Recent quarkonium results from Belle and Belle II

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on behalf of the Belle and Belle II collaborations

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Outline

Belle II analysis

- $e^+e^- \to \omega\chi_{bJ}(1P)$ and $X_b \to \omega\Upsilon(1S)$
- $e^+e^- \to B\bar{B}, B\bar{B}^*$ and $B^*\bar{B}^*$

Belle analysis

- $e^+e^- \to B_s^0\bar{B}_s^0X$

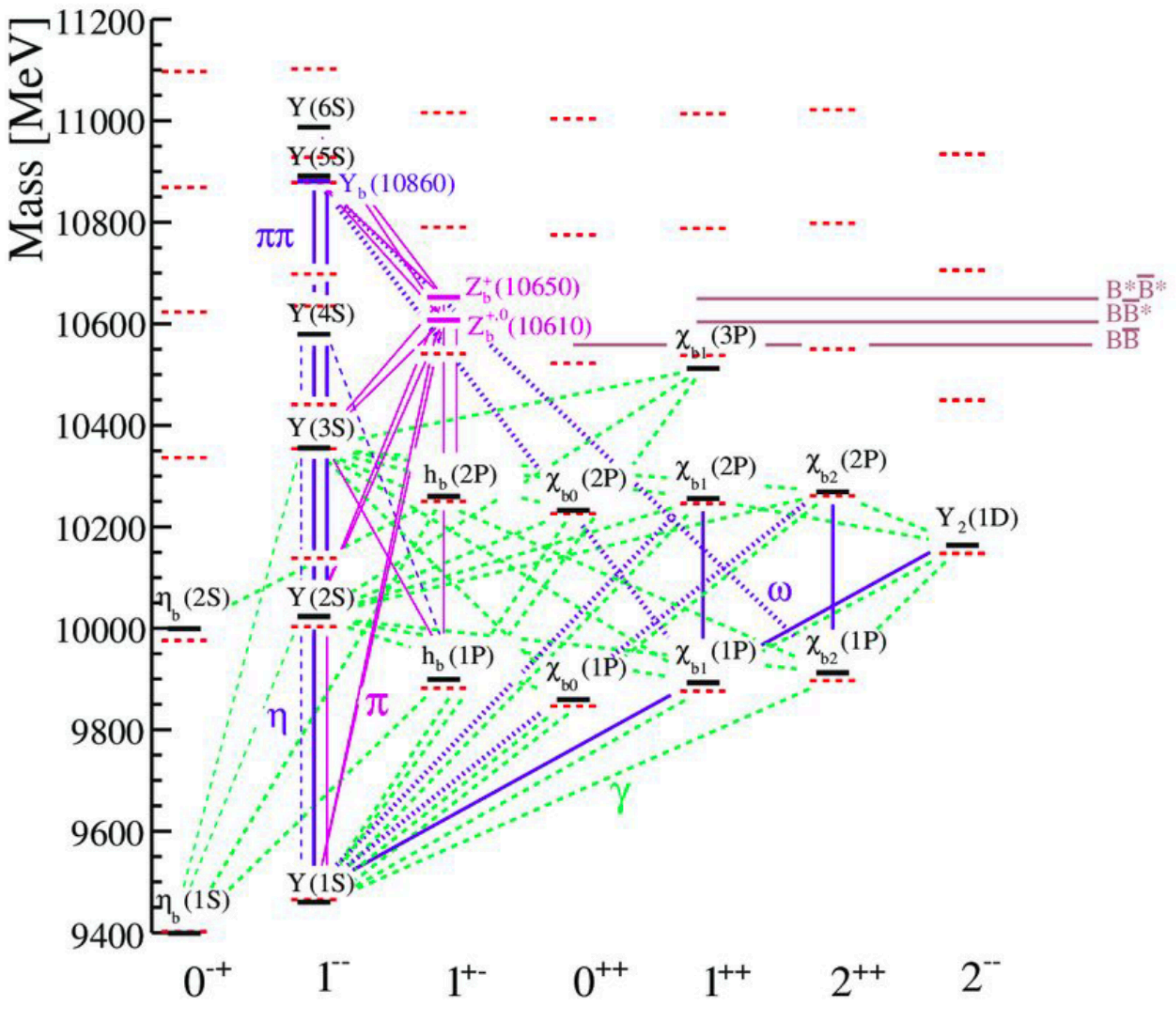
Bottomonium spectroscopy

Heavy quarkonium spectroscopy is an excellent laboratory to study non-perturbative QCD

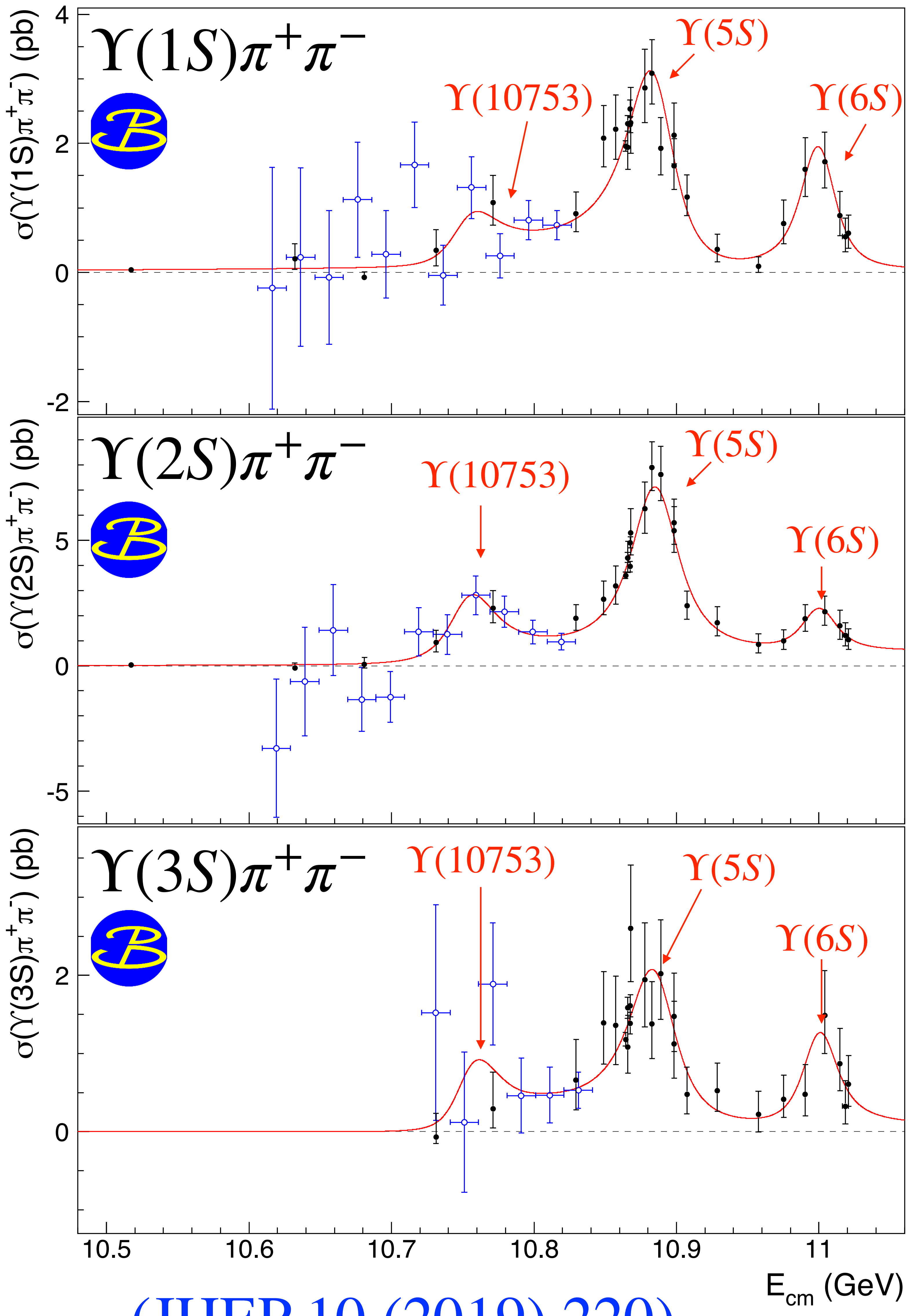
Bottomonium states below $B\bar{B}$ threshold are well described by quark model

Bottomonium states above $B\bar{B}$ threshold demonstrate unexpected properties

- Z_b and Z_b' are charged (at least 4 quarks)
- Rates of hadronic transition to lower bottomonia are higher then expected for pure $b\bar{b}$ (violate OZI)
- η transitions are not suppressed relative to dipion transitions (violate HQSS)



$\Upsilon(10753)$ state



(JHEP 10 (2019) 220)

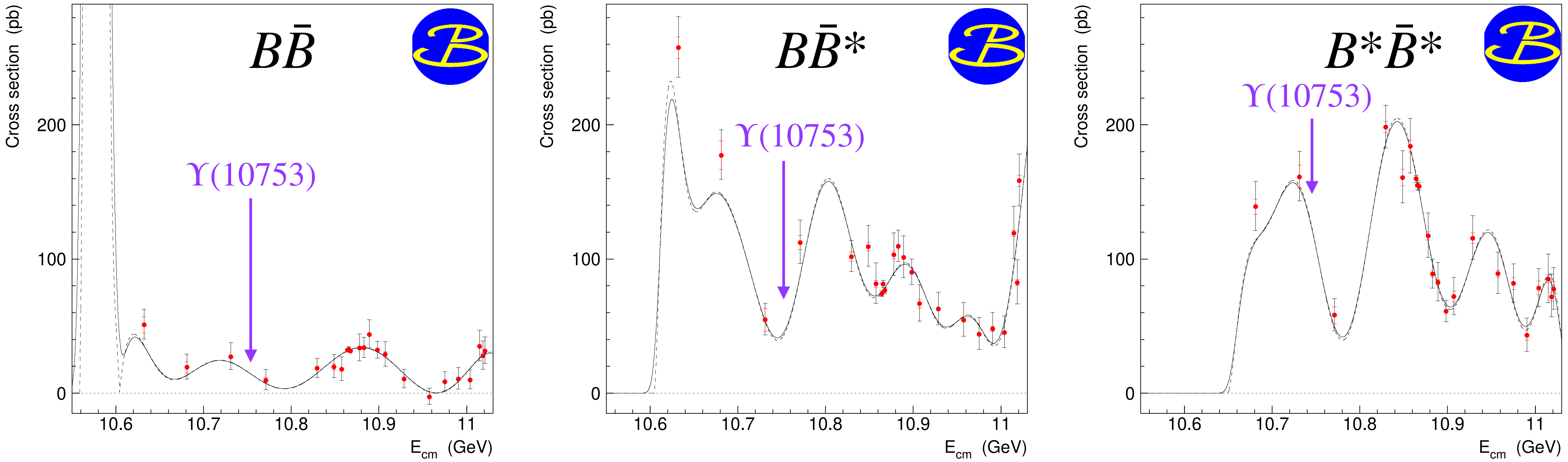
2019 — Belle (JHEP 10 (2019) 220):

Energy dependence of the $\sigma(e^+e^- \to \Upsilon(1,2,3S)\,\pi^+\pi^-)$

Observation of new structure — $\Upsilon(10753)$

	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

No clear peak in the $e^+e^- \to B\bar{B}, B\bar{B}^*$ and $B^*\bar{B}^*$ (JHEP 06 (2021), 137)



What is the nature of $\Upsilon(10753)$?

Various theoretical interpretations:

- **Conventional $b\bar{b}$ state:**

Phys.Rev.D 105, 074007 (2022), Phys.Rev.D 104, 034036 (2021), Eur.Phys.J.C 80 (2020) 1, 59, Phys.Rev.D 101, 014020 (2020), Phys.Rev.D 102, 014036 (2020), Eur.Phys.J.Plus 137, 357 (2022), Phys.Rev.D 105 (2022) 11, 114041, Phys.Lett.B 803, 135340 (2020), Phys.Rev.D 106 (2022) 9, 094013, Prog. Part. Nucl. Phys. 117, 103845 (2021), …

- **Tetraquark:**

Phys.Lett.B 802, 135217 (2020), Phys.Rev.D 103, 074507 (2021), arXiv:2205.11475, Chin. Phys. C 43, 123102 (2019), …

- **Hybrid:**

Phys.Rev.D 104, 034019 (2021), Phys. Rept. 873, 1 (2020), …

$\Upsilon(10753)$ as $\Upsilon(3D)$ state:

- width is consistent with predictions (see e.g. Eur. Phys. J. C 78, 915 (2018))
- mass does not match existing theoretical predictions
- D-wave state is not seen in e^+e^-

$\Upsilon(4S) - \Upsilon(3D)$ mixing scheme:

Phys. Rev. D 104, 034036 (2021) predictions

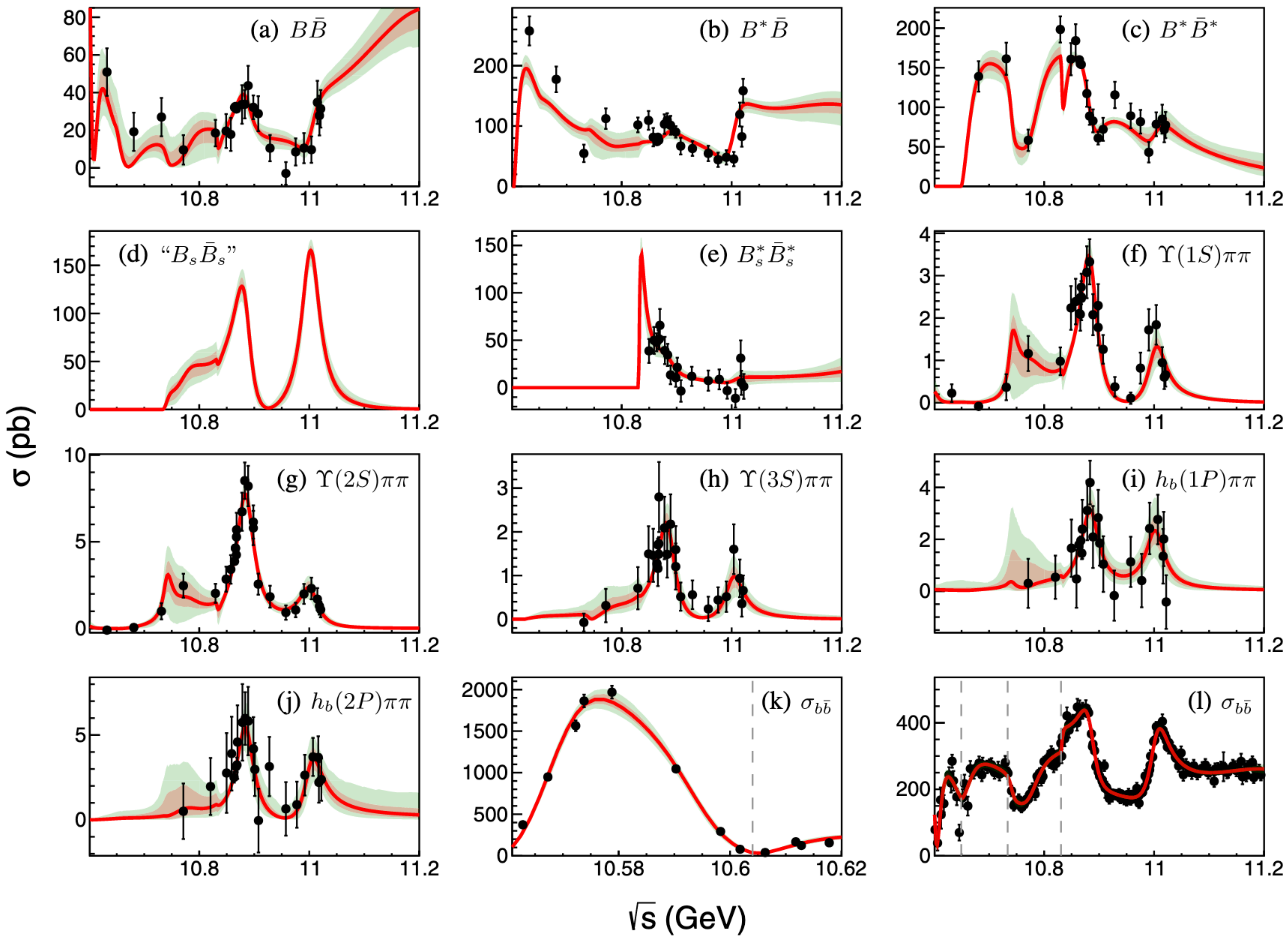
Channel	Branching fraction $(\times 10^{-3})$
$\Upsilon(10753) \to \omega\chi_{b0}$	0.73 – 6.94
$\Upsilon(10753) \to \omega\chi_{b1}$	0.25 – 2.16
$\Upsilon(10753) \to \omega\chi_{b2}$	1.08 – 11.5

Such decays could be observed at Belle II

Global phenomenological analysis

see Eric Swanson's talk on Wednesday

N. HÜSKEN, R. E. MITCHELL, and E. S. SWANSON PRD 106 (2022) 9, 094013



Used data:

$B\bar{B}, B^*\bar{B}, B^*\bar{B}^*, B_s^*\bar{B}_s^*, \Upsilon(1S)\pi^+\pi^-, \Upsilon(2S)\pi^+\pi^-, \Upsilon(3S)\pi^+\pi^-, h_b(1P)\pi^+\pi^-, h_b(2P)\pi^+\pi^-$, and $\sigma_{b\bar{b}}$

Poles for:

$\Upsilon(4S), \Upsilon(10750), \Upsilon(5S), \Upsilon(6S)$

Note:

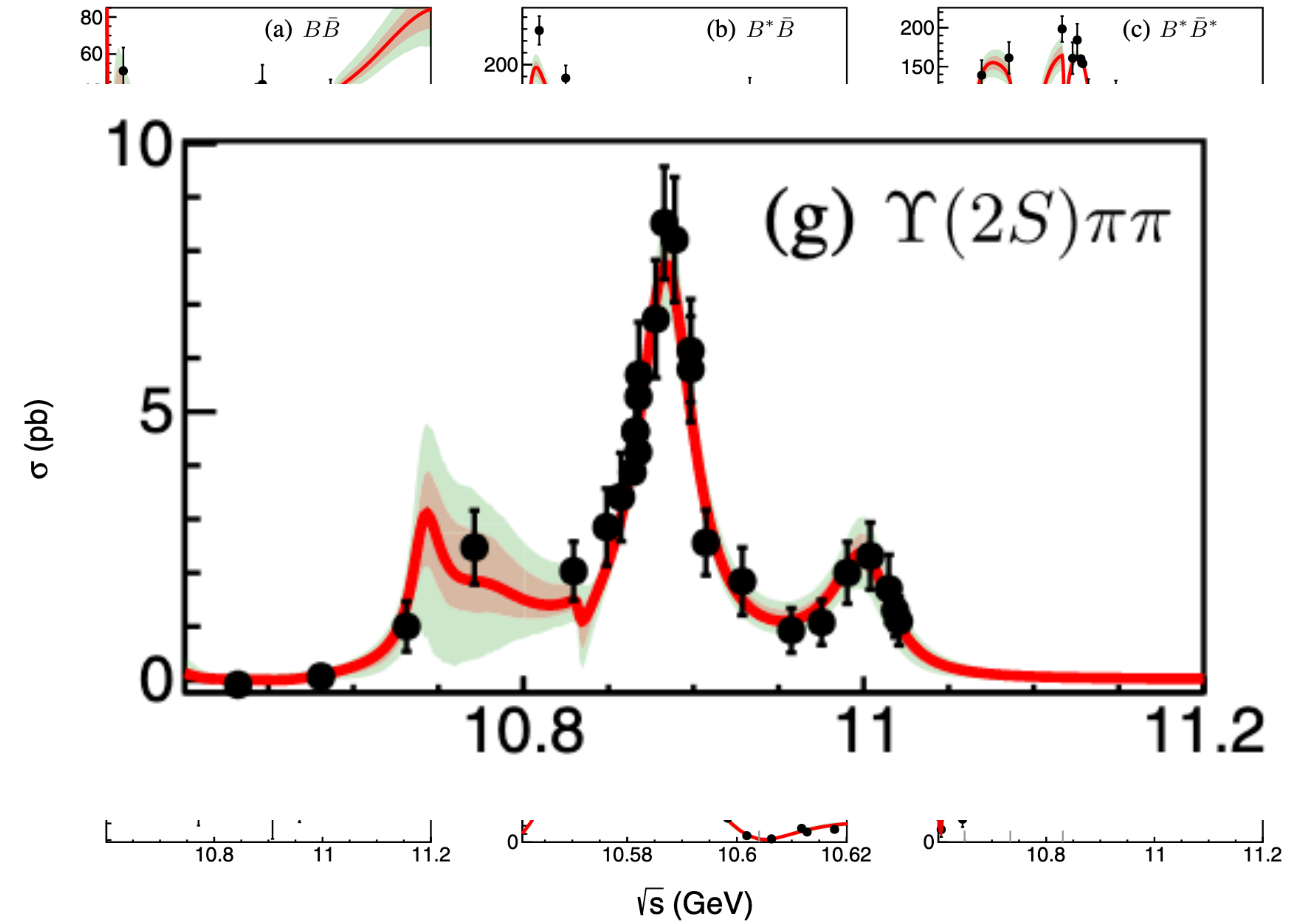
fit to the two-body data only also required $\Upsilon(10750)$

Indirect confirmation of the $\Upsilon(10750)$

Global phenomenological analysis

N. HÜSKEN, R. E. MITCHELL, and E. S. SWANSON

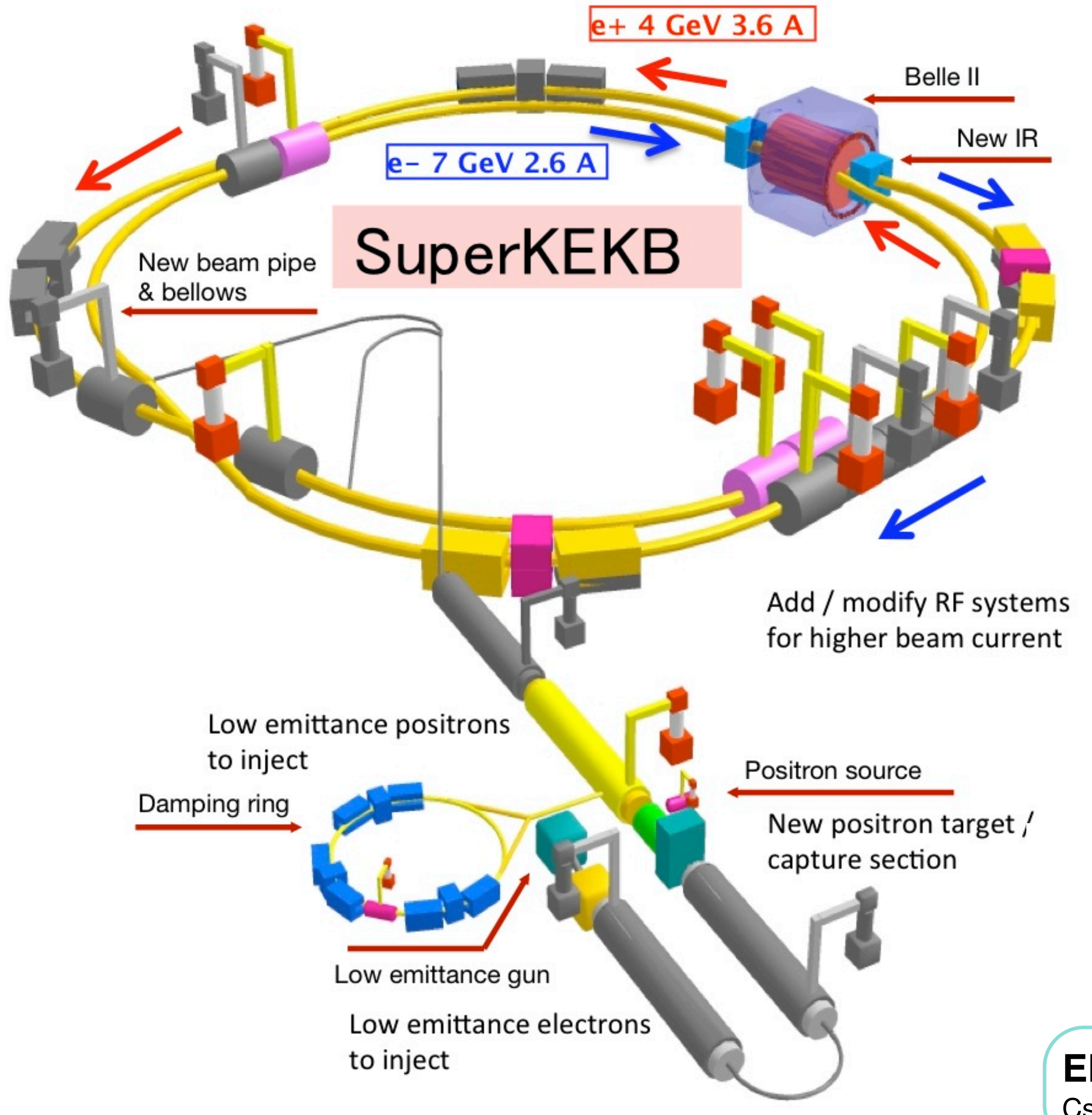
PRD 106 (2022) 9, 094013



Large gaps between scan points near 10.75 GeV

Large uncertainty in the scattering amplitudes in this energy region

More data is needed

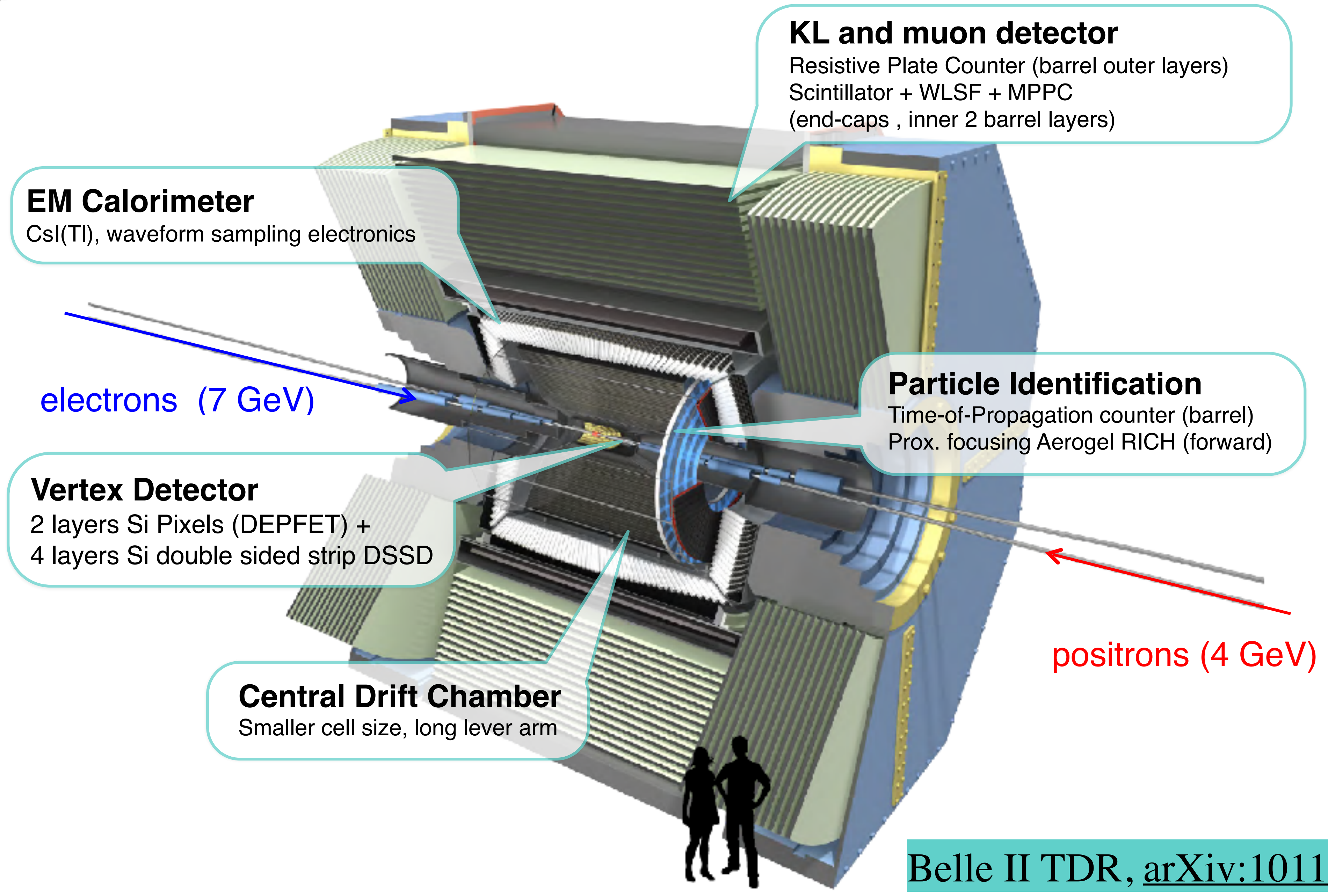


SuperKEKB:

- Asymmetric e+e− collider at KEK (Tsukuba, Japan);
- $\int \mathscr{L} dt = 424\ \text{fb}^{-1}$ collected up to now ($\sim$ BaBar, ~ 0.5 Belle);
- E_{cm} around $\Upsilon(4S)$ mass + energy scan

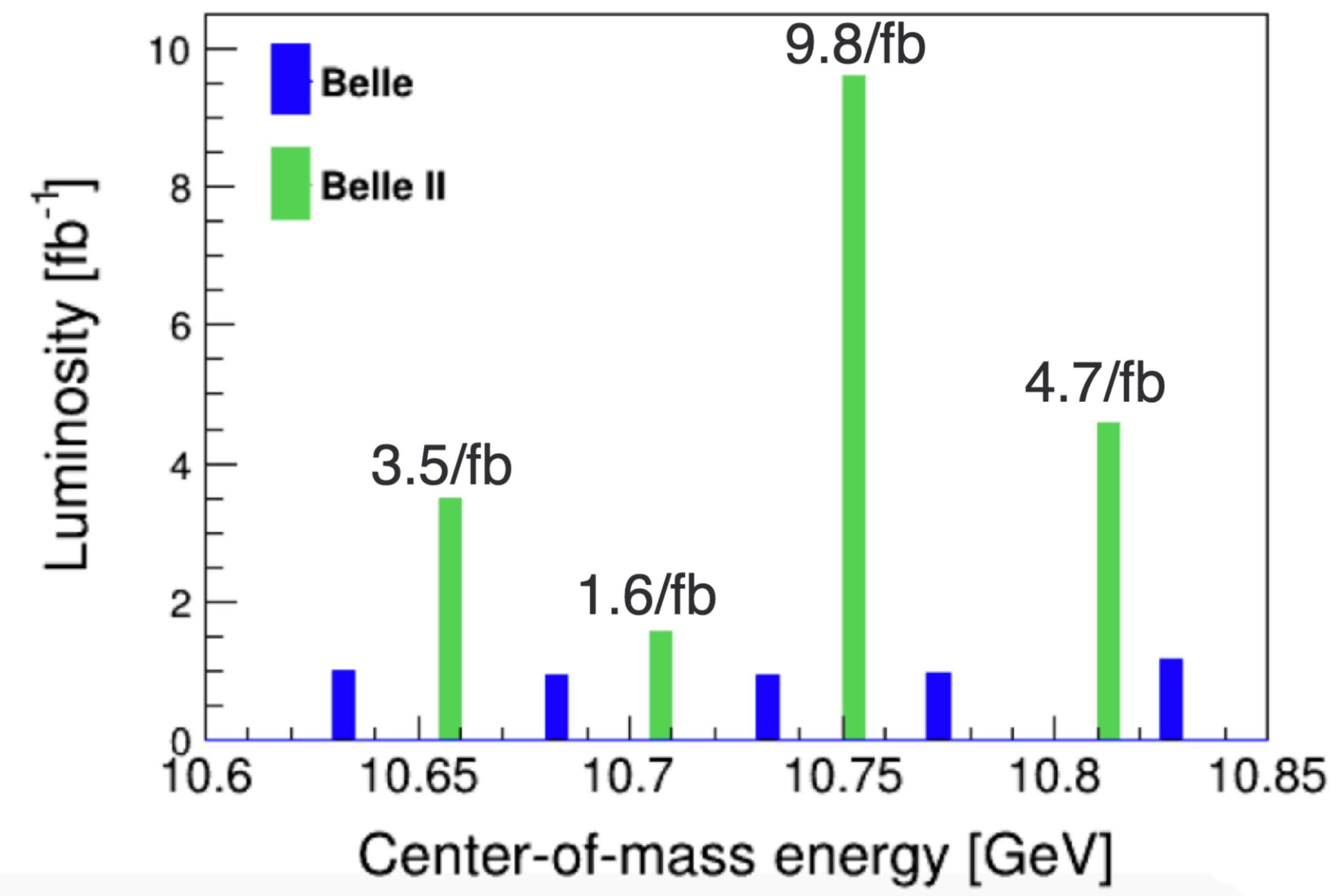
Belle II detector upgrade:

- 4π spectrometer with optimal vertexing, tracking, PID and calorimeter capabilities
- Rich physics program



Belle II TDR, arXiv:1011.0352

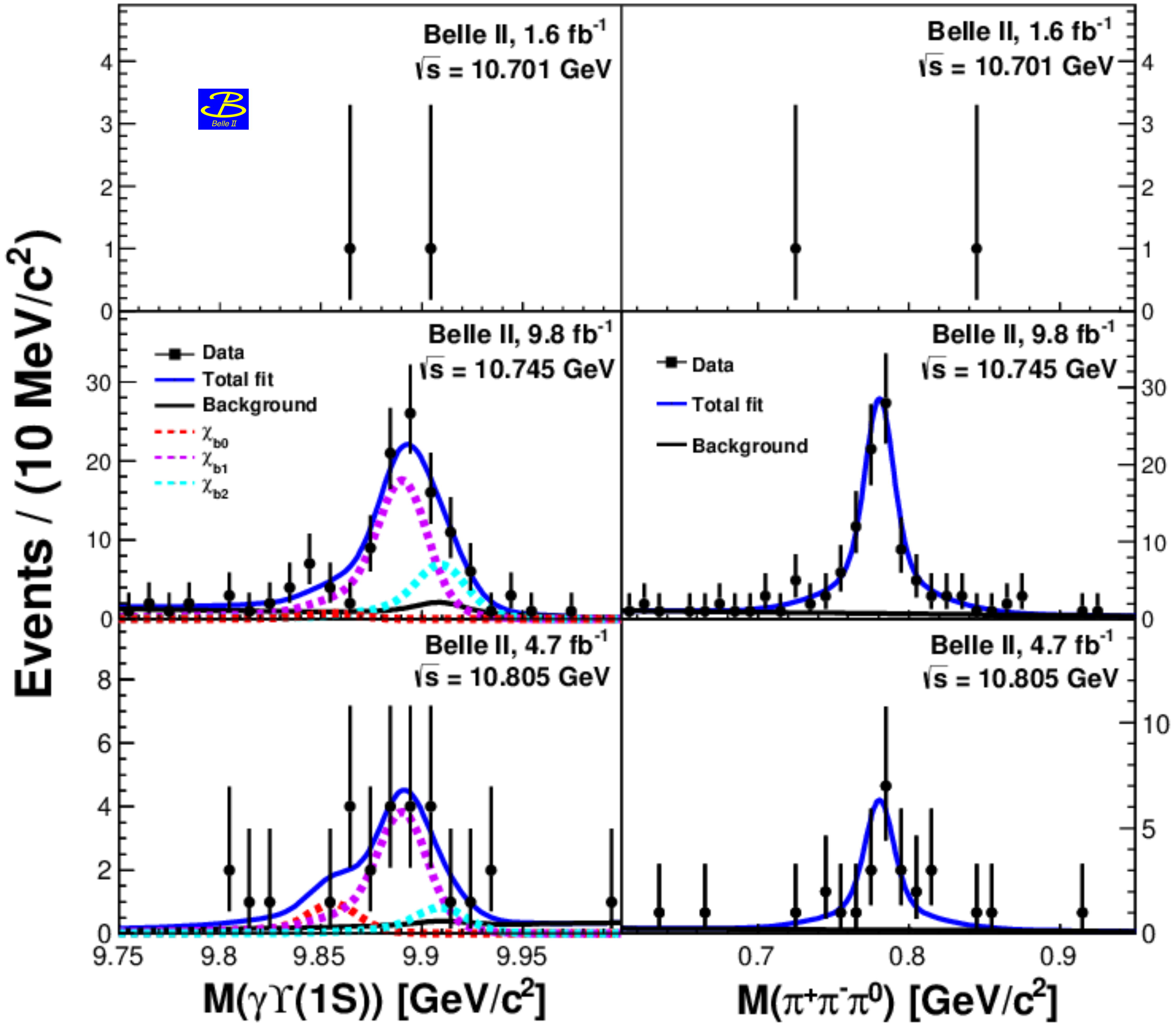
High statistical points between previous Belle energies:



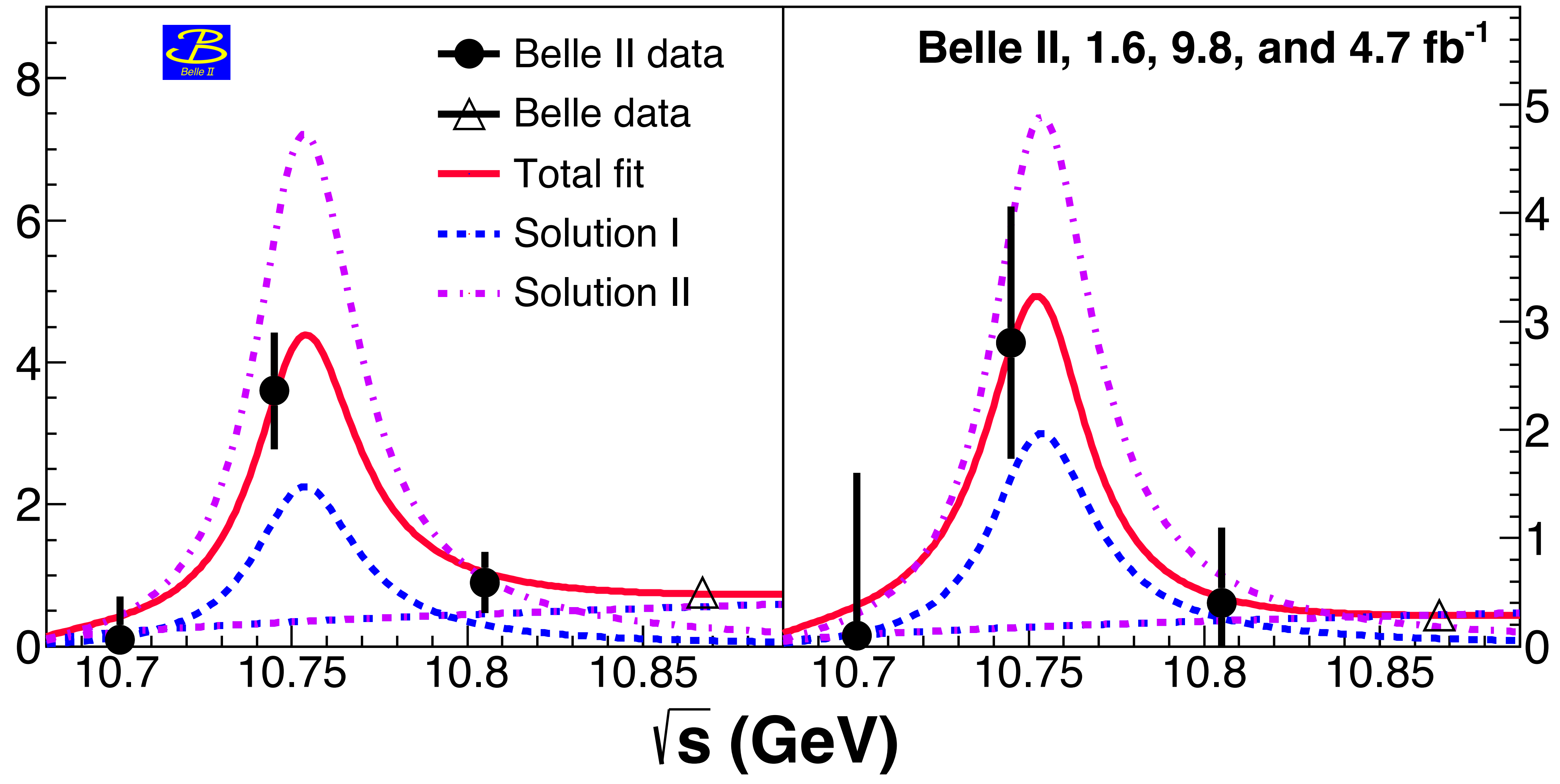
Observation of $e^+e^- \to \omega\chi_{bJ}(1P)$ at $\sqrt{s}$ near 10.75 GeV

(PRL 130 091902 (2023))

2D unbinned likelihood fit



Born cross sections from signal yield



Belle @ $\sqrt{s} = 10.867$ GeV: PRL 113 (2014) 14, 142001

$\sigma(e^+e^- \to \omega\chi_{b1}) = (0.76 \pm 0.16)$ pb

$\sigma(e^+e^- \to \omega\chi_{b2}) = (0.29 \pm 0.14)$ pb

first observation of $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$

no peak at $\Upsilon(10860)$

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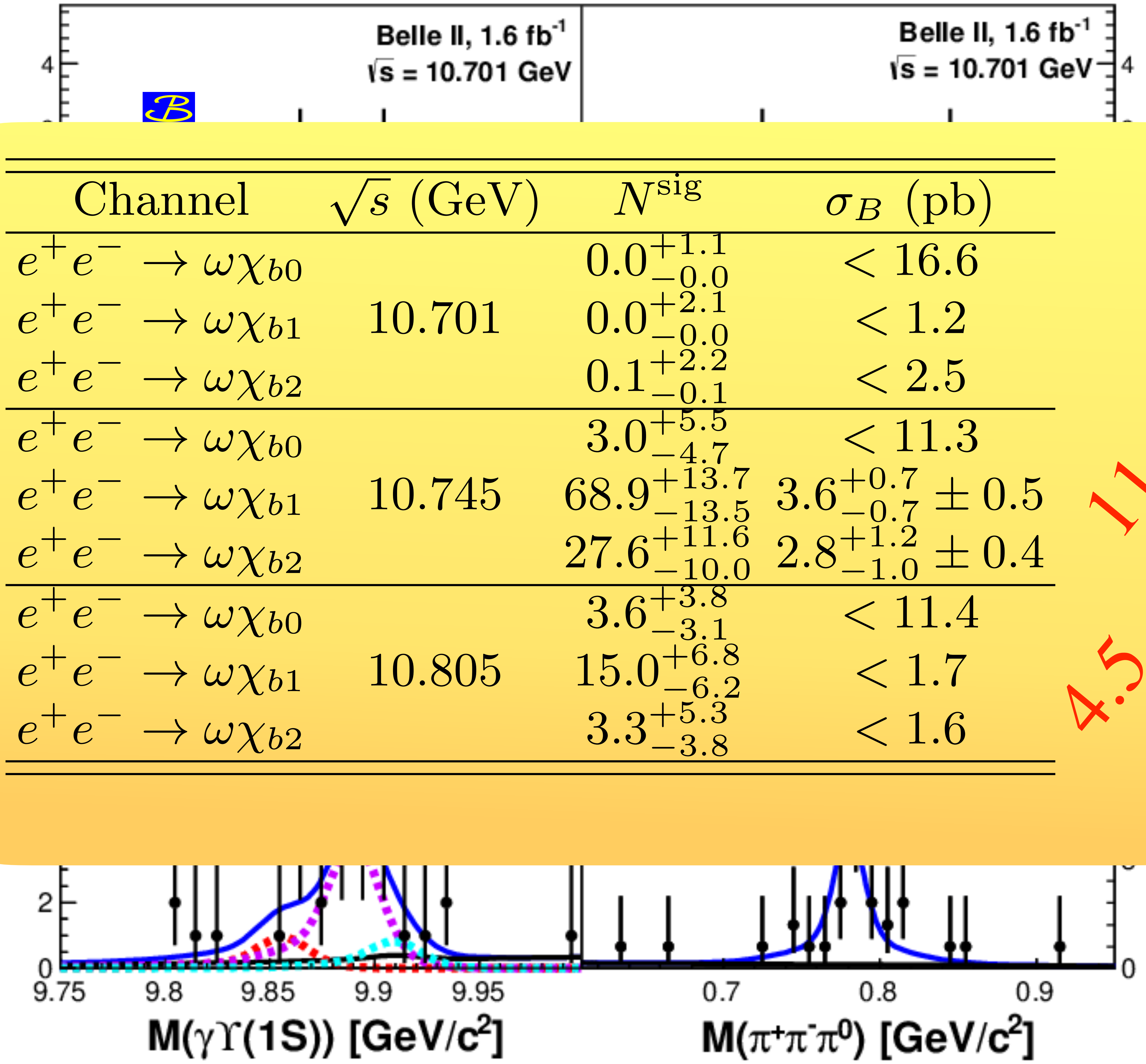
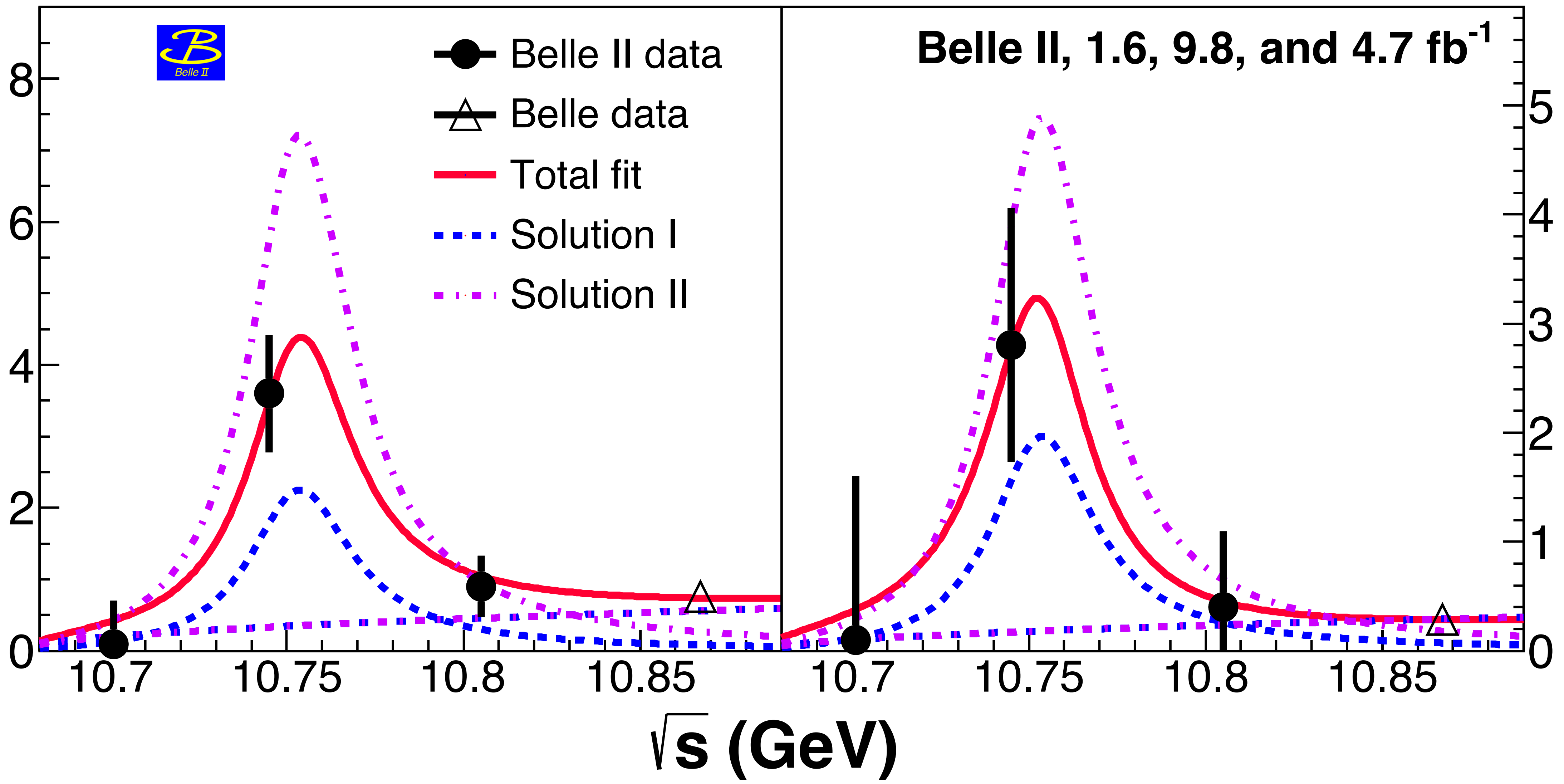


Channel	$\sqrt{s}$ (GeV)	$N^{\rm sig}$	σ_B (pb)
$e^+e^- \to \omega\chi_{b0}$		$0.0^{+1.1}_{-0.0}$	< 16.6
$e^+e^- \to \omega\chi_{b1}$	10.701	$0.0^{+2.1}_{-0.0}$	< 1.2
$e^+e^- \to \omega\chi_{b2}$		$0.1^{+2.2}_{-0.1}$	< 2.5
$e^+e^- \to \omega\chi_{b0}$		$3.0^{+5.5}_{-4.7}$	< 11.3
$e^+e^- \to \omega\chi_{b1}$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

11σ

4.5σ

Born cross sections from signal yield



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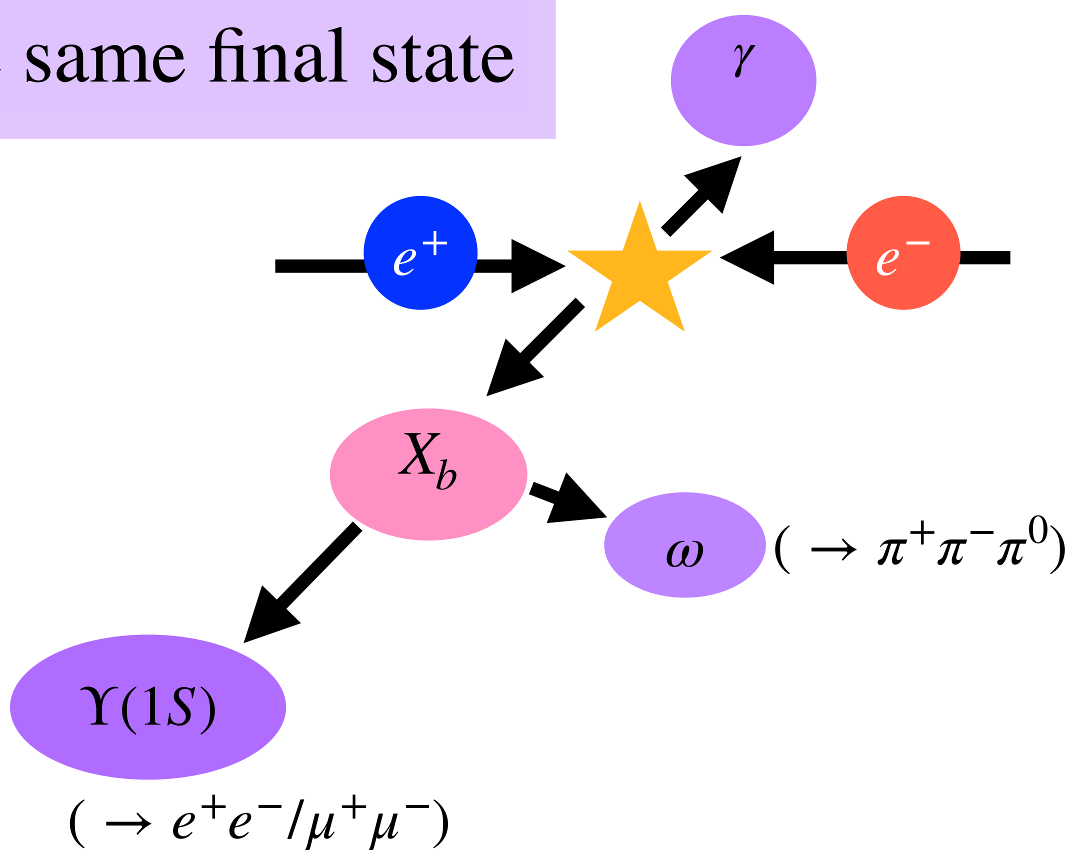
first observation of $\Upsilon(10753) \to \omega\chi_{bJ}(1P)$

no peak at $\Upsilon(10860)$

Search for X_b at $\sqrt{s}$ near 10.75 GeV (PRL 130 091902 (2023))

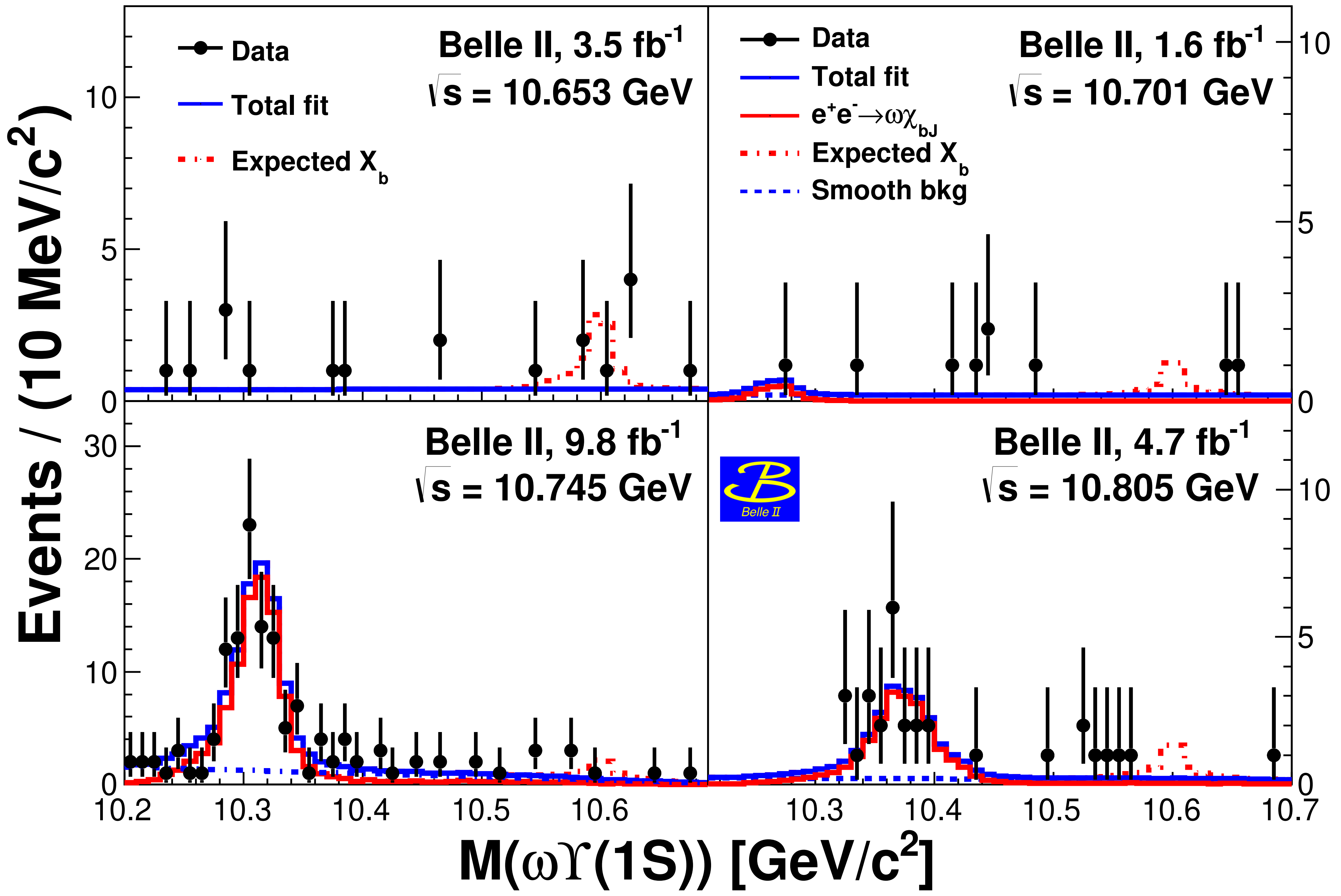
The same final state



X_b: bottomonium counterpart candidate of the X(3872) ?

Phys. Rev. Lett. 91, 262001 (2003)

Search for resonances in $M(\omega\Upsilon(1S))$:



- Reflection from $\Upsilon(10753) \to \omega\chi_{b1,2}$

  Shapes of $\Upsilon(10753) \to \omega\chi_{bJ}$ were taken from MC and normalised to data

- No significant X_b signal is observed

- Set upper limits with the Bayesian approach:

$\sqrt{s}$, GeV	$M(X_b)$, GeV/c^2	$\sigma^{UL}_{X_b}$, 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 $e^+e^- \to B\bar{B}, B\bar{B}^*$ and $B^*\bar{B}^*$ cross section at Belle II

Method

(Previous Belle analysis JHEP 06 (2021), 137)

Full reconstruction of one B meson in hadronic channels

γ from $B^* \to B\gamma$ is not reconstructed

Use $M_{\rm bc}$ to identify $B\bar{B}, B\bar{B}^*$ and $B^*\bar{B}^*$ final states

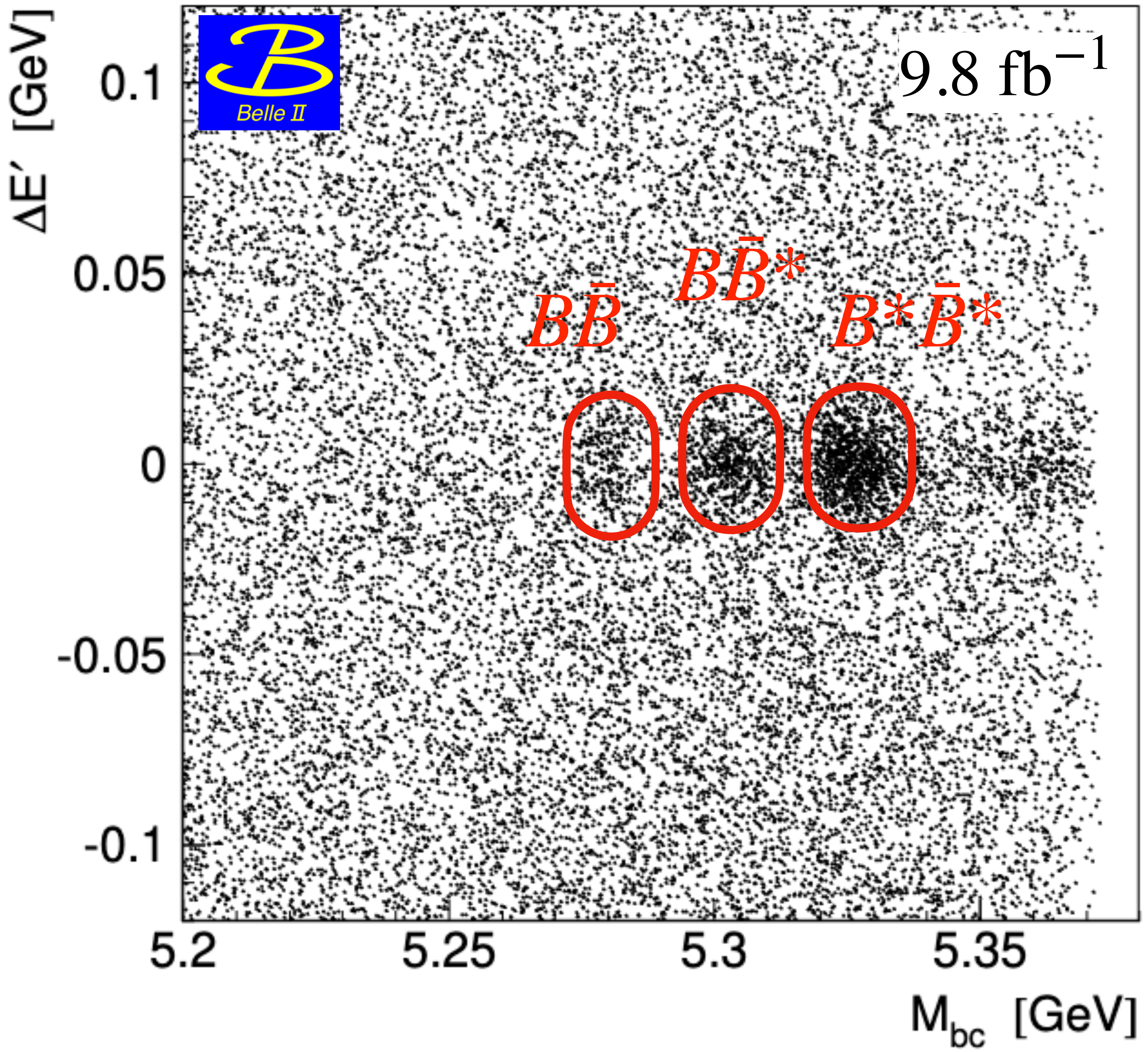
$$M_{\rm bc} = \sqrt{E_{\rm cm}^2/4 - p_B^2}$$

$$\Delta E = E_B - E_{\rm cm}/2$$

For convenience $\Delta E \to \Delta E'$

$$\Delta E' = \Delta E + M_{\rm bc} - m_B$$

The $\Delta E'$ *vs*. $M_{\rm bc}$ distributions in the $E_{\rm cm}$= 10.75 GeV data sample



M_{bc} fit at scan energies

- Good description of the data
- Distinct signals for different final states — BB, BB* and B*B*
- Visible contribution from $\Upsilon(4S)$ produced via ISR (included in the fitting function)
- Sharp cut of the data at right edge for E=10.653 GeV $\Longrightarrow$ fast rise of $B^*\bar{B}^*$ near threshold

$$B^{(*)}\bar{B}^{(*)} \quad \Longrightarrow \quad \sigma(B^{(*)}\bar{B}^{(*)})$$

Energy dependence of the cross sections

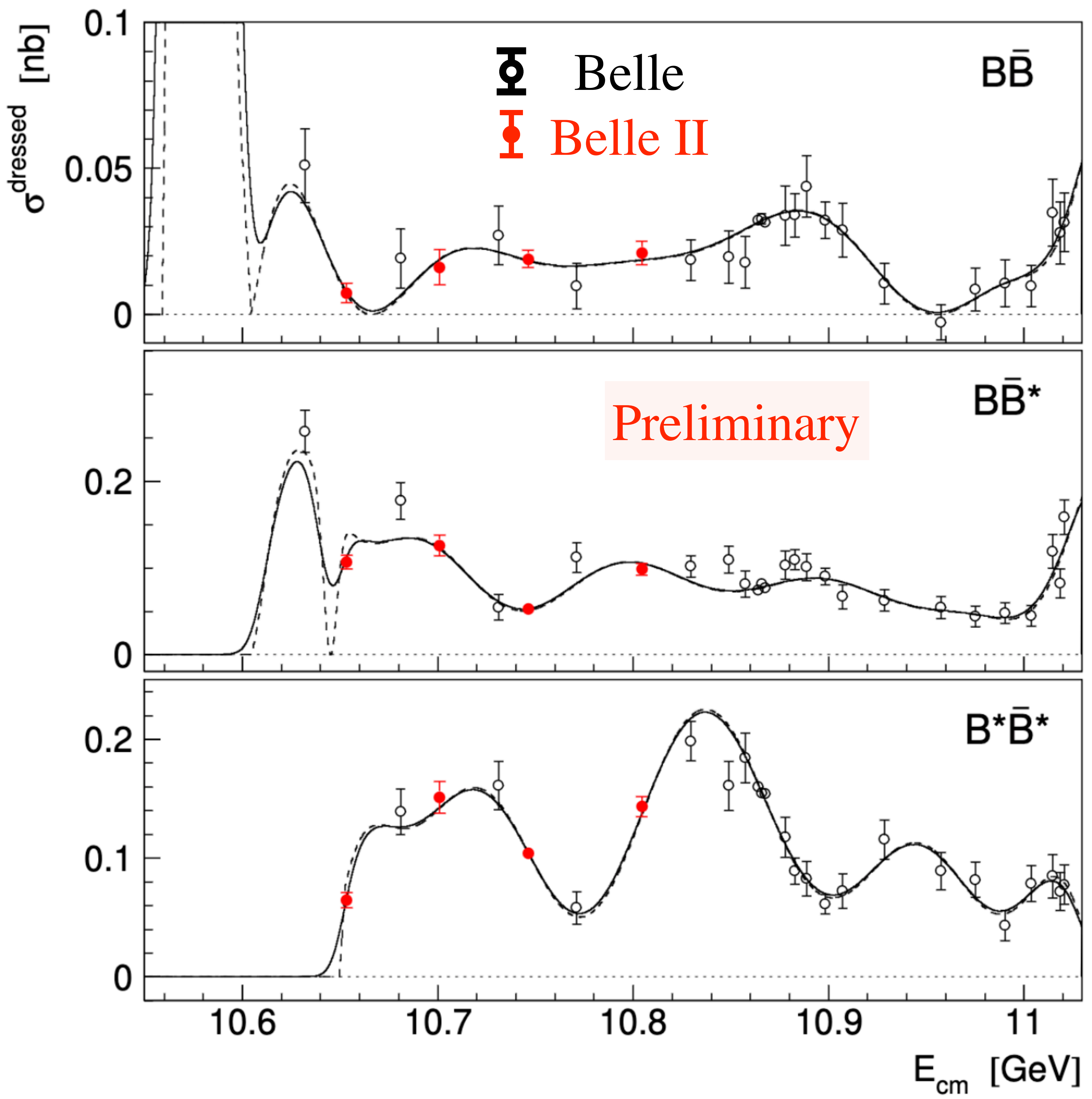
Combined Belle + Belle II:

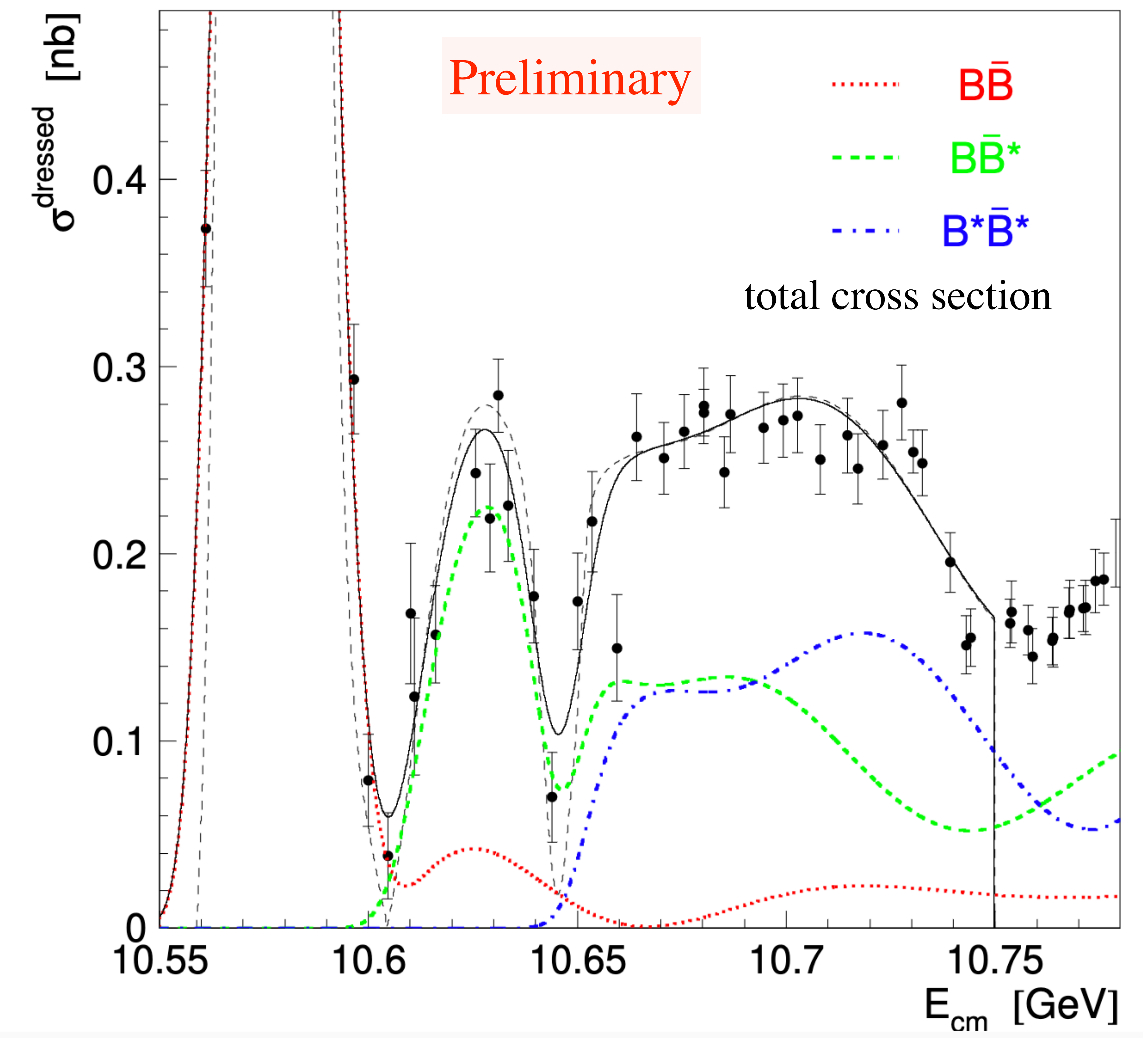
simultaneous fit to

- exclusive cross sections (previous Belle measurement JHEP 06 (2021), 137 + this work)

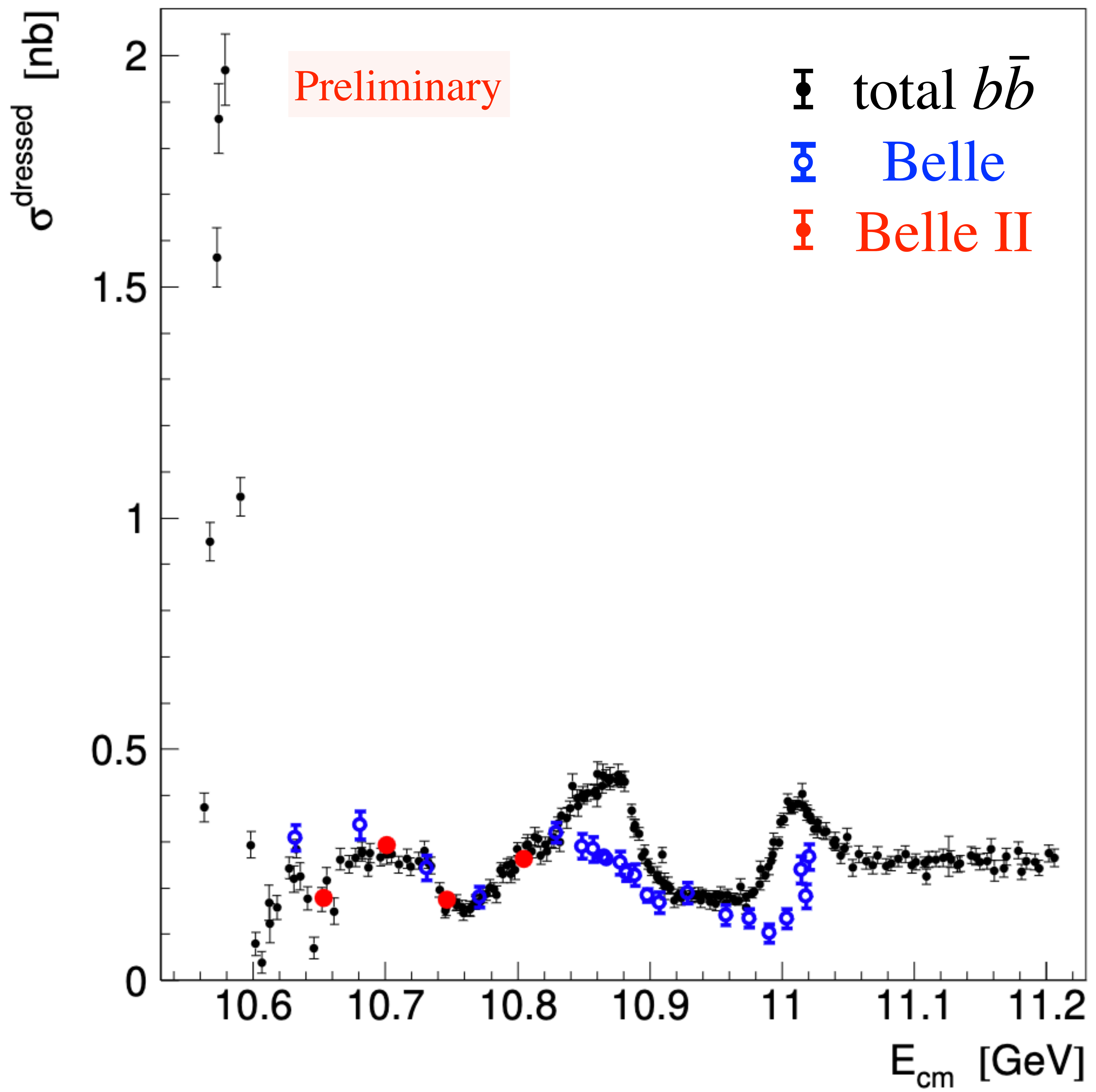
and

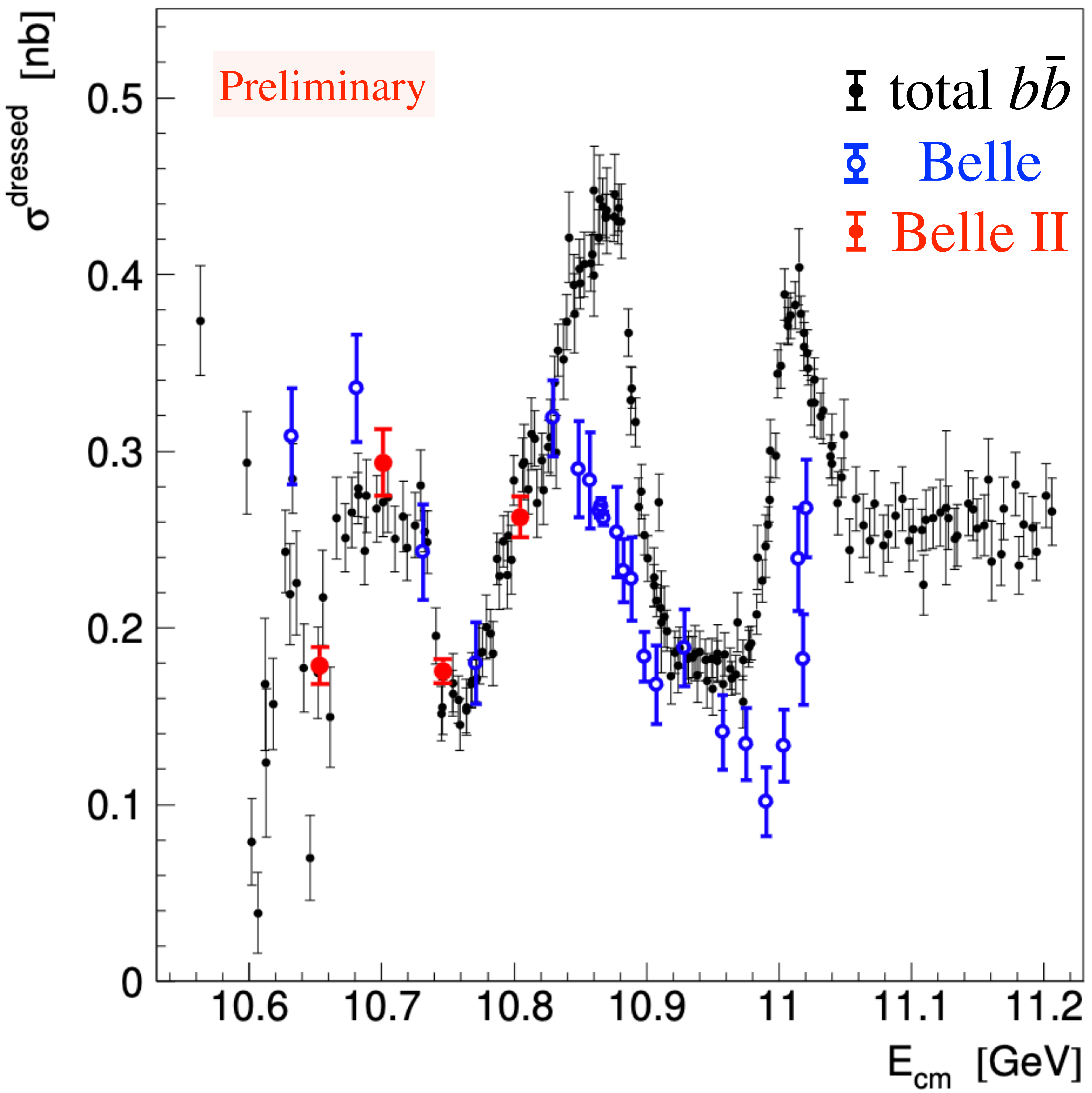
- total cross section (Chin.Phys.C 44 (2020) 8, 083001)





$\sigma_{b\bar{b}}$ vs $\sigma_{B\bar{B}} + \sigma_{B\bar{B}^*} + \sigma_{B^*\bar{B}^*}$





- In agreement at low energies — cross check
- Deviation at higher energy is due to $B_s^{(*)}$, multi-body $B^{(*)}\bar{B}^{(*)}\pi(\pi)$, and bottomonia

Discussion

New measurements significantly supplement previous Belle results
[JHEP 06 (2021), 137]

solid curve — fit to combined Belle+BelleII points,

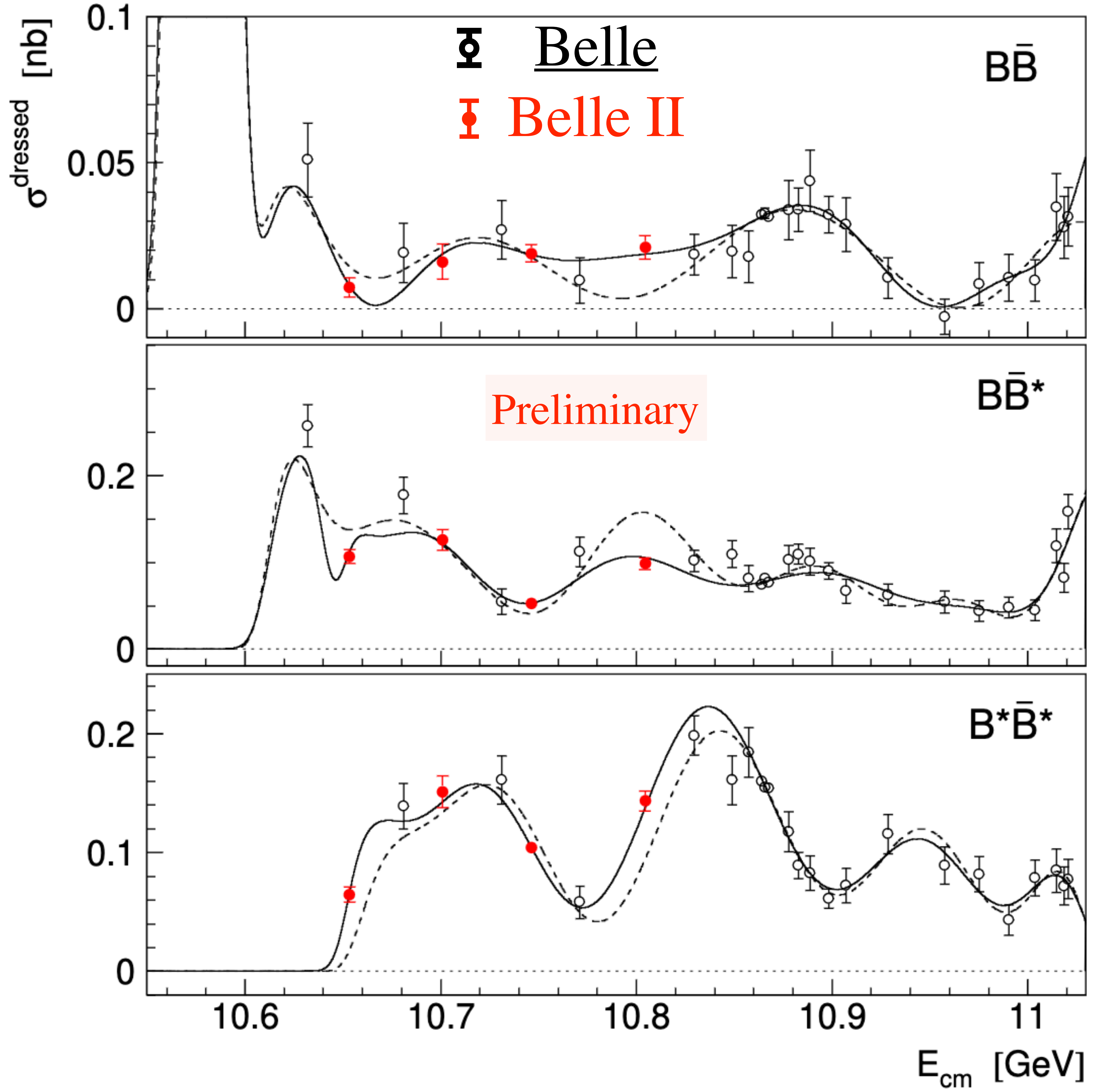
dashed curve — fit Belle points only

Above the $B^*\bar{B}^*$ threshold $\sigma(e^+e^- \to B^*\bar{B}^*)$ rises very rapidly

Similar behaviour seen for the $D^*\bar{D}^*$ cross section
([PRD 97, 012002 (2018)])

Possible interpretation: resonance or bound state near threshold
([Mod. Phys. Lett. A 21, 2779 (2006)])

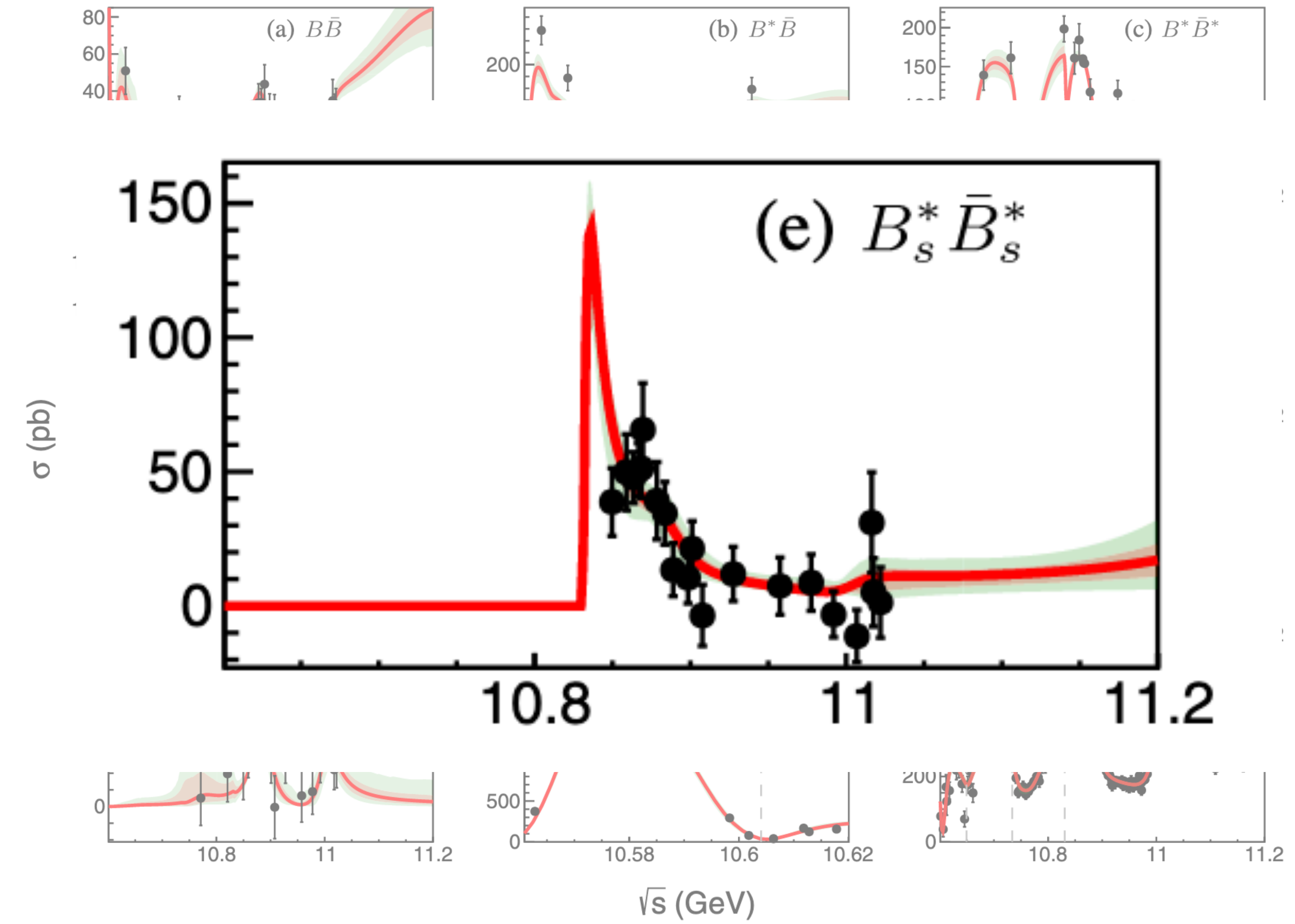
Also explains narrow dip in $e^+e^- \to B\bar{B}^*$ near $B^*\bar{B}^*$ threshold



$e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)}$

The first combined analysis of the $b\bar{b}$ system above $B\bar{B}$ threshold

N. HÜSKEN, R. E. MITCHELL, and E. S. SWANSON [PRD 106 (2022) 9, 094013](#)



$B_s^{(*)}\bar{B}_s^{(*)}$ channel — the current data doesn't constrain the fit function well

Need to improve the accuracy in $B_s^{(*)}\bar{B}_s^{(*)}$ channel

Measurement of the $e^+e^- \to B_s^0\bar{B}_s^0X$ cross section in the energy range from 10.63 to 11.02 GeV using inclusive D_s^+ and D^0 production at Belle

(arXiv:2305.10098)

- Reconstruct inclusive D_s and D^0 at each energy scan point,
- $x_p = \dfrac{p}{p_{max}}$ is used to separate continuum and $b\bar{b}$- events;

$\sigma(D_sX)$ and $\sigma(D^0X)$

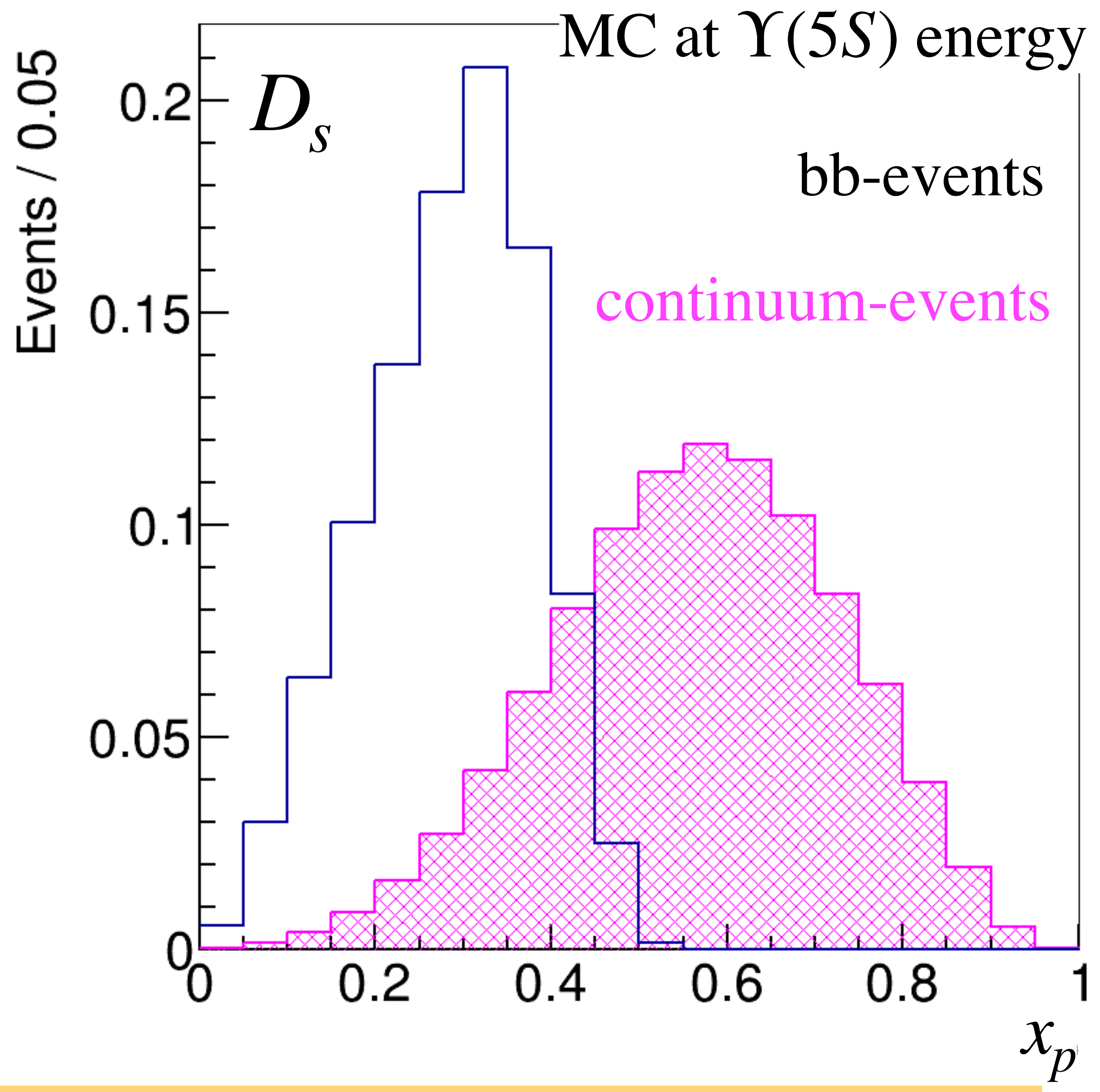
- Measured cross sections can be expressed as:

$$\begin{cases} \sigma(D_sX)/2 = \mathscr{B}(B_s \to D_sX)\cdot\sigma(B_s\bar{B}_sX) + \mathscr{B}(B \to D_sX)\cdot\sigma(B\bar{B}X) \\ \sigma(D^0X)/2 = \mathscr{B}(B_s \to D^0X)\cdot\sigma(B_s\bar{B}_sX) + \mathscr{B}(B \to D^0X)\cdot\sigma(B\bar{B}X) \end{cases}$$

Solving eq's system: $\sigma(B_s\bar{B}_sX)$ and $\sigma(B\bar{B}X)$

$\mathscr{B}(B_s \to D_sX)$ has large uncertainty

$\mathscr{B}(B_s \to D^0X)$ is not measured, only prediction



$\sigma(e^+e^- \to B_s\bar{B}_sX) = \sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})$ up to $B_s\bar{B}_s\pi^0\pi^0$ threshold (11.004 GeV)

Method

No B_s at energy point near $\Upsilon(4S)$:

Measure with high accuracy $\mathcal{B}(B \to D_s X)$, $\mathcal{B}(B \to D^0 X)$

At energy point near $\Upsilon(5S)$:

$$\sigma(D_s X)|_{\Upsilon(5S)}/2 = \mathcal{B}(B_s \to D_s X) \cdot \sigma(B_s \bar{B}_s X)|_{\Upsilon(5S)} + \mathcal{B}(B \to D_s X) \cdot \sigma(B\bar{B}X)|_{\Upsilon(5S)}$$

$$\sigma(D^0 X)|_{\Upsilon(5S)}/2 = \mathcal{B}(B_s \to D^0 X) \cdot \sigma(B_s \bar{B}_s X)|_{\Upsilon(5S)} + \mathcal{B}(B \to D^0 X) \cdot \sigma(B\bar{B}X)|_{\Upsilon(5S)}$$

$$C = \frac{\mathcal{B}(B_s \to D^0 X)}{\mathcal{B}(B_s \to D_s X)} = \frac{\sigma(D^0 X)|_{\Upsilon(5S)} - \mathcal{B}(B \to D^0 X) \cdot \sigma(B\bar{B}X)|_{\Upsilon(5S)}}{\sigma(D_s^{\pm} X)|_{\Upsilon(5S)} - \mathcal{B}(B \to D_s X) \cdot \sigma(B\bar{B}X)|_{\Upsilon(5S)}}$$

We can measure using $\Upsilon(5S)$ data

We can measure using $\Upsilon(4S)$ data

from JHEP 06 (2021) 137

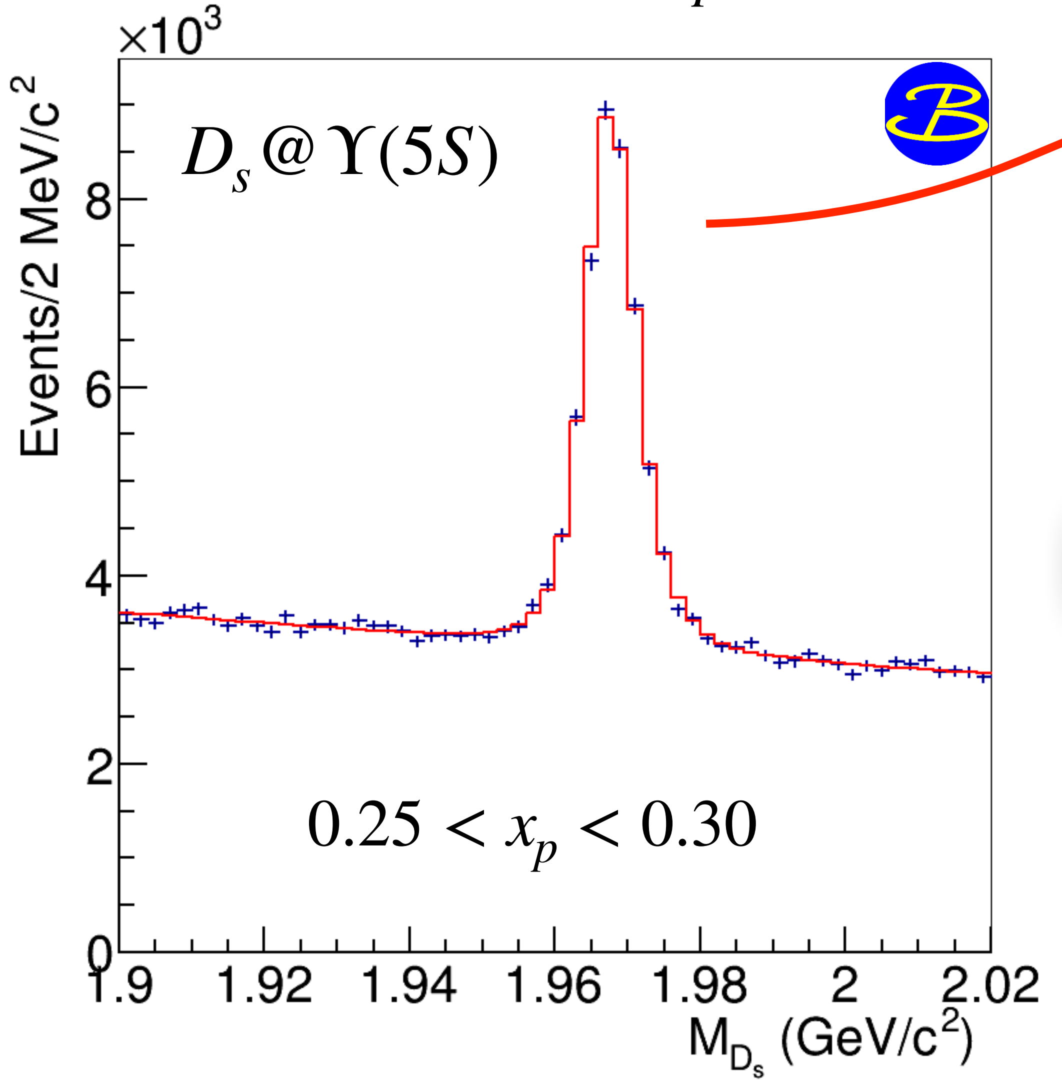
At scan points:

$$\begin{cases} \sigma(D_s X)/2 = \mathcal{B}(B_s \to D_s X) \cdot \sigma(B_s \bar{B}_s X) + \mathcal{B}(B \to D_s X) \cdot \sigma(B\bar{B}X) \\ \sigma(D^0 X)/2 = C \cdot \mathcal{B}(B_s \to D_s X) \cdot \sigma(B_s \bar{B}_s X) + \mathcal{B}(B \to D^0 X) \cdot \sigma(B\bar{B}X) \end{cases}$$

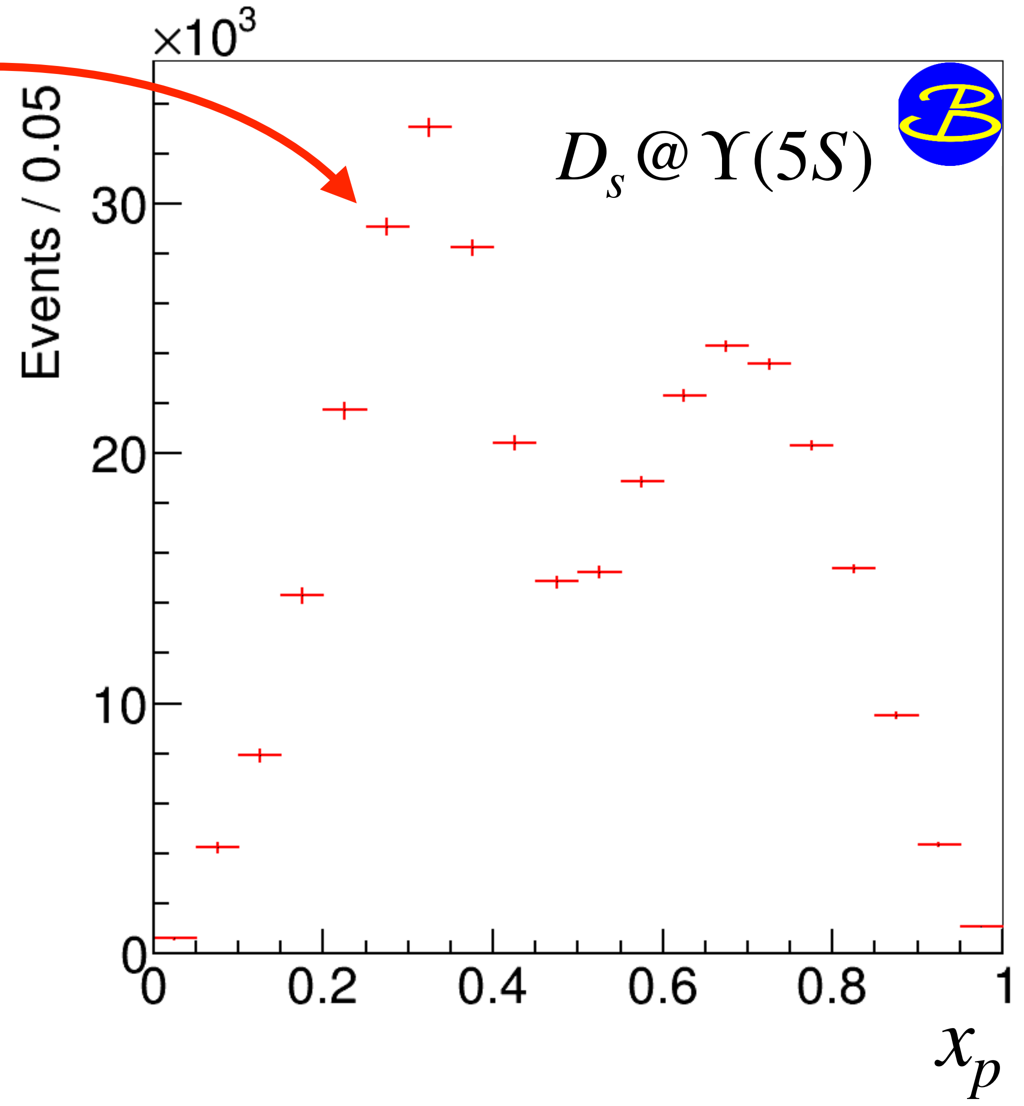
Solving eq's system: ➡ energy dependence of the $\sigma(B_s \bar{B}_s X) \cdot \mathcal{B}(B_s \to D_s X)$ and $\sigma(B\bar{B}X)$

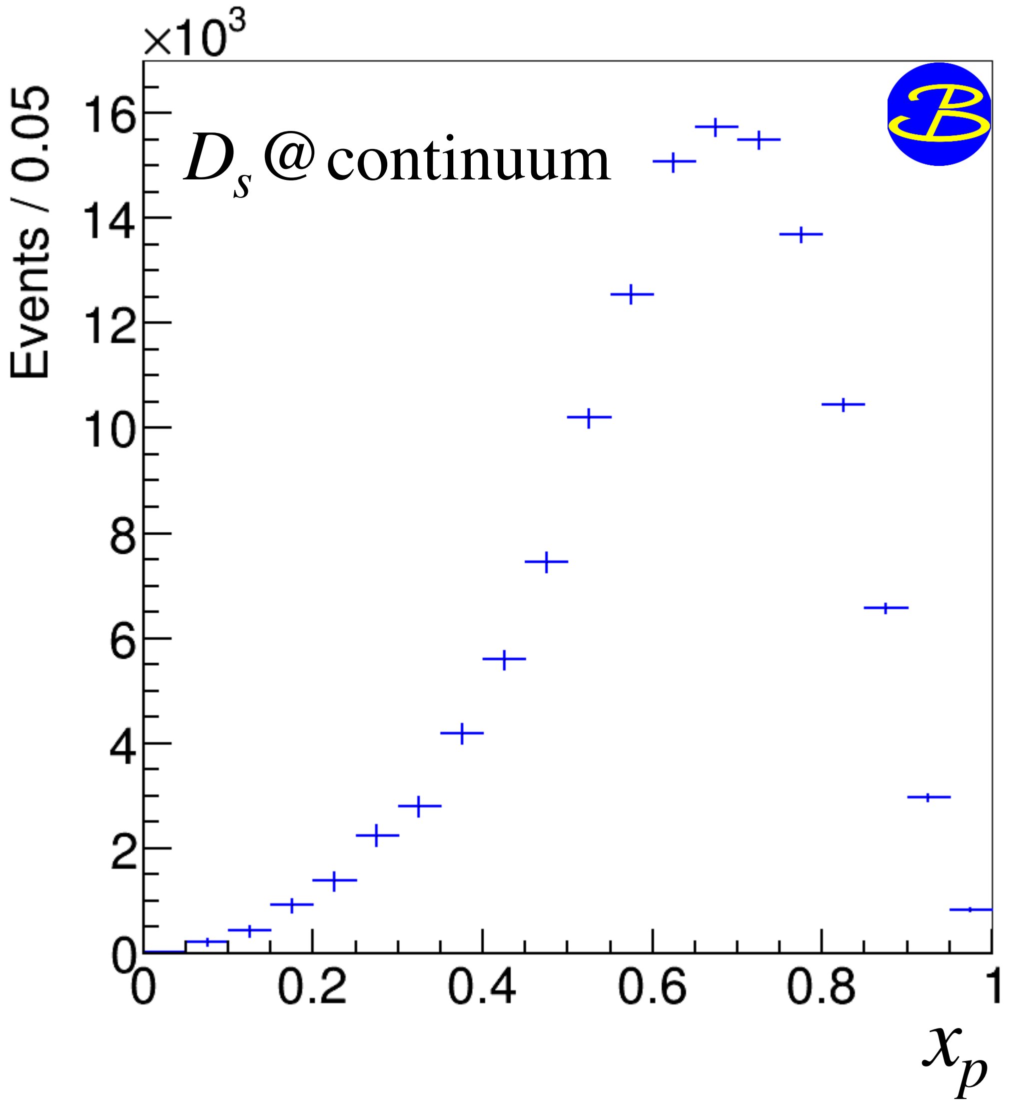
Analysis

Fit $M(Ds)$ in x_p bins

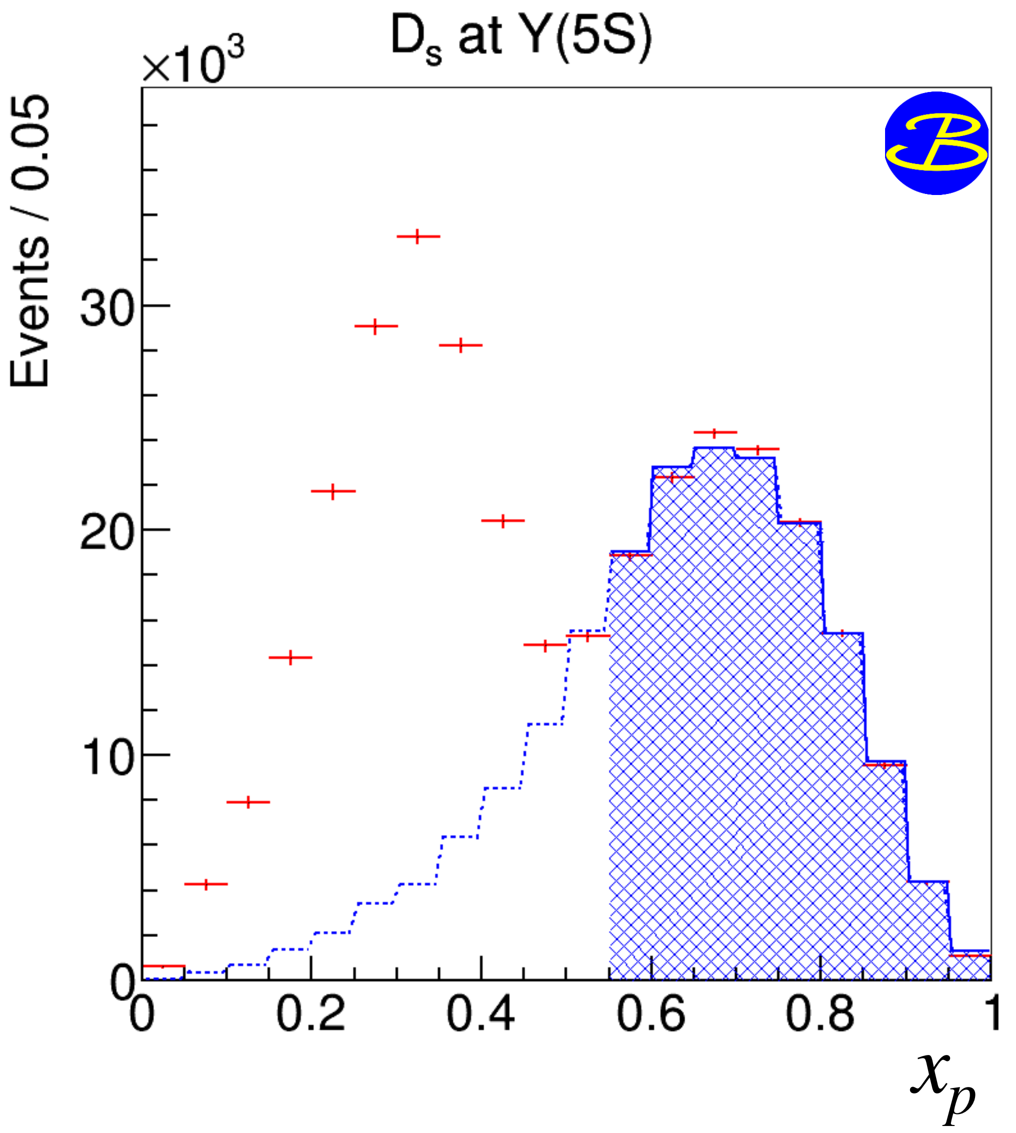


Obtain the x_p spectra

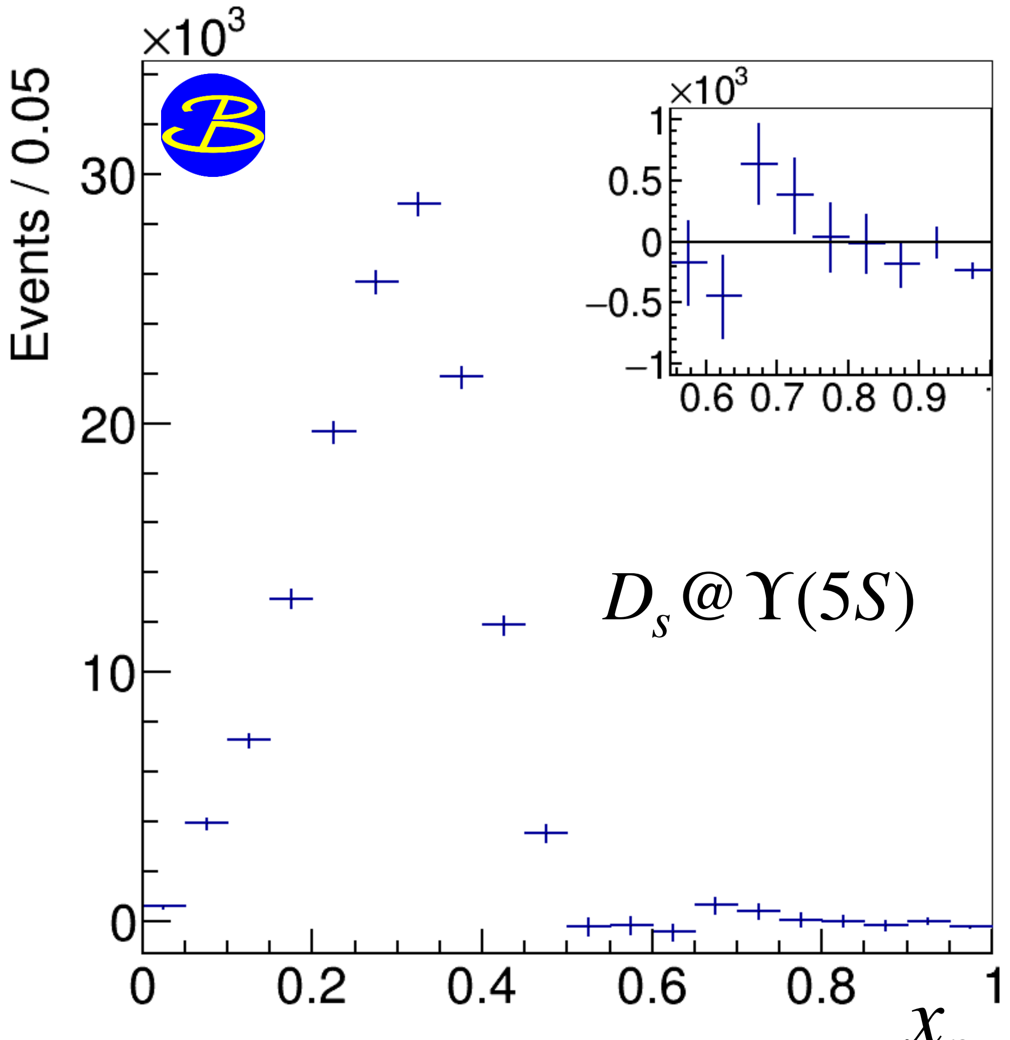




Fit in high x_p to continuum x_p



After continuum subtraction



D cross sections

D cross sections at $\Upsilon(4S)$ and $\Upsilon(5S)$:

$\mathscr{B}(B \to D_s X)$

$\mathscr{B}(B \to D^0 X)$

$$\frac{\mathscr{B}(B_s \to D^0 X)}{\mathscr{B}(B_s \to D_s X)}$$

At each scan point:

$B_s \bar{B}_s X$ and $B\bar{B}X$ cross sections

Results at $\Upsilon(4S)$ and $\Upsilon(5S)$

	This measurement	PDG full recon	PDG same method
$\Upsilon(4S)$ data: $\mathcal{B}(B \to D_s X) = \dfrac{\sigma(D_s X)\|_{\Upsilon(4S)}}{2 \cdot \sigma(e^+e^- \to b\bar{b})\|_{\Upsilon(4S)}}$	$= (11.28 \pm 0.03 \pm 0.43)\,\%$	$(10.4^{+1.3}_{-1.8})\,\%$	$(8.3 \pm 0.8)\,\%$
$\mathcal{B}(B \to D^0 X) = \dfrac{\sigma(D^0 X)\|_{\Upsilon(4S)}}{2 \cdot \sigma(e^+e^- \to b\bar{b})\|_{\Upsilon(4S)}}$	$= (66.63 \pm 0.04 \pm 1.77)\,\%$	$(71.6 \pm 4.6)\,\%$	$(61.6 \pm 2.9)\,\%$

$\Upsilon(5S)$ data:

$$C = \frac{\mathcal{B}(B_s \to D^0 X)}{\mathcal{B}(B_s \to D_s X)} = 0.416 \pm 0.018 \pm 0.092$$

Results at $\Upsilon(4S)$ and $\Upsilon(5S)$

Fractions of $B_s\bar{B}_sX$ events produced at $\Upsilon(5S)$:

This measurement

$$f_s = \frac{\sigma(e^+e^- \to B_s\bar{B}_sX)\,|_{\Upsilon(5S)}}{\sigma(e^+e^- \to b(\bar{b}))\,|_{\Upsilon(5S)}} = (23.0 \pm 0.2 \pm 2.8)\,\%$$

Belle 2013
PRD 87 (2013) 3, 031101
$(17.2 \pm 3.0)\,\%$

Belle 2022
PRD 105 (2022) 012004
$(28.5 \pm 3.2 \pm 3.7)\,\%$

To improve accuracy we fit

$$f_s = (23.0 \pm 0.2 \pm 2.8)\,\%$$

$$f_{B\bar{B}X} = (75.1 \pm 4.0)\%$$

JHEP 06 (2021) 137

$$f_{\not{B}}^{\text{known}} = (4.9 \pm 0.6)\%$$

JHEP 06 (2021) 137

with one constraint

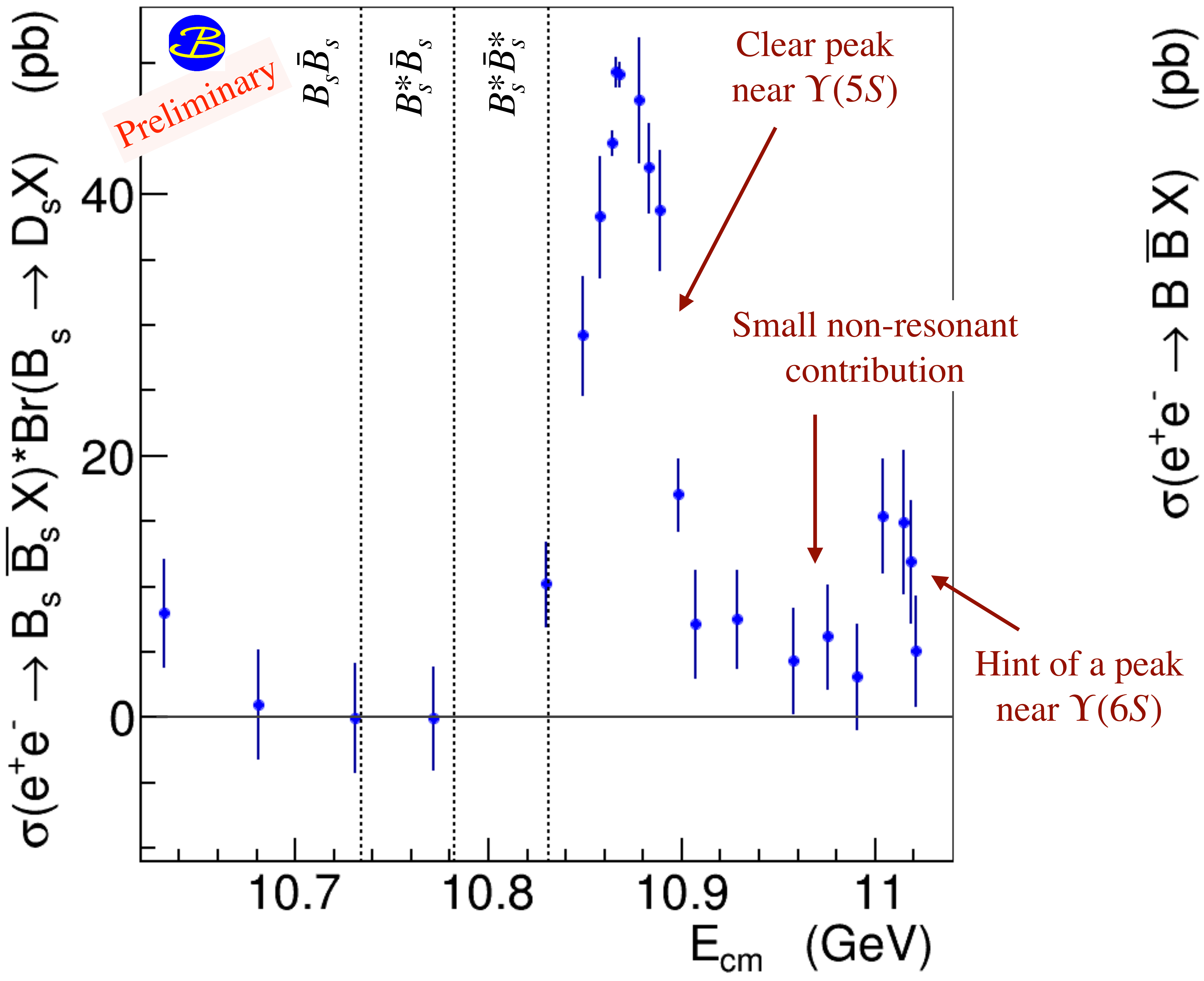
$$f_s + f_{B\bar{B}X} + f_{\not{B}} = 1$$

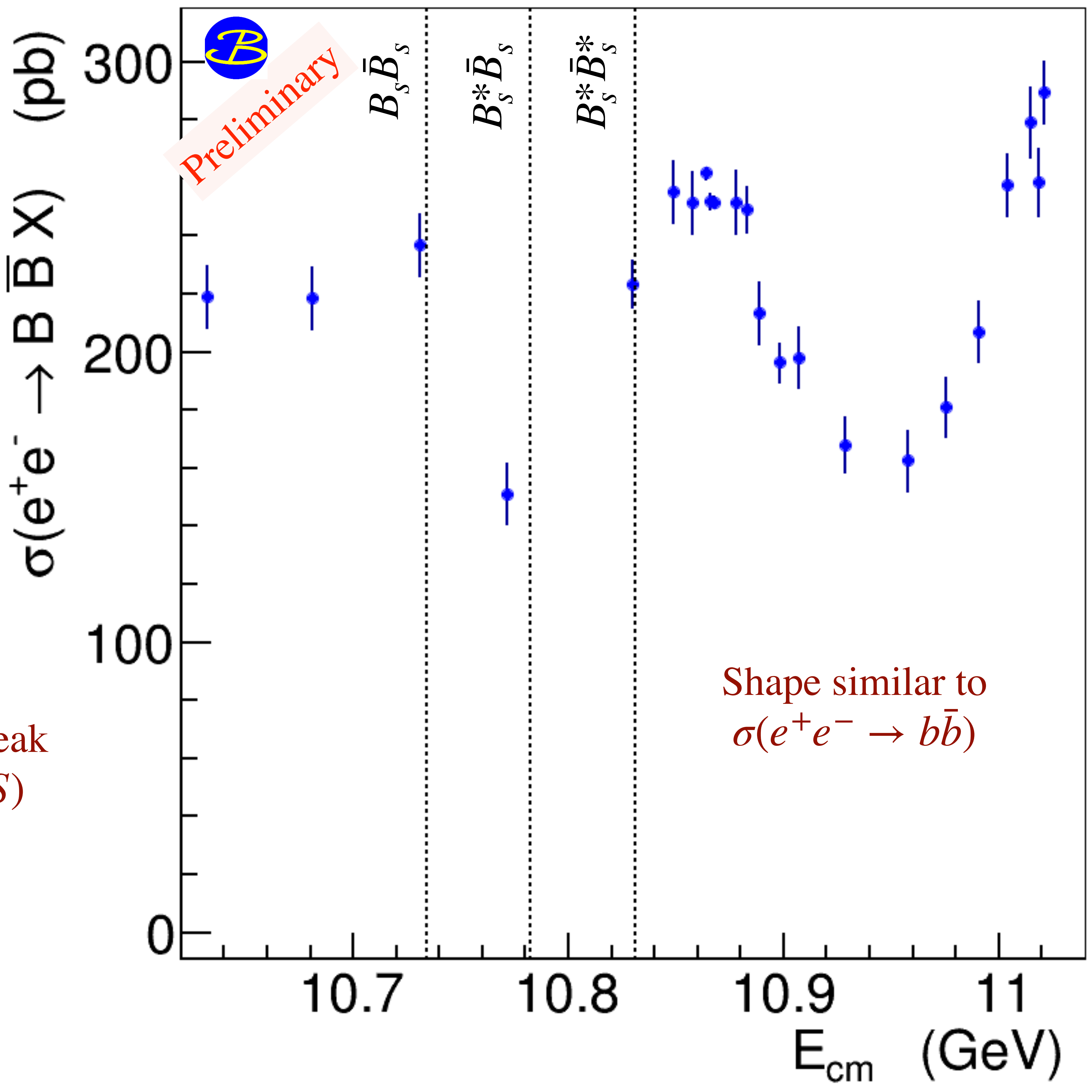
Result from the fit: $f_s = (22.0^{+2.0}_{-2.1})\,\%$

Source	Systematic uncertainty (%)
$\sigma(e^+e^- \to b\bar{b} \to D_s^\pm X)\vert_{\Upsilon(5S)}$	1.4
$\sigma(e^+e^- \to b\bar{b} \to D_s^\pm X)\vert_{\Upsilon(4S)}$	0.7
$\sigma(e^+e^- \to B\bar{B}X)\vert_{\Upsilon(5S)}$	1.4
$\mathcal{B}(B_s^0 \to D_s^\pm X)$	10.5
$\sigma(e^+e^- \to b\bar{b})\vert_{\Upsilon(5S)}$	4.5
Correlated contributions	
– tracking	1.1
– K/π identification	2.3
– r_ϕ	0.6
– $\mathcal{B}(D_s^+ \to K^+K^-\pi^+)$	1.9
Total	12.0

Belle
PRD 105 (2022) 1, 012004
$\mathcal{B}(B_s \to D_sX) = (60.2 \pm 5.8 \pm 2.3)\,\%$

Results for $\sigma(e^+e^- \to B_s\bar{B}_sX)$ and $\sigma(e^+e^- \to B\bar{B}X)$





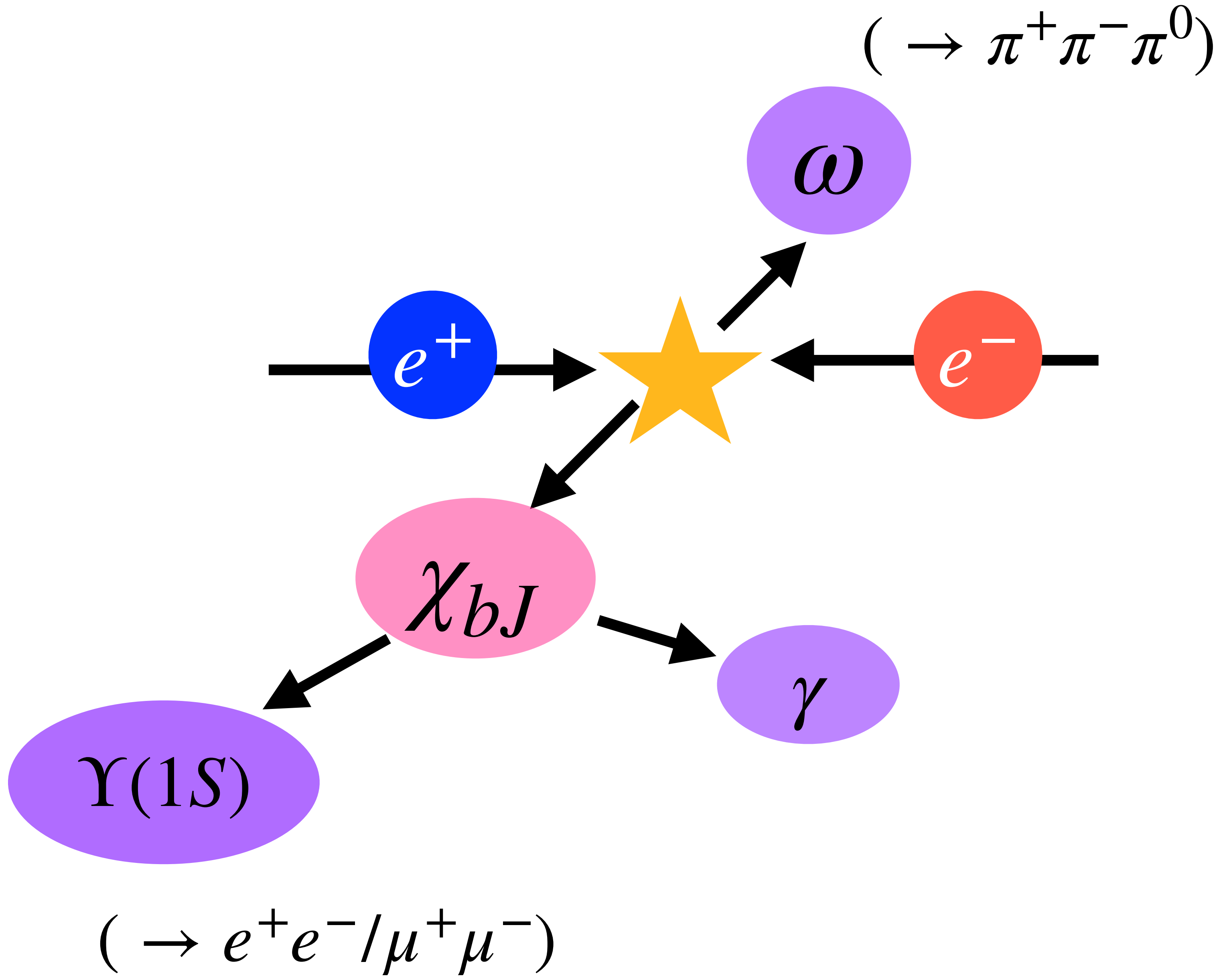
Summary

- Belle II has a rich quarkonium program
  - Unique data sample collected near $E_{\rm cm} \sim 10.75$ GeV
  - The first observation of $\Upsilon(10753) \to \omega \chi_{bJ}(1P)$
  - Measured energy dependence of $e^+e^- \to B^{(*)}\bar{B}^{(*)}$
- Belle data still in business
  - Measured energy dependence of $\sigma(e^+e^- \to B_s\bar{B}_s X)$ and $\sigma(e^+e^- \to B\bar{B}X)$

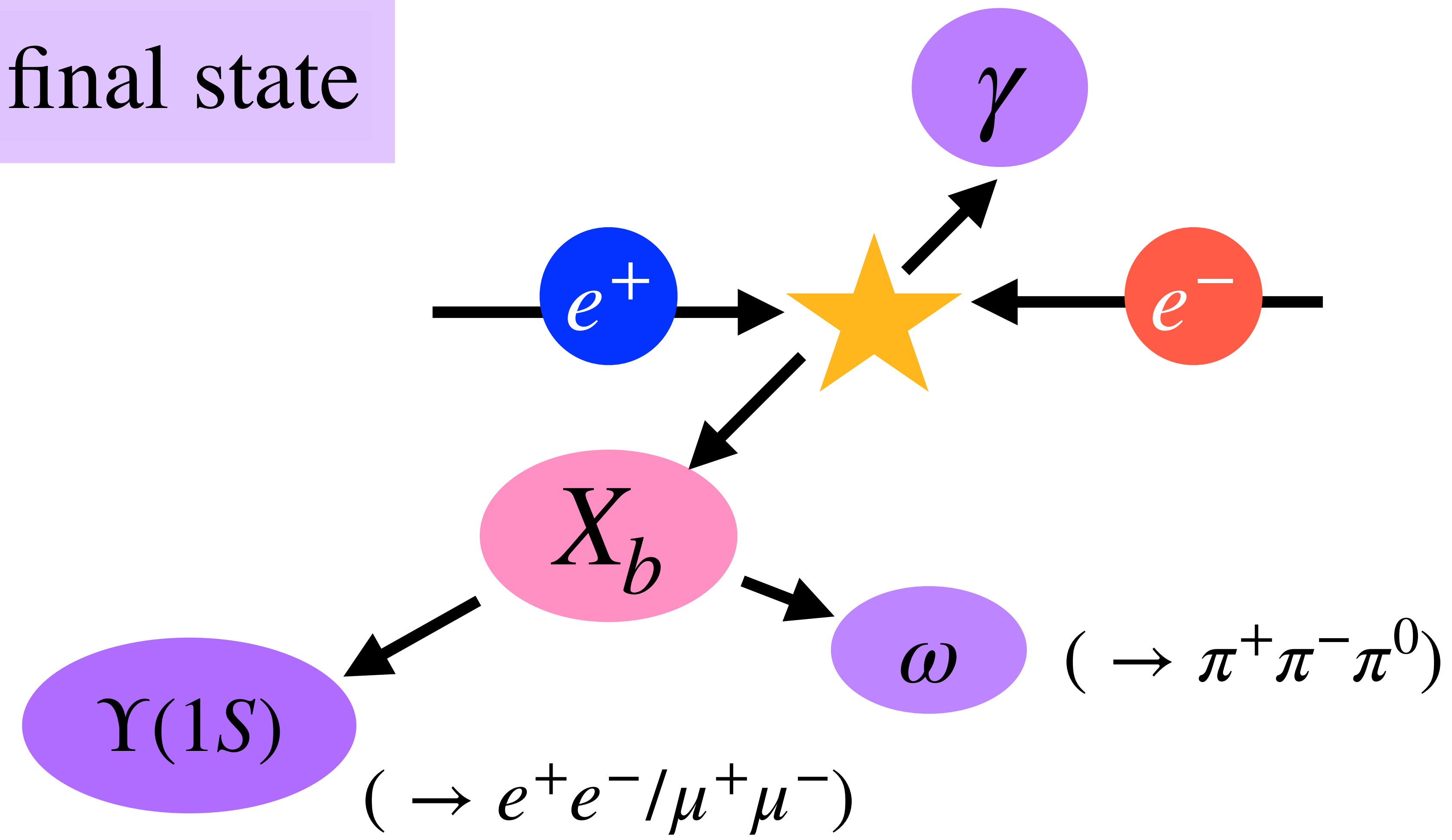
Thank you very much for your attention!

Backup

Observation of $e^+e^- \to \omega\chi_{bJ}(1P)$ and search for $X_b \to \omega\Upsilon(1S)$ at $\sqrt{s}$ near 10.75 GeV (PRL 130 091902 (2023))



The same final state

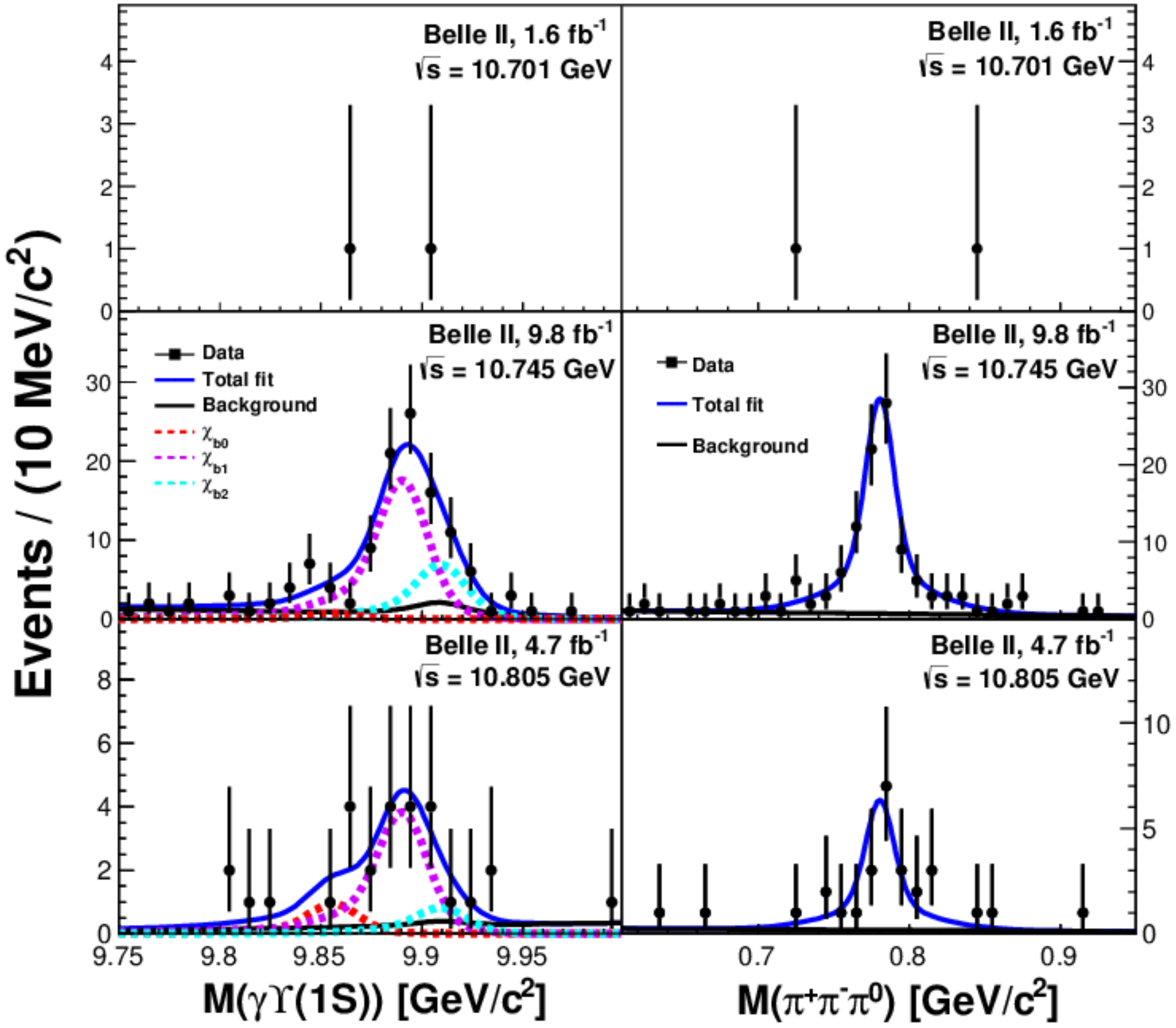


X_b: bottomonium counterpart candidate of the X(3872) ?

Phys. Rev. Lett. 91, 262001 (2003)

$e^+e^- \rightarrow \omega\chi_{bJ}(1P)$: Signal yield

2D unbinned likelihood fit
to $M(\gamma\Upsilon(1S))$ *vs.* $M(\pi^+\pi^-\pi^0)$



Fit function: Signal + Peak. BG + Comb. BG

χ_{bJ} — Crystal Ball , ω — BW ⊗ Gauss (resolution)

$$\sigma^{\text{Born}}(e^+e^- \rightarrow \omega\chi_{bJ}) = \frac{N^{\text{sig}}\,|1-\Pi|^2}{\mathscr{L}\,\varepsilon\,\mathscr{B}_{\text{int}}\,(1+\delta_{\text{ISR}})}$$

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

11.5 σ

5.2 σ

Belle @ $\sqrt{s}$ = 10.867 GeV:

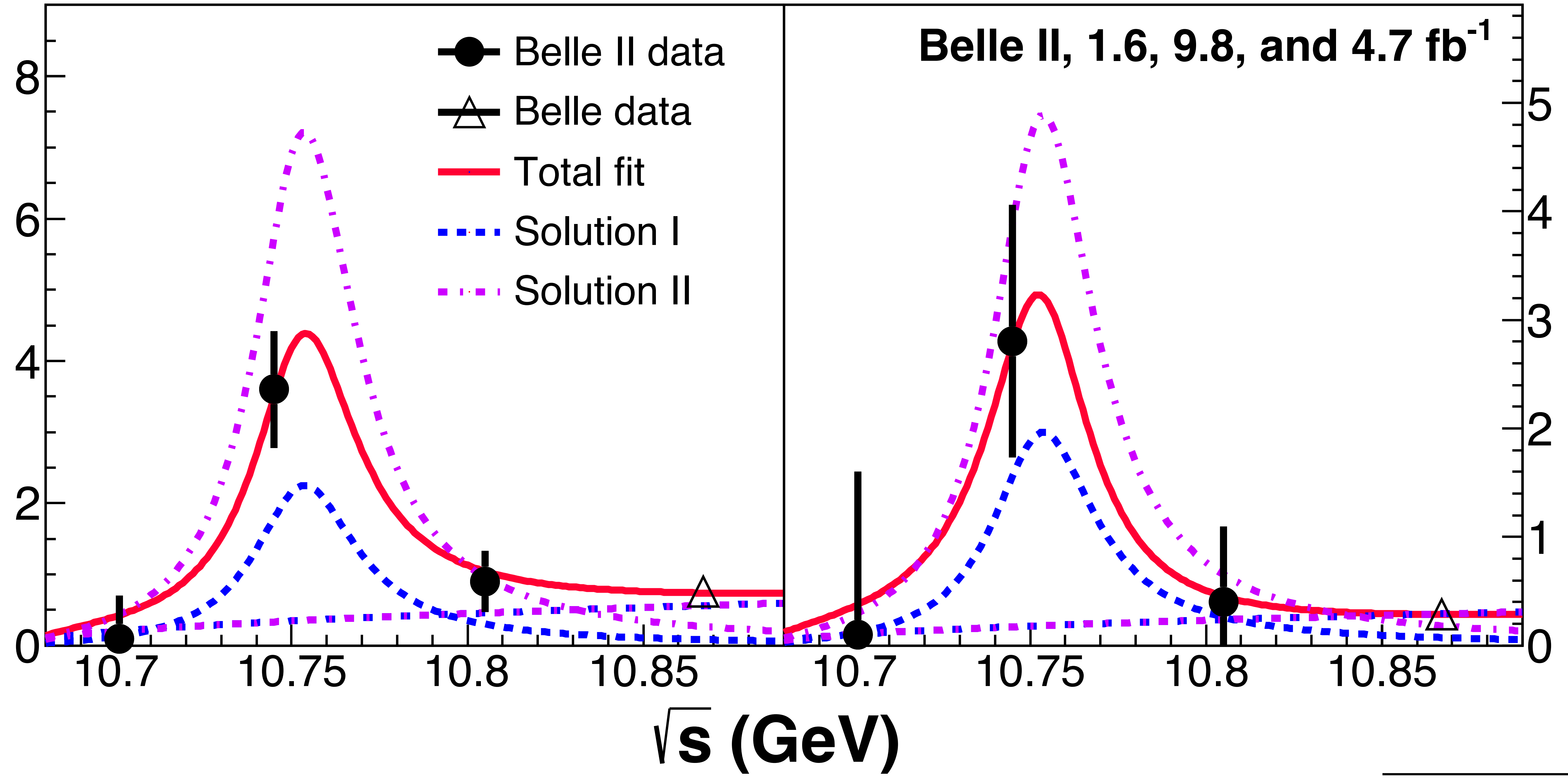
$\sigma(e^+e^- \rightarrow \omega\chi_{b1}) = (0.76 \pm 0.16)$ pb

$\sigma(e^+e^- \rightarrow \omega\chi_{b2}) = (0.29 \pm 0.14)$ pb

PRL 113 (2014) 14, 142001

Observation of $\Upsilon(10753) \to \omega\chi_{b1,2}$

$\sigma(e^+e^- \to \omega\chi_{b1})$, pb $\sigma(e^+e^- \to \omega\chi_{b2})$, pb



Belle II + Belle data @ $\sqrt{s} = 10.867$ GeV
PRL 113 (2014) 14, 142001

Fit function is BW + PHSP:

$$\left|\sqrt{\Phi_2(\sqrt{s})} + \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}_f\Gamma}}{s - M^2 - iM\Gamma}\sqrt{\frac{\Phi_2(\sqrt{s})}{\Phi_2(M)}}e^{i\phi}\right|^2$$

M and Γ of $\Upsilon(10753)$ are fixed to values obtained in JHEP 10 (2019) 220

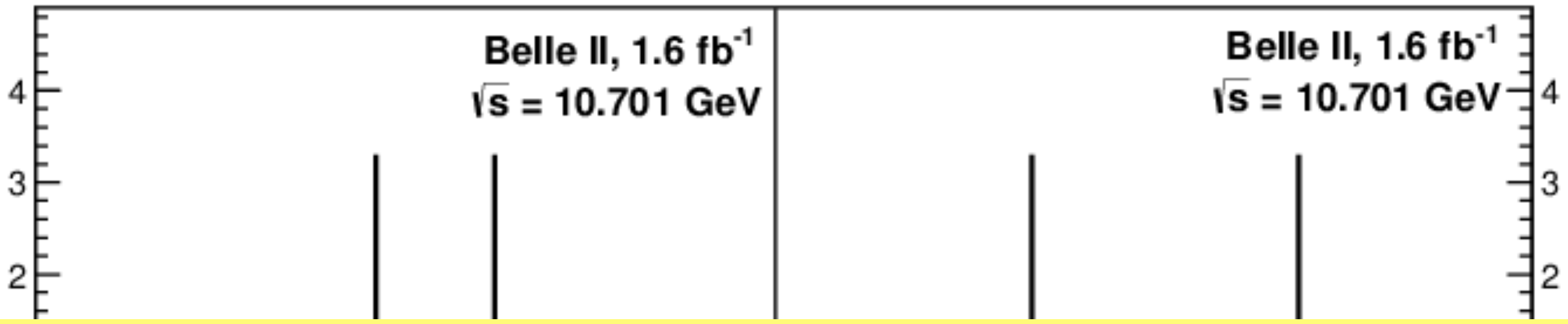
$\sigma(e^+e^- \to \omega\chi_{b1,2})$ peaks at $\Upsilon(10753)$

No obvious peak at $\Upsilon(10860)$ is found

$\Gamma_{ee}\mathcal{B}_f$	Solution I, eV	Solution II, eV
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b1})$	$0.63 \pm 0.39 \pm 0.20$	$2.01 \pm 0.38 \pm 0.76$
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b2})$	$0.53 \pm 0.46 \pm 0.15$	$1.32 \pm 0.44 \pm 0.55$

$e^+e^- \to \omega\chi_{bJ}(1P)$: Signal yield

2D unbinned likelihood fit
to $M(\gamma\Upsilon(1S))$ *vs.* $M(\pi^+\pi^-\pi^0)$



$$\sigma^{\text{Born}}(e^+e^- \to \omega\chi_{bJ}) = \frac{N^{\text{sig}}\,|1-\Pi|^2}{\mathscr{L}\,\varepsilon\,\mathscr{B}_{\text{int}}\,(1+\delta_{\text{ISR}})}$$

Channel	$\sqrt{s}$ (GeV)	N^{sig}	σ_B (pb)

Experiment vs Theory:

Measured ratio:

$$\frac{\sigma(e^+e^- \to \omega\chi_{b1})}{\sigma(e^+e^- \to \omega\chi_{b2})} \approx 1.3 \pm 0.6$$

at odds with expectations for a pure D-wave bottomonium (Phys. Lett. B 738, 172 (2014))

$$\frac{\sigma(e^+e^- \to \omega\chi_{b1})}{\sigma(e^+e^- \to \omega\chi_{b2})} = 15$$

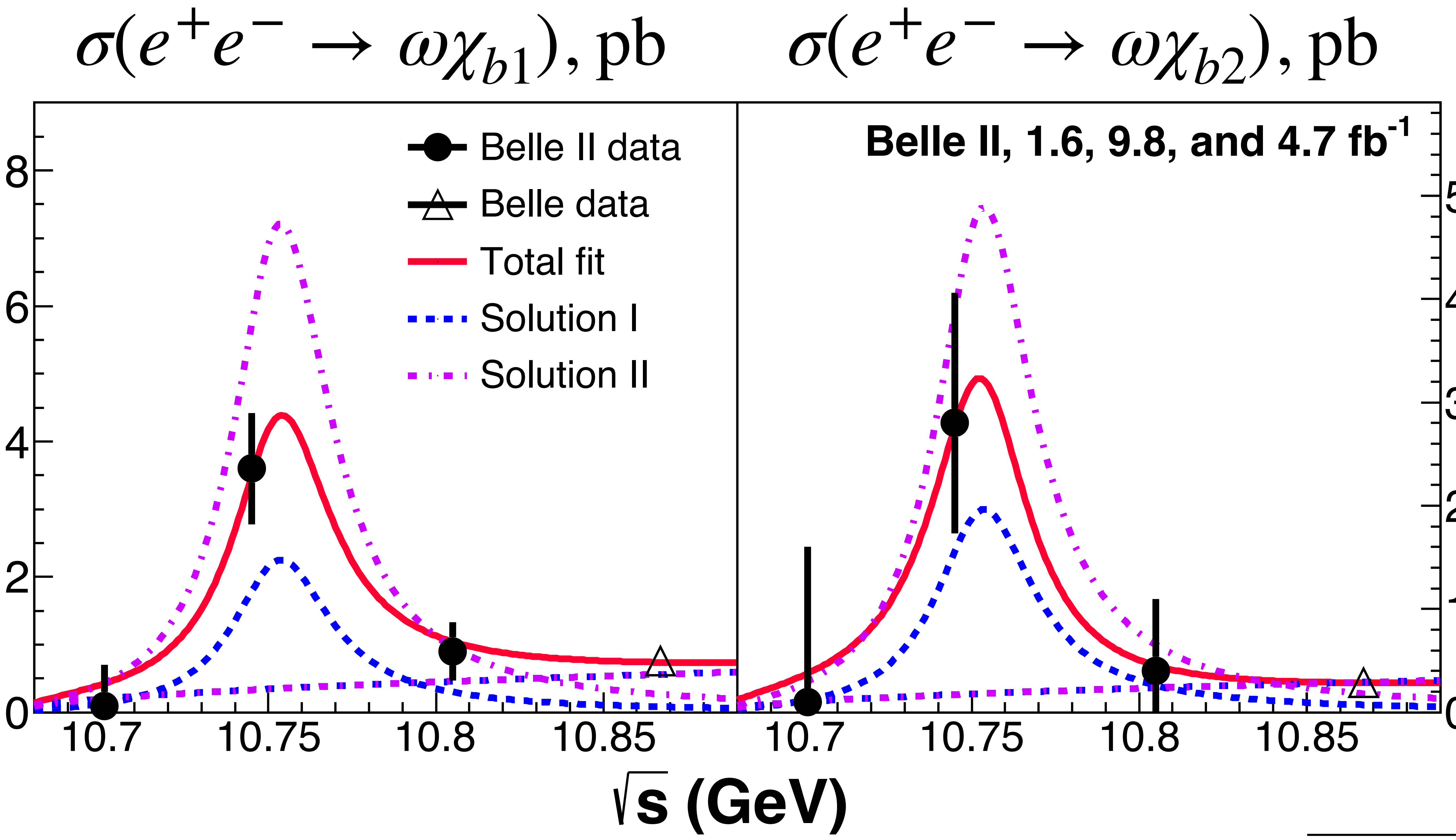
tension with prediction for a S-D-mixed state (Phys. Rev. D 104, 034036 (2021))

$$\frac{\sigma(e^+e^- \to \omega\chi_{b1})}{\sigma(e^+e^- \to \omega\chi_{b2})} = (0.18 - 0.22)$$

χ_{bJ} — Crystal Ball , ω — BW $\otimes$ Gauss (resolution)

PRL 113 (2014) 14, 142001

Observation of $\Upsilon(10753) \to \omega \chi_{b1,2}$



Belle II + Belle data @ $\sqrt{s} = 10.867$ GeV [PRL 113 (2014) 14, 142001]

Fit function is BW + PHSP:

$$\left|\sqrt{\Phi_2(\sqrt{s})} + \frac{\sqrt{12\pi\Gamma_{ee}\mathcal{B}_f\Gamma}}{s - M^2 - iM\Gamma}\sqrt{\frac{\Phi_2(\sqrt{s})}{\Phi_2(M)}}e^{i\phi}\right|^2$$

M and Γ of $\Upsilon(10753)$ are fixed to values obtained in [JHEP 10 (2019) 220]

$\sigma(e^+e^- \to \omega\chi_{b1,2})$ peaks at $\Upsilon(10753)$

No obvious peak at $\Upsilon(10860)$ is found

$\Gamma_{ee}\mathcal{B}_f$	Solution I, eV	Solution II, eV
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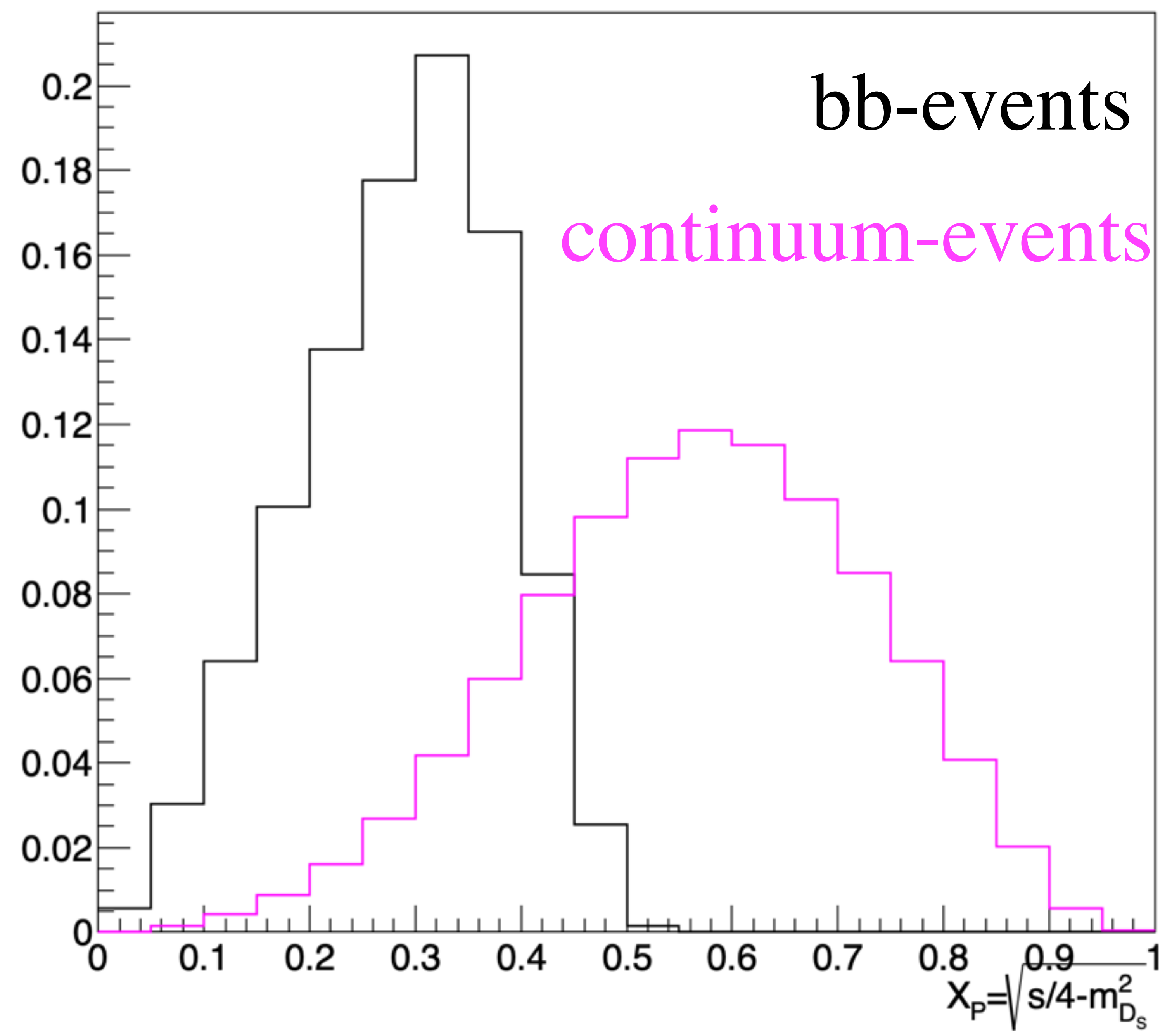
$\Gamma_{ee}\mathcal{B}(\Upsilon(10753) \to \omega\chi_{b2})$	$0.53 \pm 0.46 \pm 0.15$	$1.32 \pm 0.44 \pm 0.55$

Method

- Reconstruct inclusive D_s and D^0 at each energy scan point,
- $x_p = \dfrac{p}{p_{max}}$ is used to separate continuum and $b\bar{b}$- events;

$$\sigma(e^+e^- \to b\bar{b} \to D_s X) \text{ and } \sigma(e^+e^- \to b\bar{b} \to D^0 X)$$



- Measured cross sections can be expressed as:

$$\begin{cases} \sigma(e^+e^- \to b\bar{b} \to D_s X)/2 = \mathcal{B}(B_s \to D_s X) \cdot \sigma(e^+e^- \to B_s\bar{B}_s X) + \mathcal{B}(B \to D_s X) \cdot \sigma(e^+e^- \to B\bar{B}X) \\ \sigma(e^+e^- \to b\bar{b} \to D^0 X)/2 = \mathcal{B}(B_s \to D^0 X) \cdot \sigma(e^+e^- \to B_s\bar{B}_s X) + \mathcal{B}(B \to D^0 X) \cdot \sigma(e^+e^- \to B\bar{B}X) \end{cases}$$

Solving eq's system: $\sigma(e^+e^- \to B_s\bar{B}_s X)$ and $\sigma(e^+e^- \to B\bar{B}X)$

$\mathcal{B}(B_s \to D_s X)$ has large uncertainty

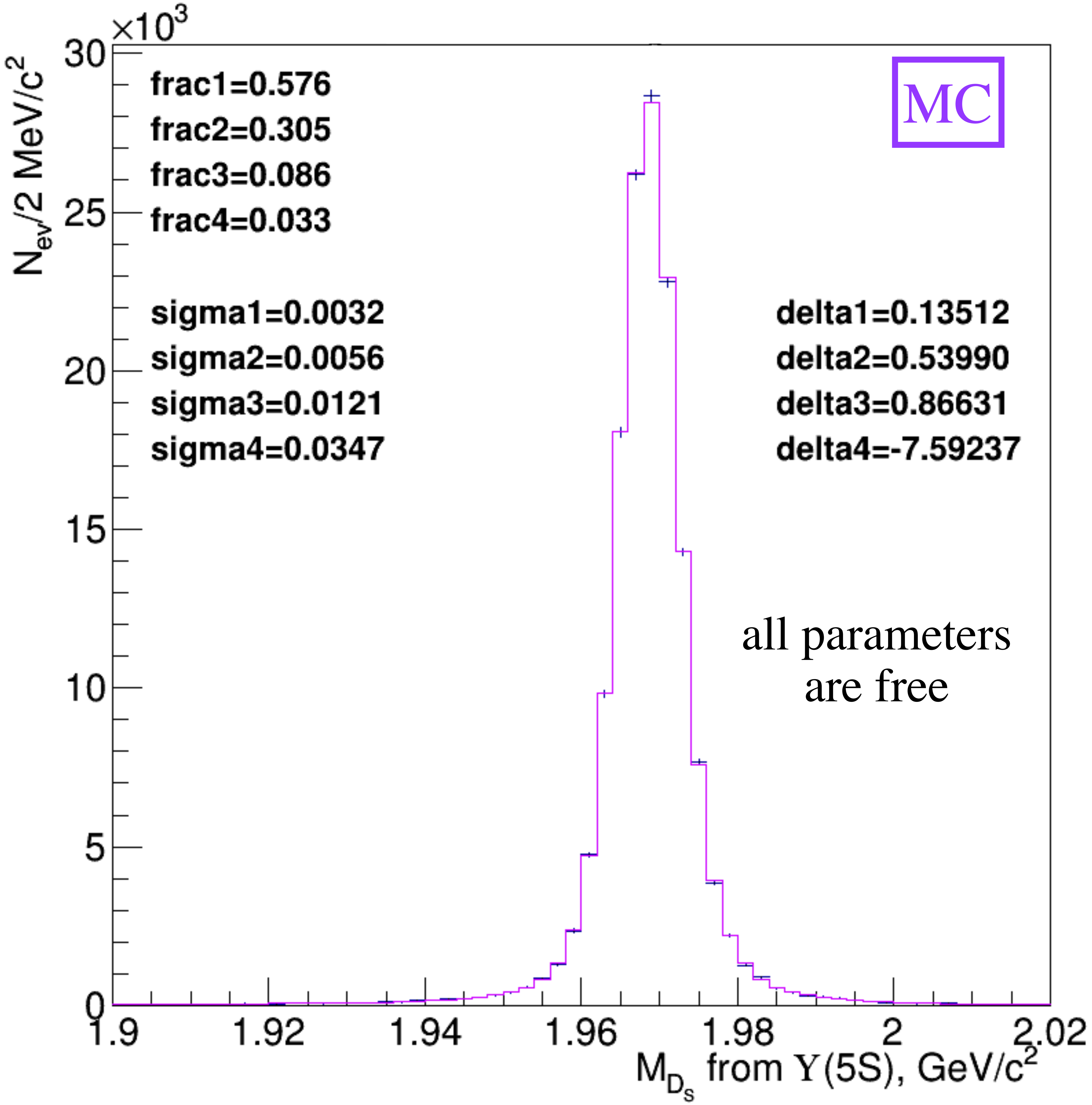
$\mathcal{B}(B_s \to D^0 X)$ is not measured, only prediction

$\sigma(e^+e^- \to B_s\bar{B}_s X) = \sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})$

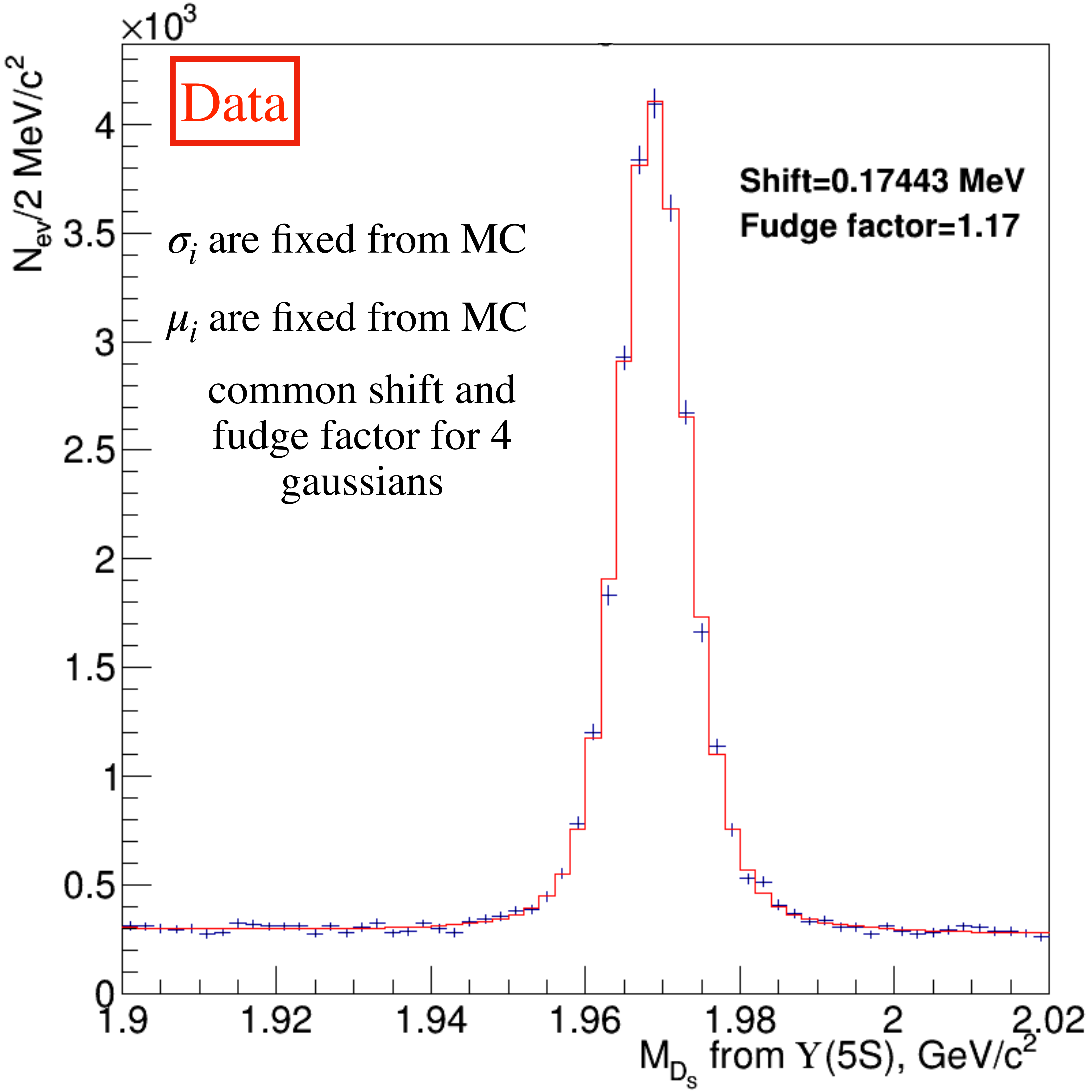
up to $B_s\bar{B}_s\pi^0\pi^0$ threshold (11.004 GeV)

$0.7 < x_p < 0.75$

Fit the D_s mass distributions in the different x_p bins at $\Upsilon(5S)$



$f_{fit}^{MC} = G1 + G2 + G3 + G4$



$f_{fit}^{DATA} = G1 + G2 + G3 + G4 + CHEB2$

x_p spectra at $\Upsilon(5S)$ and $\Upsilon(4S)$ data

Red points — on-resonance data

We fit the large x_p part of the on-resonance spectra to find the continuum contribution in the $b\bar{b}$ region

Fitting function — shape of the x_p spectra for the data below the $\Upsilon(4S)$

Blue hatched histograms — fit results
Open dashed histograms — extrapolation of the continuum component

We subtract the continuum component to obtain pure $b\bar{b}$ spectra