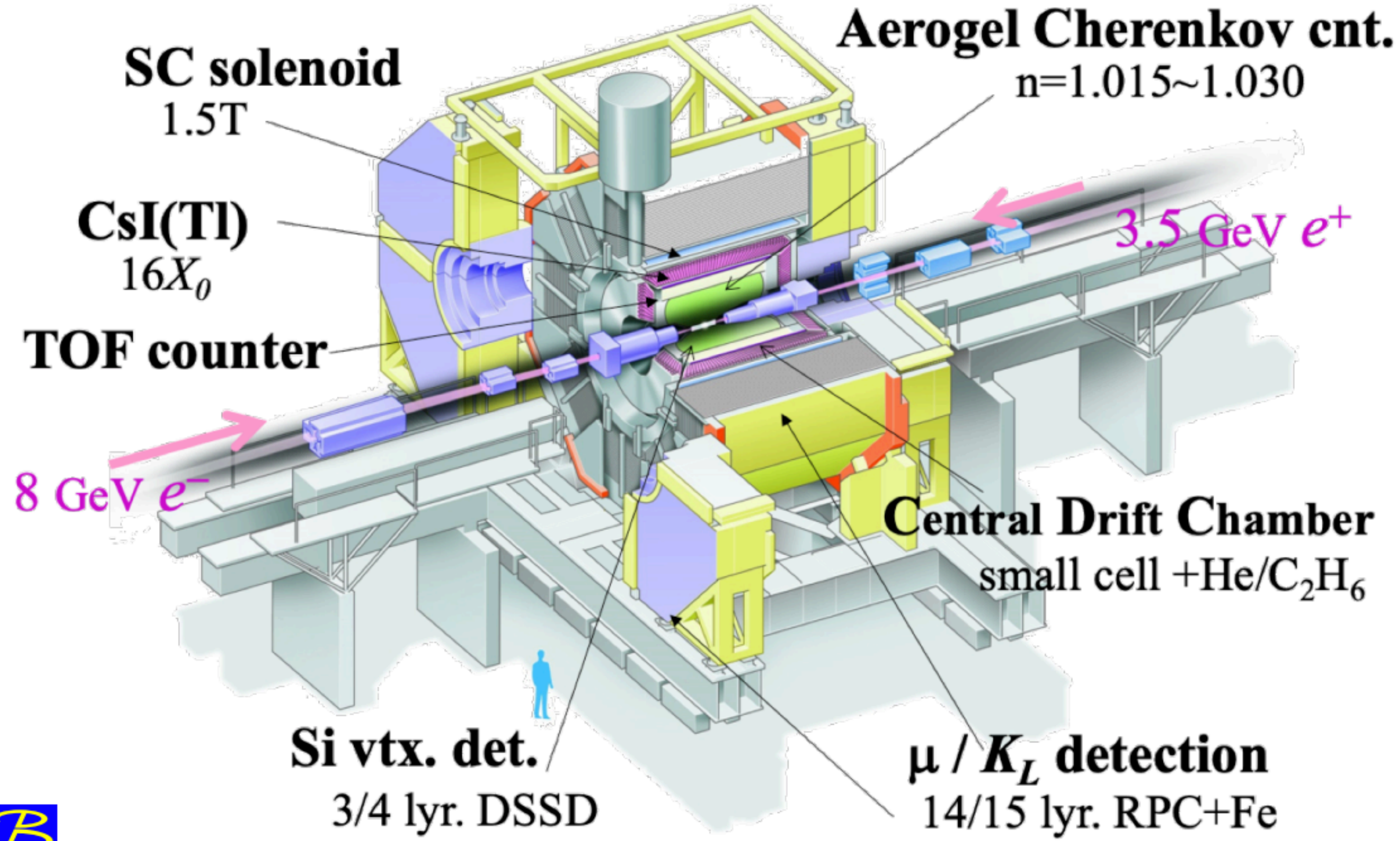
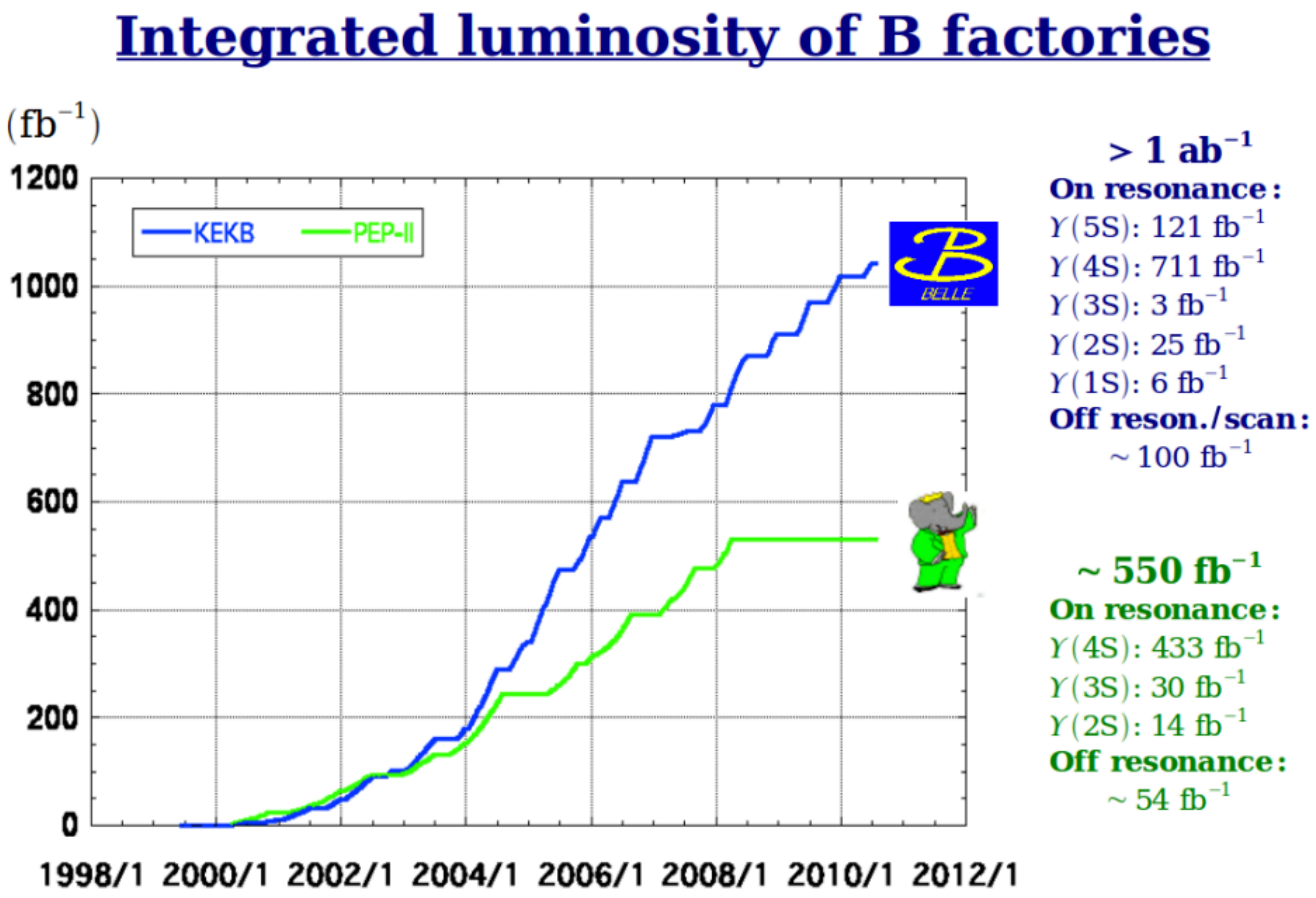
Belle & Belle II recent results

Junhao Yin *on behalf of Belle&Belle II*

Belle experiment at KEKB

- KEKB is an asymmetric-energy e^+e^- collider operating near $\Upsilon(4S)$ mass peak (~ 10.58 GeV$/c^2$, $>B\bar{B}$ threshold).
- Belle detector has good performances on momentum/vertex resolution; particle identification, etc.
- Accumulated data set of ~ 1 ab^{-1}: not only a large $B\bar{B}$ sample (B-factory); but also a large charm sample to study charm physics.

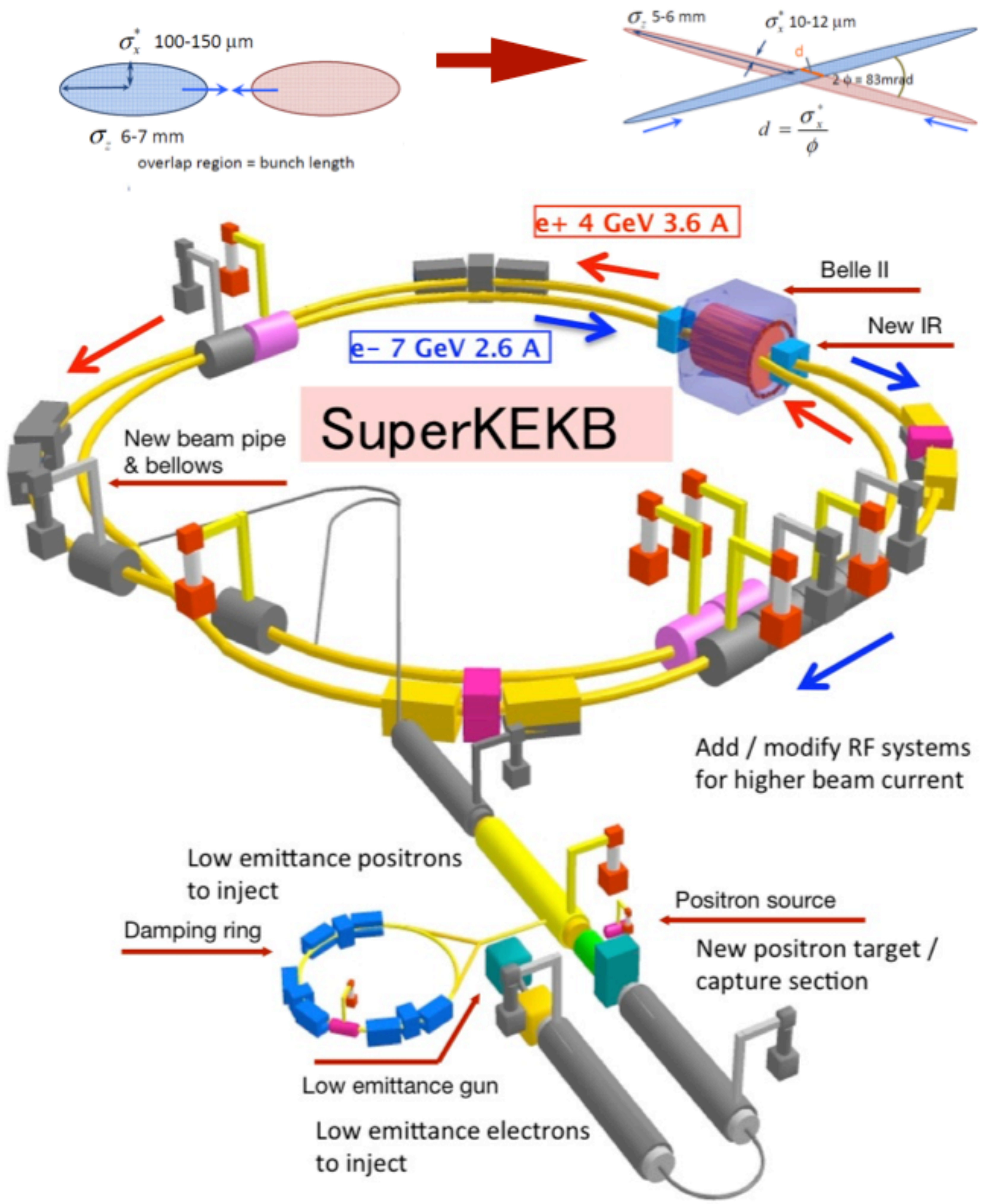


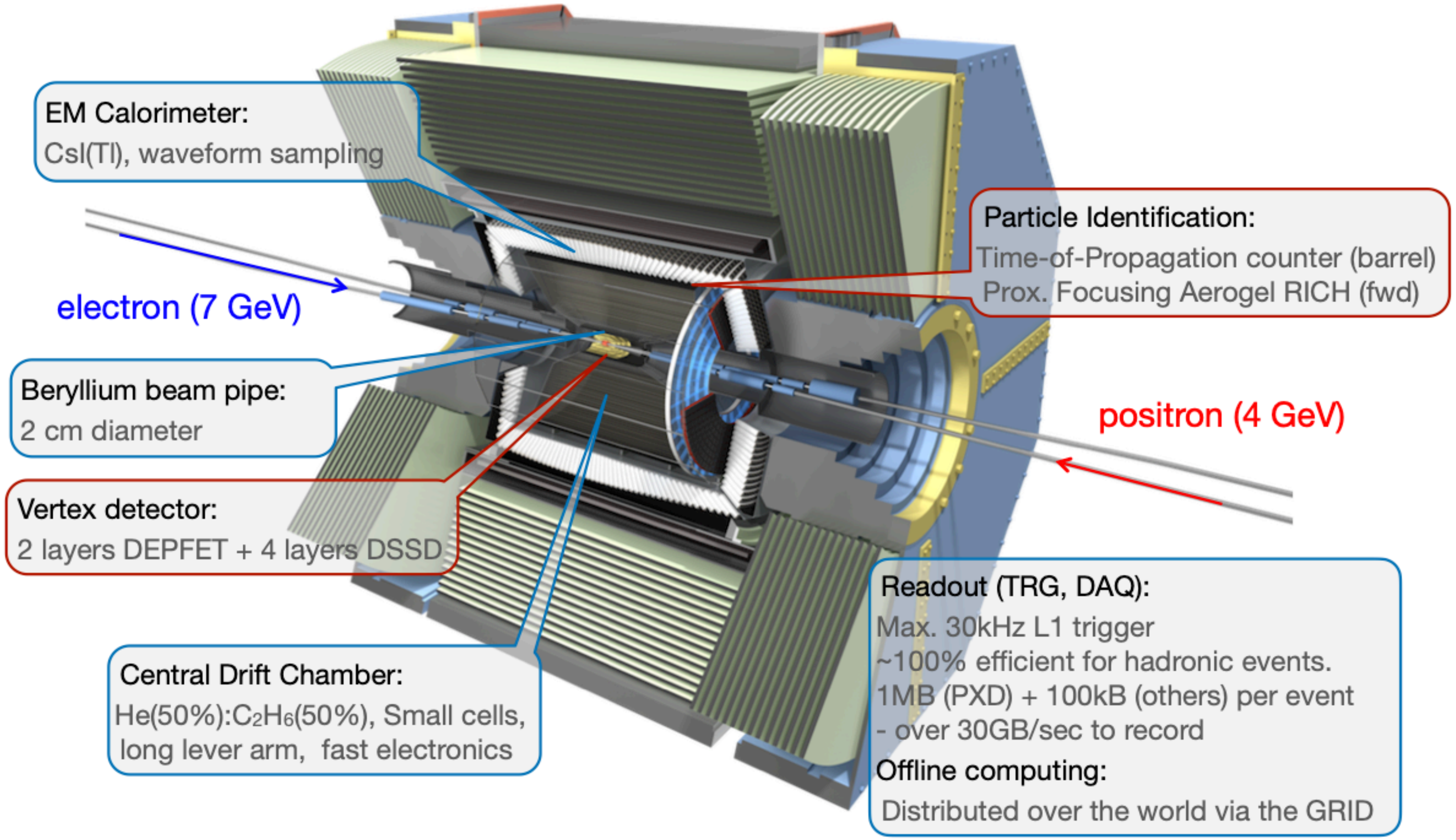


PEAK
L = 2.1 x 10^{34}/cm^2/sec

SuperKEKB and Belle II: The next generation B-factory

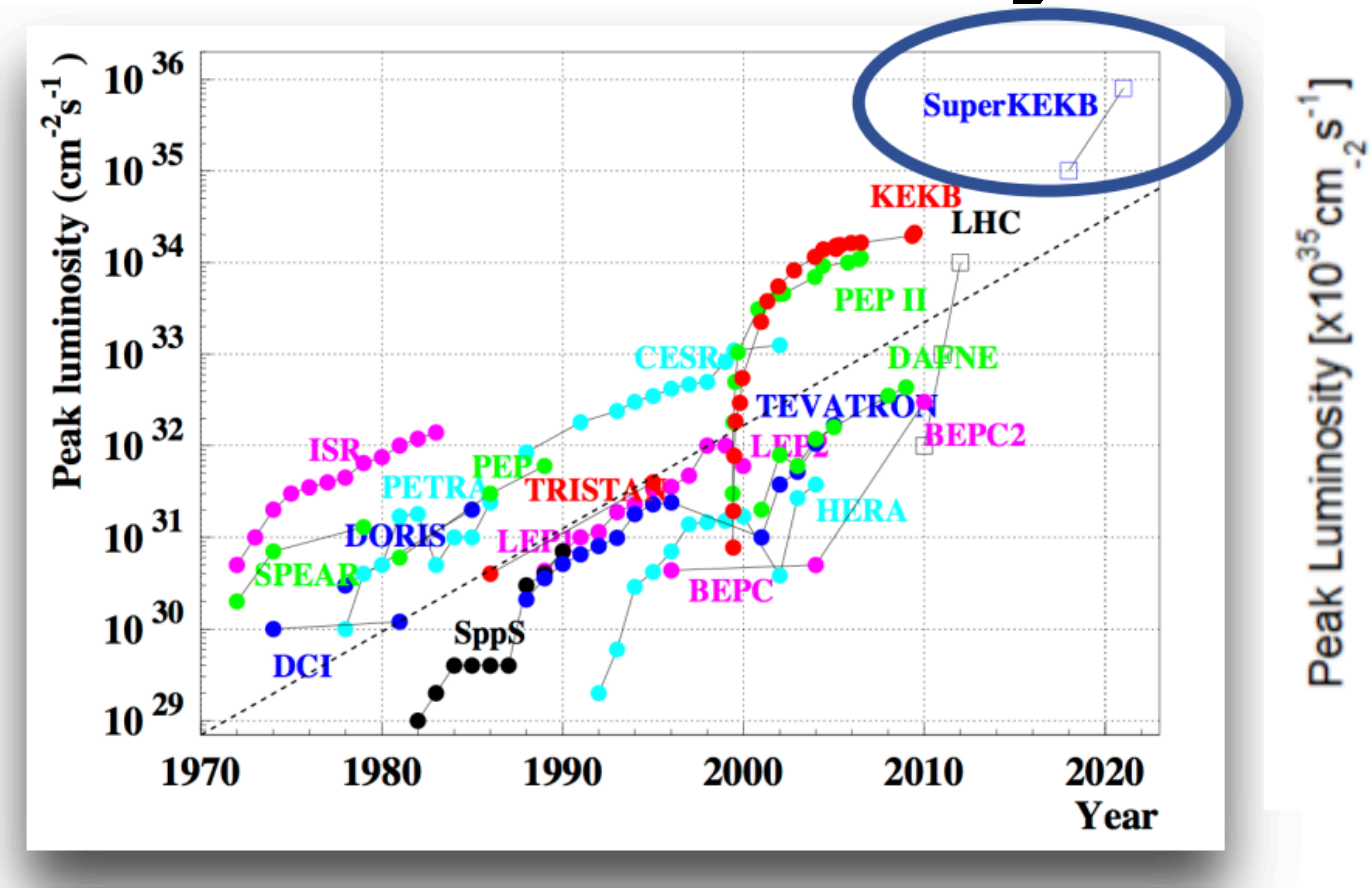
Upgraded detector and accelerator

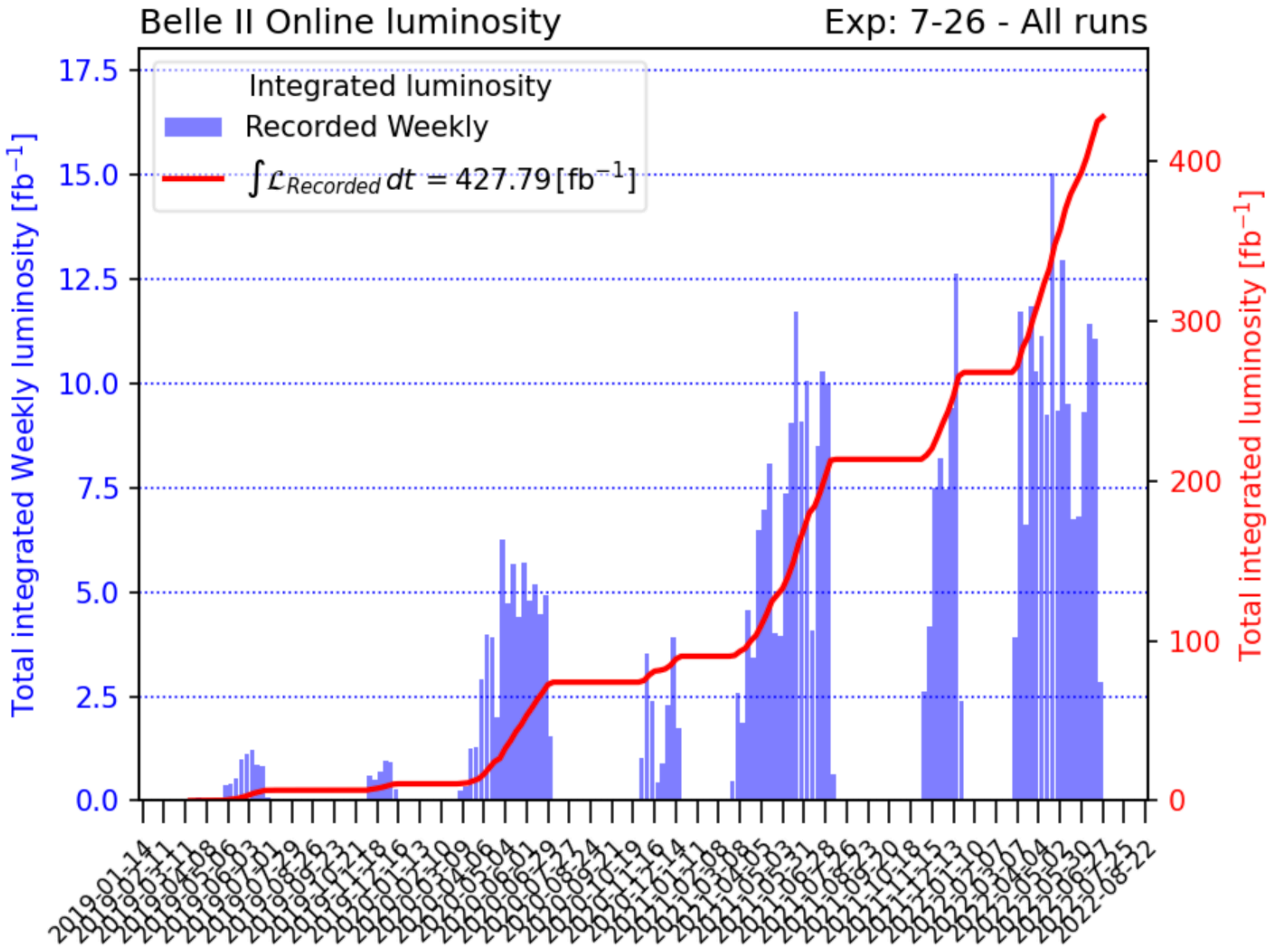




arXiv:1011.0352 [physics.ins-det]

Belle II luminosity

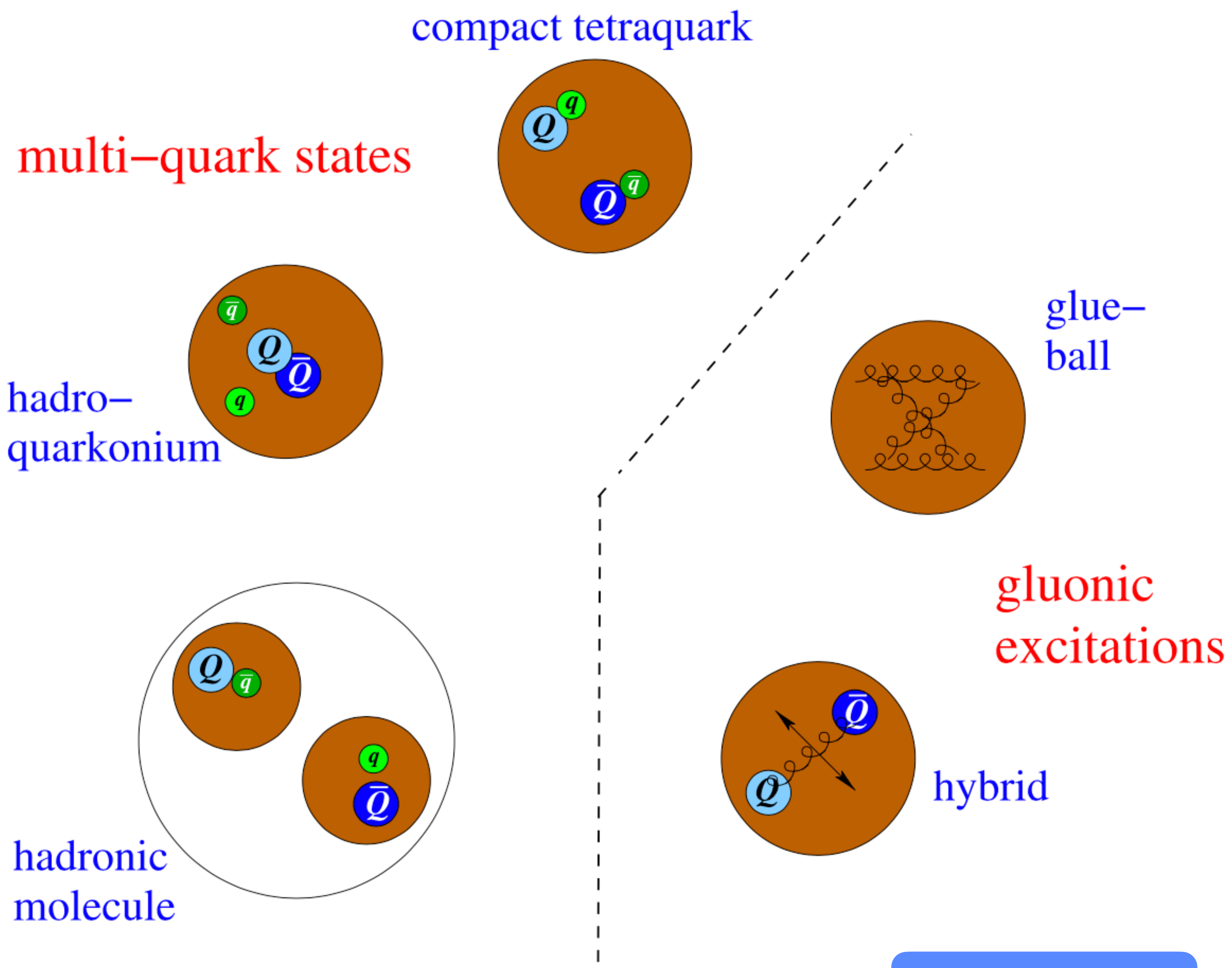




Belle II already achieve the world record instantaneous luminosity: $4.7 \times 10^{34}/cm^2/s$

Integrated luminosity: $427.79\ \mathrm{fb}^{-1}$

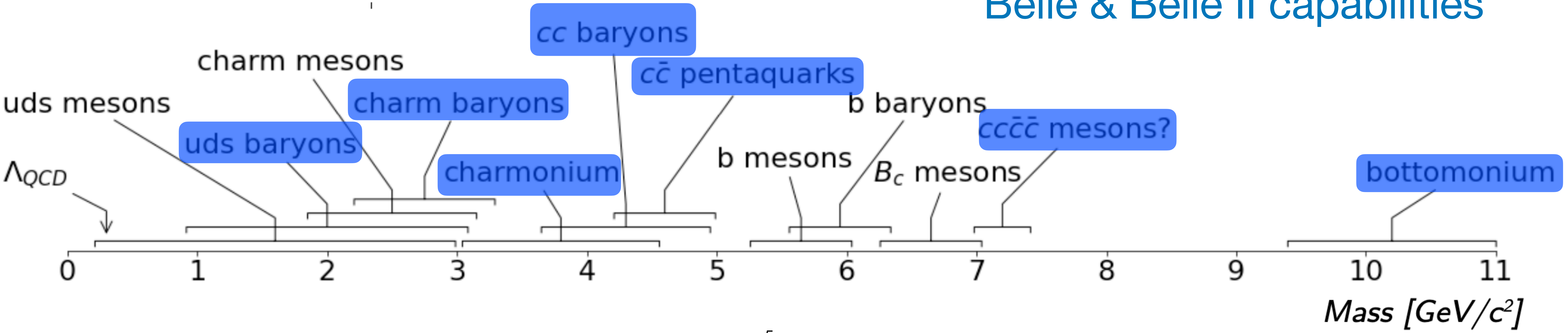
N. Brambilla, S. Eidelman, C. Hanhart et al. / Physics Reports 873 (2020) 1–154



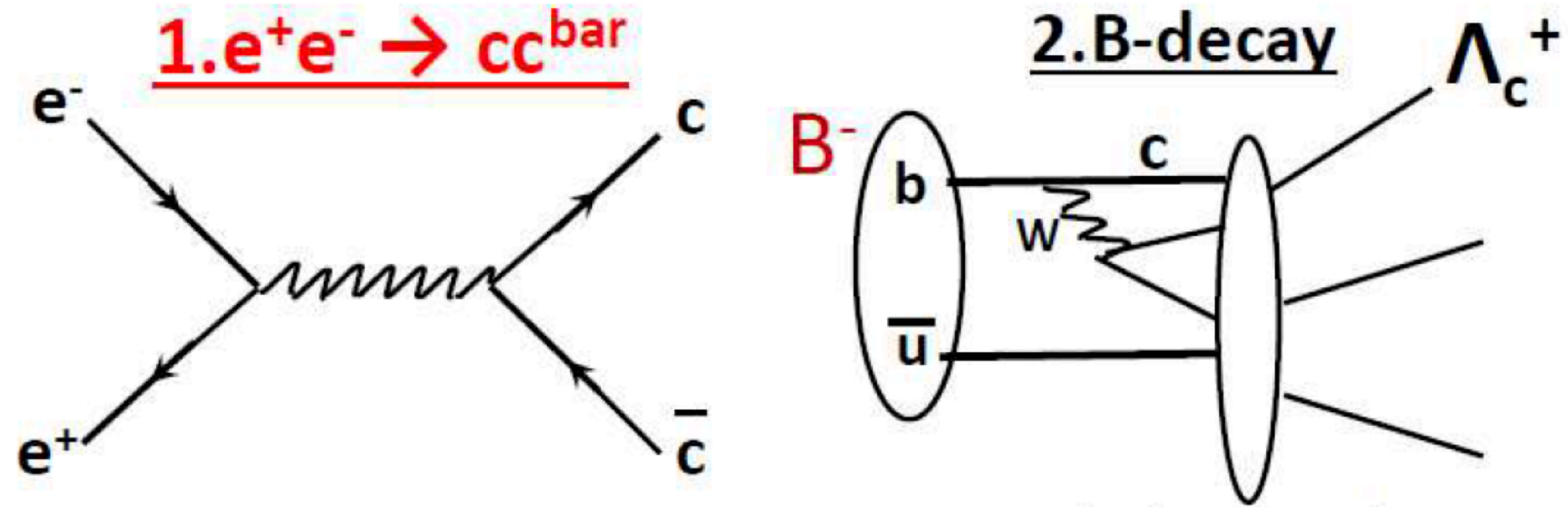
hadron spectroscopy

- New knowledge feeds back to theory.
- Perfect ground to test theoretical models.
- New viewing angle towards QCD.

Belle & Belle II capabilities



Baryon spectroscopy



Fruitful results recently

Production:

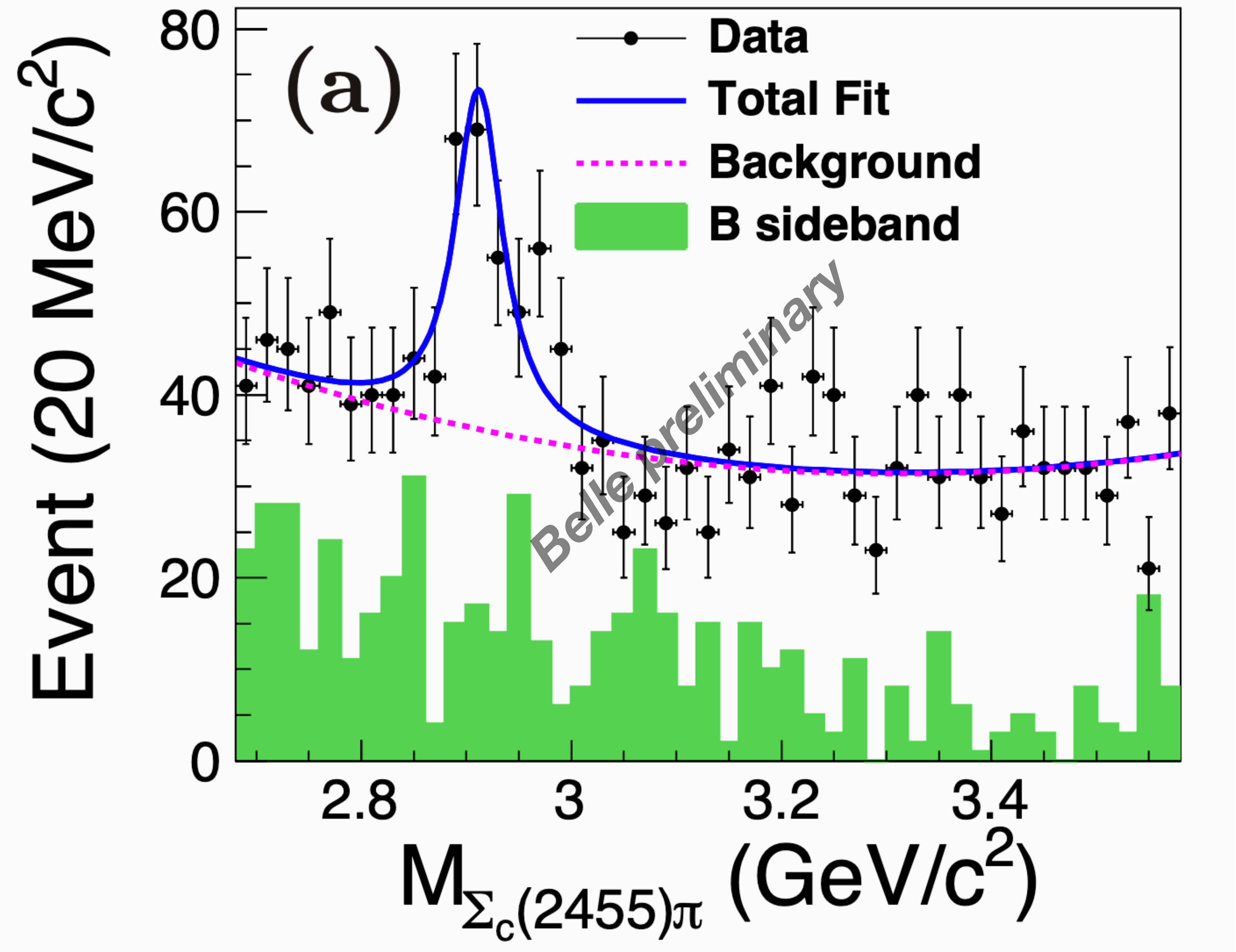
- fragmentation
- B-decays

Focus:

- Searching for new states
- Properties measurement

- Evidence of new excited charmed baryon decays to $\Sigma_c(2455)^{0,++}\pi^{\pm}$
- Observation of $\Omega(2012)^{-} \rightarrow \Xi(1530)\bar{K}$
- Measurement of $\Xi_c^0 \rightarrow \Lambda_c^+\pi^-$
- First measurement of the $\Lambda_c^+ \rightarrow p\eta'$ decay
- …

Evidence of new excited charmed baryon decays to $\Sigma_c(2455)^{0,++}\pi^{\pm}$



arXiv: 2206.08822

Based on 772×10^6 $B\bar{B}$ events on Belle

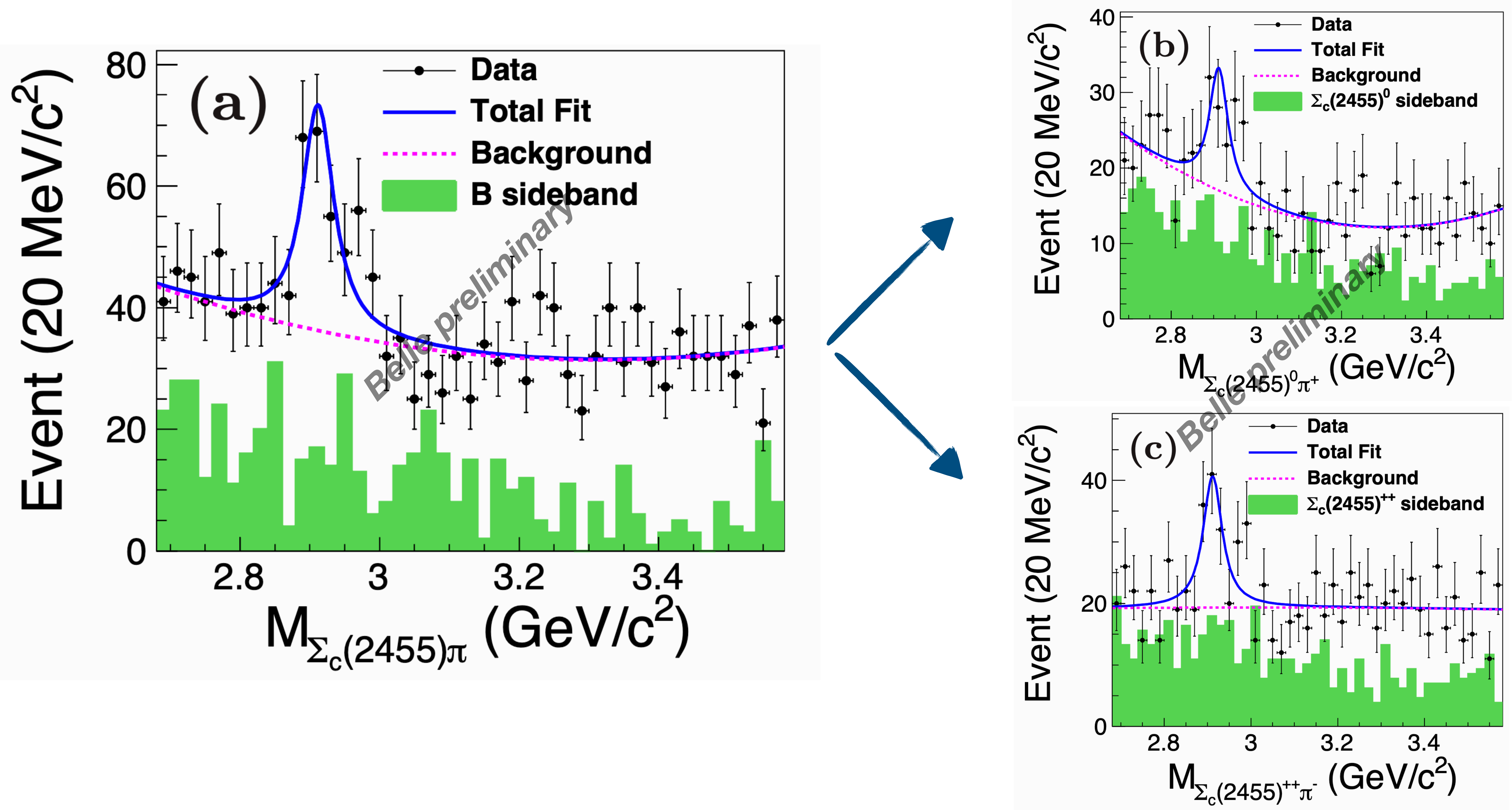
In $\bar{B}^0 \to \Sigma_c(2455)^{0,++}\pi^{\pm}\bar{p}$, resonant state is found on $M(\Sigma_c(2455)^{0,++}\pi^{\pm})$.

Significance: 4.2σ after considering possible $\Lambda_c(2880)^+$ or $\Lambda_c(2940)^+$ contribution.

State	Mass (MeV/c^2)	Width (MeV)
$\Lambda_c(2880)^+$	2881.63 ± 0.24	$5.6^{+0.8}_{-0.6}$
$\Lambda_c(2940)^+$	$2939.6^{+1.3}_{-1.5}$	20^{+6}_{-5}
$\Lambda_c(2910)^+$ (this analysis)	$2913.8 \pm 5.6 \pm 3.8$	$51.8 \pm 20.0 \pm 18.8$

Evidence of new excited charmed baryon decays to $\Sigma_c(2455)^{0,++}\pi^{\pm}$

arXiv: 2206.08822



Simultaneous fit with common resonant parameters.

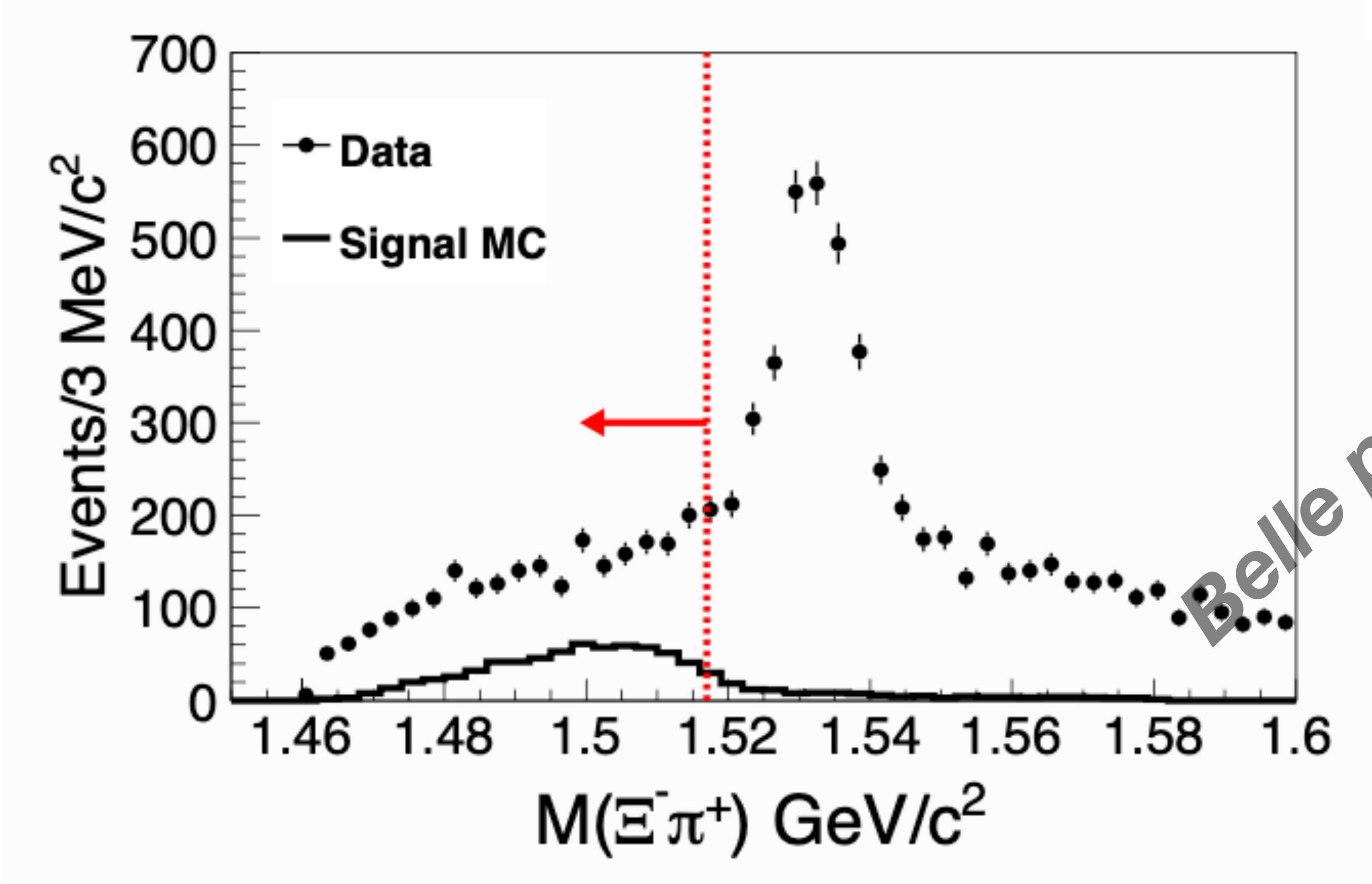
Consistent with combined fit.

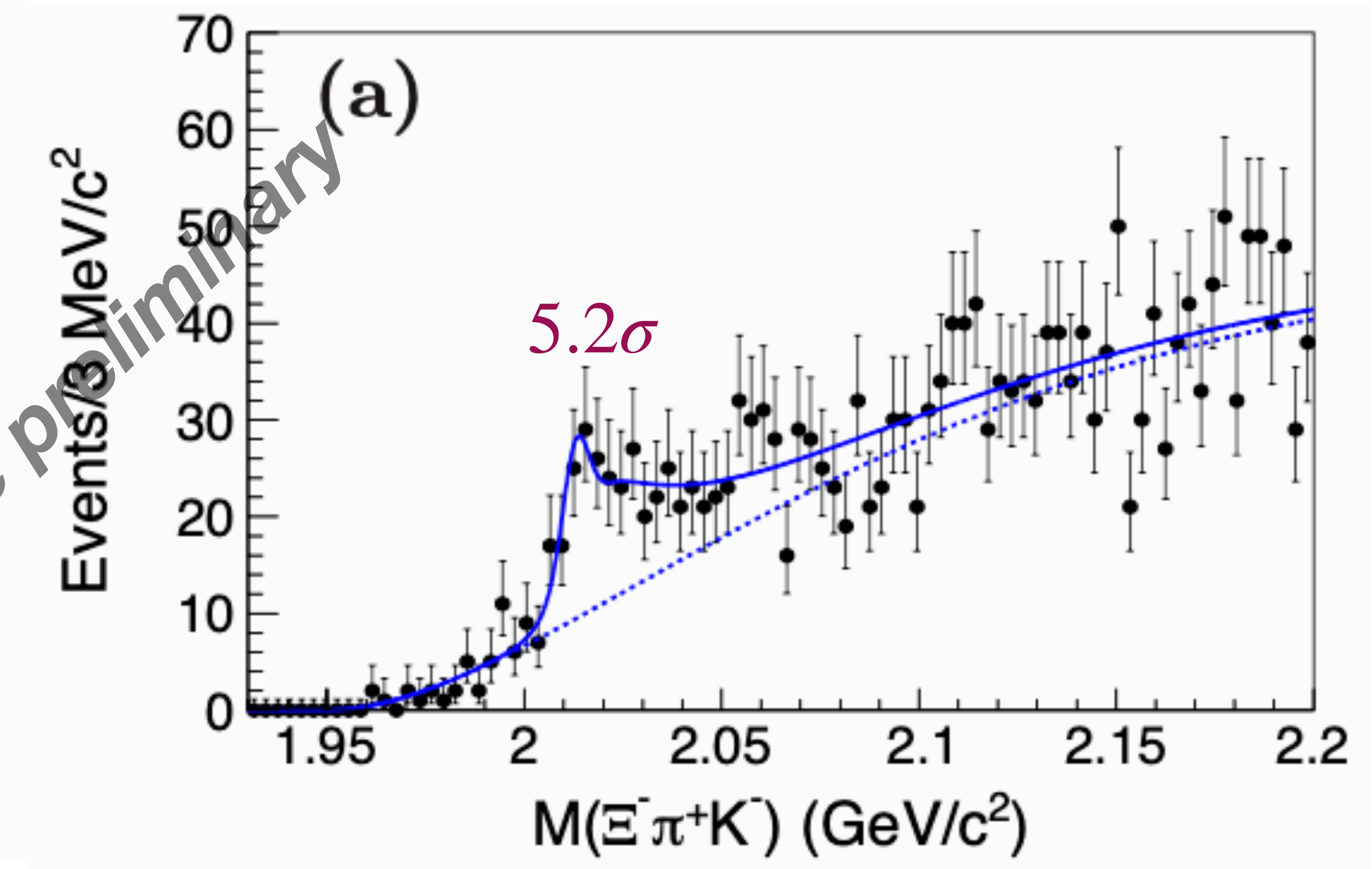
Joint BF: $\mathscr{B}(\bar{B}^0 \to \Lambda_c(2910)^+\bar{p})\mathscr{B}(\Lambda_c(2910)^+ \to \Sigma_c(2455)^0\pi^+) = (9.5 \pm 3.6 \pm 1.6) \times 10^{-6}$

$\mathscr{B}(\bar{B}^0 \to \Lambda_c(2910)^+\bar{p})\mathscr{B}(\Lambda_c(2910)^+ \to \Sigma_c(2455)^{++}\pi^-) = (12.4 \pm 3.5 \pm 1.0) \times 10^{-6}$

Observation of $\Omega(2012)^- \rightarrow \underbrace{\Xi(1530)}_{\rightarrow\ \Xi^-\pi^+}\bar{K}$

arXiv: 2207.03090





$\Upsilon(1,2,3S)$ dataset on Belle

Early search found no signal [1]. Improve the selection criteria and signal parameterization.

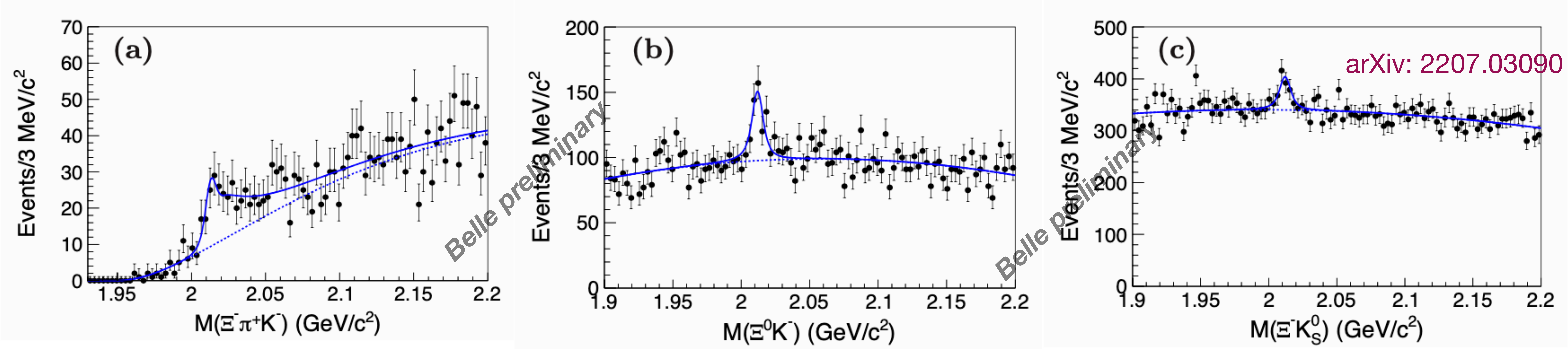
- Optimized mass window: $M(\Xi^-\pi^+) < 1.517\ \mathrm{GeV}/\mathrm{c}^2$ to remove $\Xi(1530)$ not from $\Omega(2012)$.

Clear $\Omega(2012)^-$ signal could be seen on $M(\Xi^-\pi^+K^-)$.

Significance: 5.2σ after considering systematic uncertainties

[1] Phys. Rev. D 100, 032006 (2019).

Effective coupling measurements



arXiv: 2207.03090

Simultaneous fit to $M(\Xi^-\pi^+K^-)$, $M(\Xi^0K^-)$, and $M(\Xi^-K_S^0)$, signal described with Flatté:

$$T_n(M) = \frac{g_n k_n(M)}{|M - m_{\Omega(2012)} + \frac{1}{2}\sum_{j=2,3} g_j[\kappa_j(M) + ik_j(M)]|^2},$$

g_n is the effective coupling to the n-body final state, which are fitted to be:

$$g_3 = (41.1 \pm 35.8 \pm 6.0) \times 10^{-2} \text{ and}$$

$$g_2 = (1.7 \pm 0.3 \pm 0.3) \times 10^{-2}.$$

Branching fraction ratio: $\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}} = 0.97 \pm 0.24 \pm 0.07,$

consistent with molecular interpretation for $\Omega(2012)^-$

Quarkonium spectroscopy

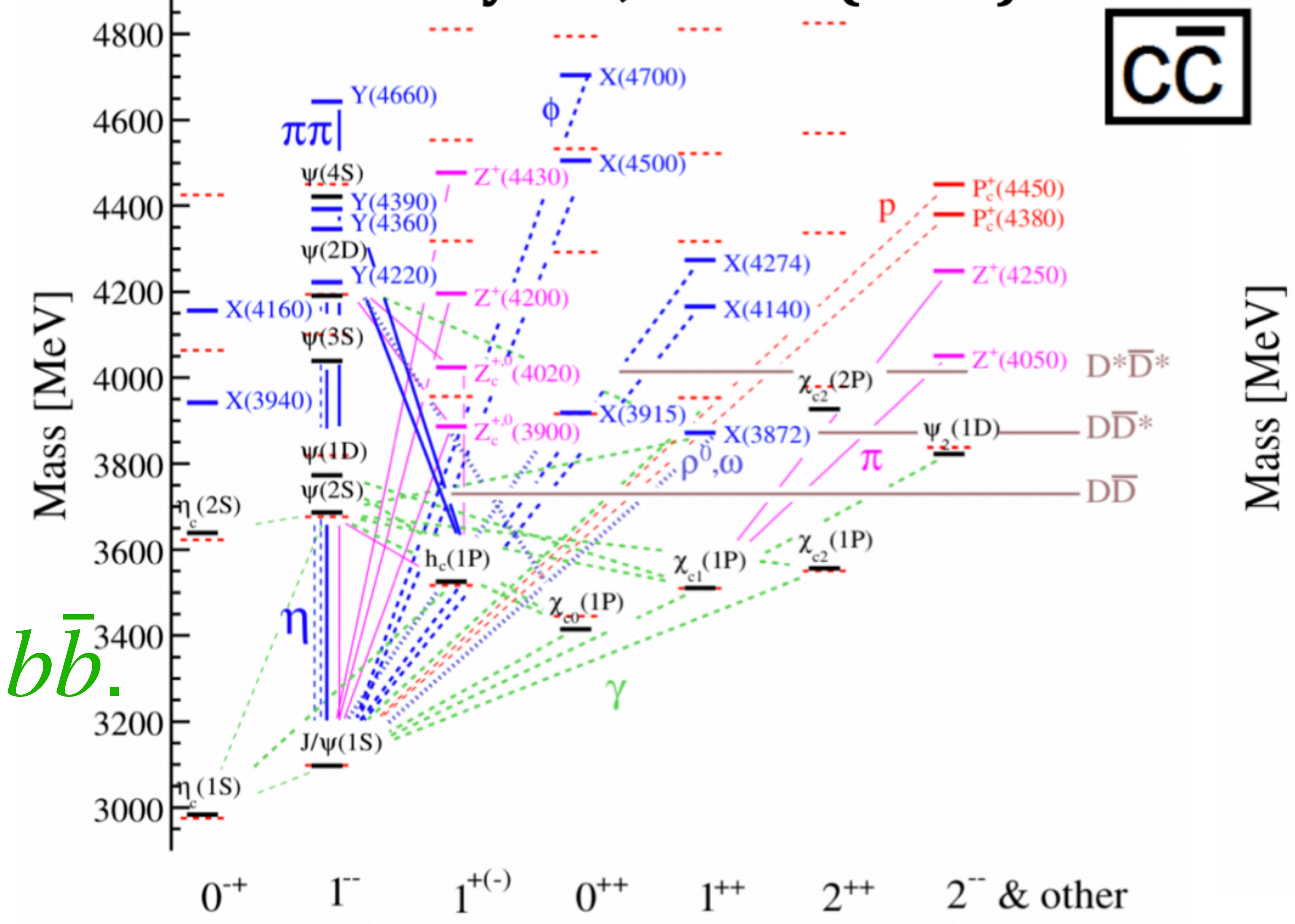
Below $D\bar{D}/B\bar{B}$ threshold:
  Good agreement!

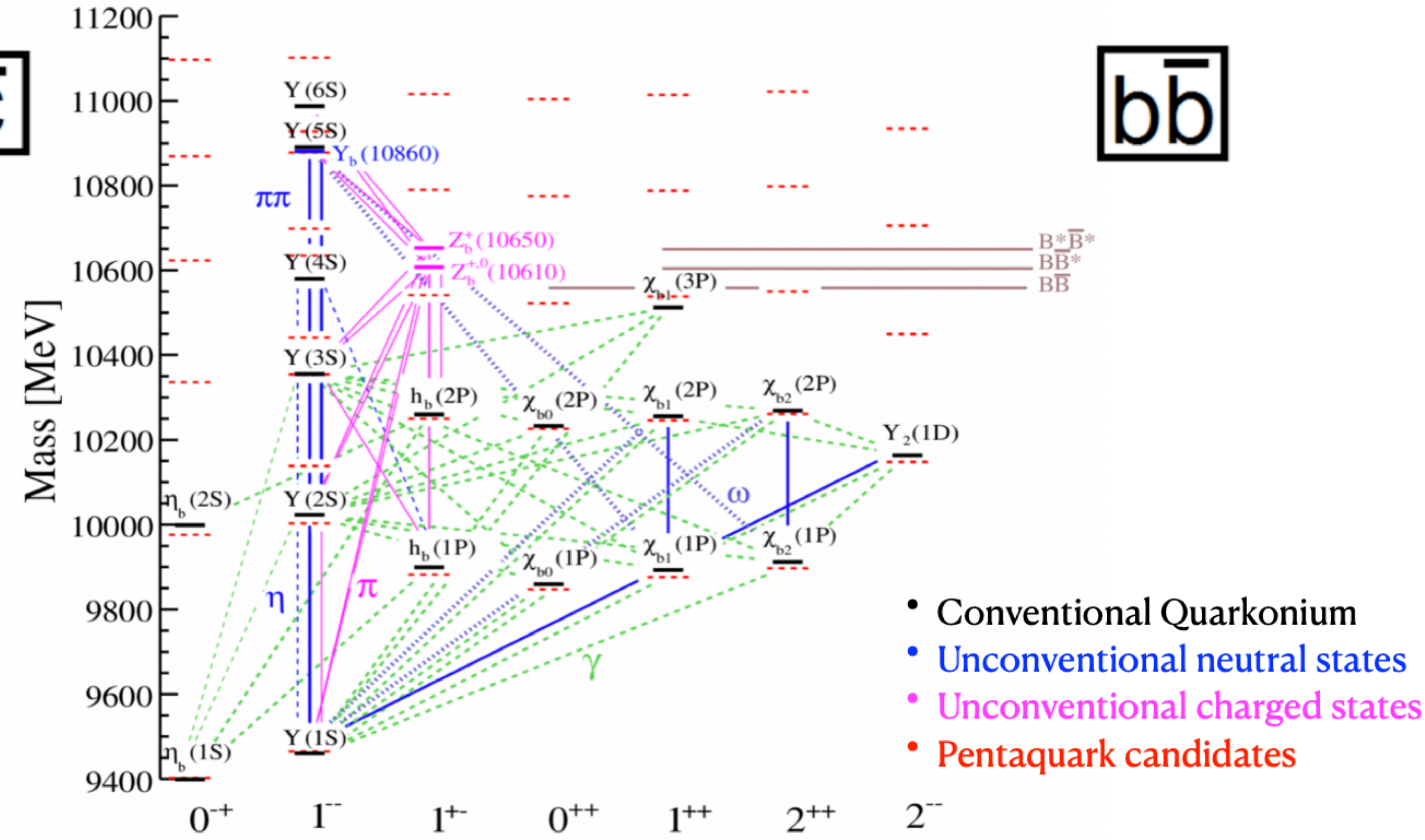
Above $D\bar{D}/B\bar{B}$ threshold:
  Exotic states!!

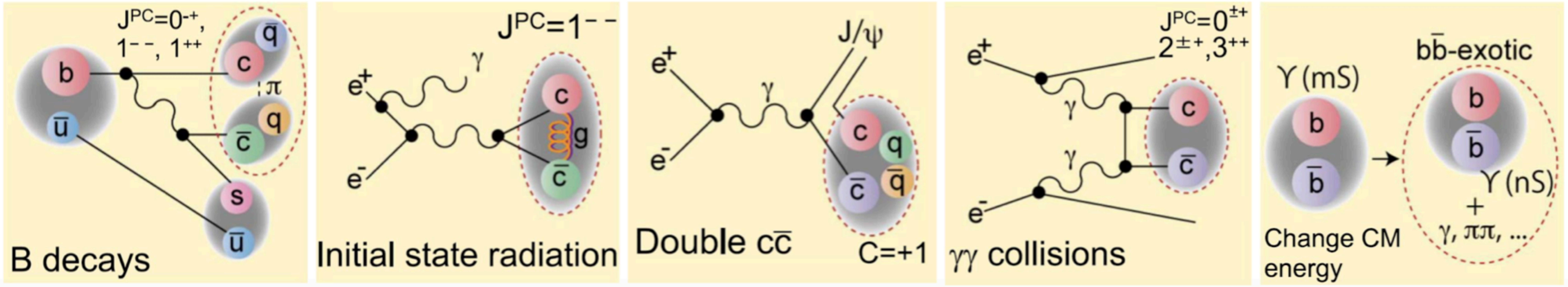
Parallel properties in $c\bar{c}$ and $b\bar{b}$.

Excellent experimental field!

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



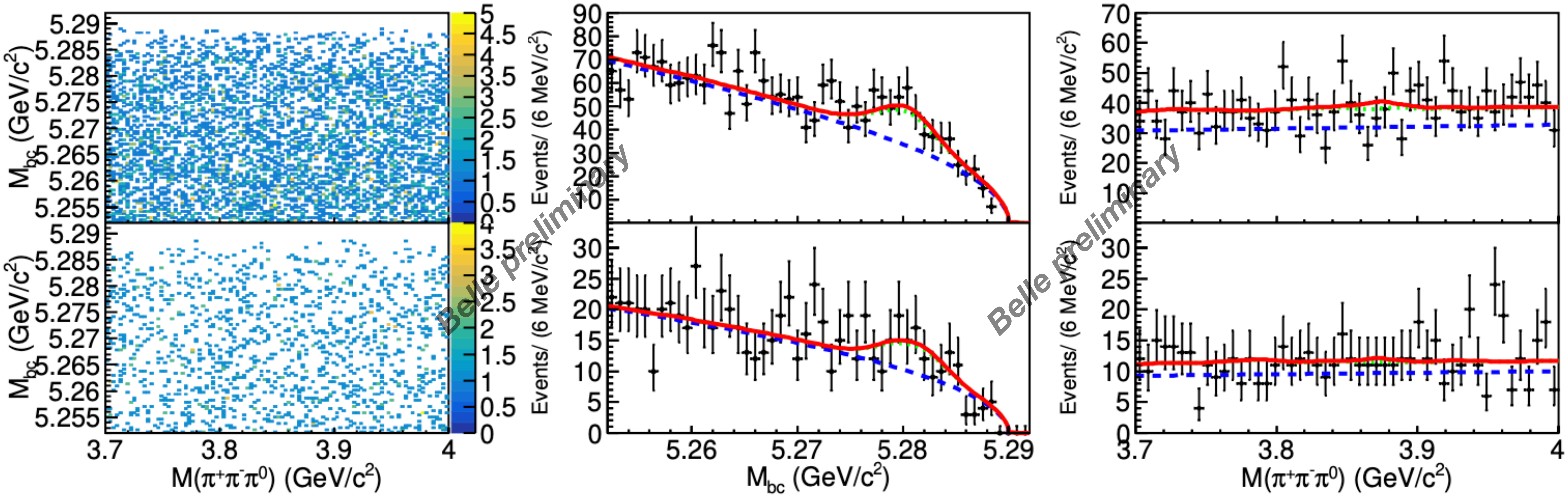




Search for $X(3872) \to \pi^+\pi^-\pi^0$ arXiv: 2206.08592

Based on 772×10^6 $B\bar{B}$ events on Belle, in $B \to KX(3872)$

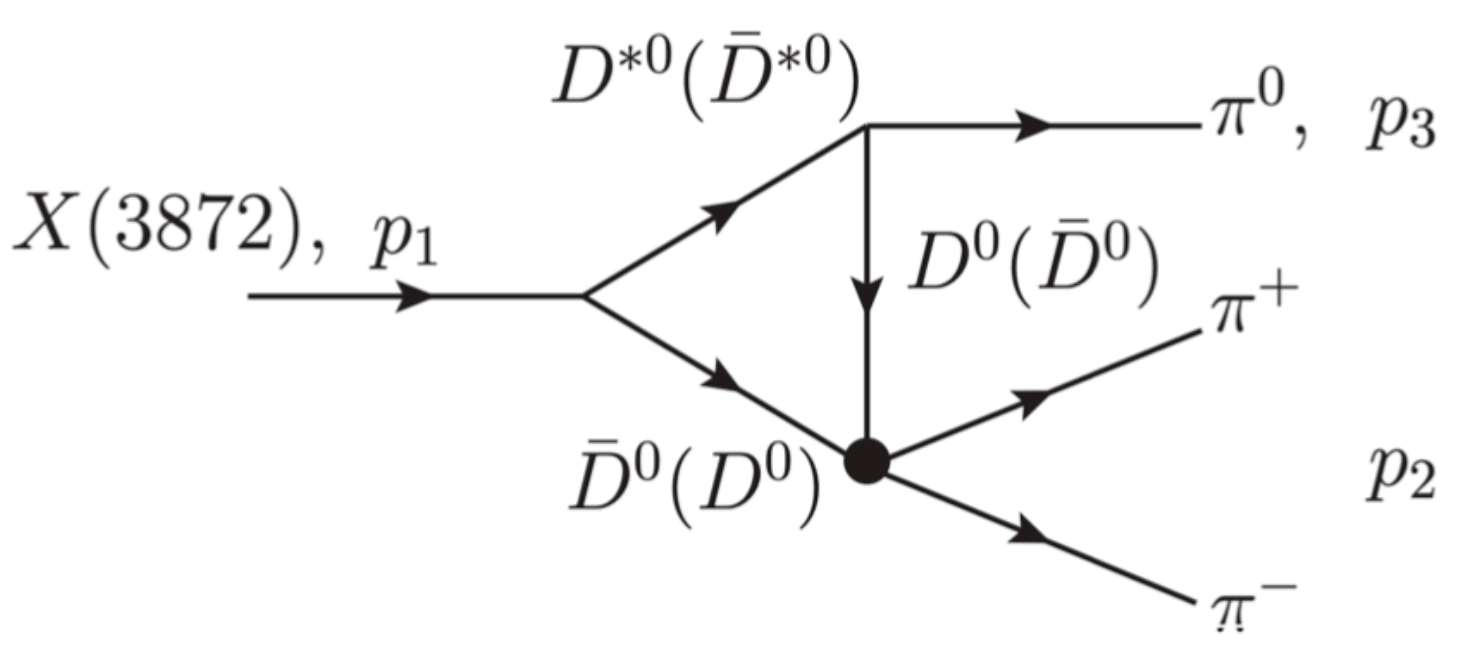
Signal is searched for in the assumption of $X(3872) \to \pi^+\pi^-\pi^0$ uniformly [*named as: case I*]

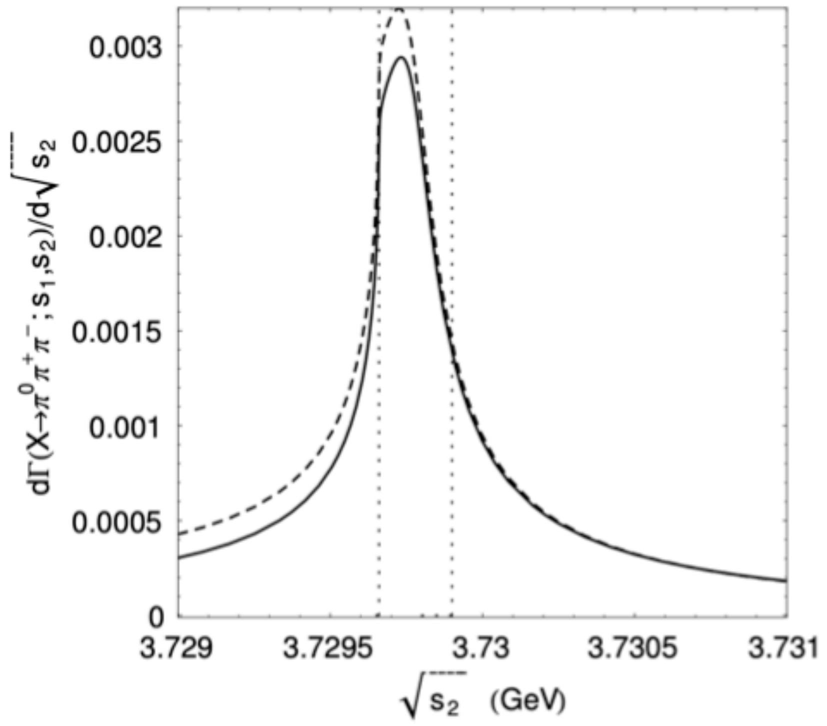


Upper limit is estimated at 90% C.L. $< 1.3\,\%$.

Quote $\mathscr{B}(B \to KX(3872))$ from ***PRD 100, 094003 (2019)***.

Phys. Rev. D 99, 116023 (2019)

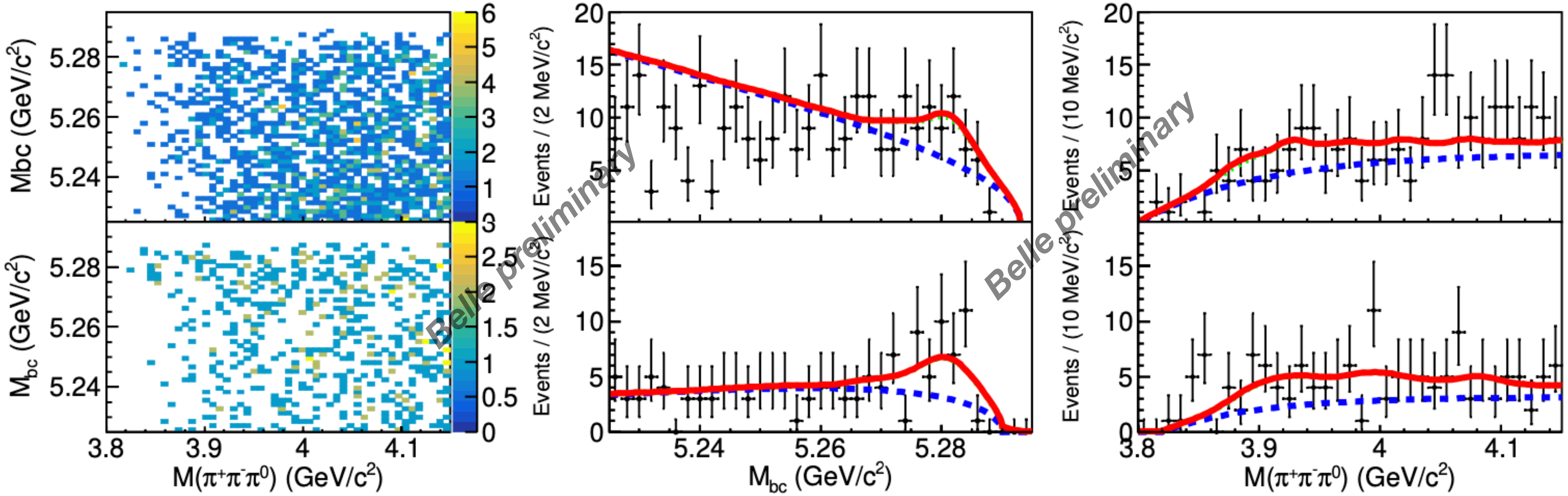




BF is predicted at the level of $10^{-3} \sim 10^{-4}$

Mass of $\pi^+\pi^-$ accumulate around $M(D^0\bar{D}^0)$

Additional requirement [named as case II]:
$M(\pi^+\pi^-) \in [3.7,\ 3.75]\ \mathrm{GeV/c^2}$



Upper limit of the joint BF is also estimated:

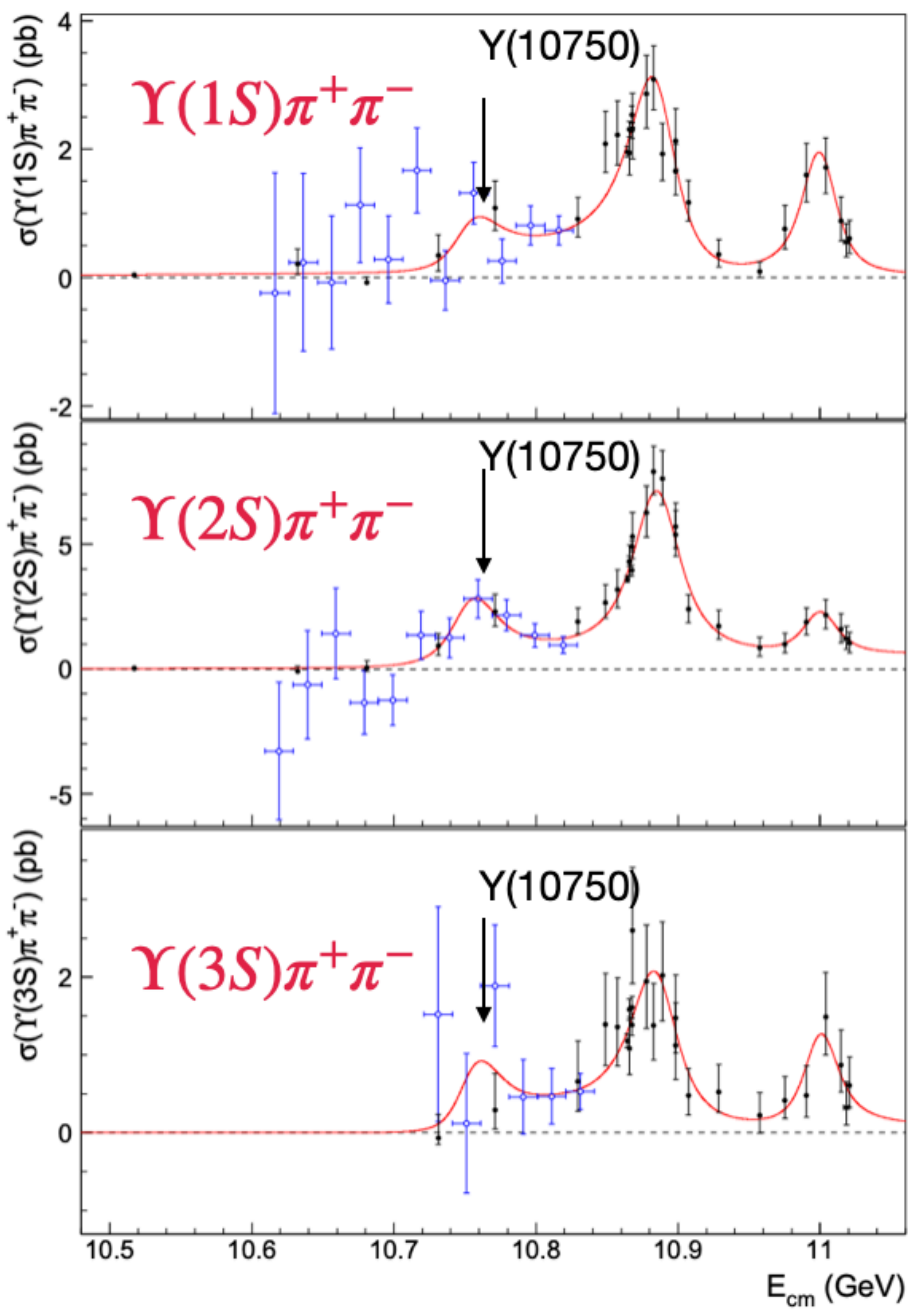
channel	case I	case II
$B^{\pm} \to K^{\pm}X(3872),\ X(3872) \to \pi^+\pi^-\pi^0$	$< 1.9 \times 10^{-6}$	$< 1.5 \times 10^{-7}$
$B^0 \to K^0X(3872),\ X(3872) \to \pi^+\pi^-\pi^0$	$< 1.5 \times 10^{-6}$	$< 1.8 \times 10^{-7}$
$X(3872) \to \pi^+\pi^-\pi^0$	$< 1.3\%$	$< 1.2 \times 10^{-3}$

Could be used to provide constraints on the triangle logarithmic singularity of $X(3872) \to D^0\bar{D}^{*0} \to D^0\bar{D}^0\pi^0$.

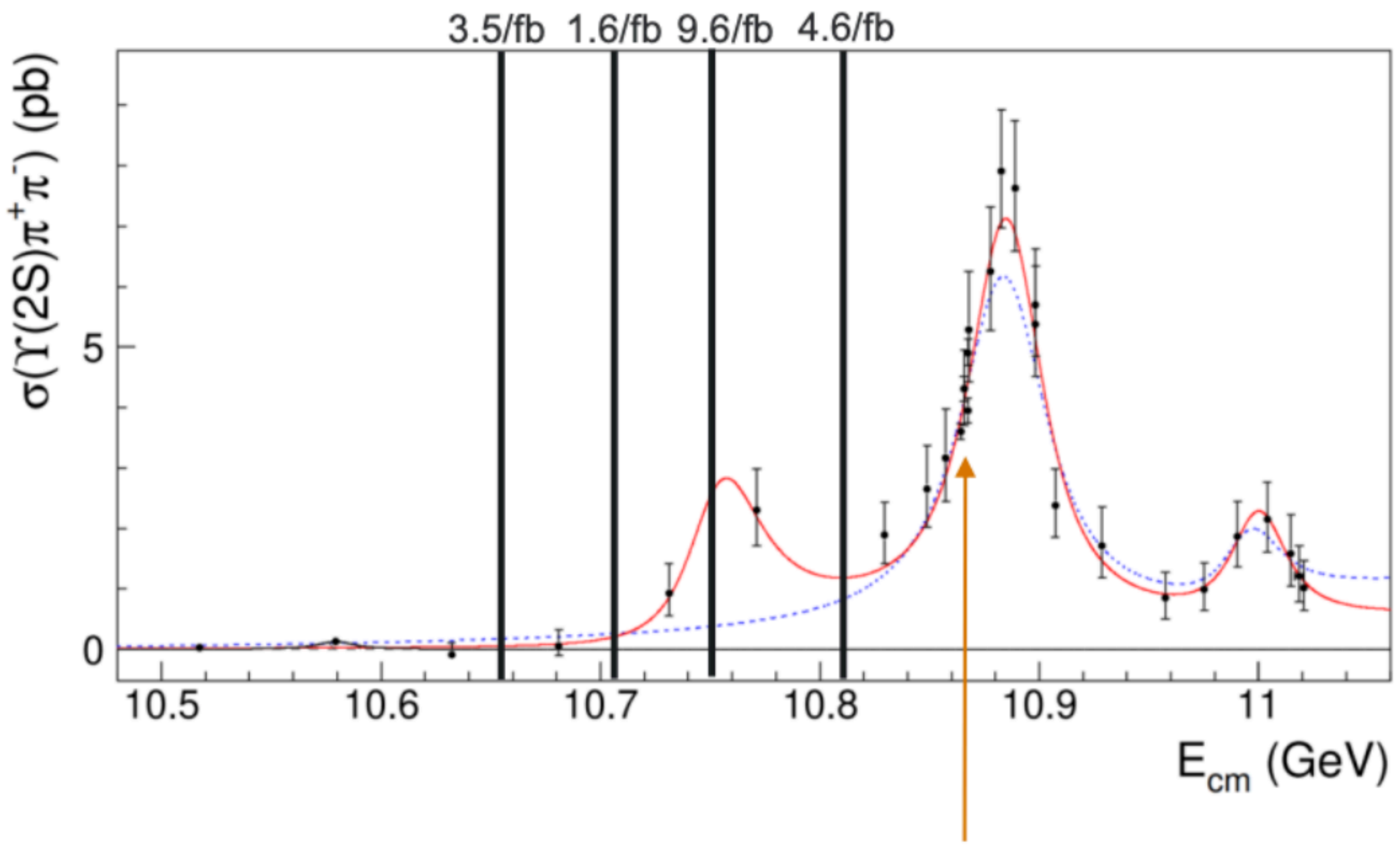
NEW from Belle II

Unique scan data near $\sqrt{s} = 10.75$ GeV

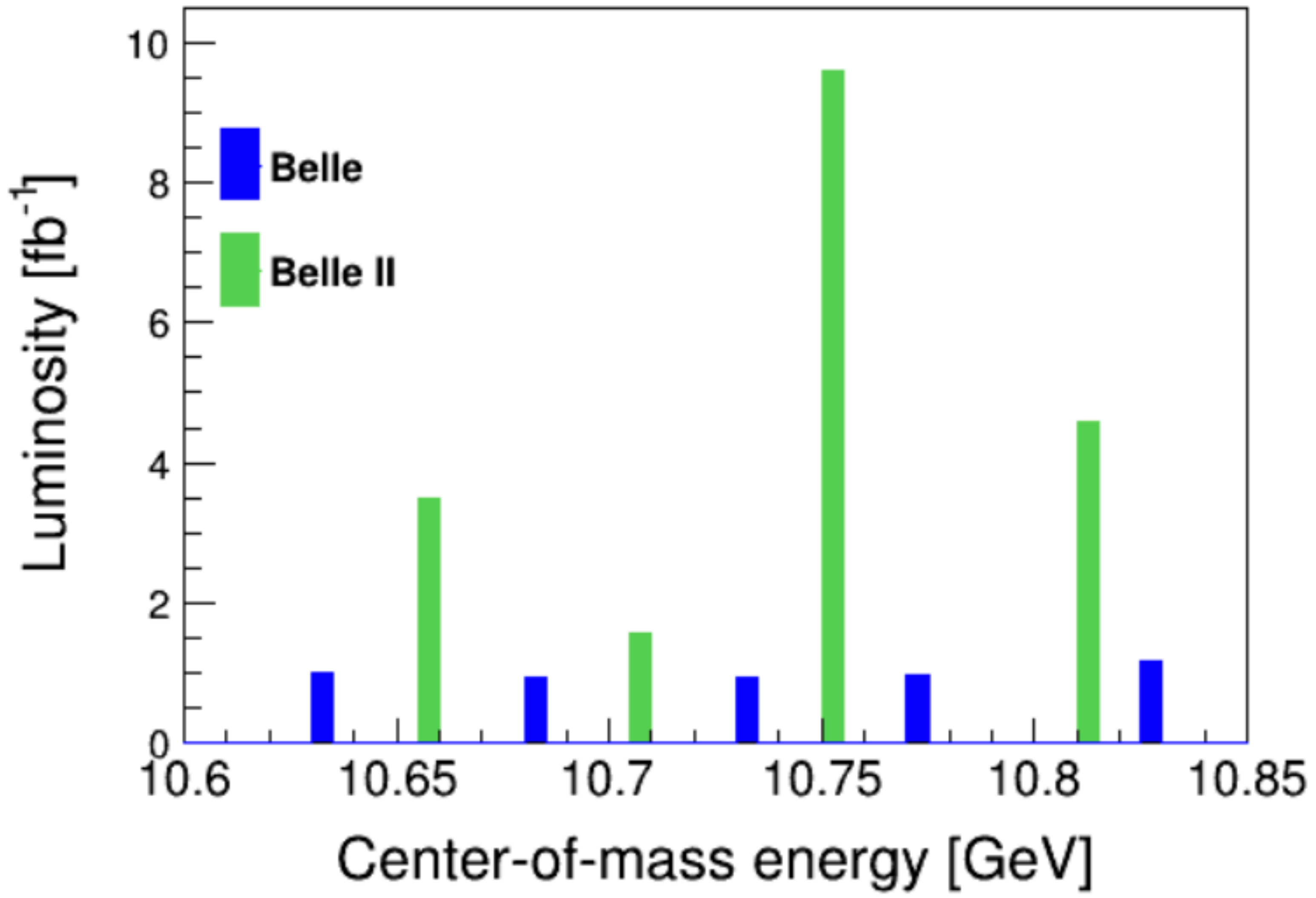
JHEP 1910, 220 (2019)



- In November 2021, Belle II collected 19fb^{-1} of unique data at energies above the $\Upsilon(4S)$: four energy scan points around 10.75 GeV
- Physics goal: understand the nature of the $Y(10753)$.

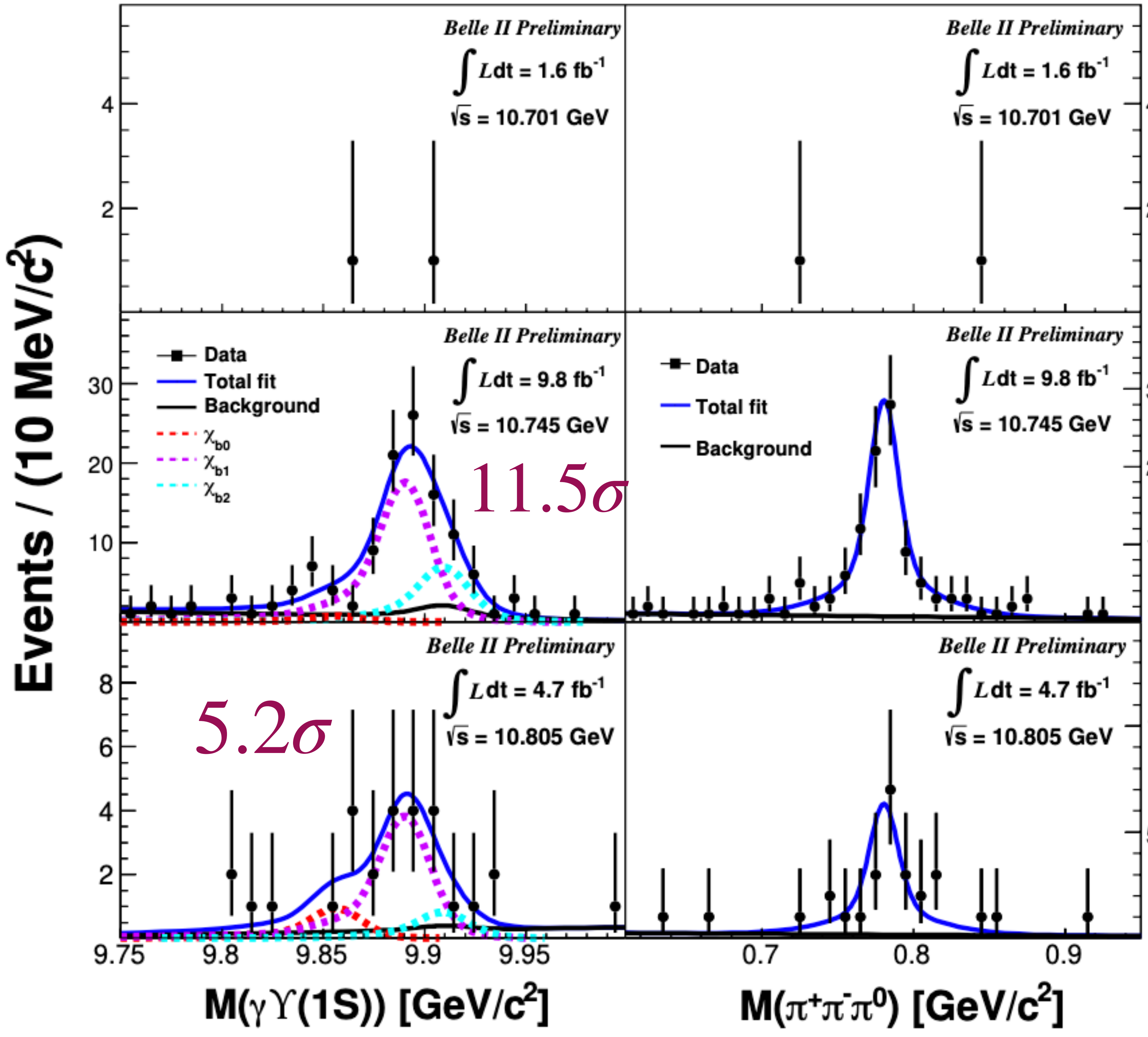


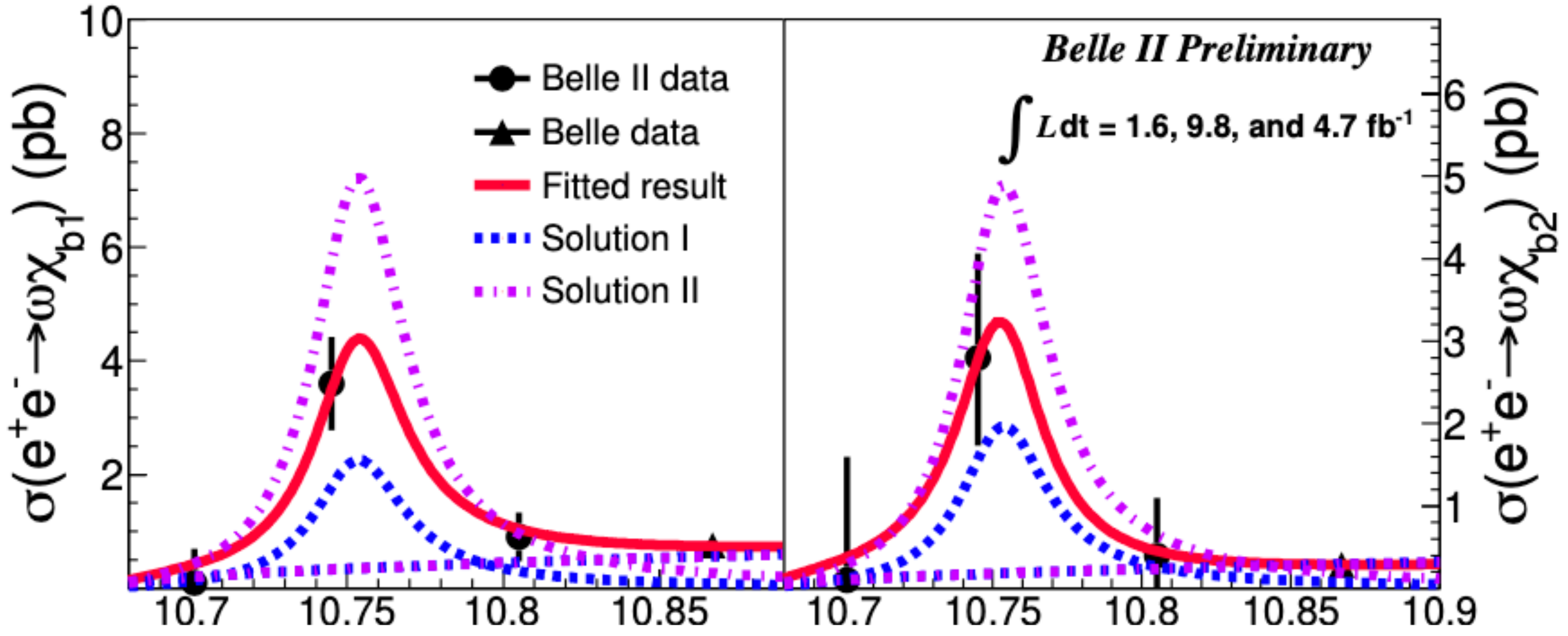
All points ~1/fb except these (~20+/fb)



Observation of $Y(10750) \to \omega\chi_{bJ}$ in $e^+e^- \to \gamma\omega\Upsilon(1S)$

With the ***new*** scan data around $\sqrt{s} = 10.75\ \mathrm{GeV}$





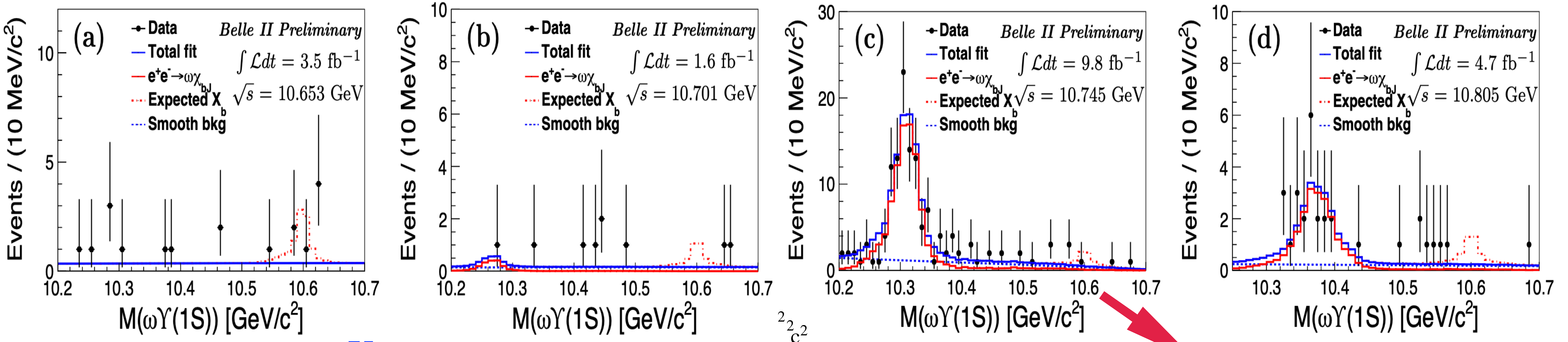
$\Gamma_{ee}\mathscr{B}_f$	Solution I	Solution II
$\Gamma_{ee}\mathscr{B}(\Upsilon(10753) \to \omega\chi_{b1})$	$(0.63 \pm 0.39 \pm 0.20)$ eV	$(2.01 \pm 0.38 \pm 0.76)$ eV
$\Gamma_{ee}\mathscr{B}(\Upsilon(10753) \to \omega\chi_{b2})$	$(0.53 \pm 0.46 \pm 0.15)$ eV	$(1.32 \pm 0.44 \pm 0.55)$ eV

- $\dfrac{\Gamma_{ee}\mathscr{B}(\Upsilon(10753) \to \omega\chi_{b1})}{\Gamma_{ee}\mathscr{B}(\Upsilon(10753) \to \omega\chi_{b2})} \sim 1.0$ agrees with the expectation for HQET[3]
- $\dfrac{\Gamma_{ee}\mathscr{B}(\omega\chi_{b1/2})}{\Gamma_{ee}\mathscr{B}(\pi^+\pi^-\Upsilon(2S))^{[2]}} \sim 1.5$ for $\Upsilon(10753)$ and ~ 0.1 for $\Upsilon(10870)$

[1]PRL 113, 142001(2014); [2]. JHEP 10, 220(2019); [3]. arXiv:hep-ph/9908366;

Implying a $\omega\chi_b$ hadro-bottomonium interpretation of $Y(10750)$

Search for $X_b \to \omega\Upsilon(1S)$ in $e^+e^- \to \gamma\omega\Upsilon(1S)$



- No significant X_b signal is observed.
- The peaks are the reflections of $e^+e^- \to \omega\chi_{bJ}$

From simulated events with $M(X_b) = 10.6$ GeV/c^2
The yield is fixed at the upper limit on 90% C.L.

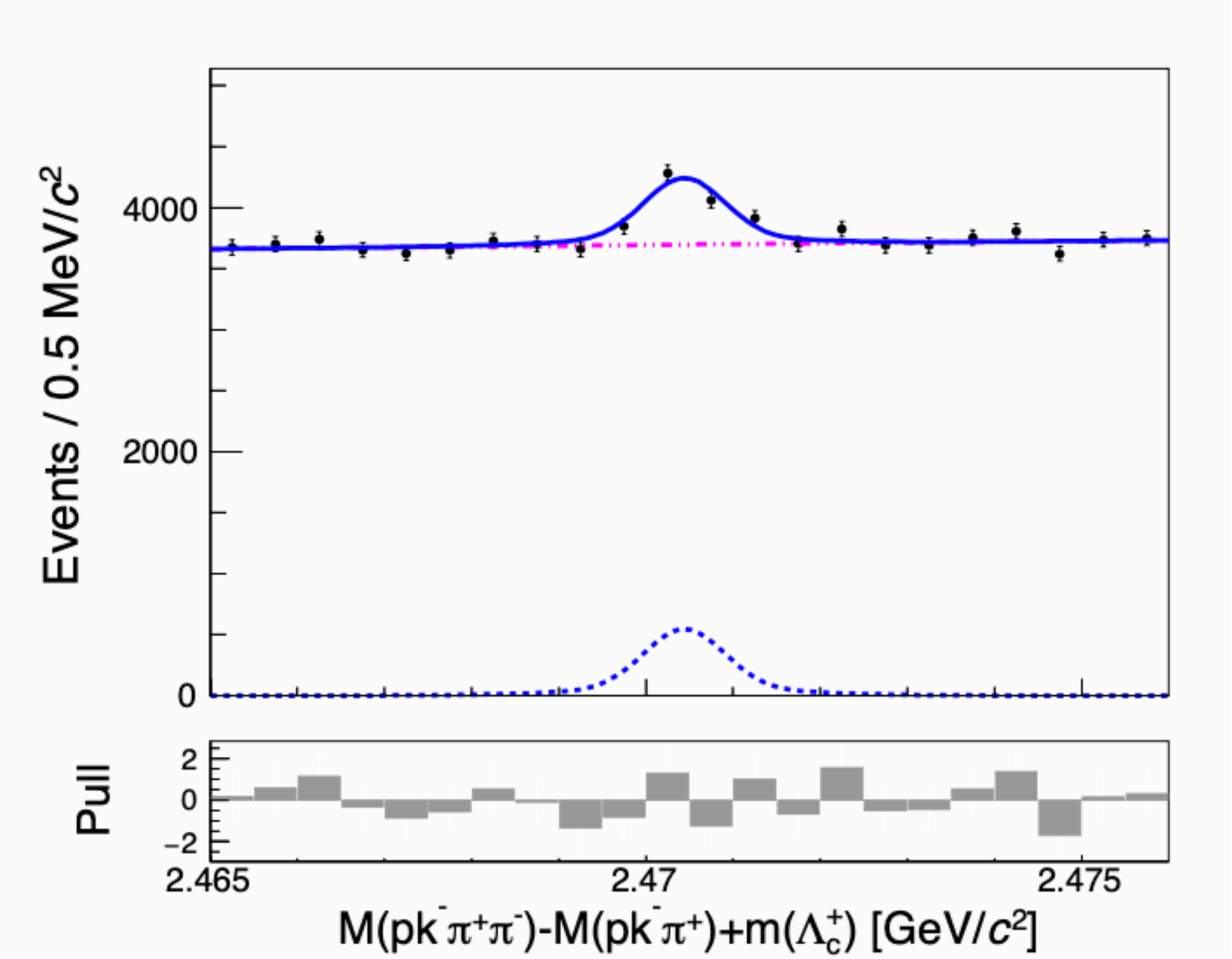
Upper limits of	$\sqrt{s}$ (GeV)	10.653	10.701	10.745	10.805
$\sigma_B(e^+e^- \to \gamma X_b)\cdot$	$M(X_b) = 10.6$ GeV/c^2	0.45	0.33	0.10	0.14
$\mathscr{B}(X_b \to \omega\Upsilon(1S))$	$M(X_b) = 10.45$ GeV/c^2	0.14	0.25	0.06	0.08
(pb) at 90% C.L.	$M(X_b) = 10.65$ GeV/c^2	0.54	0.84	0.14	0.36

Summary and outlook

- Belle and Belle II provide unique and fertile physics environment.
- Even a decade after data taking finished, the Belle experiment is producing interesting and important results.
- Belle II, the next generation B-factory, can make significant impacts in spectroscopy.
  - Precise measurement;
  - Spin-parities, transitions, and quantum numbers determination;
  - New decays searching;
  - Prediction/model/theory testing
  - …
- Belle II with $> 400\ \mathrm{fb}^{-1}$ data, including unique $\Upsilon(10750)$ scan data, can already provide physics output on the level of its predecessors.

Back up

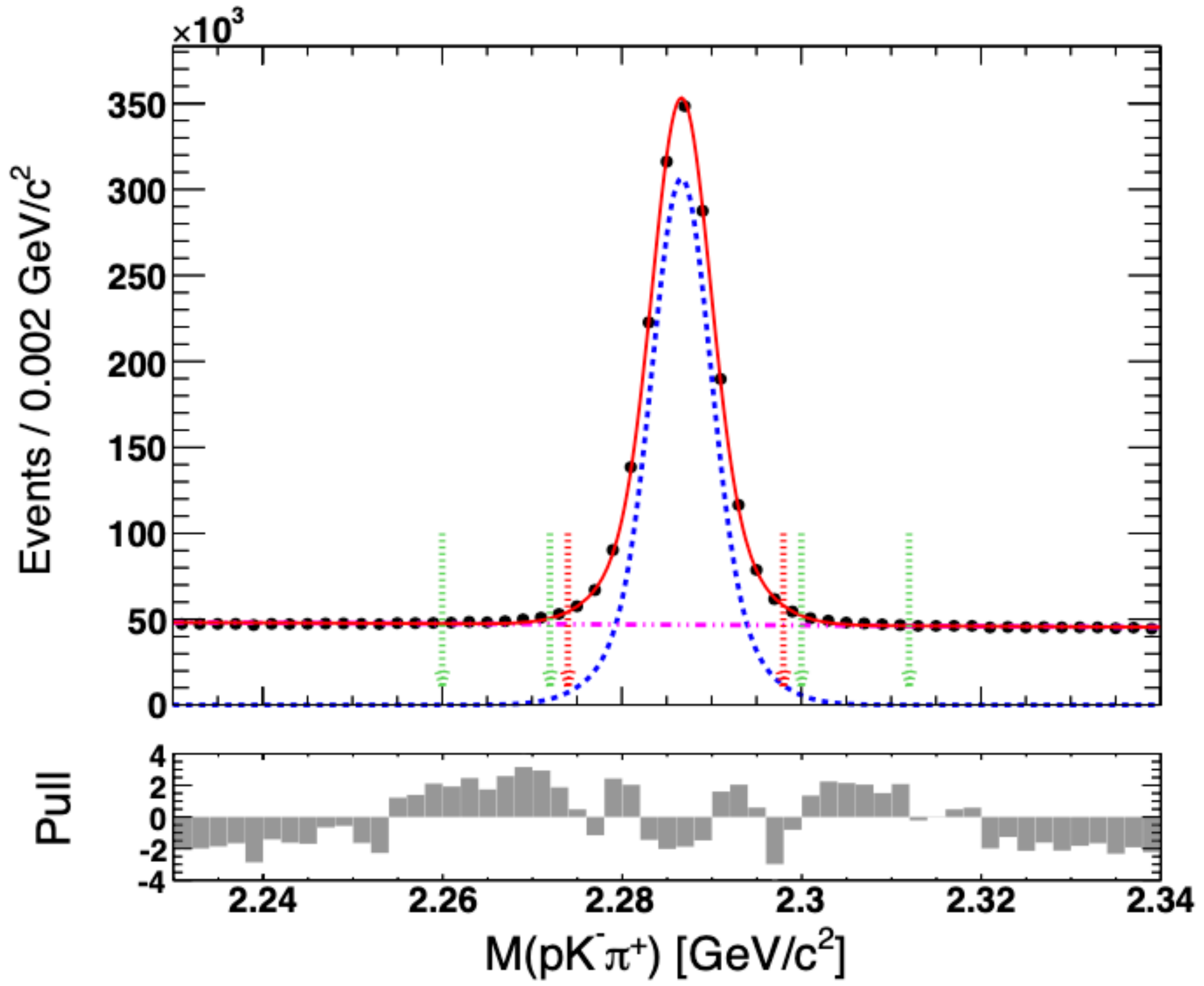
Measurement of $\Xi_c^0 \to \Lambda_c^+ \pi^-$

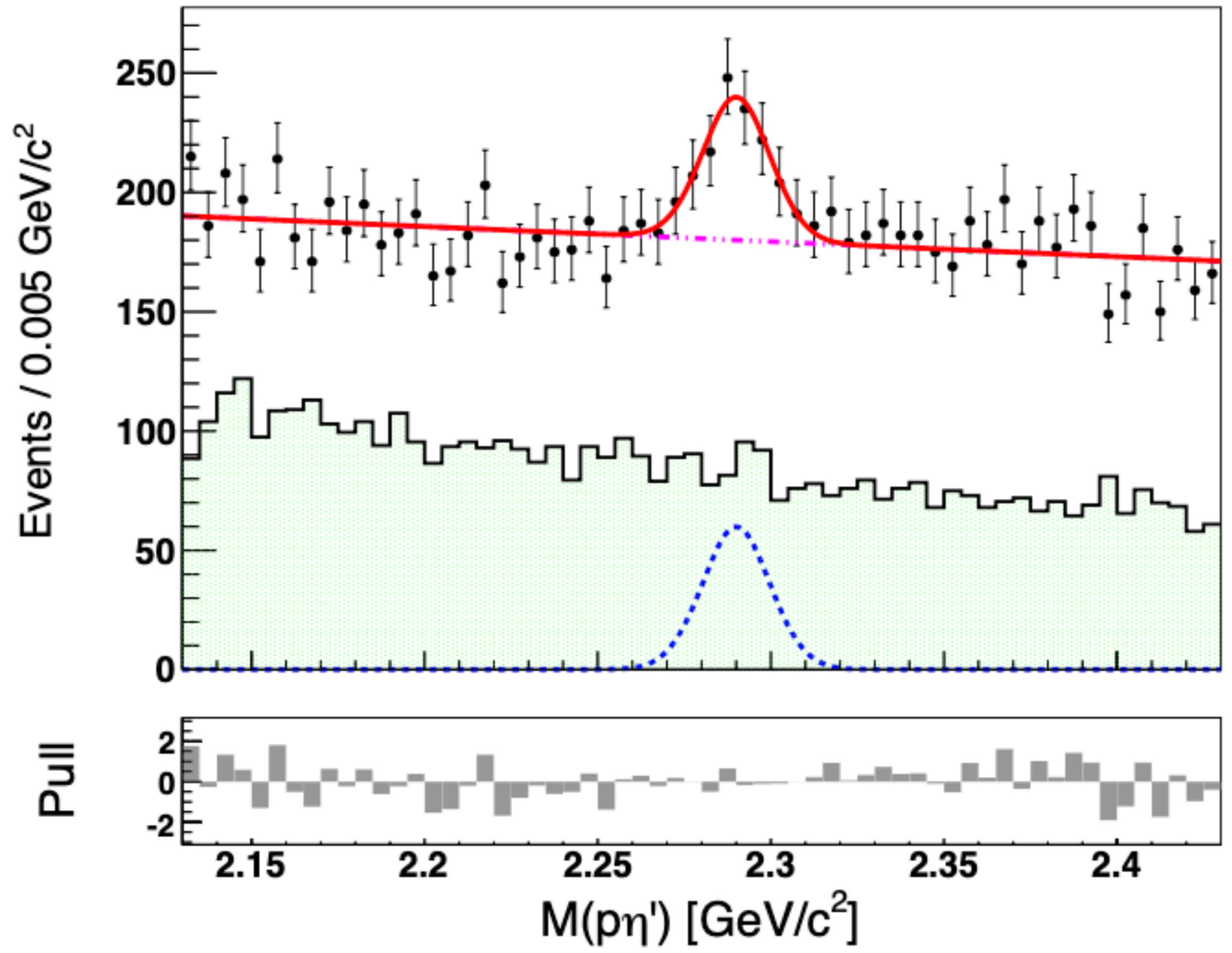


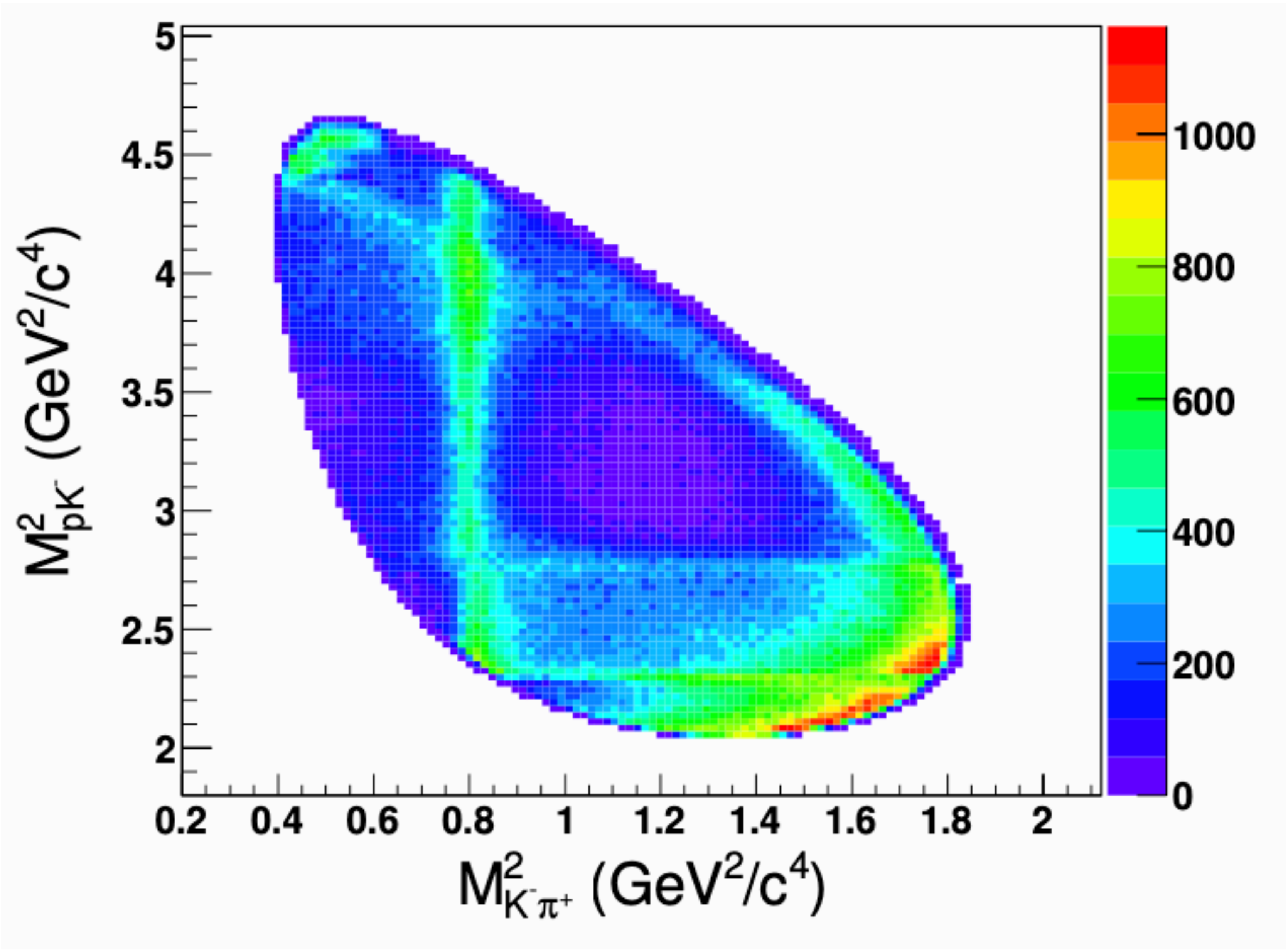
$$\frac{\mathcal{B}(\Xi_c^0 \to \Lambda_c^+ \pi^-)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} = \frac{N_{\Lambda_c \pi} \times \epsilon_{\Xi\pi}^{\mathrm{ref}} \times \mathcal{B}(\Xi^- \to \Lambda \pi^-) \times \mathcal{B}(\Lambda \to p\pi^-)}{N_{\Xi\pi} \times \epsilon_{\Lambda_c \pi}^{\mathrm{sig}} \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)}$$
$$= 0.38 \pm 0.04(\mathrm{stat.}) \pm 0.04(\mathrm{syst.}),$$

arXiv: 2206.08527

Measurement of $\Lambda_c^+ \to p\eta'$







$$\frac{\mathcal{B}(\Lambda_c^+ \to p\eta')}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (7.54 \pm 1.32 \pm 0.73) \times 10^{-3},$$

arXiv: 2112.14276