Study of the charmed-antistrange and anticharmed-strange meson pairs at Belle and status of Belle II

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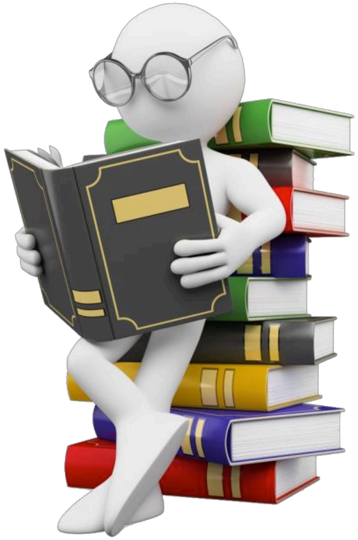
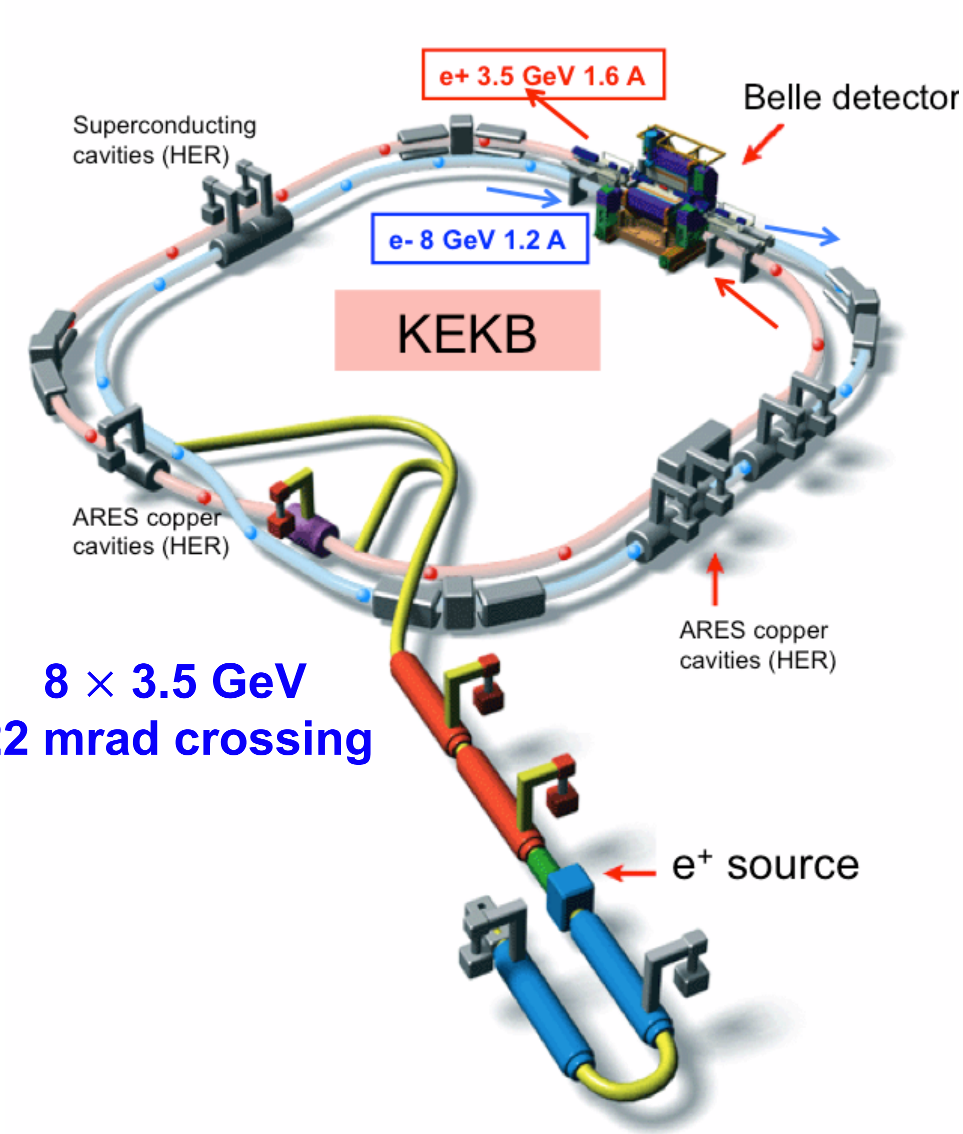
强子物理新发展研讨会

Outline

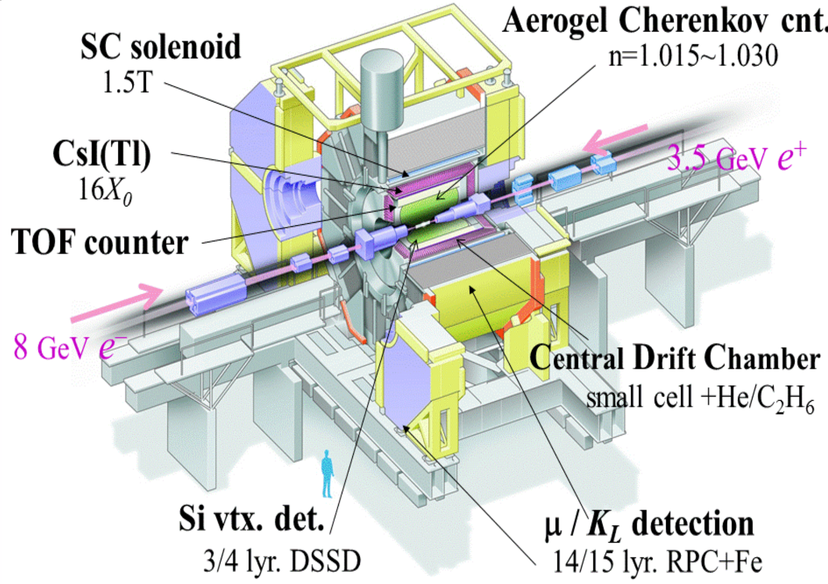


- ***Belle experiments***
- $\boldsymbol{e^+e^- \to D_s^+ D_{s1}(2536)^-}$
- $\boldsymbol{e^+e^- \to D_s^+ D_{s2}^*(2573)^-}$
- ***Summary and discussion***
- ***Status and Prospects of Belle II***

Belle experiment and data samples



8×3.5 GeV
22 mrad crossing



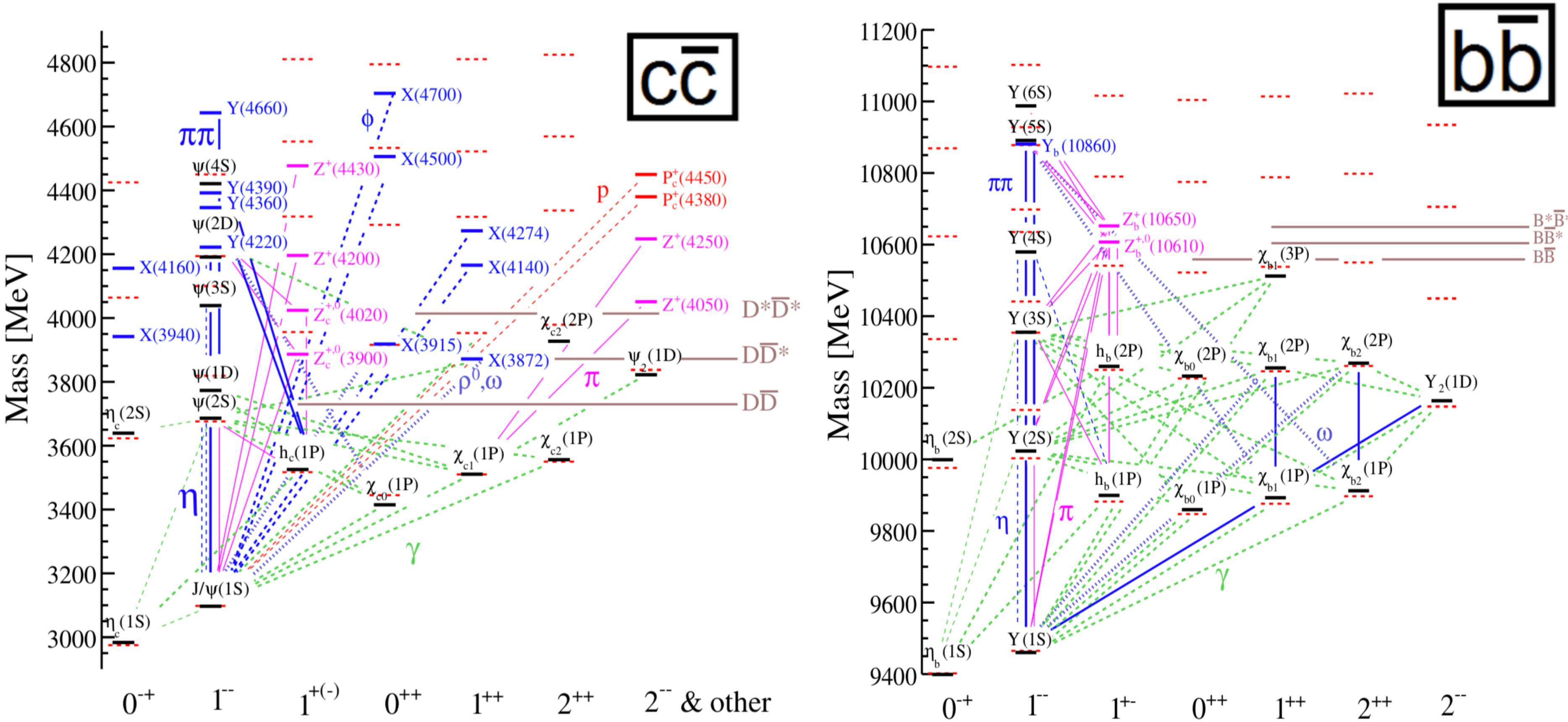
Data taking: 1999 – 2010

On/off/Scan $\Upsilon(nS)$ peaks

Total luminosity: 980 fb^{-1}

772M $B\bar{B}$ events @$\Upsilon(4S)$

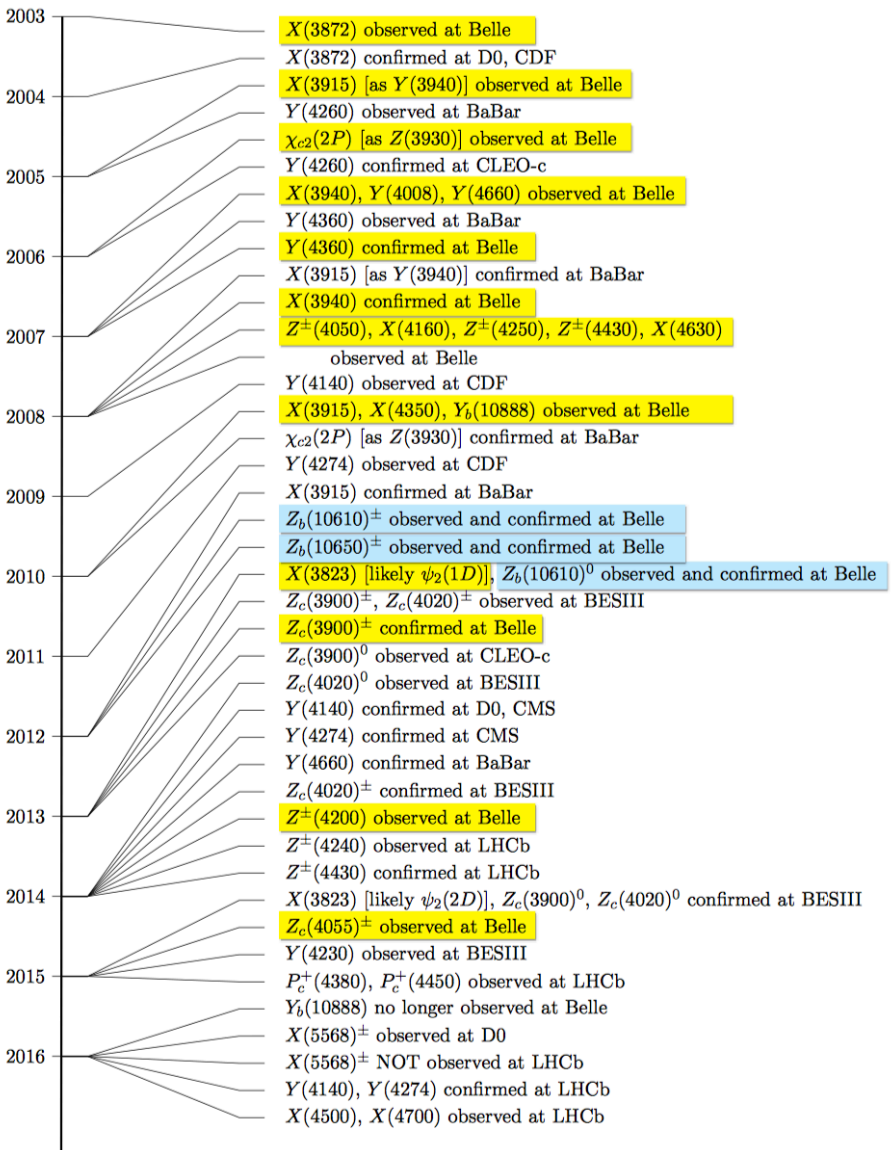
Quarknium



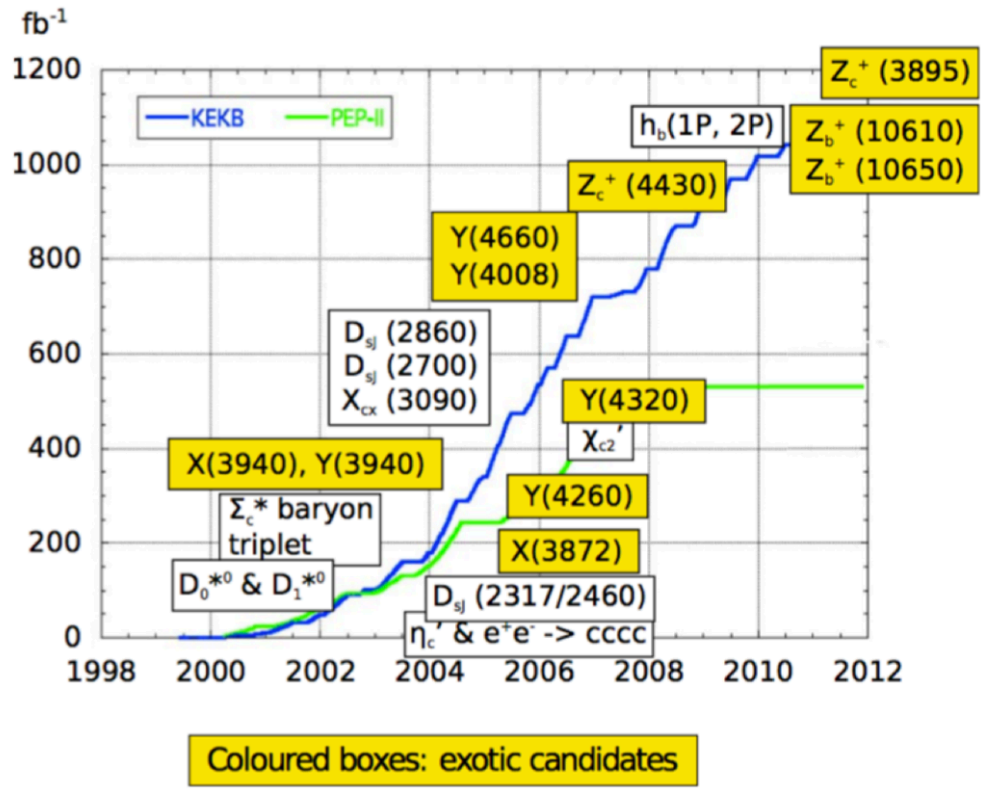
Rev. Mod. Phys. 90, 015003 (2018)

- Quarkonium: $q\bar{q}$, the simplest system of a hadron.
- Below $D\bar{D}/B\bar{B}$ thresholds – both charmonium and bottomonium are successful stories of QCD.
- But there are many exotic states observed in the past decade, and they are hard to fit in the two families.

Discoveries of XYZ states at Belle



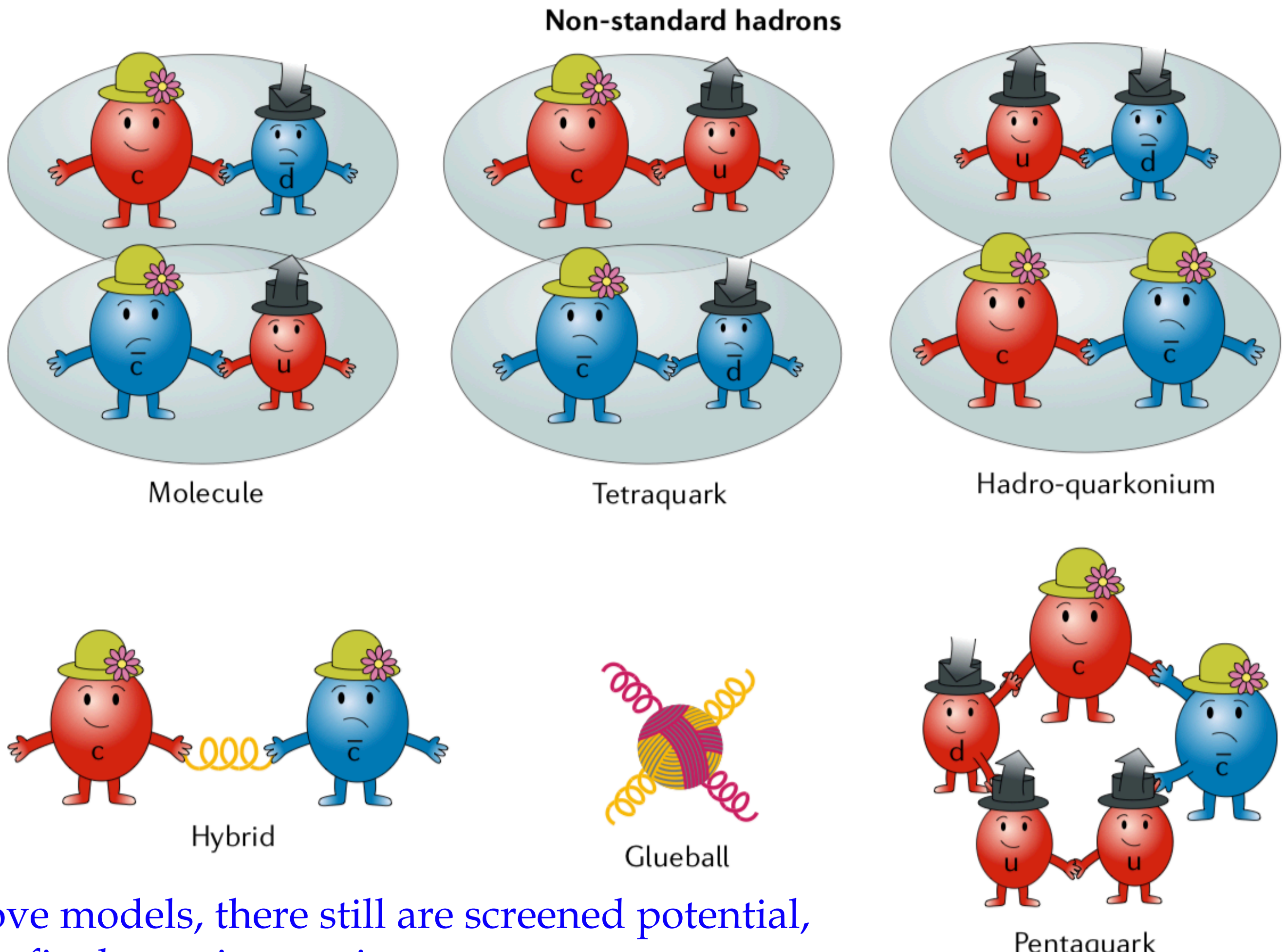
adapted from Lebed, Mitchell, Swanson, *PPNP* 93, 143 (2017)



Coloured boxes: exotic candidates

- History of the quarkonium-like exotic states
- Belle accounts for ~1/2 of the discoveries, including the very first one, X(3872)

Various interpretations of the exotic states



Nature Reviews Physics 1, 480 (2019)

Besides above models, there still are screened potential, cusps effect, final state interaction …

<u>High Priority:</u>

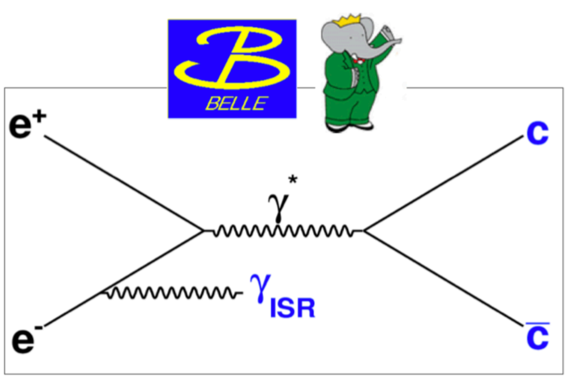
- Identify most prominent component in wave function
- Seek unique picture describing all XYZ states, not state-by-state

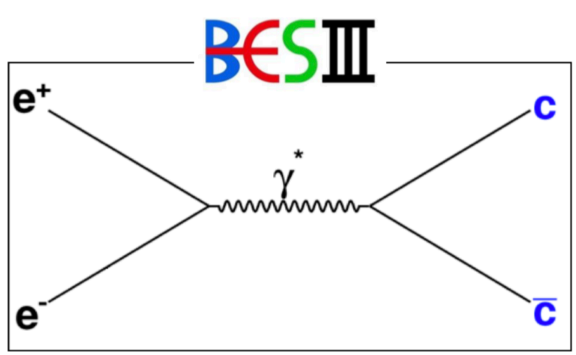
$e^+e^- \rightarrow D_s^+ D_{s1}(2536)^-$

[PHYSICAL REVIEW D 100, 111103(R) (2019)]

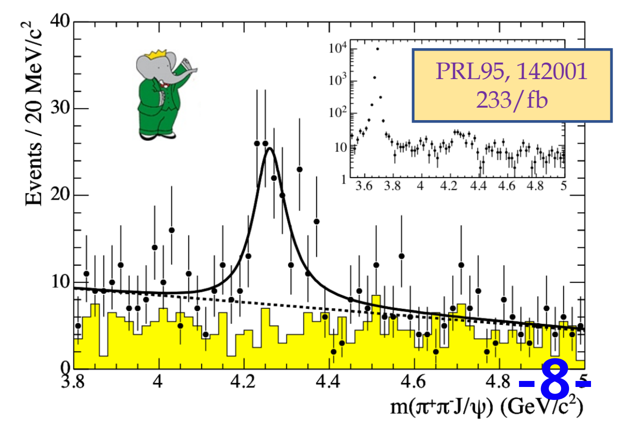
Y states

- Y(4008), Y(4260), Y(4360), Y(4630), Y(4660): $J^{PC} = 1^{--}$
- Strong coupling to hidden-charm final states in contract to the vector charmonium states in the same energy region [ψ(4040), ψ(4160), ψ(4415)], which couple dominantly to open-charm meson pairs.
- Many theoretical interpretations: tetraquark, molecule, hybrids, or hadrocharmonia?
- Observed in Initial state radiation processes (Belle and Babar) and e^+e^- annihilations in the charmonium energy region (BESIII).





The first observed Y state (Y(4260))



Y states via ISR

Y(4008)

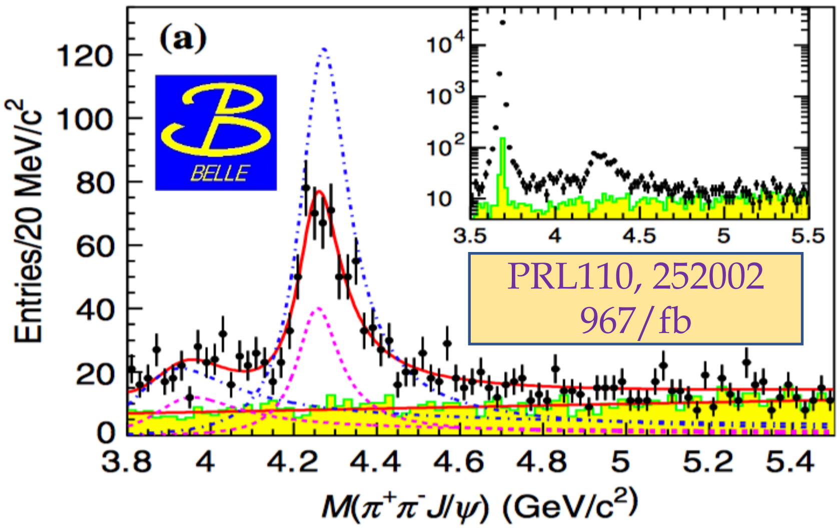
Y(4260)

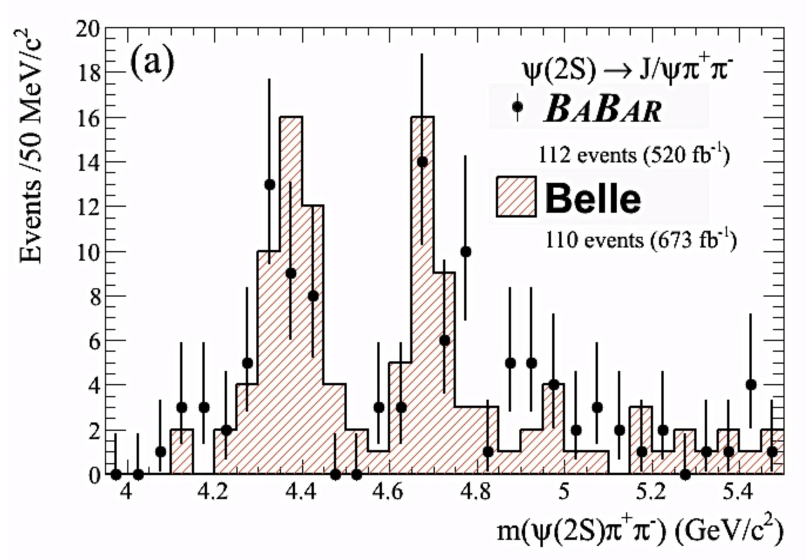
Y(4360)

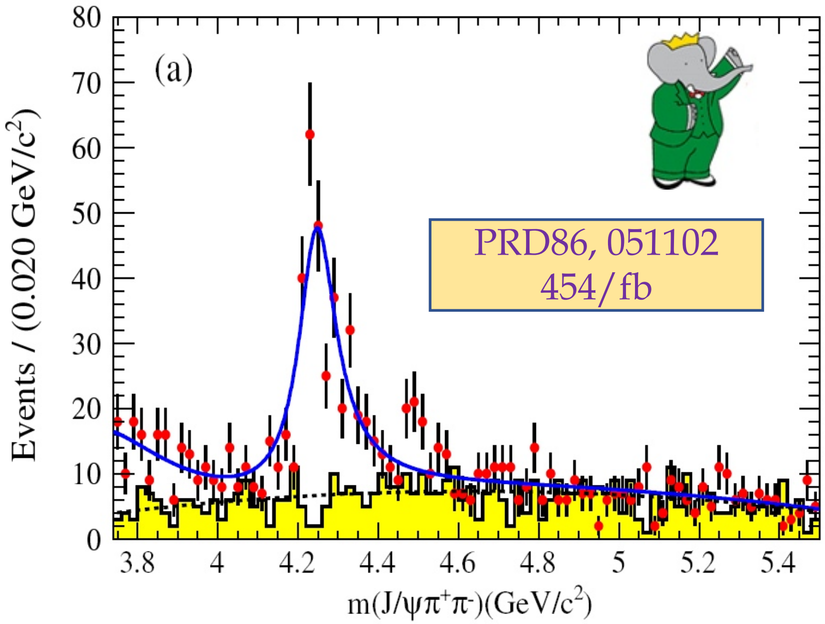
Y(4630)

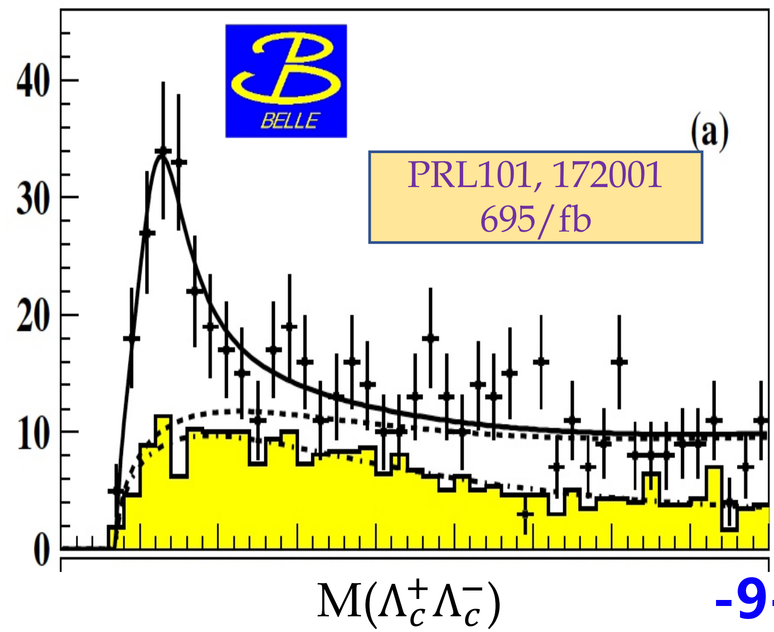
Y(4660)

Belle: PRL99, 142002, 670/fb
BaBar: PRD89, 111103, 670/fb

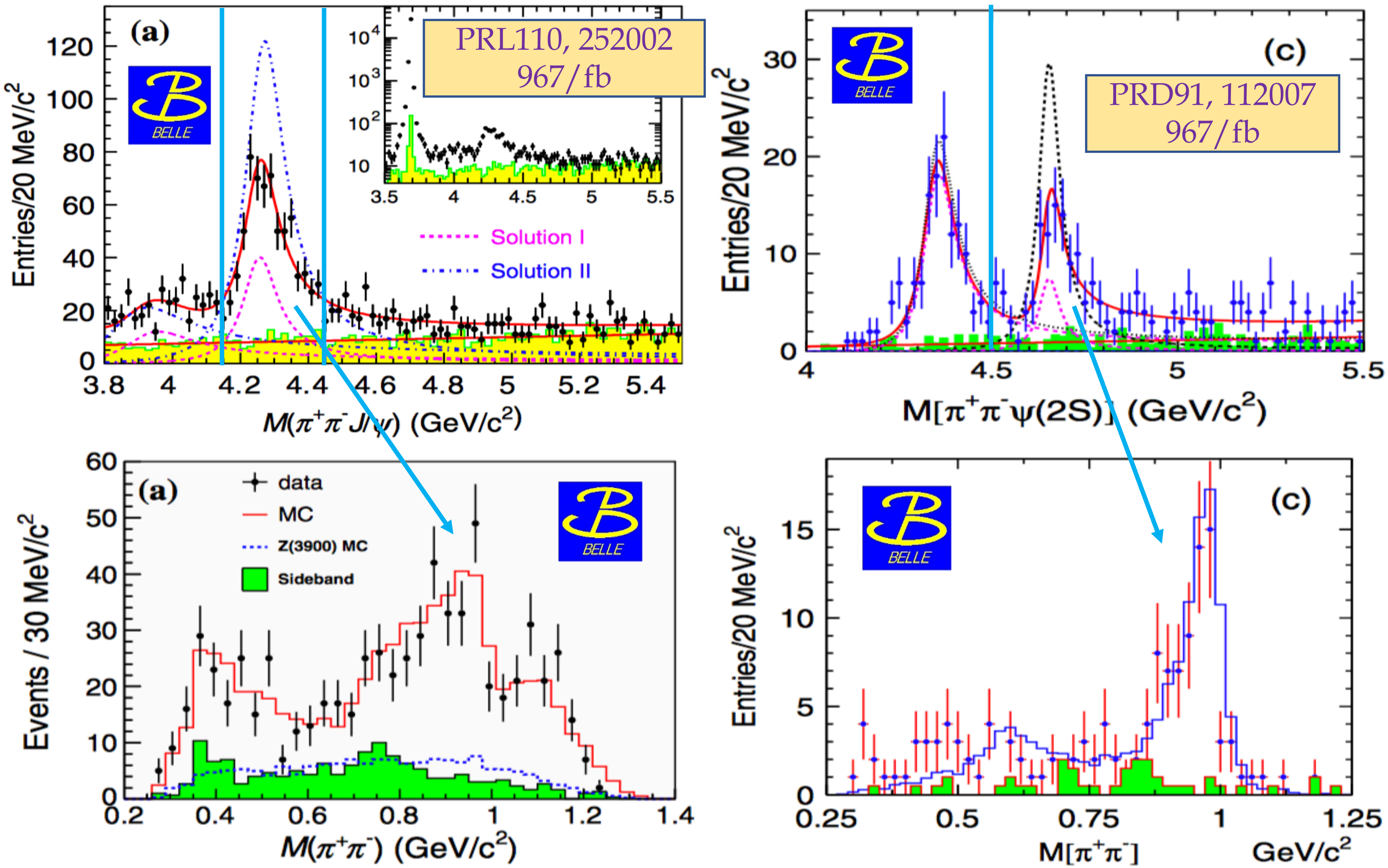








$M(\pi^+\pi^-)$ in Y(4260) and Y(4660) signal region



- $Y(4260) \to f_0(980)(\to \pi^+\pi^-)J/\psi$, $Y(4660) \to f_0(980)(\to \pi^+\pi^-)\psi(2S)$
  $f_0(980)$ has a $s\bar{s}$ component, and J/ψ has a $c\bar{c}$ component.
- **It is natural to search for such Y states with a quark component of $(c\bar{s})(\bar{c}s)$, e.g. $D_sD_{s1}(2536)$.**

Analysis method

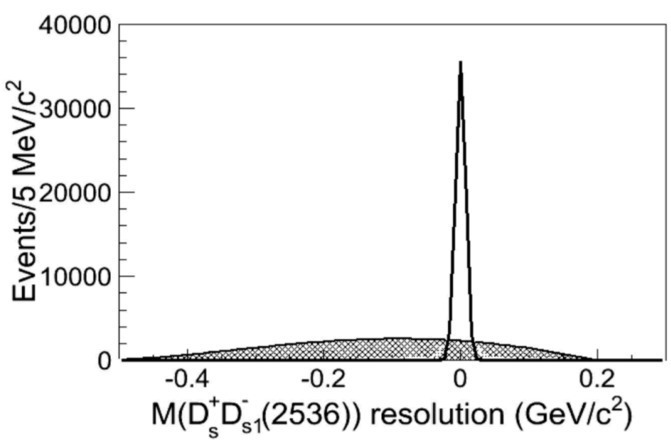
$$e^+e^- \to \gamma_{ISR} D_s^+ D_{s1}(2536)^- (\to \bar{D}^{*0} K^- / D^{*-} K_S^0)$$

We require full reconstruction of the γ_{ISR}, D_s^+ , and K^-/K_S^0.

- $D_s^+ \to \phi\pi^+, \bar{K}^{*0}K^+, K_S^0K^+, K^+K^-\pi^+\pi^0, K_S^0\pi^0K^+, K^{*+}K_S^0, \eta\pi^+$, and $\eta'\pi^+$
- For the signals, the spectrum of the mass recoiling against the $D_s^+K^-\gamma_{ISR}$ system should be accumulated at the $\bar{D}^{*0}/D^{*-}$ nominal mass.

$$M_{rec}(\gamma_{ISR} D_s^+ K^-/K_S^0) = \sqrt{(E_{c.m.}^* - E_{\gamma_{ISR} D_s^+ K^-/K_S^0}^*)^2 - \left(p_{\gamma_{ISR} D_s^+ K^-/K_S^0}^*\right)^2}$$

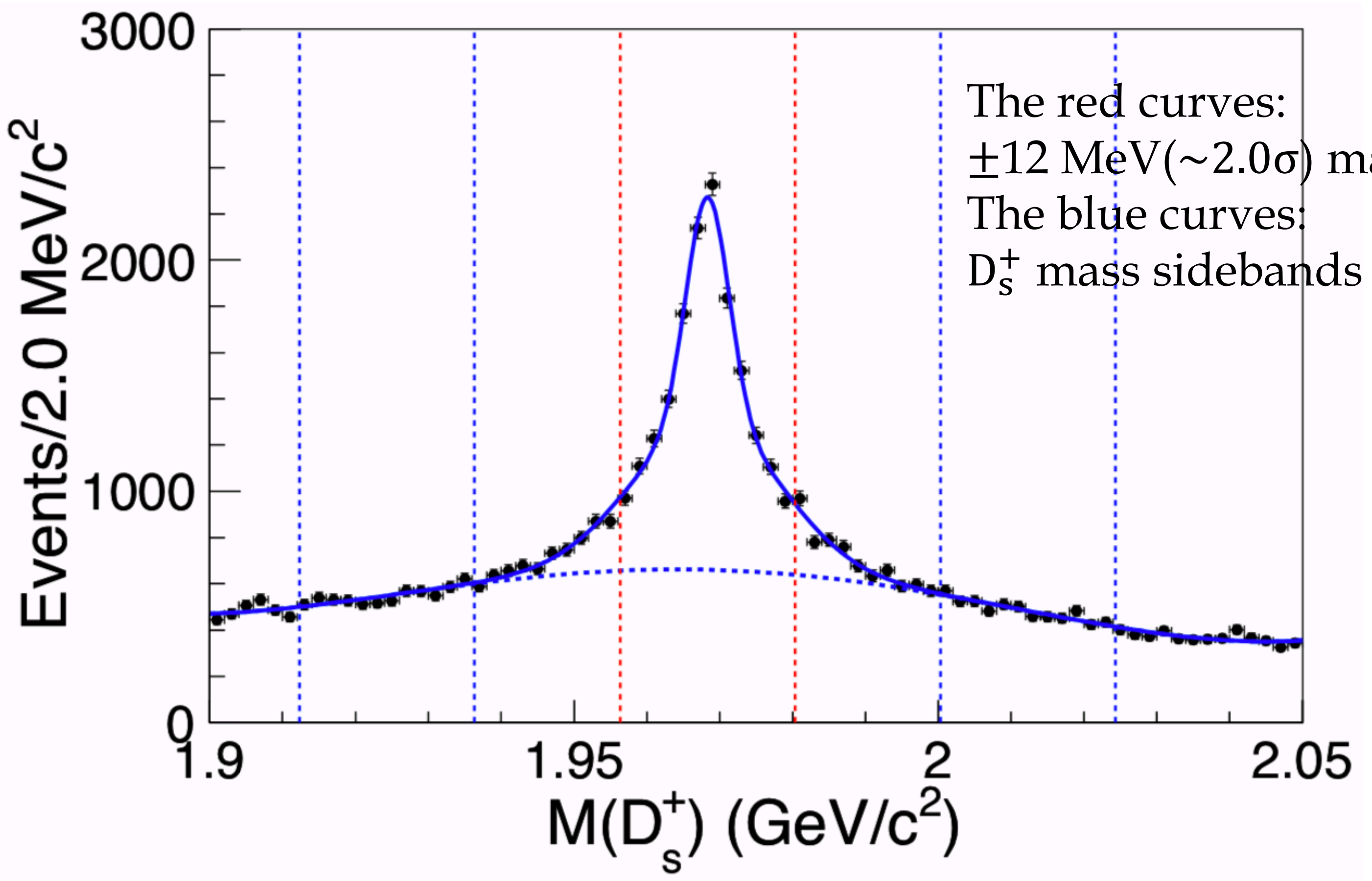
- To improve the $M_{rec}(\gamma_{ISR})$ resolution, $M_{rec}(\gamma_{ISR} D_s^+ K^-/K_S^0)$ is constrained to be the nominal mass of the $\bar{D}^{*0}/D^{*-}$. As a result, the resolution of $M_{rec}(\gamma_{ISR}) \equiv M(D_s^+ D_{s1}(2536)^-)$ is drastically improved (~180MeV → ~ 5MeV).



Data samples:

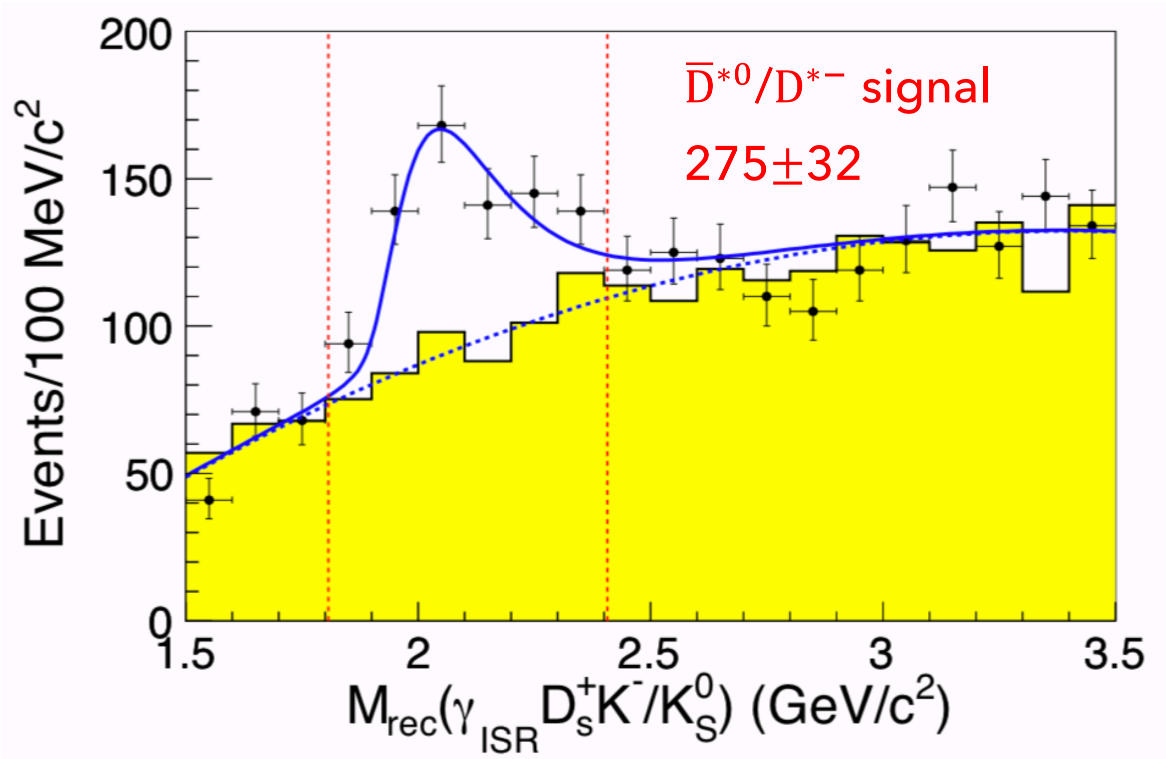
$\sqrt{s}$ (GeV)	Luminosity (fb^{-1})
10.52	89.5±1.3
10.58	711±10
10.867	121.4±1.7
Total	921.9±12.9

The invariant mass distribution for D_s^+ candidates



- Since the intrinsic width of the D_s^+ could be neglected, a double Gaussian function is used to fit the D_s^+ mass spectrum.
- The purity is $N_{sig}/(N_{sig} + N_{bkg})$=64%.

The recoil mass spectrum against $\gamma_{ISR} D_s^+ K^- / K_S^0$

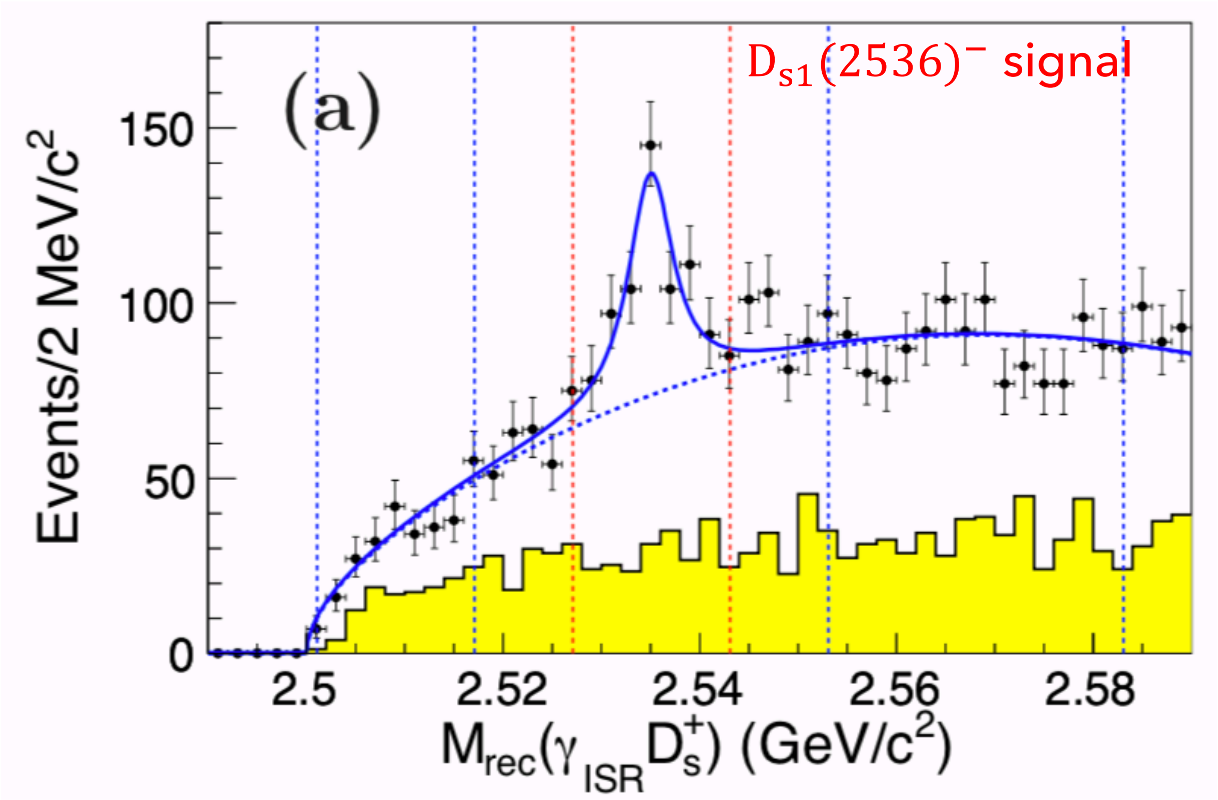


$\bar{D}^{*0}/D^{*-}$ signal: Gaussian ⊗ Novosibirsk

The combinatorial backgrounds: a second-order polynomial

- $M_{rec}(\gamma_{ISR} D_s^+ K^- / K_S^0)$ distribution is making before applying the $\bar{D}^{*0}/D^{*-}$ mass constraint.
- The yellow histogram shows the normalized $D_{s1}(2536)^-$ mass sidebands (see below).
- Due to the poor mass resolution, the $\bar{D}^{*0}/D^{*-}$ signal is very wide.

The recoil mass spectrum against $\gamma_{ISR} D_s^+$



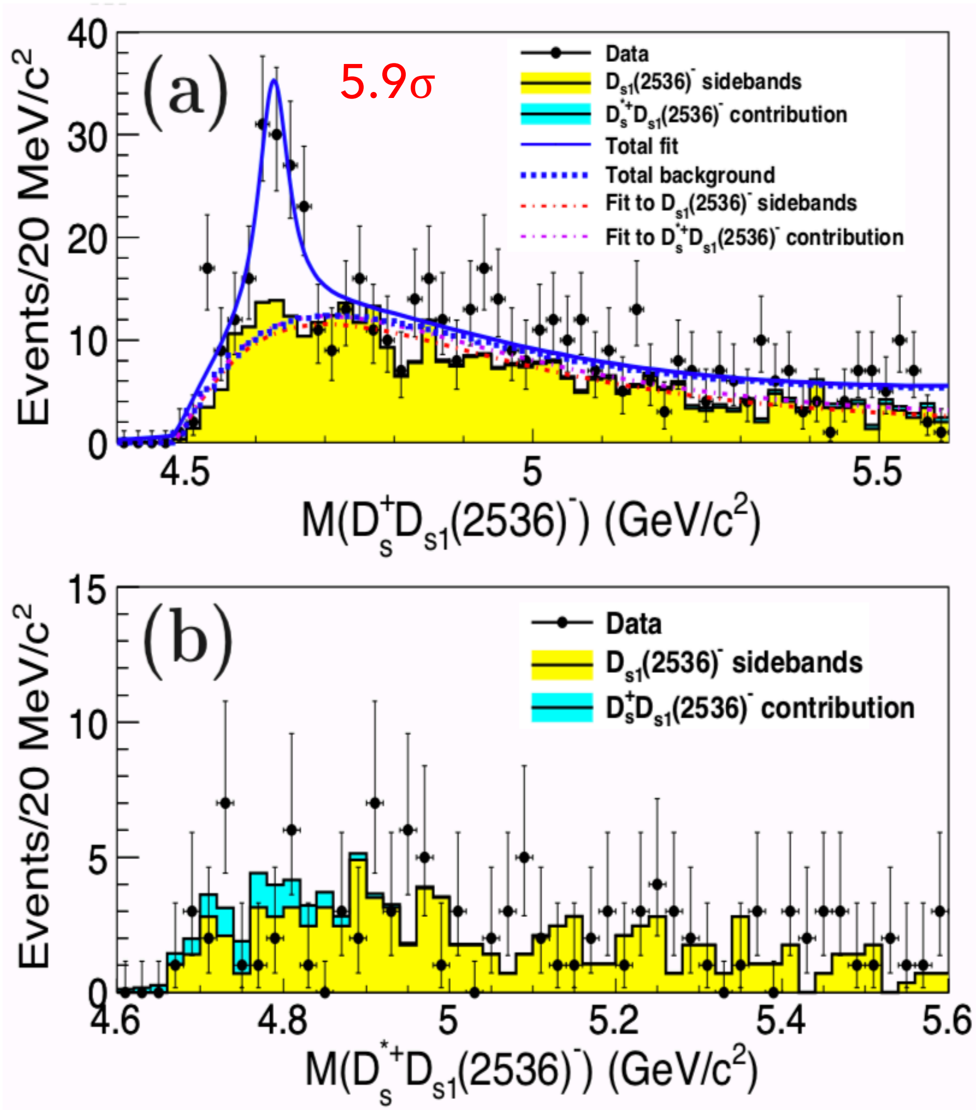
$D_{s1}(2536)^-$ signal: Double Gaussian

The combinatorial backgrounds: threshold function

- $M_{rec}(\gamma_{ISR} D_s^+)$ distribution is making after applying the $\bar{D}^{*0}/D^{*-}$ mass constraint.
- The yellow histogram shows the normalized D_s^+ mass sidebands.
- The fit yields 254±36 $D_{s1}(2536)^-$ signal events with the statistical significance of 8.0σ.

Final mass spectrum $M(D_s^+ D_{s1}(2536)^-)$

After applying the $\overline{D}^{*0}/D^{*-}$ mass constraint



An unbinned simultaneous likelihood fit:

- Signal: a BW convolved with a Gaussian function, then multiplied by an efficiency function
- $D_{s1}(2536)^-$ mass sidebands: a threshold function
- $e^+e^- \to D_s^{*+} D_{s1}(2536)^-$ background contribution: a threshold function
- A non-resonant contribution: a two-body phase space form

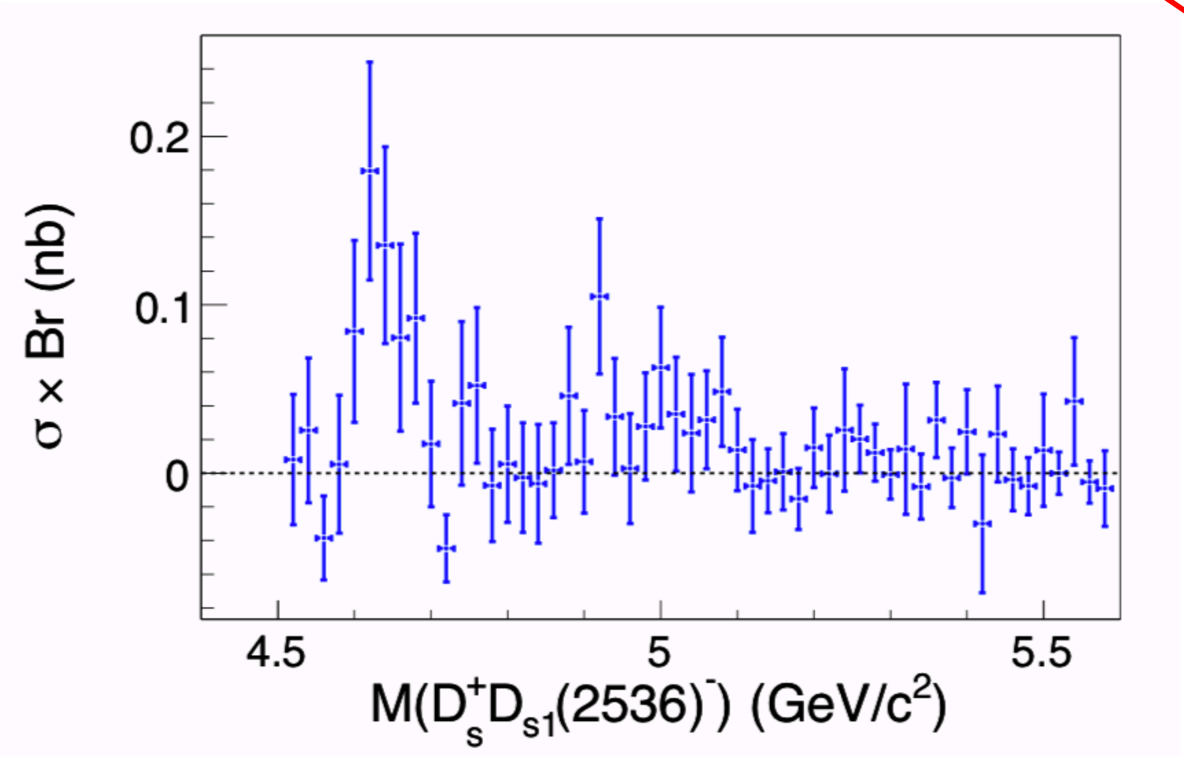
$M = (4625.9^{+6.2}_{-6.0}(\text{stat.}) \pm 0.4(\text{syst.})\ \text{MeV}/c^2$
$\Gamma = (49.8^{+13.9}_{-11.5}(\text{stat.}) \pm 4.0(\text{syst.})\ \text{MeV}$
$\Gamma_{ee} \times \mathcal{B}(Y \to D_s^+ D_{s1}(2536)^-) \times \mathcal{B}(D_{s1}(2536)^- \to \overline{D}^{*0} K^-) = (14.3^{+2.8}_{-2.6}(\text{stat.}) \pm 1.5(\text{syst.})\ \text{eV}$

One possible background is from $e^+e^- \to D_s^{*+}(\to D_s^+\gamma) D_{s1}(2536)^-$, where the photon from the D_s^{*+} remains undetected. No obvious structure is observed in the $e^+e^- \to D_s^{*+}(\to D_s^+\gamma) D_{s1}(2536)^-$.

Cross section

$$\sigma(e^+e^- \to D_s^+ D_{s1}(2536)^-)\mathcal{B}(D_{s1}(2536)^- \to \bar{D}^{*0}K^-) = \frac{N_{\rm fit}^{D_{s1}(2536)^-}}{d\mathcal{L} \times [\Sigma_i(\varepsilon_i^{\bar{D}^{*0}K^-} \times \mathcal{B}_i) + R_{\bar{D}^{*0}K^-}^{D^{*-}K_S^0} \times \Sigma_i(\varepsilon_i^{D^{*-}K_S^0} \times \mathcal{B}_i)]},$$

The yield of fitted $D_{s1}(2536)^-$ signal events after subtracting the $e^+e^- \to D_s^{*+}D_{s1}(2536)^-$ background contribution.



The peak value of the σ×Br at $M(D_s^+D_{s1}(2536)^-) \sim 4.63$ GeV/c^2 is about (0.18 ± 0.06) nb.

$$e^+e^- \rightarrow D_s^+ D_{s2}^*(2573)^-$$

arXiv:2004.02404 (2020)

Analysis method

$$e^+e^- \rightarrow \gamma_{ISR} D_s^+ D_{s2}^*(2573)^- (\rightarrow \bar{D}^0 K^-)$$

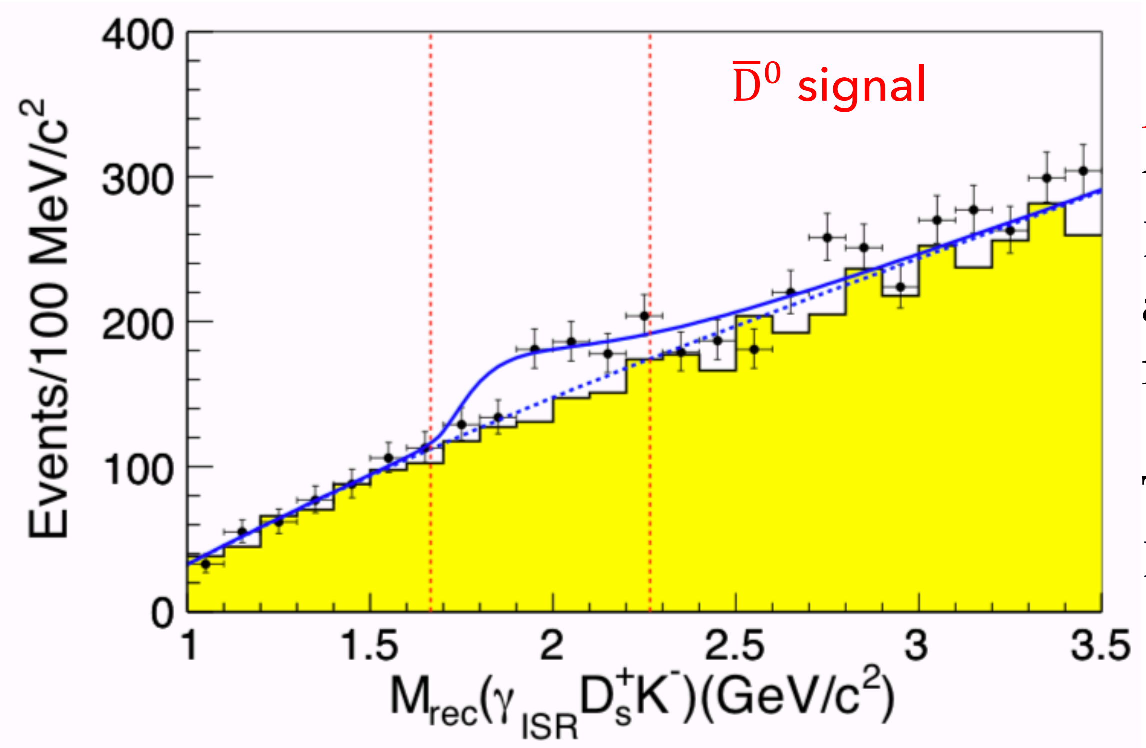
We require full reconstruction of the γ_{ISR}, D_s^+ , and K^-.

- $D_s^+ \rightarrow \phi\pi^+, K_S^0K^+, \bar{K}^{*0}K^+, \phi\rho^+, K^{*+}\bar{K}^{*0}, K^{*+}K_S^0, K_S^0K^+\pi^+\pi^-, \eta\pi^+,$ and $\eta'\pi^+$.
- For the signals, the spectrum of the mass recoiling against the $D_s^+K^-\gamma_{ISR}$ system should be accumulated at the $\bar{D}^0$ nominal mass.

$$M_{rec}(\gamma_{ISR}D_s^+K^-) = \sqrt{(E^*_{c.m.} - E^*_{\gamma_{ISR}D_s^+K^-})^2 - \left(p^*_{\gamma_{ISR}D_s^+K^-}\right)^2}$$

- To improve the γ_{ISR} resolution we refit recoil mass against $D_s^+K^-\gamma_{ISR}$ into the $\bar{D}^0$ mass. As a result, the resolution of $M_{rec}\,(\gamma_{ISR}) \equiv M(D_s^+D_{s2}^{*-}(2573))$ is drastically improved ($\sim$180MeV $\rightarrow \sim$ 5MeV).

The recoil mass spectrum against $\gamma_{ISR} D_s^+ K^-$

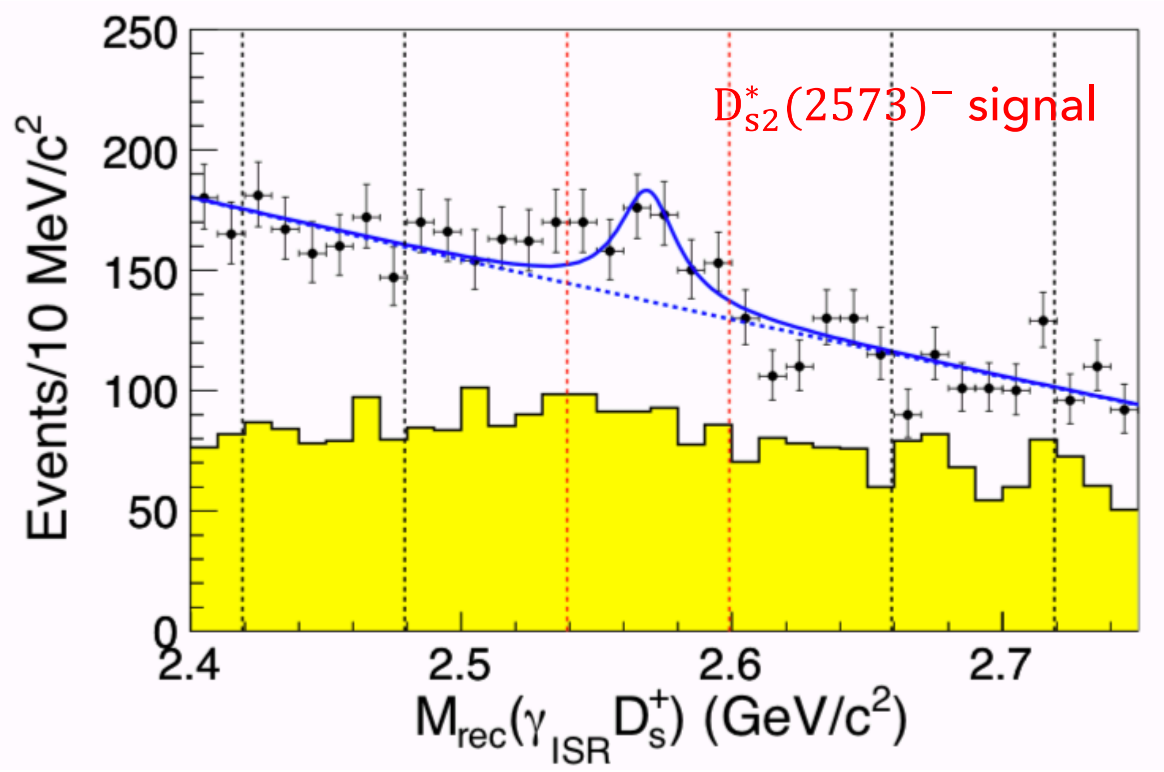


A simultaneous likelihood fit to the $M_{rec}(\gamma_{ISR} D_s^+ K^-)$ of $D_{s2}^*(2573)^-$ signal candidates and the normalized $D_{s2}^*(2573)^-$ mass sidebands is applied.

The best fit yields 224±42 $D_{s2}^*(2573)^-$ signal events.

- $M_{rec}(\gamma_{ISR} D_s^+ K^-)$ distribution is making before applying the $\bar{D}^0$ mass constraint.
- The yellow histogram shows the normalized $D_{s2}^*(2573)^-$ mass sidebands (see below).
- The $\bar{D}^0$ signal is wide and asymmetric due to the asymmetric resolution function of the ISR photon energy and higher order ISR corrections.

The recoil mass spectrum against $\gamma_{ISR} D_s^+$



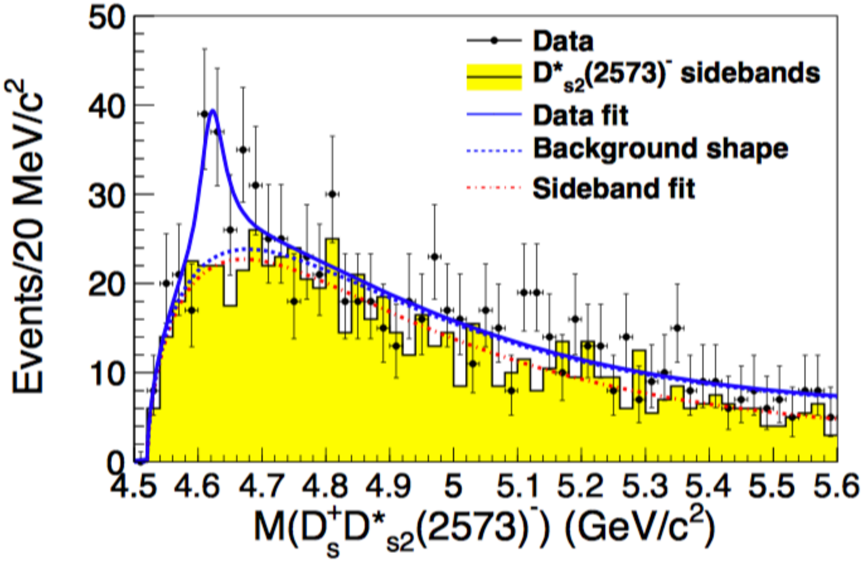
$D_{s2}^*(2573)^-$ signal:
BW ⊗ Gaussian

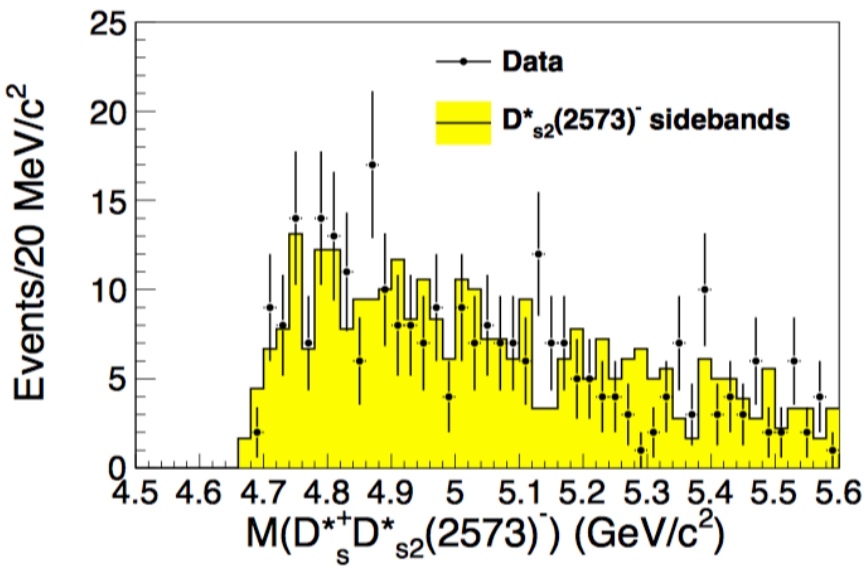
The combinatorial backgrounds:
A second-order polynomial

- $M_{rec}(\gamma_{ISR} D_s^+)$ distribution is making after applying the $\bar{D}^0$ mass constraint.
- The yellow histogram shows the normalized D_s^+ mass sidebands.
- The fit yields 182±47 $D_{s2}^*(2573)^-$signal events with the statistical significance of 4.1σ.

Final mass spectrum $M(D_s^+ D_{s2}^*(2573)^-)$

After applying the $\bar{D}^0$ mass constraint





An unbinned simultaneous likelihood fit:

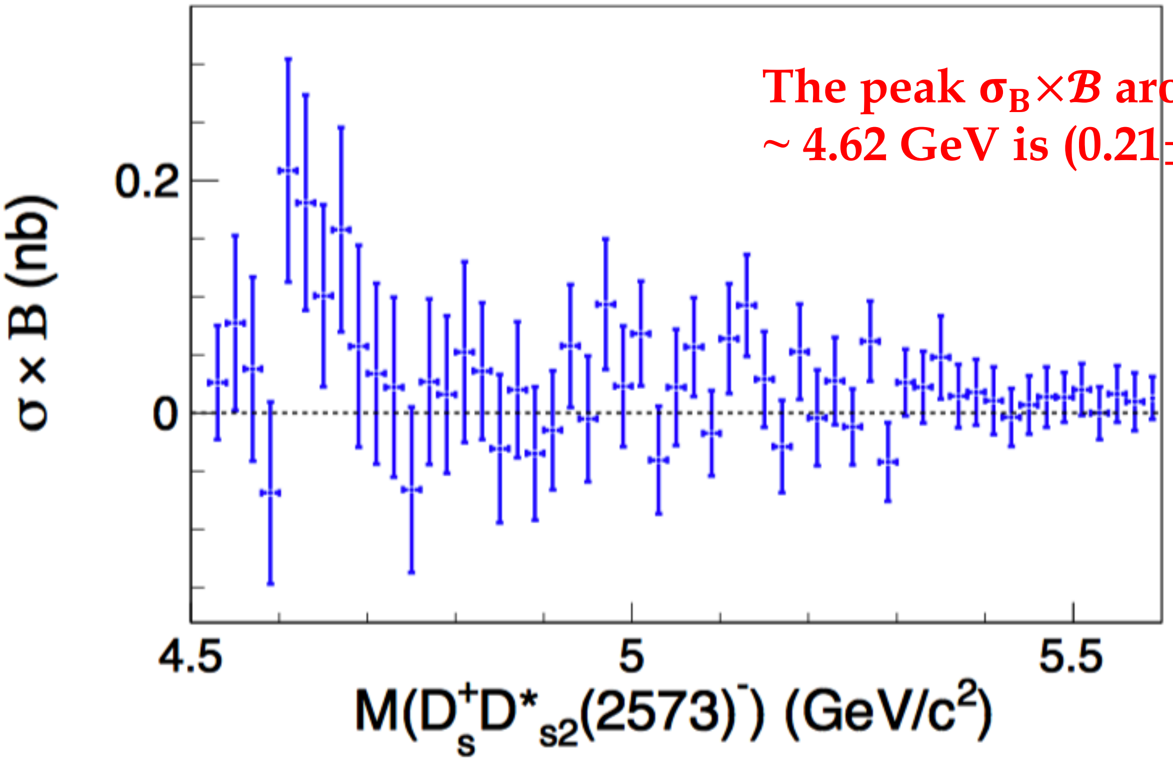
- Signal: a BW convolved with a Gaussian function, then multiplied by an efficiency function
- $D_{s2}^*(2573)^-$ mass sidebands: a threshold function
- A non-resonant contribution: a two-body phase space form

$M=(4619.8^{+8.9}_{-8.0}(\text{stat.}) \pm 2.3(\text{syst.})\ \text{MeV}/c^2$
$\Gamma = (47.0^{+31.3}_{-14.8}(\text{stat.}) \pm 4.6(\text{syst.})\ \text{MeV}$
$\Gamma_{ee} \times \mathcal{B}(Y \to D_s^+ D_{s2}^*(2573)^-) \times \mathcal{B}(D_{s2}^*(2573)^- \to \bar{D}^0 K^-) = (14.7^{+5.9}_{-4.5}(\text{stat.}) \pm 3.6(\text{syst.})\ \text{eV}$

Cross section

$$\sigma_B(e^+e^- \to D_s^+ D_{s2}^*(2573)^-)\mathcal{B}(D_{s2}^*(2573)^- \to \overline{D}^0 K^-) = \frac{N^{obs}}{\Sigma_i(\varepsilon_i \times \mathcal{B}_i) \times \Delta\mathcal{L}}$$

N^{obs}: the number of observed $e^+e^- \to D_s^+ D_{s2}^*(2573)^-$ signal events after subtracting the normalized $D_{s2}^*(2573)^-$ mass sidebands



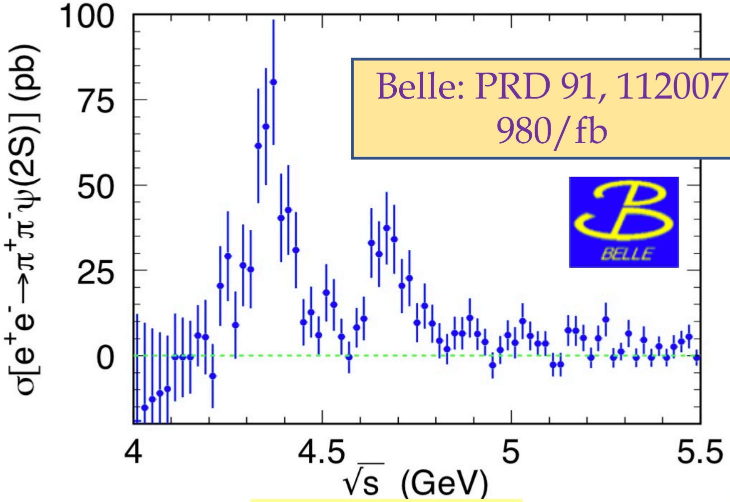
The peak $\sigma_B \times \mathcal{B}$ around $M(D_s^+ D_{s2}^*(2573)^-) \sim 4.62$ GeV is (0.21±0.10) nb.

Summary and discussion

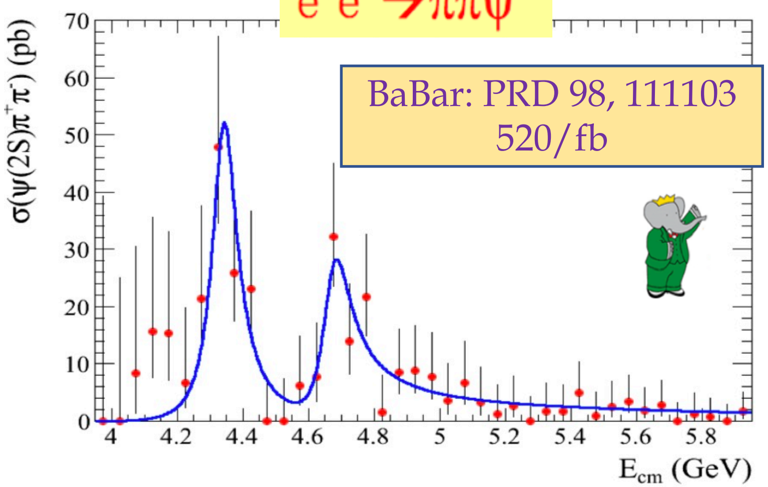
Interpretations of Y(4626)

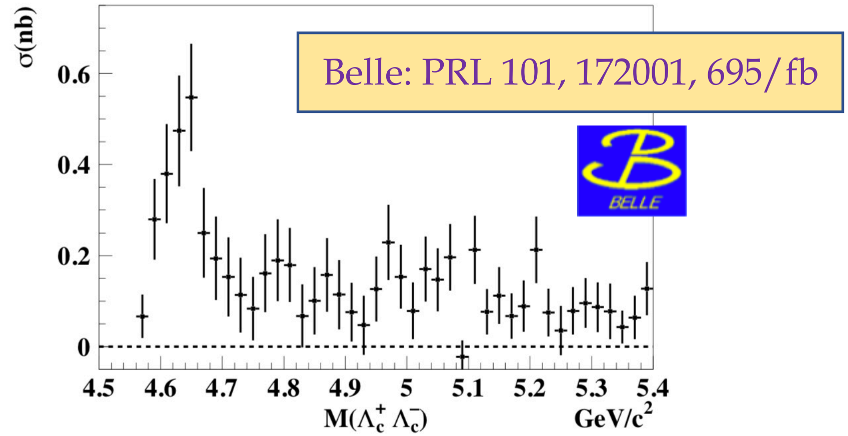
- A tetraquark state in a chiral constituent quark model with a scaling method [PRD101, 054010 (2020)].
- A P-wave tetraquark state $[cs][\bar{c}\bar{s}]$ with 1^{--} in the multiquark color flux-tube model [PRD 101, 054039 (2020)].
- A hidden-strange molecular state from $\Lambda_c^+\Lambda_c^-$ interaction [arXiv:1911.03706 (2020)].
- A molecular state from interaction $D_s^*\bar{D}_{s1}(2536)$ - $D_s\bar{D}_{s1}(2536)$ [EPJC 80, 246 (2020)].
- A tetraquark and etc instead of $D_s^*\bar{D}_{s1}(2536)$ molecular within the Bethe-Salpeter framework [arXiv:2004.03167 (2020)].
- A higher charmonium [PRD 101, 034001 (2020)].
- A P-Wave hidden-charm exotic mesons in the diquark model [arXiv:2003.02802 (2020)].

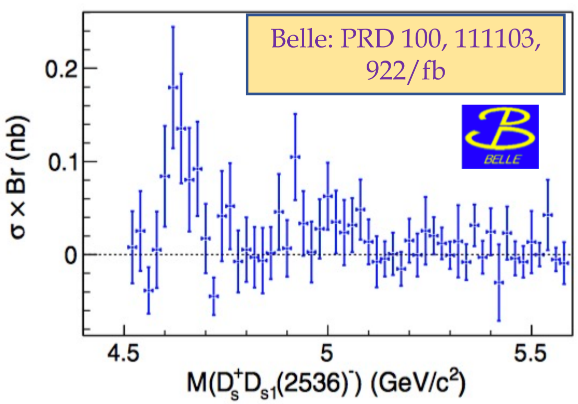
Y(4630) = Y(4660)?

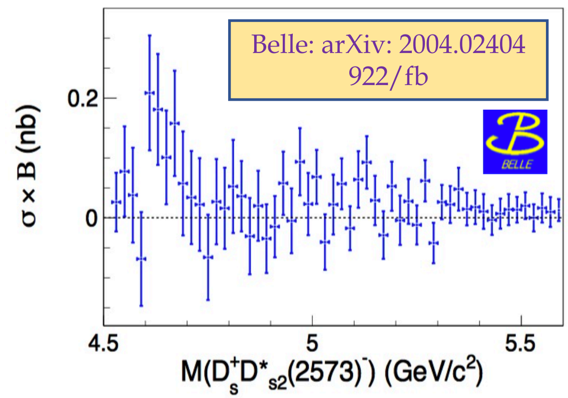


$e^+e^- \to \pi\pi\psi'$









Experiment	Mass (MeV)	Width (MeV)
Belle, $\Lambda_c^+\Lambda_c^-$	$4634^{+8}_{-7}{}^{+5}_{-8}$	$92^{+40}_{-24}{}^{+10}_{-21}$
Belle, $\pi^+\pi^-\psi(2S)$	4652±10±8	68±11±1
BaBar, $\pi^+\pi^-\psi(2S)$	4669±21±3	104±48±10
Belle, $D_s^+D_{s1}(2536)^-$	$4626^{+7}_{-7} \pm 1$	$49.8^{+14}_{-12} \pm 4$
Belle, $D_s^+D_{s1}(2536)^-$	$4620^{+9}_{-8} \pm 3$	$47.0^{+32}_{-15} \pm 5$

What is Y(4660)?

- Charmonium?
- Molecule $[f_0(980)\psi', \Lambda_c^+\Lambda_c^-]$?
- Hadron-charmonium?
- Tetraquark state?
- Hybrid?
- …

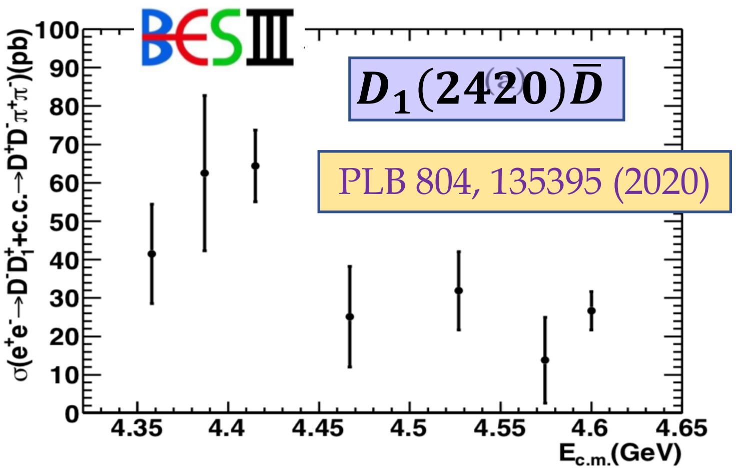
Experimental measurements:
Y(4660)→
- $D_s^* D_{s0}^*(2317)$
- $D_s D_{s1}(2460)$
- $D_s^* D_{s1}(2460)$
- $D_s^* D_{s1}(2536)$
- $D_s^* D_{s2}^*(2573)$

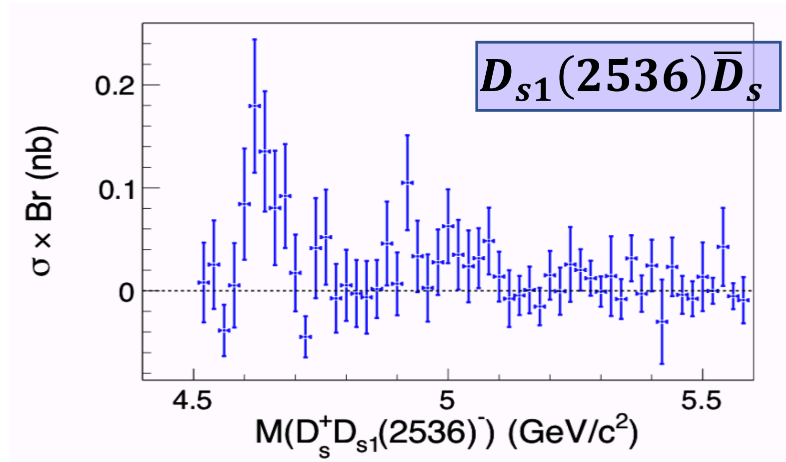
May these rates be estimated according to $D_s^+ D_{s1}(2536)^-$ and $D_s^+ D_{s2}^*(2573)^-$?

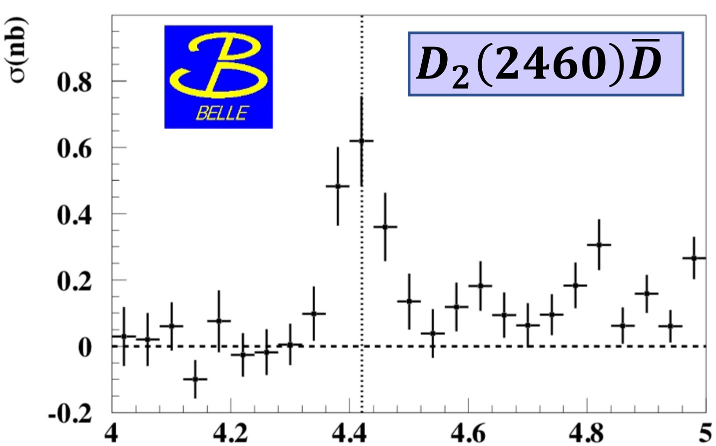
Why does Y(4660) couple to charmed baryon strongly?
Why does Y(4660) couple to $s\bar{s}$ strongly?

Extend to the charm meson pairs

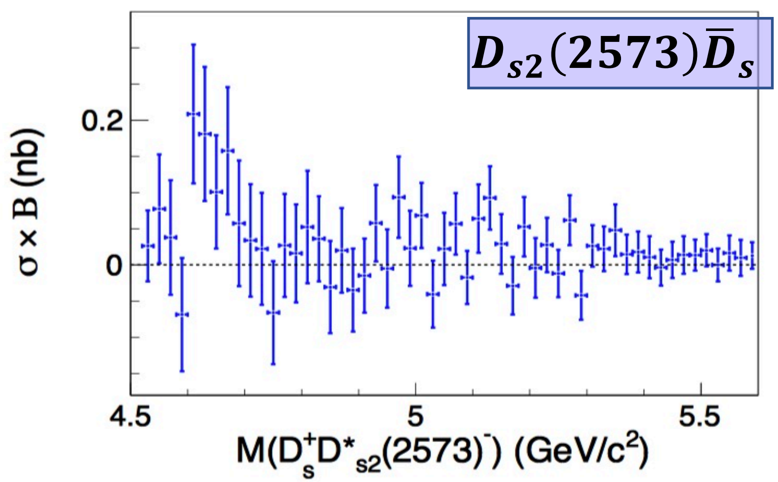
- $D_1(2420)$, $D_2(2460)$, $D_{s1}(2536)$, $D_{s2}(2573)$ are $j_l^P = \frac{3}{2}^+$ heavy-light states.
- The widths of the $D_1(2420)$, $D_2(2460)$, $D_{s1}(2536)$, $D_{s2}(2573)$ are narrow.







PRL 100, 062001 (2008)



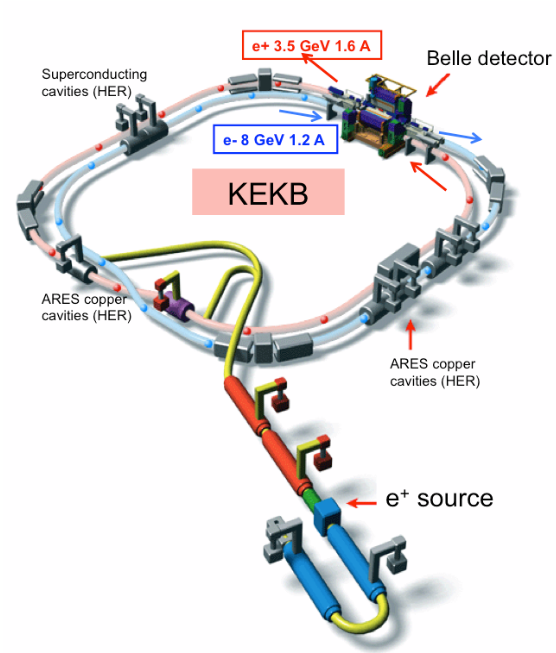
Do Y(4360)/Y(4390)/ψ(4415) & Y(4630)/Y(4660) have similar structures?

Status and Prospects of Belle II

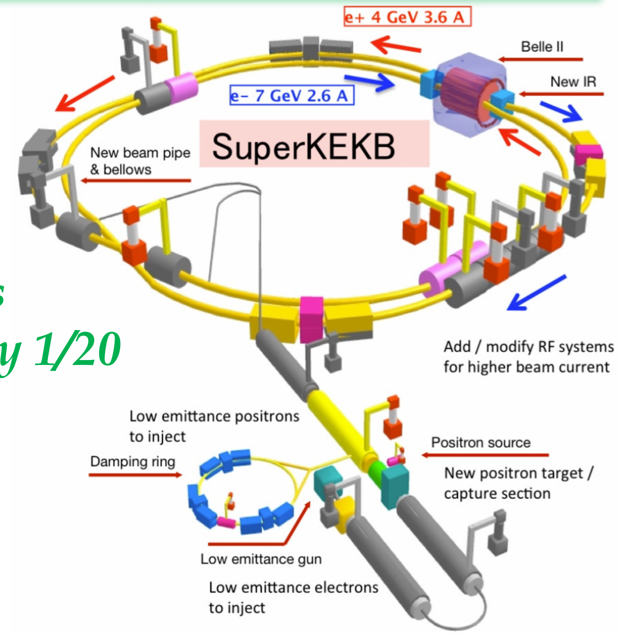
SuperKEKB

$$\int^{\text{goal}} \mathcal{L}\, dt = 50\ \text{ab}^{-1} = 50 \times \mathcal{L}^{\text{int}}_{\text{Belle}}$$

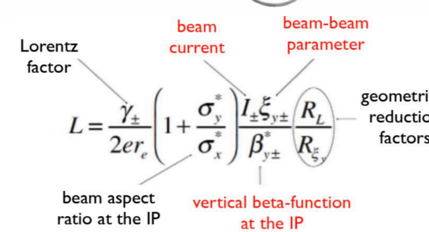
- 1^{st} Vs. 2^{nd} generation B-factory



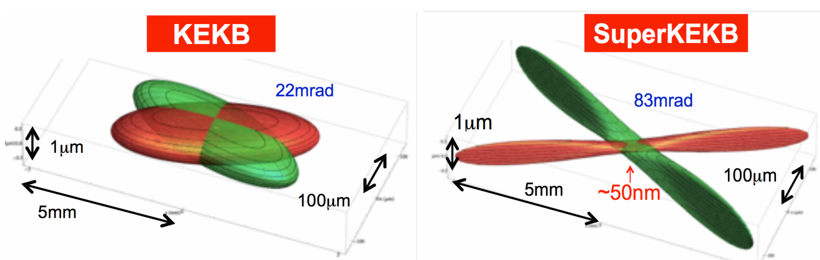
- *Double beam currents*
- *Squeeze beams @IP by 1/20*
- *Reduced CM boost*



- Nano-beam design (by P. Raimondi for SuperB)

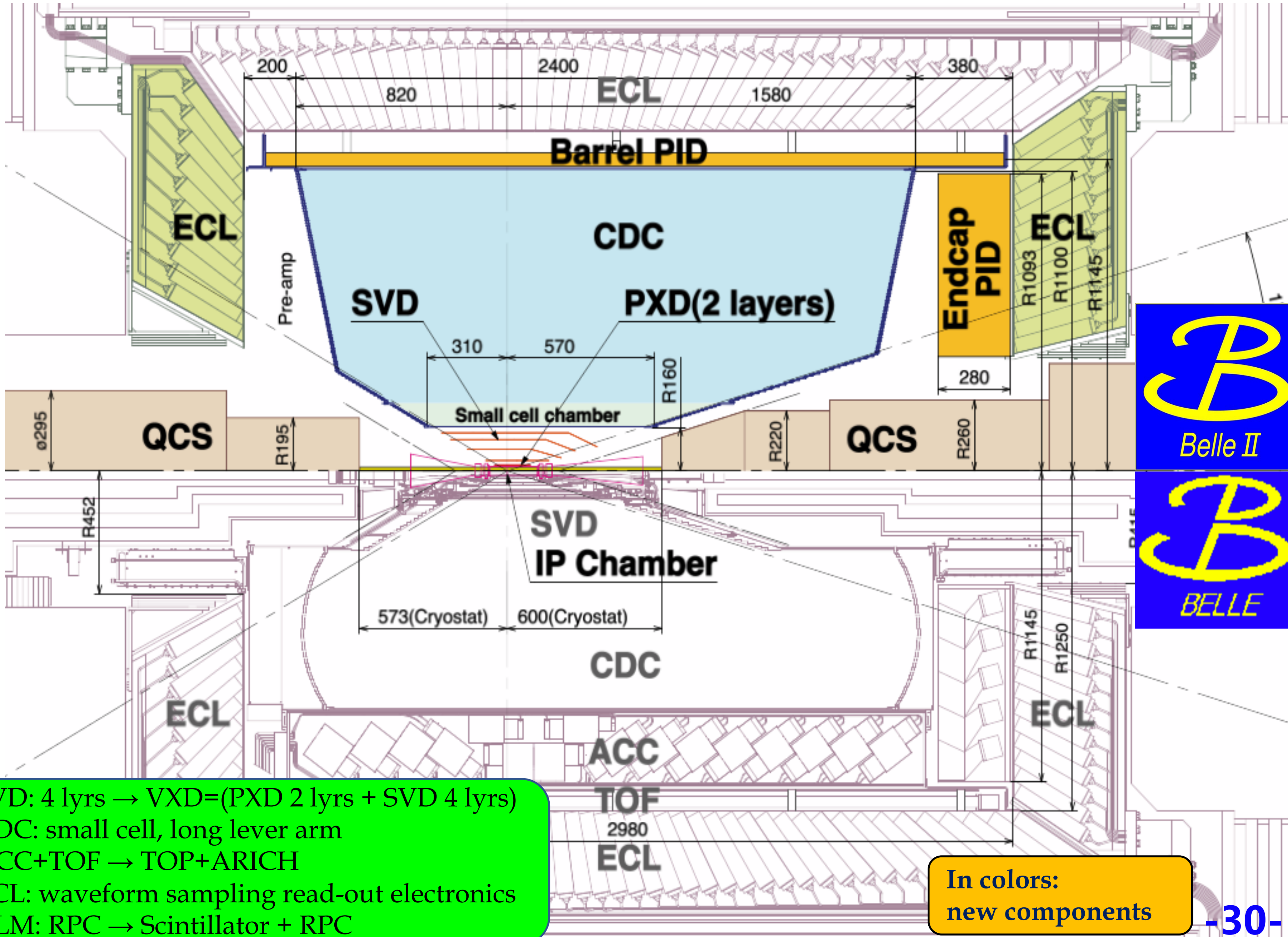


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$



	$E_\pm$ (GeV) LER/HER	Cross Angle (mrad)	$I_\pm$ (A) LER/HER	β_y^* (mm) LER/HER	$\mathcal{L}$ $(cm^{-2}s^{-1})$
KEKB	3.5/8.0	22	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	83	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma \sim 2/3$		$\times 2$	$\times 20$	$\times 40$

Detector: Belle Vs. Belle II

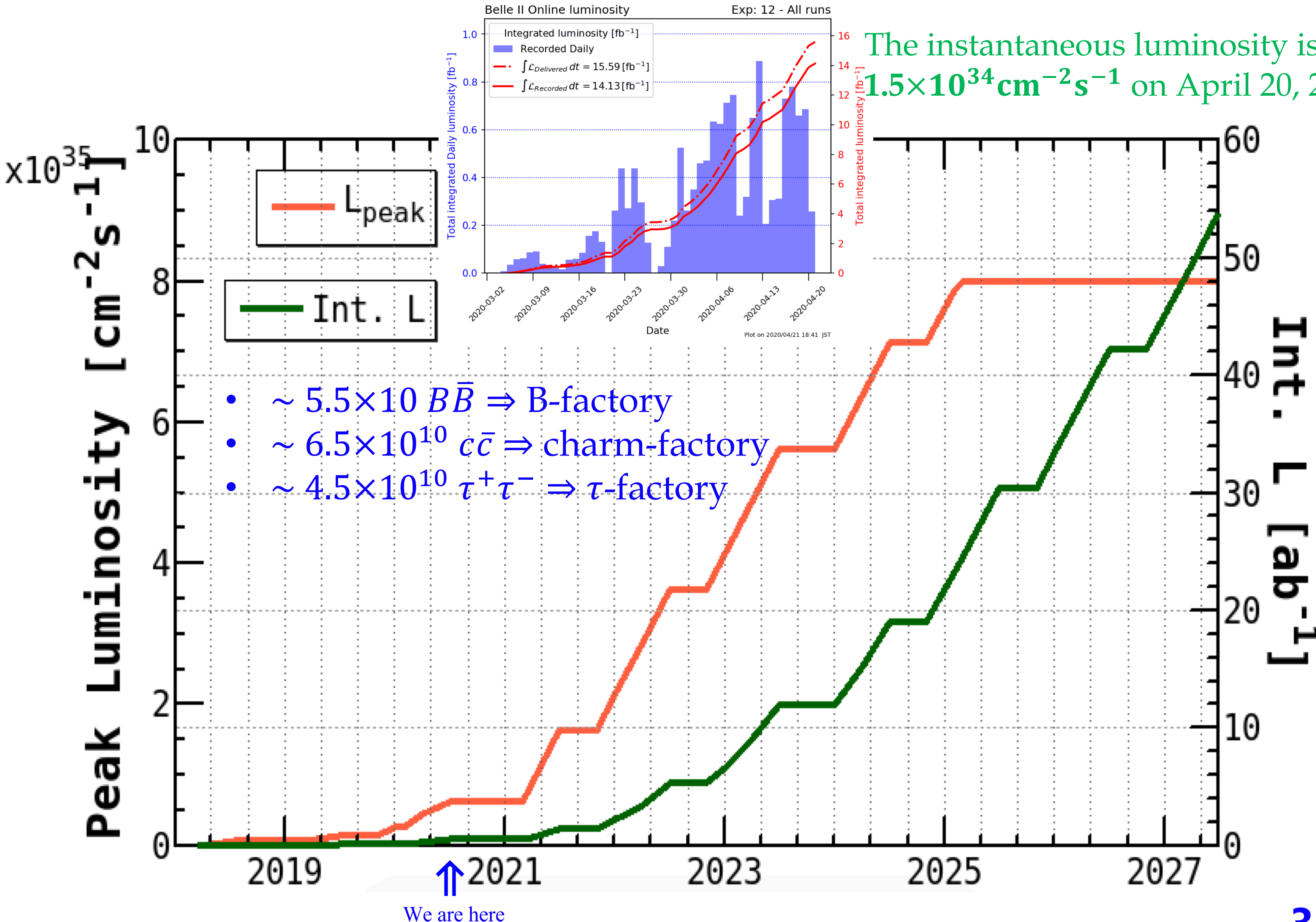


SVD: 4 lyrs → VXD=(PXD 2 lyrs + SVD 4 lyrs)
CDC: small cell, long lever arm
ACC+TOF → TOP+ARICH
ECL: waveform sampling read-out electronics
KLM: RPC → Scintillator + RPC

In colors:
new components

Dataset at Belle II

The instantaneous luminosity is $\mathbf{1.5\times10^{34}cm^{-2}s^{-1}}$ on April 20, 2020.

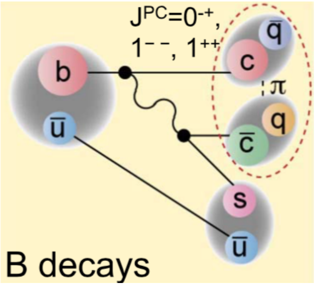


- $\sim 5.5\times10\ B\bar{B} \Rightarrow$ B-factory
- $\sim 6.5\times10^{10}\ c\bar{c} \Rightarrow$ charm-factory
- $\sim 4.5\times10^{10}\ \tau^+\tau^- \Rightarrow \tau$-factory

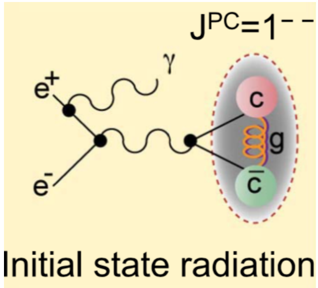
Exotic and Quarkonium Prospects at Belle II

Production of charmonium(-like) states at B-factory

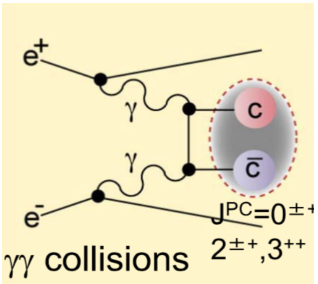
- **B decay** ($B \to KX_{c\bar{c}}$)
  - CKM favored process, large branching fractions $10^{-3} \sim 10^{-4}$
  - $J^{PC} = 0^{-+}, 1^{--}, 1^{++}, \ldots$



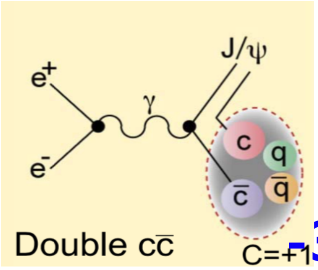
- **Initial-state radiation (ISR)**
  - $J^{PC} = 1^{--}$



- **Two-photon process**
  - $J^{PC} = 0^{-+}, 0^{++}, 2^{++}, 2^{-+}, \ldots$



- **Double charmonium**
  - e.g. $e^+e^- \to J/\psi X(3940)$ [PRL 98, 082001 (2007)]



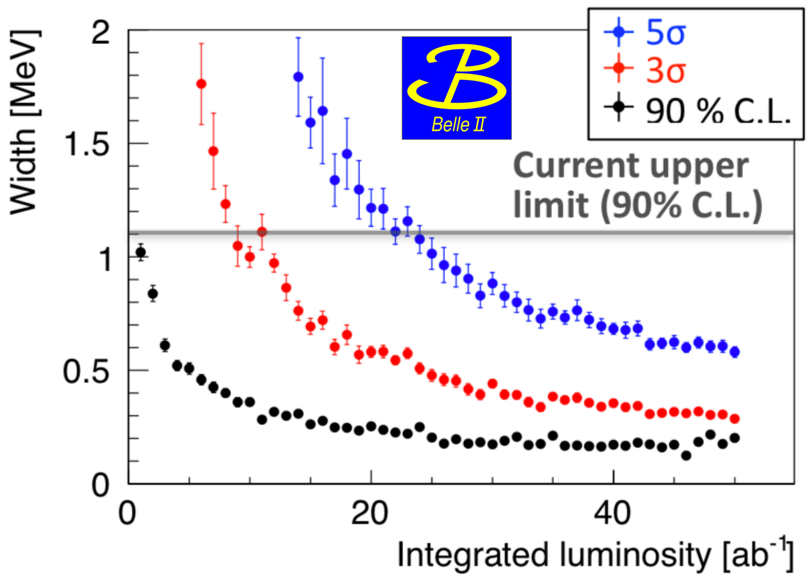
Expected statistics @50 ab^{-1} of XYZ

State	Production and Decay	N
X(3872)	$B \to KX(3872)$, $X(3872) \to J/\psi\pi^+\pi^-$	$\simeq$14400
Y(4260)	ISR, $Y(4260) \to J/\psi\pi^+\pi^-$	$\simeq$29600
Z(4430)	$B \to K^{\mp}Z(4430)$, $Z(4430) \to J/\psi\pi^{\pm}$	$\simeq$10200

Further investigations at Belle II

B decays:

- Determination of the X(3872) total width
- The branching fraction of $B \to KX(3872)$
- $X(3872) \to D^0\bar{D}^{*0}$ has been seen. Other open flavor decays? $B \to KD\bar{D}$, $KD^*\bar{D}^*$, $KD\bar{D}^{**}$, $KD^*\bar{D}^{**}$.
- Full amplitude analysis to $B \to K\omega J/\psi$ and $B \to K\pi\chi_{c1}$ to determine the spin-parities of X(3915), Z(4050), Z(4250) …
- $B \to K$ + anything, to discover new particles?



With the full data sample of Belle II (50 ab^{-1}), total width with values up to

[90% C.L.] ~ 180 keV

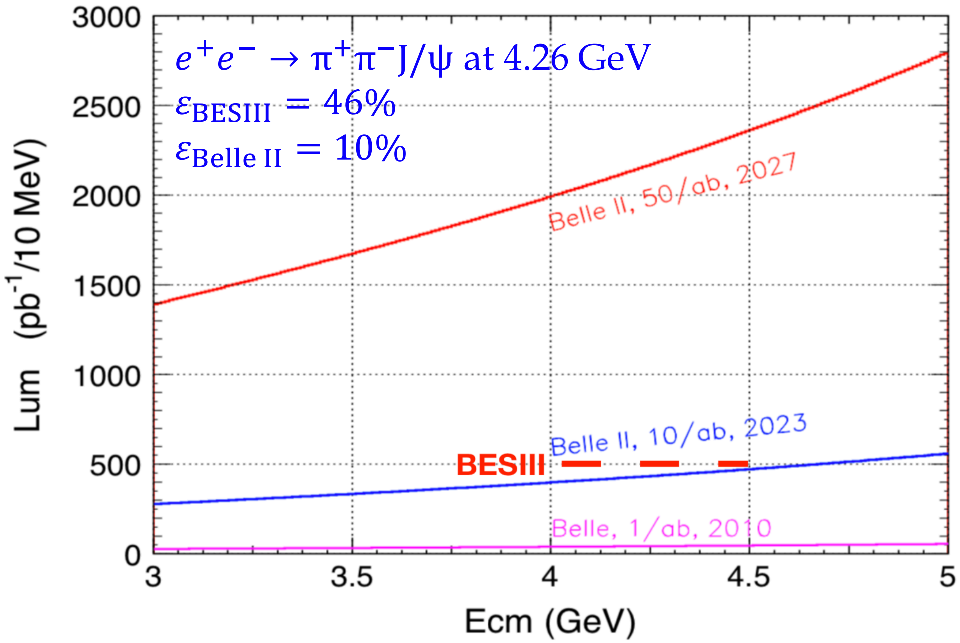
[3σ significance] ~ 280 keV

[5σ significant] ~ 570 keV

can be measured.

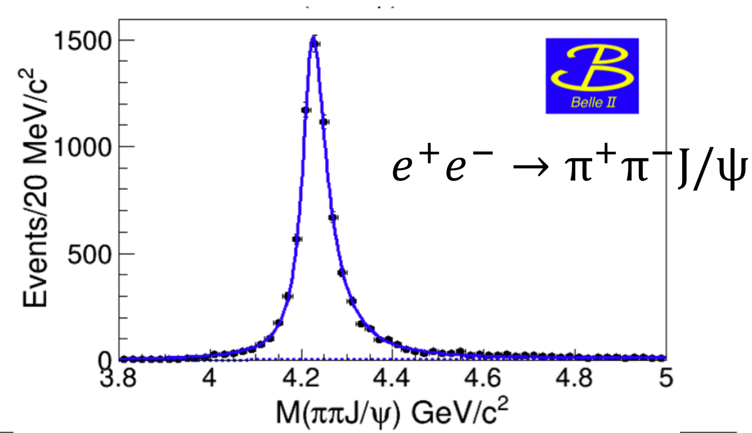
Further investigations at Belle II

ISR process



- Belle II 50 ab^{-1} ~ BESIII 500 pb^{-1}, 10 MeV scan
- Line shape of the resonance and fine structures can be investigated.

PHOKHARA simulation:



Golden Channels	$E_{c.m.}$ (GeV)	Statistical error (%)	Related XYZ states
$\pi^+\pi^- J/\psi$	4.23	7.5 (3.0)	$Y(4008)$, $Y(4260)$, $Z_c(3900)$
$\pi^+\pi^- \psi(2S)$	4.36	12 (5.0)	$Y(4260)$, $Y(4360)$, $Y(4660)$, $Z_c(4050)$
$K^+K^- J/\psi$	4.53	15 (6.5)	Z_{cs}
$\pi^+\pi^- h_c$	4.23	15 (6.5)	$Y(4220)$, $Y(4390)$, $Z_c(4020)$, $Z_c(4025)$
$\omega\chi_{c0}$	4.23	35 (15)	$Y(4220)$

10 ab^{-1} 50 ab^{-1}

Bottomonium(-like) at *B*-factories

Three ways to access bottomonia below $B\bar{B}$ threshold:

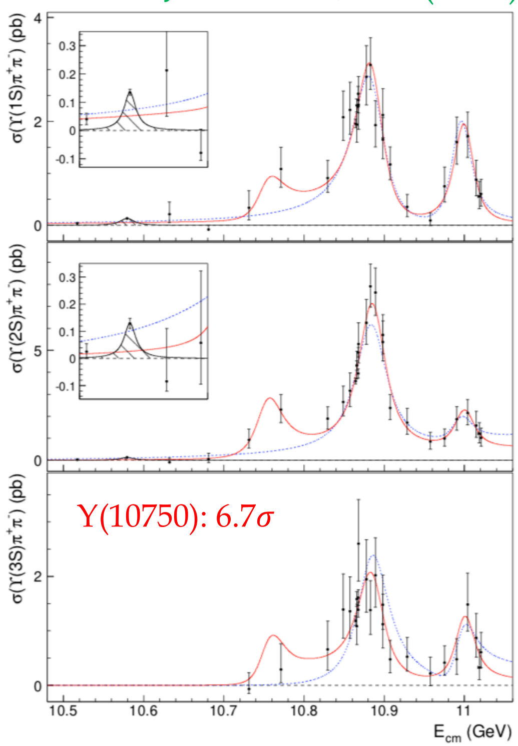
- Decays of higher mass states (e.g. Υ(4S,5S,6S))
- Production of 1^{--} states via initial-state radiation
- Direct production via operation at a lower C.M. energy.

Predicted Missing bottomonium levels below $B\bar{B}$ threshold

Name	L	S	J^{PC}	Mass, MeV/c^2	Emitted hadrons [Threshold, GeV/c^2]
$\eta_b(3S)$	0	0	0^{-+}	10336	ω [11.12], ϕ [11.36]
$h_b(3P)$	1	0	1^{+-}	10541	$\pi^+\pi^-$ [10.82], η [11.09], η' [11.50]
$\eta_{b2}(1D)$	2	0	2^{-+}	10148	ω [10.93], ϕ [11.17]
$\eta_{b2}(2D)$	2	0	2^{-+}	10450	ω [11.23], ϕ [11.47]
$\Upsilon_J(2D)$	2	1	$(1,2,3)^{--}$	10441 – 10455	$\pi^+\pi^-$ [10.73], η [11.00], η' [11.41]
$h_{b3}(1F)$	3	0	3^{+-}	10355	$\pi^+\pi^-$ [10.63], η [10.90], η' [11.31]
$\chi_{bJ}(1F)$	3	1	$(2,3,4)^{++}$	10350 – 10358	ω [11.14], ϕ [11.38]
$\eta_{b4}(1G)$	4	0	4^{-+}	10530	ω [11.31], ϕ [11.55]
$\Upsilon_J(1G)$	4	1	$(3,4,5)^{--}$	10529 – 10532	$\pi^+\pi^-$ [10.81], η [11.08], η' [11.49]

Mod. Phys. Lett. A 32, 1750025 (2017)

JHEP 1910, 220 (2019)



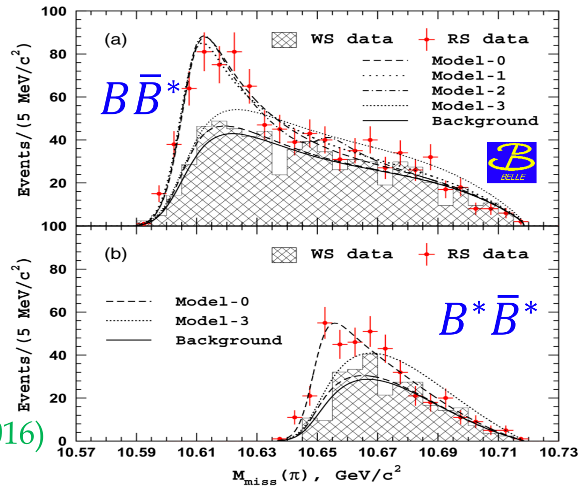
Operation energies (in fb-1 (M events))

Experiment	Υ(1S)	Υ(2S)	Υ(3S)	Υ(4S)	Υ(5S)	Υ(6S)
CLEO	1.2 (21)	1.2 (10)	1.2 (5)	16 (17.1)	0.1 (0.4)	-
BaBar	-	14 (99)	30 (122)	433 (471)	R_b scan	R_b scan
Belle	6 (102)	25 (158)	3 (12)	711 (772)	121 (36)	5.5
Belle II	200	200	200	5×10^4 (5.4×10^4)	1000 (300)	100 + 400 (scan)

More data samples provide opportunities to explore bottomonium spectrum further.

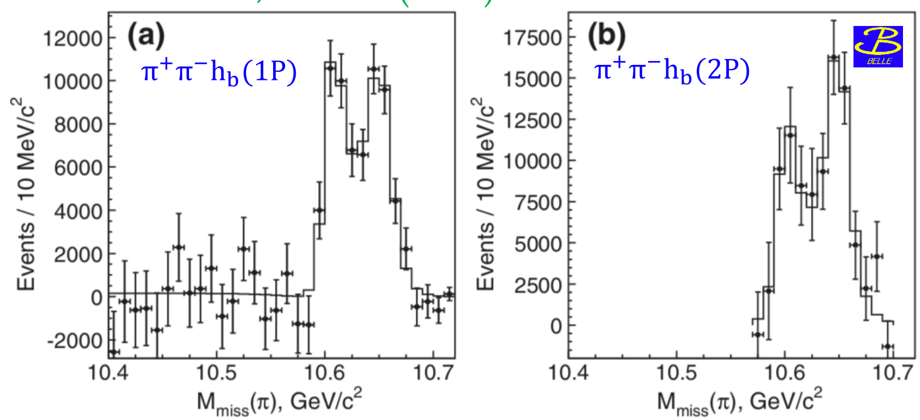
Search for new exotics at Belle II

- *Observed $Z_b(10610)$ and $Z_b(10650)$ in $\Upsilon(5S,6S)\,\pi\pi$ transitions.*
- *The decays $Z_b(10610) \to B\bar{B}^*$ and $Z_b(10650) \to B^*\bar{B}^*$ are dominant.*



PRL116, 212001 (2016)

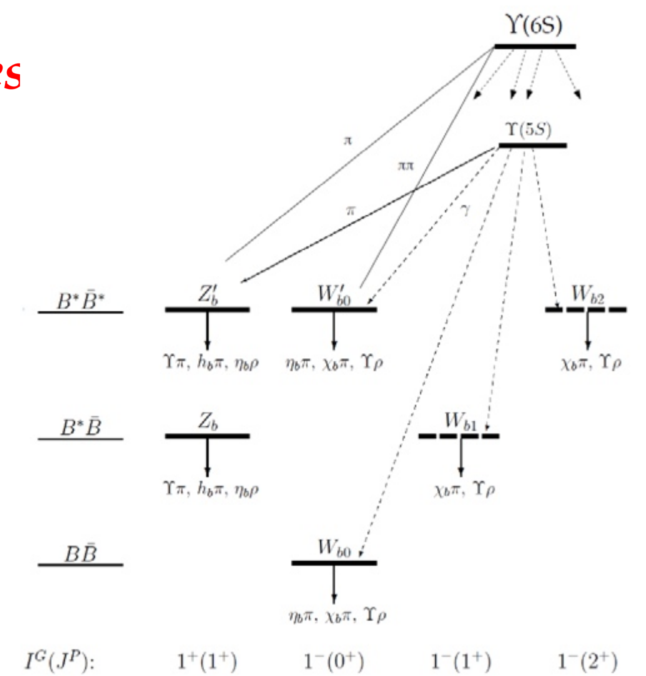
PRL108, 122001 (2012)



The expected molecular states with the structures $B\bar{B}$, $B\bar{B}^*$, and $B^*\bar{B}^*$.

$I^G(J^P)$	Name	Content	Co-produced particles [Threshold, GeV/c^2]	Decay channels
$1^+(1^+)$	Z_b	$B\bar{B}^*$	π [10.75]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^+(1^+)$	Z'_b	$B^*\bar{B}^*$	π [10.79]	$\Upsilon(nS)\pi$, $h_b(nP)\pi$, $\eta_b(nS)\rho$
$1^-(0^+)$	W_{b0}	$B\bar{B}$	ρ [11.34], γ [10.56]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(0^+)$	W'_{b0}	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$, $\eta_b(nS)\pi$
$1^-(1^+)$	W_{b1}	$B\bar{B}^*$	ρ [11.38], γ [10.61]	$\Upsilon(nS)\rho$
$1^-(2^+)$	W_{b2}	$B^*\bar{B}^*$	ρ [11.43], γ [10.65]	$\Upsilon(nS)\rho$
$0^-(1^+)$	X_{b1}	$B\bar{B}^*$	η [11.15]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^-(1^+)$	X'_{b1}	$B^*\bar{B}^*$	η [11.20]	$\Upsilon(nS)\eta$, $\eta_b(nS)\omega$
$0^+(0^+)$	X_{b0}	$B\bar{B}$	ω [11.34], γ [10.56]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$, $\eta_b(nS)\eta$
$0^+(0^+)$	X'_{b0}	$B^*\bar{B}^*$	ω [11.43], γ [10.65]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$, $\eta_b(nS)\eta$
$0^+(1^+)$	X_b	$B\bar{B}^*$	ω [11.39], γ [10.61]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$
$0^+(2^+)$	X_{b2}	$B^*\bar{B}^*$	ω [11.43], γ [10.65]	$\Upsilon(nS)\omega$, $\chi_{bJ}(nP)\pi^+\pi^-$

Mod. Phys. Lett. A 32, 1750025 (2017)



Summary

- Although Belle has stopped data taking for ~10 years ago, we are still producing exciting results.

- We reported the first vector charmonium-like state decaying to the charmed-antistrange and anticharmed-strange meson pairs $D_s^+ D_{s1}(2536)^-$ and $D_s^+ D_{s2}^*(2573)^-$ with a signal significance of 5.9σ and 3.4σ. The masses and widths are close to those of the Y(4660).

- Belle II will reach 50 ab^{-1} by 2027, which will provide greater sensitivity and precise measurements in hadron physics.

Thanks for your attentions!

Backup

Table 1

Possible S-wave resonances with two D_s mesons below 4.8 GeV. Only those states with $C=+$, permitted to couple to $J/\psi\,\phi$, are shown. Here $\Delta M \equiv M - M(J/\psi) - M(\phi)$. Exchanges are labeled "d" for direct ($A\bar{B} \to A\bar{B}$) and "x" for exchange ($A\bar{B} \to B\bar{A}$). "Rank" denotes anticipated ease of detection (see text). Allowed J^P values and rank are only shown for those states which can bind via η exchange.

States (J^P)	M (MeV)	ΔM (MeV)	Binding by η?	Binding by $f_0(980)$?	Allowed J^P	Rank
$D_s^+(0^-)\ D_s^-(0^-)$	3936.6	−179.8	No	d	–	–
$D_s^+(0^-)\ D_s^{*-}(1^-)$	4080.4	−36.0	x	d	1^+	1
$D_s^{*+}(1^-)\ D_s^{*-}(1^-)$	4224.2	107.8	d	d	$0^+, 2^+$[a]	2
$D_s^+(0^-)\ D_{s0}^{*-}(2317)(0^+)$	4286.0	169.6	x	d	0^-	2
$D_s^+(0^-)\ D_{s1}^-(2460)(1^+)$	4427.8	311.4	No[b]	d, x	$[1^-]$[b]	2
$D_s^{*+}(1^-)\ D_{s0}^{*-}(2317)(0^+)$	4429.8	313.4	No[b]	d, x	$[1^-]$[b]	3
$D_s^+(0^-)\ D_{s1}^-(2536)(1^+)$	4503.4	387.0	No	d, x	–	–
$D_s^+(0^-)\ D_{s2}^{*-}(2573)(2^+)$	4540.2	423.8	x	d	2^-	2
$D_s^{*+}(1^-)\ D_{s1}^-(2460)(1^+)$	4571.6	455.2	d, x	d, x	$0^-, 1^-, 2^-$	3
$D_{s0}^{*+}(2317)(0^+)\ D_{s0}^{*-}(2317)(0^+)$	4635.4	519.0	No	d	–	–
$D_s^{*+}(1^-)\ D_{s1}^-(2536)(1^+)$	4647.2	530.8	d, x	d, x	$0^-, 1^-, 2^-$	3
$D_s^{*+}(1^-)\ D_{s2}^{*-}(2573)(2^+)$	4684.0	567.6	d, x	d, x	$1^-, 2^-, 3^-$	3
$D_{s0}^{*+}(2317)(0^+)\ D_{s1}^-(2460)(1^+)$	4777.2	660.8	x	d	1^+	4

[a] $J^P = 1^+$ forbidden by C symmetry.

[b] Proximity of these two channels may lead to binding. See text.