JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

JENNIFER2 EU grant n.822070

Bundesministerium für Bildung und Forschung

ErUM-FSP T09 Belle II

BELLE

Belle II

Recent results from Belle and Belle II

Jens Sören Lange (Justus-Liebig-Universität Giessen)

International Workshop on Heavy Quark Physics

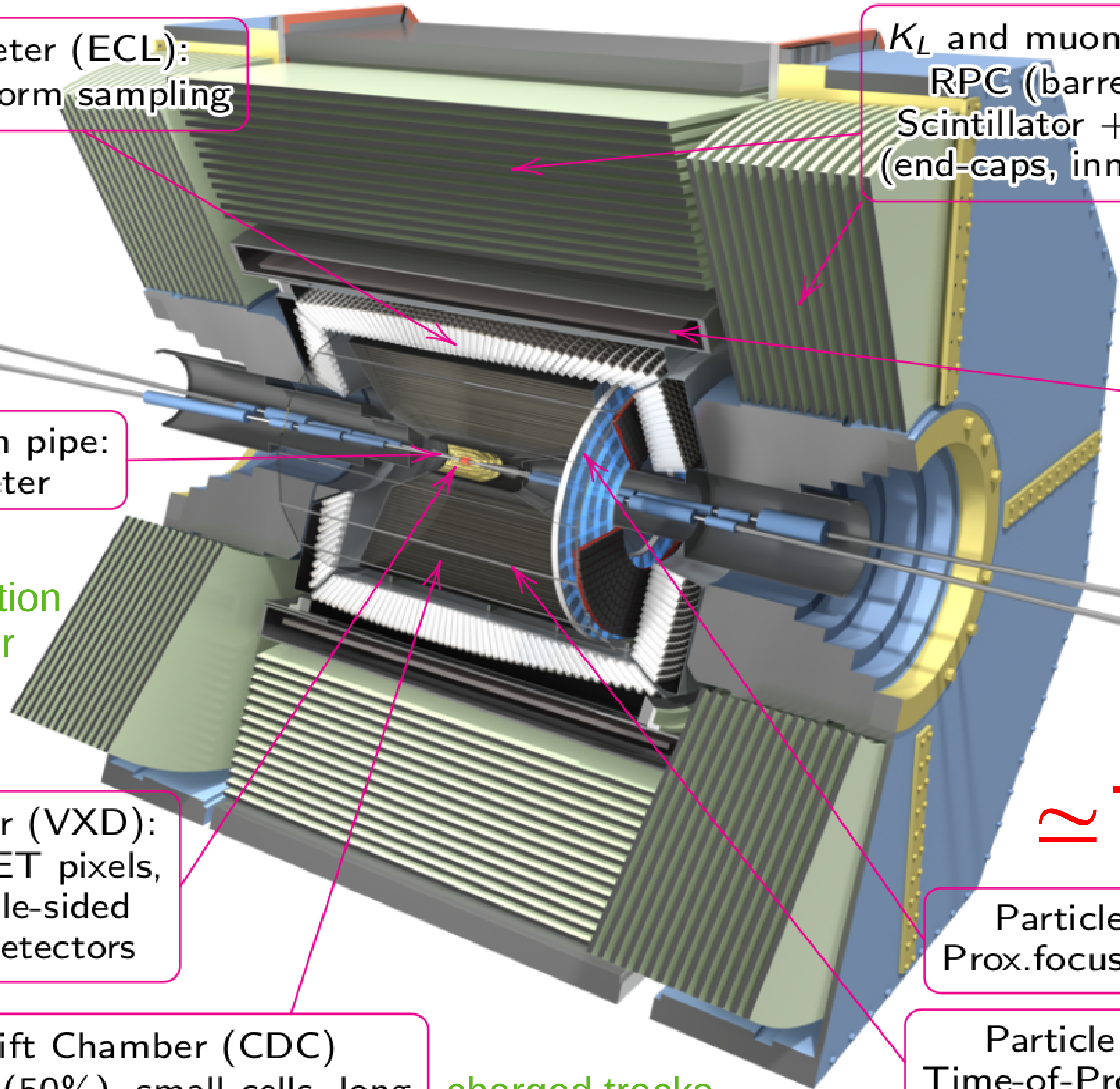
Islamabad, 23.-26.11.2021

Outline

- Belle II
  - Status and plan of data taking
  - D meson lifetime
  - $B \to K\nu\bar{\nu}$
  - X(3872)
- Belle
  - X(3872)
  - New high mass XYZ state in ISR
  - Search for R^{++}
  - Search for D-wave charmonium
  - Charmed baryons
  - Y_b scan

Emphasis on spectroscopy

Belle II



z vertex resolution
factor $\simeq$2 better
than Belle
($\geq$15 μm)

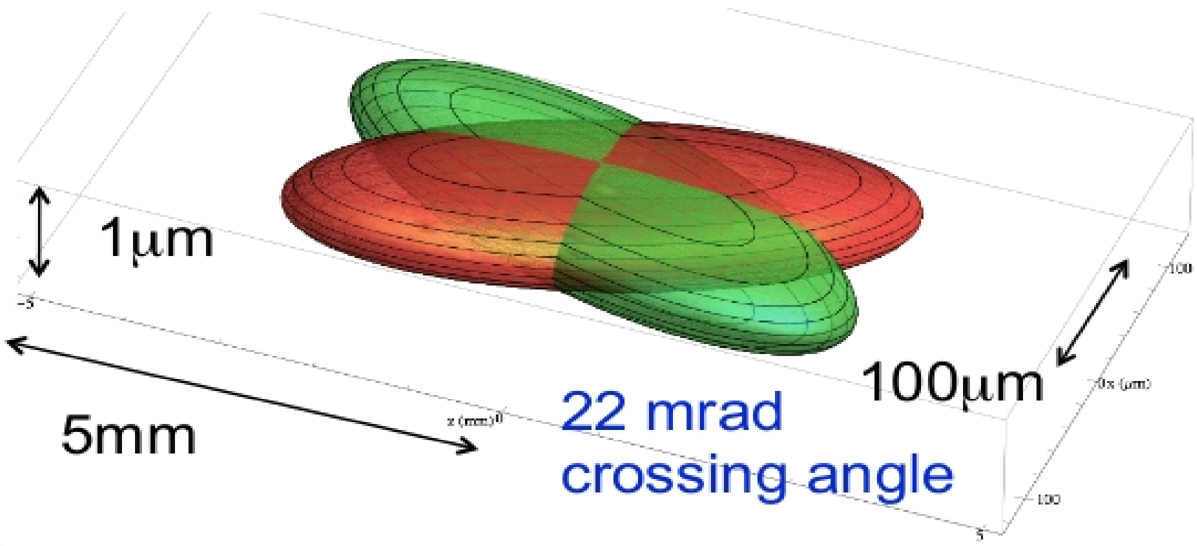
$\simeq 7\times7\times7\ \mathrm{m}^3$

charged tracks
$\simeq$20% longer than Belle

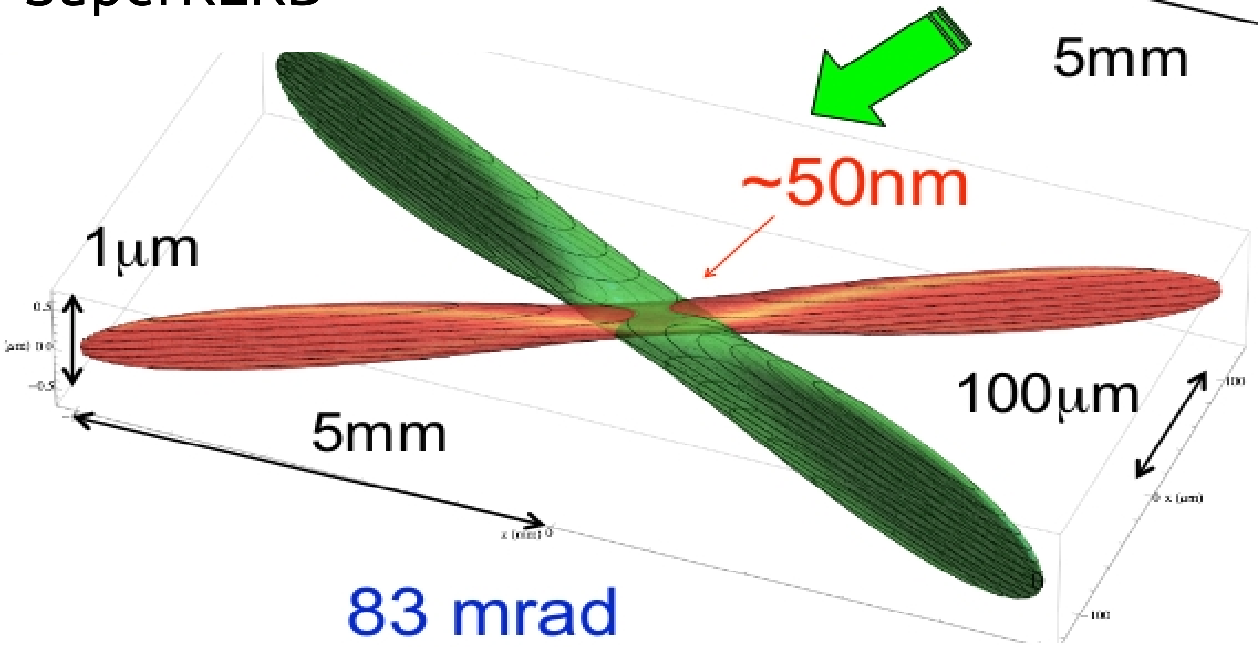
Nano-Beam Scheme

Belle → Belle II
Peak luminosity x 30

KEKB



SuperKEKB



83 mrad
crossing angle

originally proposed for SuperB by P. Raimondi (INFN)

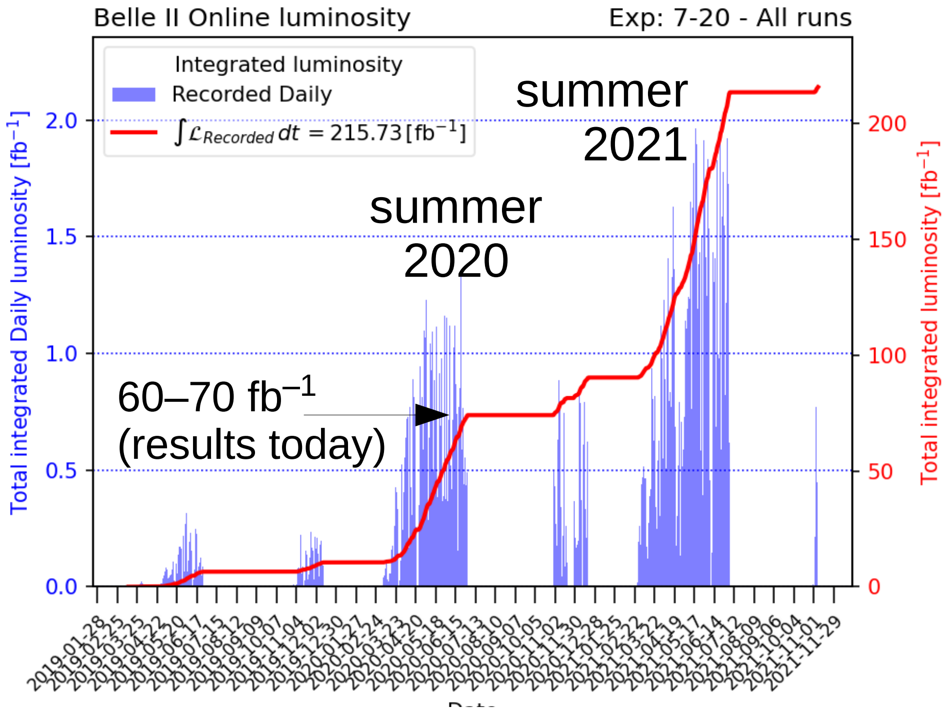
Resulting in slightly smaller boost

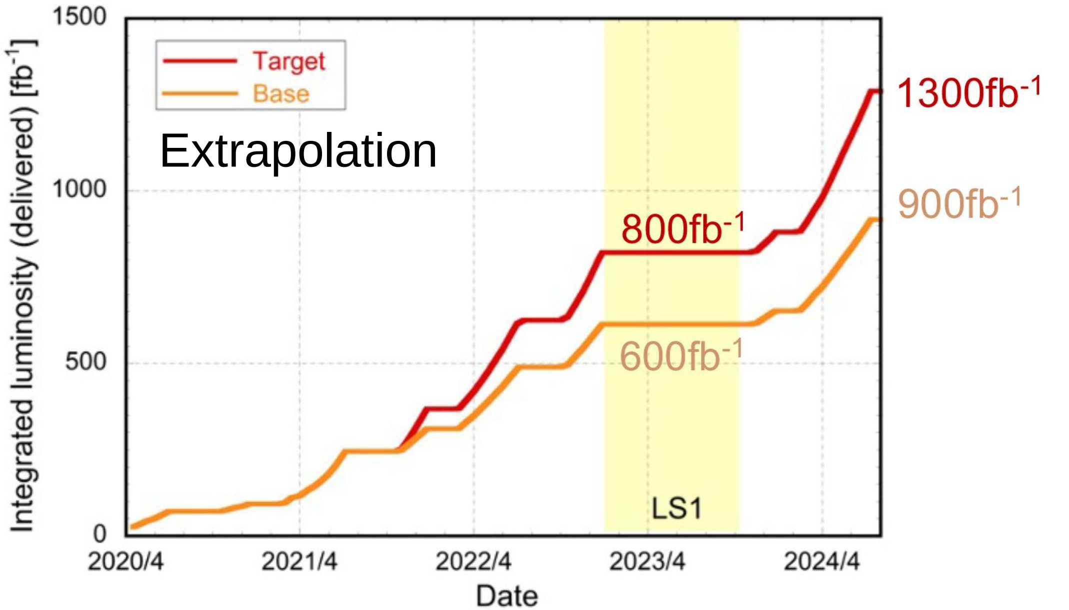
$\beta\gamma$=0.43 (Belle)

$\beta\gamma$=0.29 (Belle II)

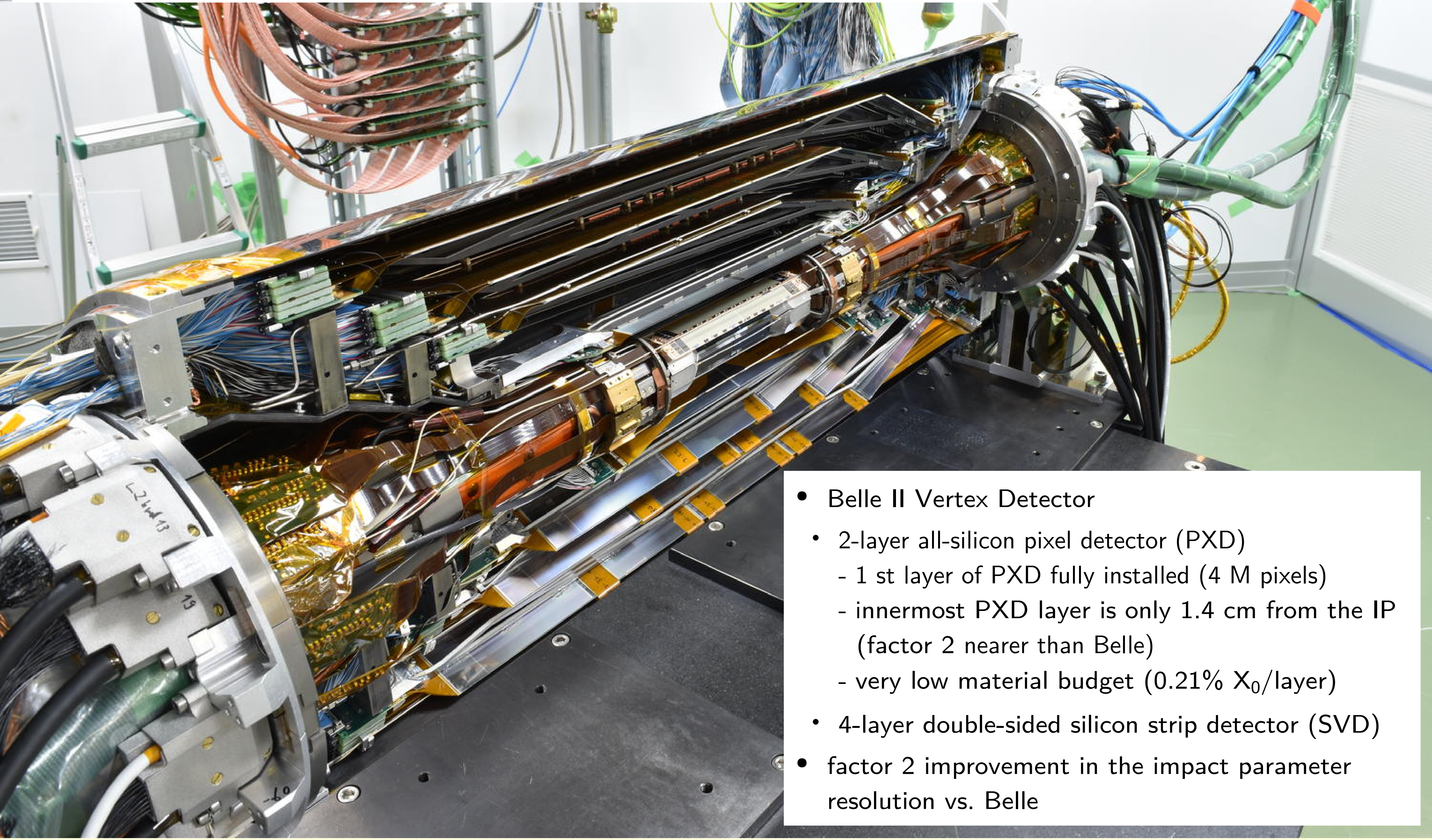
Status and plan of Belle II data taking

- Belle II collected data 215 fb^{-1}
  (~20% of Belle, ~50% of BaBar data)
  1 fb^{-1} is about 1.1 Mill. $B\bar{B}$ pairs
- Peak luminosity reached
  3.12 x 10^{34} cm^{-2} s^{-1}
  - 50% higher than previous world record by KEKB
  - factor 3 higher than KEKB design luminosity
- 89.5% data taking efficiency during the pandemic situation (remote shifts & heroic local effort)
- Plan: long shutdown in 2023 (2[nd] layer of PXD, TOP upgrade)
- Plan: 50 ab^{-1} in ≥2031





D^0 and D^+ meson lifetime at Belle II

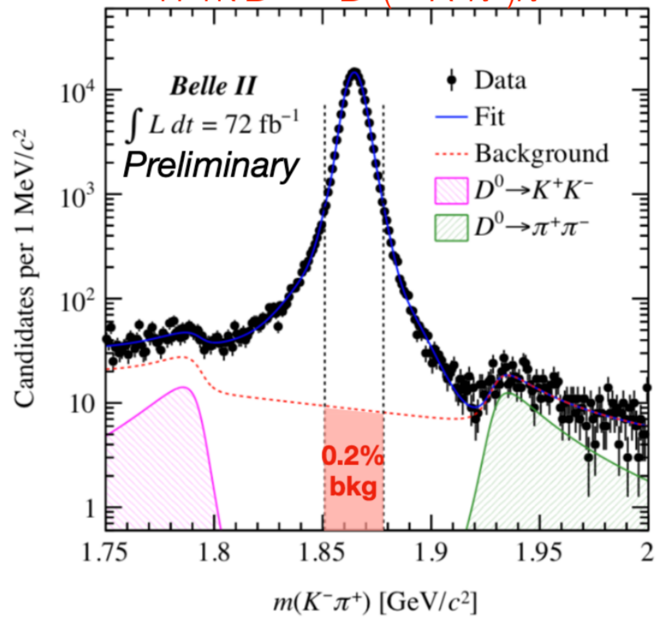


- Belle II Vertex Detector
  - 2-layer all-silicon pixel detector (PXD)
    - 1 st layer of PXD fully installed (4 M pixels)
    - innermost PXD layer is only 1.4 cm from the IP (factor 2 nearer than Belle)
    - very low material budget (0.21% X_0/layer)
  - 4-layer double-sided silicon strip detector (SVD)
- factor 2 improvement in the impact parameter resolution vs. Belle

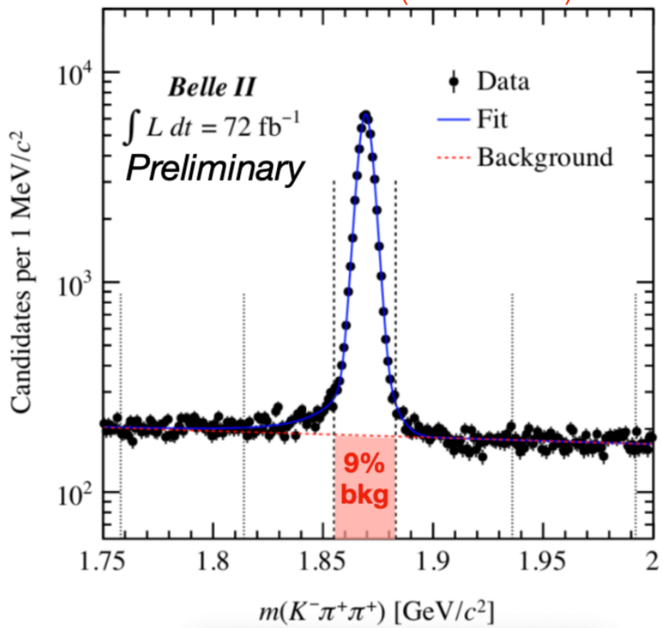
D^0 and D^+ meson lifetime at Belle II
Phys Rev. Lett. 127 (2021) 211801

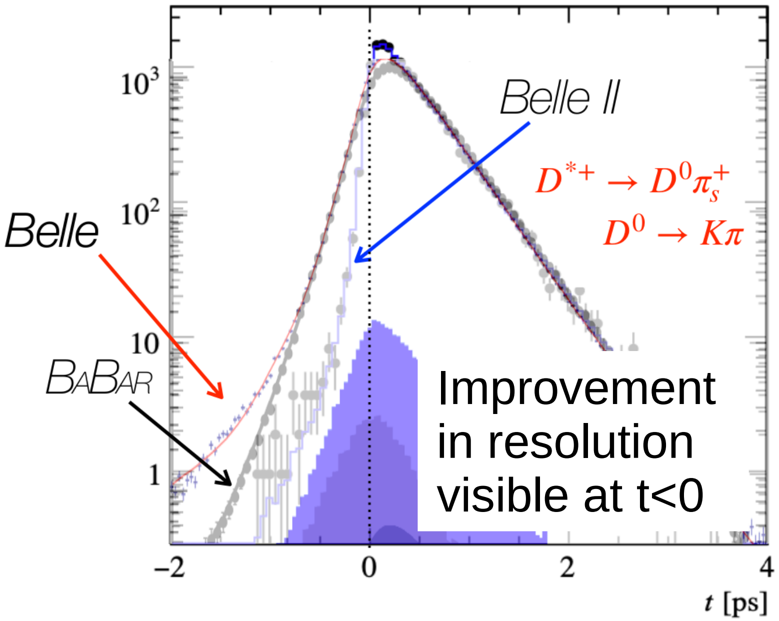
- D^* tagging
- Unbinned fit to (t,σ_t)
- Resolution ~60-70 *fs*
- Largest systematic error: alignment
  0.72 *fs* (D^0), 1.70 *fs* (D^+)

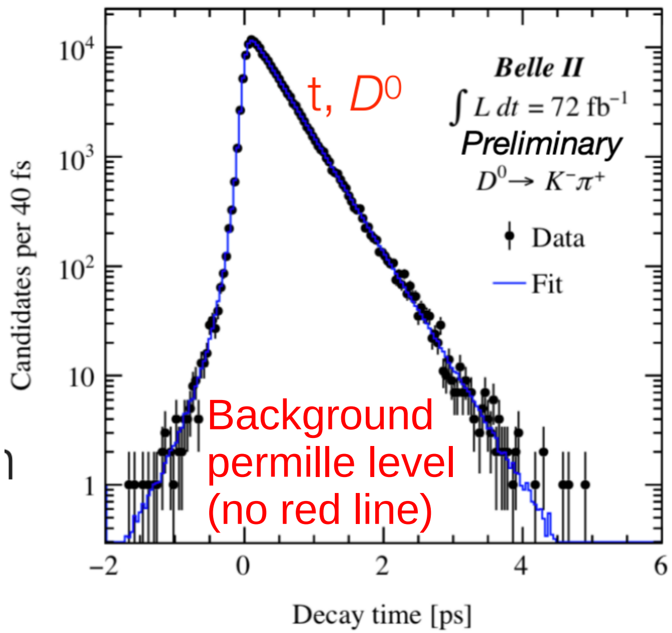
~171k $D^{*+}\to D^0(\to K^-\pi^+)\pi^+$

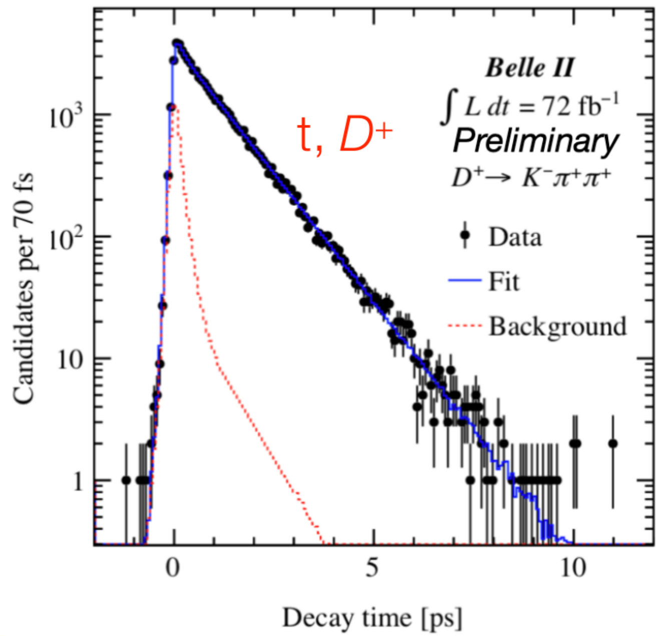


~59k $D^{*+}\to D^+(\to K^-\pi^+\pi^+)\pi^0$







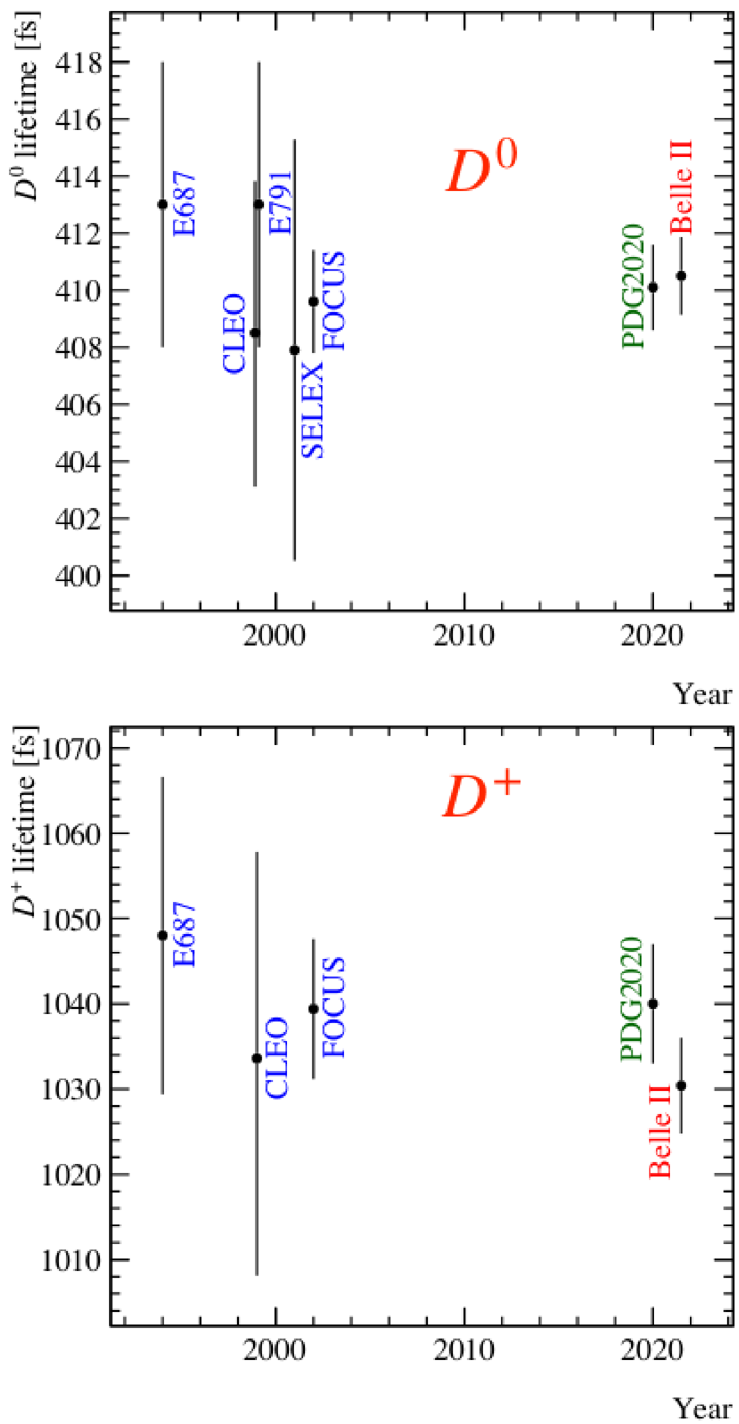


D^0 and D^+ meson lifetime at Belle II

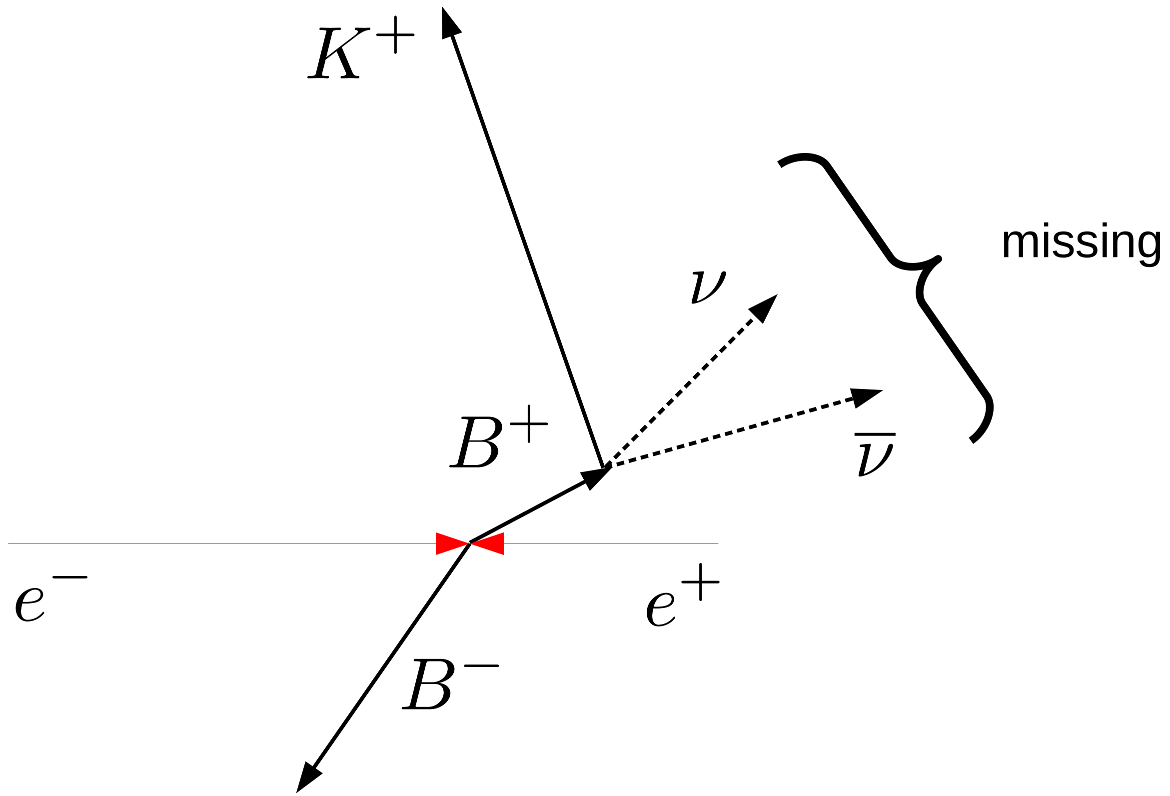
Phys Rev. Lett. 127 (2021) 211801

$$\tau(D^0) = 410.5 \pm 1.1 \pm 0.8 fs$$
$$\tau(D^+) = 1030.4 \pm 4.7 \pm 3.1 fs$$

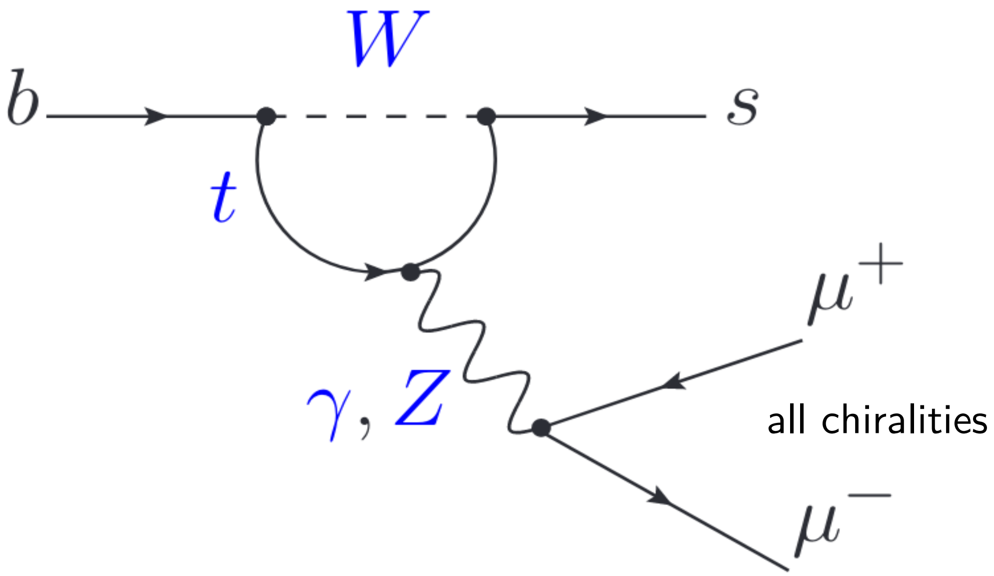
- Consistent with current world averages 410.1±1.5 *fs* (D^0) and 1040±7 *fs* (D^+)
- World's most precise measurements accuracies:
  3.5 permille (D^0) and 5.4 permille (D^+)



$B^+ \to K^+ \nu\overline{\nu}$

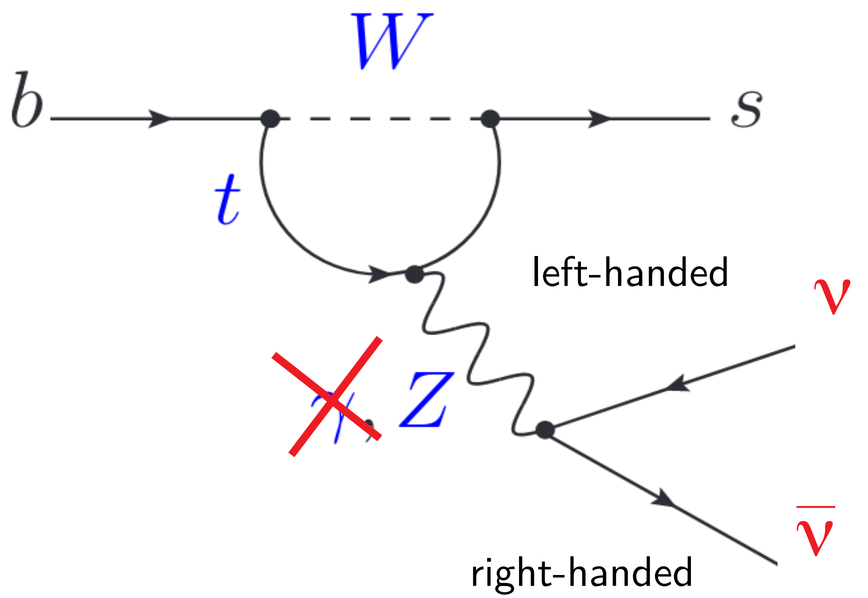


Radiative penguin



Wilson coefficients
C_7, C_9, C_{10}

„Z penguin“



Wilson coefficients
$\cancel{C_7}$, C_9, C_{10}

For definition of Wilson coefficients, see talks by Ahmed Ali and Cai-Dian Lu.

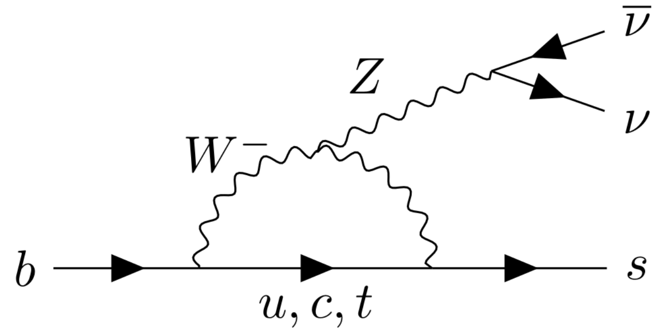
$B^+ \to K^+\nu\bar{\nu}$ at Belle

- Complementary to $b \to s l^+ l^-$
  (tensions with the SM observed)
- SM prediction

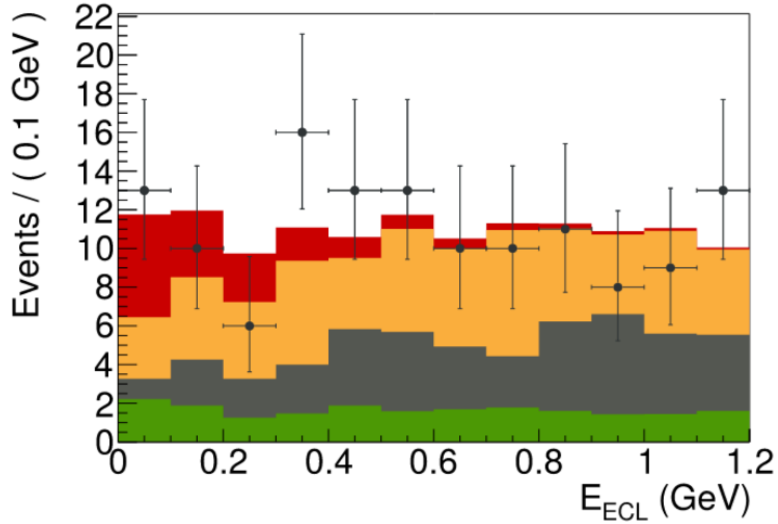
$$\mathcal{B}(B \to K\nu\bar{\nu})_{SM} = (4.6 \pm 0.5) \times 10^{-6}$$

T. Blake et al., Prog. Part. Nucl. Phys. 92 (2017) 50

- Previous analyses
  - Advantage for e^+e^- collisions, $\sqrt{s}$ is fixed
    Signature: missing energy (peaking at zero)
  - *B* meson tagging
    (full reconstruction on the opposite side)
    hadronic tagging $\varepsilon_{sig} \cdot \varepsilon_{tag} \simeq 0.04\%$
    semileptonic tagging $\varepsilon_{sig} \cdot \varepsilon_{tag} \simeq 0.20\%$
- New approach:
  "inclusive tagging"
  Belle II data (only), 63 fb^{-1}



Belle, Phys. Rev. D 96 (2017) 091101

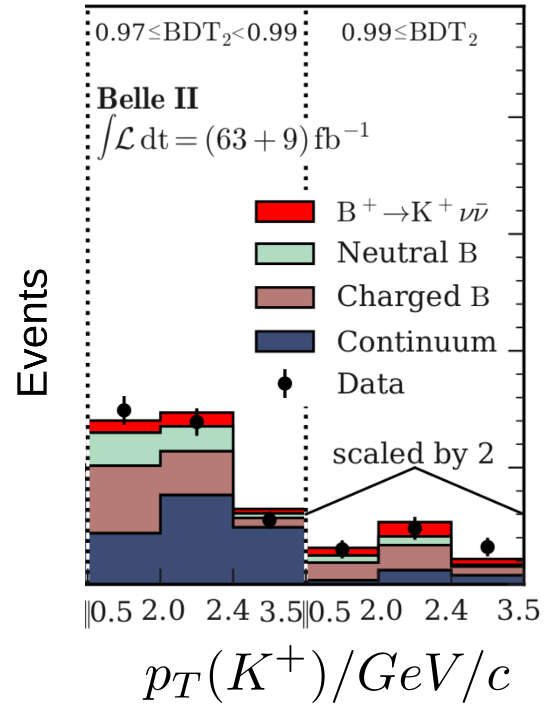


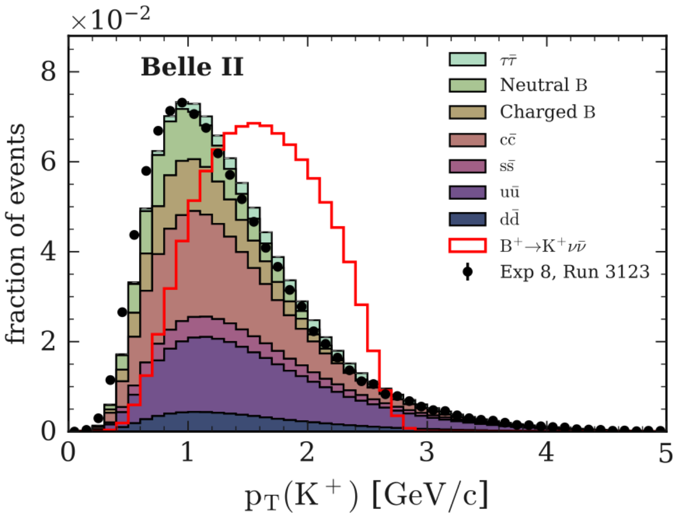
Experiment	Year	Observed limit on BR($B^+ \to K^+\nu\bar{\nu}$)	Approach	Data [fb^{-1}]
BABAR	**2013**	$< 1.6 \times 10^{-5}$ **[Phys.Rev.D87,112005]**	**SL + Had tagging**	429
Belle	**2013**	$< 5.5 \times 10^{-5}$ **[Phys.Rev.D87,111103(R)]**	**Had tagging**	711
Belle	**2017**	$< 1.9 \times 10^{-5}$ **[Phys.Rev.D96,091101(R)]**	**SL tagging**	711

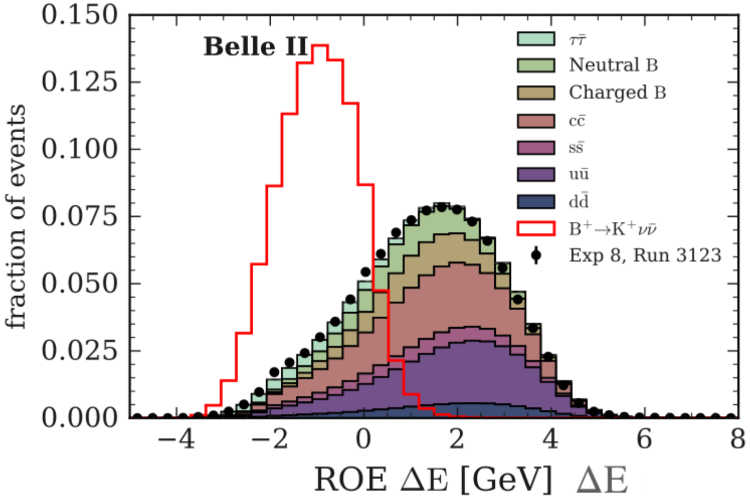
$B^+ \to K^+ \nu\bar{\nu}$ at Belle II

Phys. Rev. Lett. 127 (2021) 181802

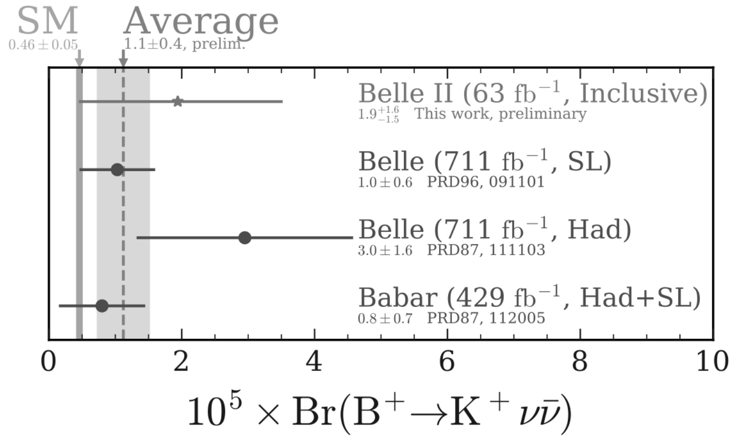
- Signal reconstructed as the highest p_T track
- Inclusive reconstruction of the <u>r</u>est–<u>o</u>f–<u>e</u>vent (ROE)
- New technique: two boosted decision trees (BDT)
  51 input parameters for background suppression
  (BDT_2 is trained with preselected events $BDT_1 > 0.9$)
- Background: e.g. K^+ from D decays
- No signal yet: upper limit determined
  $\mathcal{B}(B \to K\nu\bar{\nu}) \leq 4.1 \times 10^{-5}$ $(90\%\ CL)$







ΔE



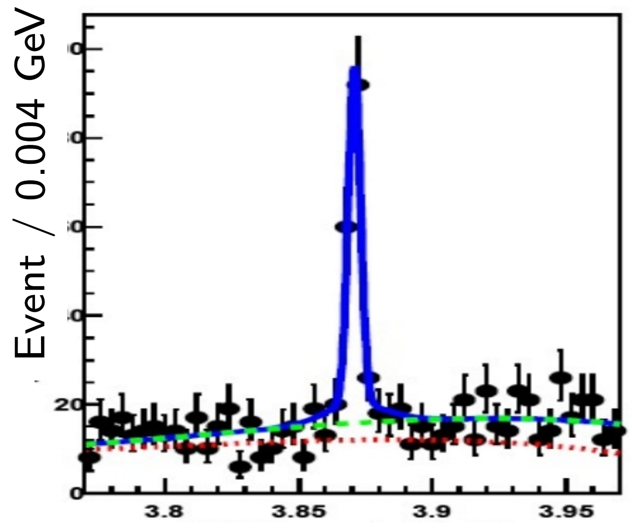
$$\Delta E = \sum_i E_i^{CMS} - E_{beam}$$

X(3872)

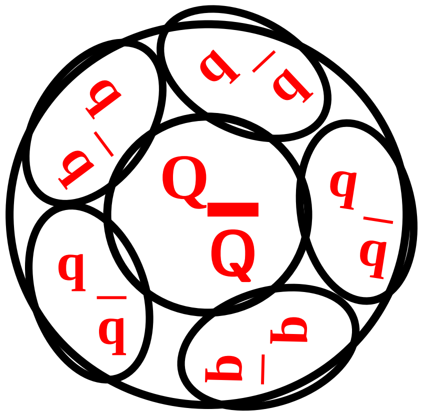
XYZ states

- Unexplained, narrow states in charmonium/bottomonium mass region
- Some of them charged (*Z* states) minimum quark content $[Q\bar{Q}q\bar{q}']$
- Historically first candidate: X(3872)
  - observed by 7 experiments
  - very narrow (≤1 MeV)
  - isopin violating decays

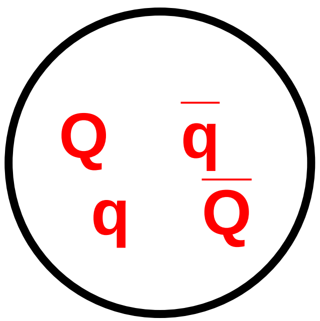
Belle, Phys Rev D84(2011)052004



HADRO-
CHARMONIUM



TETRAQUARK

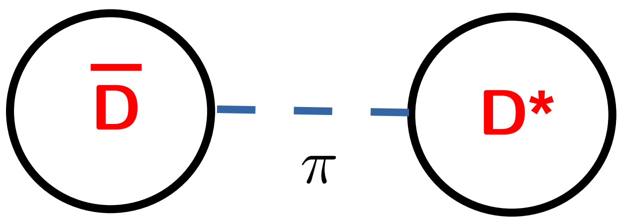


$[qQ]_8[\overline{qQ}]_8$

Diquarks

are colored

MOLECULE



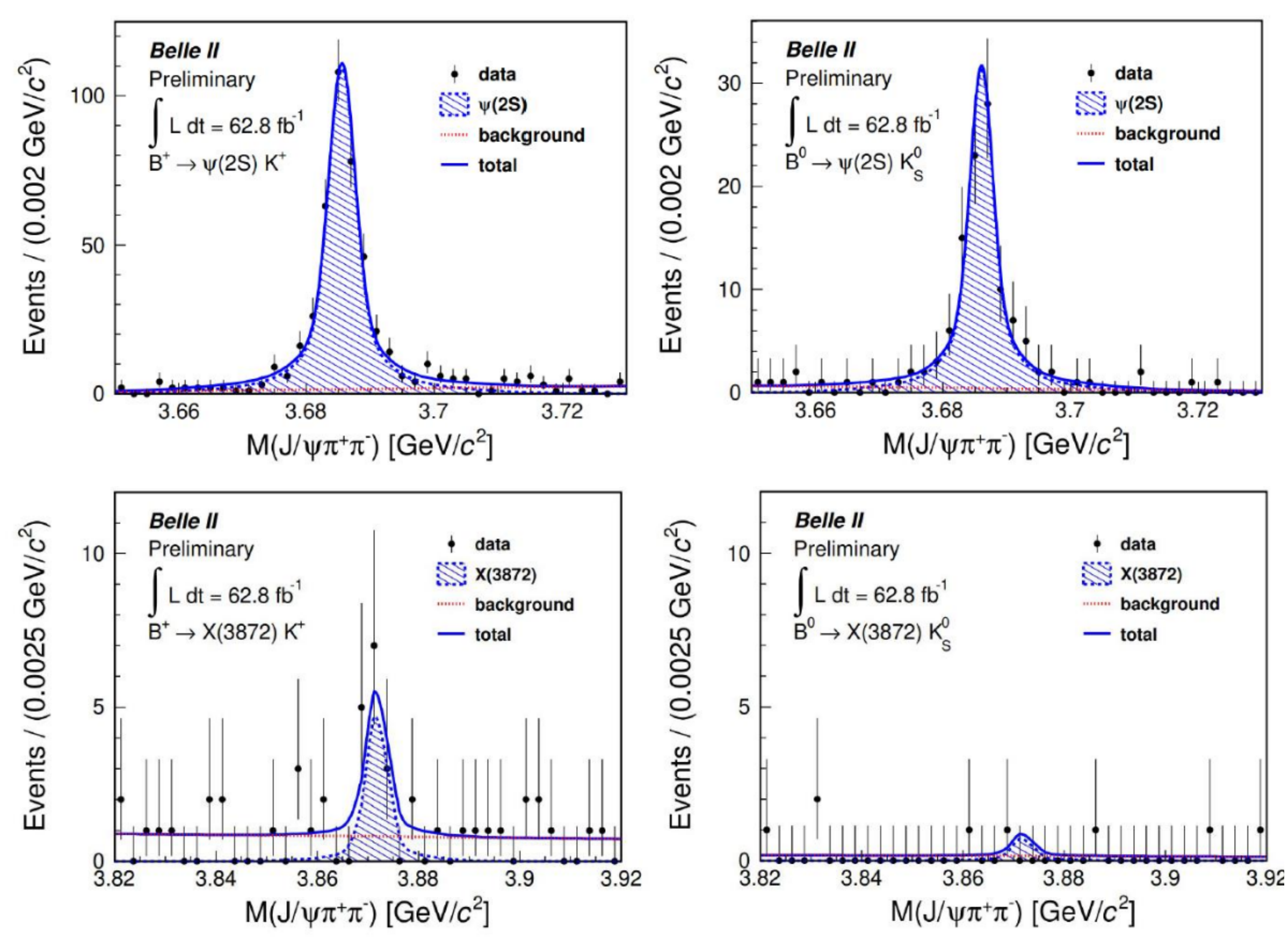
Maiani, Riquer, Piccinini, Polosa, Burns;
Ebert, Faustov, Galkin; Chiu, Hsieh;
Ali, Hambrock, Wang *(b quarks)*

Tornqvist; Swanson; Braaten, Kusonoki,
Wong; Voloshin; Close, Page
Guo, Hanhart, Meißner, Wang, Zhao, Zou

Voloshin, Dubynskiy
Wang, Cleven, Guo, Hanhart,
Meißner, Wu, Zhao; Ferretti

$X(3872)$ at Belle II (new 2021)

Efficiency 22.9%



Efficiency 17.5%

Unbinned maximum likelihood fit with triple Gaussian and 1st order Chebyshev polynomial

By now, already factor 3 more data on tape

$X(3872)$ in neutral and charged B meson decays

- Ratio is sensitive to the nature of the $X(3872)$
- If $X(3872)$ is a $D\overline{D}*$ molecule, ratio should be small (<0.1)

  B^0, K^0 contain d quarks --- B^+, K^+, D^0, $\overline{D}^{*0}$ contain u quarks

  Braaten, Lu, Phys. Rev. D77 (2008) 014029
- If $X(3872)$ is charmonium, hybrid, glueball,

  ratio should be large ($=1$)
- Exotic nature of $X(3872)$ is already seen in present Belle II data

  but caution: simultaneous fit of B^0 and B^+, and ratio was fixed to 0.5

$$\frac{\mathcal{B}(B^0 \to K_s^0 \psi(2S))}{\mathcal{B}(B^+ \to K^+ \psi(2S))} = \frac{(5.8 \pm 0.5) \times 10^{-4}}{(6.24 \pm 0.20) \times 10^{-4}} \simeq 0.93$$

PDG 2021

$$\frac{\mathcal{B}(B^0 \to K_s^0 X(3872))}{\mathcal{B}(B^+ \to K^+ X(3872))} = \frac{(1.1 \pm 0.4) \times 10^{-4}}{(2.1 \pm 0.7) \times 10^{-4}} \simeq 0.52$$

Belle results

Belle collected data $\sim$1 ab^{-1}

(711 fb^{-1} on $\Upsilon(4S)$, 121 fb^{-1} on $\Upsilon(5S)$)

Evidence for $\gamma\gamma \to X(3872)$

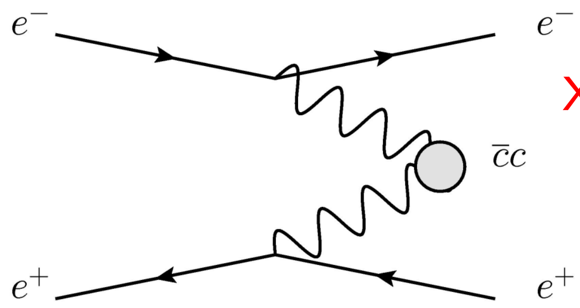
Belle, Phys. Rev. Lett. 126 (2021) 122001, 825 fb^{-1}

- X(3872) has $J^{PC}=1^{++}$
- Landau–Yang theorem: coupling of J=1 particle to two real photons is forbidden
- Here: at least one of the photon is virtual

$$\Gamma_{\gamma\gamma}\mathcal{B}(X \to J/\psi\pi^+\pi^-) = 5.5^{+4.1}_{-3.8}(stat.) \pm 0.7(syst.)\ eV$$

- Upper limit from BESIII Phys. Lett. B749 (2015) 414

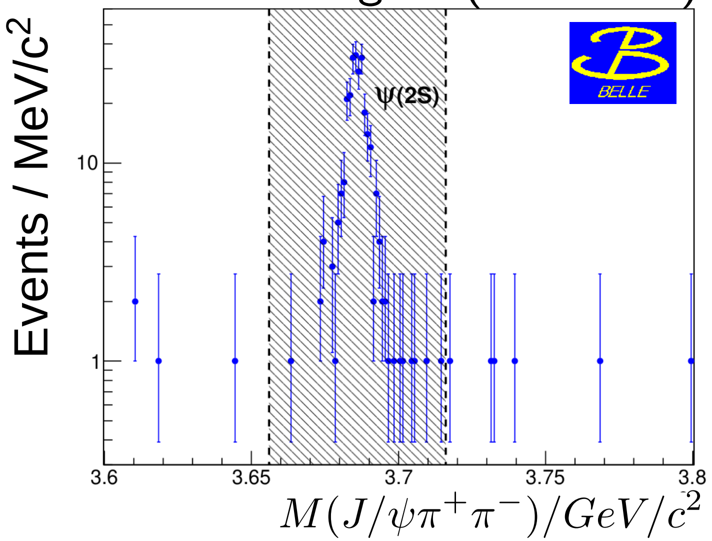
$$\Gamma_{ee}\mathcal{B}(X \to J/\psi\pi^+\pi^-) < 0.13\ eV$$

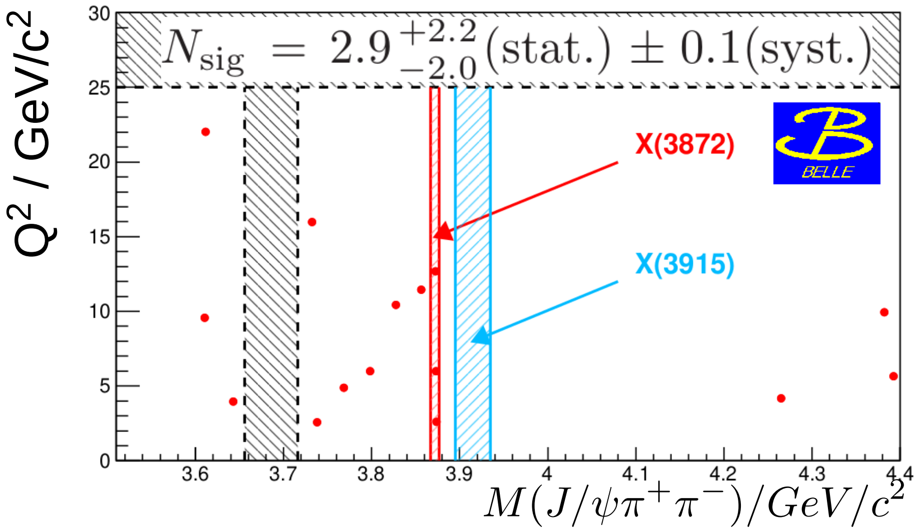


X(3872)
or
ψ(2S)

(Belle result is measurement, not upper limit, with QED vertex factor relates to 0.50 eV)

Reference signal ($J^{PC}=1^{--}$)



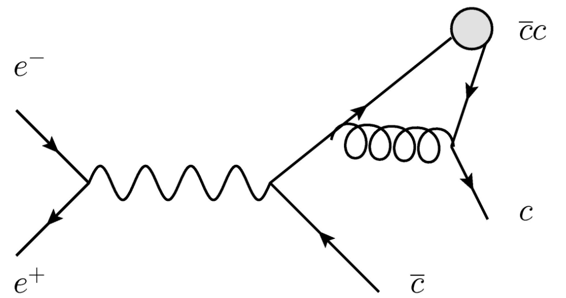


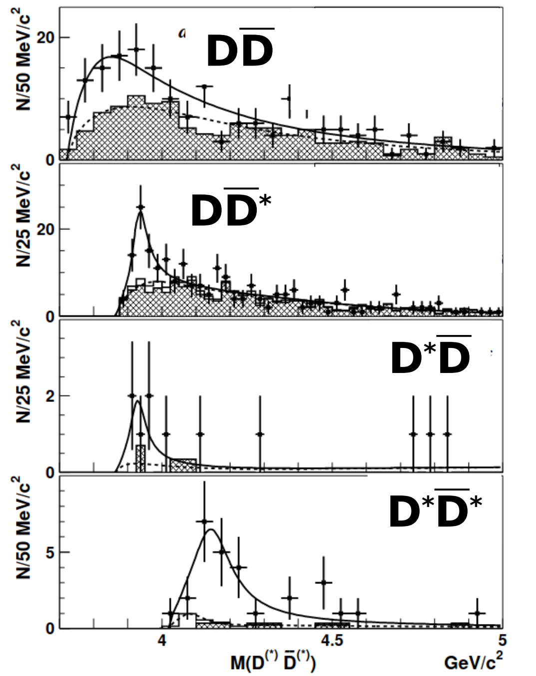
Q^2 calculated from momentum of single tagging electron

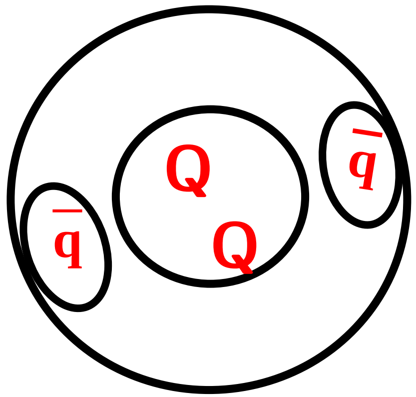
Significance 3.2σ (background 0.11±0.10 events)

XYZ States decaying into $D^{(*)}D^{(*)}$

- Many states observed
  - X(3872) decays, J^P=1+, [*D anti-D*$^{(*)}$]
  - Z states, J^P=1+, [*D anti-D*$^{(*)}$] and [*D*$^{(*)}$ *anti-D*$^{(*)}$]
  - States in double charmonium production
    J^P=0+, 2+, … Belle, Phys. Rev. Lett. 100 (2008) 202001, 693 fb^{-1}
  - All of them above threshold, order few MeV → not bound
- T_{cc}^{+}, *[DD*+]* state LHCb, arXiv: 2109.01038 [hep-ex]
  [meson meson], not [meson anti-meson]
  in tetraquark picture: a baryon (QQq)
  with q replaced by $\overline{qq}$ pair (color-equivalent in QCD)
- Below threshold! And very narrow!
- What can Belle (II) do ? → J^P=1– states

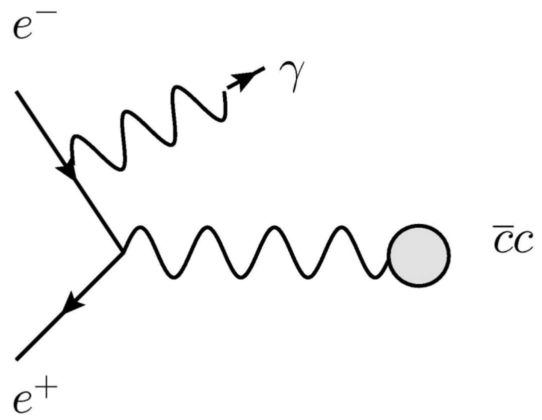






New *XYZ* state in ISR (Initial State Radiation)

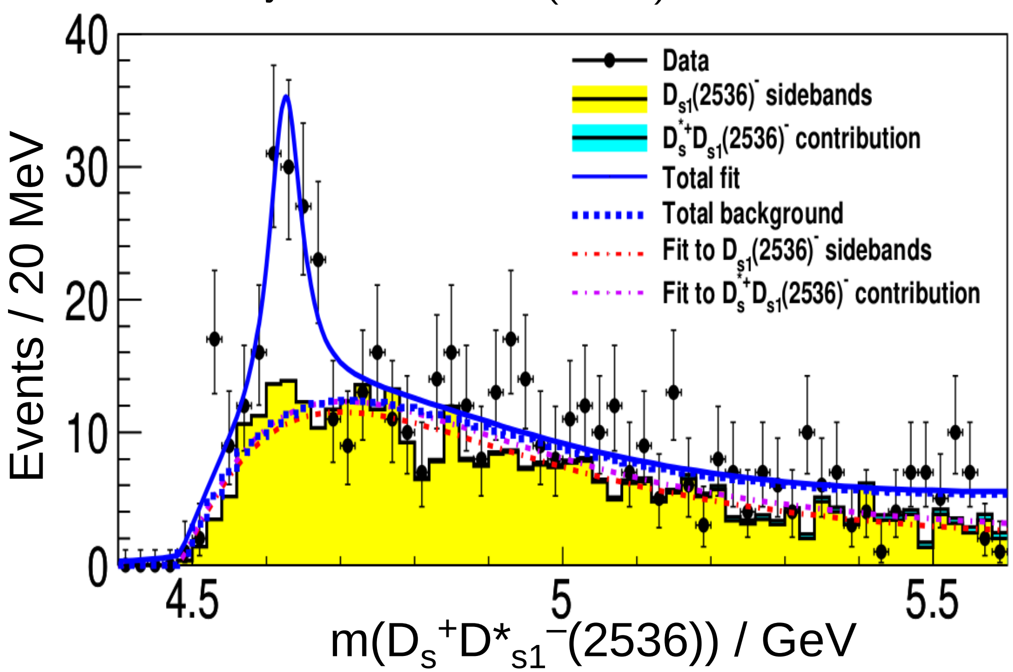
- Only observable in e+e– collisions, not at hadron colliders
- Quantum numbers fixed J^{PC}=1– –



$[c\bar{c}s\bar{s}]$

$D_s\bar{D}_{s^*}$

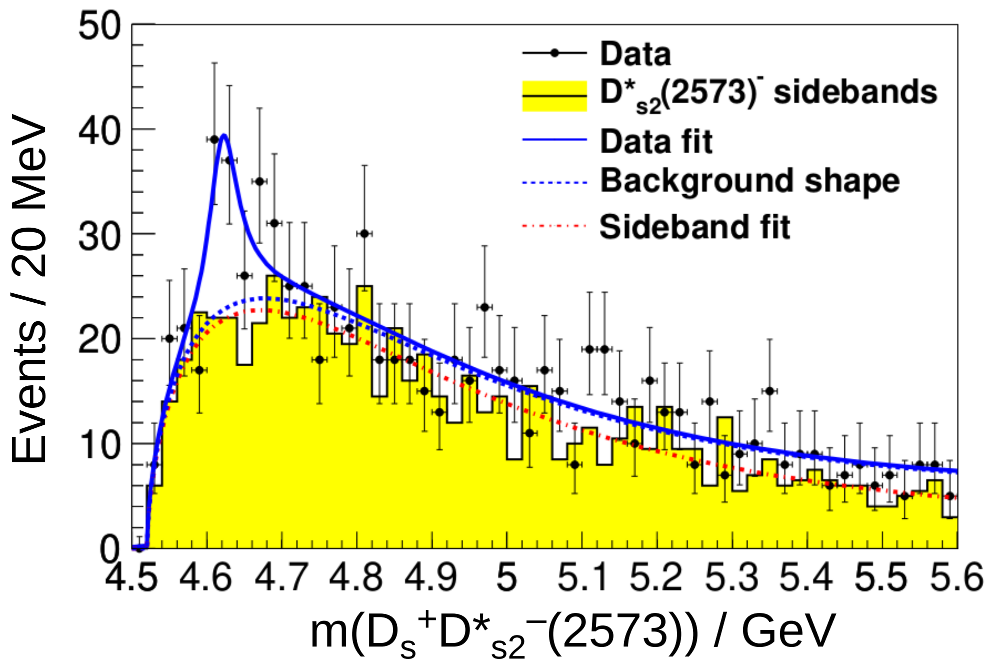
Belle, Phys. Rev. D100 (2019) 111103, 922 fb^{-1}



J^{PC}=1– – (S-wave)

Above threshold (not bound)

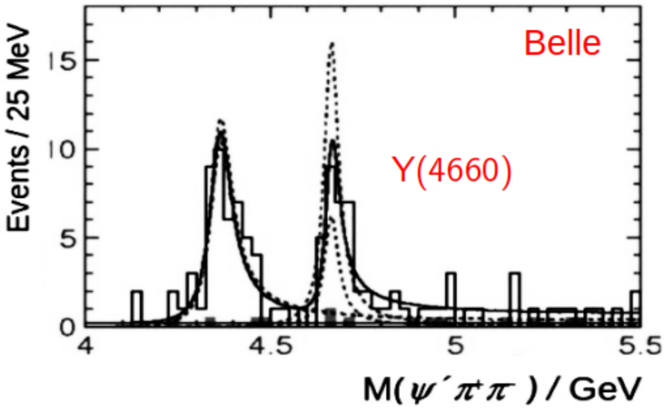
Belle, Phys. Rev. D 101 (2020) 091101, 922 fb^{-1}

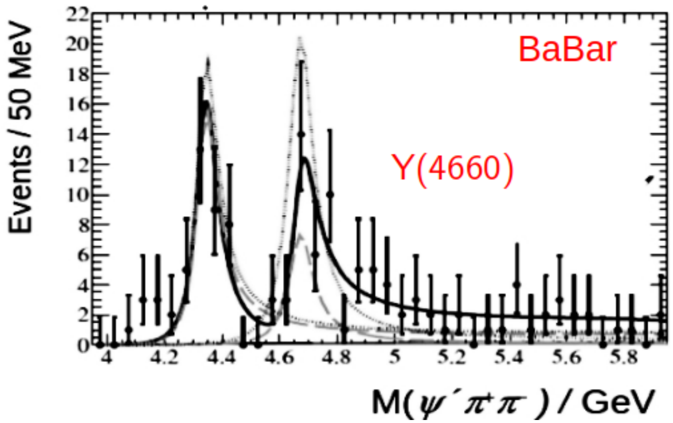


J^{PC}=1– – (P-wave)

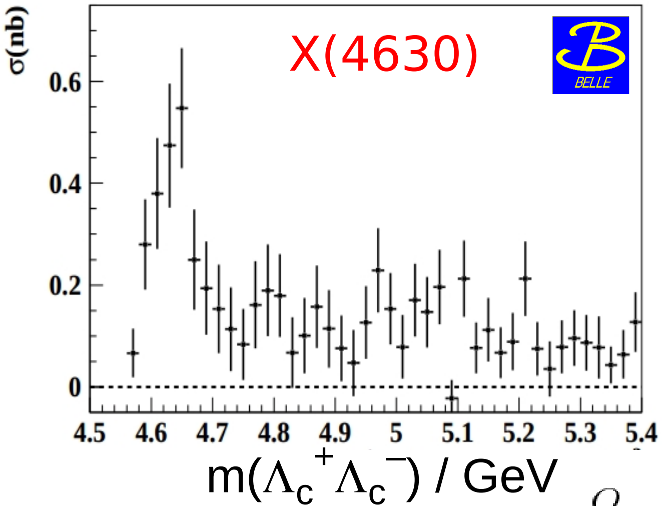
Above threshold (not bound)

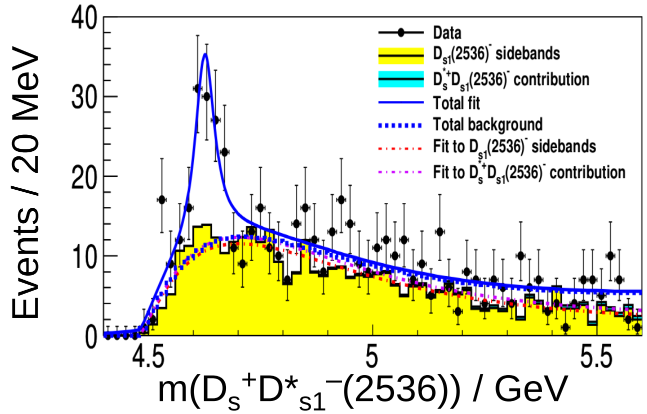
XYZ states with high mass (above 4.6 GeV)

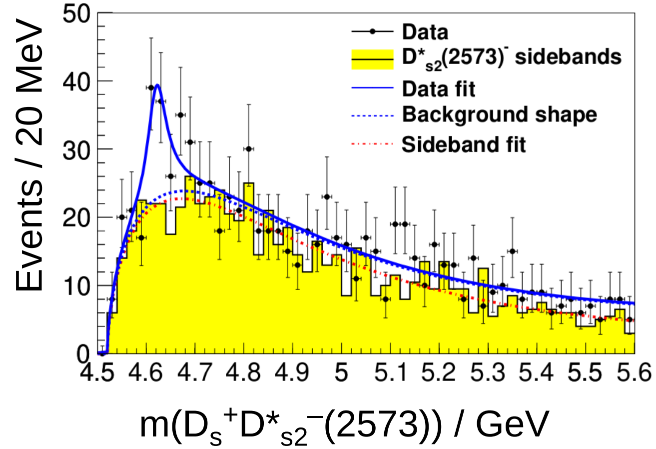


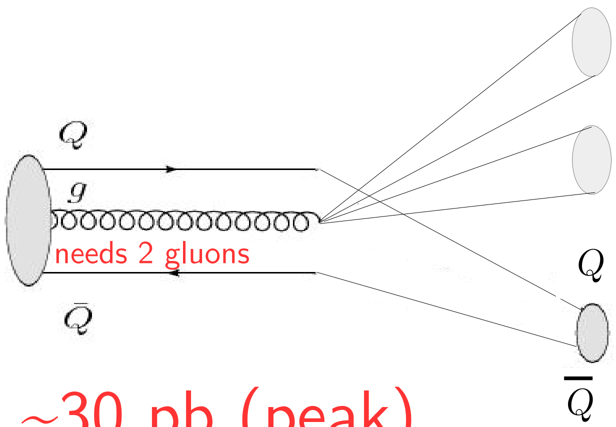


Only XYZ state so far decaying into baryons, possible hexaquark $[uud\bar{d}\bar{d}c\bar{c}]$

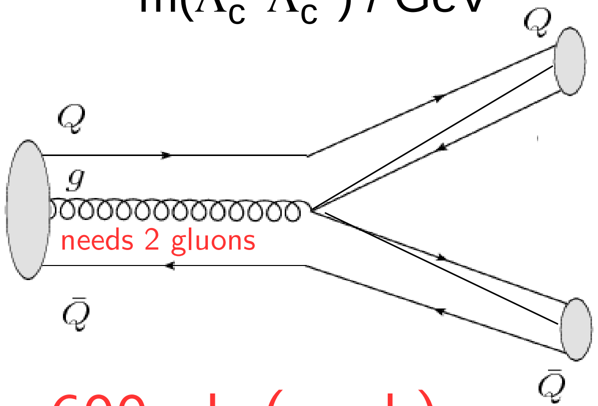




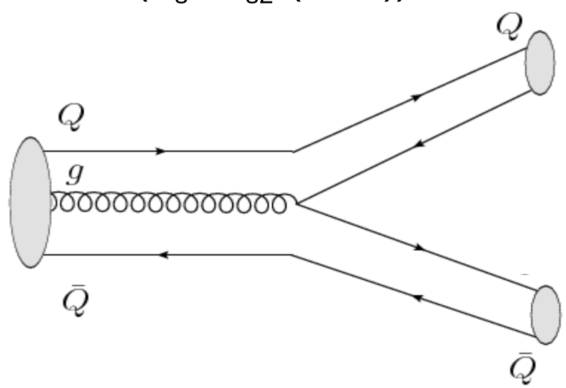




~30 pb (peak)



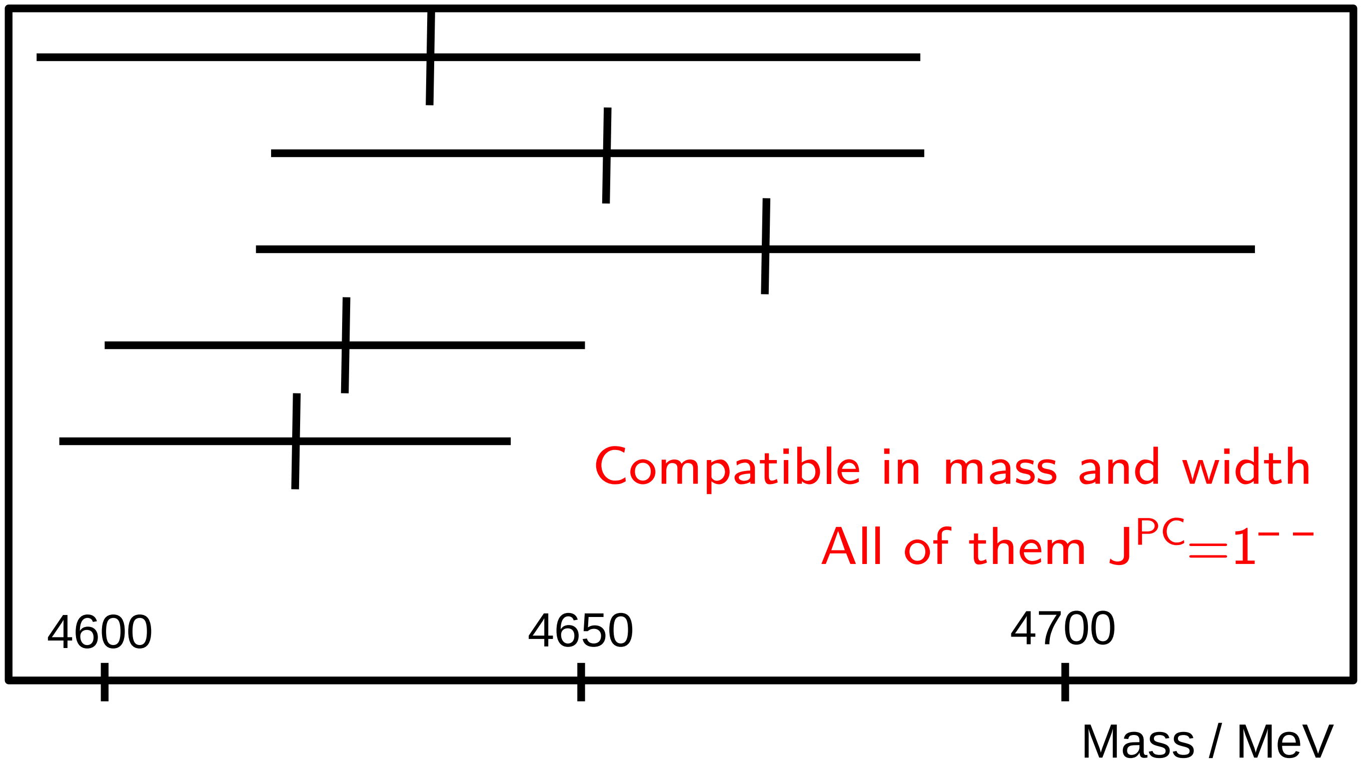
~600 pb (peak)



new, ~200 pb (peak)

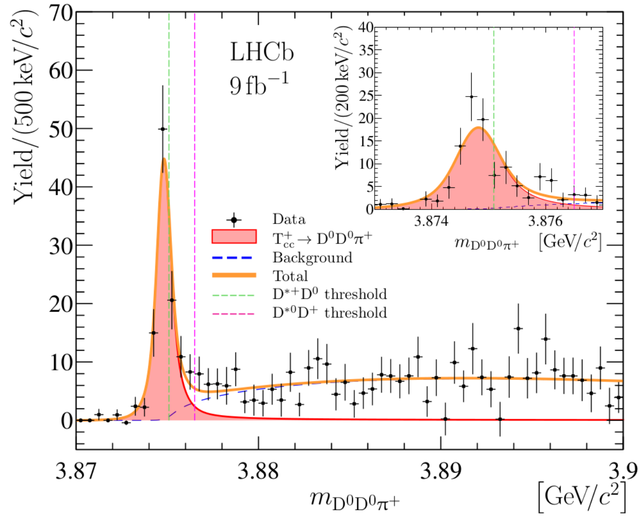
XYZ states with high mass (above 4.6 GeV)

		Mass (MeV)	Width (MeV)		
Belle	$\Lambda_c^+ \ \Lambda_c^-$	4634^{+8+5}_{-7-8}	92^{+40+10}_{-24-21}	Phys. Rev. Lett. 101(2008)172001	695 fb^{-1}
Belle	$\psi(2S)\pi^+\pi^-$	$4652 \pm 10 \pm 8$	$68 \pm 11 \pm 1$	Phys. Rev. D91(2015)112007	980 fb^{-1}
BaBar	$\psi(2S)\pi^+\pi^-$	$4669 \pm 21 \pm 3$	$104 \pm 48 \pm 10$	Phys. Rev. D98(2014)111103	520 fb^{-1}
Belle	$D_s^+ D_{s1}^-(2536)$	$4626^{+7}_{-7} \pm 1$	49.8^{+14}_{-12}	Phys. Rev. D100(2019)111103	922 fb^{-1}
Belle	$D_s^+ D_{s2}^{*-}(2573)$	$4620^{+9}_{-8} \pm 3$	$47.0^{+32}_{-15} \pm 5$	Phys. Rev. D101(2020)091101	922 fb^{-1}

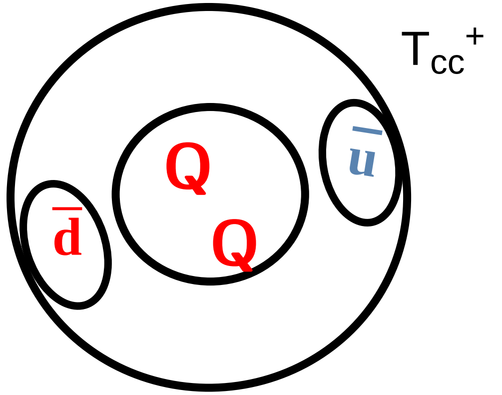


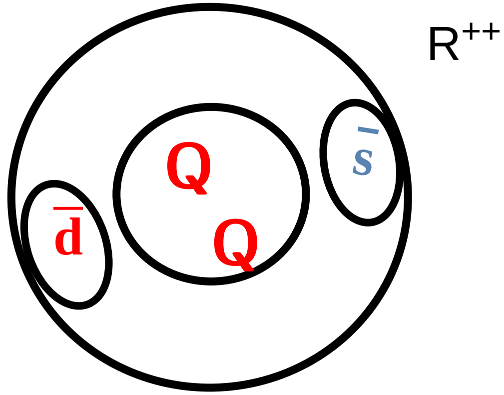
Search for R^{++}

LHCb, arXiv: 2109.01038 [hep-ex]



- Remember T_{cc}^{+}, as $[D^0 D^{*+}]$ state at LHCb
- $[D^+ D_{s0}^{*+}(2317)]$
  predicted [DDK] molecular state by kaon exchange
  Sanchez Sanchez et al., Phys. Rev. D 98 (2018) 054001
  5-15 MeV binding energy
  mass 4.13–4.17 GeV
- $D_{s0}^{*+}(2317)$ decay to DK kinematically forbidden,
  but decay to $[D^+ D_s^{*+}]$ possible by triangle diagram
- Needs two charm quarks,
  thus also two anti-charm quarks
  $\Upsilon(nS) \to cc\bar{c}\bar{c}X$
- $\to$ take $\Upsilon(1S)$ and $\Upsilon(2S)$ decays
  and inclusive production in e+e-
  at three energies (continuum, $\Upsilon(4S)$ and $\Upsilon(5S)$)
  Belle, Phys. Rev. D 102 (2020) 112001

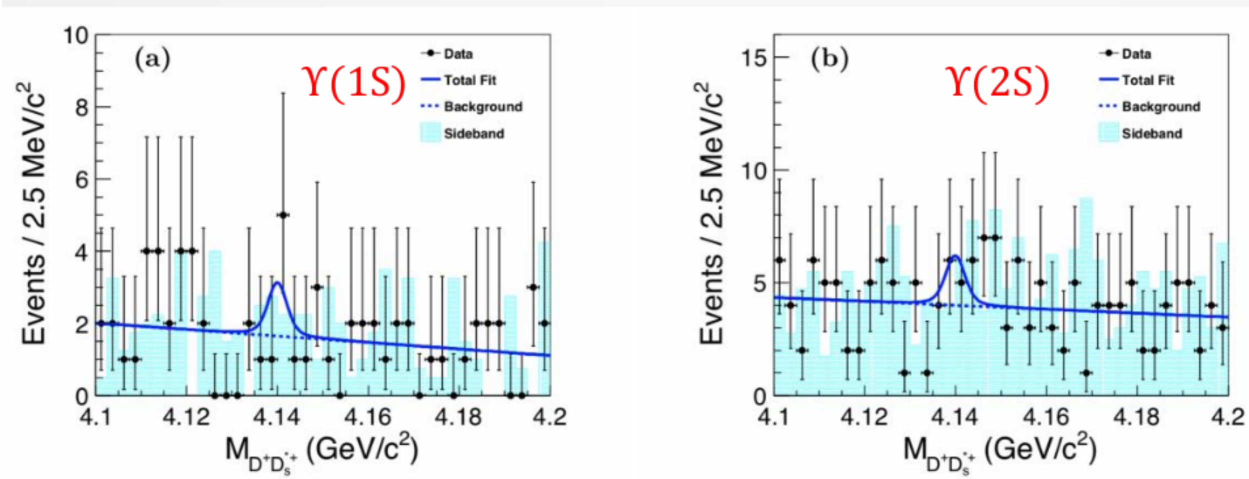


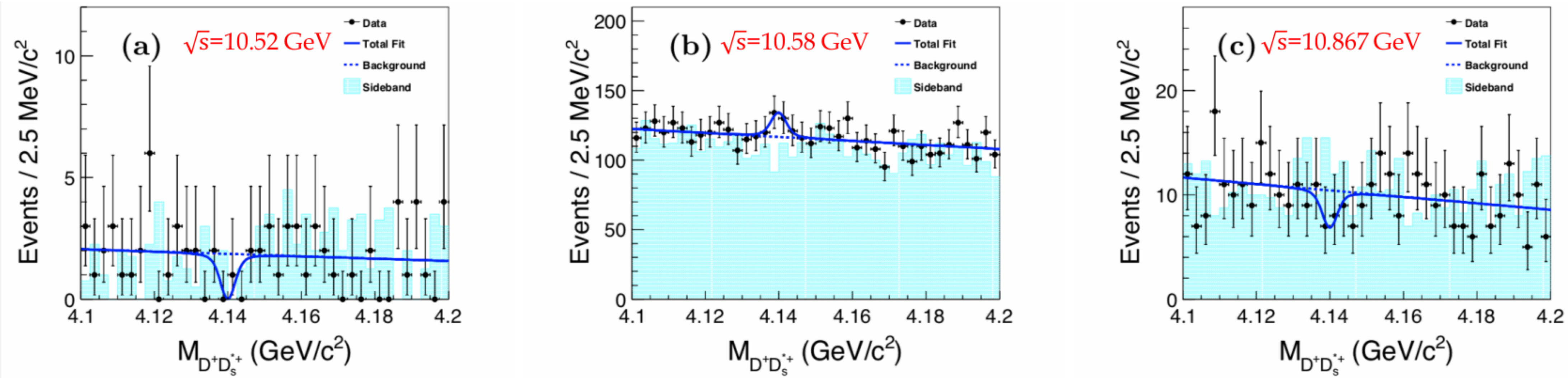


Search for R^{++}

Belle, Phys. Rev. D 102 (2020) 112001

Fit examples for fixed mass 4.14 GeV/c^2 and fixed width 2 MeV





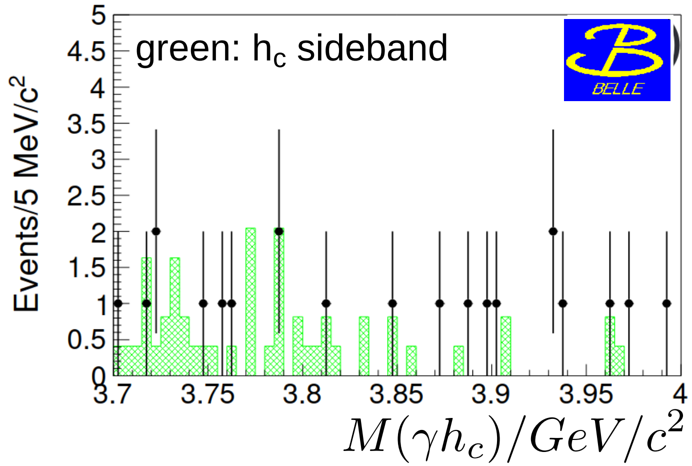
No signal observed. Upper limits on cross sections are small (order of few fb)

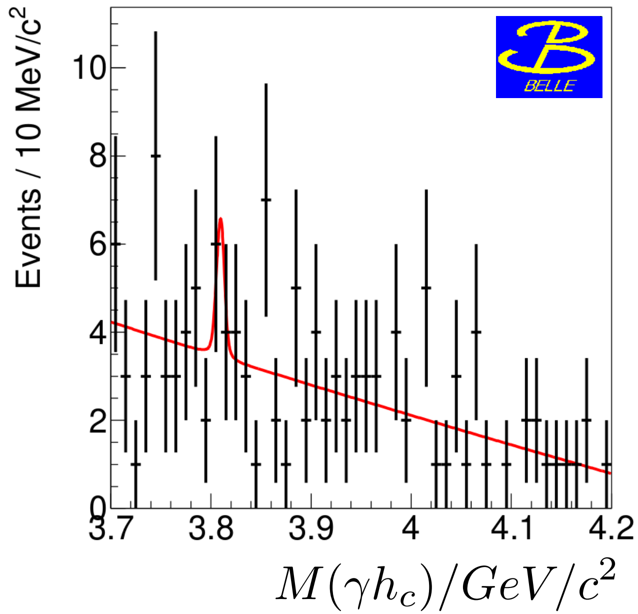
Search for $\eta_{c2}\ (^1D_2)$

$$\eta_{c2} \to \gamma h_c, h_c \to \gamma \eta_c$$

η_c reconstructed in 10 decay channels

- D-wave state ($L=2$)
- Last missing charmonium state below $D\bar{D}^*$ threshold ! $J^{PC}=2^{-+}$
- One of the $X(3872)$ interpretations before determination of quantum numbers
  LHCb, Phys. Rev. Lett. 110 (2013) 222001
- Predicted width very narrow Γ=0.46 MeV
  $D\bar{D}^*$ and $D^*\bar{D}^*$ decays kinematically forbidden
  $D\bar{D}$ decay forbidden by parity
  Eichten, Lane, Quigg, Phys. Rev. Lett. 89 (2002) 162002
- Search in e^+e^- direct production
  $\sigma(e^+e^- \to \gamma\eta_{c2}(1D))\mathcal{B}(\eta_{c2}(1D) \to \gamma h_c(1P)) < 4.9$ fb
  Belle, Phys. Rev. D104 (2021) 012012
- Search in B decays
  $\mathcal{B}(B^+ \to \eta_{c2}(1D)K^+) \times \mathcal{B}(\eta_{c2}(1D) \to h_c\gamma) < 3.7 \times 10^{-5}$
  Belle, JHEP 2005 (2020) 034

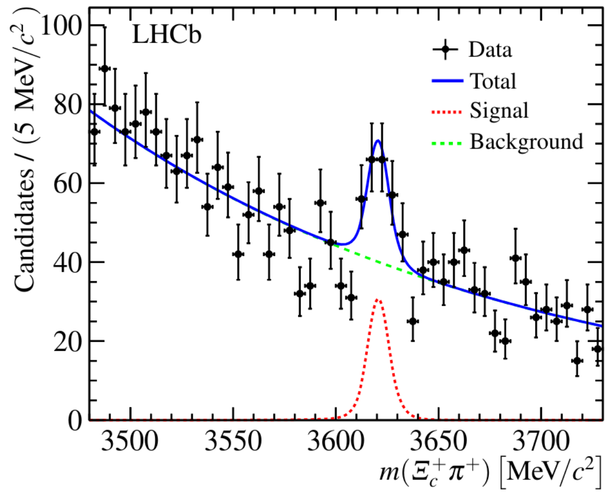




CHARMED BARYONS

Introduction to charmed baryons $\Xi_c^0\ (dsc), \Xi_c^+\ (usc)$

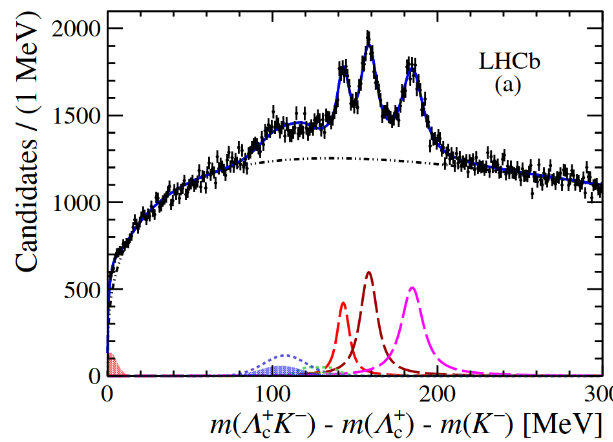
- After decades of searches, double charmed baryon discovered by LHCb
  $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^-$
  LHCb, Phys. Rev. Lett. 119 (2017) 112001



- Confirmed in $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+, \Xi_c^+ \to p K^- \pi^+$
  LHCb, Phys. Rev. Lett. 121 (2018) 162002

- Isospin partner (ccu instead of ccd) still missing
  would decay $\Xi_{cc}^+ \to \Xi_c^+ \pi^- \pi^+$
  experimentally difficult, lifetime predicted factor 2-4 smaller

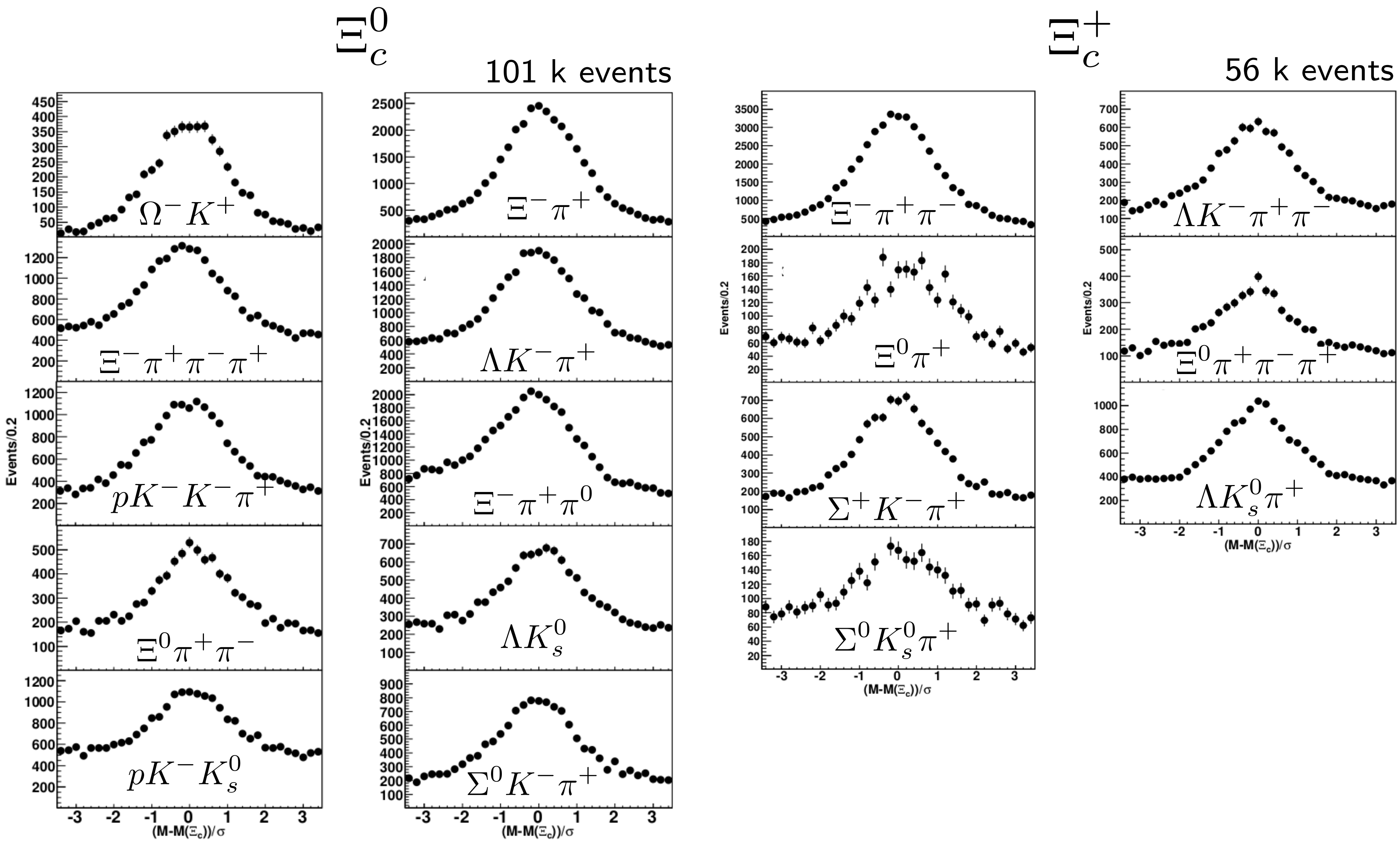
- Important input for predictions of stable tetraquarks ($cc\overline{qq}$) e.g. $T_{cc}{}^+$
  Eichten, Quigg, Phys. Rev. Lett. 119 (2017) 202002
  Karliner, Rosner, Phys. Rev. Lett. 119 (2017) 202001



- Three new states discovered
  $\Xi_c^0(2923)$, $\Xi_c^0(2939)$, $\Xi_c^0(2965)$, orbital excitations?
  LHCb, Phys. Rev. Lett. 124 (2020) 222001

Ξ_c decay channels at Belle

All decays are Cabibbo allowed (V_{cs} transition).



Belle, Phys. Rev. D 94 (2016) 052011

New Ξ_c branching fractions in 2021

$$\Xi_c^0 \to \Lambda \overline{K}^{*0}, \Sigma_0 \overline{K}^{*0}, \Sigma^+ K^{*-}$$

Belle, JHEP 2106 (2021) 160, 980 fb^{-1}

$$\Xi_c^0 \to \Xi^0 K^+ K^-$$

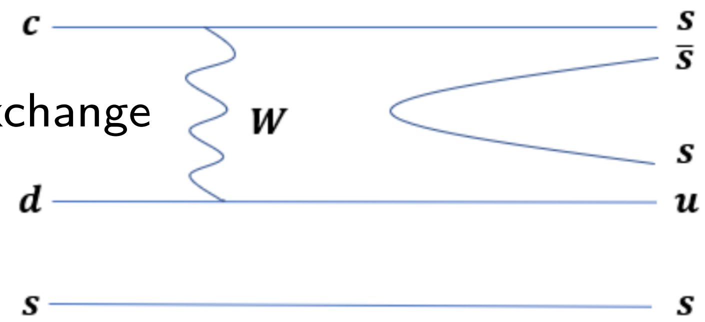
Belle, Phys. Rev. D103 (2021) 112002, 980 fb^{-1}

$$\Xi_c^0 \to \Xi^- l^+ \nu_l$$

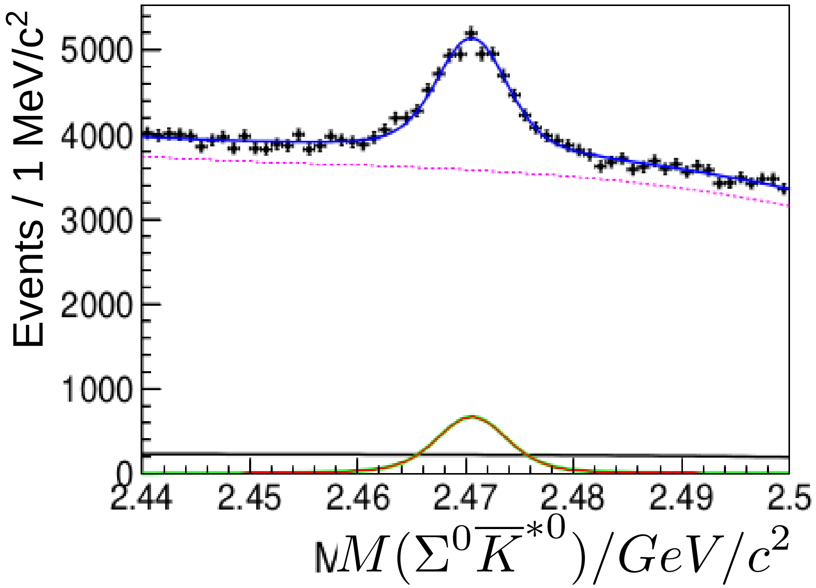
Belle, Phys. Rev. Lett. 127 (2021) 121803, 800 fb^{-1}

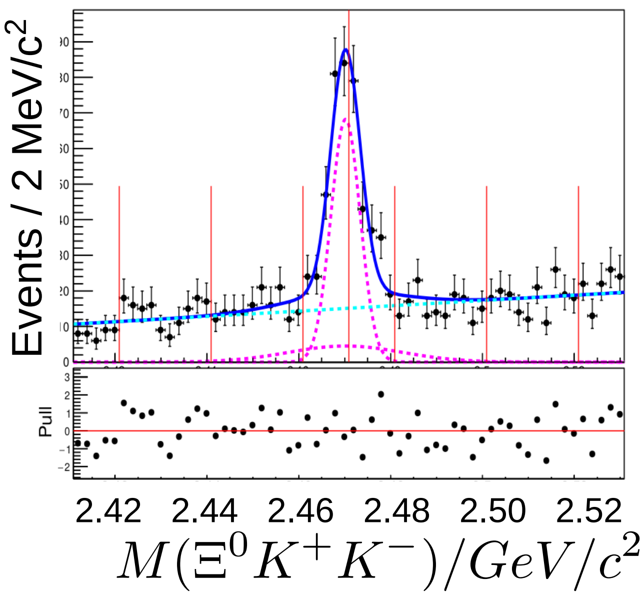
Parity violation (hyperon polarization)

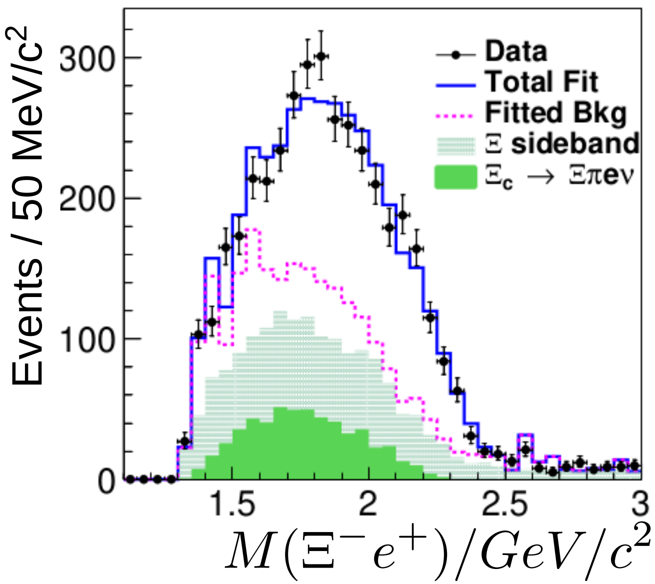
W exchange



Semileptonic decay

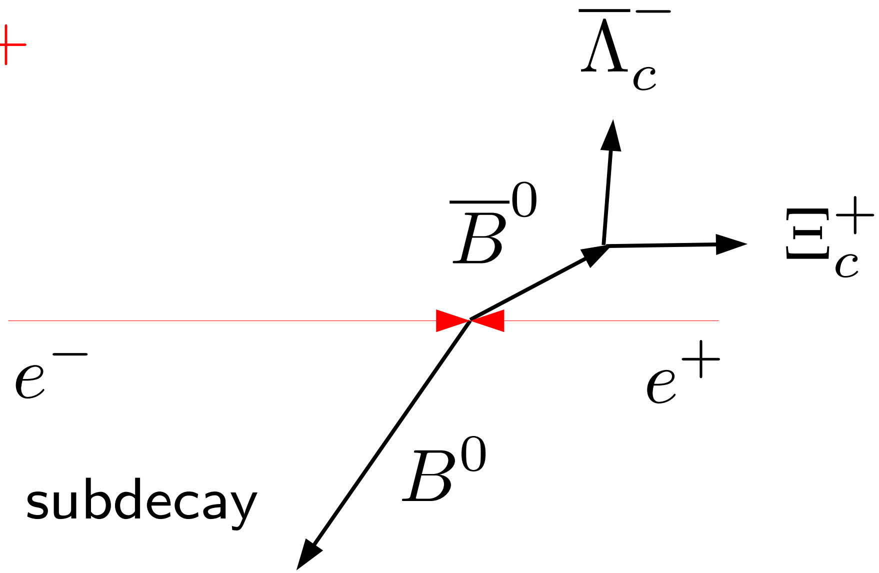






Absolute branching fraction of Ξ_c^+

- $\overline{B}^0 \to \overline{\Lambda}_c^- \Xi_c^+$
- Reconstruct $\overline{\Lambda}_c^- \to \overline{p} K^+ \pi^-$
- Measure Ξ_c^+ exclusive decays
- Recoil mass of $\overline{\Lambda}_c^-$ w/o reconstructing Ξ_c^+ subdecay (normalization of 100% branching fraction)
- Tag B^0 (on the opposite side, normalization of absolute yield)

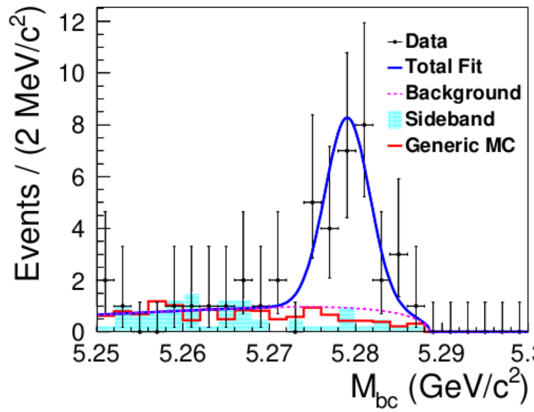


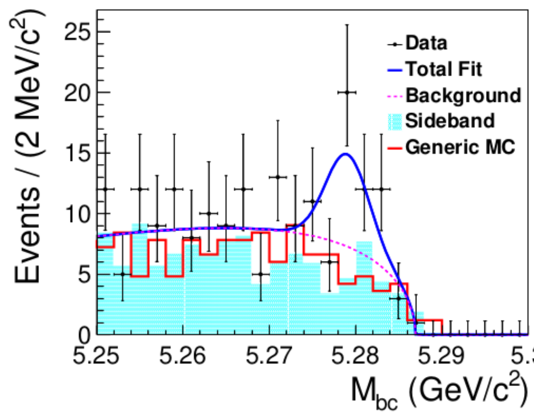
$$\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) = (2.86 \pm 1.21 \pm 0.38)\%$$

$$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+) = (0.45 \pm 0.21 \pm 0.07)\%$$

Belle, Phys. Rev. D 100 (2019) 031101, 711 fb^{-1}

Both decays are Cabibbo suppressed (V_{cd} transition)



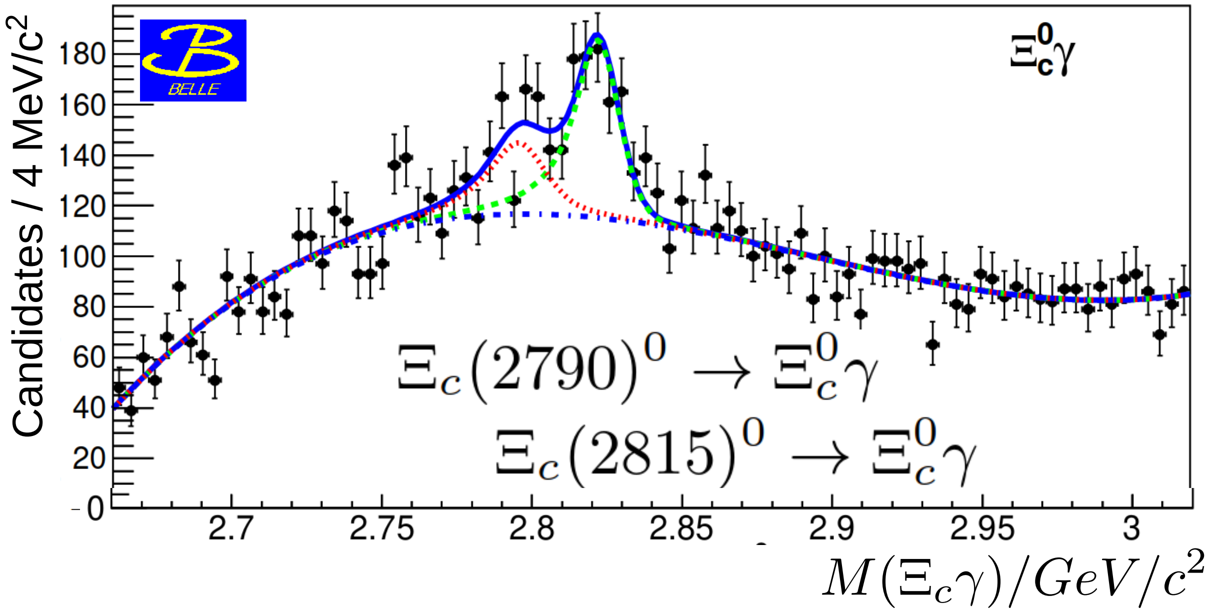


$\to$ Conclusion: Only 24.4% of Ξ_c^+ branching fractions known (PDG2021)

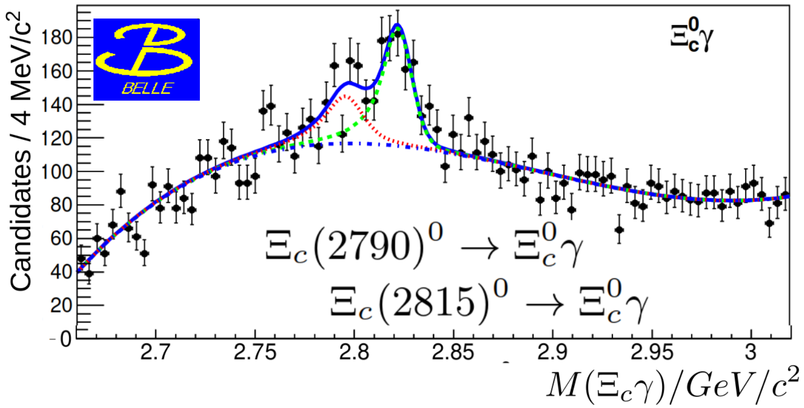
Radiative decays of orbitally Ξ_c excited states

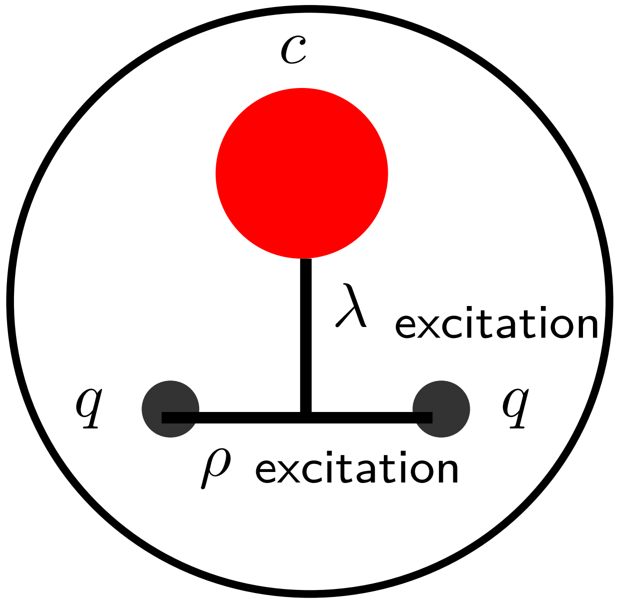
- Strong decays dominant in charmed baryons
- EM decays
  - only observed in rare cases,
    e.g. if pion transition forbidden by kinematics (e.g. $\Xi_c' \rightarrow \Xi_c\ \gamma$)
  - allowed, if parity flip possible ($L=1$ transition)
  - first observation of an EM decay
    of an orbitally-excited charmed baryon (significance 8.6σ)

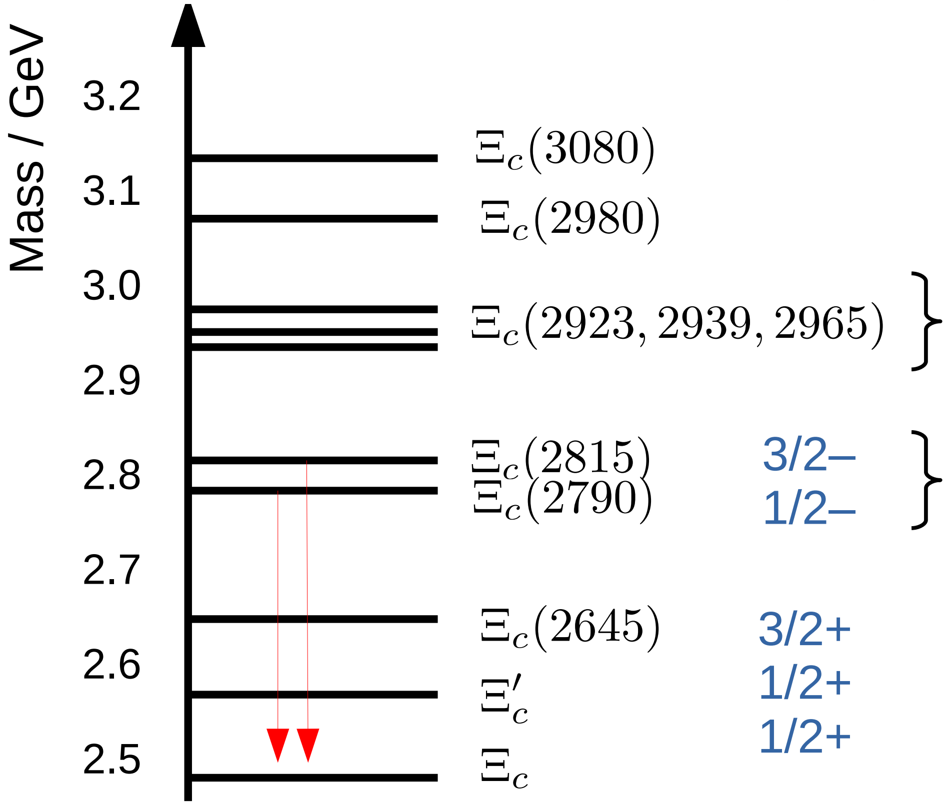
Belle, Phys. Rev. D 102 (2020) 071103, 980 fb^{-1}



Radiative decays of orbitally excited Ξ_c states







Orbital λ excitation L=1 with spin-1 diquark

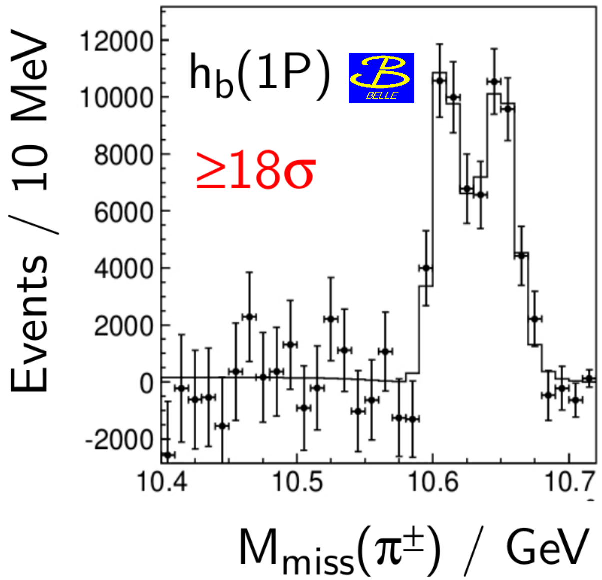
Orbital λ excitation L=1 with spin-0 diquark

Decay of orbitally excited charged Ξ_c^+ not observed, [+ –] vs. [++] diquark
$\rightarrow$ ρ excitation disfavored

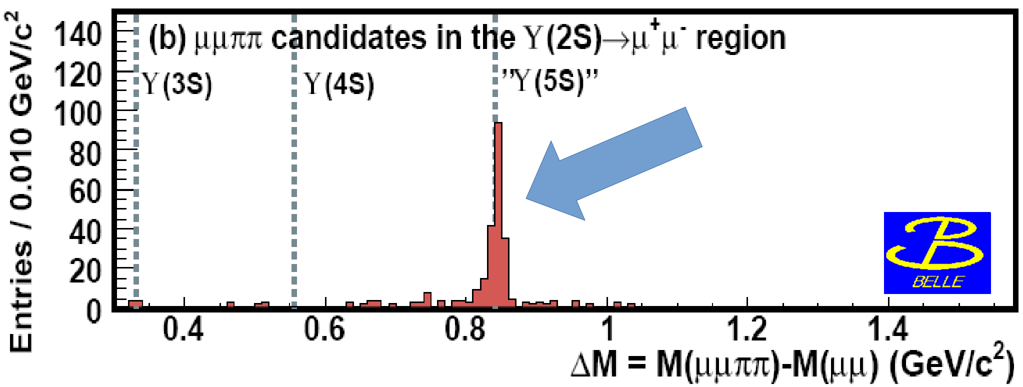
Y_b SCAN

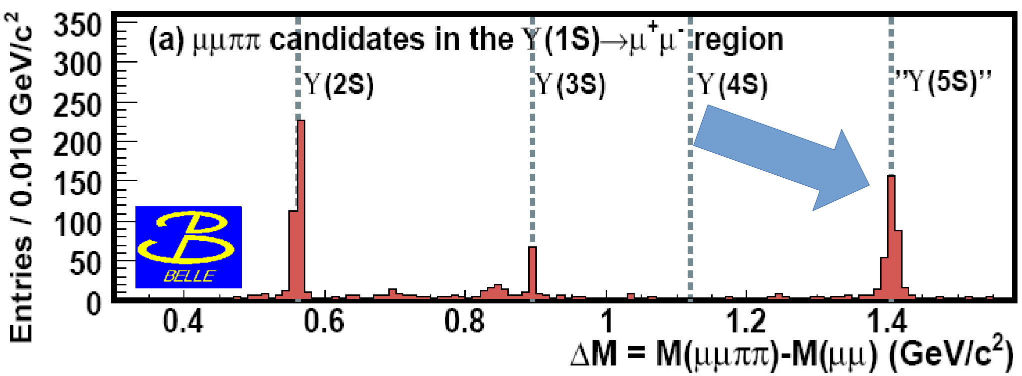
BOTTOMONIUM

- $\Upsilon(5S)$ never observed at LHC
- Branching of $\Upsilon(5S) \rightarrow \Upsilon(nS)\pi\pi$ is factor $\simeq 1000$ larger than $\Upsilon(4S) \rightarrow \Upsilon(nS)\pi\pi$
  $\rightarrow$ $\Upsilon(5S)$ exotic itself?
- Charged Z_b states observed in $\Upsilon(5S)$ decays
  Belle, Phys. Rev. D91 (2015) 072003
  peculiar properties:
  spin flip in decays not suppressed
- New state observed: $Y_b(10750)$



$Z_b(10610)^{\pm}$ m=10607.2±2.0 MeV
2.6 MeV above $\bar{B}B^*$ threshold
$Z_b'(10650)^{\pm}$ m=10652.2±1.5 MeV
2.0 MeV above $\bar{B}^*B^*$ threshold
confirmed in 5 decay modes

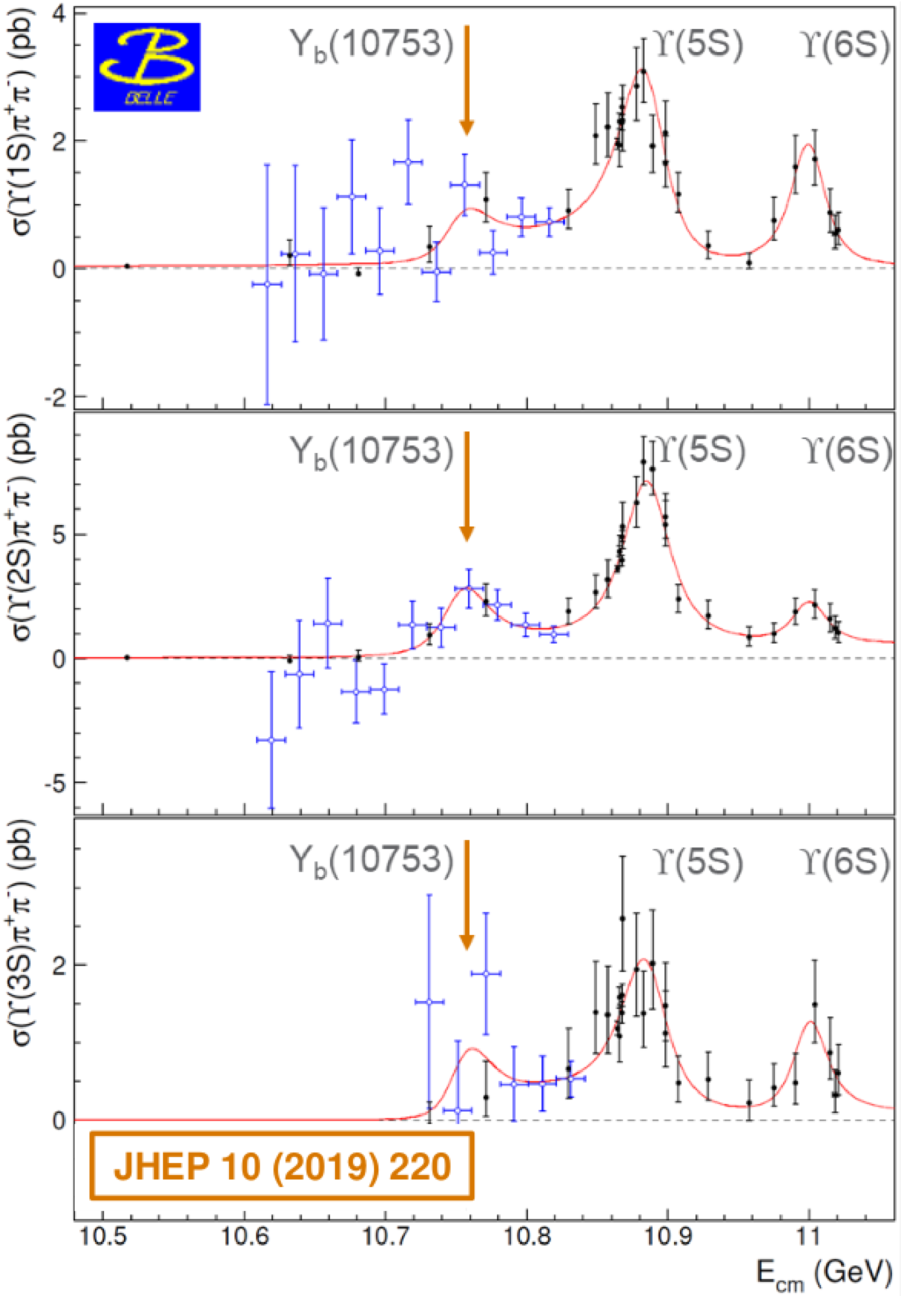




Belle Phys. Rev. Lett. 100, 112001 (2008)

$Y_b(10750)$

- Seven scan points below $\Upsilon(5S)$ at Belle, each $\simeq$1 fb^{-1}
- New structure observed in $\Upsilon(nS)\pi\pi$



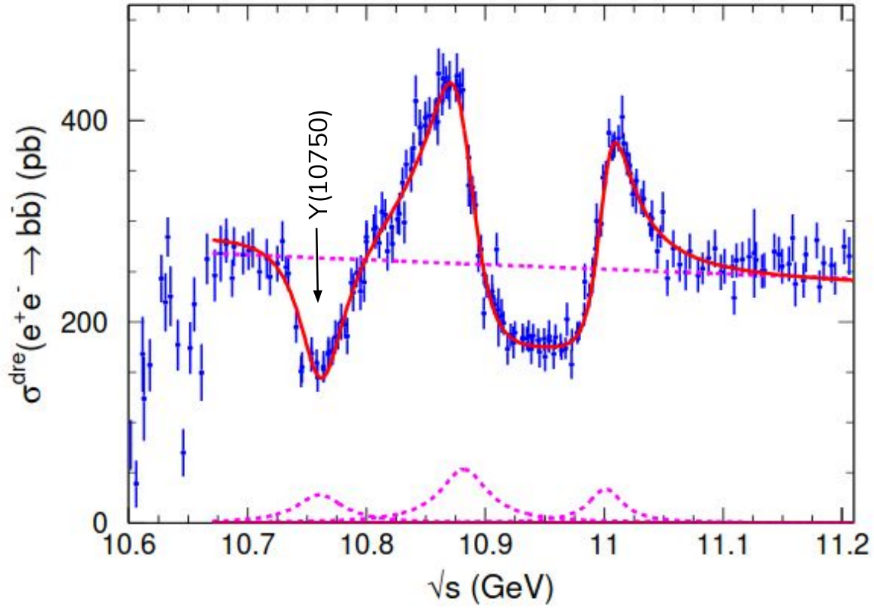
	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
M (MeV/c^2)	$10885.3 \pm 1.5\,^{+2.2}_{-0.9}$	$11000.0^{+4.0}_{-4.5}\,^{+1.0}_{-1.3}$	$10752.7 \pm 5.9\,^{+0.7}_{-1.1}$
Γ (MeV)	$36.6^{+4.5}_{-3.9}\,^{+0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8}\,^{+0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3}\,^{+3.9}_{-3.3}$

Further evidence in destructive interference

Refit of BaBar and Belle scan data

Dong et al., Chin. Phys. C 44 (2020) 8, 083001

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



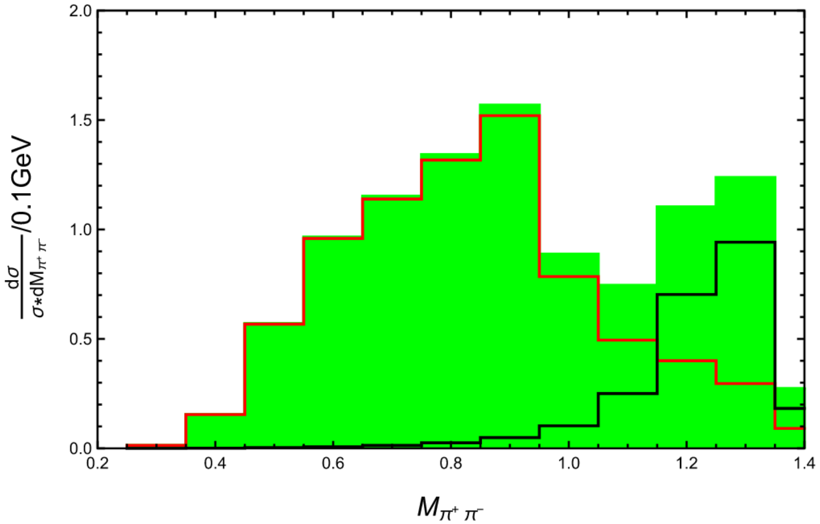
New Y_b Scan at Belle II (ongoing)

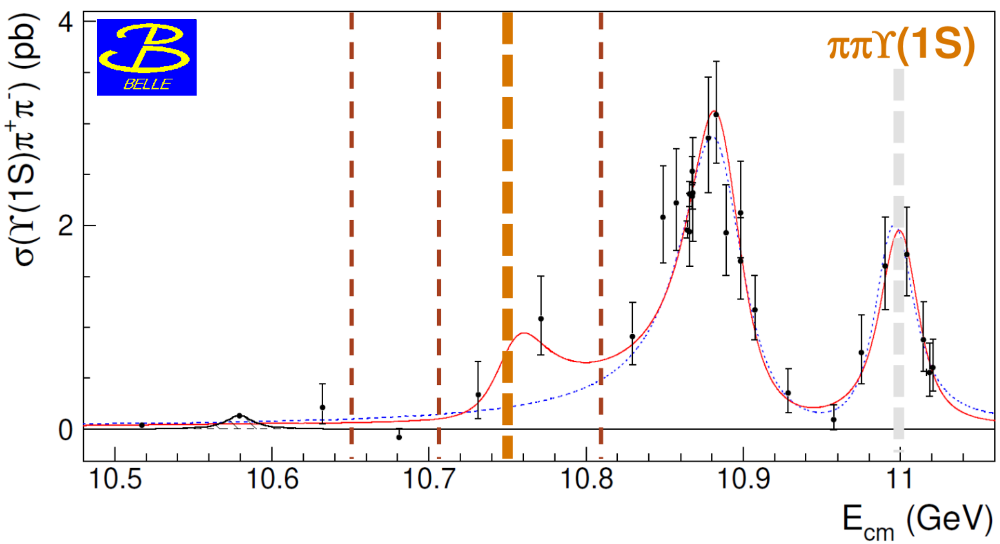
- Accelerator energies are changed
- Scan started 11.11.2021
- Prediction for $Y_b(10750) \to \Upsilon(1S)\pi\pi$

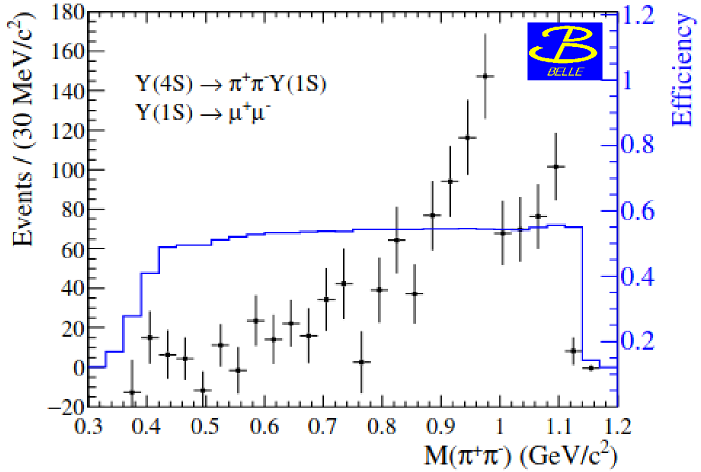
  Ali, Maiani, Parkhomenko, Wang,
  Phys. Lett. B 802 (2020) 135217

  - $\Upsilon(5S)$ decay is dominated by Z_b states but Y_b decay to Z_b suppressed/forbidden
  - $\pi\pi$ Mass distribution: tetraquark should have strong contribution from scalar f_0 states

Energy	Int. Luminosity
10.751 GeV	$\simeq 10\ fb^{-}1$
10.657	$\simeq 1\ fb^{-}1$
10.706	$\simeq 1\ fb^{-}1$ Plan
10.810	$\simeq 1\ fb^{-}1$







Belle, Phys. Rev. D96 (2017) 052005

New Y_b Scan at Belle II (ongoing) – $B\bar{B}$ decomposition

$q\bar{q}$ pair is present in the system

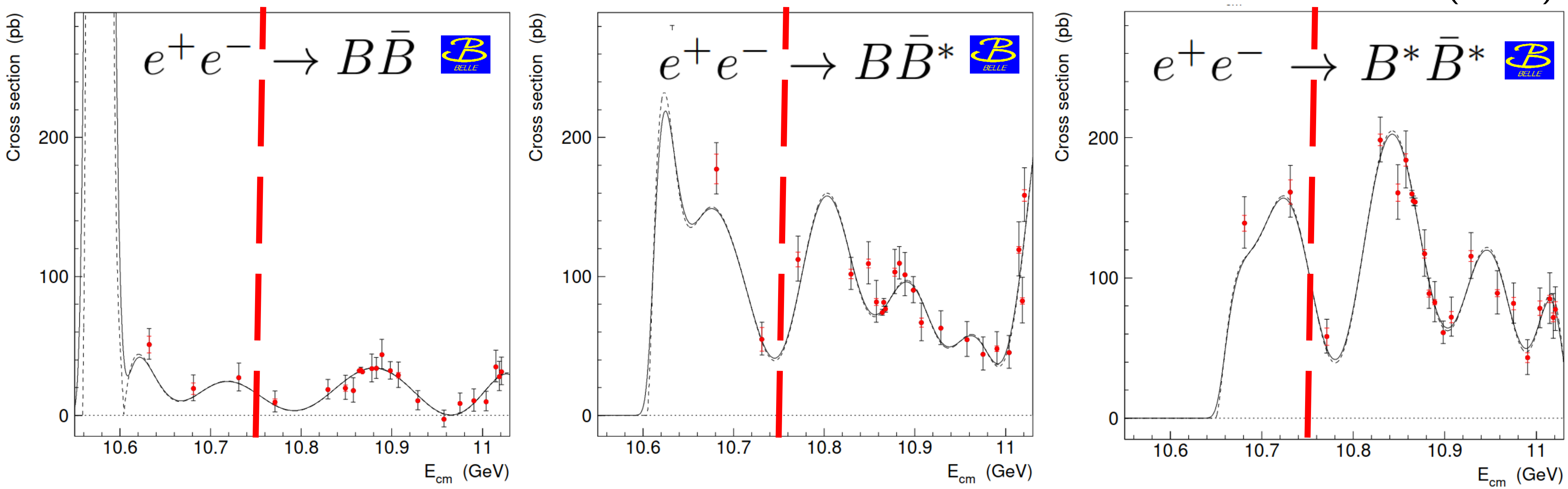
$q\bar{q}$ pair is created from vacuum
$^3P_0$ model

Mode	$\mathcal{B}(4q)$ (%)	$\mathcal{B}(b\bar{b})$ (%)
$B\bar{B}$	$39.3^{+38.7}_{-22.9}$	21.3
$B\bar{B}^*$	~ 0.2	14.3
$B^*\bar{B}^*$	$52.3^{+54.9}_{-31.7}$	64.1
$B_s\bar{B}_s$	-	0.3

Heavy Quark Spin Symmetry
1
4
7

Liang et al., Phys. Lett B 803 (2020) 135340

Belle, JHEP 2106 (2021) 137



Conclusion

- New analysis results from Belle still appearing
- Data taking at Belle II progressing
- First Belle II publications,
  new techniques enabling competitive measurements
  (not shown today: dark sector, τ mass, CKM angles, ...)
- Belle II upgrade planned for 2023