Istituto Nazionale di Fisica Nucleare
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Υ(nS) decays at Belle

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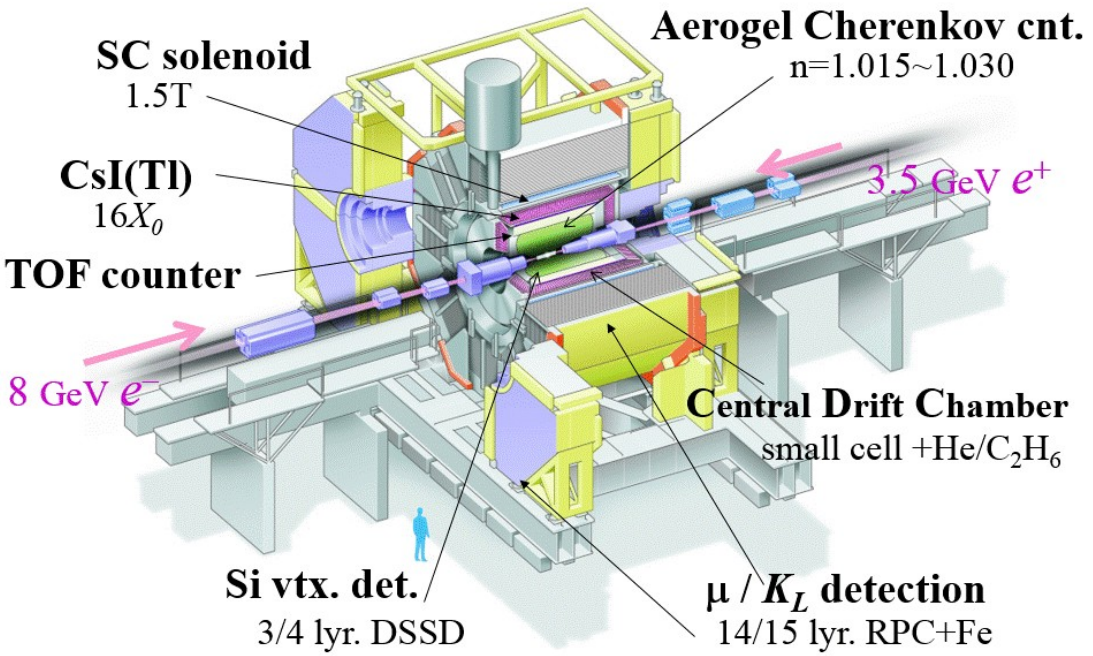
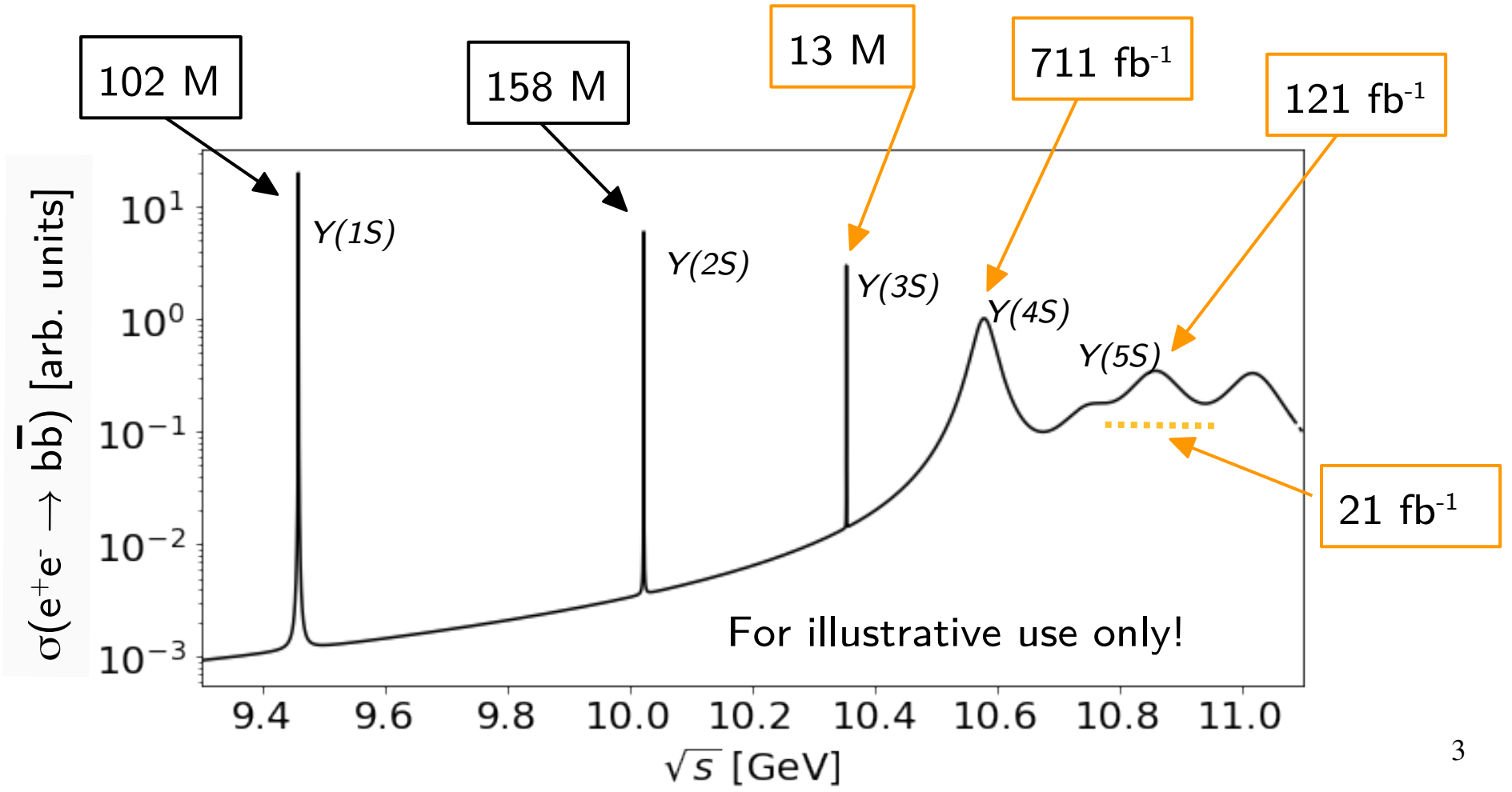
In this talk

Three main analyses revolving around bottomonium decays:

1) Search for $\chi_{b0}(2P) \rightarrow \omega\ \Upsilon(1S)$
2) Search for $\Upsilon(5S) \rightarrow \eta\ \Upsilon(1S, 2S)$
3) Search for $\Upsilon(5S) \rightarrow \eta'\ \Upsilon(1S)$



Belle relevant datasets

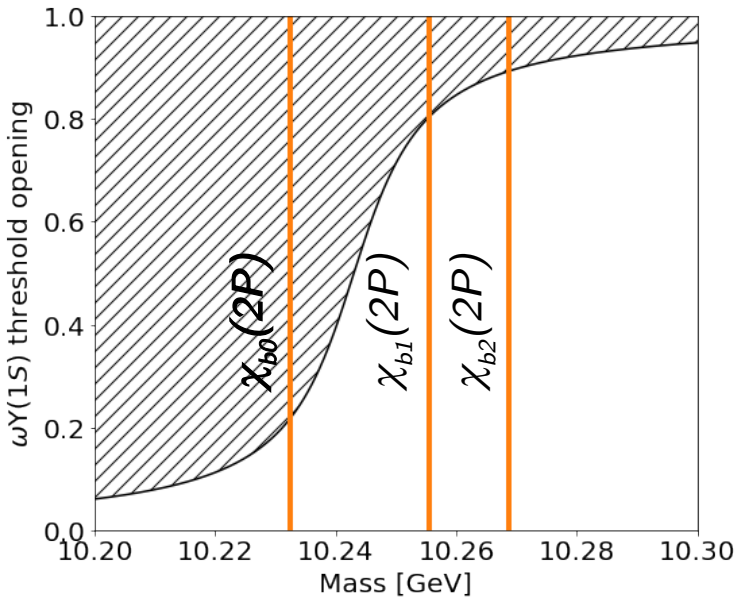


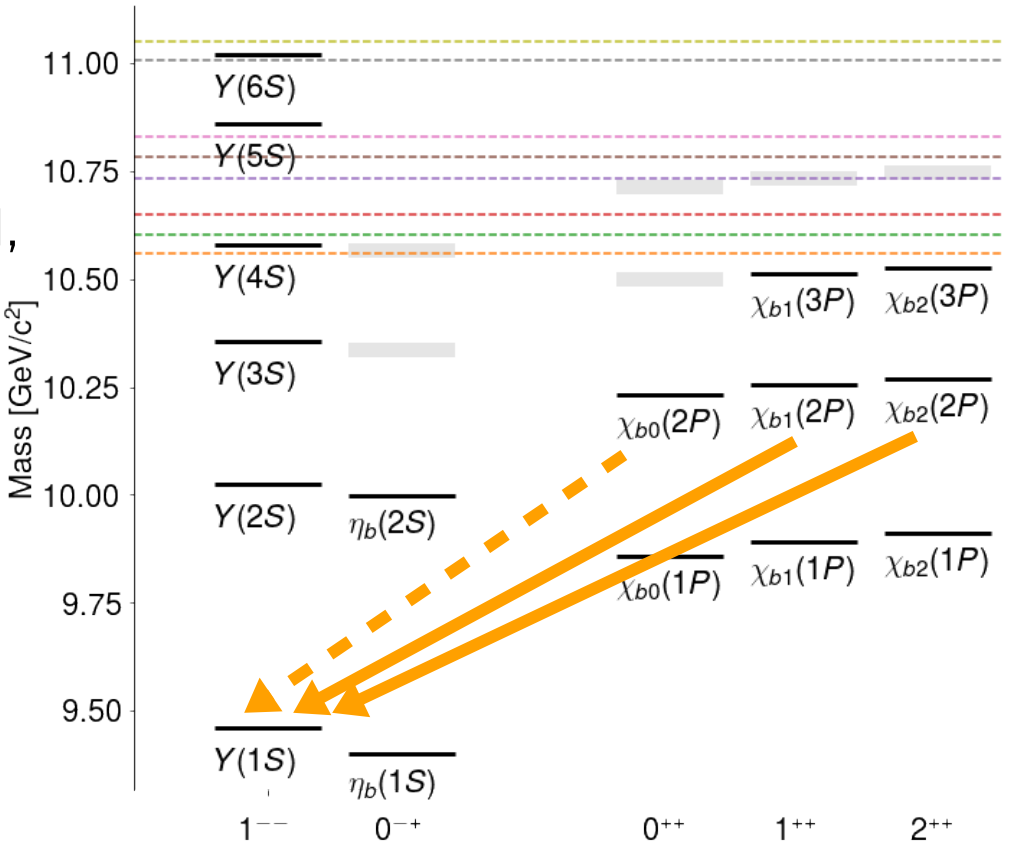
$\chi_{b0}(2P) \rightarrow \omega Y(1S)$

Peculiar features

→ ω Y(1S) threshold between χ_{b0} and χ_{b1}

→ $\chi_{b0}(2P)$ decay still possible sub-threshold, like in X(3872) → ω J/ψ





$\chi_{b0}(2P) \rightarrow \omega Y(1S)$

Peculiar features

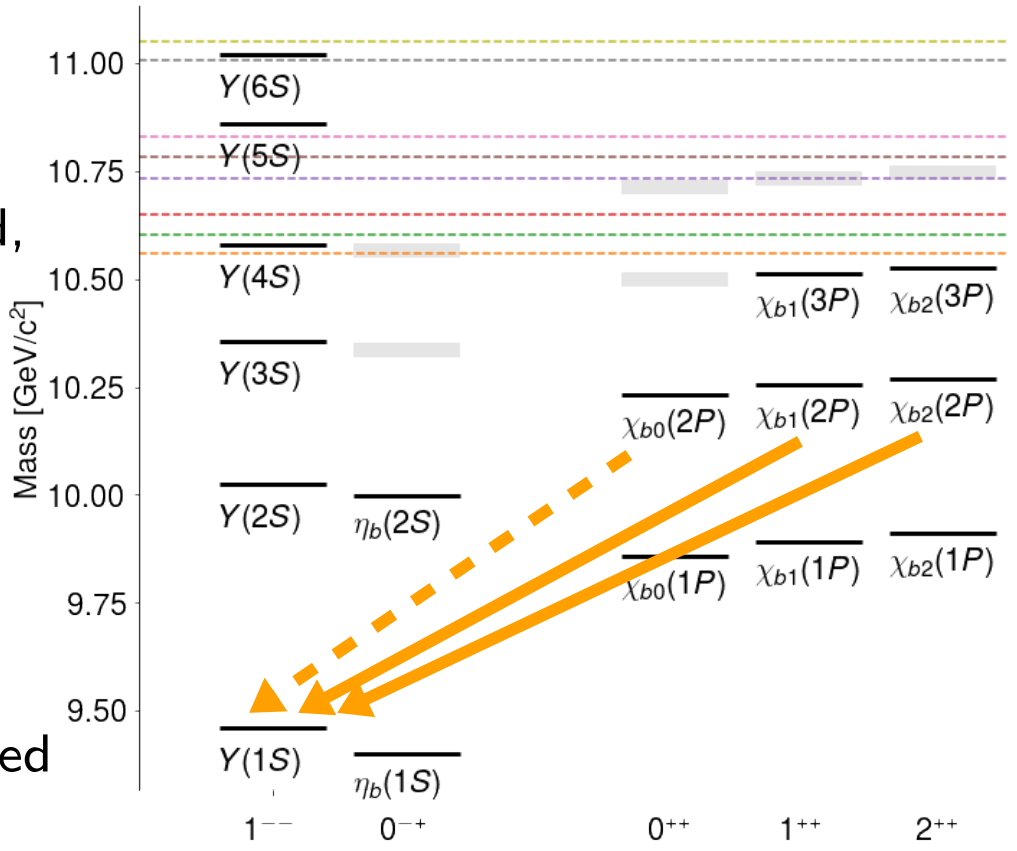
$\rightarrow$ ω Y(1S) threshold between χ_{b0} and χ_{b1}

$\rightarrow$ χ_{b0}(2P) decay still possible sub-threshold, like in X(3872) $\rightarrow$ ω J/ψ

Reconstruction strategy:

Mass of $\omega + \mu\mu$ pair

$\rightarrow$ χ_b(2P) produced by non-reconstructed radiative decay of Y(3S)



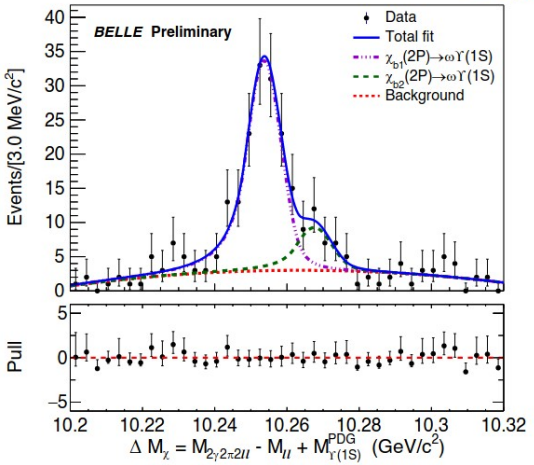
$\chi_{b0}(2P) \rightarrow \omega\Upsilon(1S)$

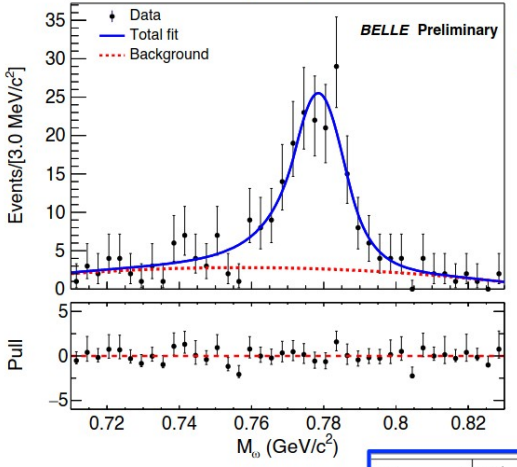
At QWG last year…

VIRGINIA TECH

Search for $\chi_{bJ}(nP) \rightarrow \omega\Upsilon(1S)$

Perform a Simultaneously Fit of M_ω and ΔM_χ n 3.0 fb^{-1} of $\Upsilon(3S)$ data





Data Sample: 3.0 fb^{-1} of **on-resonance $\Upsilon(3S)$ data**

$-$ $\Upsilon(3S)$ Population $-$

$(12.7 \pm 0.1 \pm 0.4) \cdot 10^6$

Calculate Branching Fractions as ratio with $\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)[\ell^+\ell^-]$

$$\mathcal{B}(\chi_{bJ}(2P) \rightarrow \omega\Upsilon(1S)) = \frac{N_{\chi J}}{N_{\pi\pi\Upsilon}} \frac{\epsilon_{\pi\pi\Upsilon}}{\epsilon_{\chi J}} \frac{\mathcal{B}(\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S))}{\mathcal{B}(\Upsilon(3S) \rightarrow \gamma\chi_{bJ}(2P))\mathcal{B}(\omega \rightarrow \pi^+\pi^-\pi^0)\mathcal{B}(\pi^0 \rightarrow \gamma\gamma)}$$

Results

Channel	$\mathcal{B}(\chi_{bJ}(2P) \rightarrow \omega\Upsilon(1S))$	Significance
J=1	$(2.20^{+0.24}_{-0.23} \pm 0.22)$ %	12.2σ
J=2	$(0.44^{+0.16}_{-0.15} \pm 0.06)$ %	3.3σ

Compare with PDG

Channel	Branching Fraction	Consistency
J=1	$(1.63^{+0.35+0.12}_{-0.31-0.11})$ %	1.3σ
J=2	$(1.10^{+0.32+0.08}_{-0.28-0.07})$ %	2.0σ

$\chi_{b0}(2P) \to \omega Y(1S)$

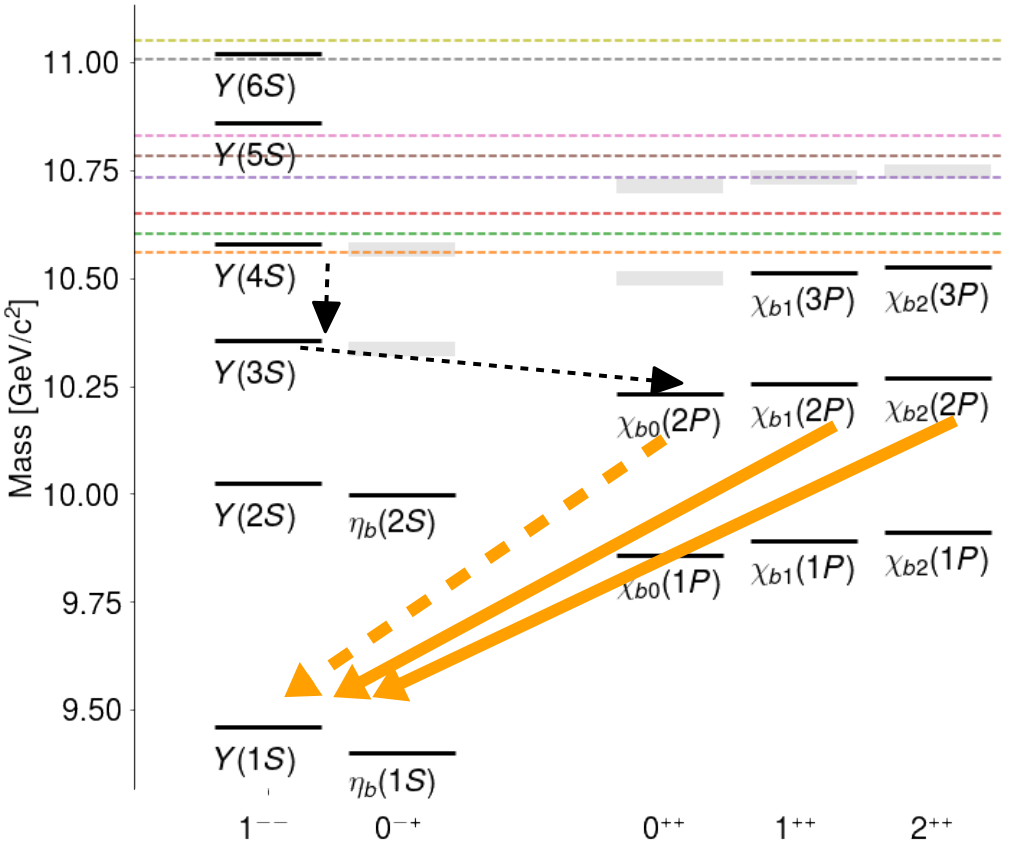
Update of the data sample

28.2 $\pm$ 0.9 Million events

12.7 M on resonance

15.5 M via ISR from Y(4S)

Meson	σ_V^I (nb)	σ_V^{II} (nb)	$N_{total}, 10^6$
$\Upsilon(4S)$	-	3.40	34
$\Upsilon(3S)$	0.038	0.031	0.31
$\Upsilon(2S)$	0.016	0.015	0.15
$\Upsilon(1S)$	0.021	0.019	0.19

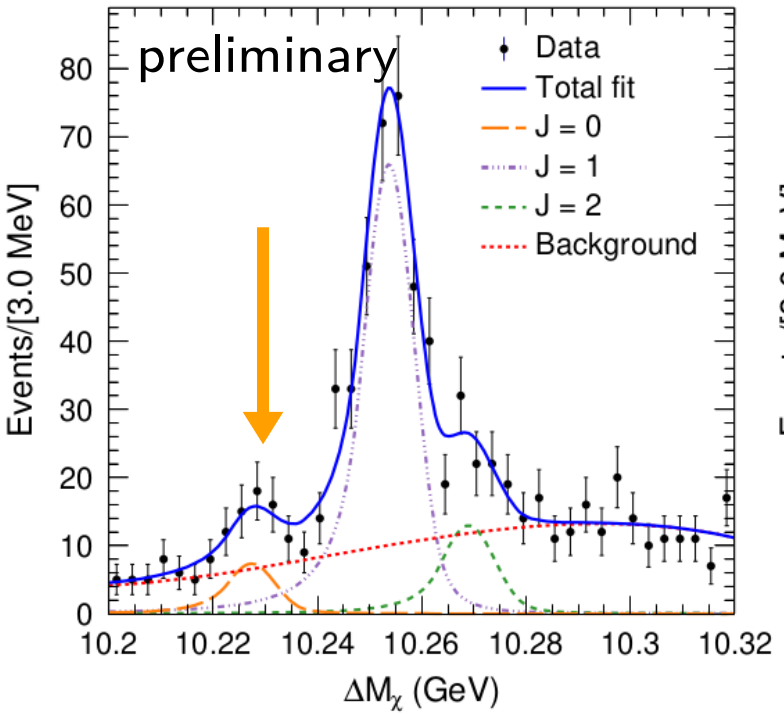


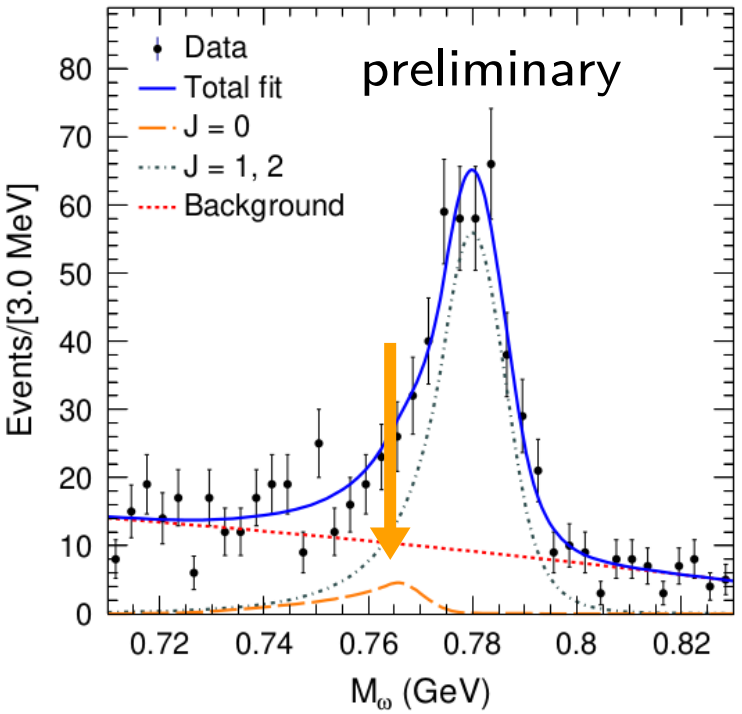
$\chi_{b0}(2P) \to \omega\Upsilon(1S)$

First evidence of $\chi_{b0} \to \omega\ \Upsilon(1S)$ $(3.6\ \sigma)$ *preliminary*

NEW

$$\mathcal{B}\left(\chi_{b0}(2P) \to \omega\Upsilon(1S)\right) = \left(0.54^{+0.19}_{-0.18} \pm 0.07\right)\%$$

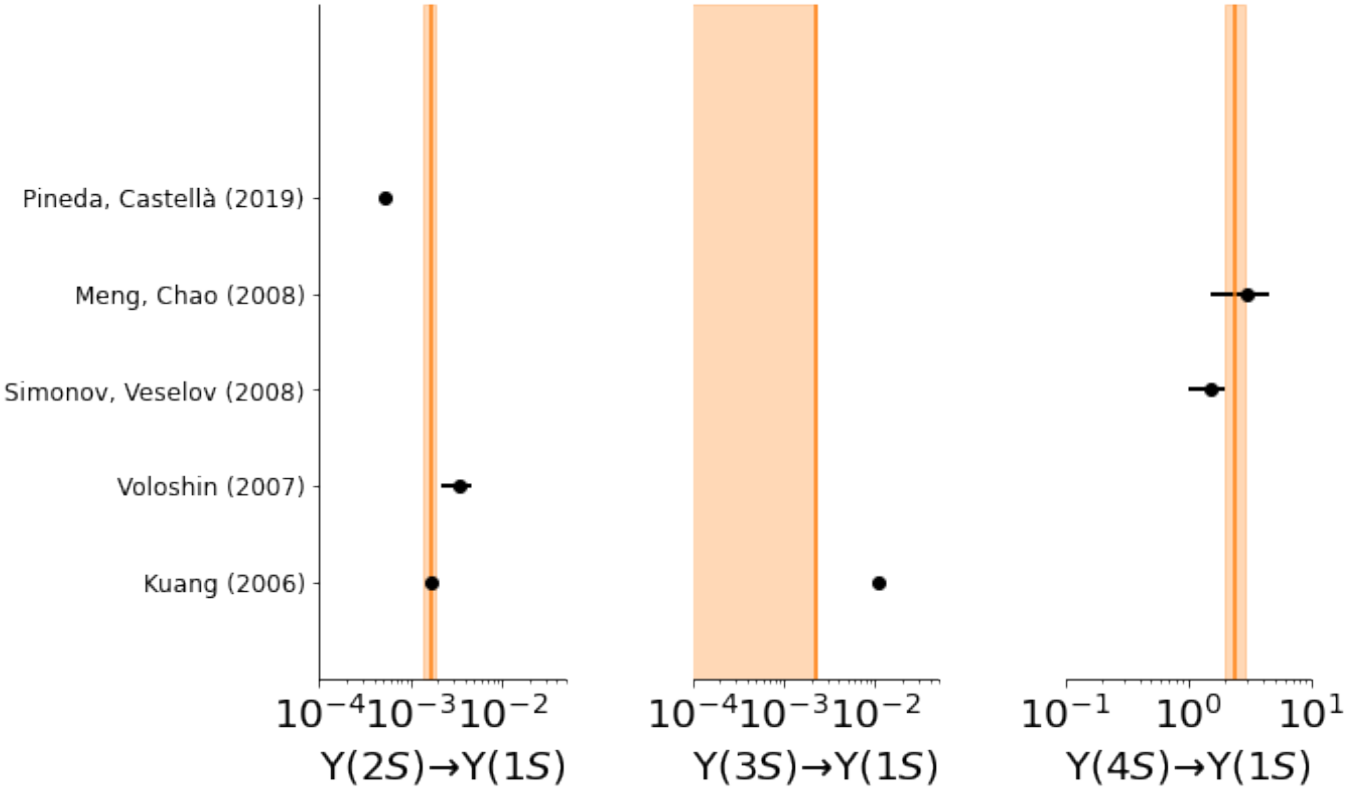




$Y(5S) \to \eta\, Y(1S, 2S)$

[Phys.Rev.D 104 (2021) 11, 112006]

η and $\pi\pi$ transitions connect the same states and their ratios is predicted by several models

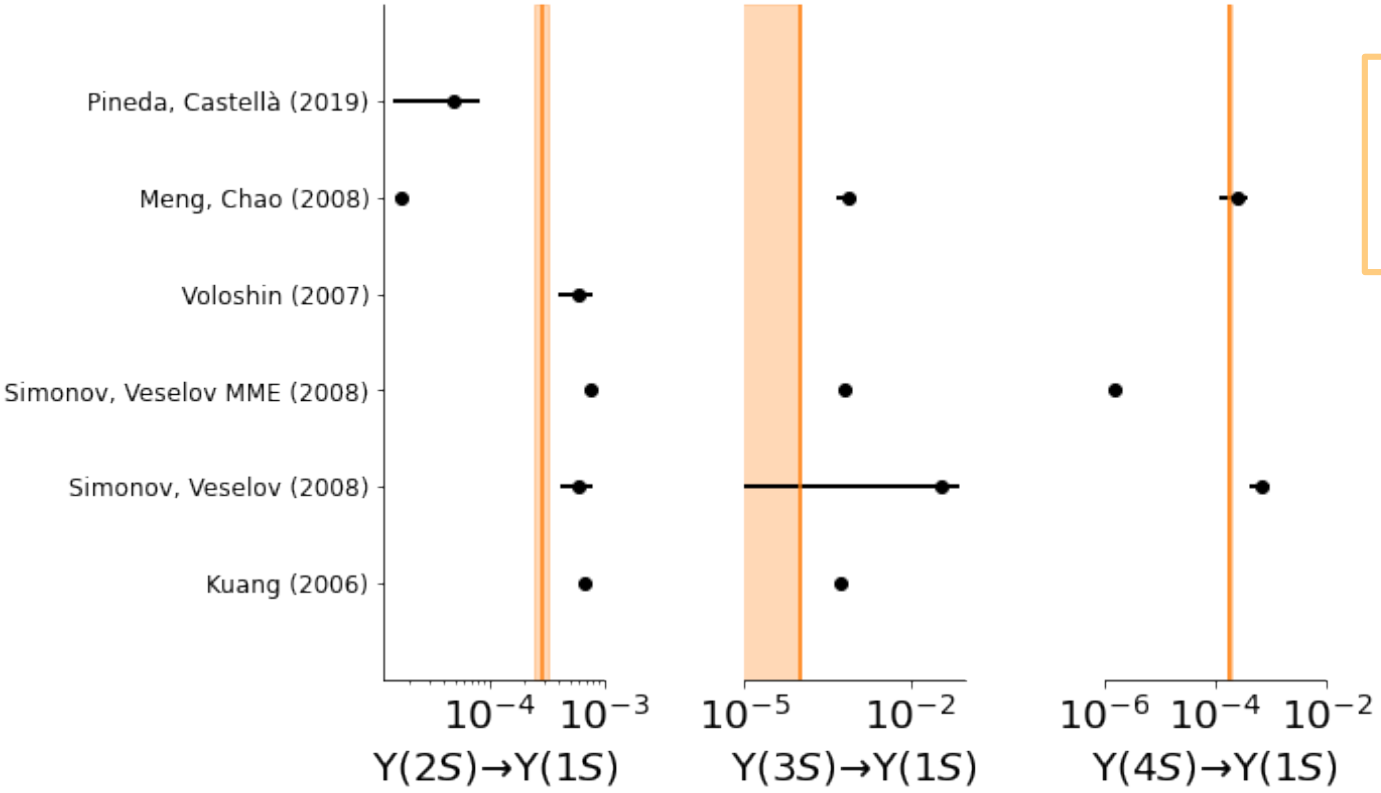


$$\text{Ratio} \quad \frac{\Upsilon(nS) \to \eta\, \Upsilon(mS)}{\Upsilon(nS) \to \pi\pi\, \Upsilon(mS)}$$

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

[Phys.Rev.D 104 (2021) 11, 112006]

The rate of η transitions seems quite challenging to predict



BF $\Upsilon(nS) \to \eta\, \Upsilon(mS)$

$Y(5S) \to \eta\, Y(1S, 2S)$

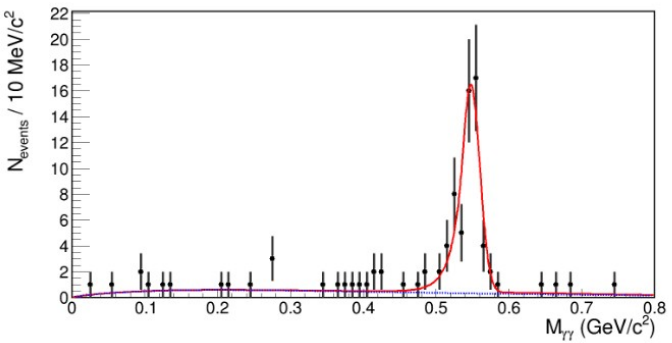
[Phys.Rev.D 104 (2021) 11, 112006]

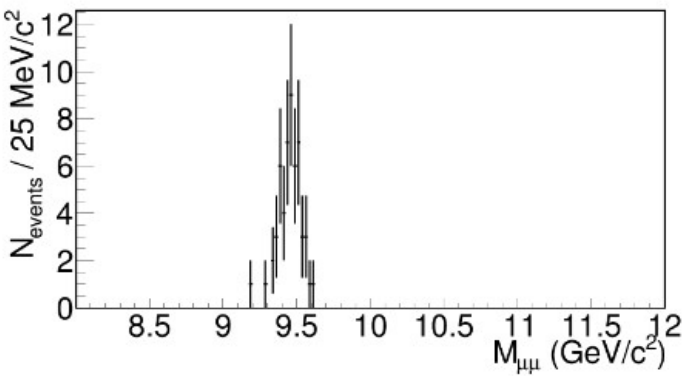
New analysis of η and η' transitions from the Y(5S) region.

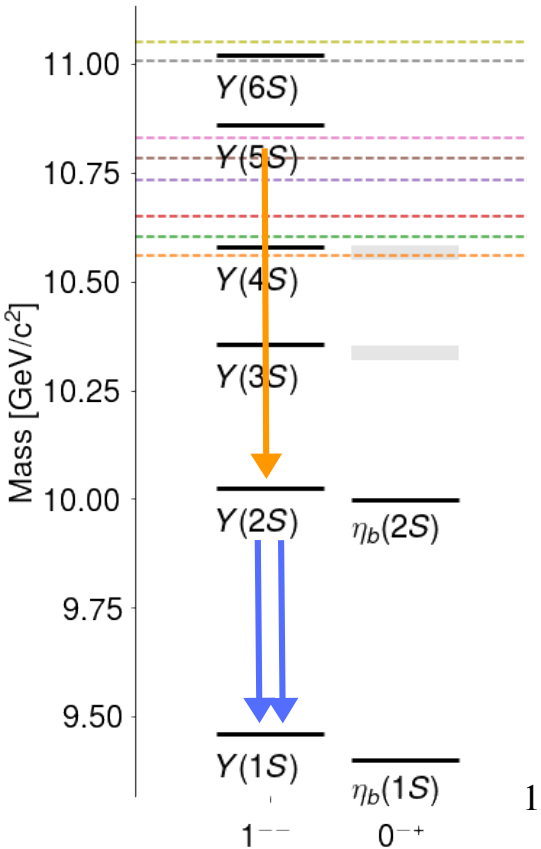
One final state, several decays: $\mu^+\mu^-$ $\pi^+\pi^-$ $\gamma\gamma$

Y(2S)[γγ]: $\mu^+\mu^-$ $\pi^+\pi^-$ $\gamma\gamma$

Y(1S) 2S→ 1S transition η







$Y(5S) \to \eta\, Y(1S, 2S)$

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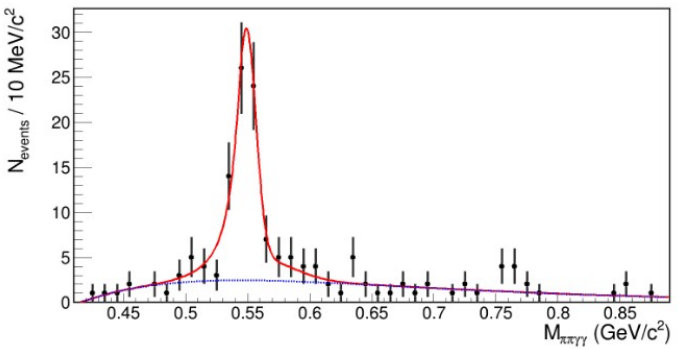
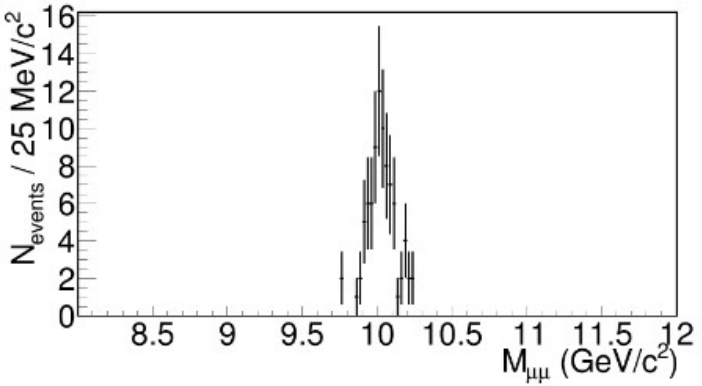
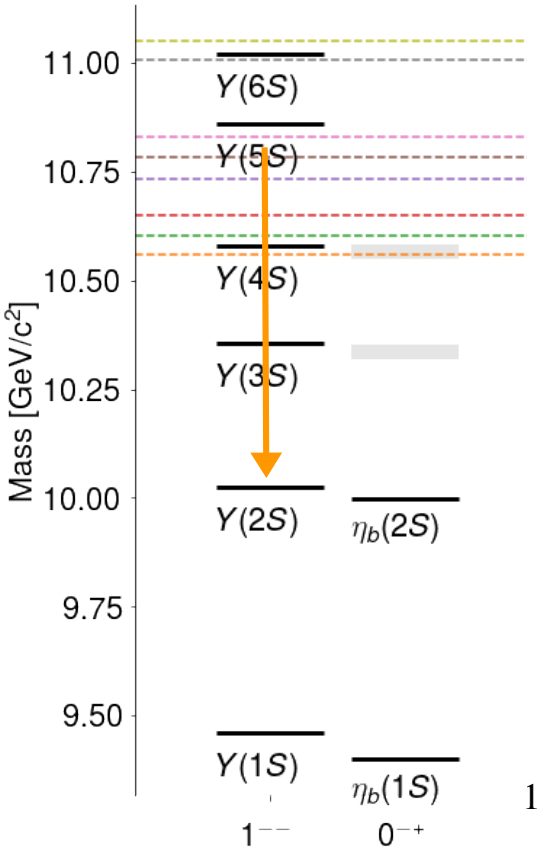
Y(2S)[3π]: $\mu^+\mu^-$ $\pi^+\pi^-$ $\gamma\gamma$

Y(2S) η







$Y(5S) \to \eta\, Y(1S, 2S)$

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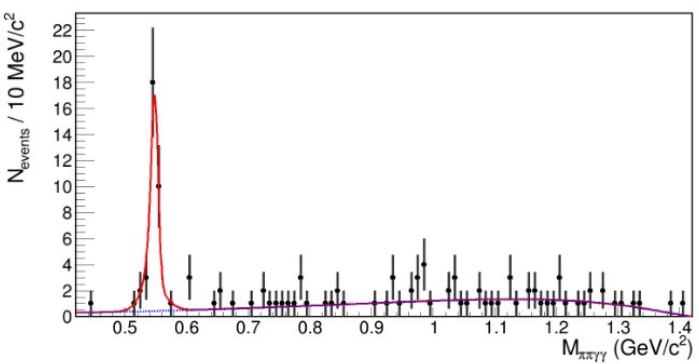
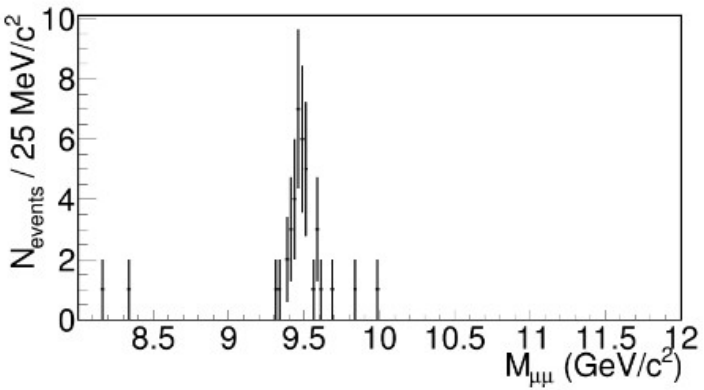
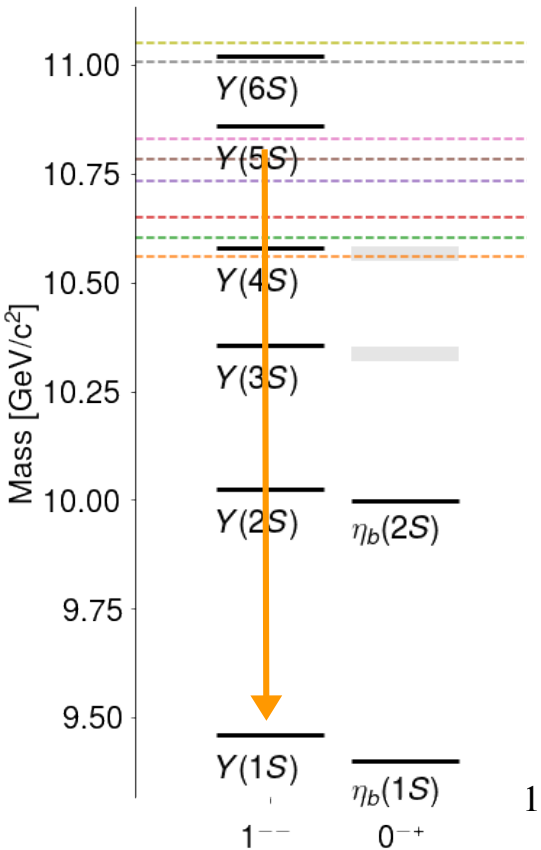
Y(1S)[3π]: $\mu^+\mu^-$ $\pi^+\pi^-$ $\gamma\gamma$

Y(1S) η







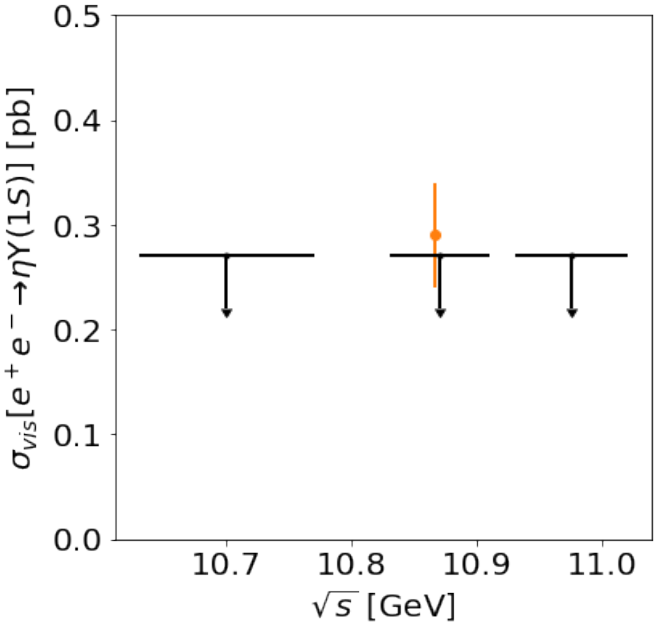
$\Upsilon(5S) \to \eta\, \Upsilon(1S, 2S)$

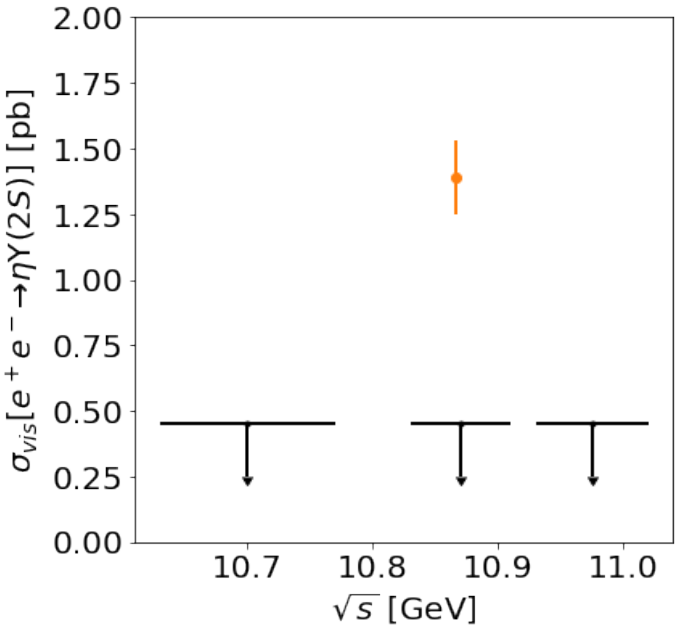
[Phys.Rev.D 104 (2021) 11, 112006]

Results of the combined decays modes:

$$\sigma_{\rm B}(e^+e^- \to \Upsilon(2S)\eta) = 2.07 \pm 0.21 \pm 0.19 \text{ pb},$$
$$\sigma_{\rm B}(e^+e^- \to \Upsilon(1S)\eta) = 0.42 \pm 0.08 \pm 0.04 \text{ pb},$$

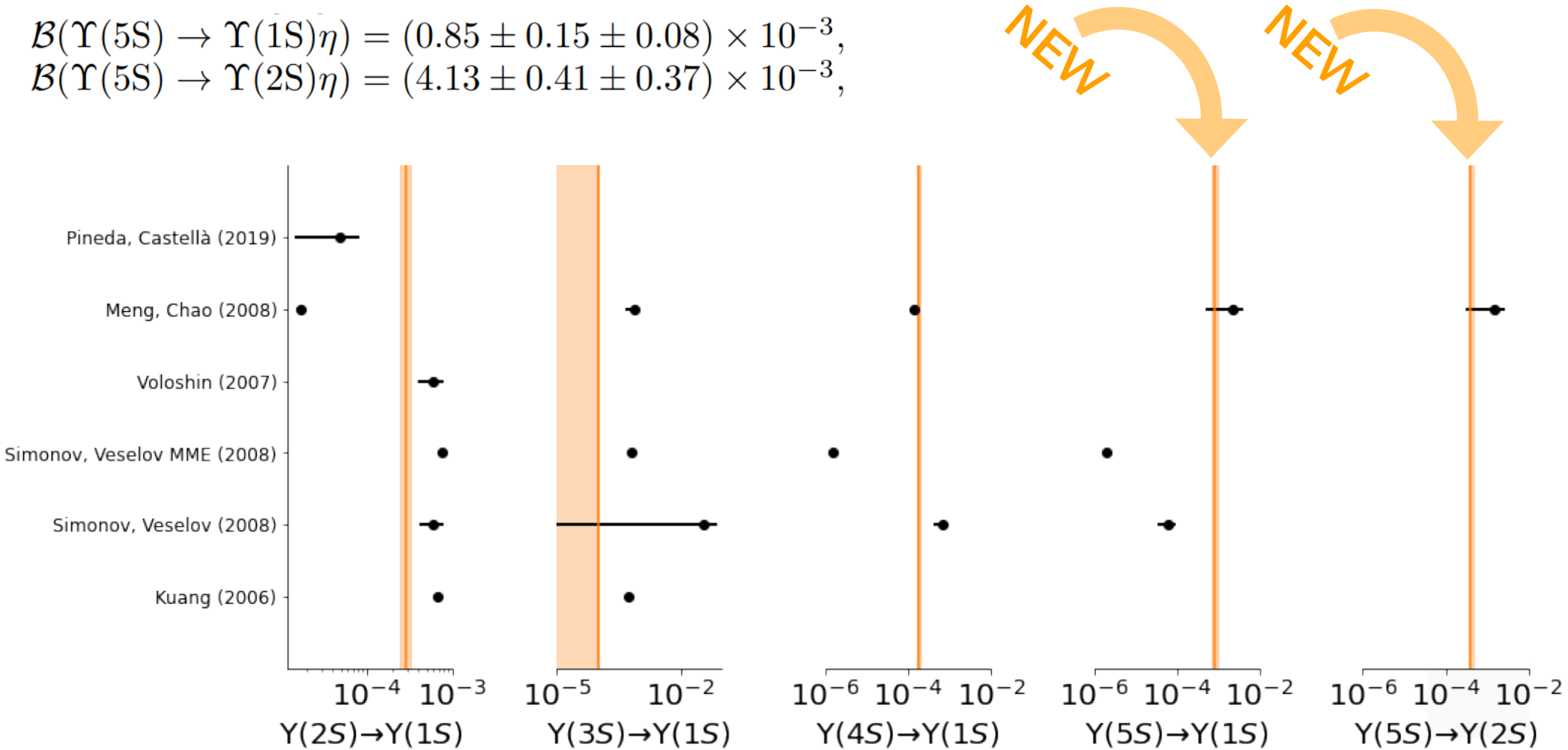
No Significant yield in the Belle scan data outside the Y(5S)





η transitions updated

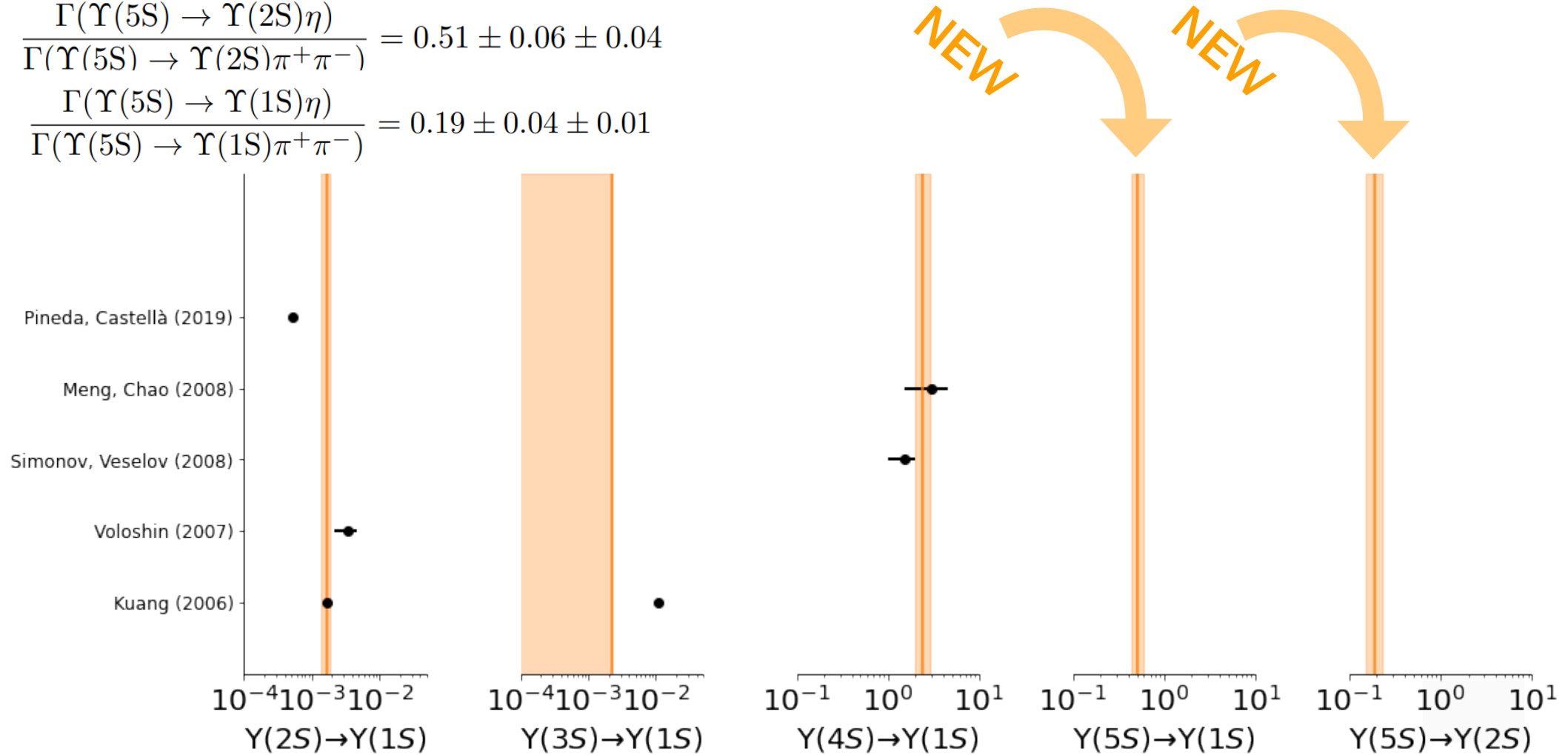
$$\mathcal{B}(\Upsilon(5S) \to \Upsilon(1S)\eta) = (0.85 \pm 0.15 \pm 0.08) \times 10^{-3},$$
$$\mathcal{B}(\Upsilon(5S) \to \Upsilon(2S)\eta) = (4.13 \pm 0.41 \pm 0.37) \times 10^{-3},$$



$\eta/\pi\pi$ Ratio updated

$$\frac{\Gamma(\Upsilon(5S) \to \Upsilon(2S)\eta)}{\Gamma(\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-)} = 0.51 \pm 0.06 \pm 0.04$$

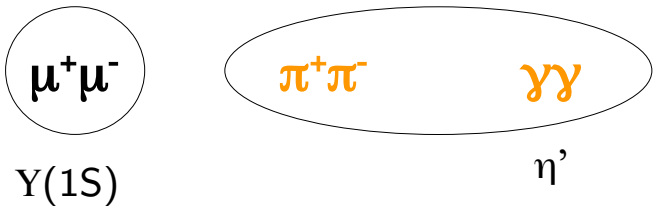
$$\frac{\Gamma(\Upsilon(5S) \to \Upsilon(1S)\eta)}{\Gamma(\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-)} = 0.19 \pm 0.04 \pm 0.01$$



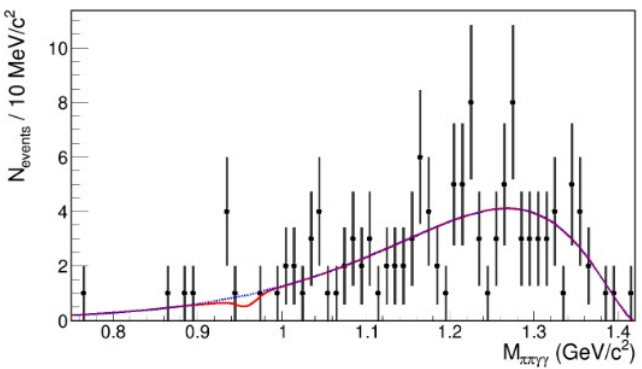
$Y(5S) \rightarrow \eta'\, Y(1S)$

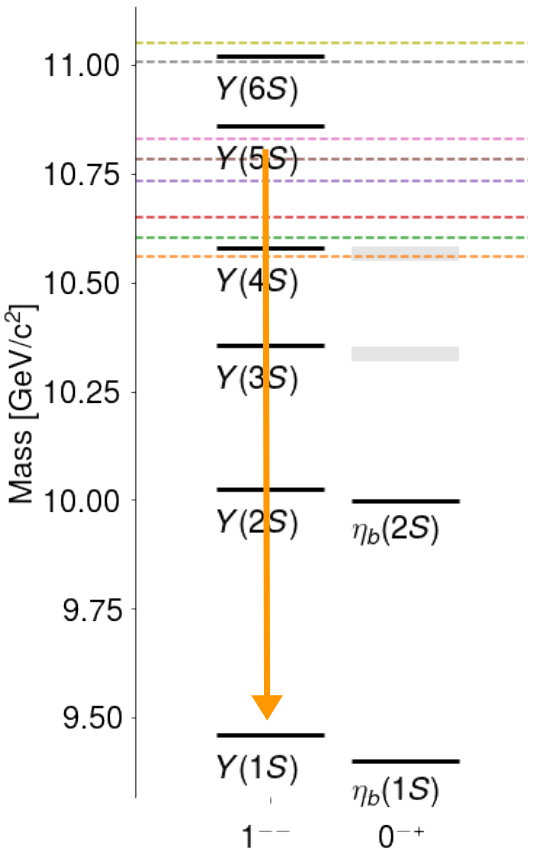
[Phys.Rev.D 104 (2021) 11, 112006]

The same final state also brings some η'



Two final states:
ππη





$Y(5S) \rightarrow \eta'\, Y(1S)$

[Phys.Rev.D 104 (2021) 11, 112006]

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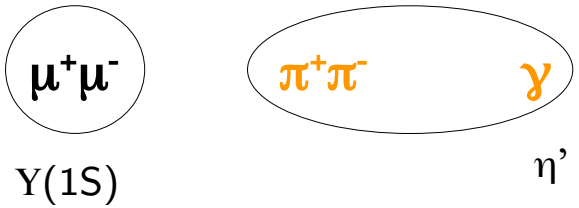
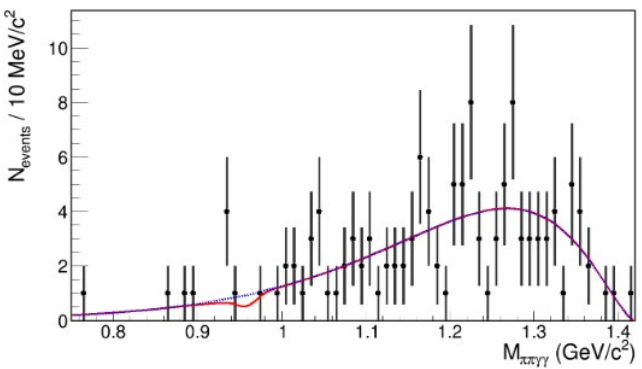
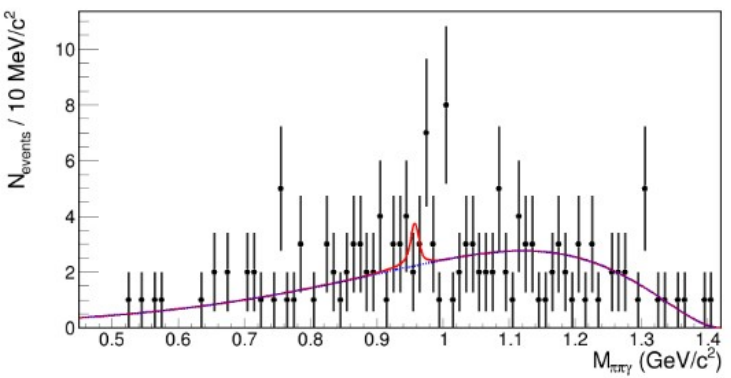
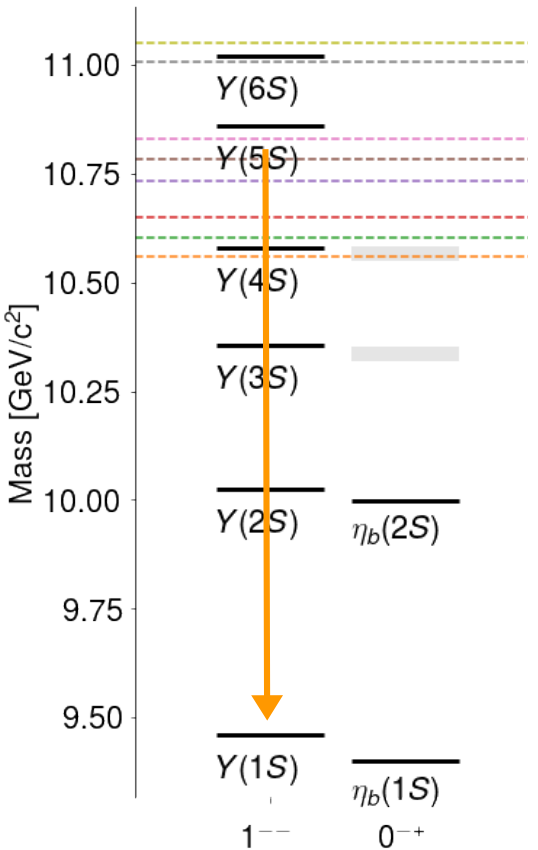


Two final states:
ππη
ργ





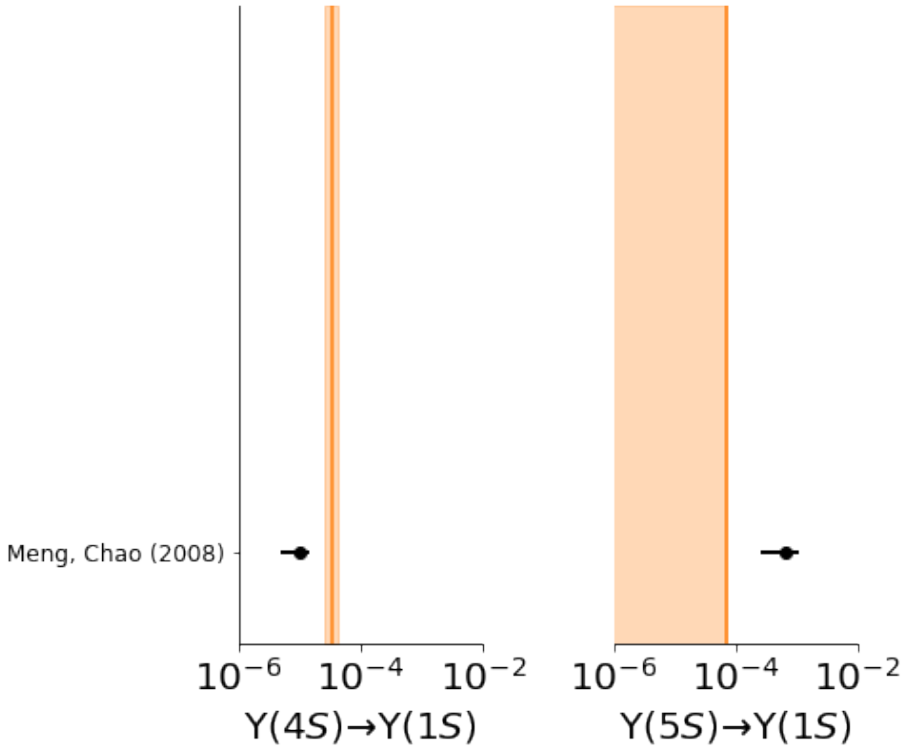


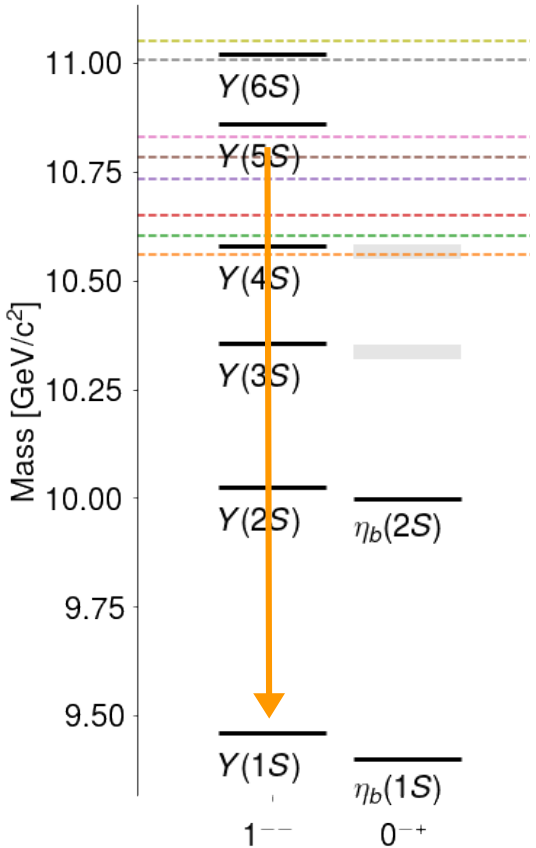
$Y(5S) \rightarrow \eta'\ Y(1S)$

[Phys.Rev.D 104 (2021) 11, 112006]

Combining the two decay modes:

$$\mathcal{B}(\Upsilon(5S) \rightarrow \Upsilon(1S)\eta') < 6.9 \times 10^{-5},\ CL = 90\%.$$



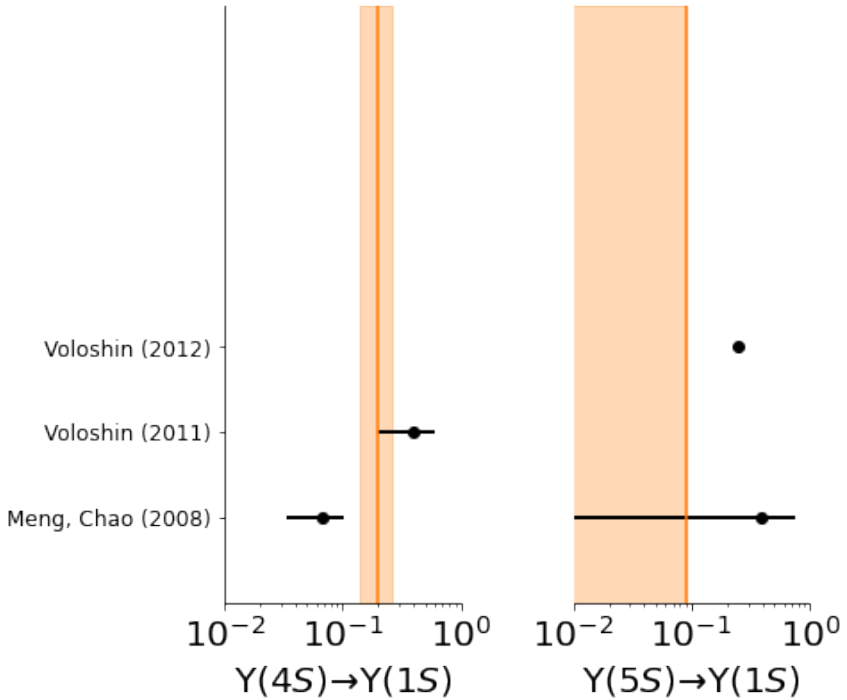


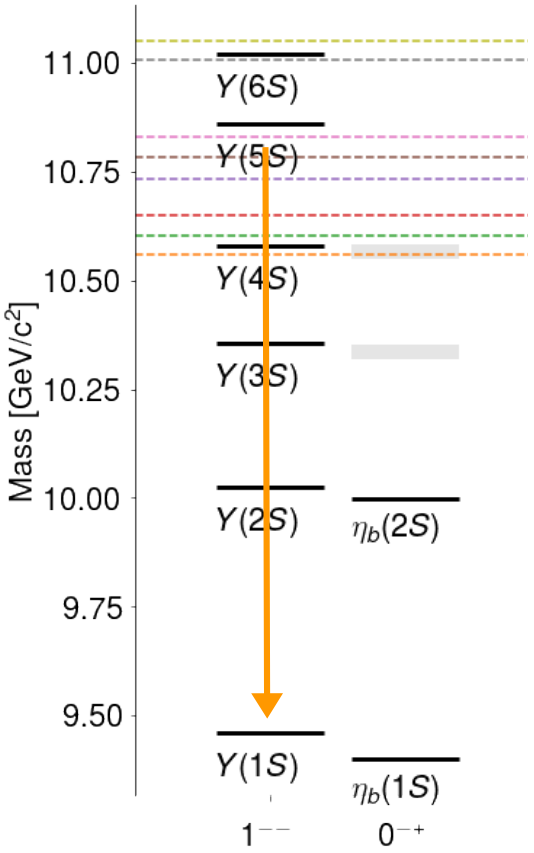
$\Upsilon(5S) \to \eta' \Upsilon(1S)$

[Phys.Rev.D 104 (2021) 11, 112006]

Combining the two decay modes:

$$\frac{\Gamma(\Upsilon(5S) \to \Upsilon(1S)\eta')}{\Gamma(\Upsilon(5S) \to \Upsilon(1S)\eta)} < 0.09 \ (CL = 90\%)$$





Conclusions

Belle measured two new hadronic transitions:

→ **First evidence of $\chi_{b0}(2P) \rightarrow \omega\, \Upsilon(1S)$**

→ Can this teach us something about the X(3872)?

→ **(almost) Last missing η transition, the Υ(5S) → Υ(1S).**

→ Pattern for breakdown of QCDME above threshold confirmed

→ No evidence of η' transition, upper limit below the observed rate at the Υ(4S)

→ **What next? h_b decays, hindered radiative transtions…**

Backup

References

Kuang (2006): *Front. Phys. China 1 (2006) 19-37*

Voloshin (2007): *Prog. Part. and Nuc. Phys. Vol 61, Issue 2, pp. 455-511*

Simonov, Veselov (2008): *Phys. Lett. B, Vol 673, Issue 3, pp. 211-215*

Meng, Chao (2008): *Phys. Rev. D 78, 074001*

Voloshin (2011): *Mod. Phys. Lett. A Vol. 26, No. 11, pp. 773-778*

Voloshin (2012): *Phys. Rev. D 85, 034024*

Pineda, Castellà (2019): *Phys. Rev. D 100, 054021*