Exotic Hadron Spectroscopy at BELLE & Belle II

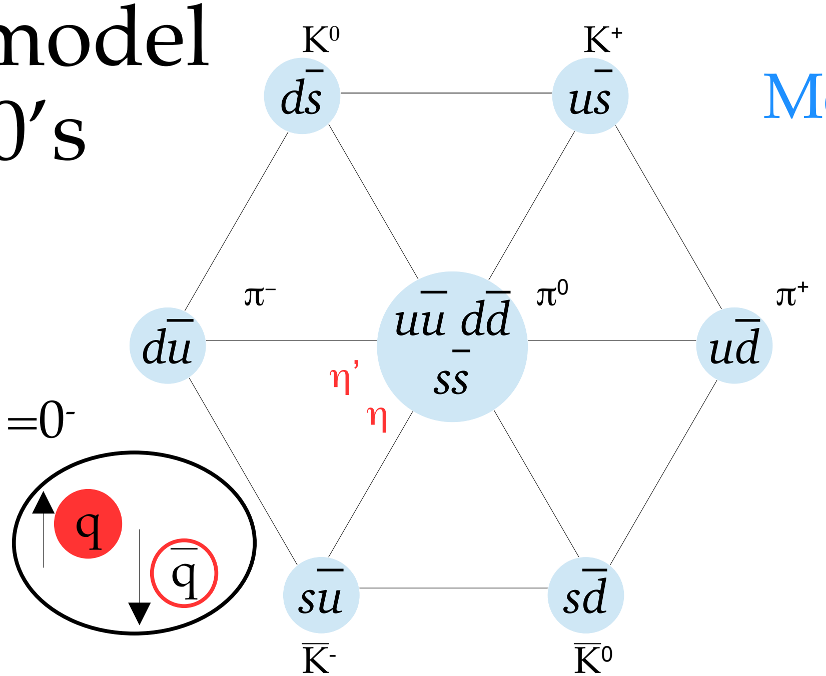
Roberto Mussa INFN TORINO

42nd Physics in Collisions 2023/10/11

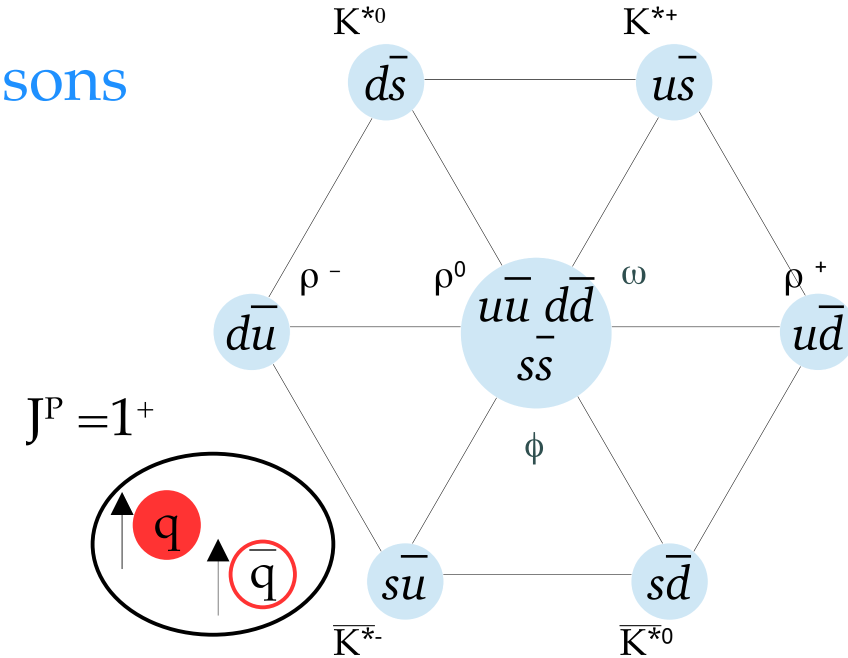
Outline

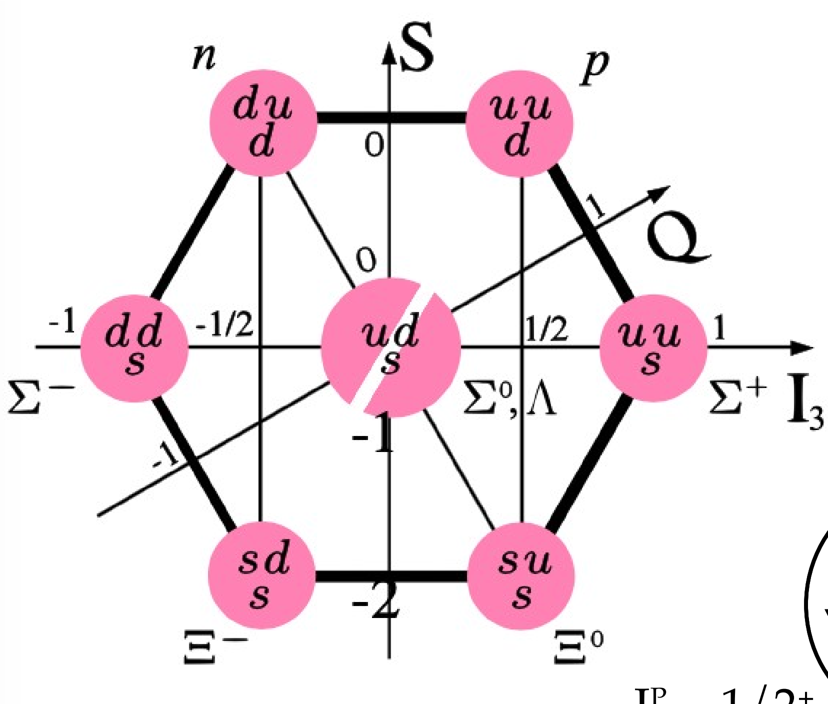
- Quark model: 1964-2001, 2001-now
- High energy scans at Belle and Belle-II
- $B^{(*)}\overline{B}^{(*)}$ cross sections
- Discovery of the $\Upsilon(10753)$ in $\Upsilon(nS)\pi\pi$
- Transitions to $\omega\chi_{bJ}$, $\omega\eta_{bJ}$, γX_b
- Double charmonium

Quark model in the 60's

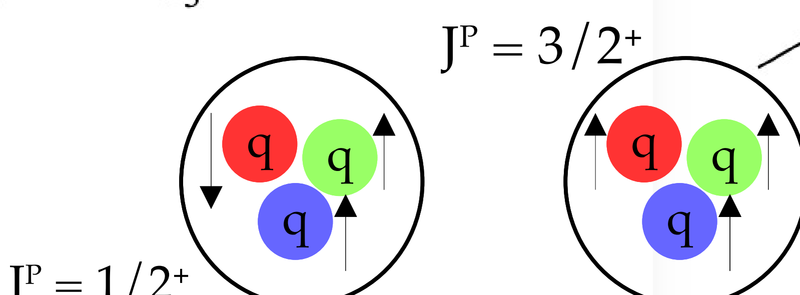


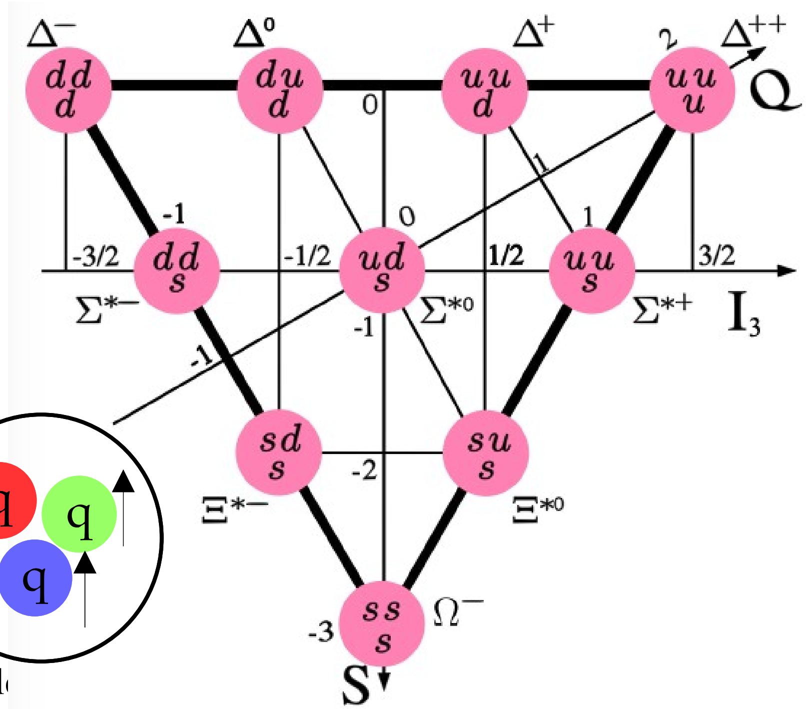
Mesons





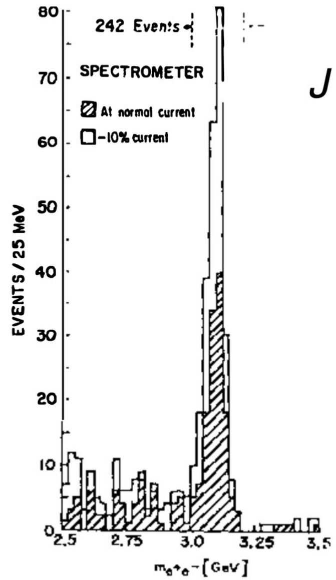
Baryons

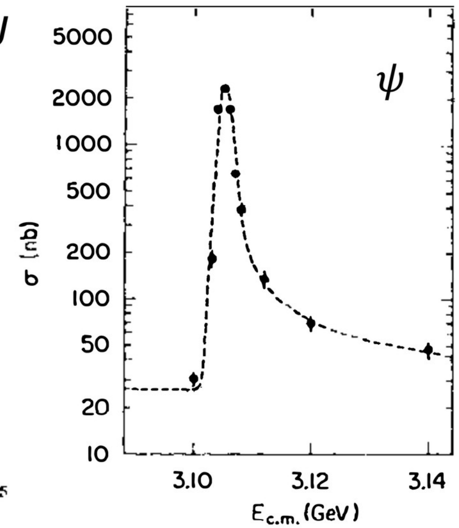


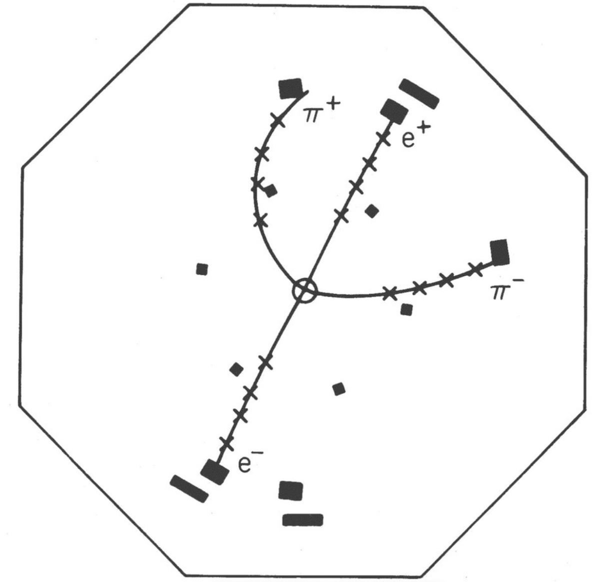


Quark model 1974-81

$e^+e^- \to \psi' \to \pi^+\pi^- J/\psi$

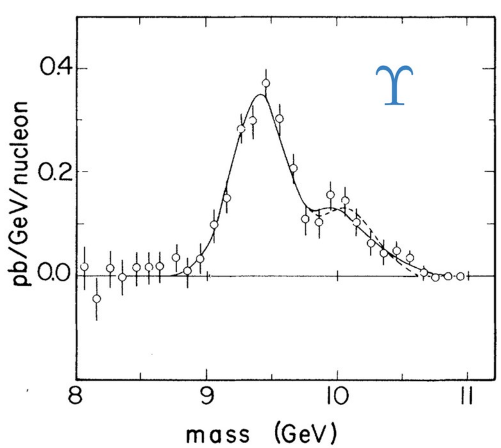


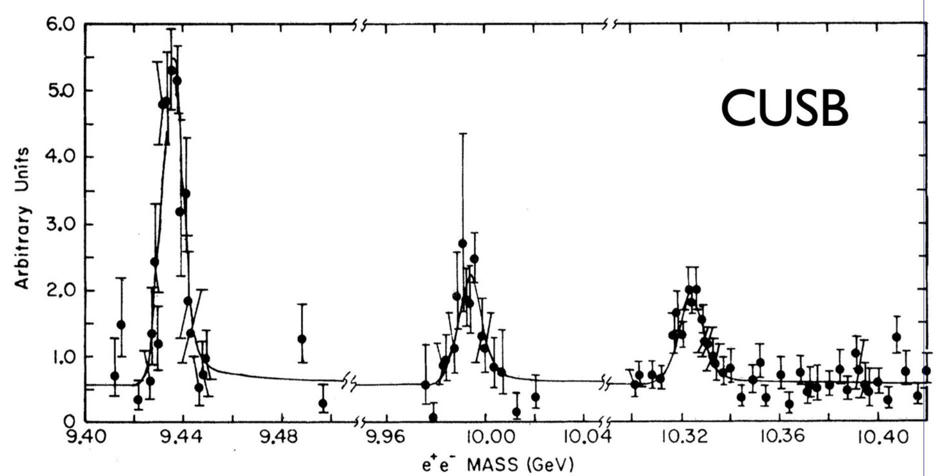




1974 Charm

1976 D mesons



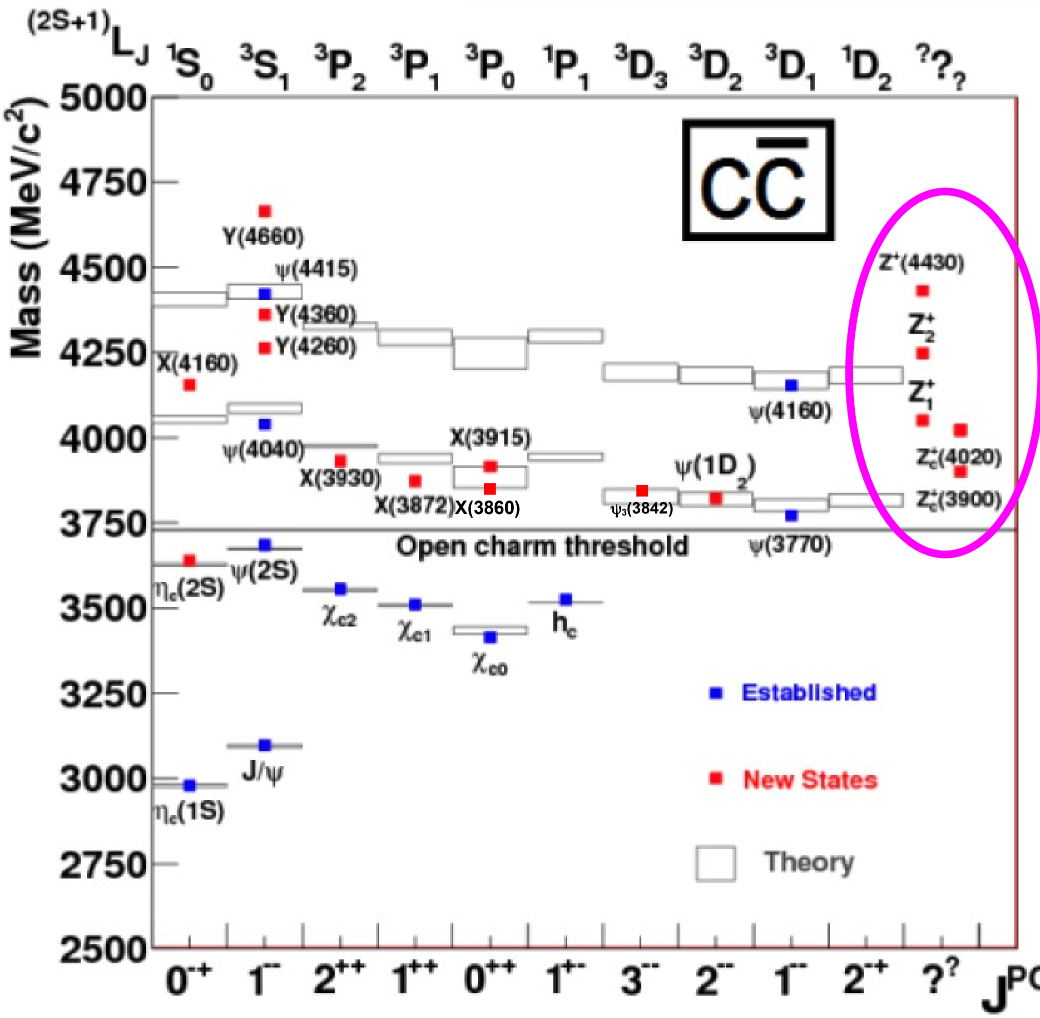


1977 Bottom

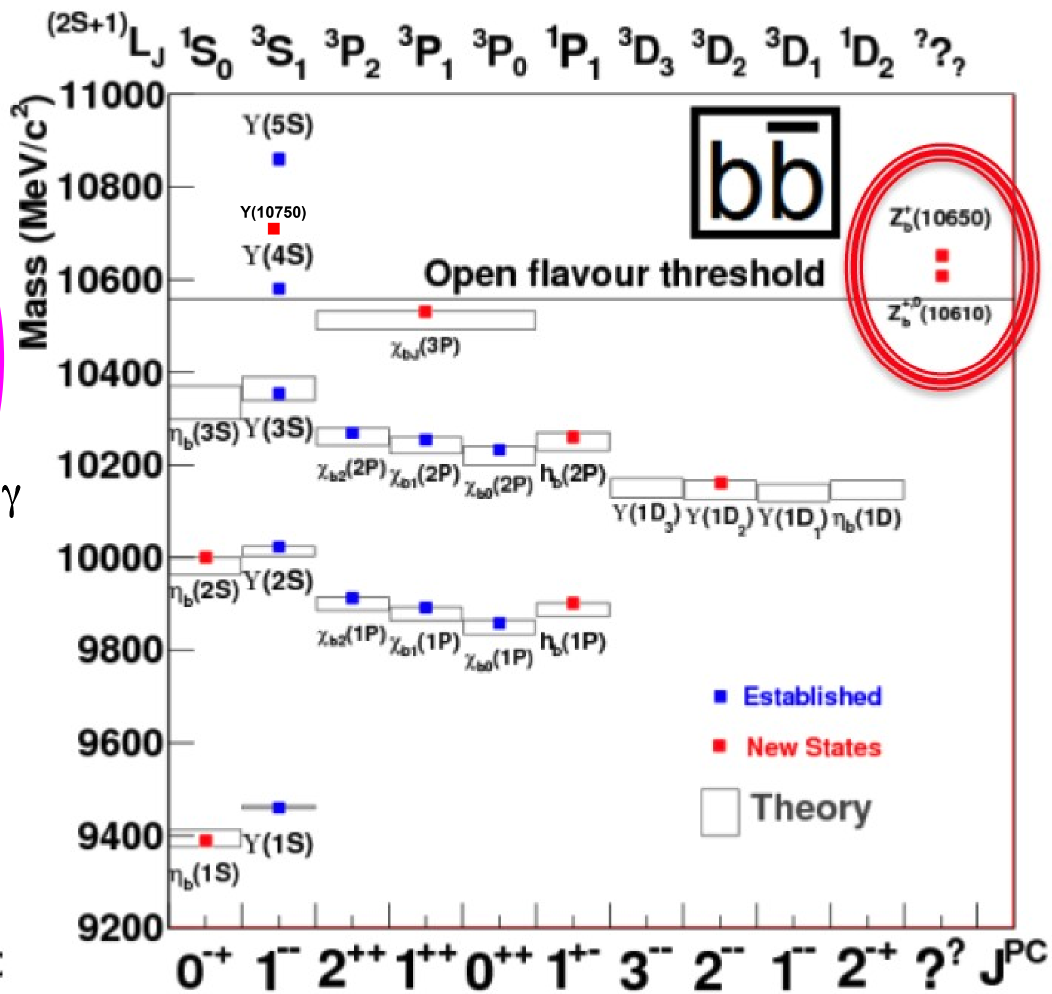
1981 B mesons

2002-now: beyond Heavy Quarkonia

Besides discovering many missing conventional quarkonium states, the B-factories and BES-III found many meson states not compatible with quarkonium models, dubbed the XYZ states.



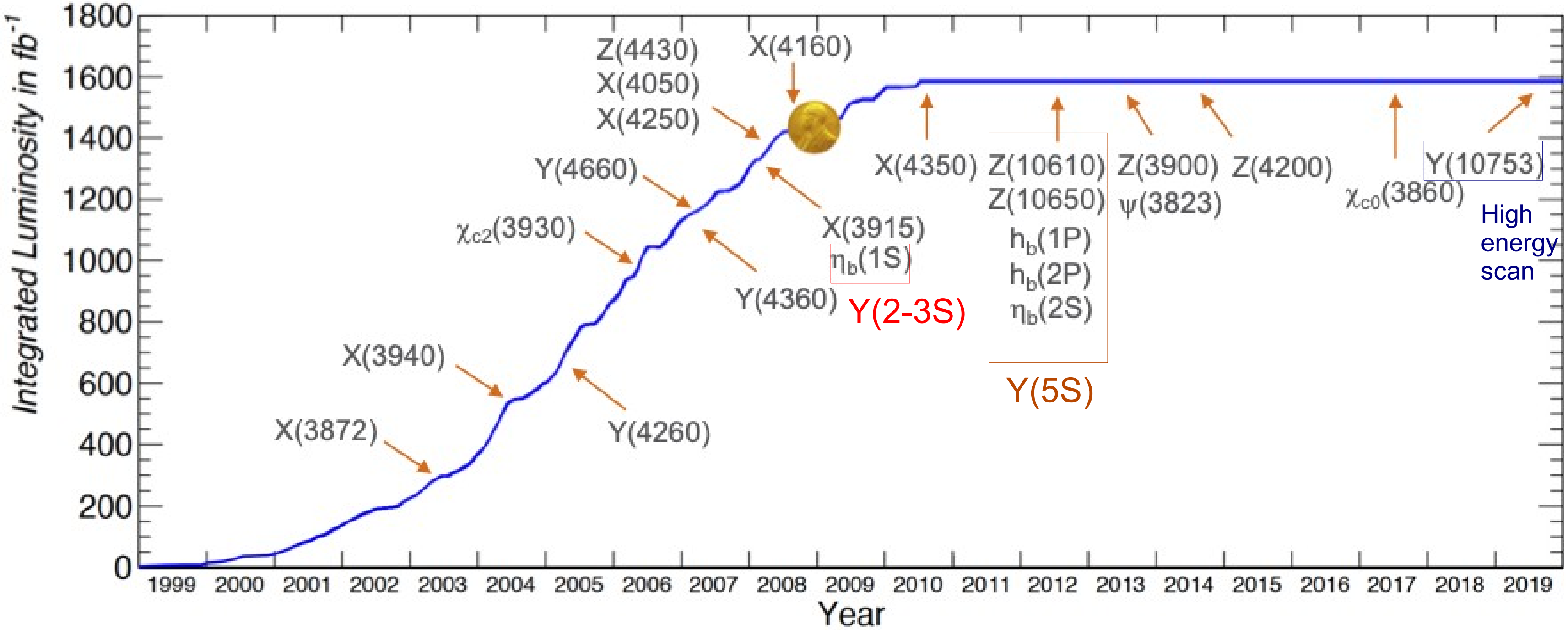
γ



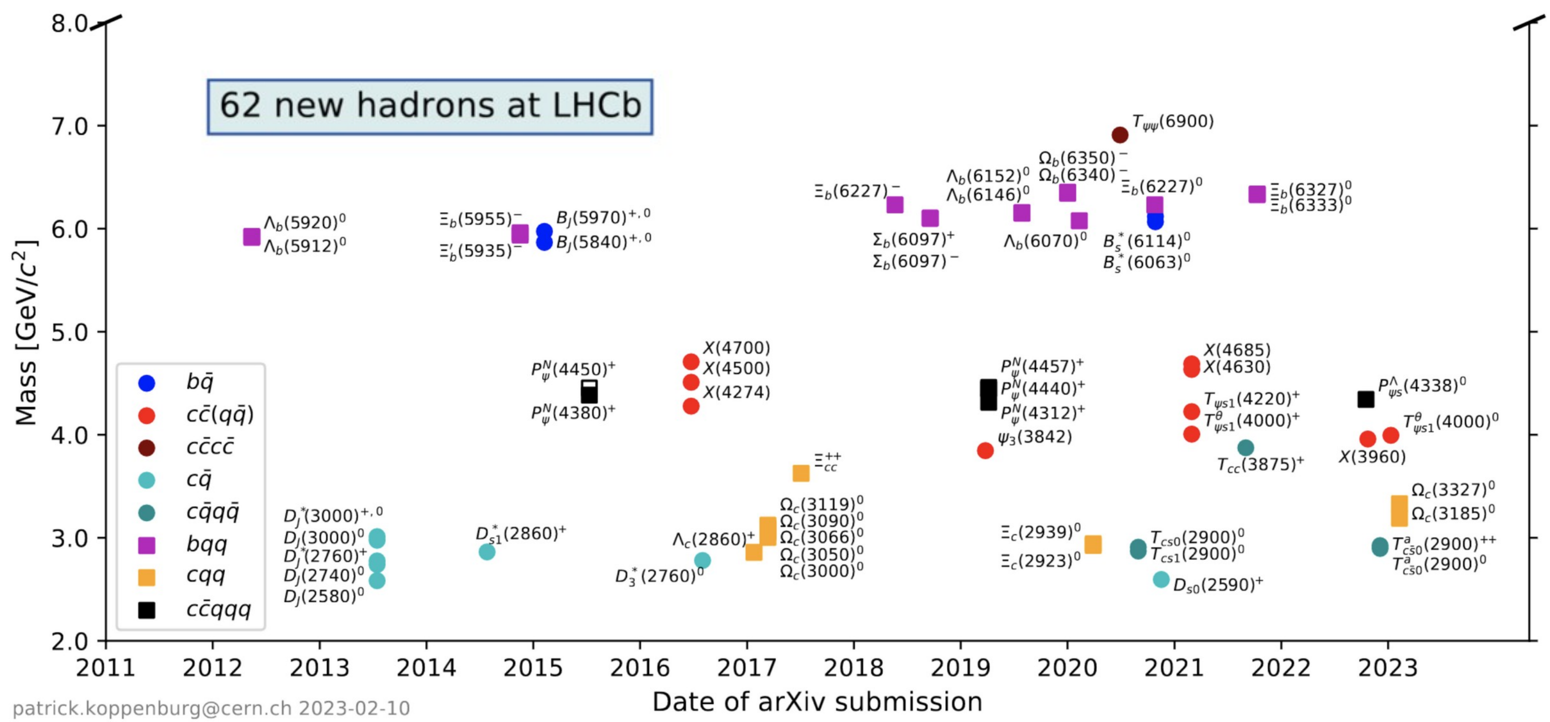
The need to introduce light quark degrees of freedom to describe the XYZ states was finally confirmed with observation of charged charmonium-like (Z_c) and bottomonium-like(Z_b) states.

2002-now: the role of B-factories

e^+e^-



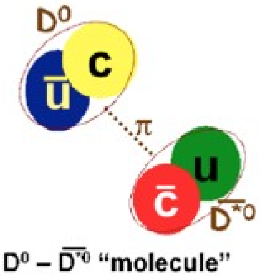
pp



R,Mussa, PIC2023, Arica

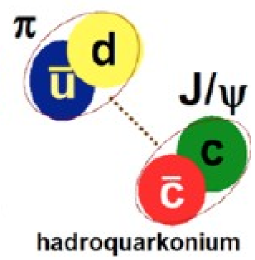
What are the XYZ states?

The plethora of new charmonium-like and bottomonium-like states found by B-factories and LHC experiments in the last 20 years has been stimulating very lively debates in the QCD theory community. A short compilation of the various models here:



Meson Molecules (Guo et al, Rev.Mod.Phys.90,015004 (2018))
weakly bound states of two mesons

Tetraquarks (Polosa et al, PRD89, 114010 (2014))
Diquark-antidiquark states bound by the color force



Hybrids (Barnes, PRD 52,5242 (1995)
Meyer and Swanson, Prog.Part.Nucl.Phys. 82, 21 (2015))
colored $Q\bar{Q}$ states with a bound excited gluon

Hadroquarkonium (Dubinskij et al, PLB 666, 344 (2008))
$Q\bar{Q}$ bound state surrounded by a cloud of light quarks

Standard quarkonia (Swanson, PRD 91, 034009 (2015))

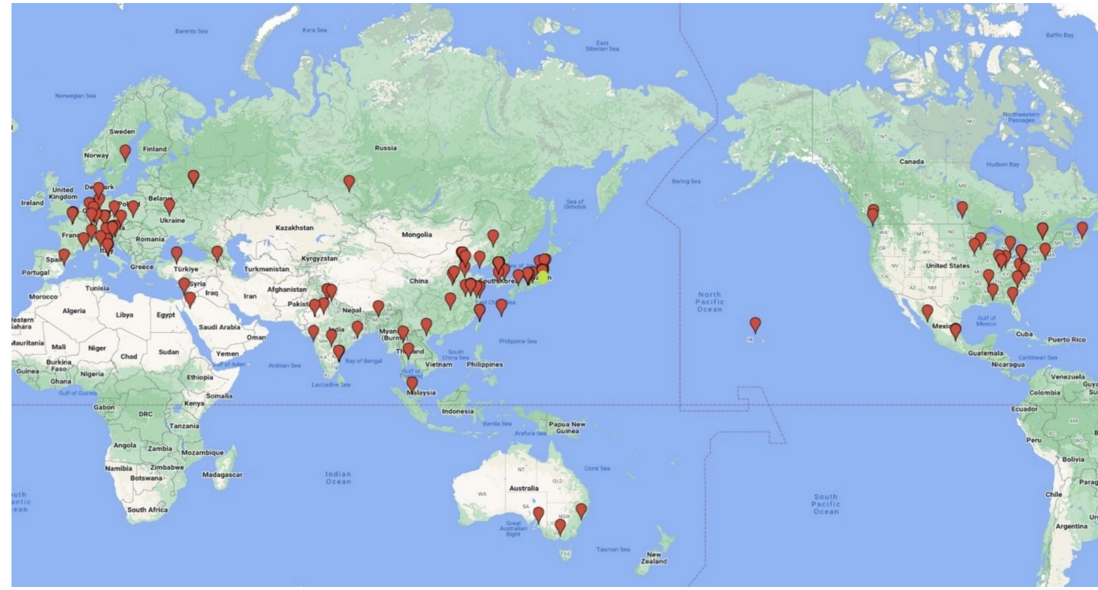
Full comprehensive reviews in:

- Brambilla *et al*, Eur.Phys J C(2011)1534
- Olsen *et al*, Rev.Mod.Phys. 90 (2018) 015003

See also: qwg.ph.tum.de

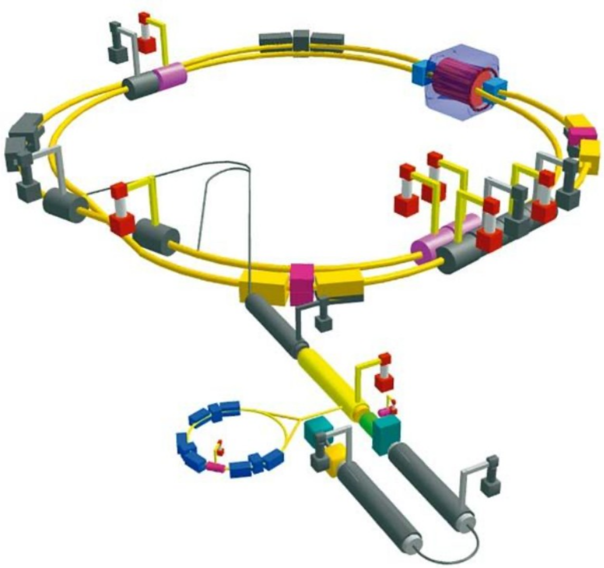
Super-B factory at KEK

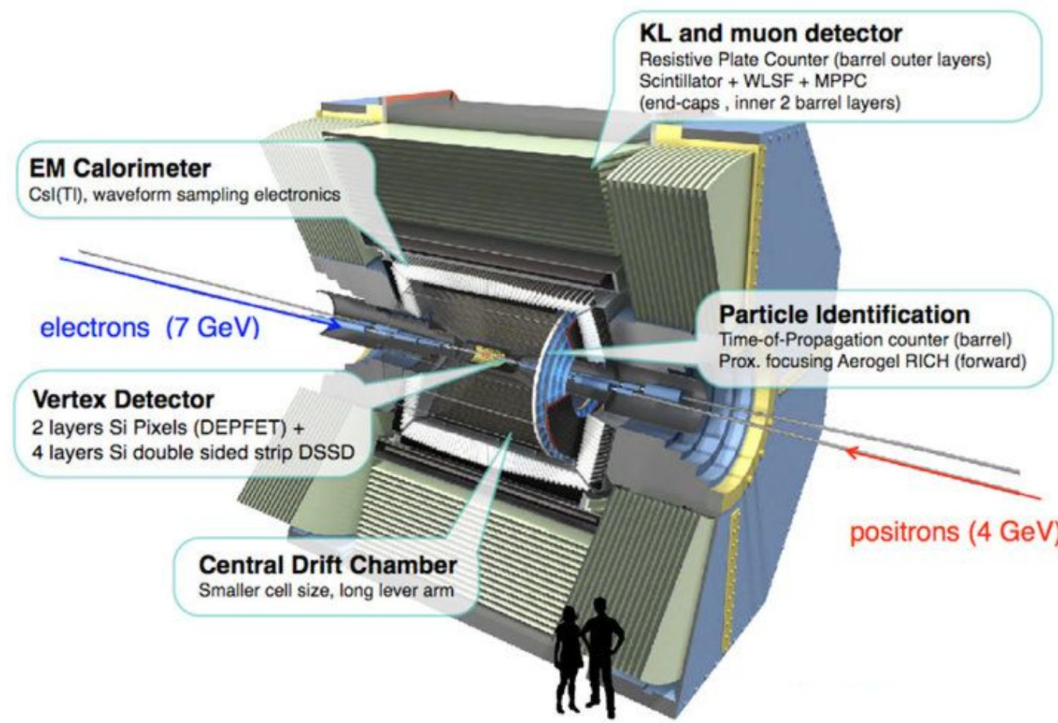
1168 active members
123 institutes
27 countries
(as of September 2023)



Asymmetric **e^+e^- collider**

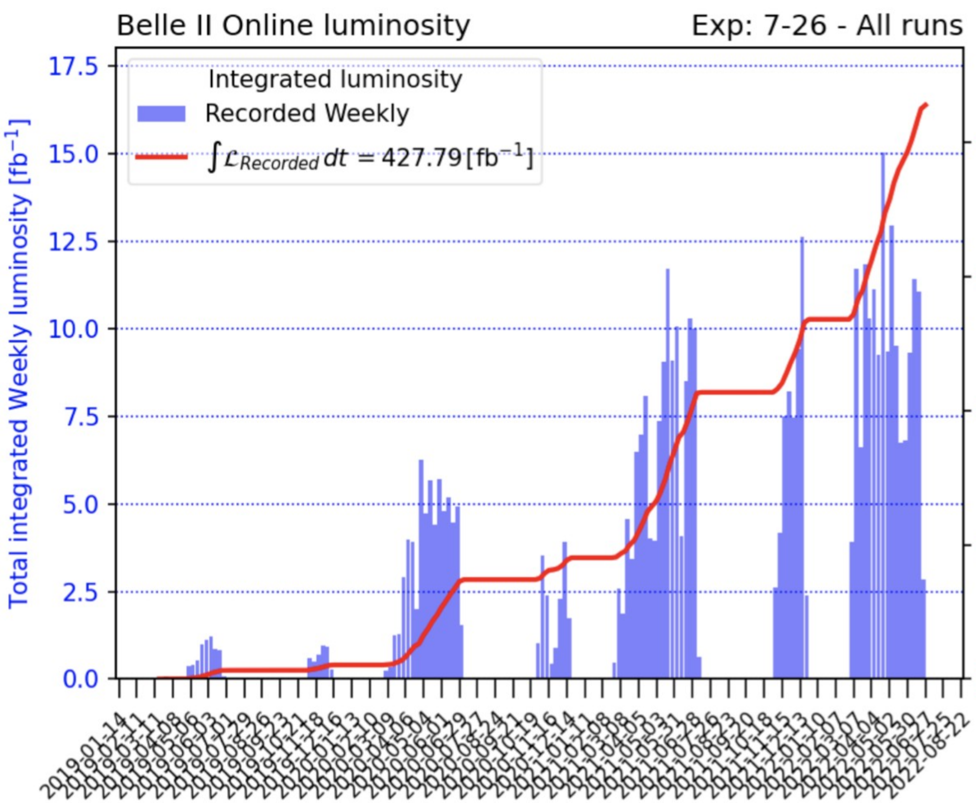
⇒ **$J^{PC}=1^{--}$** states directly produced



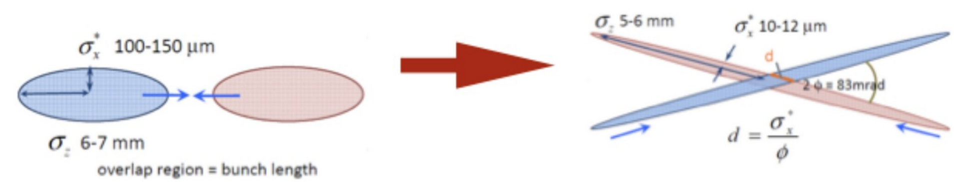


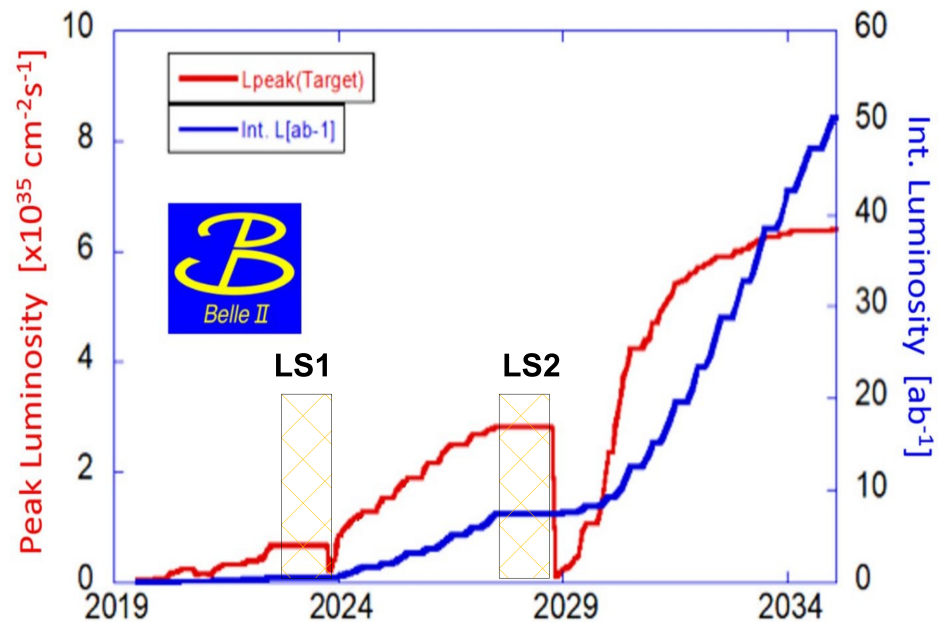
$\sqrt{s} \sim 9 - 11\ GeV$ ⇒ $b\bar{b}$ energy region

Belle-II Luminosity



KEKB SuperKEKB





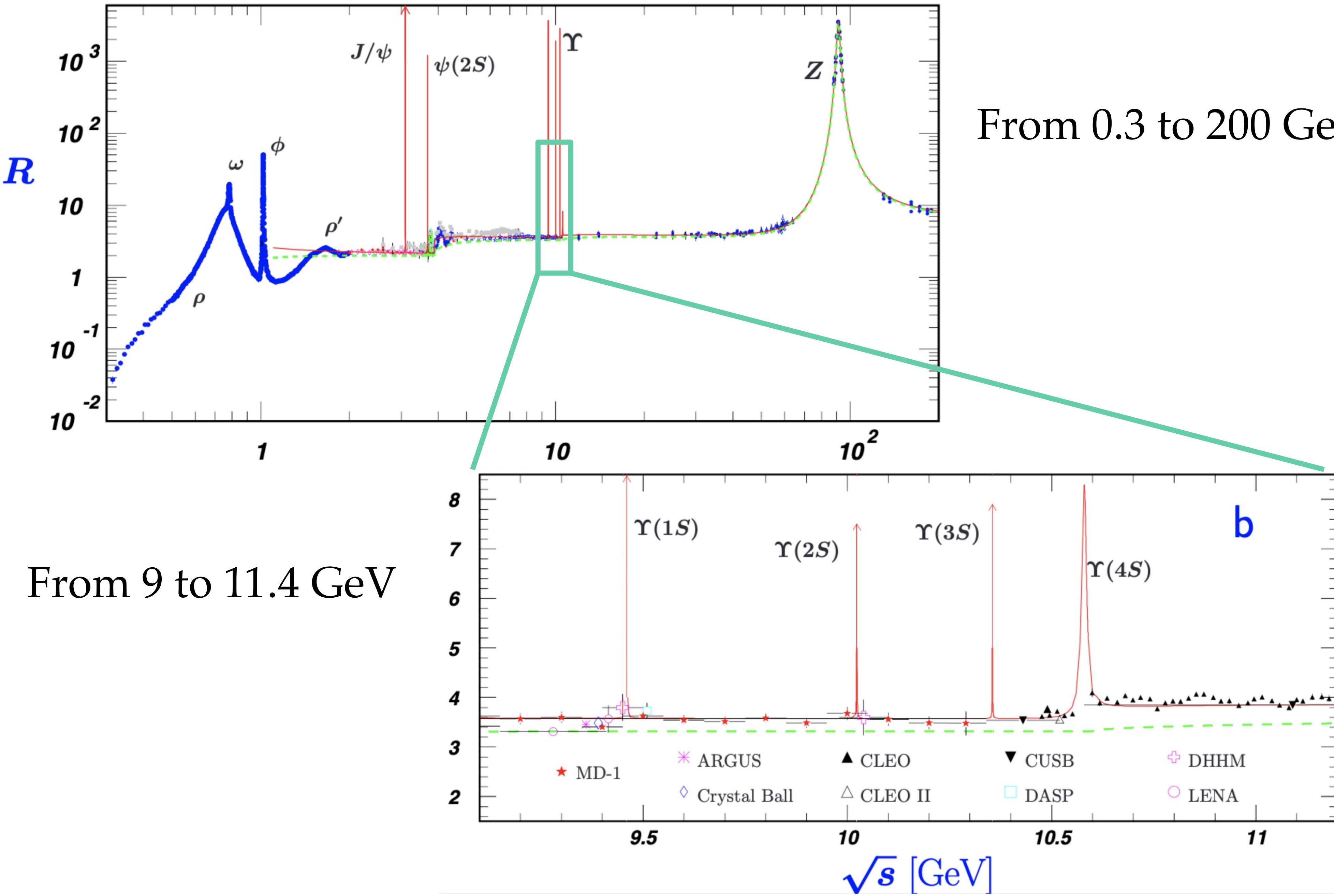
Results before Long Shutdown 1 (LS1):

Record instantaneous Luminosity: 4.7x10^{34} cm^{-2} s^{-1}

Integrated Luminosity ~ 427 fb^{-1}

(364.8 at 4S peak , 42.3 at E=10.52 GeV, 19.7 in the 4-pt scan)

Scans: $R = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$



From 0.3 to 200 GeV

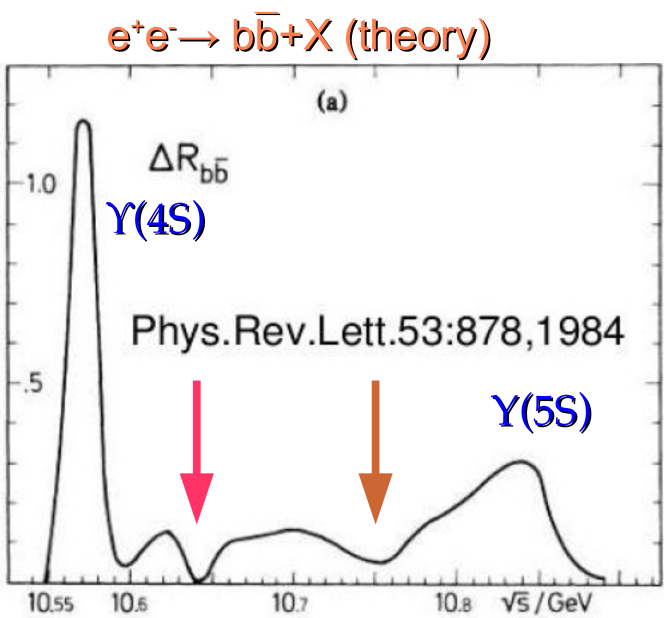
From 9 to 11.4 GeV

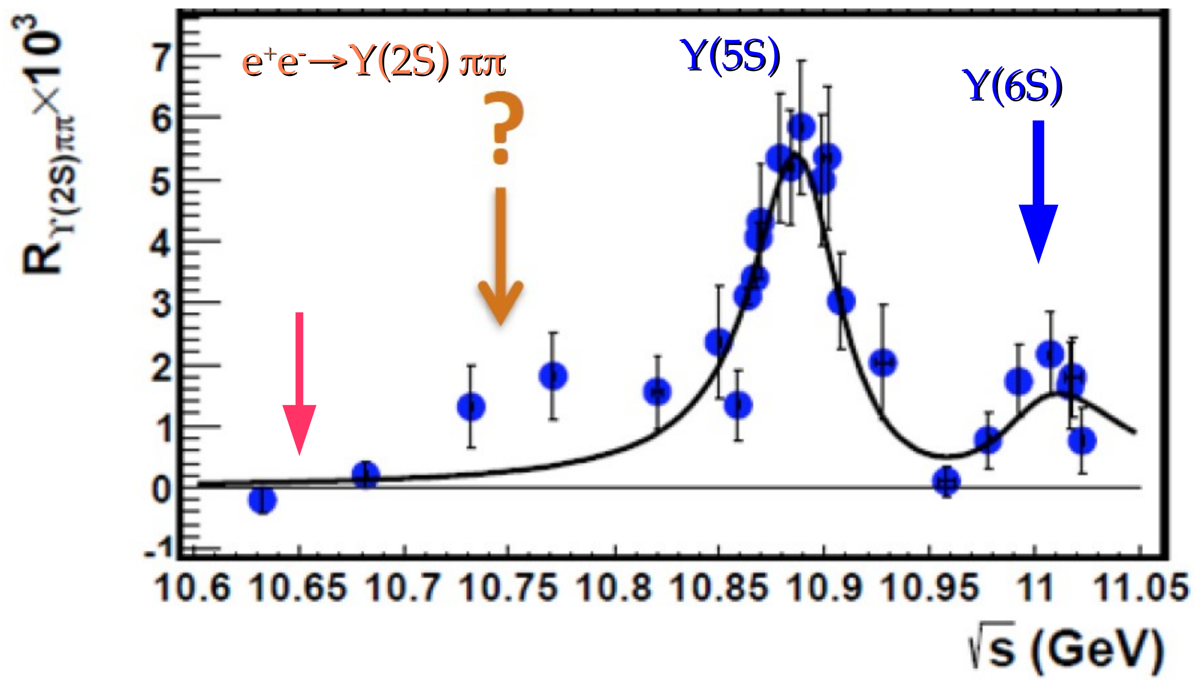
High energy scans

Belle data samples:
- 121.4 fb^{-1} on Υ(5S) peak, $\sqrt{s}$ = 10865 GeV
- 61 points, 50 pb^{-1}, $\sqrt{s}$ = 10.75-11.05 GeV
- 16 points, 1 fb^{-1} , $\sqrt{s}$ = 10.63-11.02 GeV
- continuum data at $\sqrt{s}$ = 10520 GeV

$R_b = \sigma(b\bar{b}+X)/\sigma(\mu\mu)$
Peaks at 10.86, 11 GeV
Dips at 10.65, 10.75 GeV (Tornqvist 84)

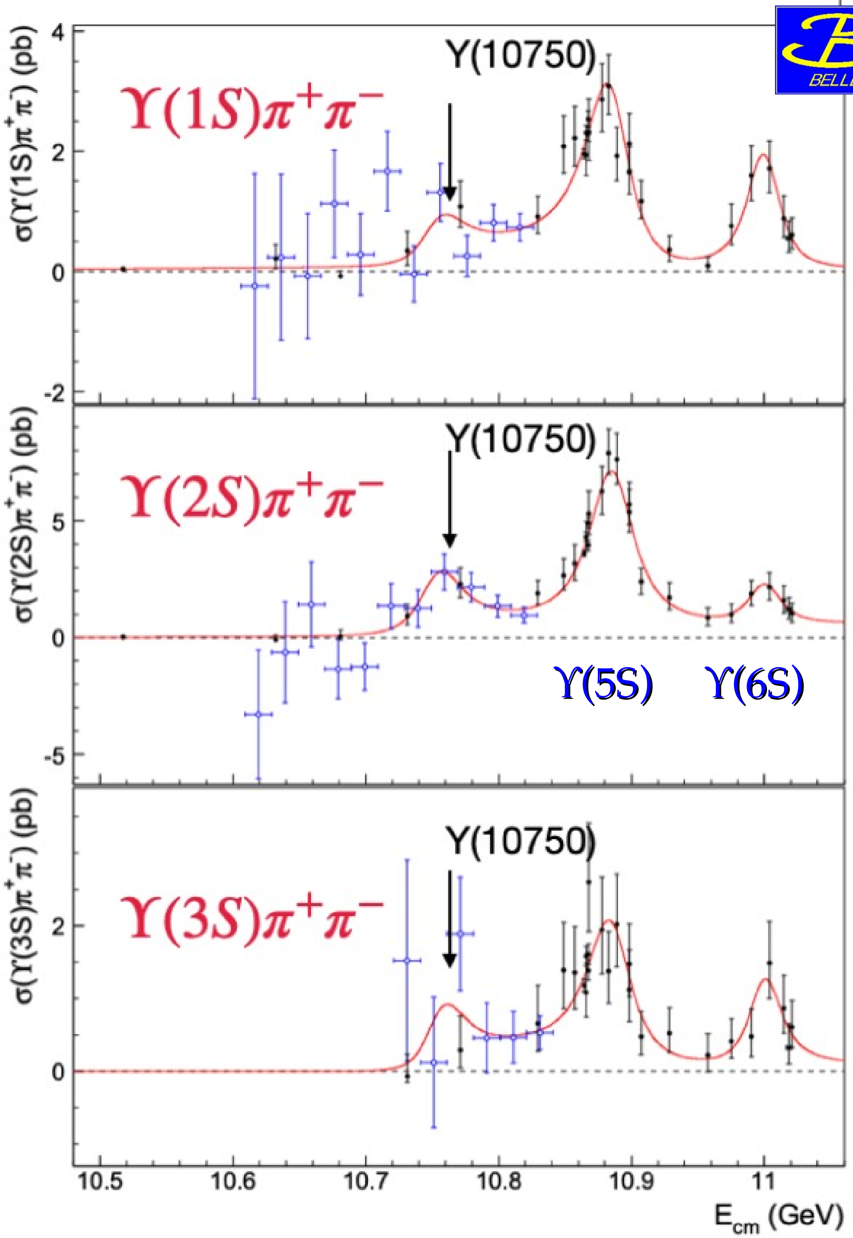
$R_{\Upsilon\pi\pi} = \sigma(\Upsilon\pi\pi)/\sigma(\mu\mu)$
Peaks at 10.89, 11; **bump at 10.75?**





Discovery of Y(10753)

BELLE:JHEP 10 (2019) 220

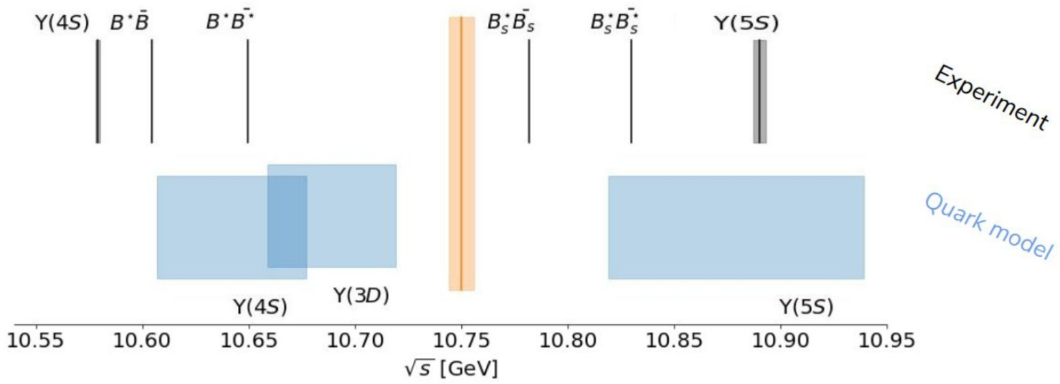


	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

A wide variety of interpretations:

Conventional D- or S-D mixed state

Chen et al., PRD 101 (2020) 1, 014020
Liang et al., PLB 803 (2020) 135340
Li et al., EPJC 80 (2020) 1, 59



Exotic

Bicudo et al., ArXiV:2008.05605 (Dynamic resonance)
Wang, Chin.Phys.C 43 (2019) 12, 123102 (Tetraquark)
Ali et al., PLB 802 (2020) 135217 (Tetraquark)
Giron & Lebed, PRD 102 (2020) 1, 014036 (Υ(5S) is 4q)

First full $B\bar{B}+B\bar{B}^*+B^*\bar{B}^*$ separation of high energy scan data

JHEP 06 (2021)137

Full Event Interpretation : B meson reconstruction improved using Belle-II new algorithms on Belle high energy data.

B and D decay modes:

$B^+ \to$	$B^0 \to$
$\bar{D}^0\pi^+$	$D^-\pi^+$
$\bar{D}^0\pi^+\pi^+\pi^-$	$D^-\pi^+\pi^+\pi^-$
$\bar{D}^{*0}\pi^+$	$D^{*-}\pi^+$
$\bar{D}^{*0}\pi^+\pi^+\pi^-$	$D^{*-}\pi^+\pi^+\pi^-$
$D_s^+\bar{D}^0$	$D_s^+D^-$
$D_s^{*+}\bar{D}^0$	$D_s^{*+}D^-$
$D_s^+\bar{D}^{*0}$	$D_s^+D^{*-}$
$D_s^{*+}\bar{D}^{*0}$	$D_s^{*+}D^{*-}$
$J/\psi K^+$	$J/\psi K_S^0$
$J/\psi K_S^0\pi^+$	$J/\psi K^+\pi^-$
$J/\psi K^+\pi^+\pi^-$	
$D^-\pi^+\pi^+$	$D^{*-}K^+K^-\pi^+$
$D^{*-}\pi^+\pi^+$	

$D^0 \to$	$D^+ \to$	$D_s^+ \to$
$K^-\pi^+$	$K^-\pi^+\pi^+$	$K^+K^-\pi^+$
$K^-\pi^+\pi^0$	$K^-\pi^+\pi^+\pi^0$	$K^+K_S^0$
$K^-\pi^+\pi^+\pi^-$	$K_S^0\pi^+$	$K^+K^-\pi^+\pi^0$
$K_S^0\pi^+\pi^-$	$K_S^0\pi^+\pi^0$	$K^+K_S^0\pi^+\pi^-$
$K_S^0\pi^+\pi^-\pi^0$	$K_S^0\pi^+\pi^+\pi^-$	$K^-K_S^0\pi^+\pi^+$
K^+K^-	$K^+K^-\pi^+$	$K^+K^-\pi^+\pi^+\pi^-$
$K^+K^-K_S^0$		$K^+\pi^+\pi^-$
		$\pi^+\pi^+\pi^-$

Key variables for analysis are

$$M_{bc} \equiv \sqrt{(E_{beam,CM})^2 - (p_{B,CM})^2}$$

and

$$\Delta E' \equiv \Delta E - M_{bc} + M_B$$

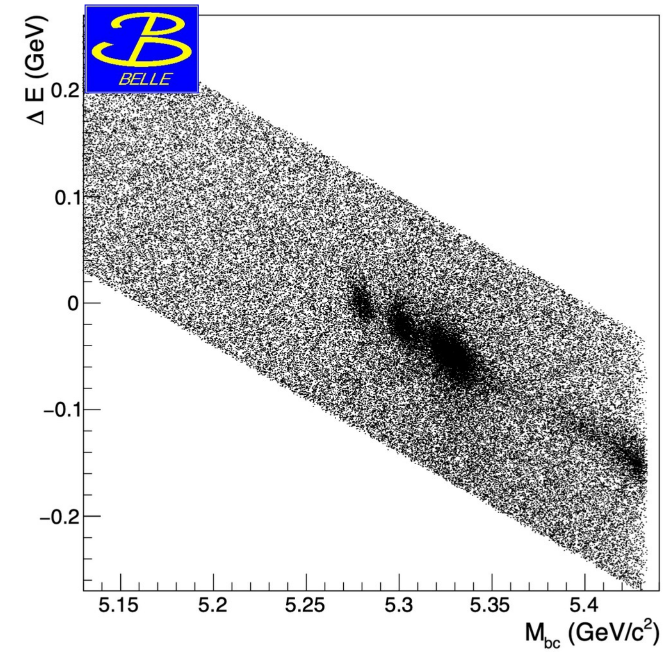
where

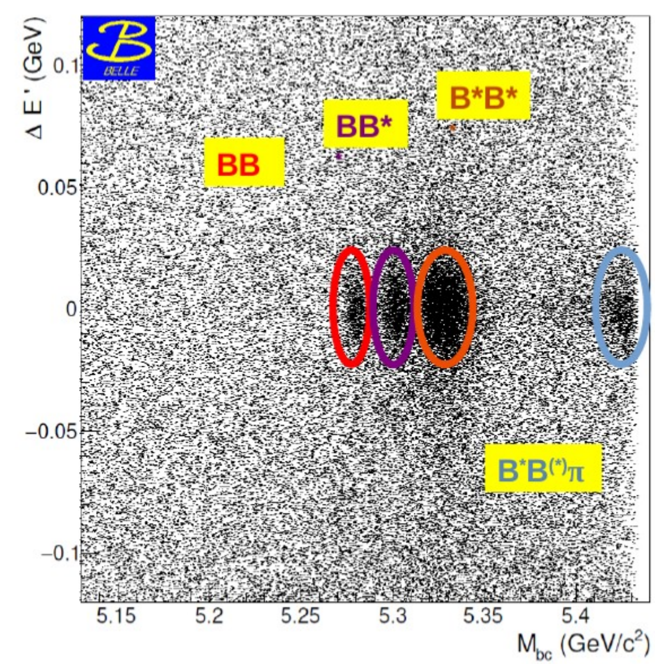
$$\Delta E \equiv E_{B,CM} - E_{beam,CM}$$

This has improved resolution and allows all decays to be selected with a common cut on energy difference.

$\varepsilon = (0.589 \pm 0.012)\times 10^{-3}$

(25.5% higher than in Belle)

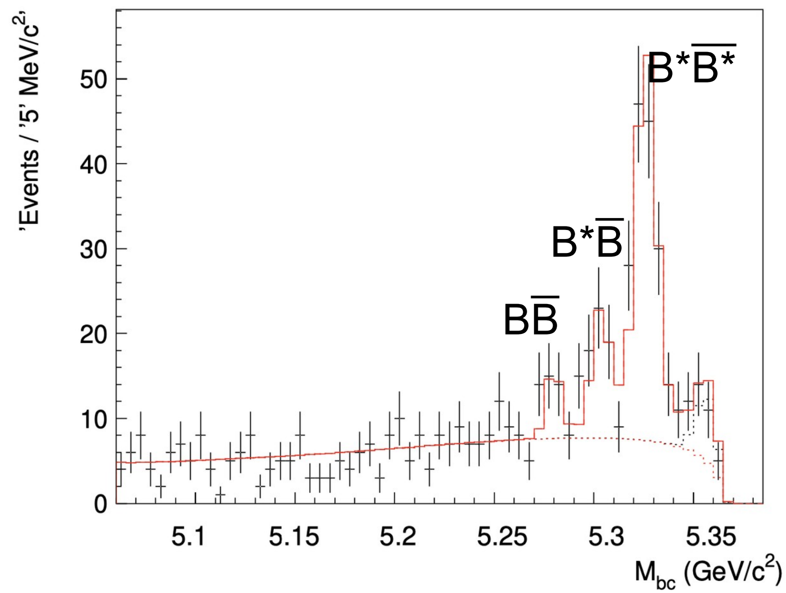


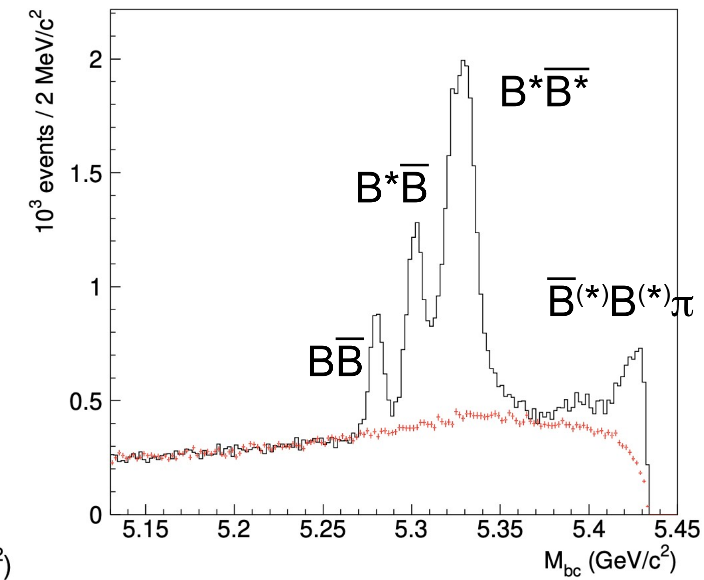


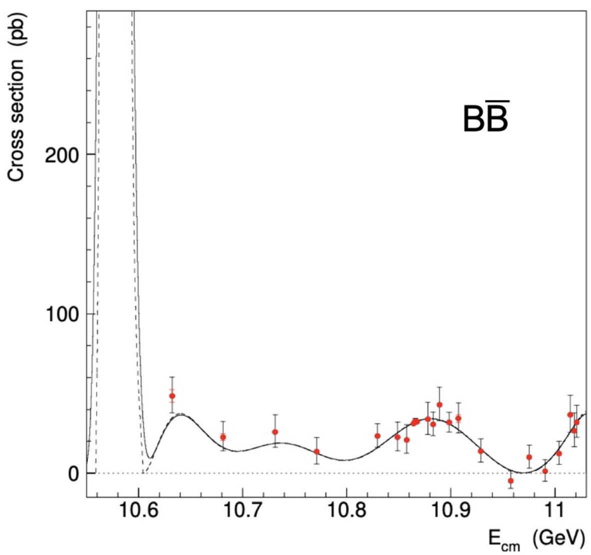
First full $B\bar{B}$+$B\bar{B}^*$+$B^*\bar{B}^*$ separation of high energy scan data

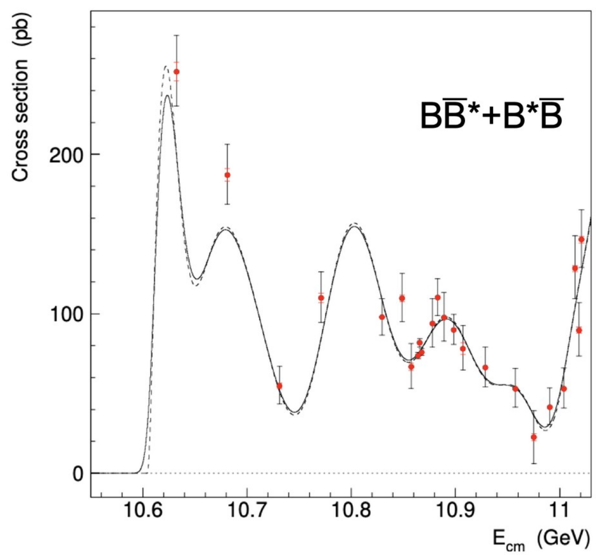
JHEP 06 (2021)137

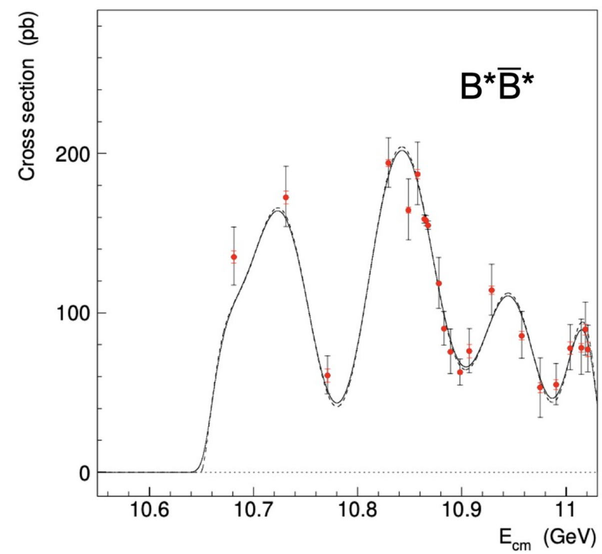
Two body cross sections extracted from the fits of the three peaks at each energy points (right) and fitted with Chebyshev polynomials (below).





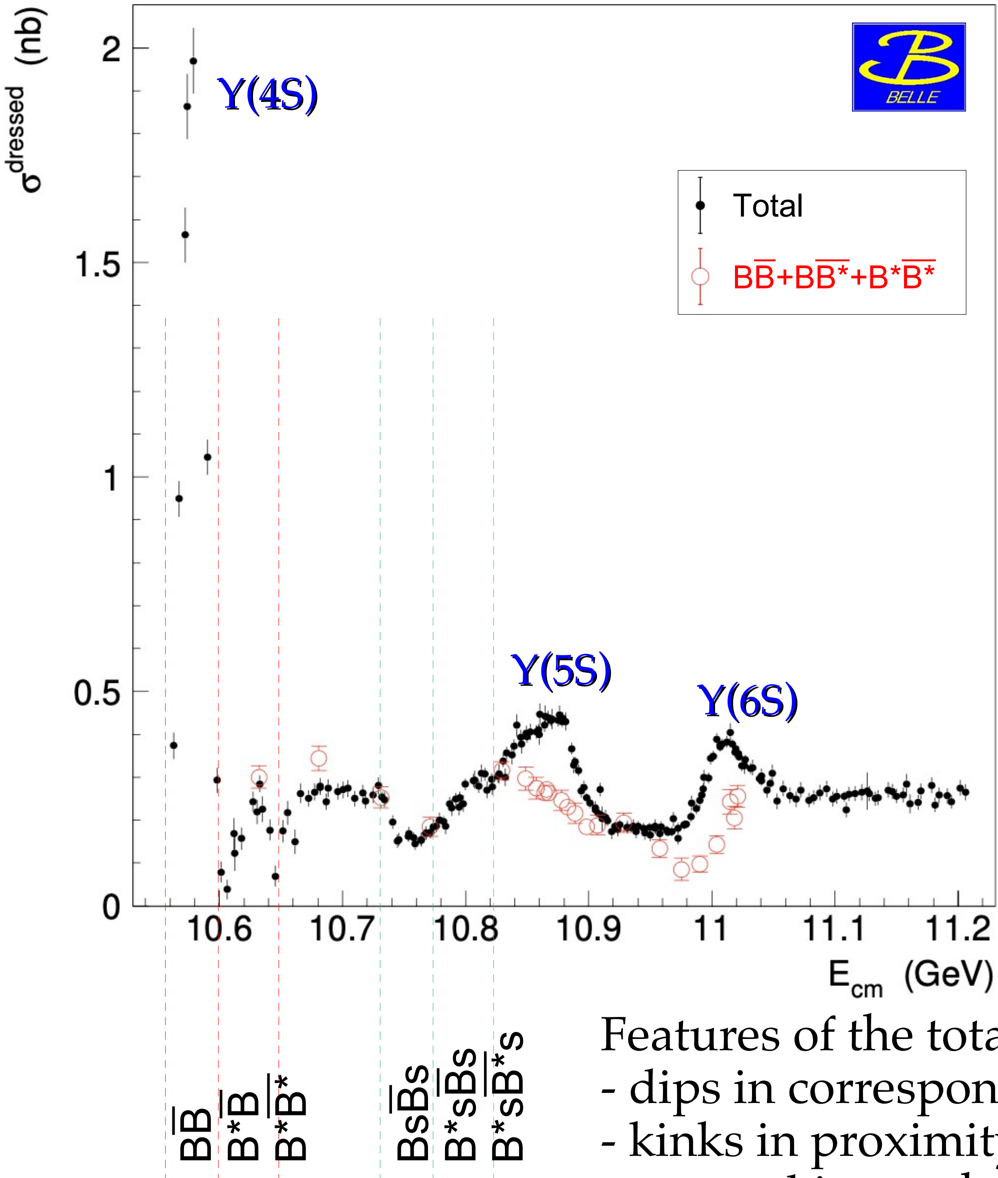


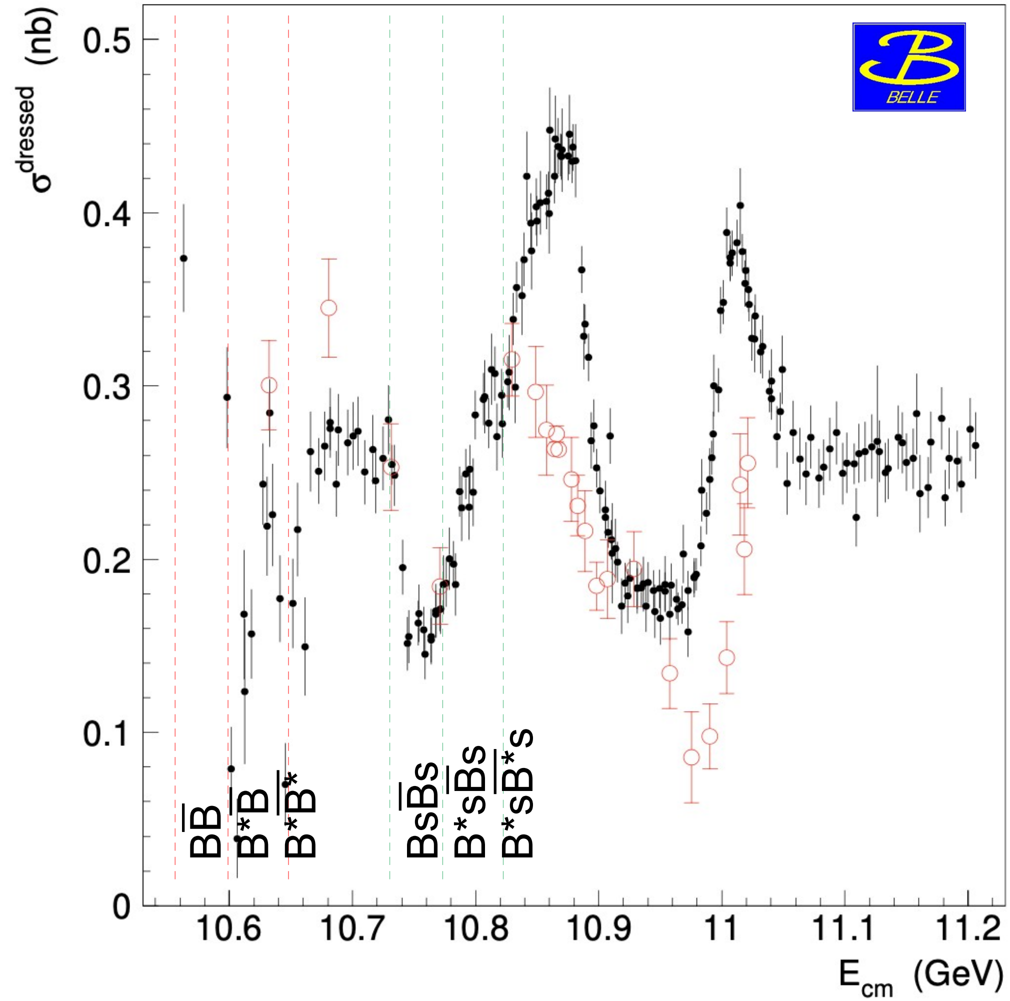




First full $B\bar{B}+B\bar{B}^{*}+B^{*}\bar{B}^{*}$ separation of high energy scan data

JHEP 06 (2021)137





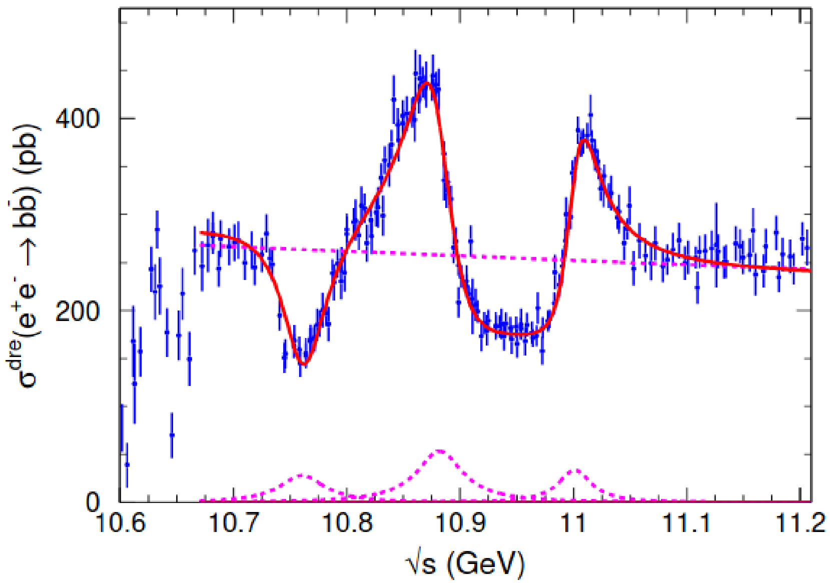
Features of the total cross section:

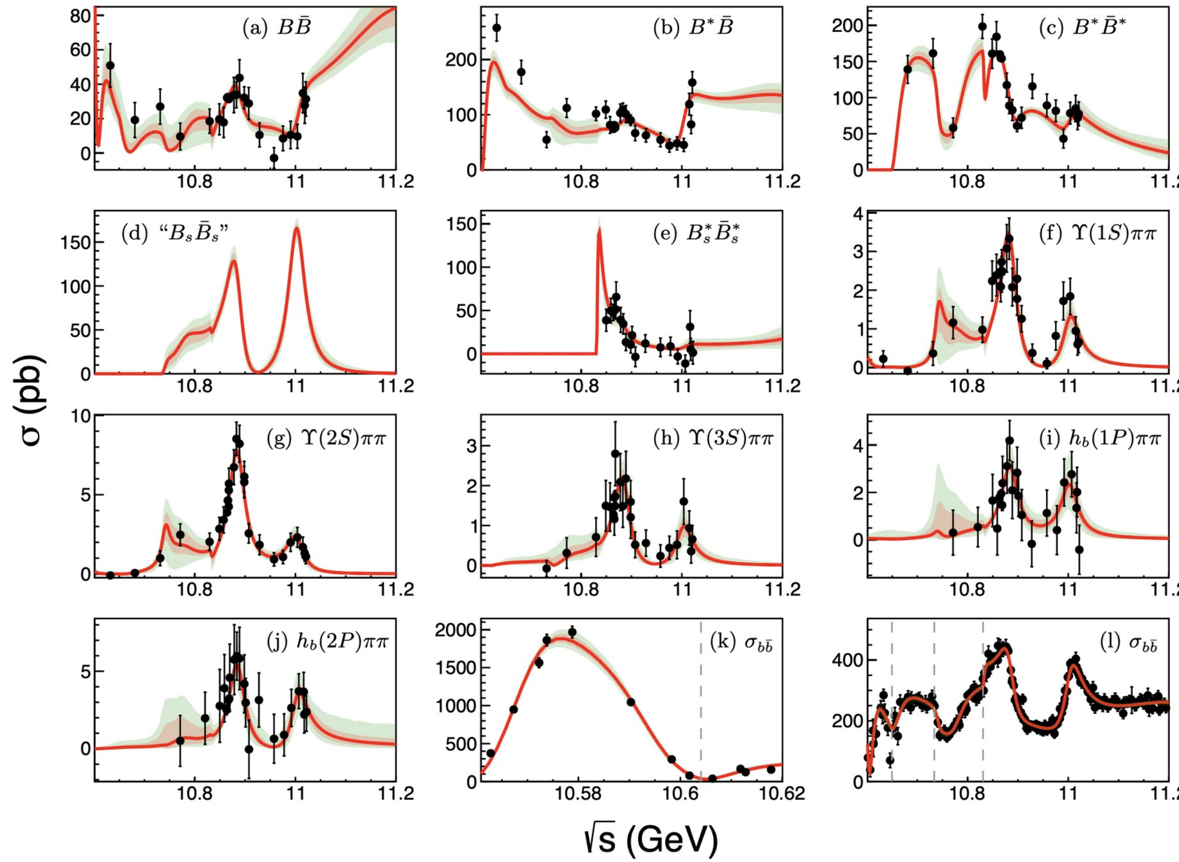
- dips in correspondence of $B\bar{B}^{*}$ and $B^{*}\bar{B}^{*}$ thresholds
- kinks in proximity of $B_s\bar{B}_s$ and $B^{*}{}_s\bar{B}^{*}{}_s$ thresholds
- not peaking at the Υ(5S) peak energy

Evidence of Y(10753) refitting the scans

Hüsken et al, PRD 106 (2022) 9, 094013

Dong et al, Chin.Phys.C 44 8, 083001





Refit of Babar and Belle data

Dip at 10753 generated by destructive interference with a smooth continuun

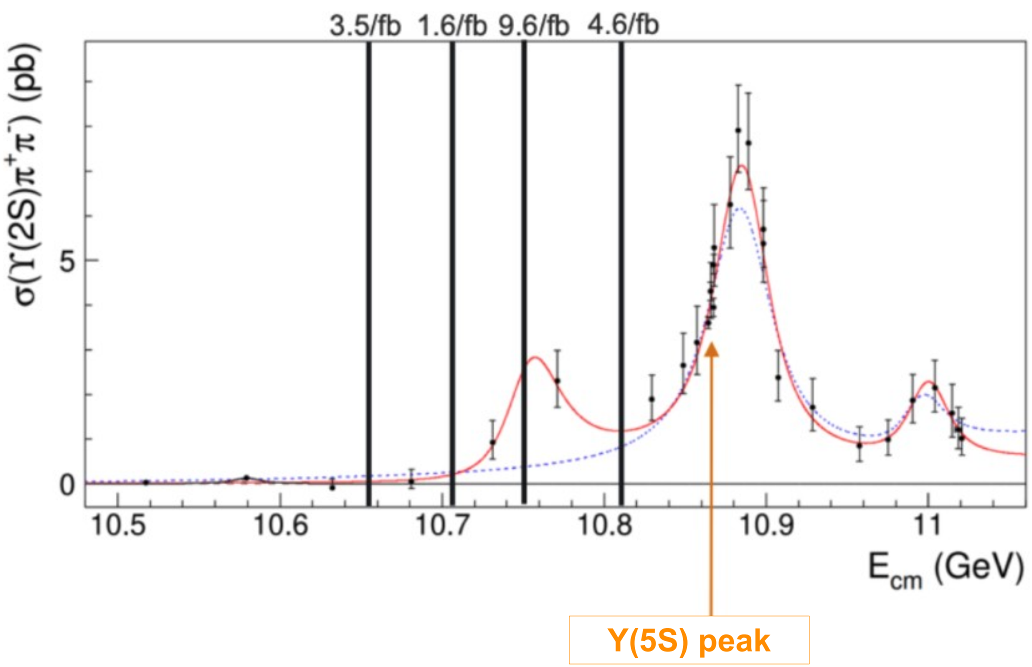
Parameter	$Y(10750)$	$\Upsilon(5S)$	$\Upsilon(6S)$
Mass/(MeV/c^2)	10761 ± 2	10882 ± 1	11001 ± 1
Width/MeV	48.5 ± 3.0	49.5 ± 1.5	35.1 ± 1.2

Coupled channel analysis of high energy scan data using the K-matrix formalism

Belle-II restarts from Υ(10753)

Data taking outside the Y(4S) peak was very fruitful at Belle, with unique record data samples at Y(1,2,5S) peak energies, and the high energy scans just shown, which raised new questions about the possible existence of new vector bottomonium-like states.

Therefore, the first motivation for data taking not at Y(4S) peak was to investigate the nature of the Y(10753): 4 points, 19.7fb^{-1} total.



Mode	Status @ Belle
BBar decomposition	***JHEP 06 (2021) 137***
$e^+e^- \to \pi\pi Y(nS)$	***JHEP 10 (2019) 220***
Di-pion Dalitz	Need more data
$Y(10750) \to \omega\, \eta_b(1S)$	***PRD 102 (2020) 9, 092011(*)***
$Y(10750) \to \pi\pi\, h_b(nP)$	Need more data
$Y(10750) \to \eta\, h_b(1P)$	Need more data
$Y(10750) \to Y(nS)$ inc.	Need more data
$Y(10750) \to \omega\, \chi_b(1P)$	In pub / Need more points
$Y(10750) \to \eta Y(nS)$	Need more data
$Y(10750) \to \eta' Y(nS)$	Need more data

(*) only limits from data at Y(4S) and Y(5S) peaks

Many analyses, suggested by recent theory papers are ongoing.

First results from this dataset in the next slides ….

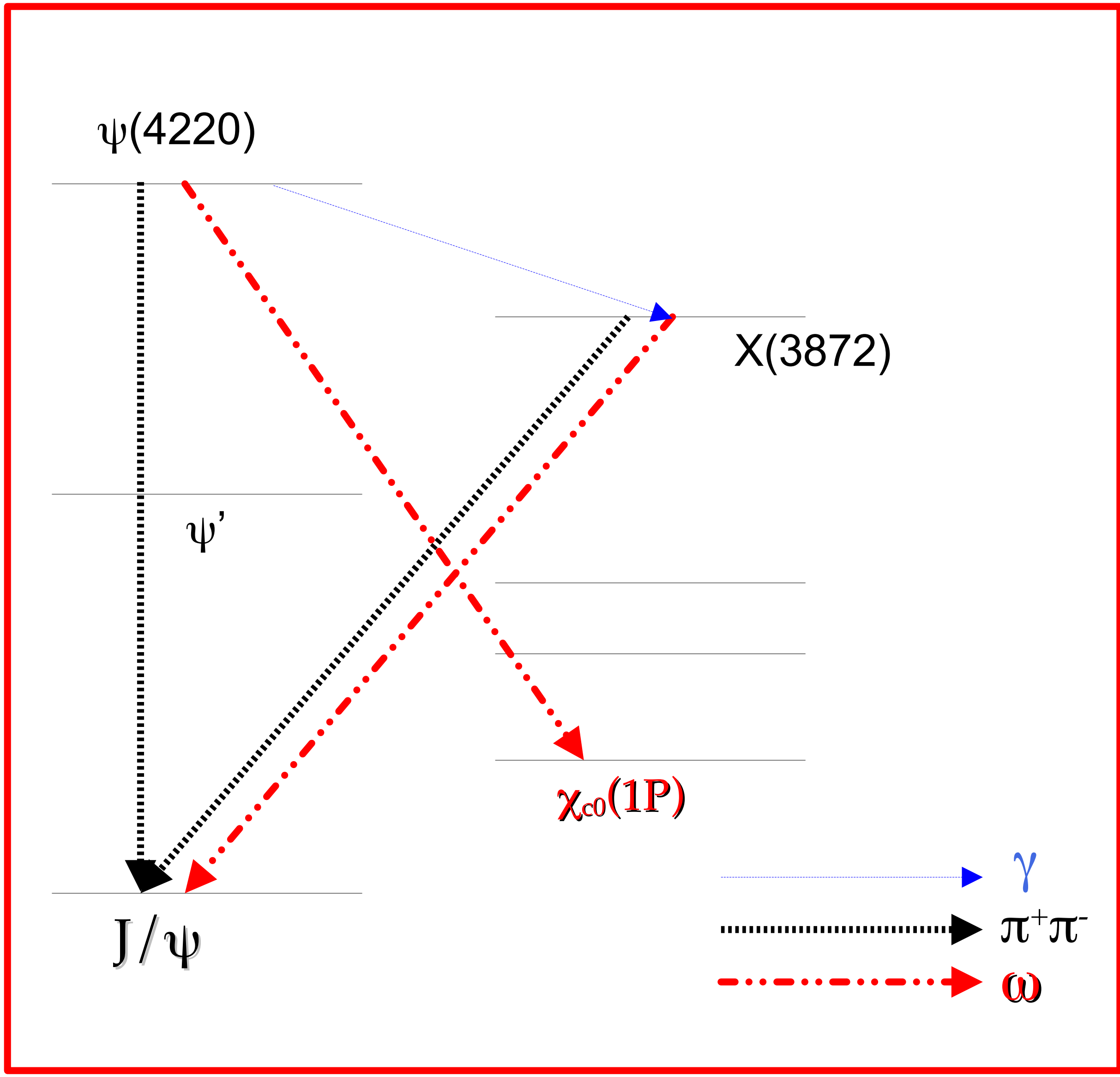
Study of $\Upsilon(10753) \rightarrow (\pi^+\pi^-\pi^0)\,\gamma\,\Upsilon(1S)$

Inspired by decay modes of $\psi(4220)$, observed by BES-III:

- $J/\psi\,\pi^+\pi^-$
- $\chi_{c0}(1P)\,\omega$
- $\gamma X(3872)$

Search for the bottomonium analogue of X(3872), X_b, and the $\omega\chi_{bJ}(1P)$ transition, in the process:

$$e^+e^- \rightarrow (\pi^+\pi^-\pi^0)\,\gamma\,\Upsilon(1S)$$



Study of $\Upsilon(10753) \to (\pi^+\pi^-\pi^0)\,\gamma\,\Upsilon(1S)$

Inspired by decay modes of $\psi(4220)$, observed by BES:

- $J/\psi\,\pi^+\pi^-$
- $\chi_{c0}(1P)\,\omega$
- $\gamma X(3872)$

Search for the bottomonium analogue of X(3872), X_b, and the $\omega\chi_{bJ}(1P)$ transition, in the process:

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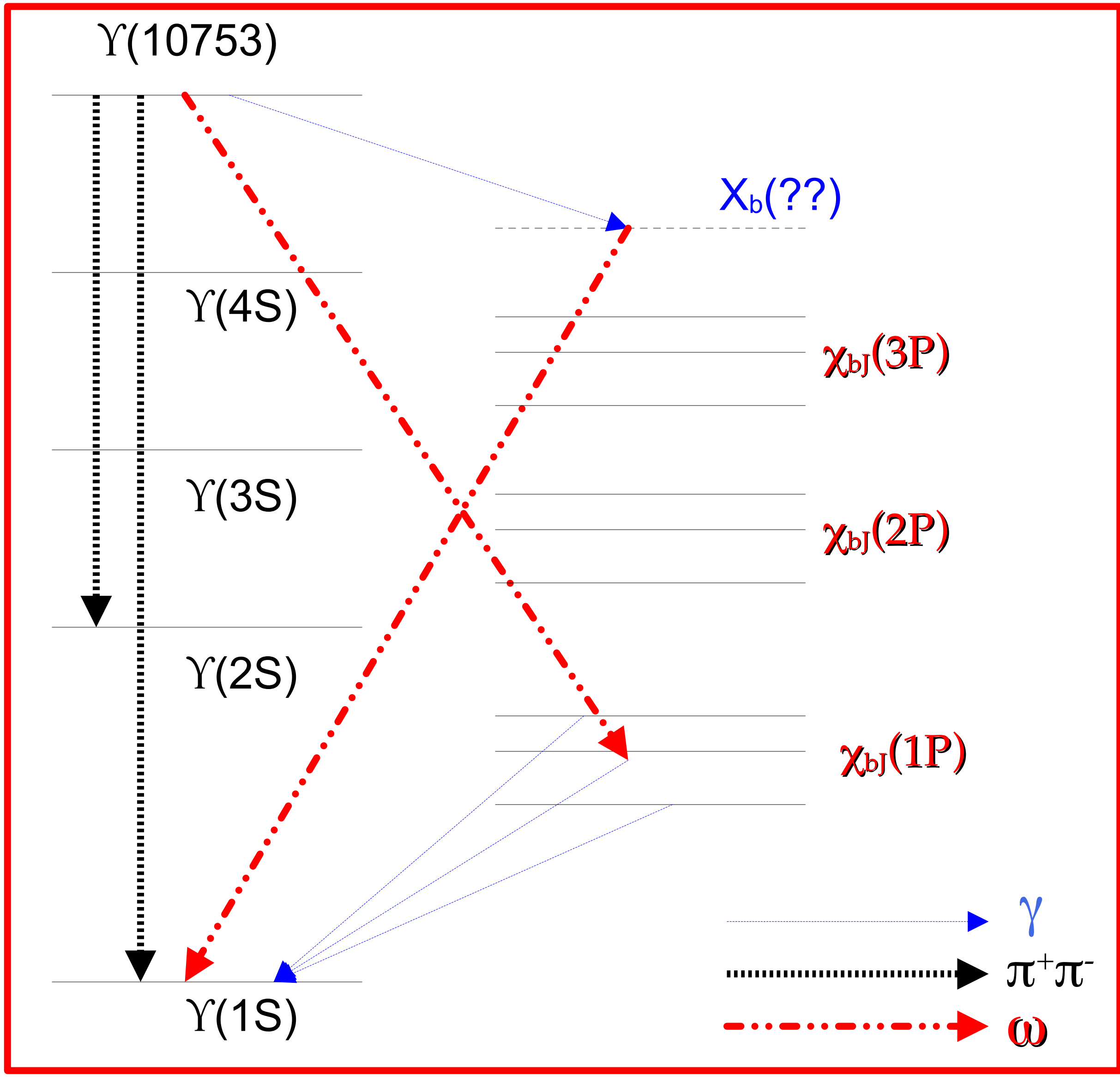


Observation of $\Upsilon(10753) \to \chi_{bJ}(1P)\,\omega$

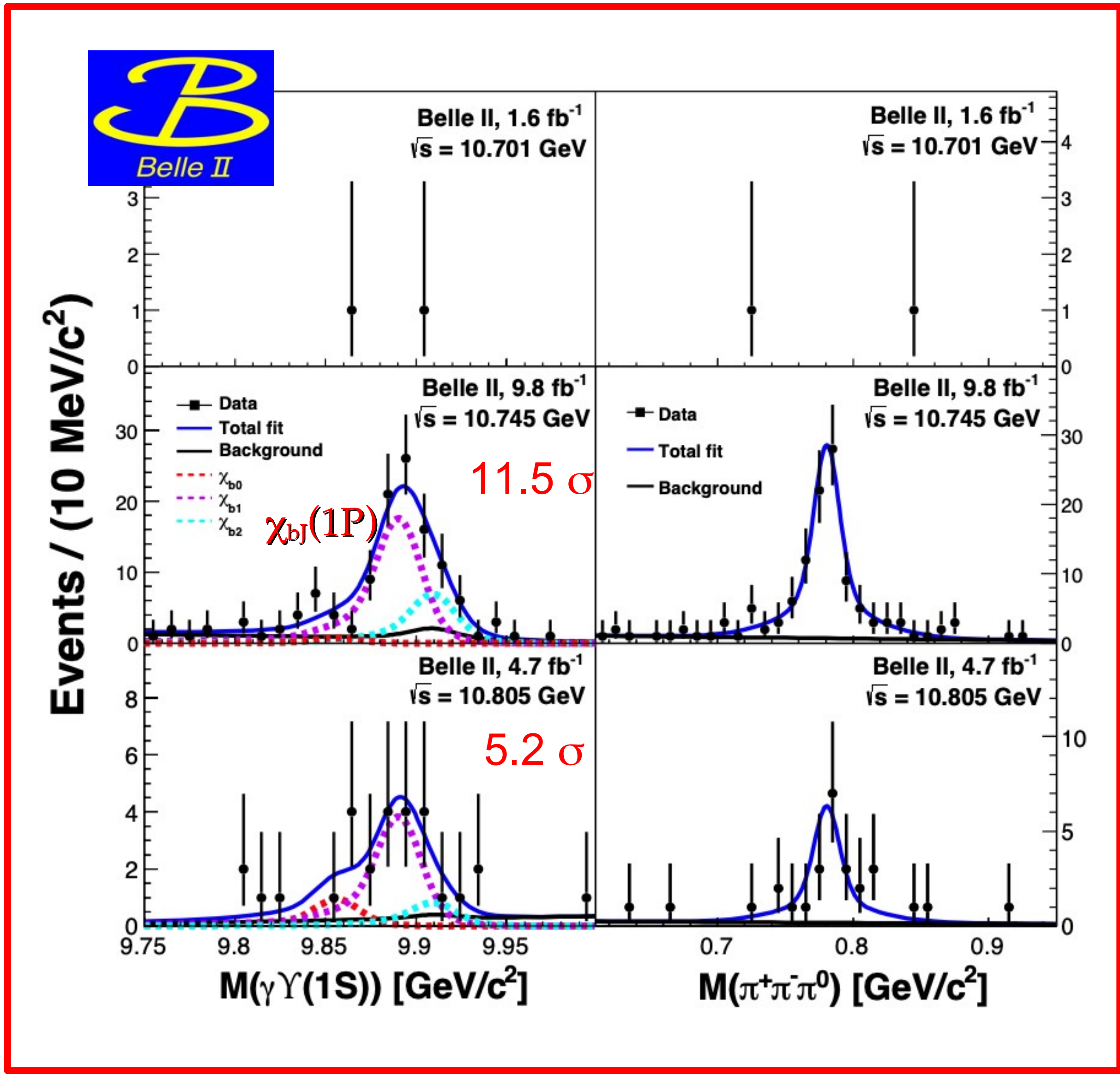
PRL 130, 091902 (2023)

Inspired by decay modes of Y(4220), observed by BES:

- $J/\psi\, \pi^+\pi^-$
- $\chi_{c0}(1P)\, \omega$
- $\gamma X(3872)$

Search for the bottomonium analogue of X(3872), X_b, and the $\omega\chi_{bJ}(1P)$ transition, in the process:

$$e^+e^- \to (\pi^+\pi^-\pi^0)\, \gamma\, \Upsilon(1S)$$



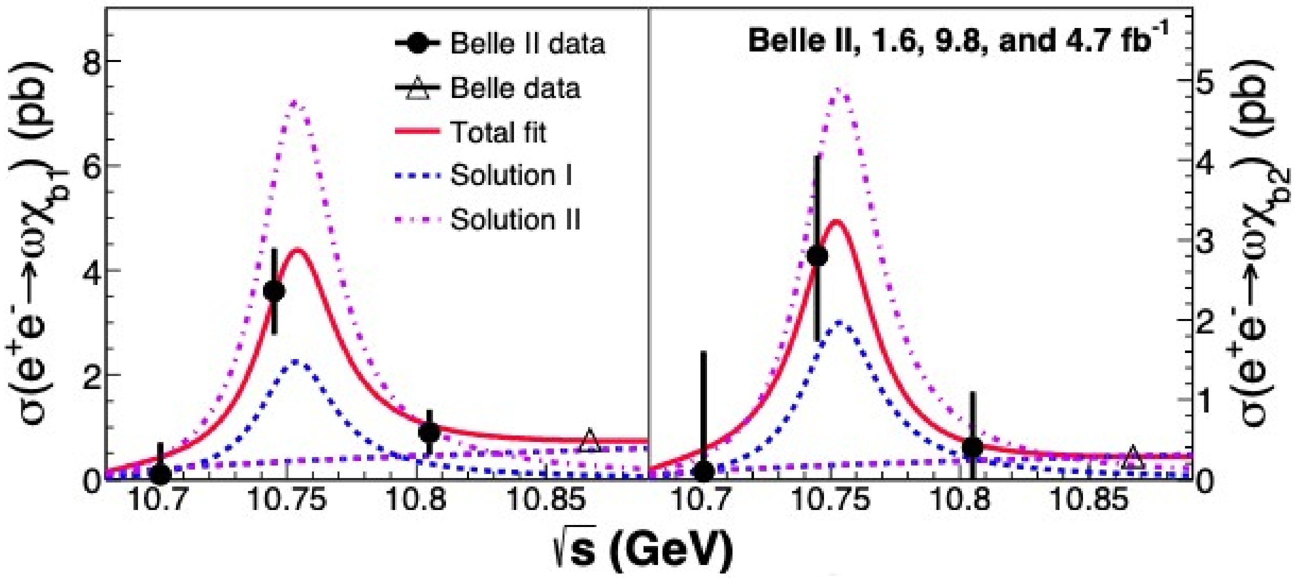
Observation of $\Upsilon(10753) \to \chi_{bJ}(1P)\,\omega$

PRL 130, 091902 (2023)

The signal seen is larger than $\Upsilon(10753) \to \Upsilon(2S)\,\pi^+\pi^-$ [1]

The signal seen at 5S [2] is probably a TAIL of this.

[1] JHEP 10 (2019)220
[2] PRL 113 (2014)142001



Numerical results change assuming constructive (sol.I) or destructive (sol.II) with continuum.

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

$\Gamma_{ee}BR(\chi_b(1P)\,\omega) \sim$ **1.5** $\Gamma_{ee}BR(\Upsilon(2S)\,\pi^+\pi^-)$ at 10.75 [1]
$\Gamma_{ee}BR(\chi_b(1P)\,\omega) \sim$ **0.15** $\Gamma_{ee}BR(\Upsilon(2S)\,\pi^+\pi^-)$ at 10.87 [2]

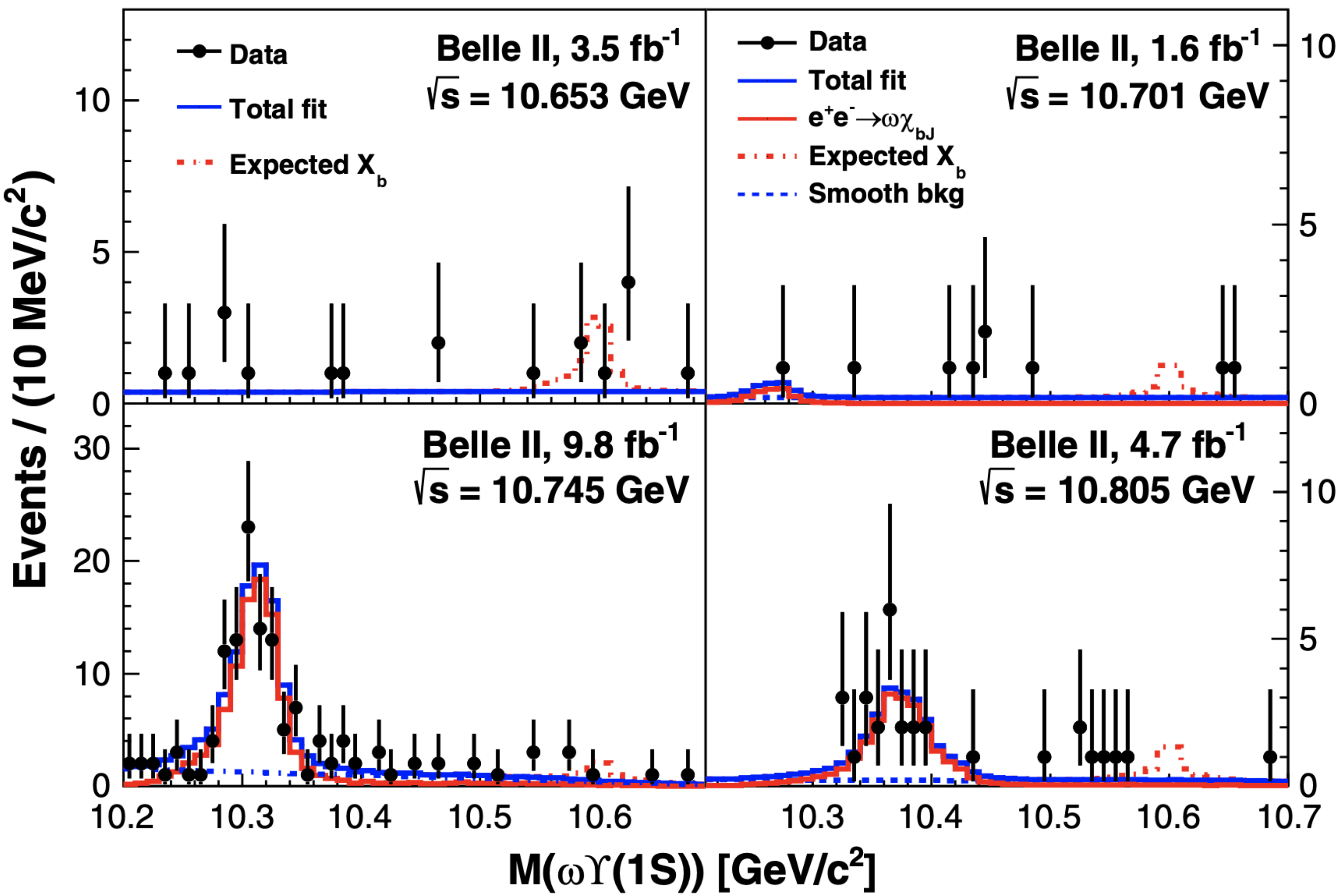
$$\frac{\sigma(e^+e^- \to \chi_{b1}(1P)\,\omega)}{\sigma(e^+e^- \to \chi_{b2}(1P)\,\omega)} = 1.3 \pm 0.6$$

O(10) in 120 MeV for two 1^{--} states indicate different structure of the two states
A pure $\Upsilon(3D)$ state would have given **15** *Guo et al, PLB 738 (2014),172*
A mixed 4S-3D state would give **0.18-0.22** , i.e. **1.8 σ smaller** *Li et al. PRD 104 (2021) 034036*

Search for X_b at $\Upsilon(10753)$

No peaking of events about 10.6 GeV is observed.

The excess of events around 10.3 GeV/c^2 is a reflection of the $\omega\chi_{bJ}(1P)$ transition.



Upper limits at 90% C.L. for X_b at 10.6 GeV/c^2

E_{cm},GeV	10.653	10.701	10.745	10.805
$\sigma(e^+e^- \to \gamma X_b)\, B(X_b \to \omega\Upsilon)$,pb	0.45	0.33	0.10	0.14

Search for $\Upsilon(10753) \to \chi_{b0}(1P)\,\omega,\ \eta_b(1S)\,\omega$

Motivation

Theory prediction of a strong enhancement of the decay :
$\Upsilon(10753) \to \eta_b(1S)\,\omega$ (30 x $\Upsilon(2S)\,\pi^+\pi^-$) using a compact tetraquark interpretation. ***Chin.Phys.C 43 (2019)12,123102***

Experimental observation (BESIII, PRD99 (2019) 091103) of an enhancement of $\psi(4220) \to \chi_{c0}(1P)\omega$ compared to $\psi(4220) \to \chi_{c1,2}(1P)\omega$

Strategy

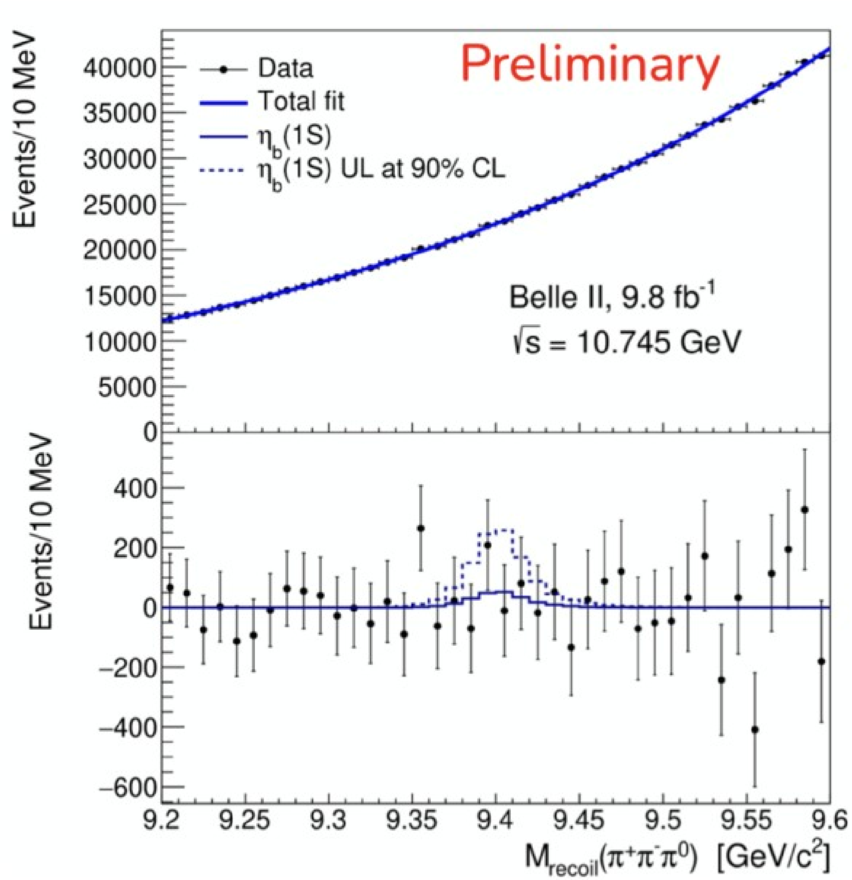
As both $\eta_b(1S)$ and $\chi_{b0}(1P)$ do not have few body decay channels with high branching ratio, an inclusive search is done by calculating the mass recoiling against the ω :

$$M_{\text{recoil}}(\pi^+\pi^-\pi^0) = \sqrt{\left(\frac{E_{\text{c.m.}} - E^*}{c^2}\right)^2 - \left(\frac{p^*}{c}\right)^2}$$

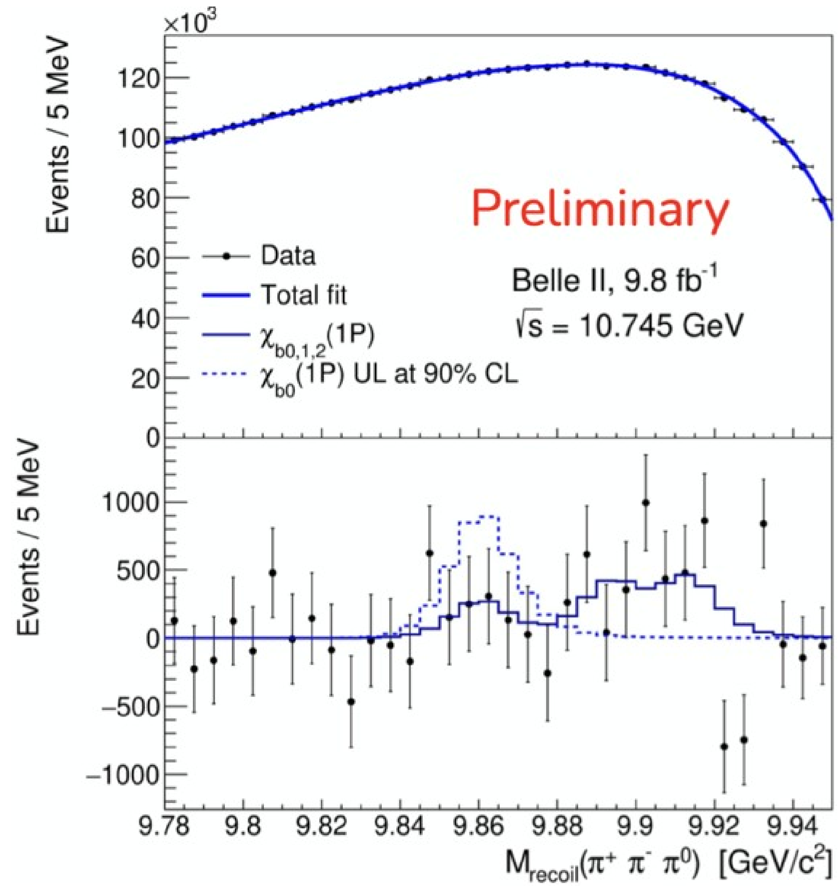
Search for $\Upsilon(10753) \to \chi_{b0}(1P)\,\omega$, $\eta_b(1S)\,\omega$

Shown at EPS 2023

$\eta_b(1S)\,\omega$



$\chi_{b0}(1P)\,\omega$



90% CL upper limits:

$\sigma[e^+e^- \to \omega\eta_b(1S)] < 2.5$ pb

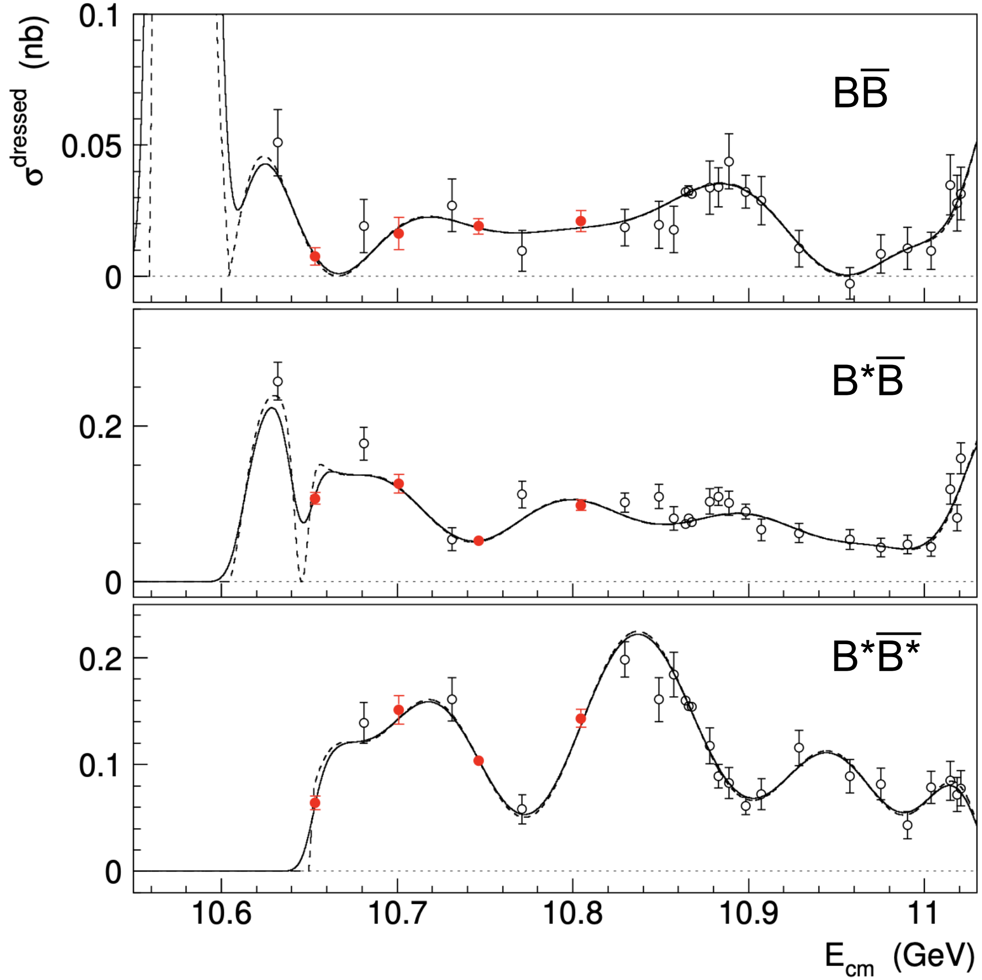
c.f. $\sigma[e^+e^- \to \Upsilon(nS)\pi^+\pi^-] \sim 2.0$ pb

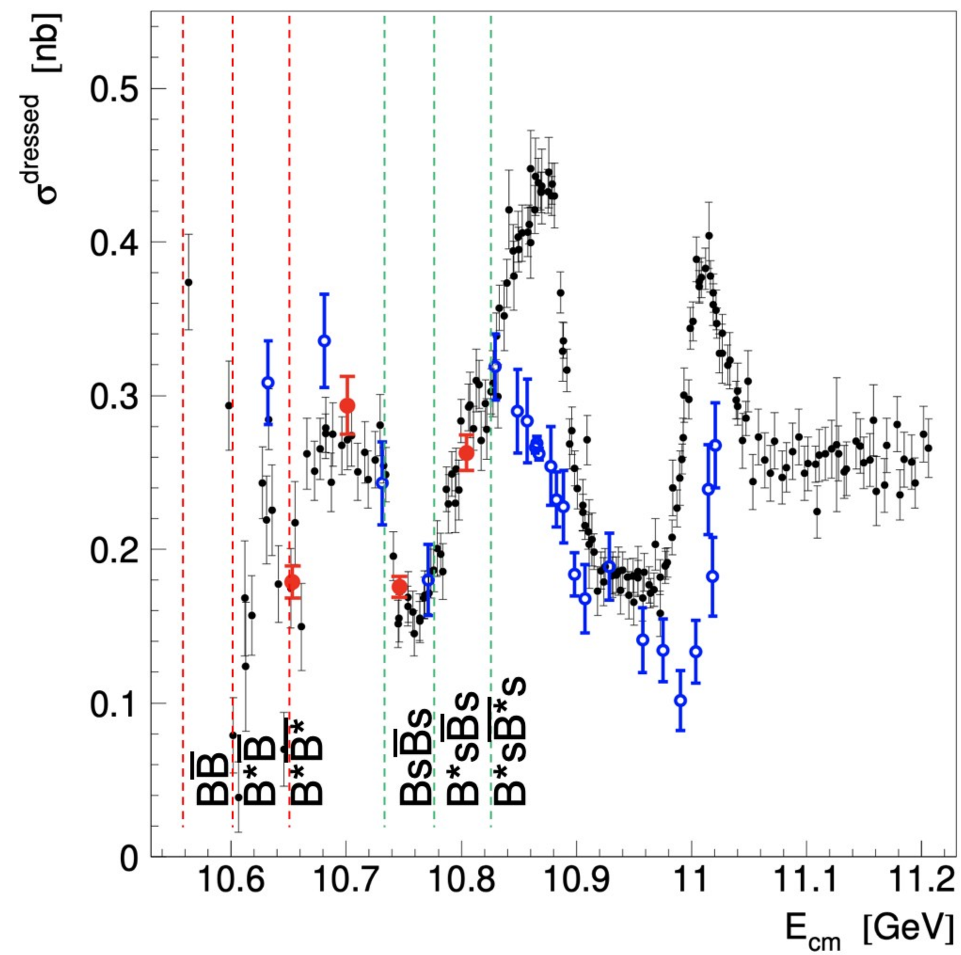
$\sigma[e^+e^- \to \omega\chi_{b0}(1S)] < 8.7$ pb

Disconfirms compact
tetraquark model prediction

$B\bar{B}+B\bar{B}^*+B^*\bar{B}^*$ cross sections in the 10.65-10.8 GeV region

Shown at Moriond QCD 2023,
to appear on JHEP





Individual 2-body cross sections fitted with Chebychev polinomials.

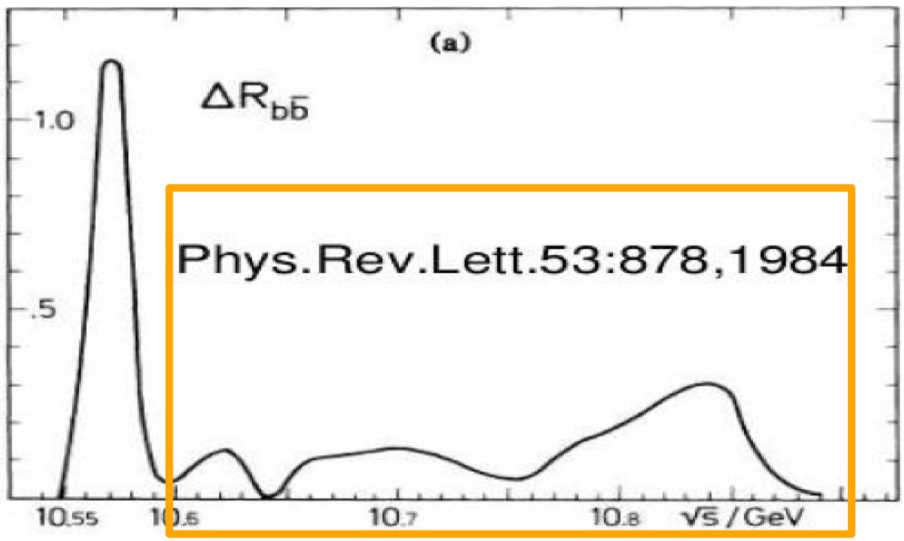
The steep rise of $B^*\bar{B}^*$ cross section suggest the existence of a molecular state at threshold.

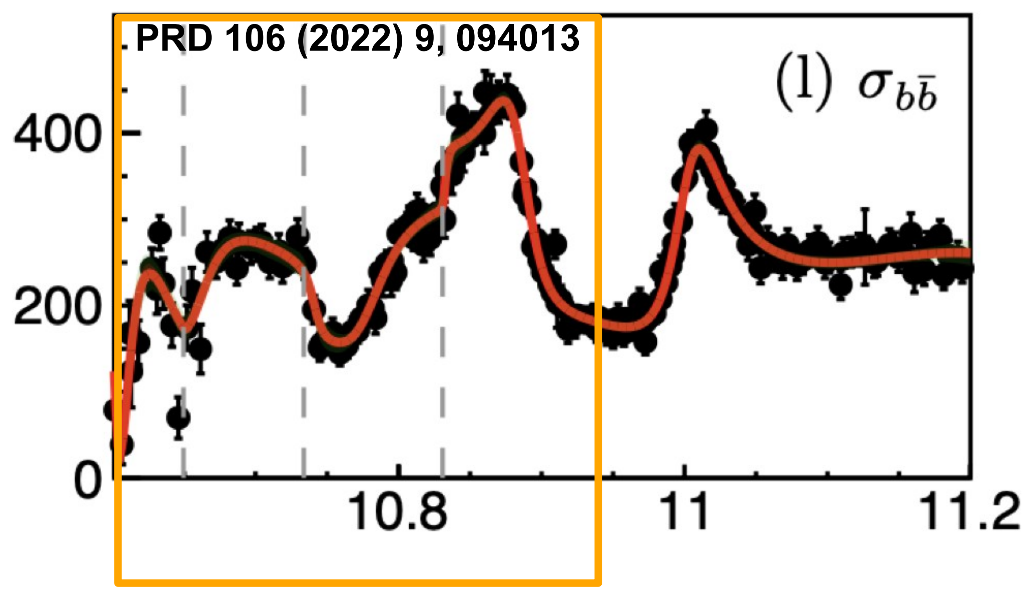
Total cross section: the four new points are in red.

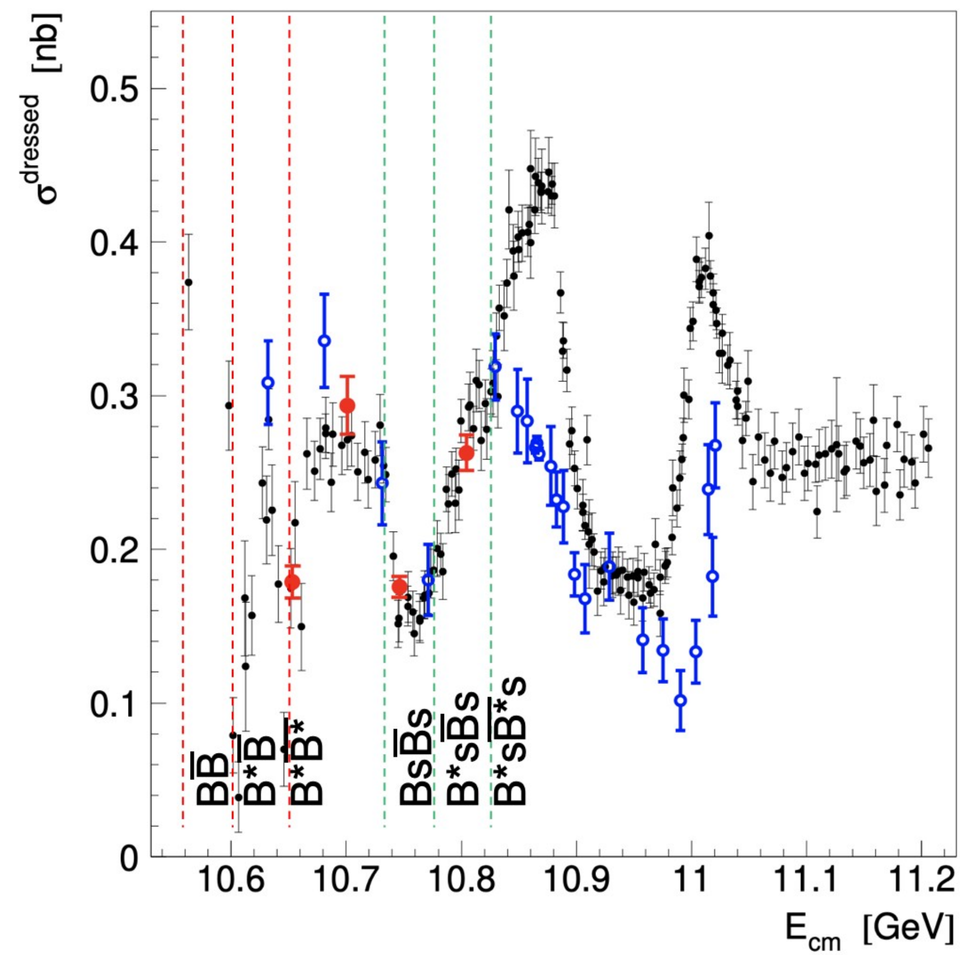
$B\bar{B}+B\bar{B}^*+B^*\bar{B}^*$ cross sections in the 10.65-10.8 GeV region

Coupled Channel Analysis : 1984 vs 2022

Shown at Moriond QCD 2023, to appear on JHEP







Total cross section: the four new points are in red.

Dipion transitions at 4S: from Belle-I to Belle-II

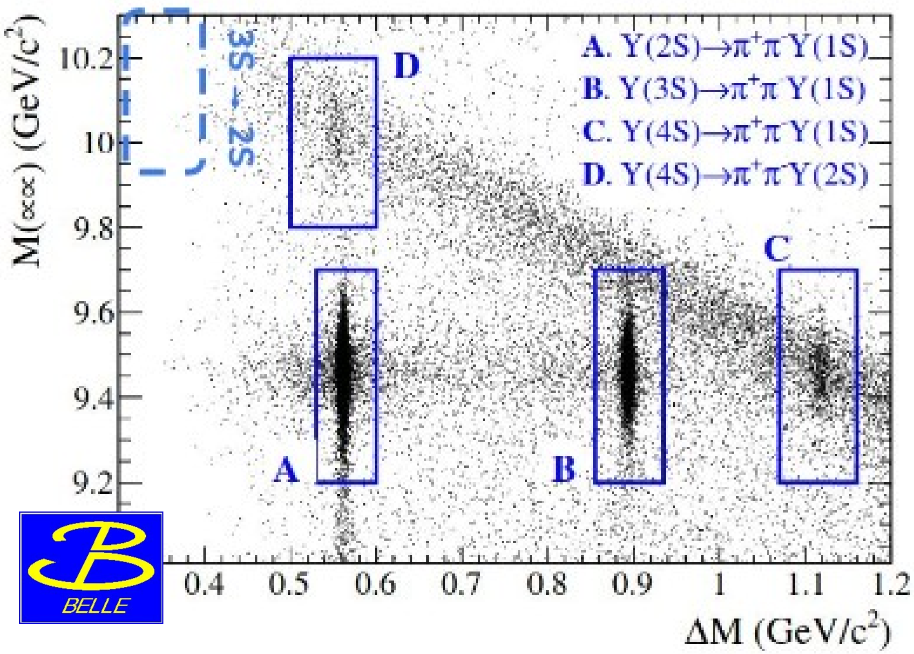
Control channel to prepare unblinding of data taken at 10.6-10.85 GeV

Searched in μμππ mode, asking for N_{tracks}=4,5.

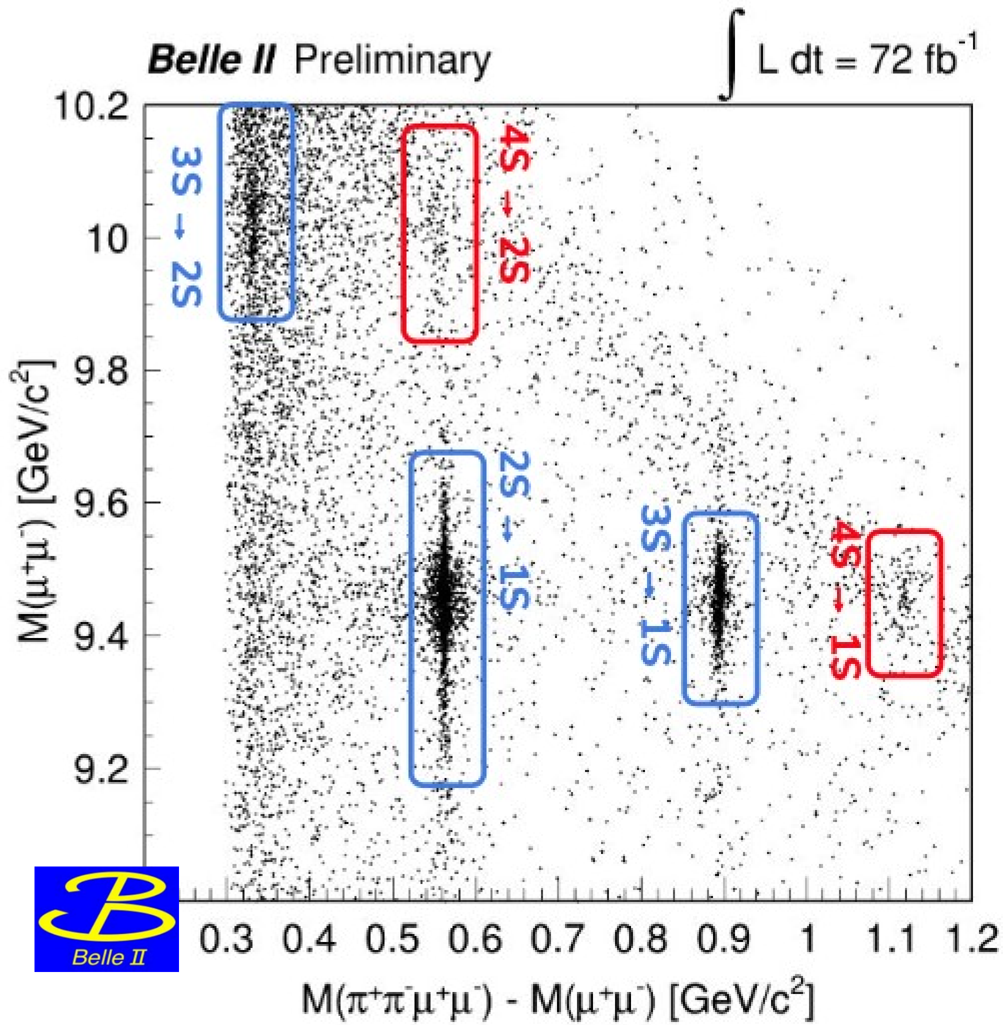
Study $e^+e^- \to \pi^+\pi^-\mu^+\mu^-$ (+γ undetected)

- $\Upsilon(4S) \to \pi^+\pi^-\Upsilon(nS)$
- $e^+e^- \to \gamma_{ISR}\Upsilon(mS)$, $\Upsilon(mS) \to \pi^+\pi^-\Upsilon(nS)$

Compare with Belle, 496 fb^{-1} [PRD 96 (2017) 5, 052005]



Improved low momentum tracking



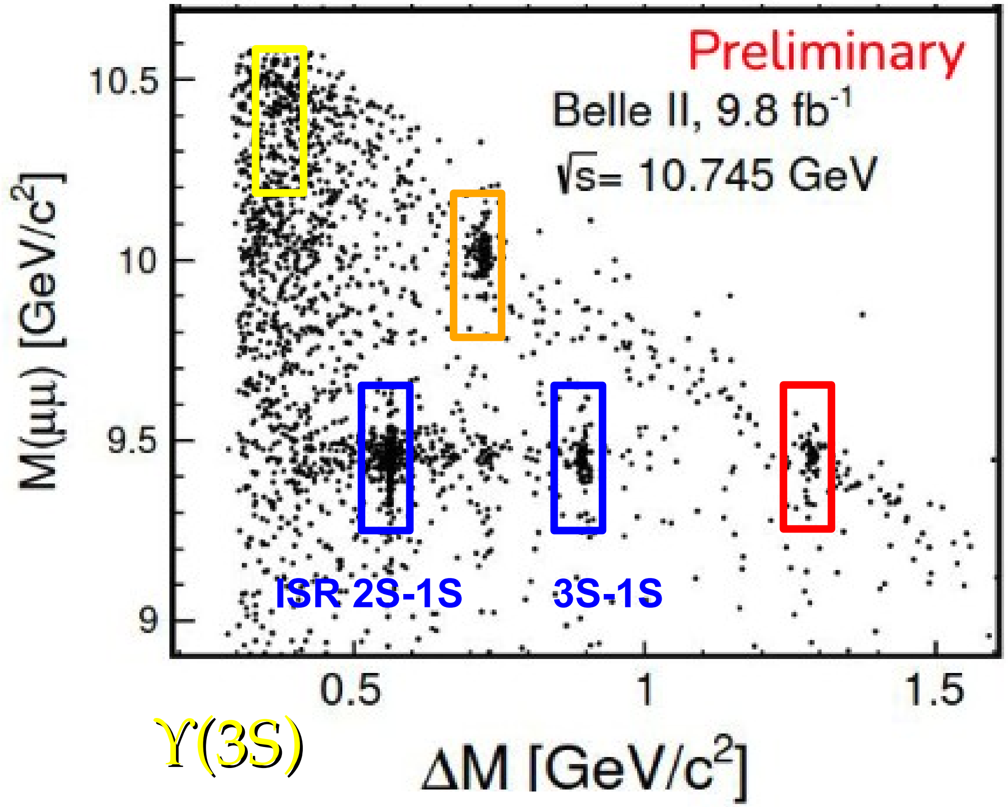
Signals from Ecm = 10.745 GeV

Searched in $\mu\mu\pi\pi$ mode, asking for N_{tracks}=4,5

Plot of $M(\mu^+\mu^-)$ vs $\Delta M = M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)$

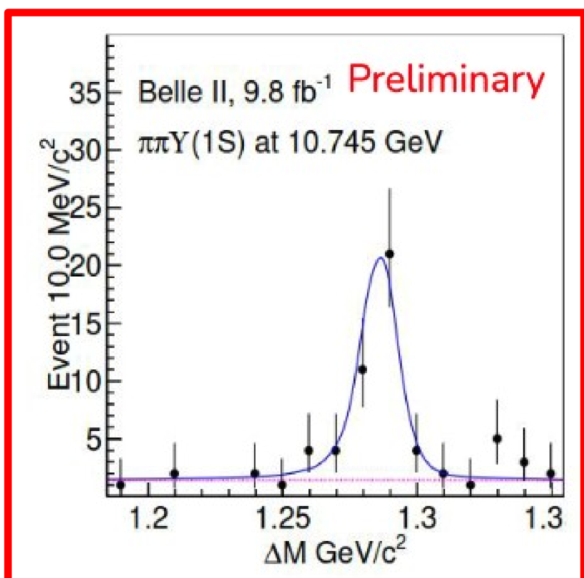
$P^*(\mu^+\mu^-\pi^+\pi^-)$<100 MeV/c to reject ISR

Clear signals of $\Upsilon(1S)\,\pi^+\pi^-$ and of $\Upsilon(2S)\,\pi^+\pi^-$
No evidence of $\Upsilon(3S)\,\pi^+\pi^-$

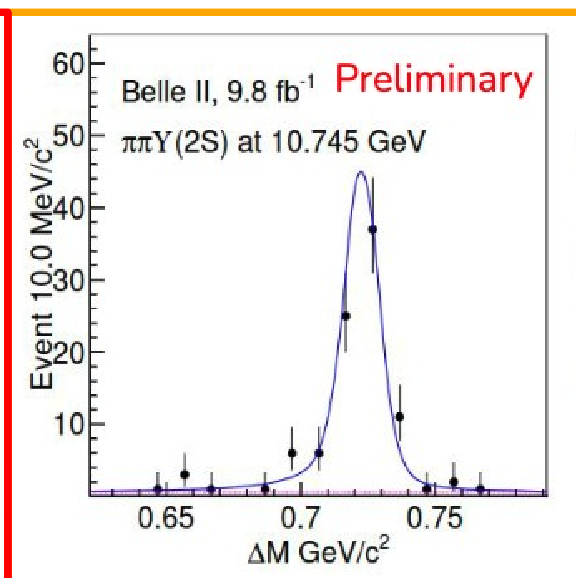


Dipion transitions from 10.745 to:

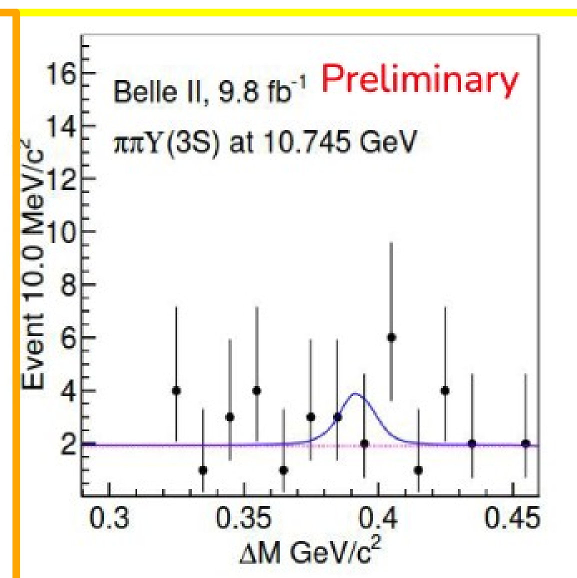
$\Upsilon(1S)$



$\Upsilon(2S)$



$\Upsilon(3S)$



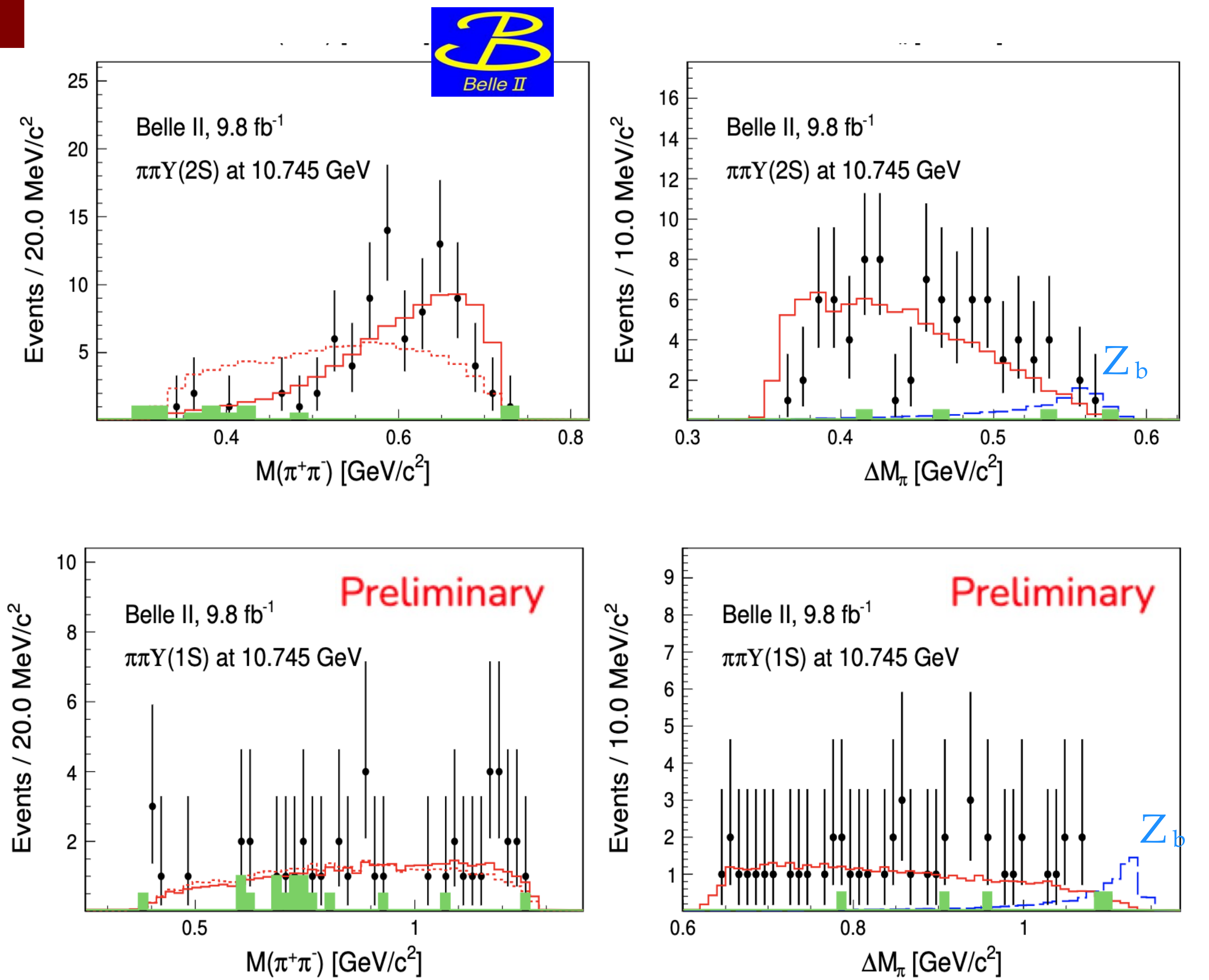
Dalitz Plot projections

Υ(10753) to Υ(2S) similar to Υ(2S) to Υ(1S)

Fitted with standard Cleo parametrization assuming the spin-flip term C=0, as more statistics is needed to test Heavy Quark Spin Symmetry violations.

Despite low efficiency in the high ΔM_π region, we can exclude strong Z_b contributions.

Transition to Υ(1S) still consistent with phase space, we need more statistics to compare with Υ(4S) to Υ(1S).



Dalitz Plot projections

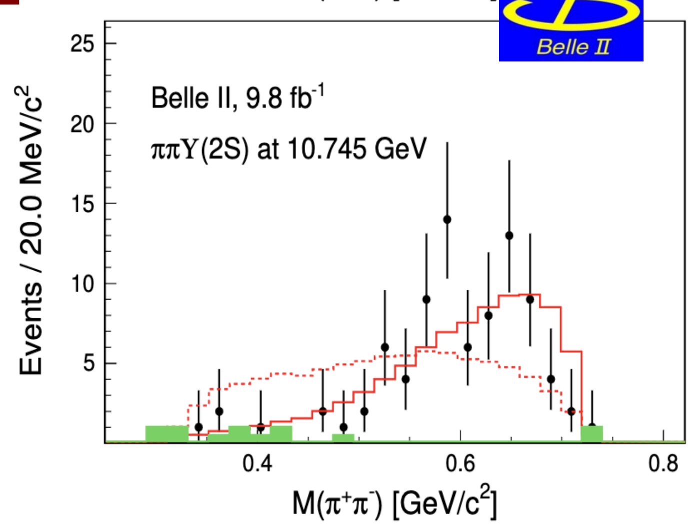
Phys. Rev.D96 (2017) 052005

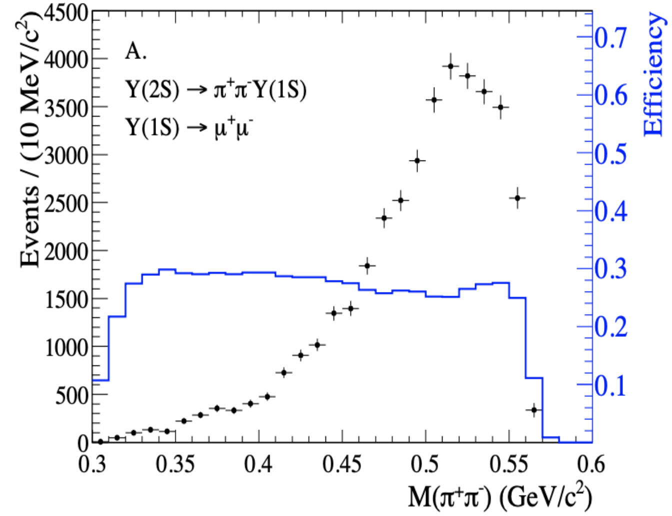
ϒ(10753) to ϒ(2S) similar to ϒ(2S) to ϒ(1S)

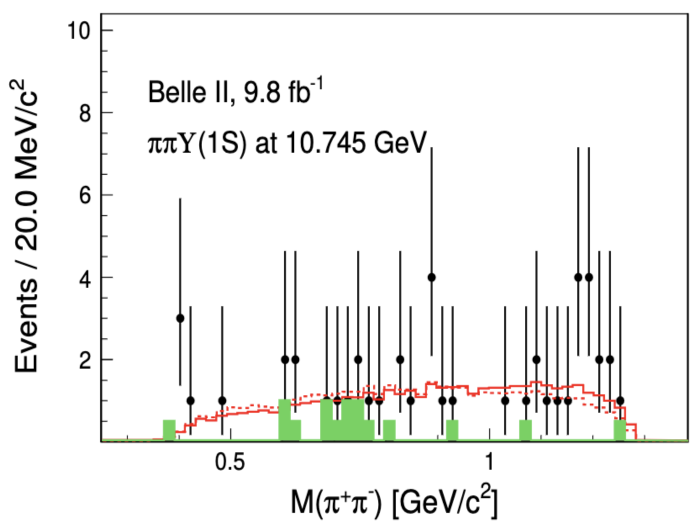
Fitted with standard Cleo parametrization assuming the spin-flip term C=0, as more statistics is needed to test Heavy Quark Spin Symmetry violations.

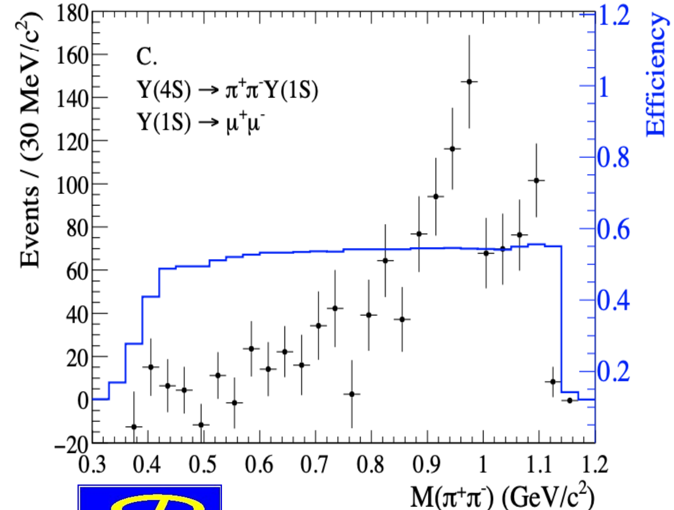
Despite low efficiency in the high ΔM_π region, we can exclude strong Z_b contributions.

Transition to ϒ(1S) still consistent with phase space, we need more statistics to compare with ϒ(4S) to ϒ(1S).

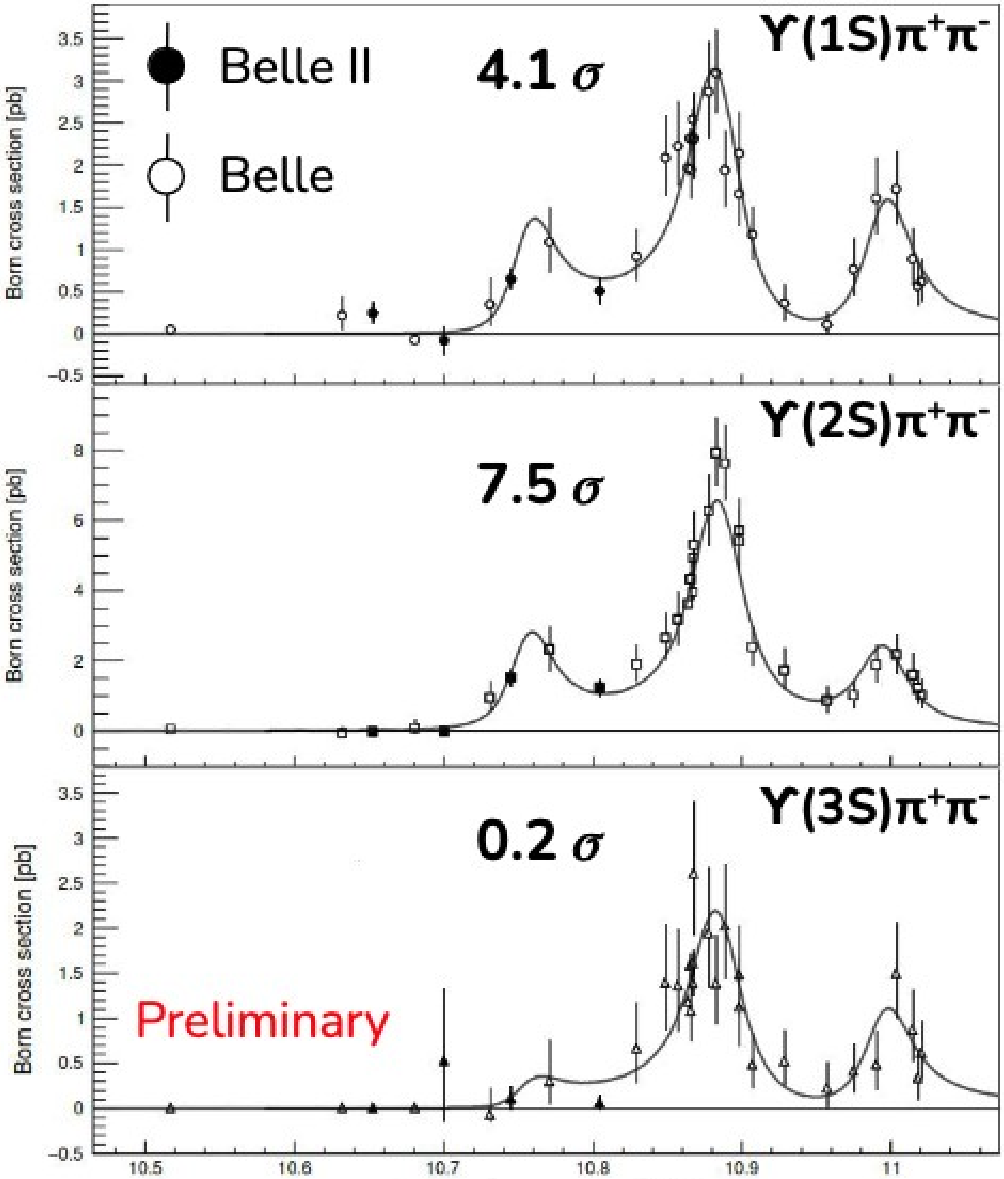








Signals vs E_{cm}



We confirm the Belle result

Cross section fit of 10.75 peak:
BW+gaussian to account for Ecm spread

Mass: $10756.3 \pm 2.7_{stat} \pm 0.6_{syst}$ MeV/c^2
Width: $29.7 \pm 8.5_{stat} \pm 1.1_{syst}$ MeV

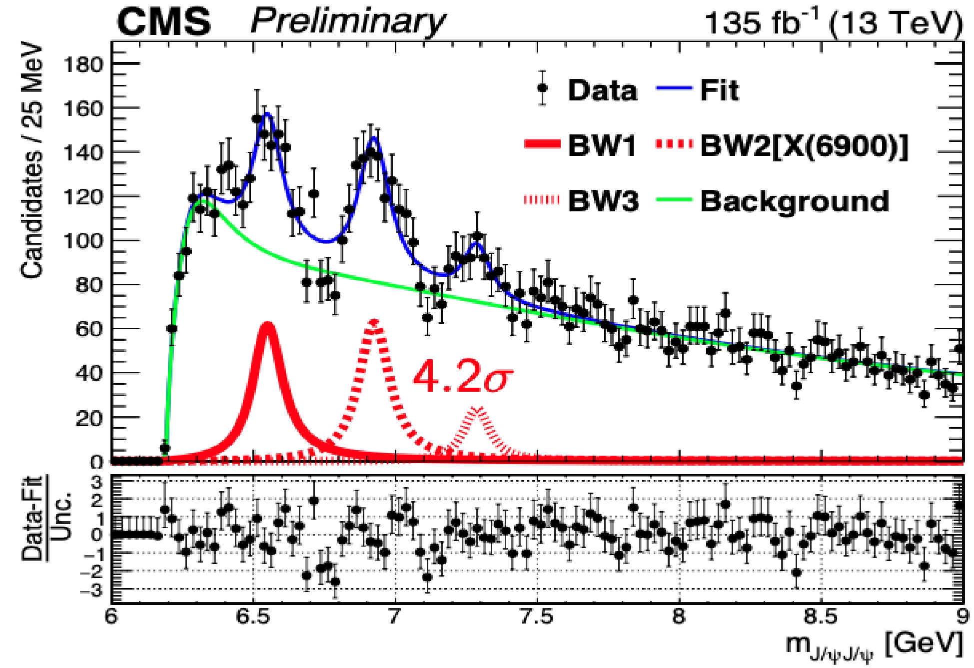
...but … We should have taken data at 10.750, not 10.745...

Double charmonium resonances

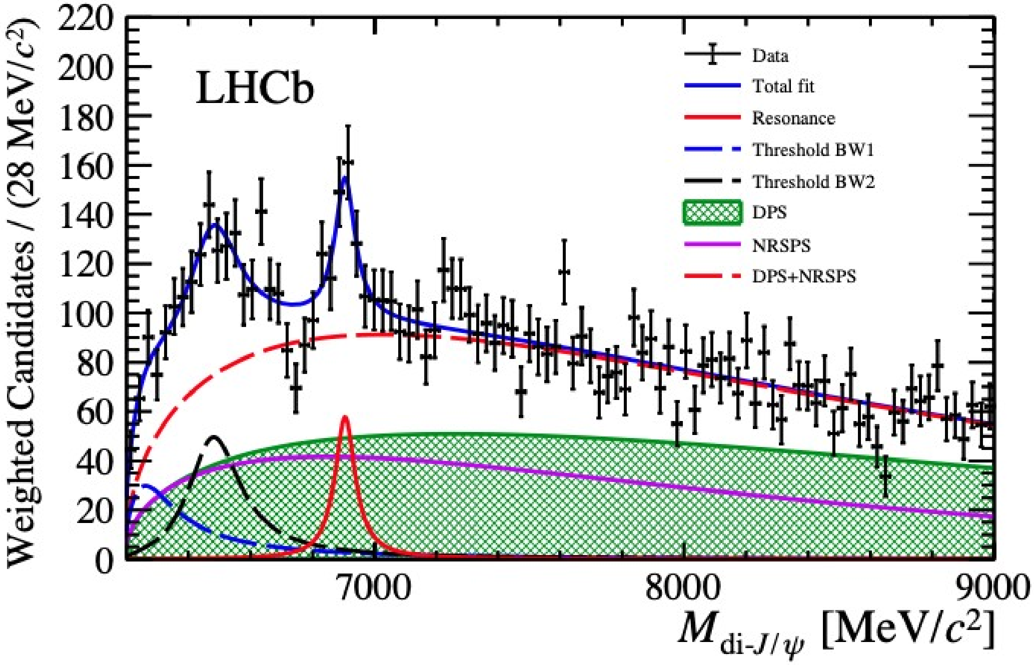
In 2020, LHCb discovered structures in prompt double J/ψ production in pp collisions. Smooth continuum is due either to Double Parton Scattering (DPS) or to Non Resonant Single Parton Scattering (NRSPS). Peaks and dips are modeled are as interference effects between continuum and Resonant SPS, due to $c\bar{c}c\bar{c}$ bound states.

The X(6900) is close to the $\chi_{c0}(1P)$ $\chi_{c1}(1P)$ threshold. Evidence of another state is seen at CMS.

CMS-PAS-BPH-21-003

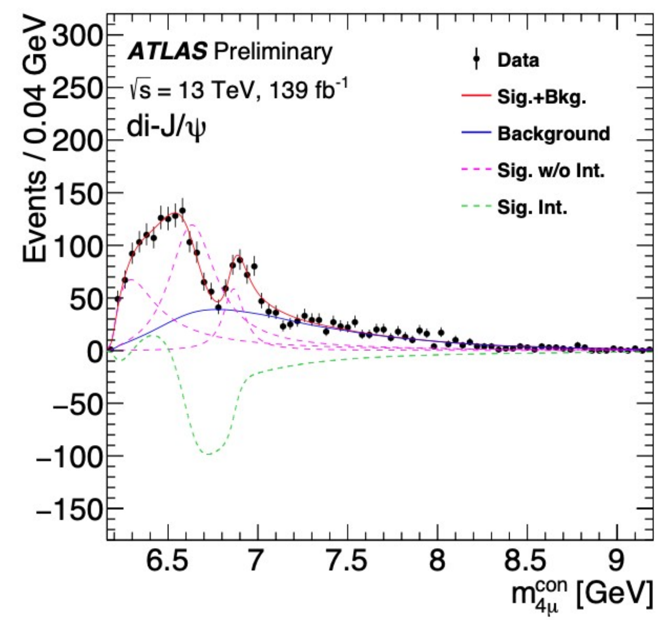


Sci.Bull. 65 (2020) 23, 1983

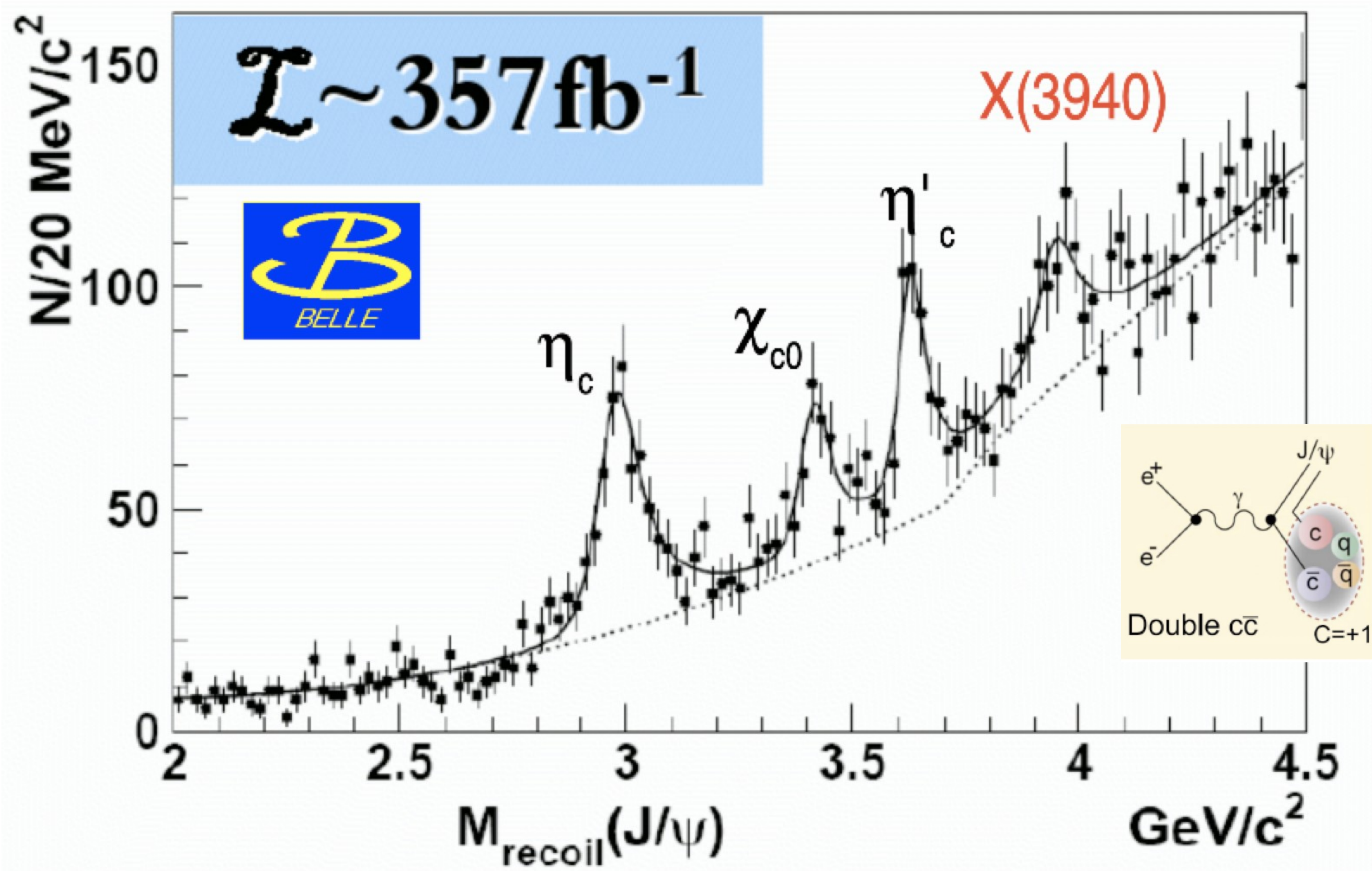


y at Belle I&II

ATLAS-CONF-2022-040



2002 : double charmonium at Belle



Clean observation of J=0 charmonium peaks ... AND an unexpected discovery : the X(3940)

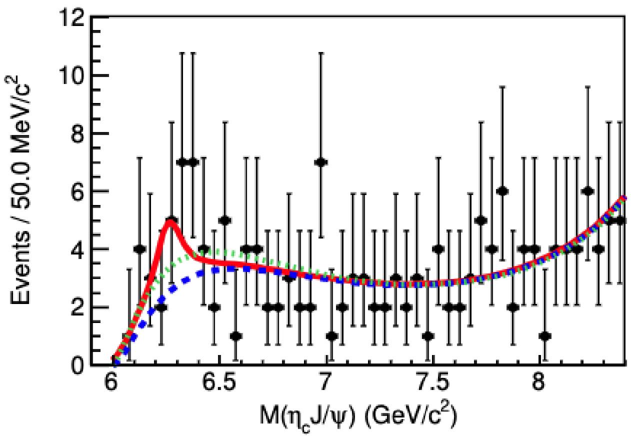
Double charmonium vs E_{cm} in Belle

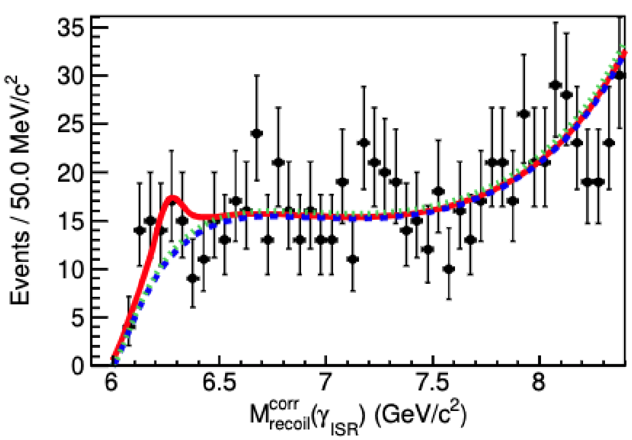
JHEP08(2023)121

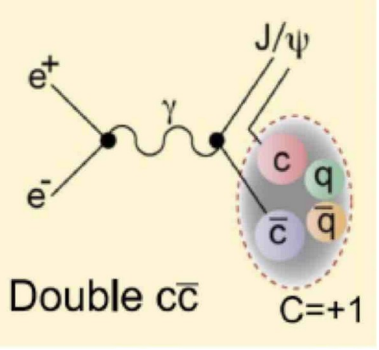
ISR scanning of $\sigma(\eta_c J/\psi)$ in the threshold region (6-8.5 GeV)

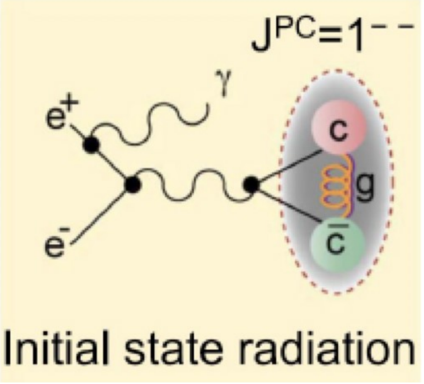
Data sample : 980 fb^{-1}, full Belle dataset

Two reconstruction methods:
1) Inclusive reconstruction of J/ψ and ISR photon, selection of recoil mass in the η_c region. Plot of photon recoil mass.
2) Full Exclusive Reconstruction of η_c in 6 decay modes ($p\bar{p}$, $pp\pi^0$, $K_S K^{\pm}\pi^{\mp}$, $K^+K^-\pi^0$, $K^+K^-K^+K^-$, $2(\pi^+\pi^-\pi^0)$).
Selection of $M^2_{rec}(\eta_c J/\psi)$ in [-1,2]GeV^2 range.
Plot of the $M(\eta_c J/\psi)$ distribution.









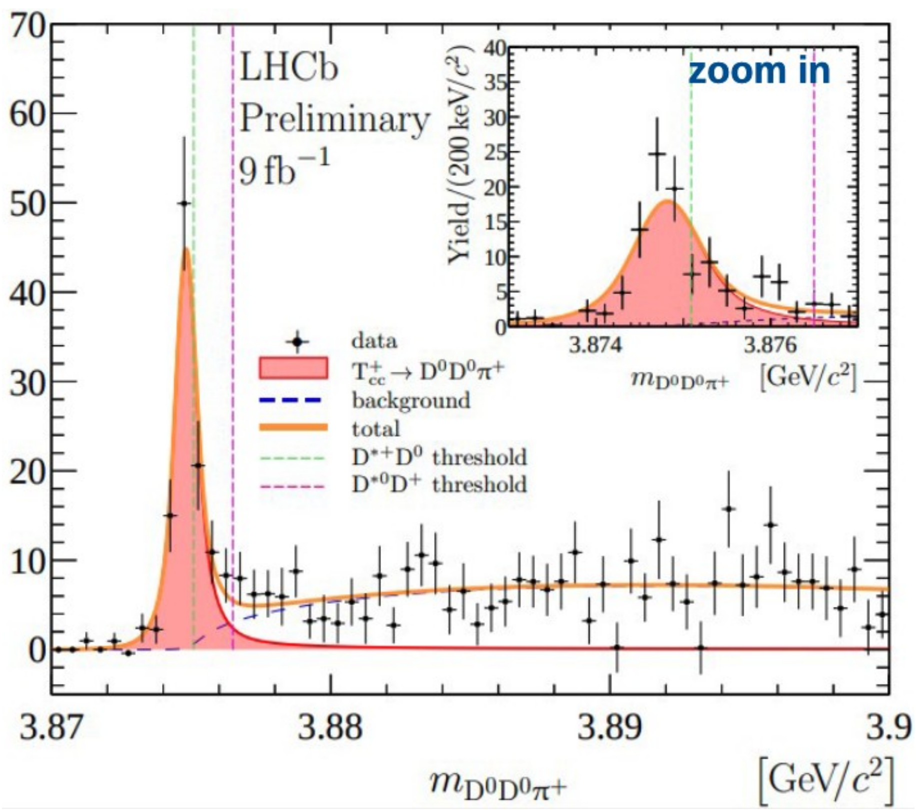
3.3 σ evidence of threshold enhancement, need more data at Belle-II

More prospects for Belle-II

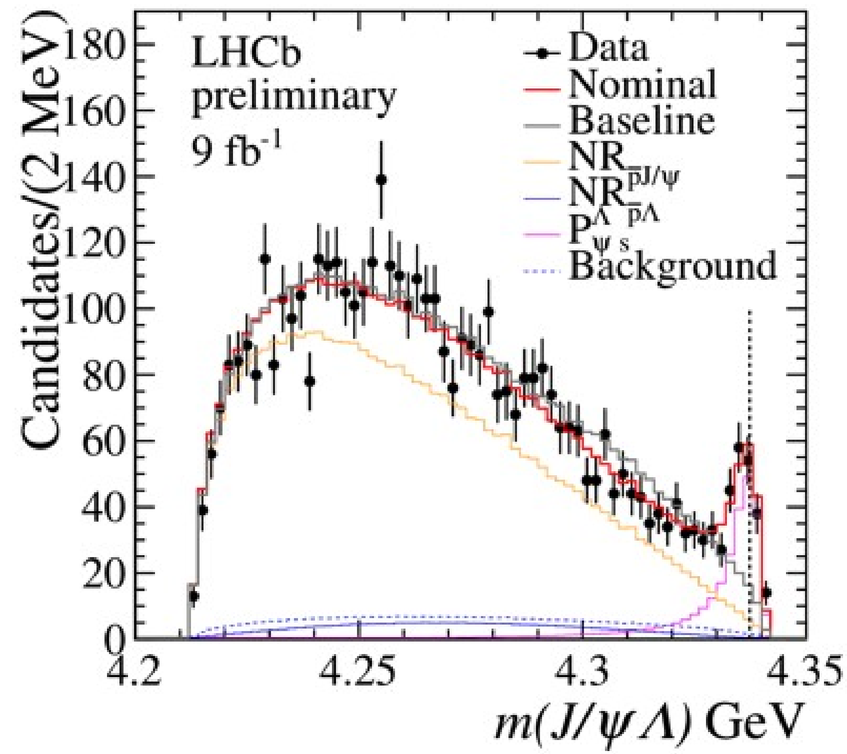
With 10 ab^{-1} and more, Belle-II will be able to search for more exotic hadrons to confirm states found by LHCb and further study their spectra:

- the T_{cc} produced in double charmonium processes
- the pentaquarks in either B decays or continuum

T_{cc} : $cc\overline{ud}$ bound state at 3875 MeV / c^2



Pentaquark in $B^- \to \Lambda\ J/\psi\ \bar{p}$



In conclusion …

The advent of B factories (Belle, Babar, LHCb) have led to a renaissance of hadron spectroscopy. More complex ensembles of heavy and light quarks (i.e. $Q\overline{Q}q\overline{q}$, $QQ\overline{q}\overline{q}$, $Q\overline{Q}qqq$, $QQ\overline{Q}\overline{Q}$) have been discovered and more results are expected for the coming years, from Belle-II, LHCb, and other experiments.

Above the open flavor thresholds, vector bottomonium and charmonium-like states exhibit analogies and differences, and are a quite fertile field of study. Stimulated by the discovery of Y(10753) by Belle, the first scan of the 10.6-10.8 GeV region at Belle-II is inspired by the studies done by BES-III in the 4.2-4.4 GeV region in charmonium, pioneered by Babar and Belle.

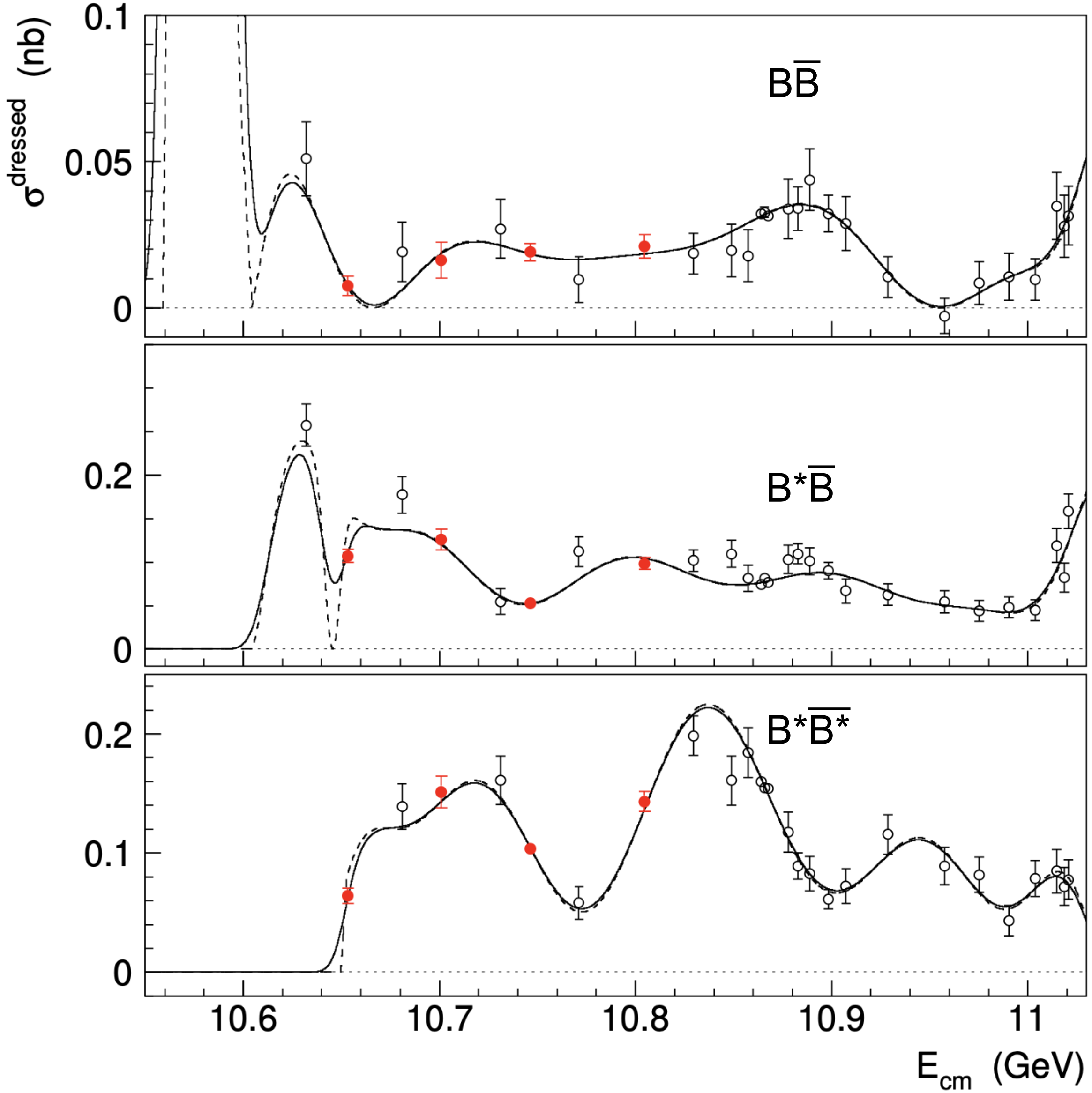
At 10.753 GeV, the transition $\omega\chi_{b1,2}(1P)$ is even stronger than the discovery mode $\Upsilon(nS)\,\pi^+\pi^-$ and the large variation of ratio between these two transitions at 10.75 and at 10.86 GeV gives insights on the difference in the nature of these two bound states.
Searches for other ω transitions to $\eta_b(1S)$ and $\chi_{b0}(1P)$ have yielded upper limits which already can disconfirm some theory predictions; more results will be ready soon.

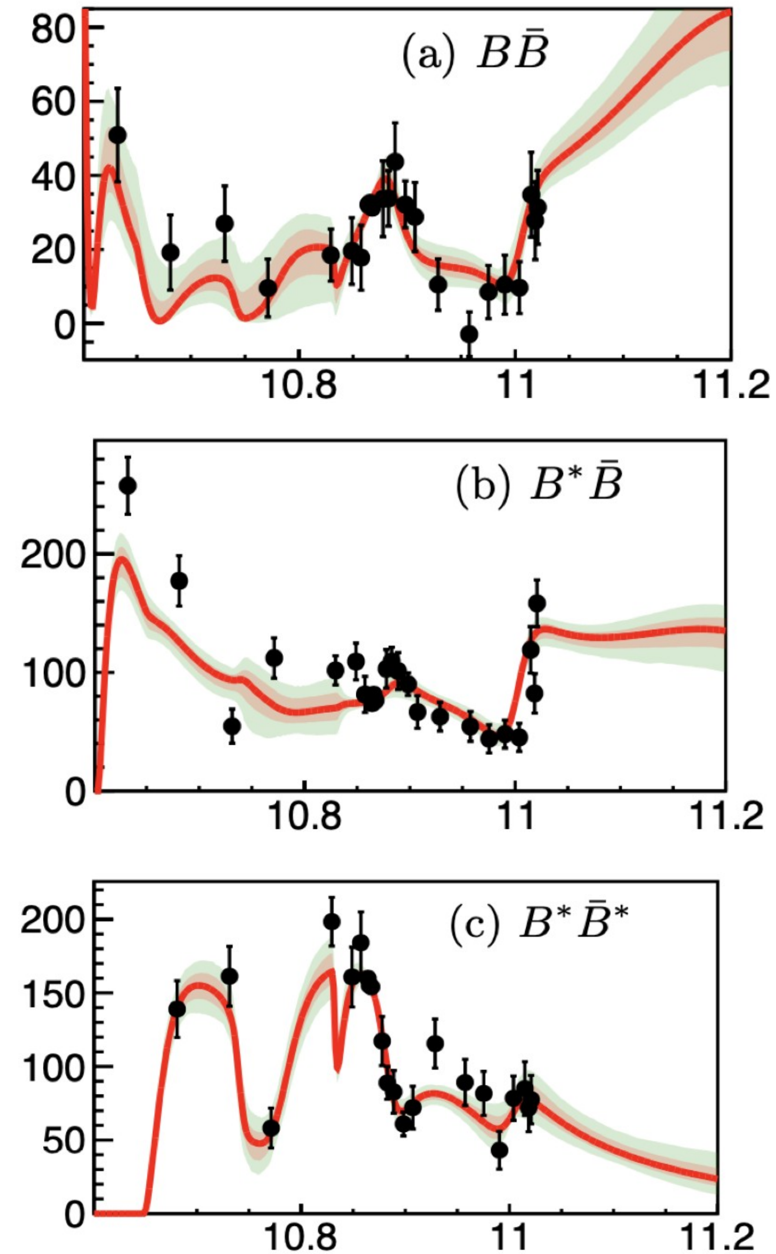
The shift between the peaks of B, Bs, and narrow $b\overline{b}$ meson production at $\Upsilon(5S)$ show that its modeling of this state as a pure $b\overline{b}$ state may be naive as well. More scan data up to the peak of $\Upsilon(6S)$ will be necessary to complete the picture.

Structures seen at LHCb in double charmonium may lead to a whole new spectroscopy with doubly and fully heavy tetraquarks. Also in this sector, the radiative return technique and larger statistics, may allow Belle-II to complement studies done at LHCb.


Thanks for your attention ！

$B\bar{B}+B\bar{B}^*+B^*\bar{B}^*$ cross sections in the 10.65-10.8 GeV region





2002 : double charmonium at Belle

Mass spectrum of what recoils against a D(*) meson and a J/ψ

Another development:

D^+ reconstructed in 3 decay modes (12%):

$K^-\pi^+\pi^-$, $K^+K^-\pi^+$, $K_S^0\pi^+$

D^0 reconstructed in 5 decay modes (29%):

$K^-\pi^+$, K^+K^-, $K^-\pi^+\pi^-\pi^+$, $K_S^0\pi^+\pi^-$, $K^+K^-\pi^0$