QUARKONIUM/ QCD RESULTS AT BELLE II

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On behalf of the Belle II Collaboration

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Beauty 2023

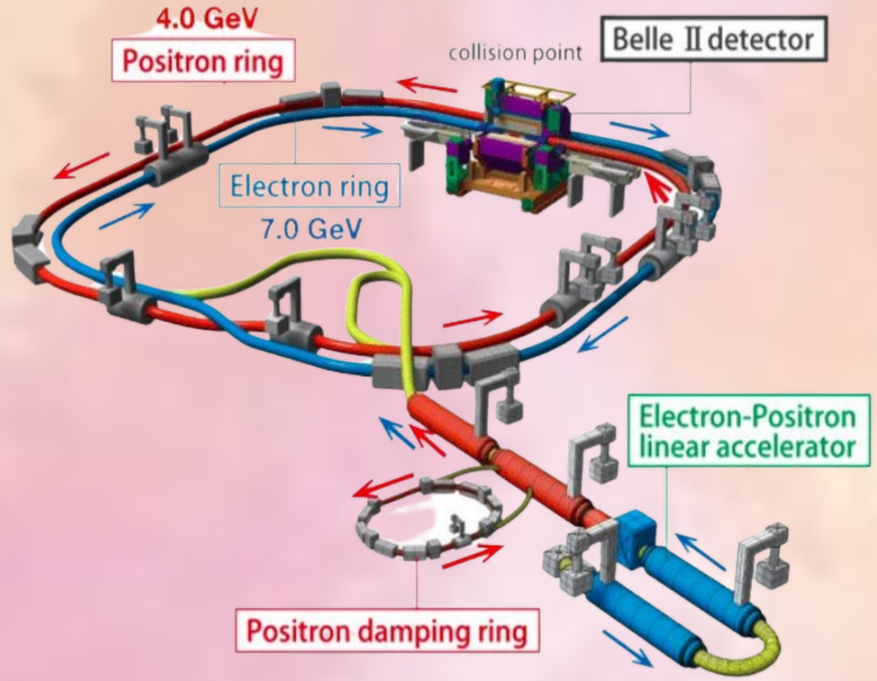
BELLE II EXPERIMENT

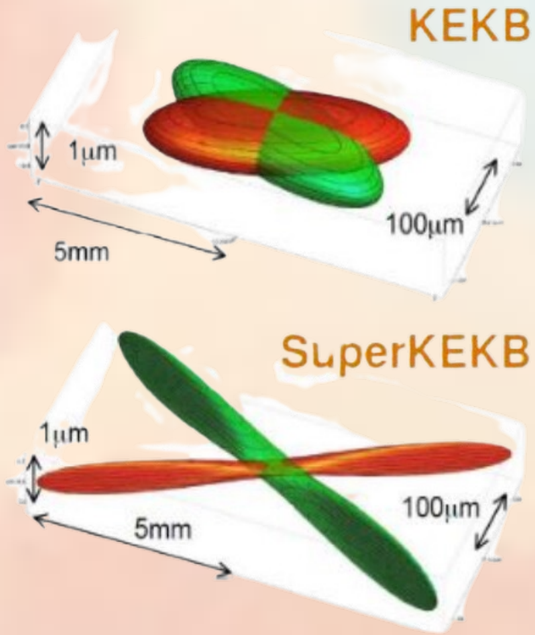
Asymmetric e^+e^- collider in Tsukuba, Japan

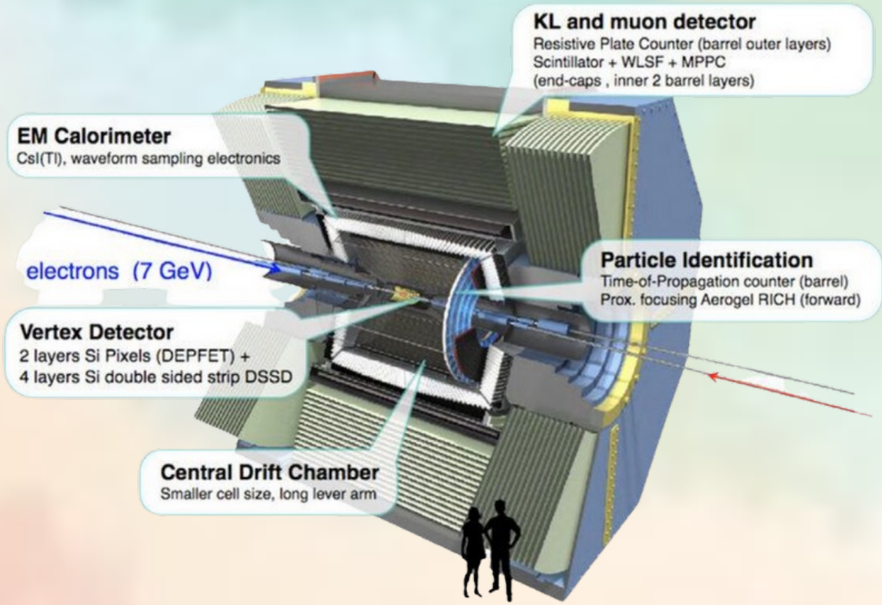
Nano-beam interaction point

Tunable E_{cm} around $\Upsilon(4S)$ mass

$\mathcal{L} = 4.7\times10^{34}\ cm^{-2}s^{-1}$ (record), $L = 424\ fb^{-1}$





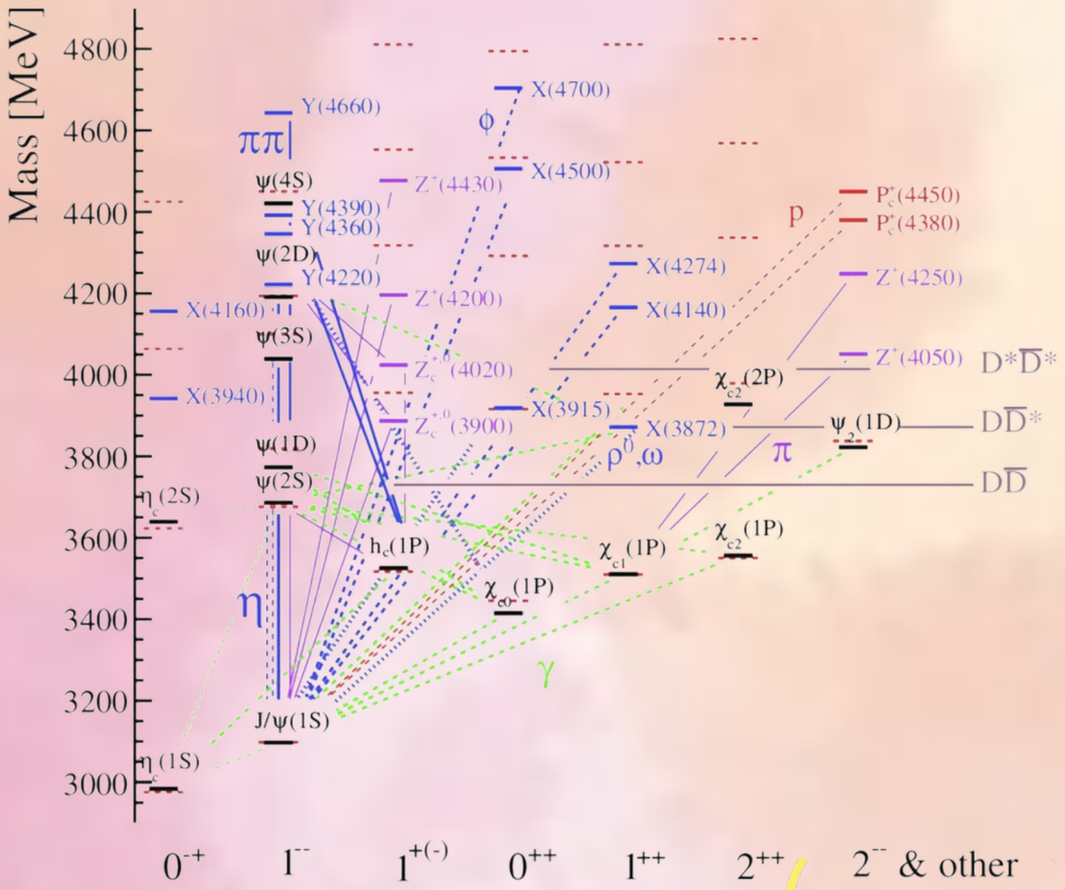


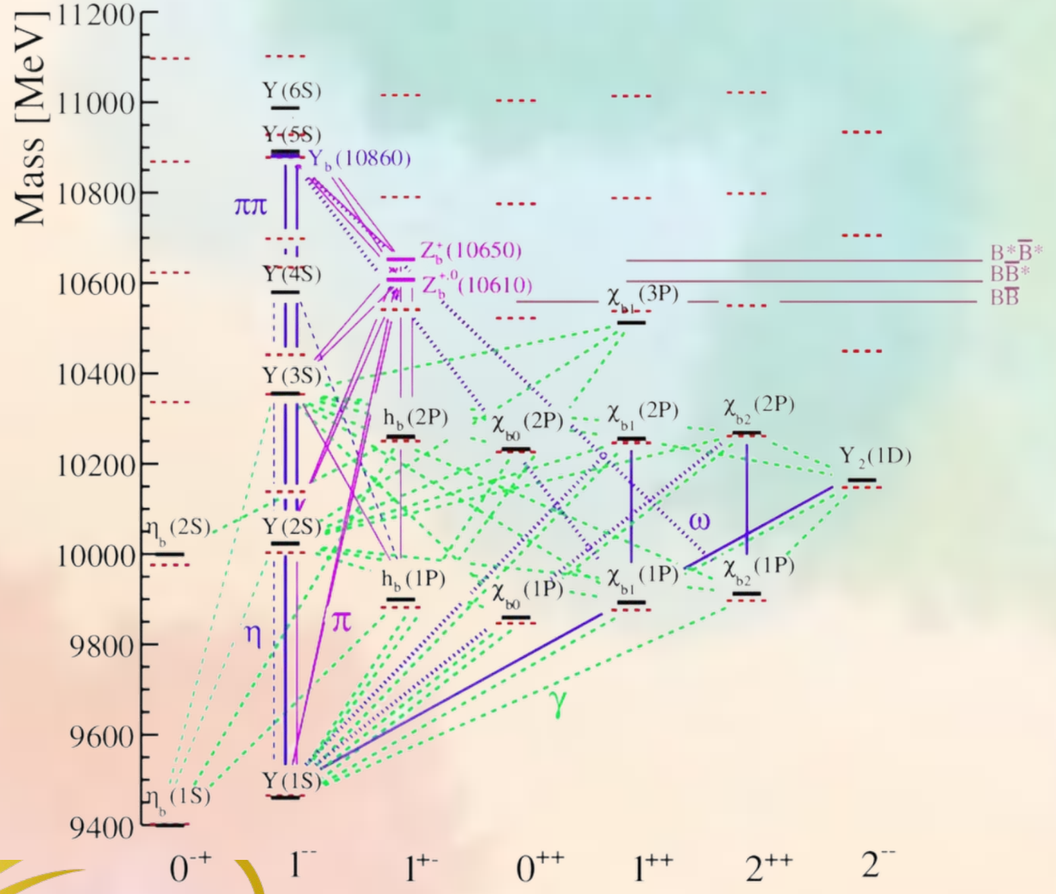
SuperKEKB

Belle II detector

QUARKONIA

= $\bar{c}c$ and $\bar{b}b$ mesons (or charmonia and bottomonia)

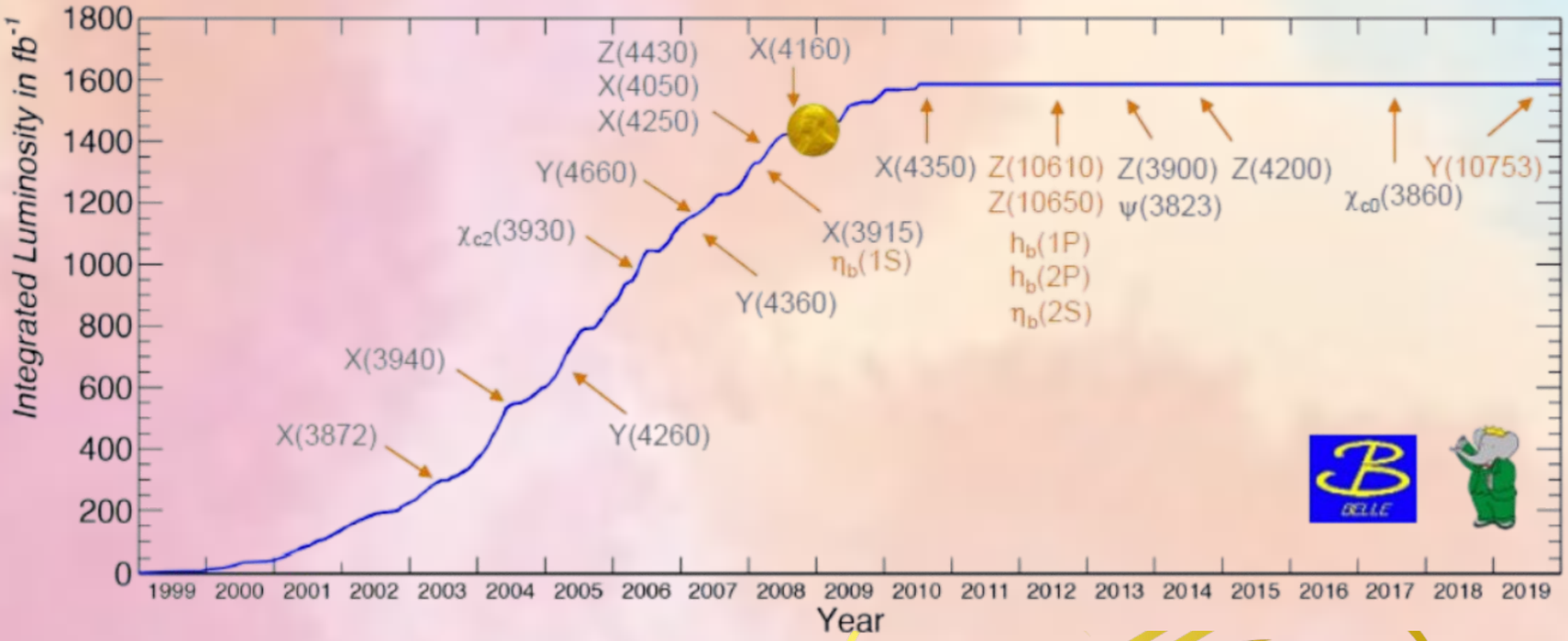


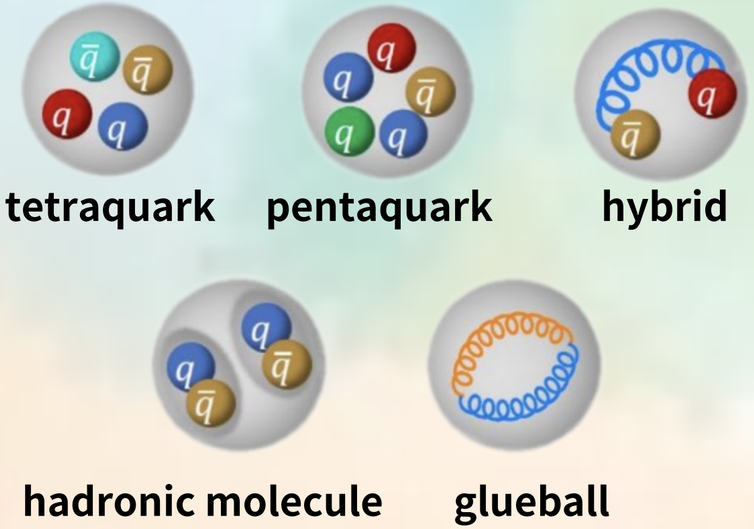


EXOTIC HADRONS

XYZ states:
lots of them in charmonium
bottomonium analogues: Yb, Zb, Z'b

what are they?
⇔
which partons compose them?





THE BELLE LEGACY

Belle@KEKB (B-factory) → optimized for

$$e^+e^- \to \Upsilon(4S) \to B\overline{B}$$

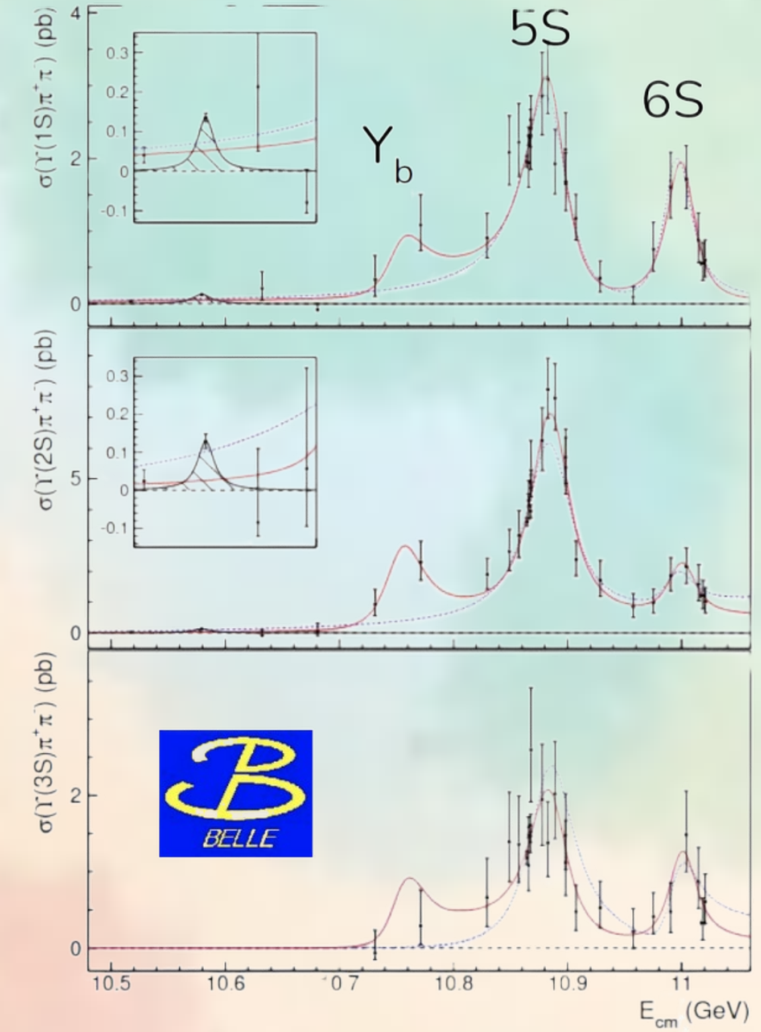
However

ϒ(5S): discovery of hb(1,2P), ηb(2S), Zb(10610,10650)

[PR D91 072003, PRL 109 232002]

exotic states and anomalous ππ transition widths

Process	Partial width
$\Upsilon(10860) \to \Upsilon(3S)\pi^+\pi^-$	$(0.59 \pm 0.04 \pm 0.09)\ MeV$
$\Upsilon(10860) \to \Upsilon(2S)\pi^+\pi^-$	$(0.85 \pm 0.07 \pm 0.09)\ MeV$
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	$(0.52^{+0.20}_{-0.17} \pm 0.10)\ MeV$
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	$(8.9 \pm 0.8) \times 10^{-4}\ MeV$

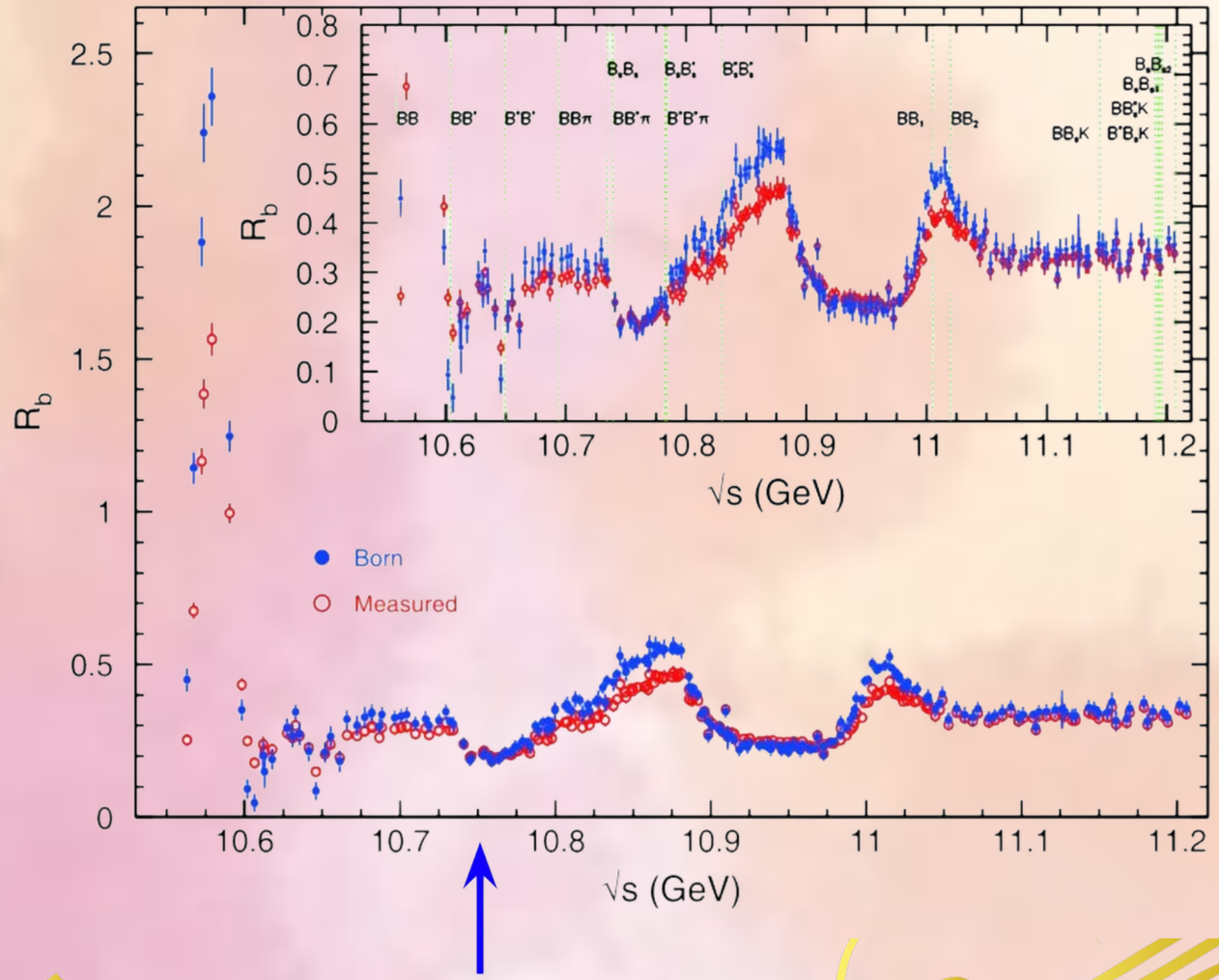


JHEP10 (2019) 220

Energy scan data: Y(10753) aka Yb

rise in hadronic transition cross sections (resonance)

Y(10753): WHY IT'S IMPORTANT



$$R_b = \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

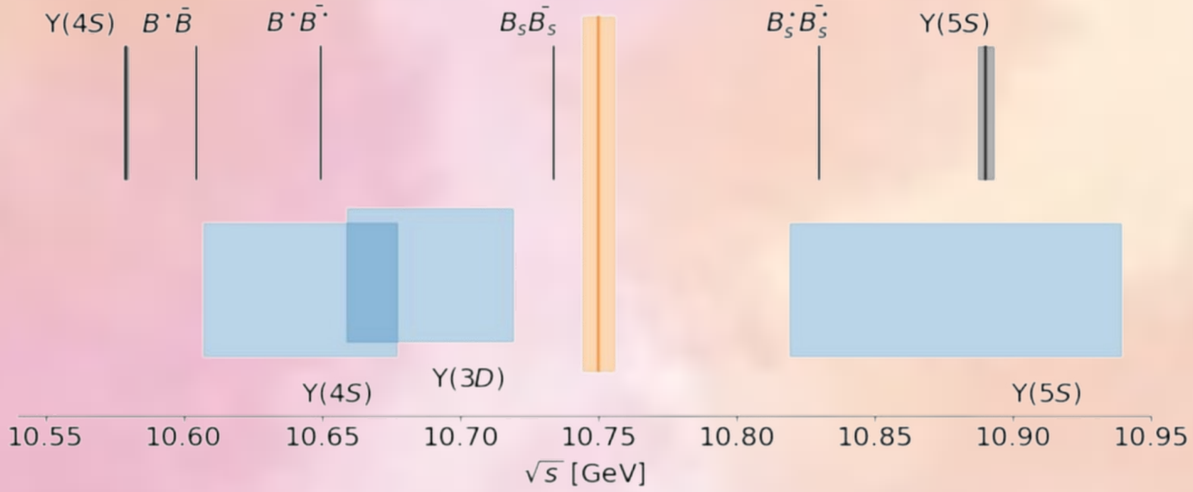
Dip likely caused by **interference** between BW and smooth component

[Chin. Phys. C 44 (2020) 8, 083001]

Y(10753): WHY IT'S IMPORTANT

Uncertain nature:

- No clear conventional $b\bar{b}$ candidate
- Y(4S)-Y(3D) mixing?
- Molecule?
- Tetraquark?



10.75 GeV ~ $Z_b(10610)\pi$ threshold

Conventional interpretations:

Chen, Zhang & He, PRD 101, 014020 (2020)
Giron & Lebed, PRD 102, 014036 (2020)
Li et al., EPJC 80, 59, (2020)
Li et al., PRD 104, 034036 (2021)
van Beveren & Oset, PPNP 117, 103845 (2021)
Bai et al., PRD 105, 074007 (2022)
Husken, Mitchell & Swanson, arXiv:2204.11915 (2022)
Kher et al., EPJ+ 137, 357 (2022)
Li, Bai & Liu, arXiv:2205.04049 (2022)
Liang, Ikeno & Oset, PLB 803, 135340 (2020)
...

Exotic interpretations:

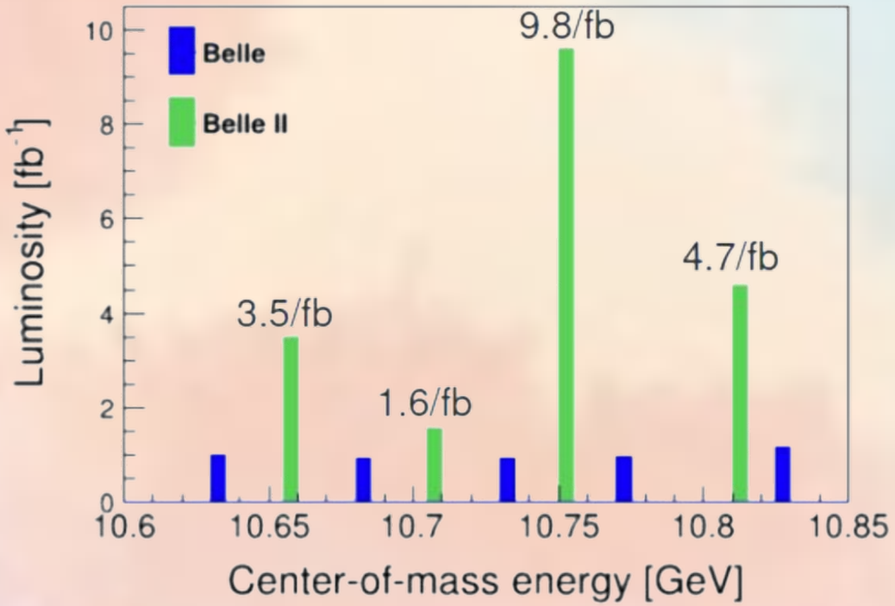
Wang, CPC 43, 123102 (2019)
Ali, Maiani, Parkhomenko & Wang, PLB 802, 135217 (2020)
Bicudo, Cardoso & Wagner, PRD 103, 074507 (2020)
Castella & Passemar, PRD 104, 034019 (2021)
...

ABOVE Υ(4S): NOV. 2021 ENERGY SCAN

Analyses at Υ(10753): limited luminosity requirement (~O(15 fb^{-1}))

The scan was successful: **19 fb^{-1}** collected at four E_{cm} points (between Belle's)

Belle: ~1 fb^{-1} per point



What are we doing with these data?

OBSERVATION OF $e^+e^- \to \omega X_{bJ}(1P)$ AND SEARCH FOR $X_b \to \omega \Upsilon(1S)$ AT $\sqrt{s}$ NEAR 10.75 GeV

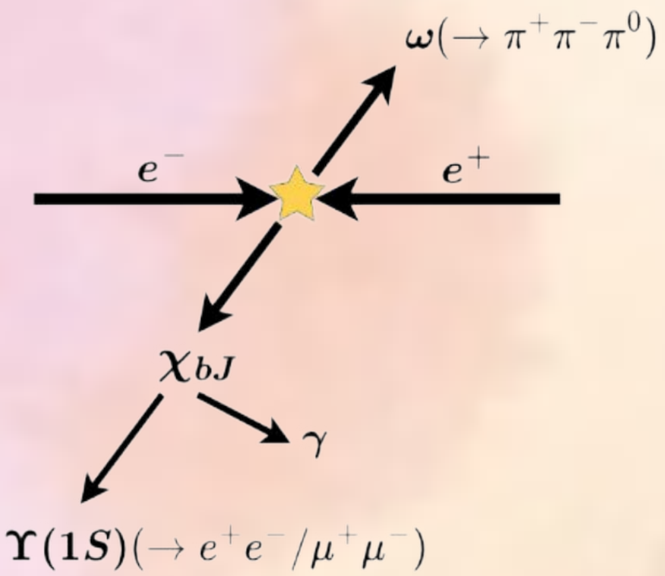
PRL 130 091902 (2023)

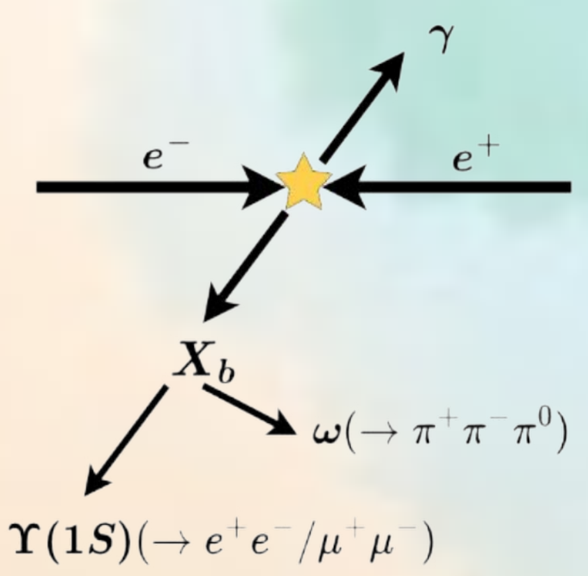
MOTIVATION

Predictions for the
4S-3D mixing
[PR D104 034036 (2021)] :

BR comparable with
$Y_b \to \pi^+\pi^- Y(nS)$

$$\frac{\mathcal{B}(\omega\chi_{b1})}{\mathcal{B}(\omega\chi_{b2})} \sim \frac{1}{5}$$





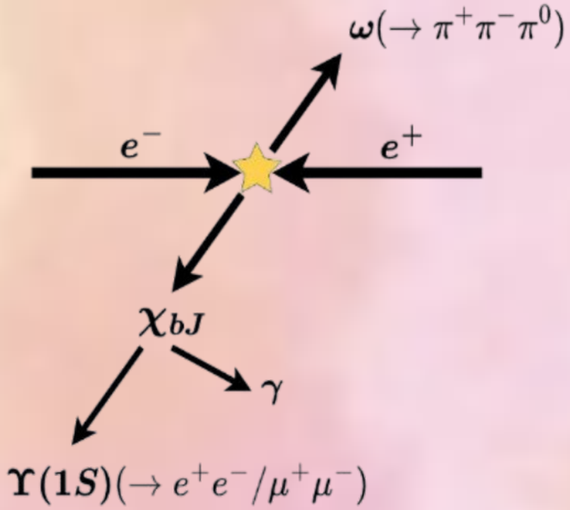
Same final state

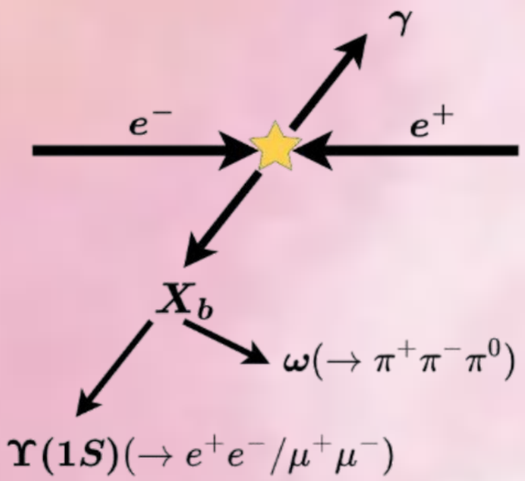
X_b predicted by molecular and tetraquark models

Analog of X(3872)

Production: analogous to
$e^+e^- \to Y(4220) \to \gamma X(3872) \to \gamma\omega\, J/\psi$

EVENT SELECTION



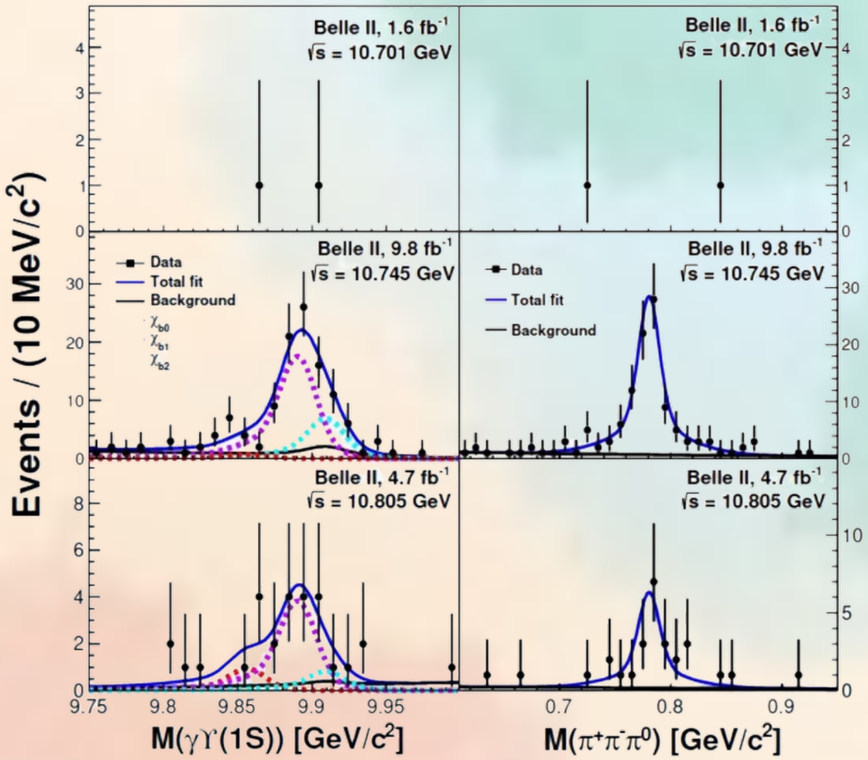


- 4 – 5 charged tracks
- standard Belle II PID (90 – 95% eff.)
- $E(\gamma) > 50$ MeV
- $105 < M(\gamma\gamma) < 150$ MeV/c^2 (90% eff.)
- bremsstrahlung and FSR correction
- 4C kinematic fit
- best candidate selection based on fit χ^2

Y(10753)→ $\omega X_{bJ}(1P)$: FIT TO SIGNAL YIELDS

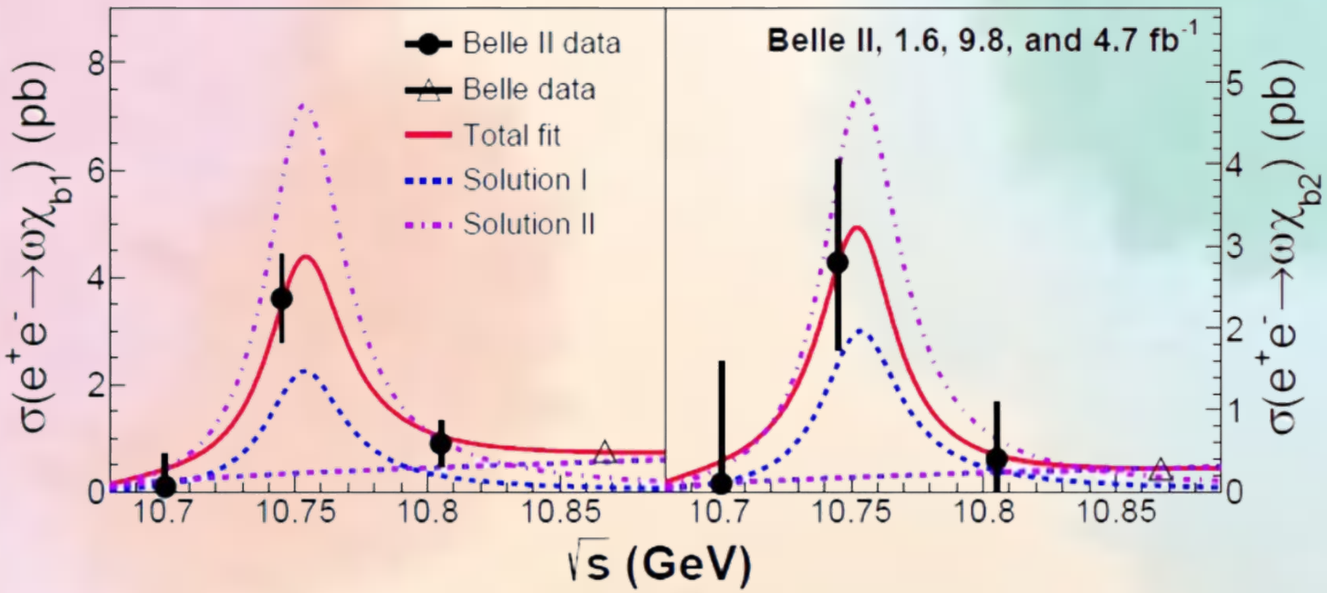
2D fit to M(γY(1S)) vs M($\pi^+\pi^-\pi^0$)
Model:
- signal (CB for χ_{bJ}, Voigt for ω) +
- peaking bkg (same) +
- comb. bkg

Channel	$\sqrt{s}$ (GeV)	N_{sig}	σ^B (pb)
$e^+e^- \to \omega\chi_{b0}$	10.701	$0.0^{+1.1}_{-0.0}$	<16.6
$e^+e^- \to \omega\chi_{b1}$		$0.0^{+2.1}_{-0.0}$	<1.2
$e^+e^- \to \omega\chi_{b2}$		$0.1^{+2.2}_{-0.1}$	<2.5
$e^+e^- \to \omega\chi_{b0}$	10.745	$3.0^{+5.5}_{-4.7}$	<11.3
$e^+e^- \to \omega\chi_{b1}$		$68.9^{+13.7}_{-13.5}$	$3.6 \pm 0.7 \pm 0.5$
$e^+e^- \to \omega\chi_{b2}$		$27.6^{+11.6}_{-10.0}$	$2.8^{+1.2}_{-1.0} \pm 0.4$
$e^+e^- \to \omega\chi_{b0}$	10.805	$3.6^{+3.8}_{-3.1}$	<11.4
$e^+e^- \to \omega\chi_{b1}$		$15.0^{+6.8}_{-6.2}$	<1.7
$e^+e^- \to \omega\chi_{b2}$		$3.3^{+5.3}_{-3.8}$	<1.6



Peaks on $\chi_{b1,2}(1P)$ | Peaks on ω

$\Upsilon(10753) \to \omega X_{bJ}(1P)$: FIT TO σ^B



Triangle in plot: Belle result

Now we can see that the **peak is at 10.75 GeV**

No clear peak at 10.860 GeV (aka Y(5S))

Fixed parameters:

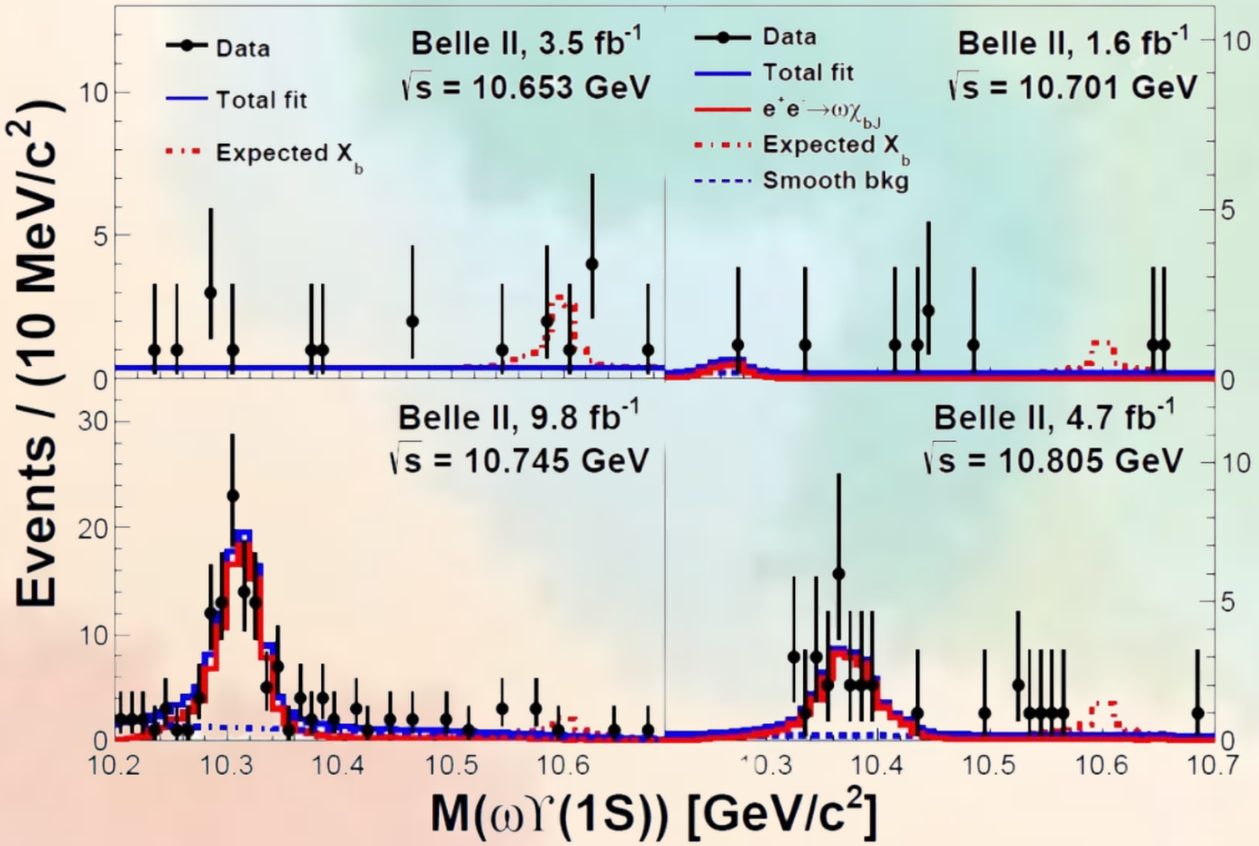
- mass = 10752.7 MeV
- width = 35.5 MeV

SEARCH FOR $X_b \to \omega\Upsilon(1S)$

- Search for resonances in M(ωΥ(1S))
- Reflection from Υ(10753) → ωχ_{bJ}(1P)
- No evidence for X_b signal

⇒ Upper limit to σ_{Xb}

$\sqrt{s}$ (GeV)	M_{X_b} (GeV)	$\sigma^{UL}_{X_b}$ (pb)
10.653	10.59	0.55
10.701	10.45	0.84
10.745	10.45	0.14
10.805	10.53	0.47



MEASUREMENT OF THE ENERGY DEPENDENCE OF THE $e^+e^- \to B\overline{B},\ B\overline{B}^*,\ B^*\overline{B}^*$ CROSS SECTIONS

MOTIVATION

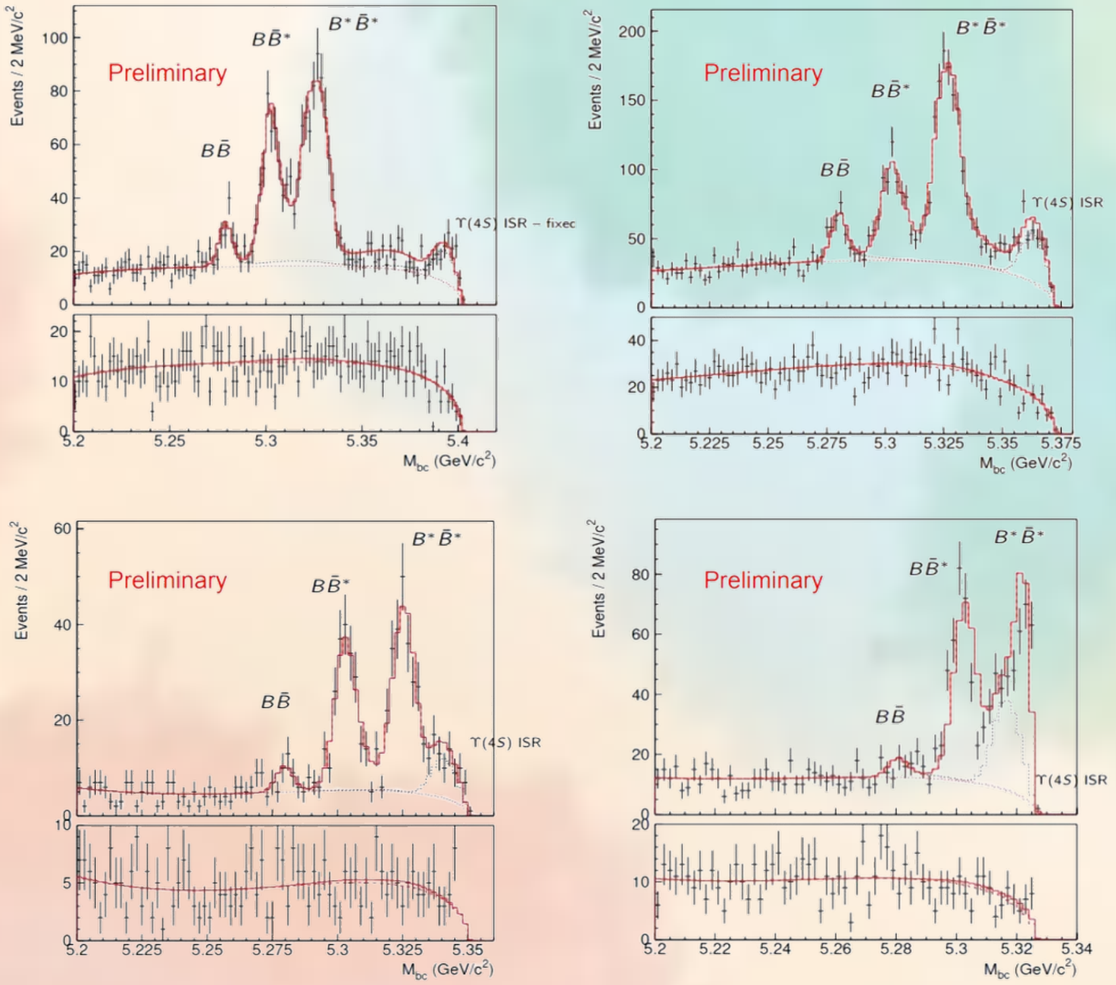
All $b\bar{b}$ above $B\overline{B}$ threshold exhibit anomalous properties

Broad Belle II program to measure exclusive cross sections

Method:

- fully reconstruct one B in had decays
- identify signals with M_{bc}
- combine with Belle measurement [JHEP 06, 137 (2021)]

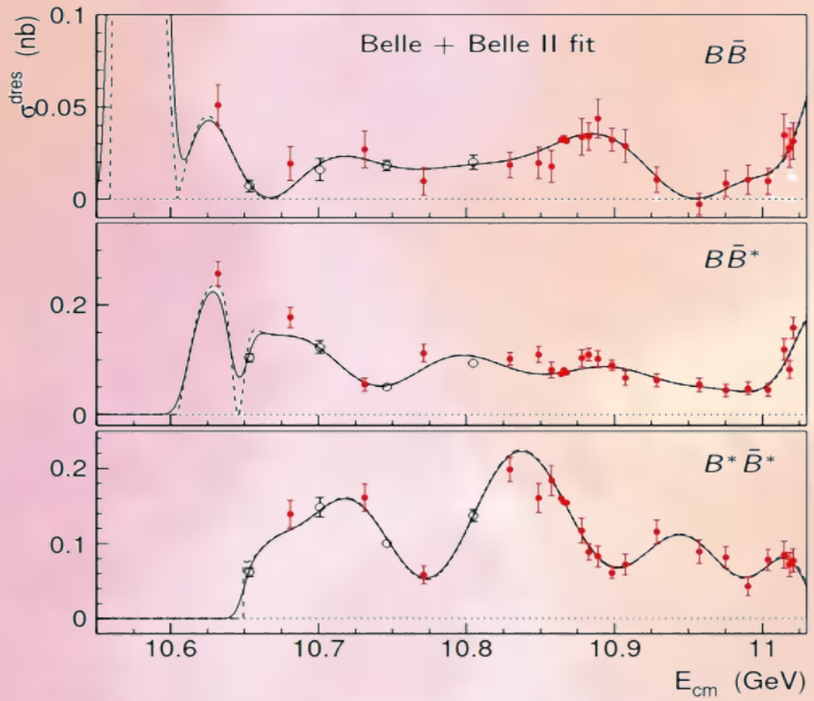
$$M_{\mathrm{bc}} = \sqrt{(E_{\mathrm{cm}}/2)^2 - p_B^2}$$

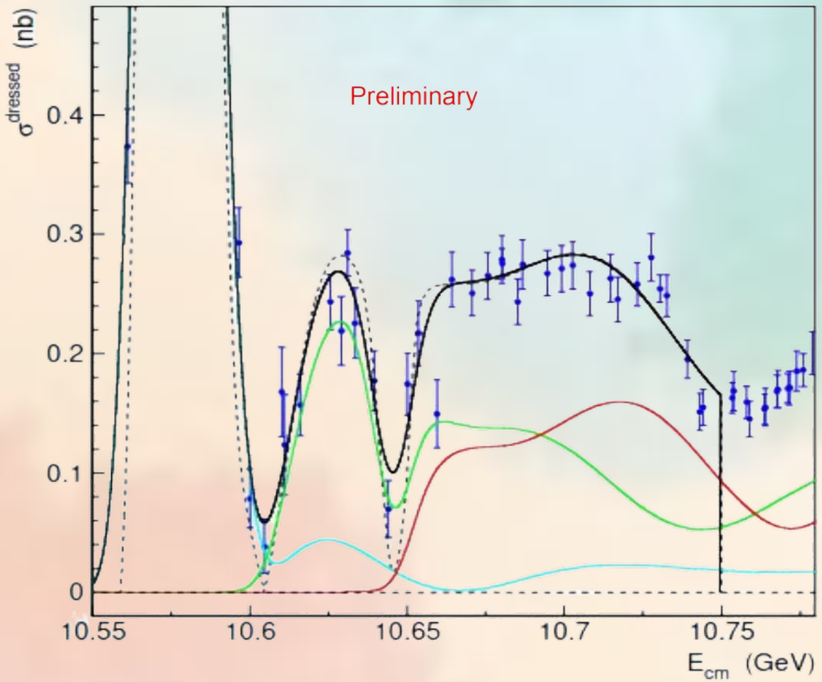


FIT TO CROSS SECTION VS E_{cm}

Fits to both exclusive and total σ

Preliminary





Y(10753) SCAN @BELLE II: THE FUTURE

Golden Modes
$e^+e^- \to \pi^+\pi^-\Upsilon(pS)(\to \ell^+\ell^-)$
$B\overline{B}$ decomposition
$\pi^+\pi^-$ Dalitz
$Y_b \to \omega\eta_b(1S)$
$Y_b \to \omega\chi_{bJ}(1P)$
Silver Modes
$Y_b \to \pi^+\pi^- X$ (inclusive)
$Y_b \to \eta X$ (inclusive)
$Y_b \to \eta\Upsilon(1S, 2S)(\to \ell^+\ell^-)$
$Y_b \to \eta'\Upsilon(1S)(\to \ell^+\ell^-)$
$Y_b \to \Upsilon(1S)$ (inclusive)
Bronze Modes
$Y_b \to \gamma X_b$
$Y_b \to \pi^0\pi^0\Upsilon(pS)(\to \ell^+\ell^-)$
$Y_b \to KK(\phi)\Upsilon(pS)(\to \ell^+\ell^-)$
$Y_b \to \pi^0\pi^0 X$ (inclusive)
$Y_b \to \pi^0 X$ (incl. or excl.)
...

- Reconstruction of hadronic/EM transitions
- Branching ratio measurement
- Cross sections vs. E_{cm} measurement
- Precise decomposition of the R_b ratio
- Systematic exploration of threshold regions
- Search for new exotic states

SUMMARY

We are at the beginning of a rich quarkonium physics program

Belle II collected unique data near E_{cm} ~ 10.75 GeV

- Unique quarkonium production at SuperKEKB
- Resonant transition $\Upsilon(10753) \rightarrow \omega\chi_{bJ}(1P)$ observed for the 1st time
- No evidence for X_b
- Preliminary results on σ vs E_{cm}

Many ongoing analyses on 4S and scan data!