexpected structures in the inclusive hadronic cross section:

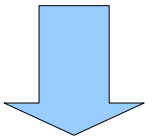
$$R_b = \frac{\sigma(e^+e^- \to bb(\gamma))}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \to \frac{4\pi\alpha^2}{3s}$$



- *Exclusive approach:*
  - Look for signals in specific decay channels (like $\Upsilon(nS)\pi\,\pi$) inspired by the new charmonia decay channels (like $J/\psi\,\pi\,\pi$)

BaBar Scan

- BaBar performed a 10 day long energy scan starting on March 28th, 2008:
  - Steps of 5 MeV from 10.54 to 11.20 GeV;
  - about 25 pb^{-1} per step (3.3 fb^{-1} total);
  - 8 additional steps in the $\Upsilon(6S)$ region (10.96 to 11.10 GeV) corresponding to 600 pb^{-1}.



30 times more luminosity

and

4 times finer steps

w.r.t. previous scan (@ Cornell in 1984)

One Week at SuperB...

- Let's assume:
  - Luminosity ~ 1 x 10^{36} cm^{-2} s^{-1} ~ 100 x PEP II;
  - Same down time as during the BaBar Scan;
  - Same energy range (10.54 to 11.20 GeV);
  - 5 MeV steps (look for Γ ~ 50 MeV resonances, without missing narrow states);
- We can collect:
  - 40 fb^{-1} per day → 280 fb^{-1} in one week;
  - 130 steps → 2.3 fb^{-1} per step.

Inclusive Measurements

Strategy

$$R_b = \frac{\sigma(e^+e^- \to b\bar{b}(\gamma))}{\sigma^0(e^+e^- \to \mu^+\mu^-)} = \frac{\sigma(e^+e^- \to \mu^+\mu^-)}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \cdot \frac{N_{b\bar{b}}(s)}{N_{\mu\mu}(s)}$$

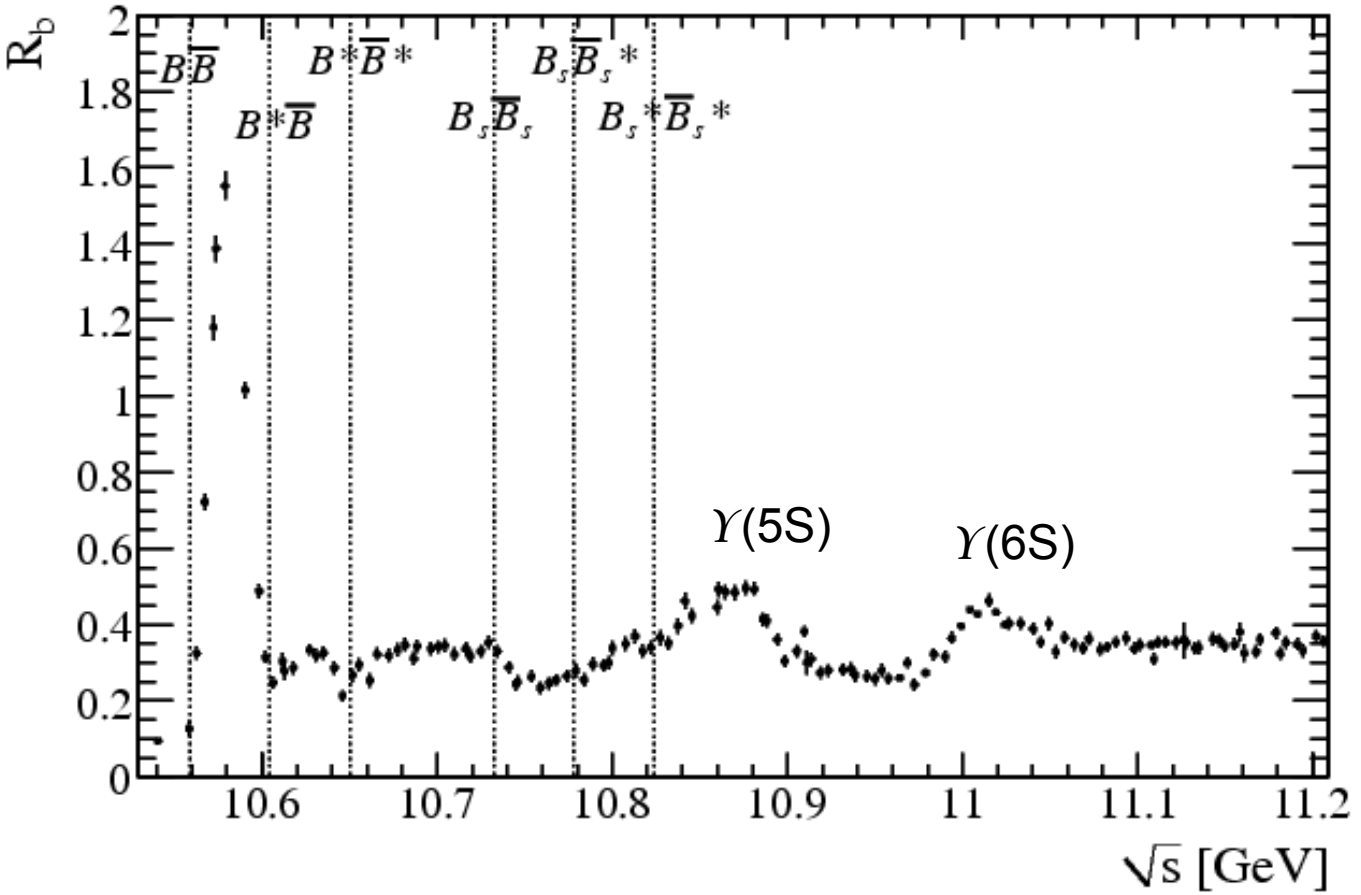
from theory
(MC calculation by PHOTOS)

Number of data events in a $b\bar{b}$ and a $\mu\mu$ samples
(corrected for background and efficiencies)

- Selection of a $b\bar{b}$ and a $\mu\mu$ samples;
- Backgrounds estimated at a reference point ($\sqrt{s}$ = 10.54 GeV) below the $B\bar{B}$ threshold;
- Efficiencies from MC samples.

BaBar Results

- Region explored with *unprecedented detail*;
- Interpretation made difficult by *thresholds*.



$\sigma_{stat} < 3\%$

$\sigma_{syst} < 2\%$

Phys.Rev.Lett.102:012001,2009

A Wide Impact...

A case for hidden $b\bar{b}$ tetraquarks based on $e^+e^- \to b\bar{b}$ cross section between $\sqrt{s}=10.54$ and 11.20 GeV Today, 1:00 AM
Ali, Ahmed arXiv:0911.2787 Read more...

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Gonzalez, P. Phys.Rev.D80:054010,2009 arXiv:0909.1204 Read more...

New bottomonium spectroscopy and transitions Today, 1:00 AM
West, Chris PoS Confinement8:095,2008 Read more...

Production of hadron pairs in e+ e- annihilation near the K+ K-, D anti-D, B anti-B and Lambda(c)+ Lambda(c)- thresholds Today, 1:00 AM
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On the possibility to observe higher n3 D(1) bottomonium states in the e+ e- processes** Today, 1:00 AM
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Charm and Bottom Quark Masses: An Update
Chetyrkin, K.G. Phys.Rev.D80:074010,2009 arXiv:0907.2110 Read

Interpretation & Perspectives

- Interpretation requires an explicit model for the interplay between quarkonium production and decay (e.g. Eichten *et al.* Phys.Rev.D17:3090,1978)
- Not just "interference", but "mixing" of different states:
  - mass eigenstates are not pure nL_J states;
  - cross section is not expected to be a superposition of Breit-Wigner's;
  - Differences among exclusive and inclusive shapes.
- Need for a theoretical (more than experim.) developments:
  - Help can come from exclusive $e^+e^- \rightarrow B\bar{B}$ decays.

Exclusive Measurements

Strategy

- Get inspired by $J/\psi\,\pi\,\pi$ exotic charmonia decays:
  - σ x BR at the level of few pb;
- Looks for $\Upsilon(nS)\,\pi\,\pi$ (KK, η, etc.) final states:
  - $\Upsilon(nS) \rightarrow l^+l^-$ ($l = e, \mu$), $n = 1, 2, 3$;
  - $\Upsilon(2S) \rightarrow \Upsilon(1S)\,\pi^+\pi^-$, $\Upsilon(1S) \rightarrow l^+l^-$;

  } BR ~ 4 - 5%
- 3 kind of selections for 3 kinds of production processes:
  - "alone" production ($e^+e^- \rightarrow \Upsilon(nS)$);
  - "ISR" production ($e^+e^- \rightarrow \Upsilon(nS)\,\gamma_{ISR}$);
  - "pair" production ($e^+e^- \rightarrow \Upsilon(nS)\,X$).

Expectations at BaBar

- BaBar analysis not finalized (lack of manpower...);
- Sensitivity expectations from MC (Signal) and data (Bkg.):
  - $\Gamma_{\Upsilon} \sim 140$ MeV;
  - cut & count within a 140 MeV *"moving window"*;
- Which is the value of $\sigma(e^+e^- \rightarrow Y_b) \times BR(Y_b \rightarrow \Upsilon(nS)X)$ that we could discover at a 3σ level (stat. only)?

Decay Mode	$\varepsilon \times BR(\Upsilon \rightarrow final)$	σ_{bgk} [pb]	$\sigma \times BR$ Sens. [pb]	Discovery Sig. Yield
$Y_b \rightarrow \Upsilon(1S)_{\mu^+\mu^-}\pi^+\pi^-$	0.95%	0.0017	1.5	3.9
$Y_b \rightarrow \Upsilon(2S)\pi^+\pi^-$	1.18%	0.0028	1.6	5.1
$Y_b \rightarrow \Upsilon(1S)_{\mu^+\mu^-}\eta_{\pi\pi\pi^0}$	0.20%	0.0087	3.0	2.7
$Y_b \rightarrow \Upsilon(1S)_{\mu^+\mu^-}\omega_{\pi\pi\pi^0}$	0.45%	0.0003	1.5	1.86
$Y_b \rightarrow \Upsilon(1S)_{\mu^+\mu^-}\pi^0$	0.69%	0.0111	4.9	9.3
$Y_b \rightarrow \Upsilon(1S)_{\mu^+\mu^-}\pi^+\pi^-\pi^0$	0.56%	0.0015	1.1	4.1

Perspectives at SuperB

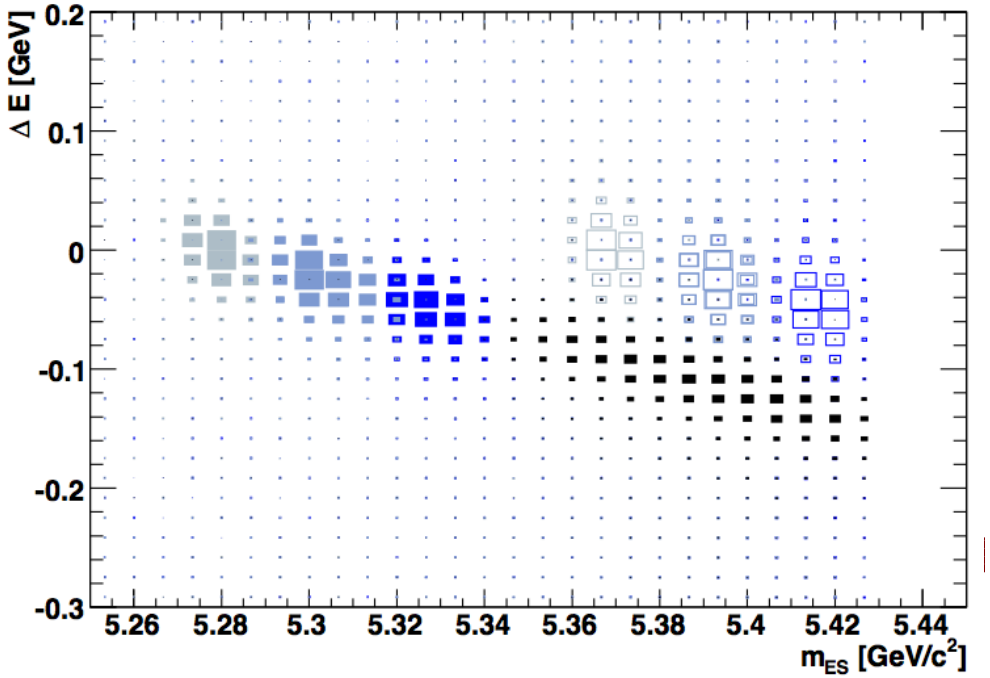
- From a rapid exchange with machine background experts:
  - Background for this analysis shouldn't be dramatically different w.r.t. BaBar;
- Scaling with luminosity:
  - 85 times more statistics.

Decay Mode	$\varepsilon \times BR(\Upsilon \to final)$	σ_{bgk} [pb]	$\sigma \times BR$ Sens. [pb]	Discovery Sig. Yield
$Y_b \to \Upsilon(1S)_{\mu^+\mu^-}\pi^+\pi^-$	0.95%	0.0017	0.13	29.0
$Y_b \to \Upsilon(2S)\pi^+\pi^-$	1.18%	0.0028	0.14	38.0
$Y_b \to \Upsilon(1S)_{\mu^+\mu^-}\eta_{\pi\pi\pi^0}$	0.20%	0.0087	0.2	15.5
$Y_b \to \Upsilon(1S)_{\mu^+\mu^-}\omega_{\pi\pi\pi^0}$	0.45%	0.0003	0.12	13.0
$Y_b \to \Upsilon(1S)_{\mu^+\mu^-}\pi^0$	0.69%	0.0111	0.45	72.5
$Y_b \to \Upsilon(1S)_{\mu^+\mu^-}\pi^+\pi^-\pi^0$	0.56%	0.0015	0.09	27.0

Exclusive BB states (I)

- Development of theoretical predictions for R_b could take advantage from a measurement of the exclusive $e^+e^- \rightarrow B_{d,s}(*)\overline{B}_{d,s}(*)$ rates:
  - Calculations provide excl. and incl. rates together;
- A very good semi-exclusive $B \rightarrow DX$ technique available from BaBar/Belle:
  - efficiency ~ 0.4%;
- $B_{d,s}(*)\overline{B}_{d,s}(*)$ can be separated in the $(m_{ES}, \Delta E)$ plane.

Baracchini et al. JHEP 0708:005,2007



Exclusive BB states (II)

- Let's assume:
  - 2.3 fb^{-1} per step;
  - σ_{bb} ~ 0.24 nb (corresponding to R_b ~ 0.3);
  - 0.4% efficiency (one B is enough!) in all channels;
- We expect:
  - Sig. yield ~ 2200 & Bkg. yield ~ 30000 per scan point.
- We can aim at a 10% error level for each point (5 MeV steps) at least in the most frequent channels:
  - to be compared with ≥ 5% and 20 MeV steps in the charm sector (CLEO Collab., Phys.Rev.D80:072001,2009);

Conclusions

- BaBar Scan provided a precise measurement of the inclusive $e^+e^- \to b\bar{b}$ cross section above the $\Upsilon(4S)$:
  - Theoretical models already challenged;
  - Need for a theoretical (more than experimental) development;
- Exclusive Ψ_b searches not yet finalized at BaBar:
  - Sensitivity at the level of $\sigma \times BR \sim 1.5$ pb in some channels;
  - SuperB can reach the 0.1 pb level;
- Exclusive $e^+e^- \to B\bar{B}$ feasible at SuperB:
  - could help in the interpretation of the $e^+e^- \to b\bar{b}$.