Exotic vectors in the Heavy Bottomonium region

JPAC

EXOHAD

EXOTIC HADRONS TOPICAL COLLABORATION

States above $\Upsilon(4S)$ ($J^{PC} = 1^{--}$)

- First observations in '80s at CLEO, CUSB in e^+e^- annihilation
- Coupled-channel models used to extract open-bottom contributions

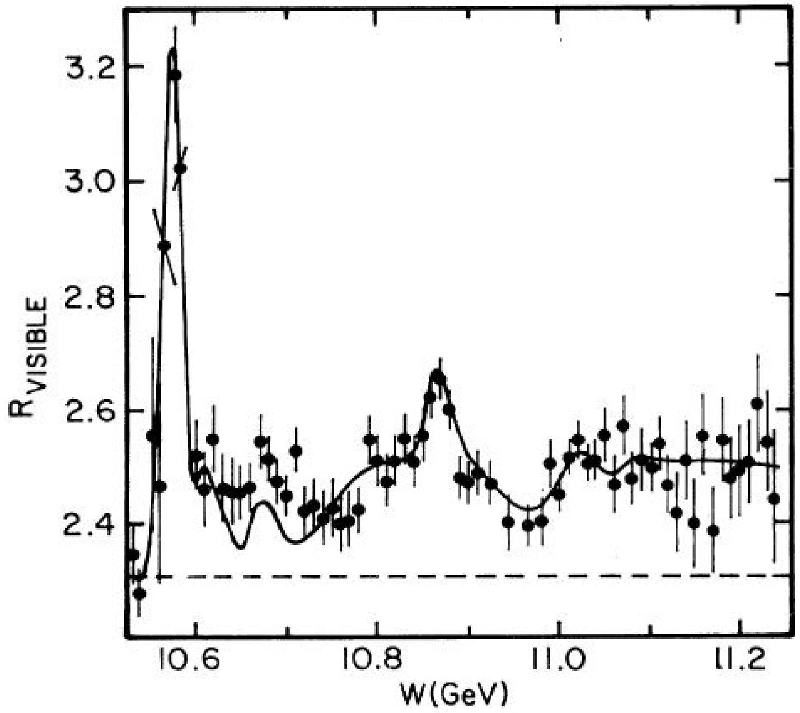


FIG. 2. Model calculation superimposed on data.

Lovelock et al. 1985

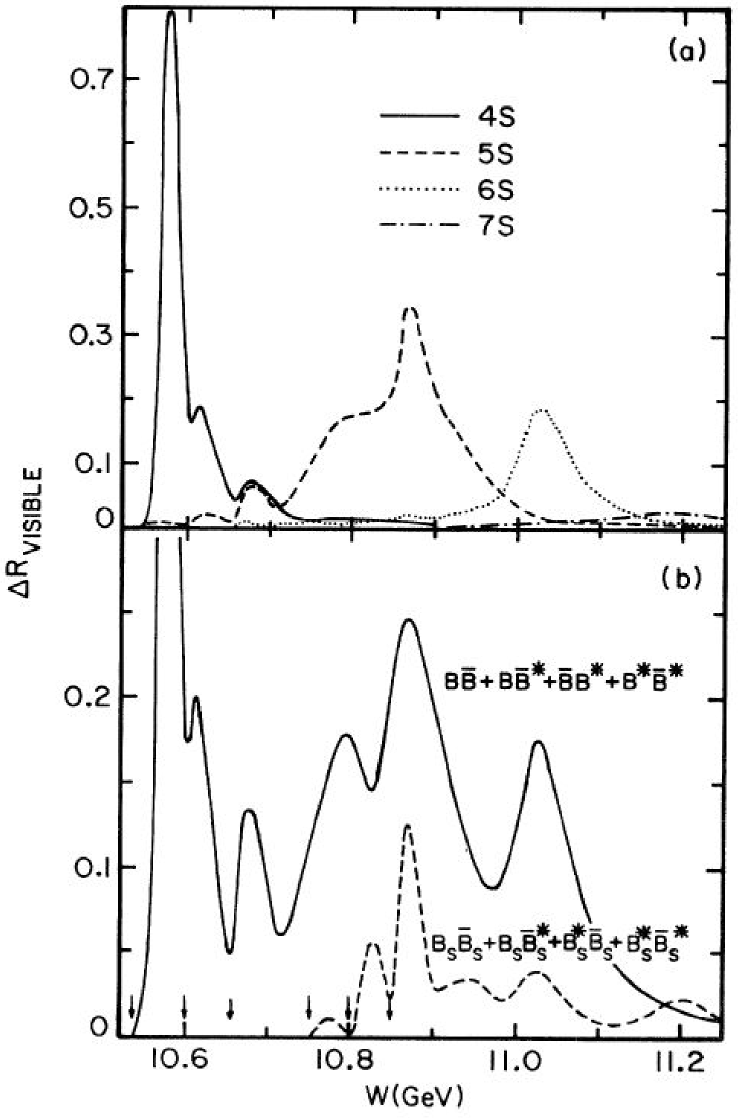


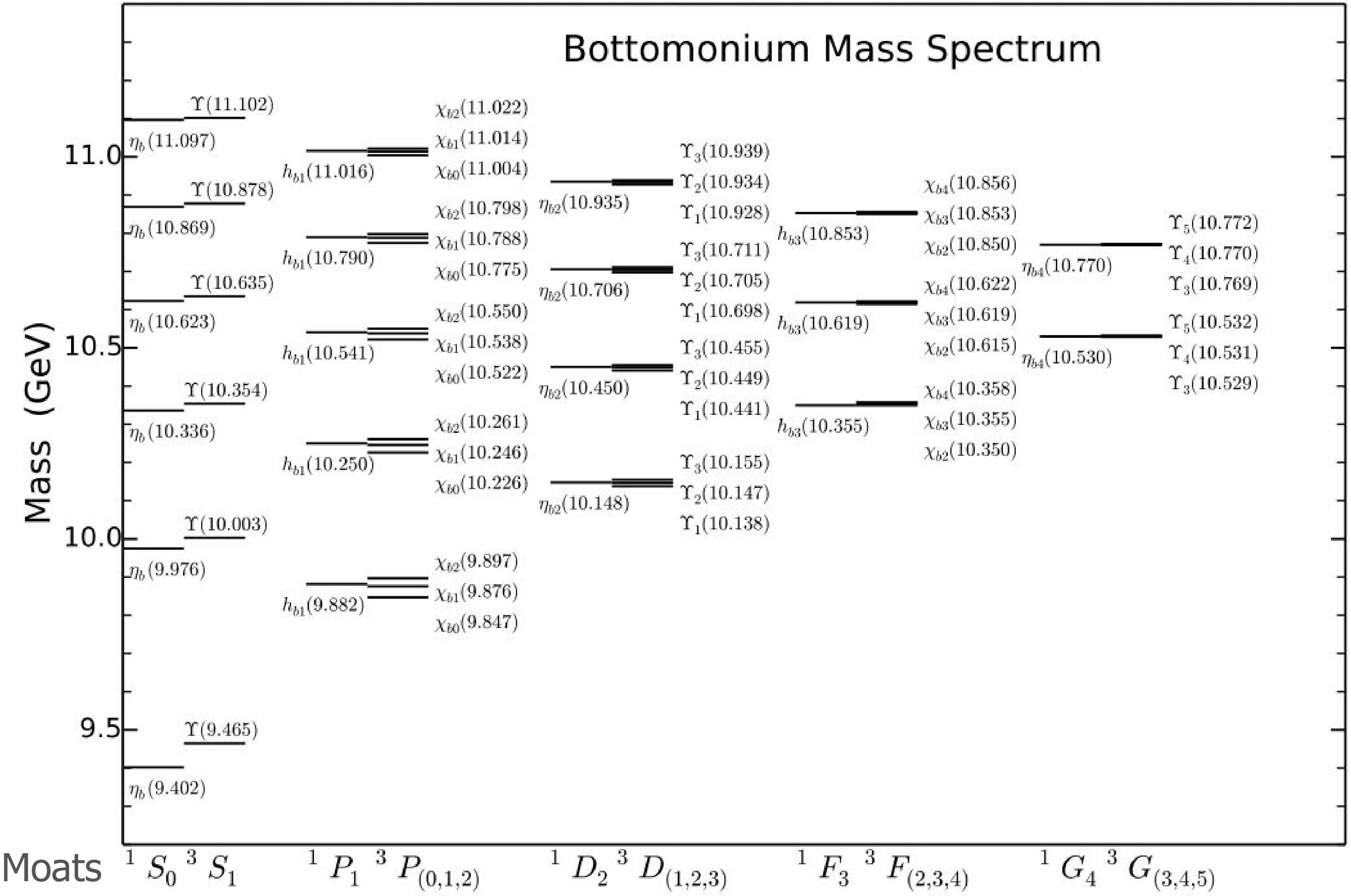
FIG. 3. (a) Contributions of the four Υ's to R, for two-body decays. (b) Contribution to R from B mesons (solid curve) and strange B mesons (dashed curve). Arrows indicate thresholds: $B\bar{B}$(10.545 GeV), $B\bar{B}^*$(10.600 GeV), $B^*\bar{B}^*$(10.655 GeV), $B_s\bar{B}_s$(10.751 GeV), $B_s\bar{B}_s^*$(10.801 GeV), $B_s^*\bar{B}_s^*$(10.851 GeV).

- Spectrum predictions based on relativized quark model
- Cornell potential takes care of confinement (Ideal for bottomonium)

$$V(r) = A + \frac{B}{r} + \sigma r$$

TABLE I: Masses and effective harmonic oscillator parameter values (β) for S-, P- and D-wave Bottomonium mesons.

Meson	M_{theo} (MeV)	M_{exp} (MeV)	β (GeV)
$\Upsilon(1^3S_1)$	9465	9460.30 ± 0.26 [a]	1.157
$\eta_b(1^1S_0)$	9402	9398.0 ± 3.2 [a]	1.269
$\Upsilon(2^3S_1)$	10003	10023.26 ± 0.31 [a]	0.819
$\eta_b(2^1S_0)$	9976	$9999.0 \pm 3.5^{+2.8}_{-1.9}$ [a]	0.854
$\Upsilon(3^3S_1)$	10354	10355.2 ± 0.5 [a]	0.698
$\eta_b(3^1S_0)$	10336	10337 [b]	0.719
$\Upsilon(4^3S_1)$	10635	10579.4 ± 1.2 [a]	0.638
$\eta_b(4^1S_0)$	10623	10567 [b]	0.654
$\Upsilon(5^3S_1)$	10878	10876 ± 11 [a]	0.600
$\eta_b(5^1S_0)$	10869	10867 [b]	0.615
$\Upsilon(6^3S_1)$	11102	11019 ± 8 [a]	0.578
$\eta_b(6^1S_0)$	11097	11014 [b]	0.593



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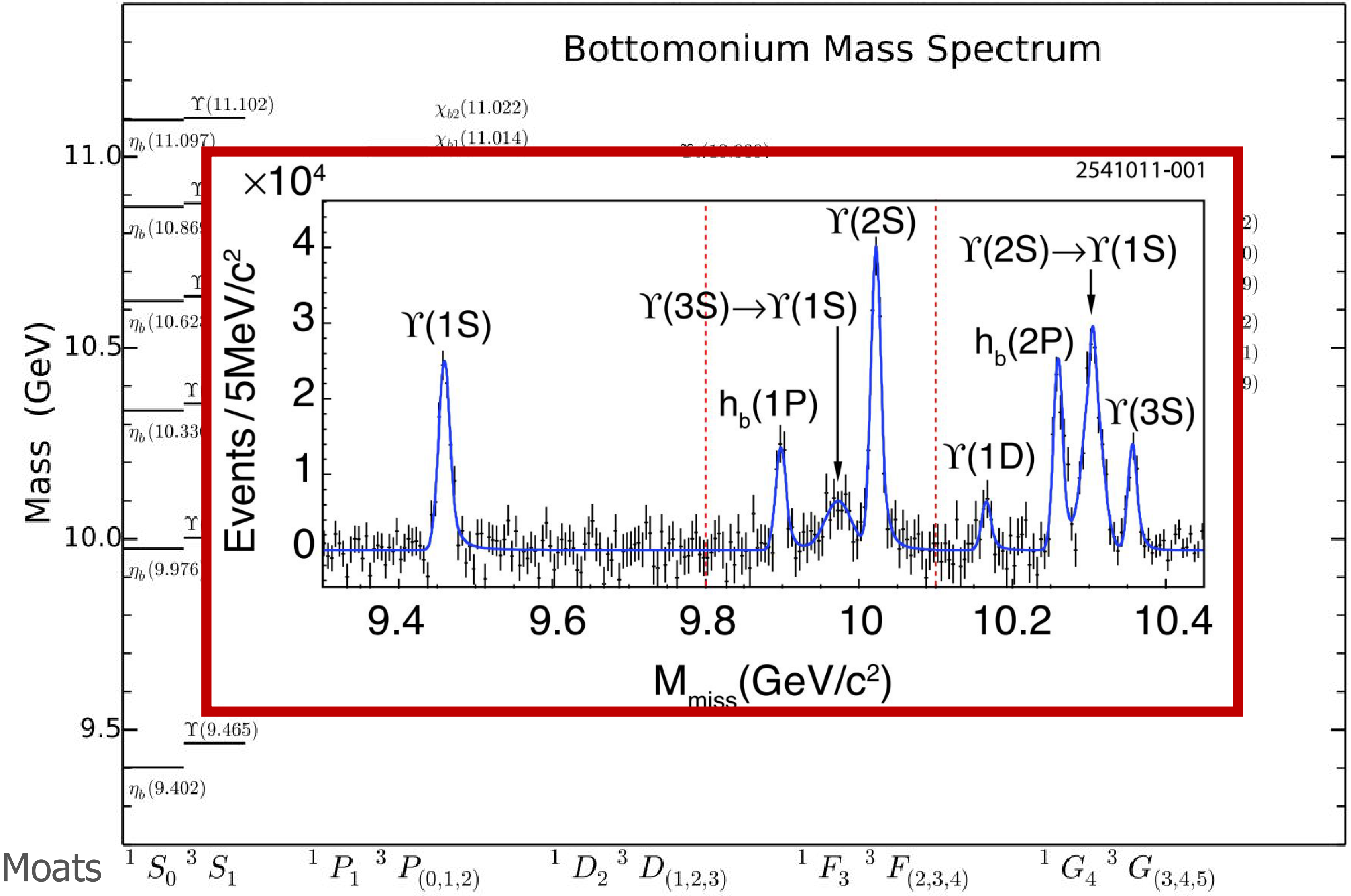

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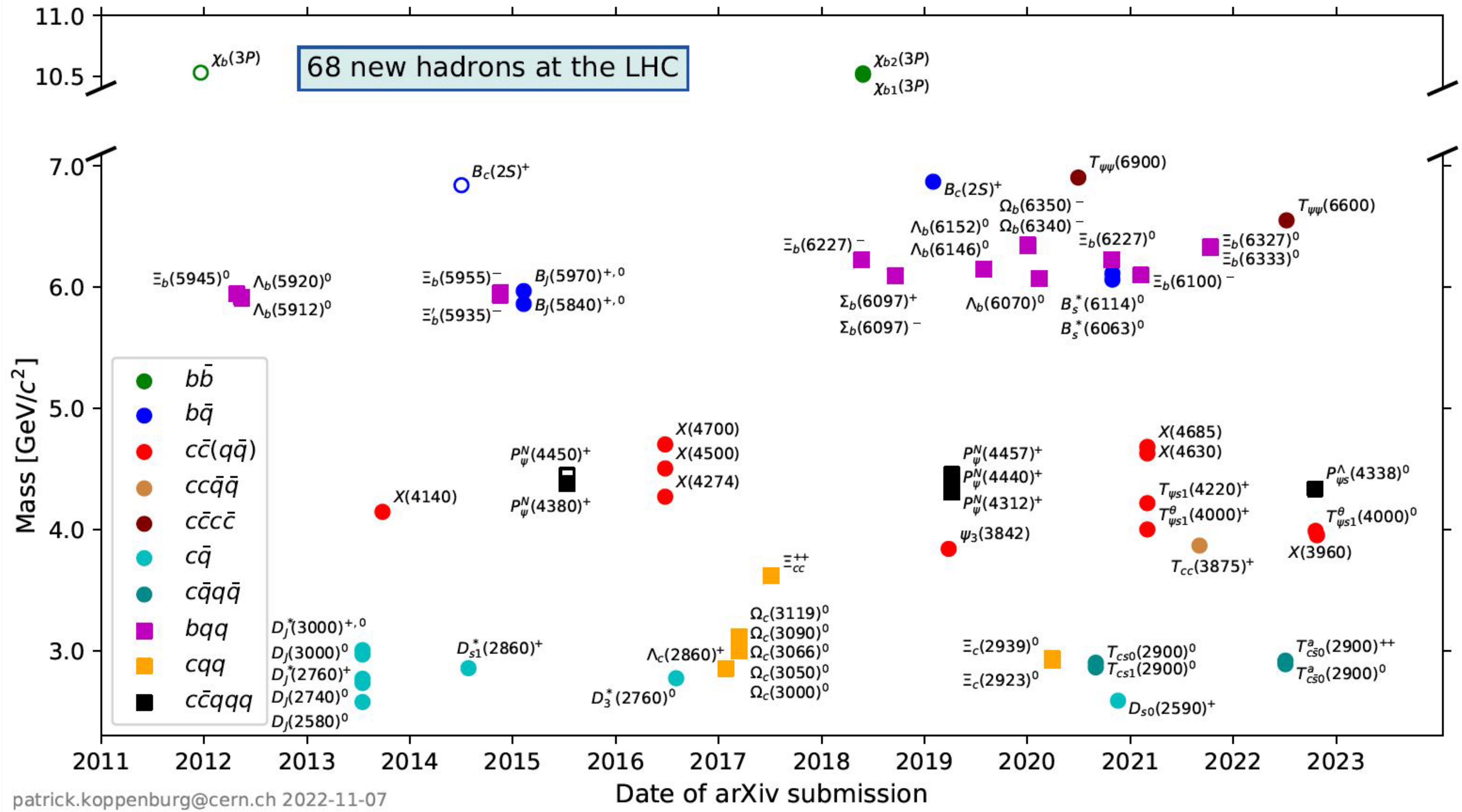
Enter the Exotics

- Discovery of the X(3872) at Belle changes everything!



New Data (Babar 2009)

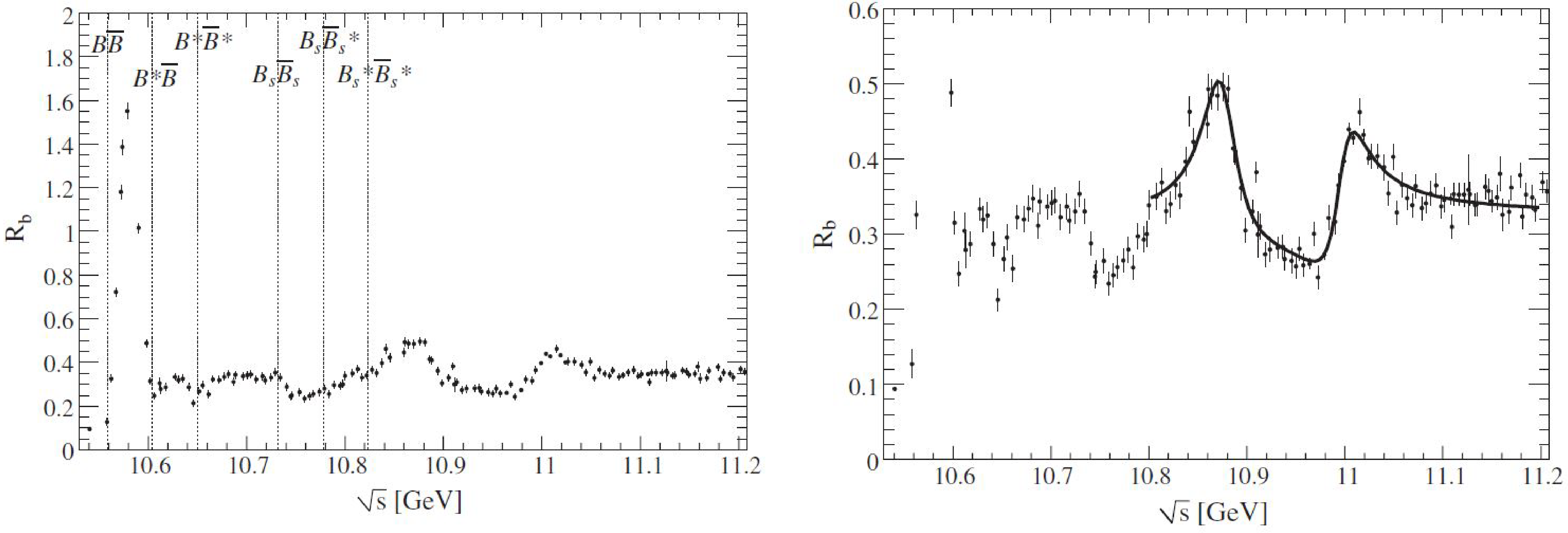


FIG. 1. Left: Measured R_b as a function of $\sqrt{s}$ with the position of the opening thresholds of the $e^+e^- \to B^{(*)}_{(s)}\bar{B}^{(*)}_{(s)}$ processes indicated by dotted lines. Right: A zoom of the same plot with the result of the fit described in the text superimposed. The errors on data represent the statistical and the uncorrelated systematic errors added in quadrature.

PRL **102,** 012001 (2009)

New Data (Belle 2016)

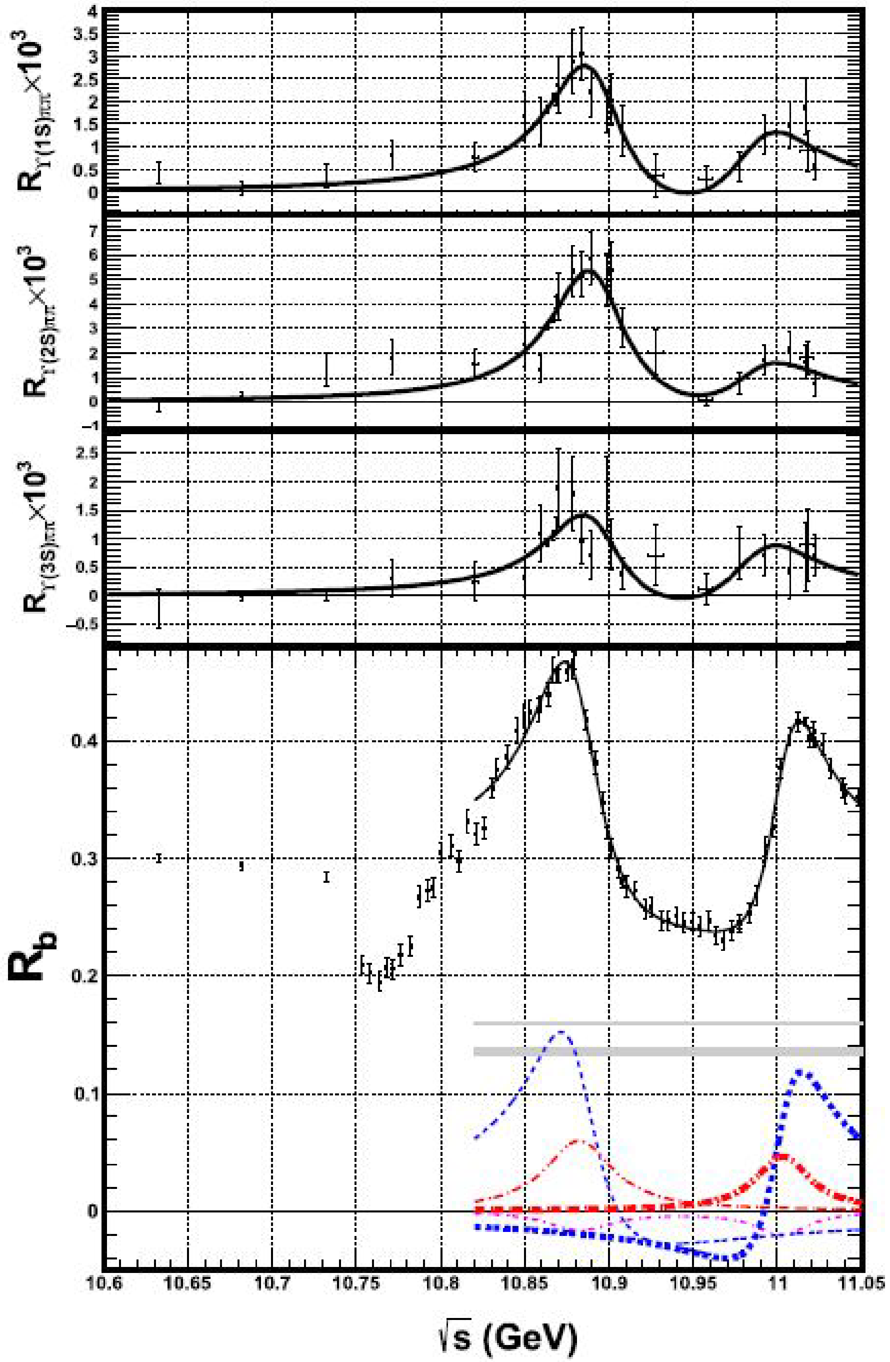
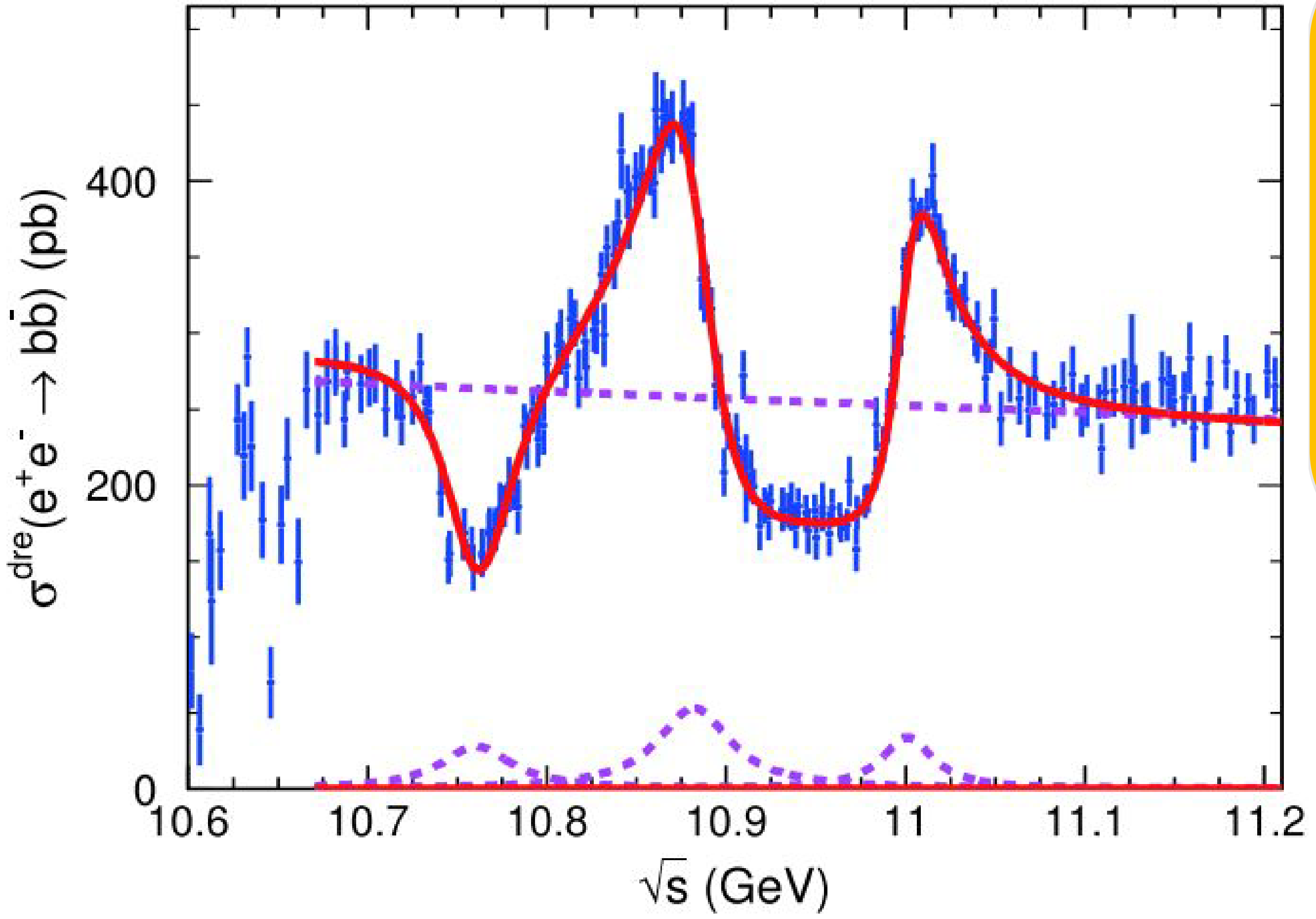


FIG. 1. (From top) $R_{\Upsilon(nS)\pi\pi}$ data with results of our nominal fi for $\Upsilon(1S)$; $\Upsilon(2S)$; $\Upsilon(3S)$; R_b', data with components of fit: tota (solid curve), constants $|A_{ic}|^2$ (thin), $|A_c|^2$ (thick); for $\Upsilon(5S$ (thin) and $\Upsilon(6S)$ (thick): $|f|^2$ (dot-dot-dash), cross terms with A (dashed), and two-resonance cross term (dot-dash). Error bar include the statistical and uncorrelated systematic uncertainties

PHYSICAL REVIEW D **93,** 011101(R) (2016)

New resonance?



- New resonance $\Upsilon(10750)$
- states renamed $\Upsilon(5S) \to \Upsilon(10860)$ and $\Upsilon(6S) \to \Upsilon(11020)$
- PDG Branching ratios still based on Breit-Wigner parameterizations

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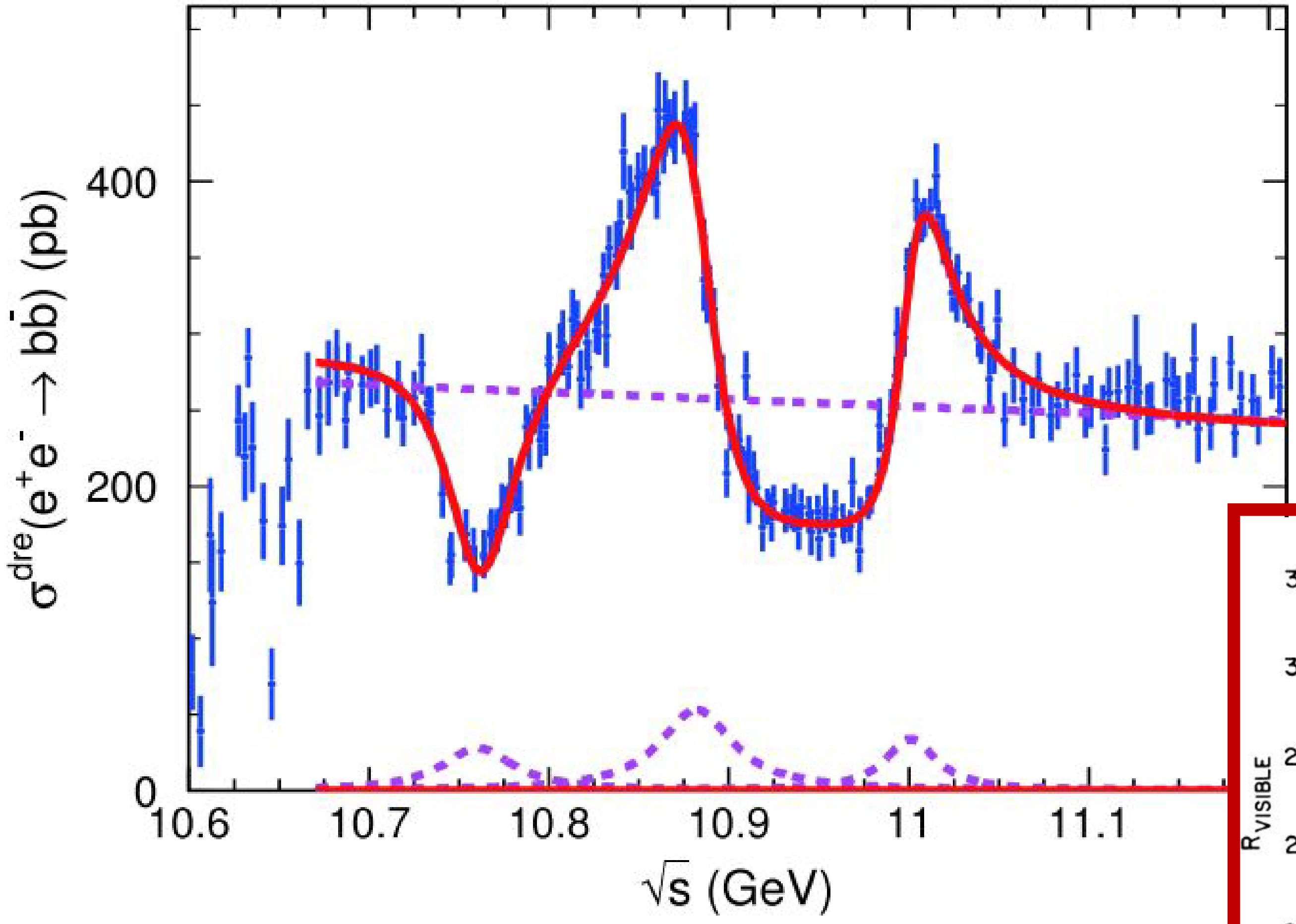
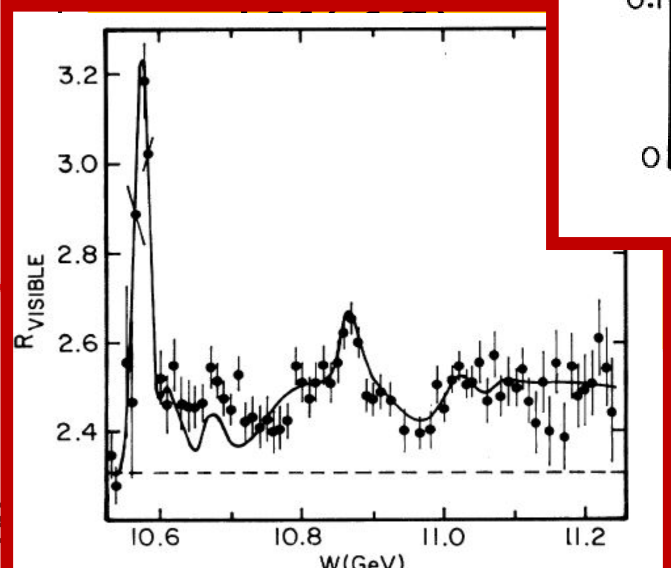
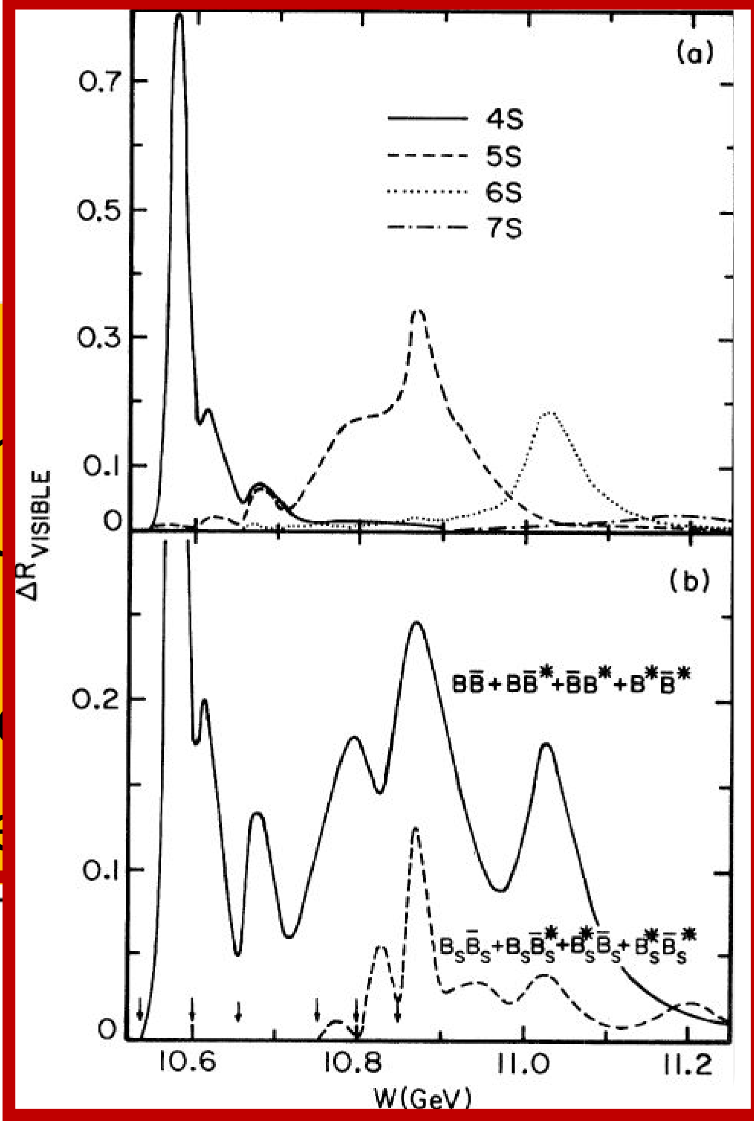
New Data!



- New data fro
  (2016) show u
  above $\Upsilon(4S)$
- New resonanc
- states rename





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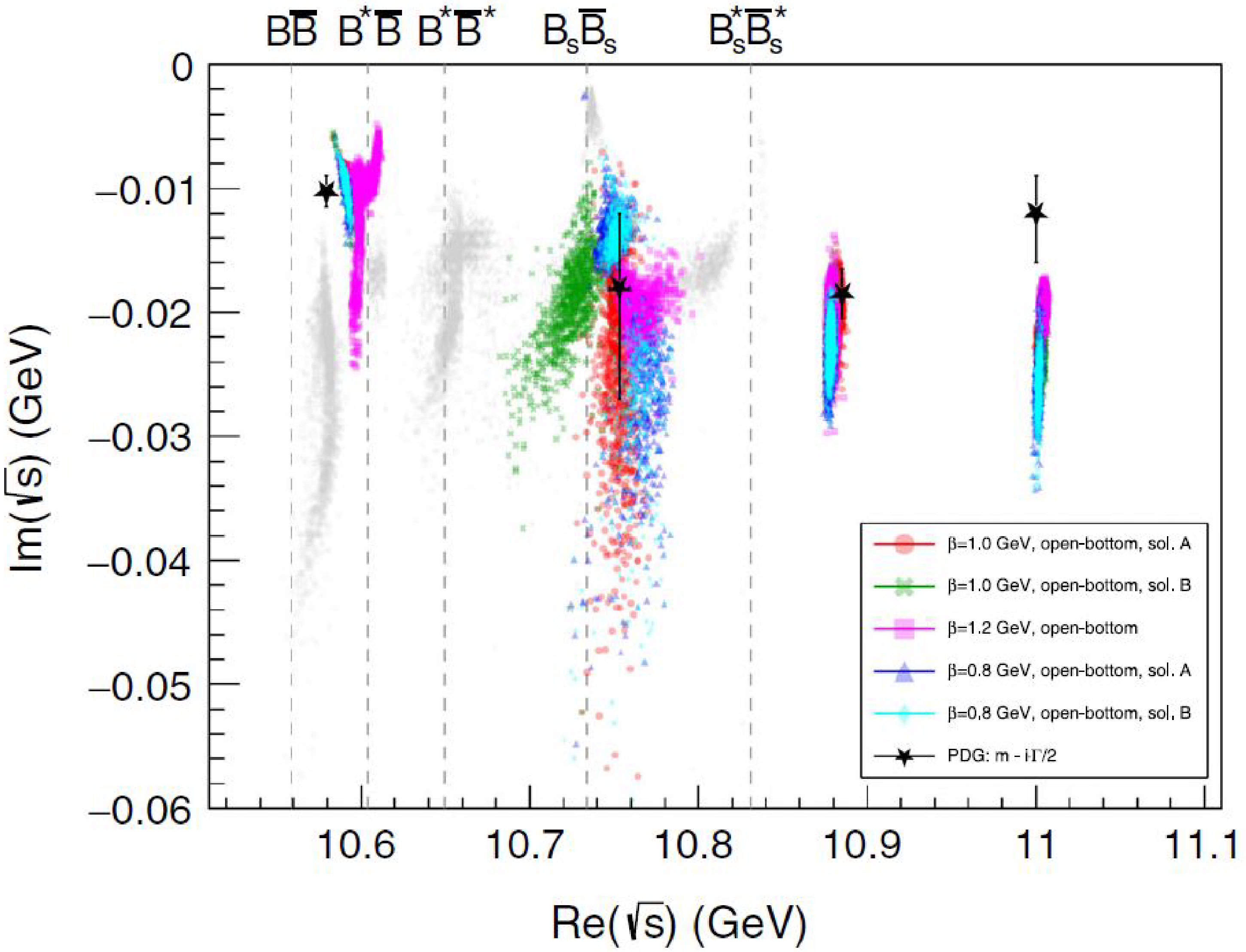
K-Matrix Analysis

- Found evidence for the existence of the $\Upsilon(10750)$
- Systematic uncertainties seem to be large
- Complicated analytic behavior from amplitude parameterization



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K-Matrix Analysis

- Significant difference in branching ratios from PDG

TABLE IX. $\Upsilon(6S)$ branching ratios (%).

Channel	RPP	Our estimate	GM	SOEF
$B\bar{B}$	...	(0.8–8.6)	3.9	5.3
$B^*\bar{B}$	...	(1.9–12)	22.4	19.6
$B^*\bar{B}^*$	...	(0.2–6.2)	17.4	15.0
"$B_s\bar{B}_s$"	...	(70–90)	...	...
$B_s^*\bar{B}_s^*$	...	(0.04–9.7)	0.9	2.6
$\Upsilon(1S)\pi\pi$	...	(0.3–1.2)	...	0.35
$\Upsilon(2S)\pi\pi$	...	(0.3–2.9)	...	8.0×10^{-3}
$\Upsilon(3S)\pi\pi$	...	(0.2–1.0)	...	0.049
$h_b(1P)\pi\pi$	...	(0.5–2.1)	...	...
$h_b(2P)\pi\pi$	...	(0.2–4.3)	...	...

TABLE VIII. $\Upsilon(5S)$ branching ratios (%).

Channel	RPP[a]	Our estimate	GM	SOEF
$B\bar{B}$	5.5	(0.6–31)	19.5	22.3
$B^*\bar{B}$	14	(0.03–3.2)	60.6	42.4
$B^*\bar{B}^*$	38	(2.9–17)	8.8	0.3
"$B_s\bar{B}_s$"	[25]	(31–77)	...	...
$B_s^*\bar{B}_s^*$	18	(0.9–33)	7.3	27.4
$\Upsilon(1S)\pi\pi$	0.53	(0.6–2.5)	...	0.023
$\Upsilon(2S)\pi\pi$	0.78	(1.6–5.2)	...	0.033
$\Upsilon(3S)\pi\pi$	0.48	(0.2–1.7)	...	0.01
$h_b(1P)\pi\pi$	0.35	(0.3–2.8)	...	...
$h_b(2P)\pi\pi$	0.57	(0.9–4.0)	...	...

[a] Obtained using ratios of cross sections near the $\Upsilon(5S)$ mass.

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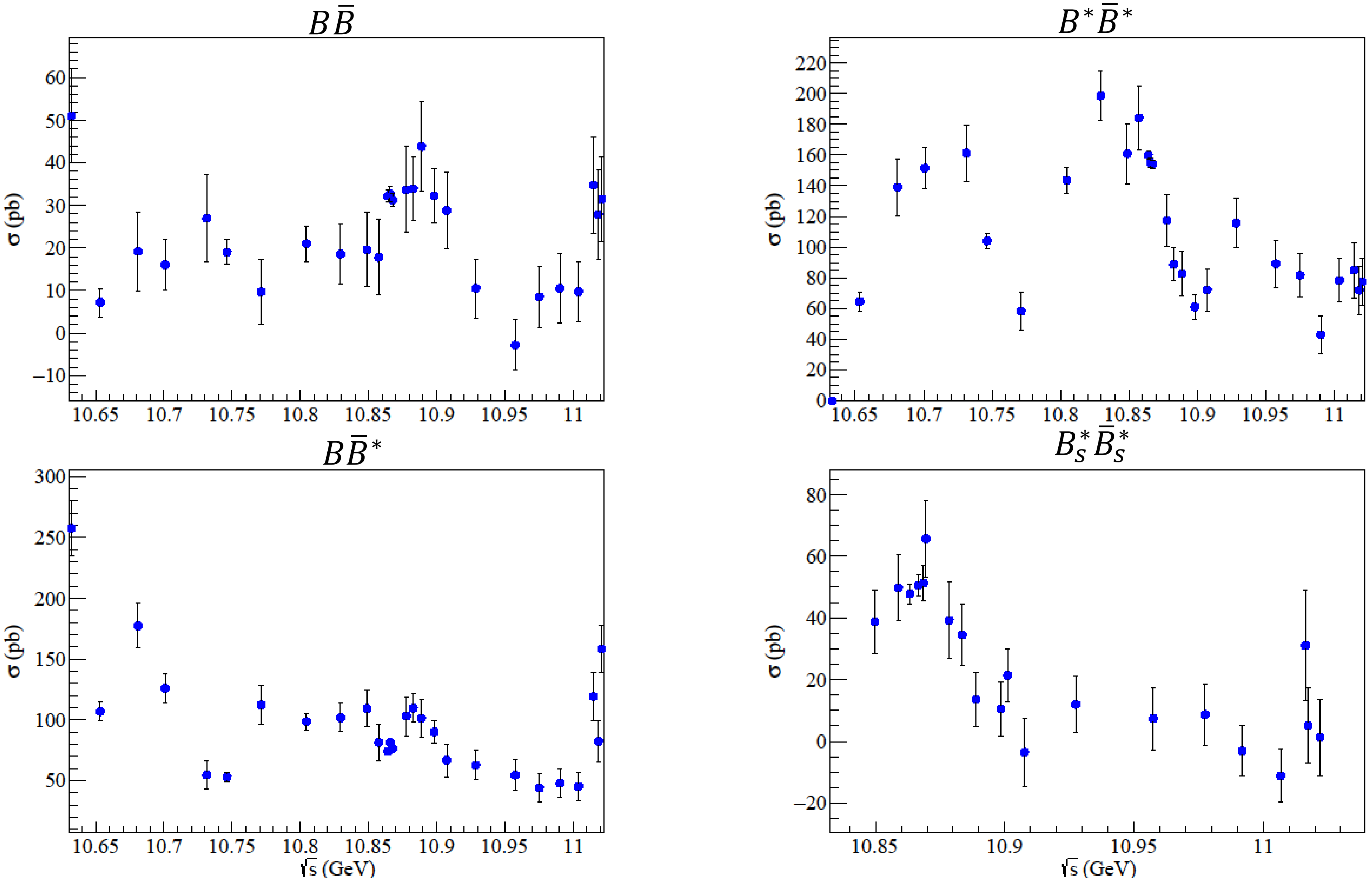
- Even more new data now available for exclusive cross sections! (Belle Preliminary)



Coupled Channel N/D Model

$$A_i^J = \kappa p_i^J \sum_k n_k^J(s) \, {(D^J)_{ki}}^{-1}$$

- Basic idea is to separate left-hand and right-hand cuts explicitly

$$n_k^J(s) = \sum_{n=0}^{n_{max}} a_n^{J,k} T_n[\omega(s)] \qquad \omega(s) = \frac{s}{s + s_0}$$

- n is parameterized by an effective polynomial expansion, with s_0 as a scale parameter

Coupled Channel N/D Model

$$D^J_{ki}(s) = [K^J(s)^{-1}]_{ki} - \frac{s}{\pi}\int_{m_{th}^2}^{\infty} ds' \frac{\rho N^J_{ki}(s')}{s'(s'-s-i\epsilon)}$$

- D is parameterized by a K-matrix and dispersive integral

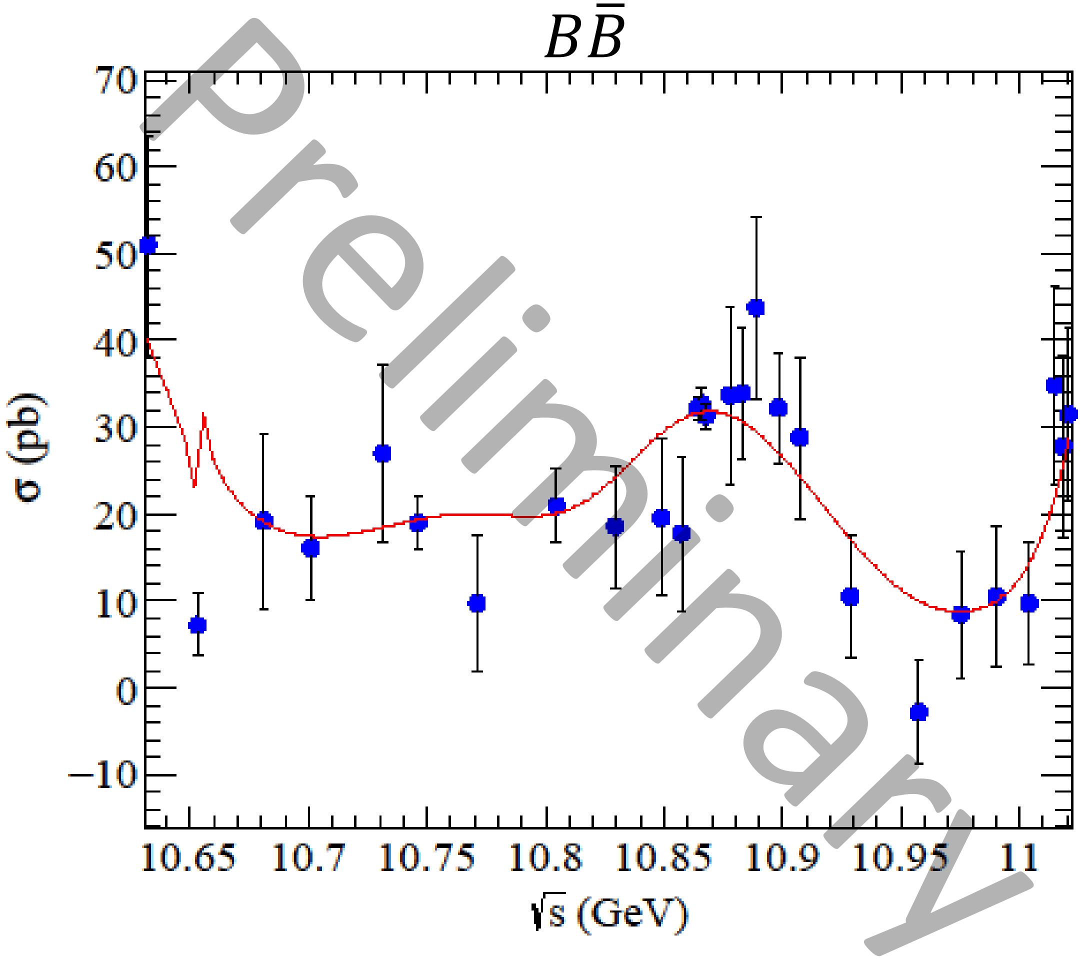
$$\rho N^J_{ki}(s') = \delta_{ki} \frac{(2p_i)^{2J+1}}{(s'+s_L)^{2J+\alpha}}$$

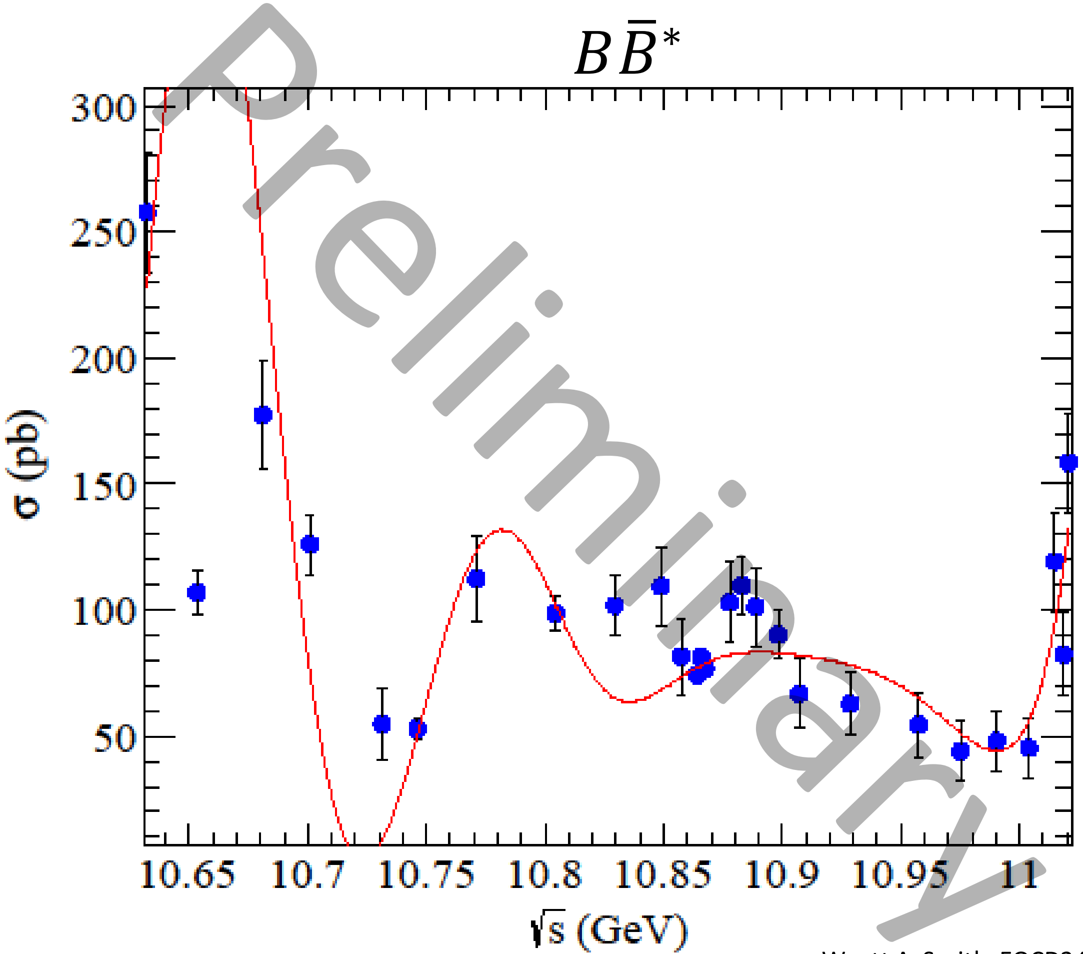
$$K^J_{ki}(s) = \sum_R \frac{g_k^{J,R} g_i^{J,R}}{m_R^2 - s} + c^J_{ki} + d^J_{ki} s$$

- Want to use a flexible model framework capable of describing significant possible model variation
- ‘Model of models’ for ML (in the future!)

Preliminary Fits

- Exclusive fits to $B\bar{B}, B\bar{B}^*, B^*\bar{B}^*$





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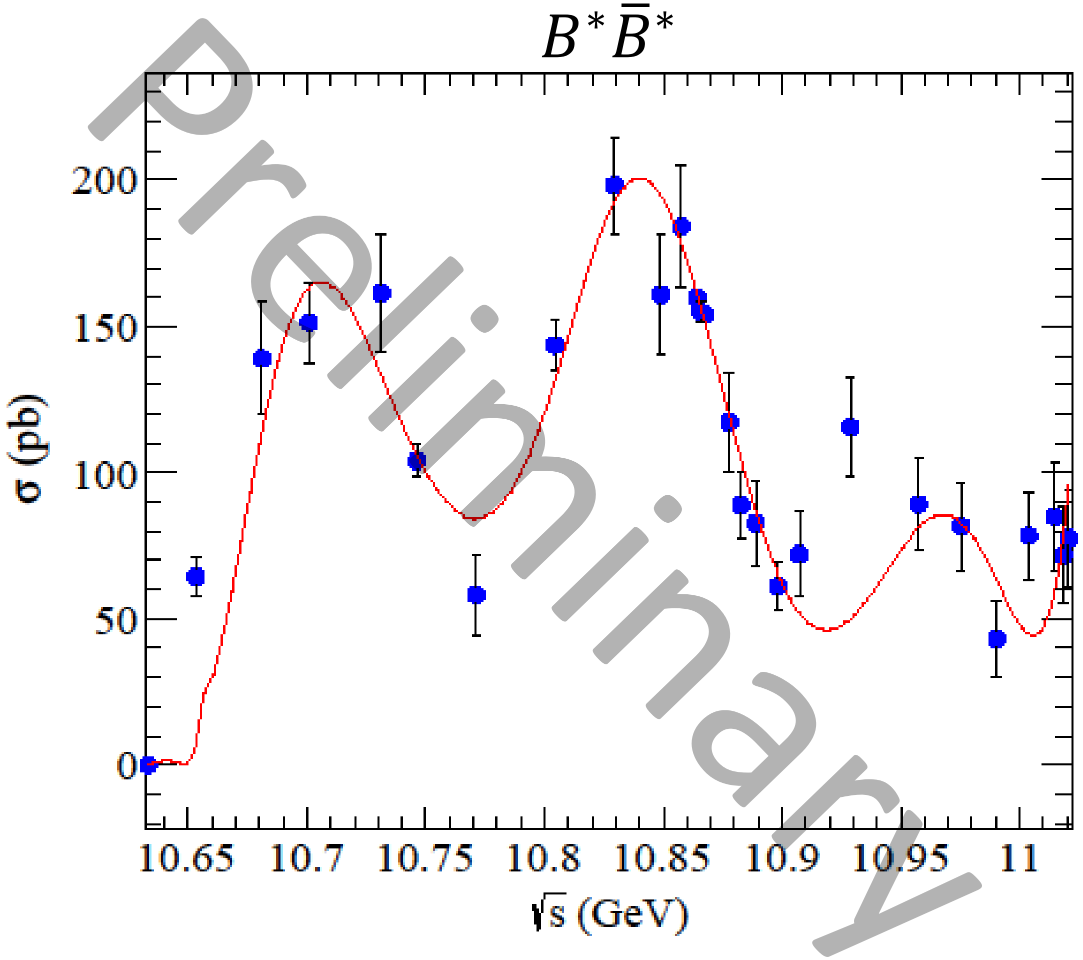
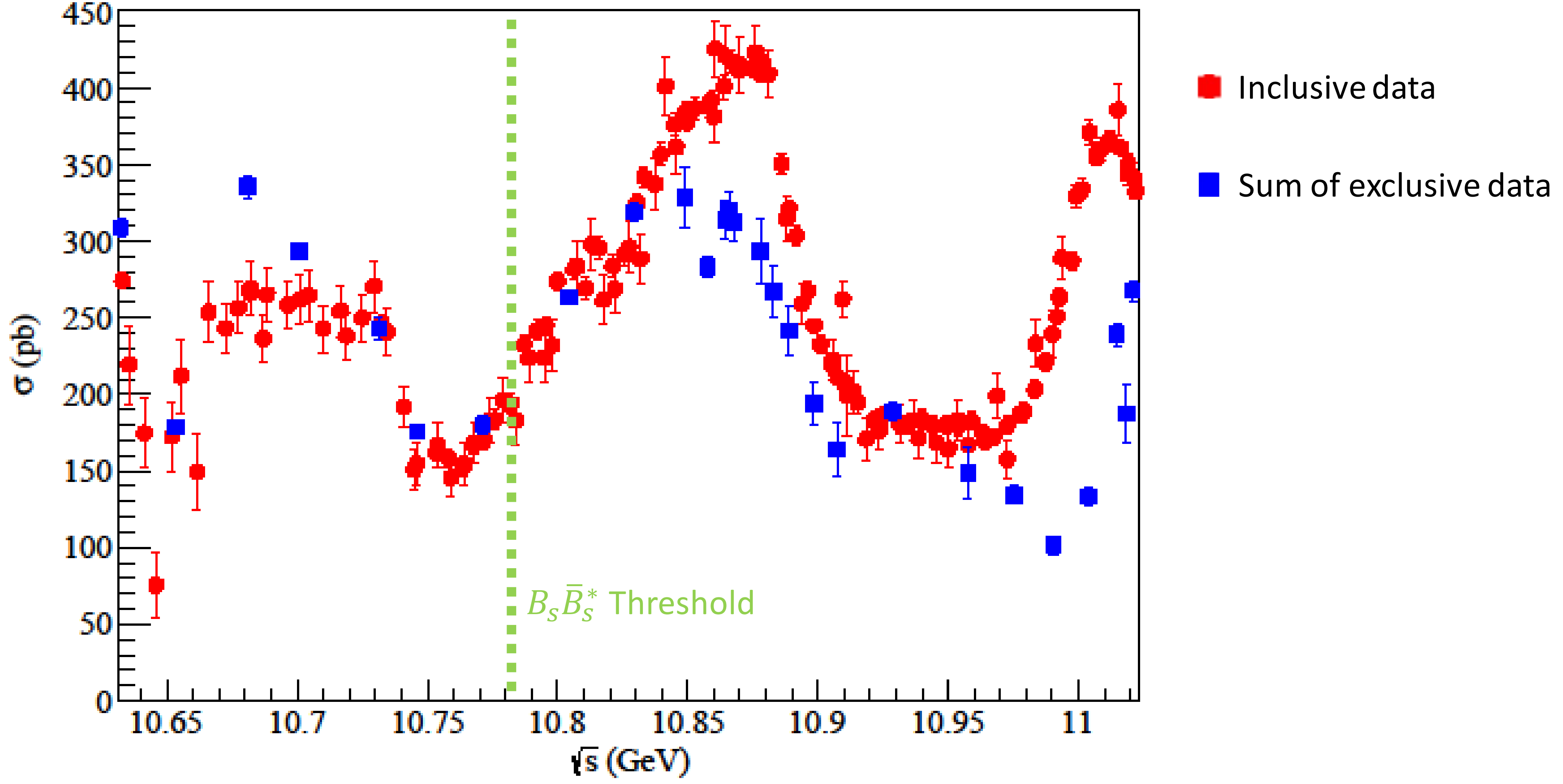


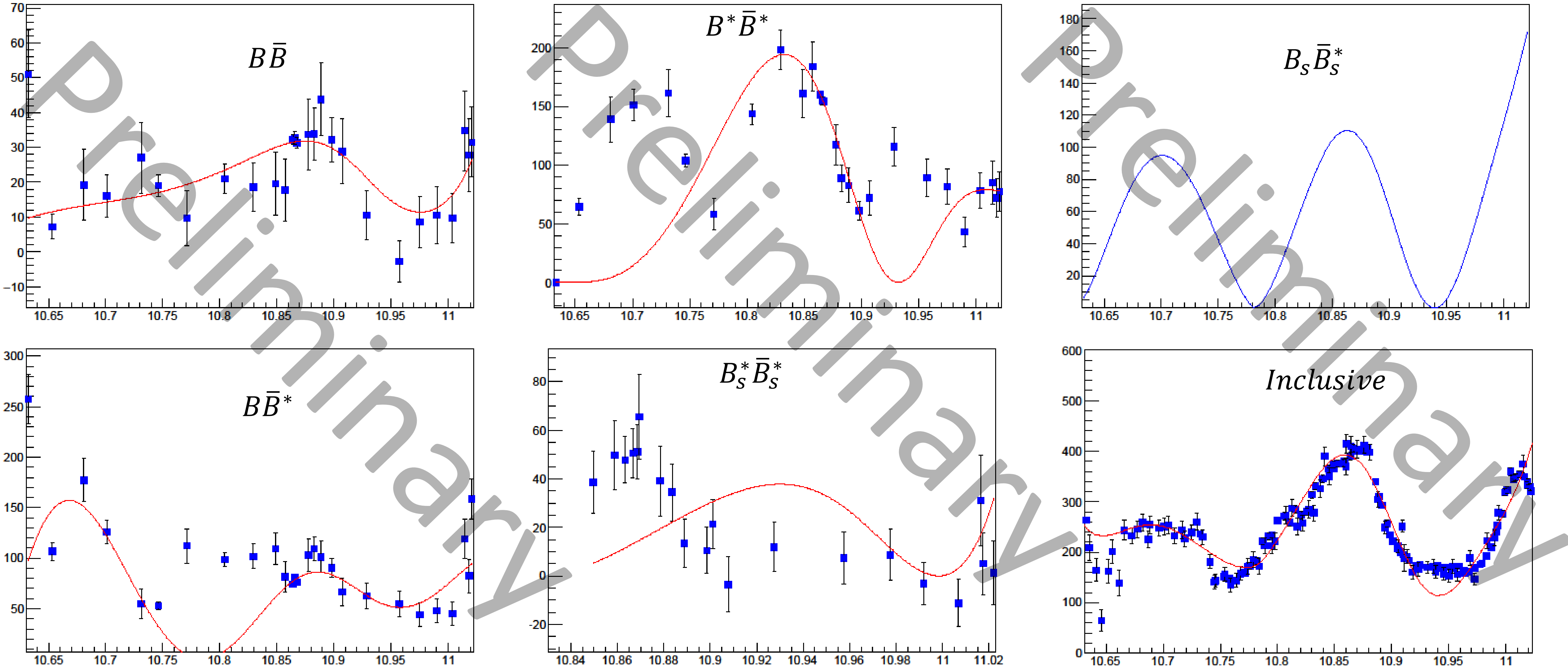
Preliminary Fits

- Closest channel to visible difference between inclusive, sum of exclusive data is $B_s\bar{B}_s^*$ → add it to absorb differences



Preliminary Fits

- Simultaneous fits to inclusive data and $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$, $B_s^*\bar{B}_s^*$, and $B_s\bar{B}_s^*$



Summary

- Bottomonium spectrum above $\Upsilon(4S)$ not so simple—Exotics?
- Breit-Wigners don't cut it—need coupled channel analysis
- Need better assessment of systematics, more model variation

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