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Recent Belle results on (charmed) baryons and Belle II prospects of baryons

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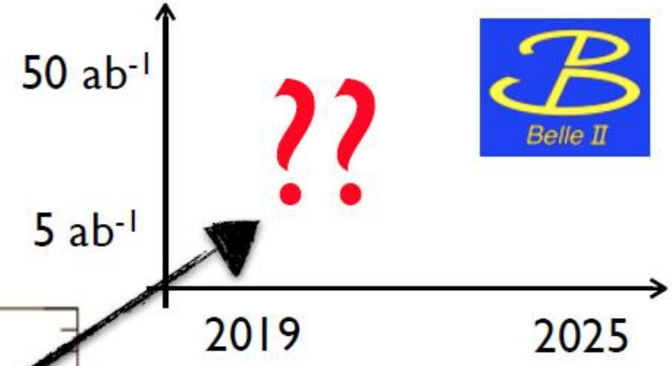
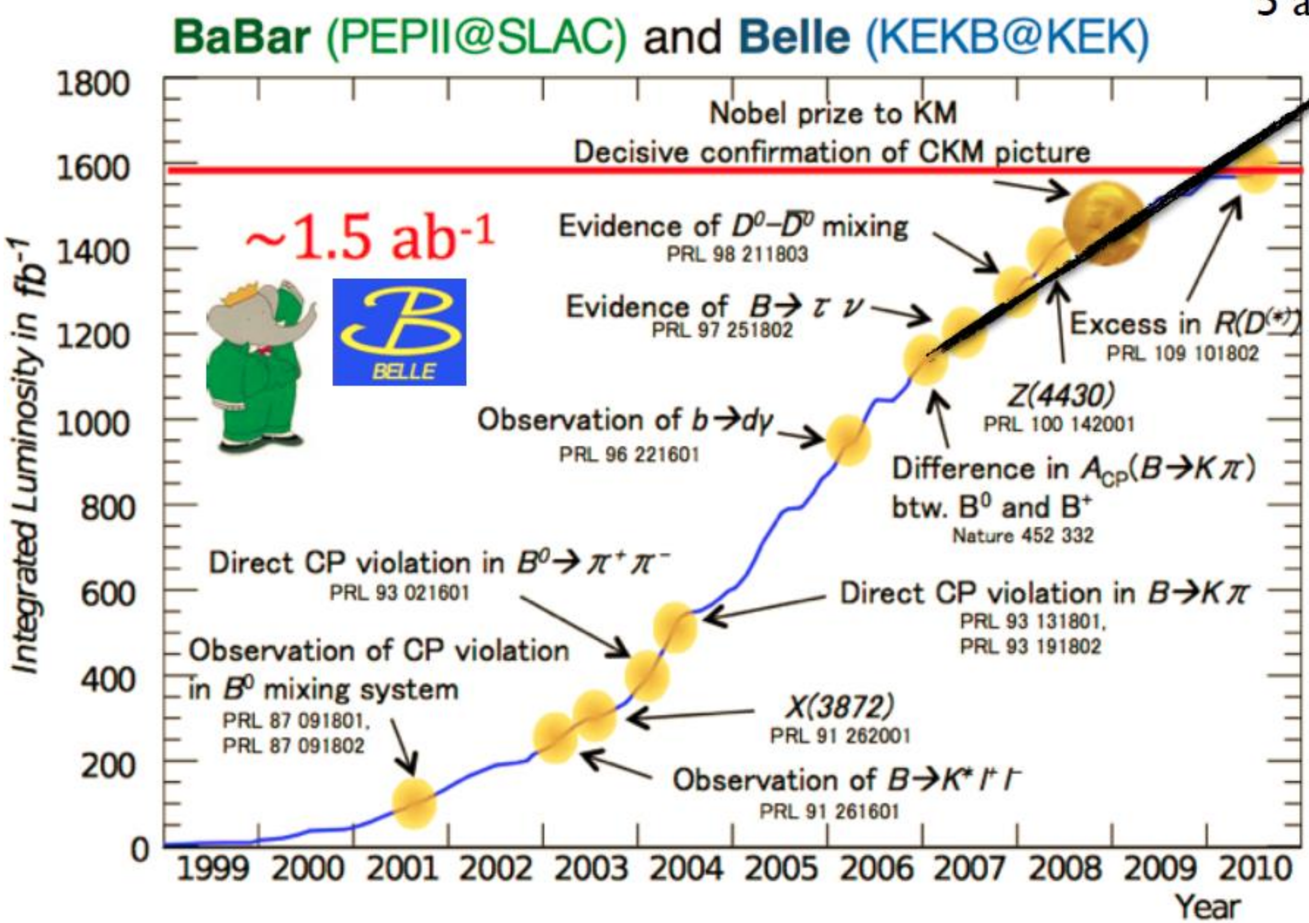
Outline

- Introduction
- Singly (Charmed) Baryon results at Belle
- Belle II status
- Prospects of baryon study at Belle II
- Summary

B-factories in the last decade





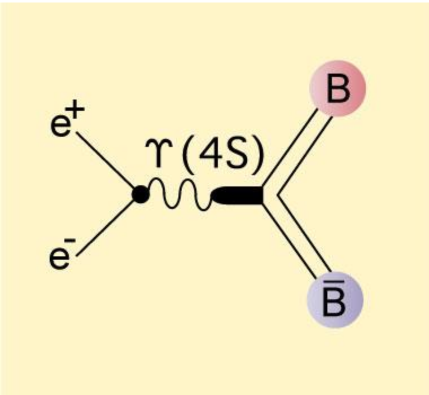
- Belle and BABAR have produced a large number of important results, since the beginning of their data taking
- Competition between the two experiments has helped in pulling out the best from the two datasets

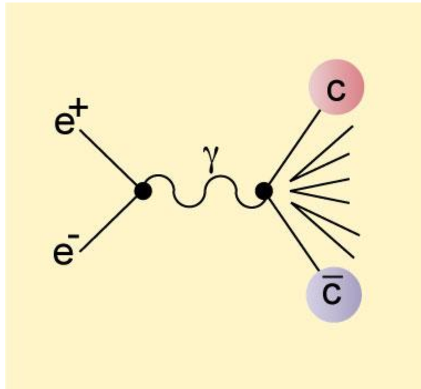
The Physics of B factories
EPJC 74, 3026 (2018)

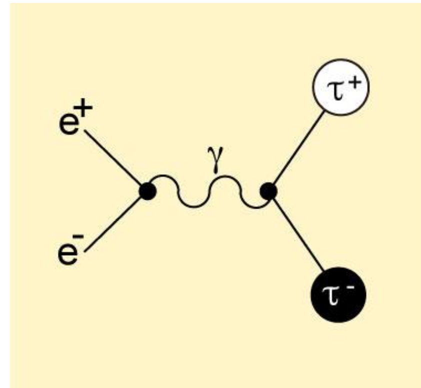
Belle II will provide a significantly larger data sample (x50 Belle) that will allow to continue the investigation with a much more powerful instrument

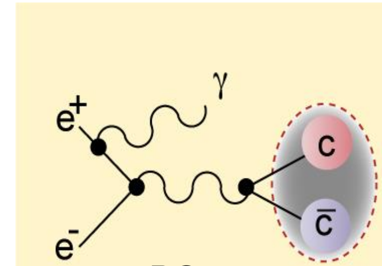
arXiv:1808.10567

The Physics Program





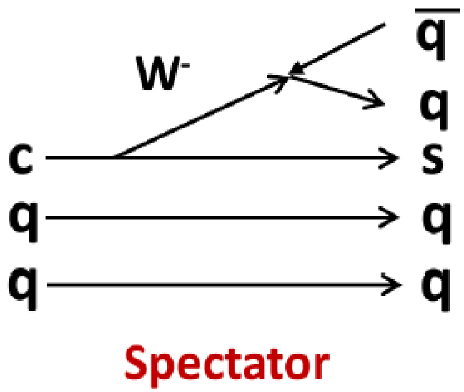


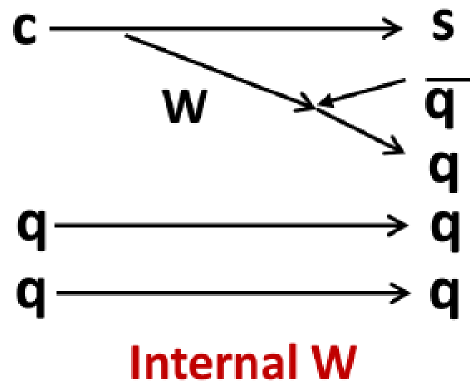


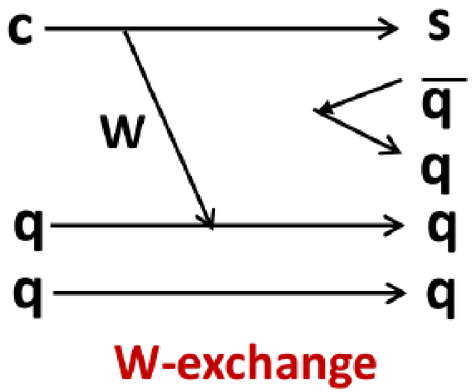
$J^{PC}=1^{--}$.
Initial state radiation

- a (Super) B-factory (~1.1 x 10^9 $B\bar{B}$ pairs per ab^{-1});
- a (Super) charm factory (~1.3 x 10^9 $c\bar{c}$ pairs per ab^{-1});
- a (Super) τ factory (~0.9 x 10^9 $\tau^+\tau^-$ pairs per ab^{-1});
- thanks to the Initial State Radiation, we can effectively scan the range [0.5 – 10] GeV and measure the $e^+e^- \rightarrow$ light hadrons cross-section very precisely;
- finally we can exploit the clean e^+e^- environment to probe the existence of exotic hadrons, dark photons/Higgs, light Dark Matter particles, …

The Charmed Baryon Physics

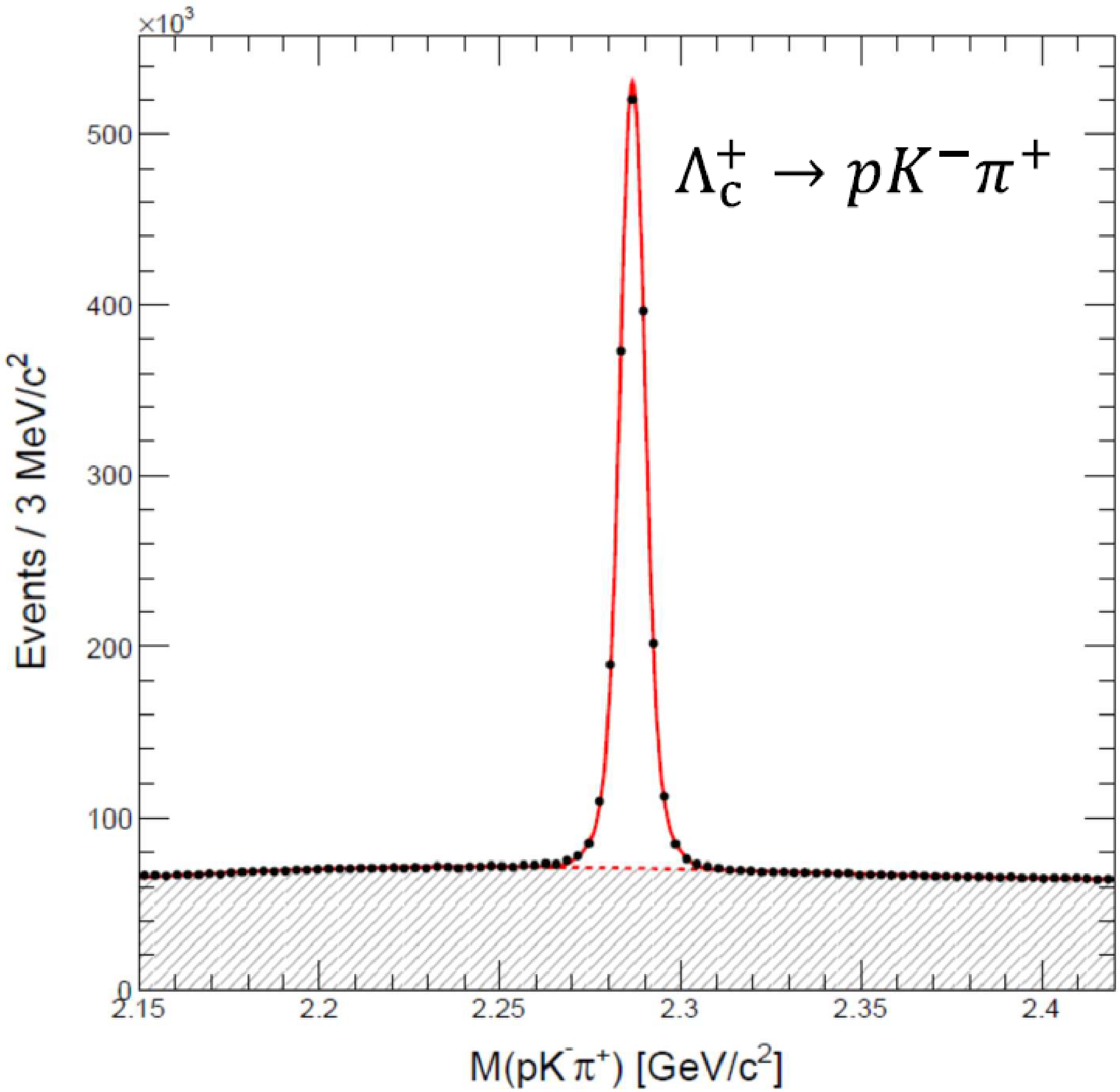


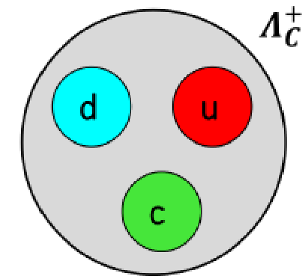




- The weak decay of charmed baryon has not been understood well.
- Three diagrams contribute in the tree level, but their strengths are not known.
- Ground state charm baryon is a good laboratory for studying strange baryons as decay proceed via $c \to s$ transition.
- Belle has collected $\sim 1\ \mathrm{ab}^{-1}\ \mathrm{e}^+\mathrm{e}^-$ data samples (mainly at $\Upsilon(4S)$).
  - $10^9\ e^+e^- \to c\bar{c}$ samples
  - $7.7 \times 10^8\ B\bar{B}$ samples
- Huge data sample enable to study various charmed baryons.

Huge statistics, good quality





> 1 M events reconstructed

Resolution:
< 10 MeV FWHM

S/N ~ 10

$\Gamma(\Lambda_c \to p^+K^-\pi^+)/\Gamma_{total}$		
$5.84 \pm 0.27 \pm 0.23$	BES3	2016
$6.84 \pm 0.24^{+0.21}_{-0.27}$	Belle	2014

Observation of an excited Ω^- baryon

Ω^- = s s s (S=-3, I=0) *PRL 121, 052003 (2018)*

1. Ω^- excited states have proved difficult to find

- Only one excited Ω^- states, $\Omega(2250)$, has been confirmed until now.
- In addition, the evidence for two other states of Ω^- were reported.
- These Ω^- excited states' masses are much higher than the ground state (>600MeV).

2. $\Omega^{*-} \to \Omega^- + \pi^0$ is highly suppressed since Ω^- is isospin zero

3. Preferred modes

- $\mathbf{\Omega^{*-} \to \Xi^- + K^0_S}$ ✓
- $\mathbf{\Omega^{*-} \to \Xi^0 + K^-}$ ✓
- low-lying states
- Analogous to $\Omega^0_c \to \Xi^+_c K^-$

[R. Aaij et al. PRL 118, 182001 (2017)]
[J. Yelton et al. PRD 97, 051102 (2018)]

Data sample	Luminosity(fb^{-1})	Events ($\times 10^8$)
$\Upsilon(1S)$	5.7	1.02
$\Upsilon(2S)$	24.9	1.58
$\Upsilon(3S)$	2.9	-

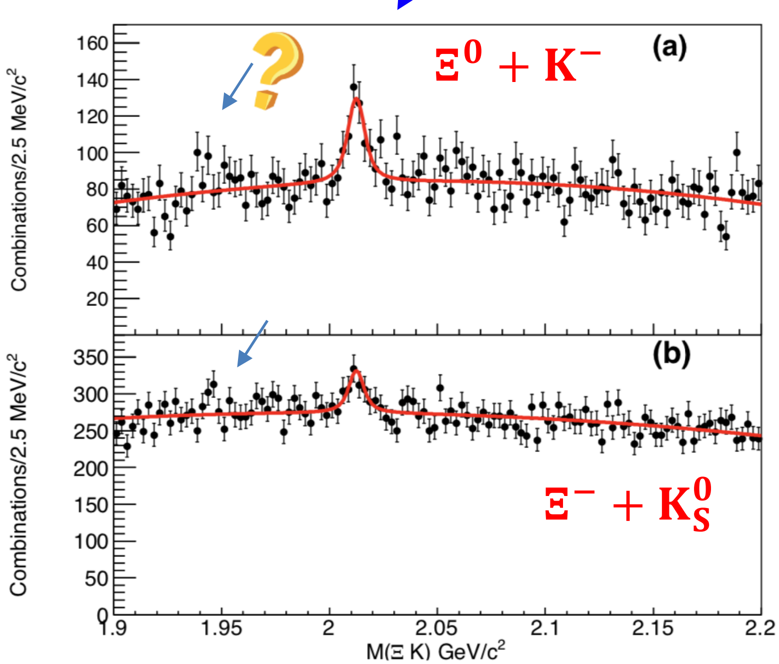
- The decays of these narrow resonances proceed via gluons.
- The production of baryon are enhanced.

Observation of an excited Ω^- baryon

Results & Summary

$\mathcal{R} = \frac{\mathcal{B}(\Omega^{*-}\to\Xi^0 K^-)}{\mathcal{B}(\Omega^{*-}\to\Xi^-\bar{K}^0)}$ =1.2±0.3

Data	Mode	Mass (MeV/c^2)	Yield	Γ(MeV)	χ^2/d.o.f.	n_σ
$\Upsilon(1S,2S,3S)$	$\Xi^0 K^-$, $\Xi^- K^0_S$ (simultaneous)	2012.4 ± 0.7	242 ± 48, 279 ± 71	$6.4^{+2.5}_{-2.0}$	227/230	8.3
$\Upsilon(1S,2S,3S)$	$\Xi^0 K^-$	2012.6 ± 0.8	239 ± 53	6.1 ± 2.6	115/114	6.9
$\Upsilon(1S,2S,3S)$	$\Xi^- K^0_S$	2012.0 ± 1.1	286 ± 87	6.8 ± 3.3	101/114	4.4
Other	$\Xi^0 K^-$	2012.4 (Fixed)	209 ± 63	6.4 (Fixed)	102/116	3.4
Other	$\Xi^- K^0_S$	2012.4 (Fixed)	153 ± 89	6.4 (Fixed)	133/116	1.7



PRL 121, 052003 (2018)

- The gap in the spectrum between the ground state and this excited state (~340 MeV) is smaller than other Ω^- excited states, which is more close to the negative-parity orbital excitations of many other baryons.
- The narrow width observed implies that the quantum number $J^P = \frac{3}{2}^-$ is preferable.

Theoretical interpretation for the $\Omega^*(2012)$

It is generally accepted that $\Omega^*(2012)$ is 1P orbital excitation of the ground state Ω baryon with three strange quark, whose quantum numbers are $J^P = \frac{3}{2}^-$.

From PRD 98, 056013 (2018)

Notably, the newly observed $\Omega^*(2012)$ is revealed as a KΞ(1530) hadronic molecule.

[PRD 98, 054009 (2018), PRD 98, 056013 (2018), arXiv:1807.02145, arXiv:1807.06485, arXiv:1807.06485]

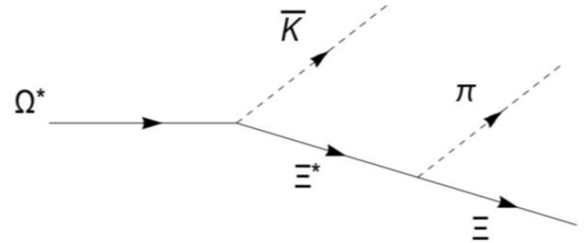


FIG. 1: The three-body decays of Ω(2012) in the $K\Xi(1530)$ molecular picture.

The $K\Xi\pi$ three-body component is largely dominant.

Mode	$J^P = \frac{3}{2}^-$ Ω(2012) ($K\Xi(1530)$) Widths (MeV)	Branch Ratio(%)
$K\Xi$	0.4	14.3
$K\pi\Xi$	2.4	85.7
Total	2.8	100.0

The number of expected Ω(2012) events at Belle

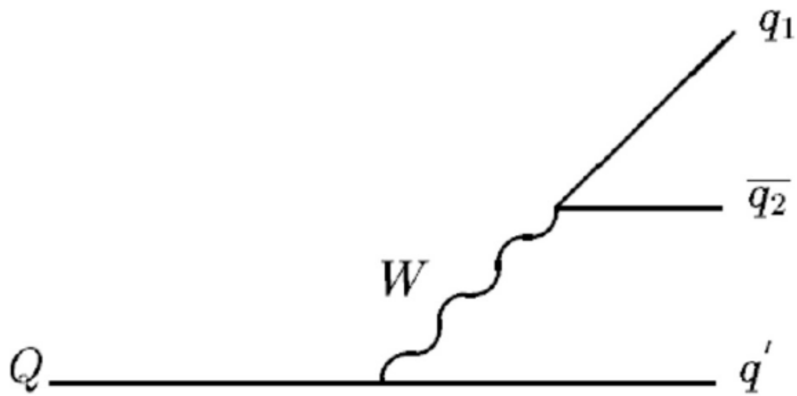
$$N^{\text{expected}} = N_{\Omega}^{\text{total}} \times \mathcal{B}^{\text{product}} \times \varepsilon \times \mathcal{B}(\Omega(2012) \to K\Xi/K\Xi\pi)$$

Channel	ε	$\mathcal{B}^{\text{decay}}$	$\mathcal{B}(\Omega(2012) \to K\Xi/K\Xi\pi)$	N^{obs}	N^{expected}
$\Xi^- K_S^0$	15.7%	$\mathcal{B}(K_S^0 \to \pi^+\pi^-) \times \mathcal{R}(\bar{K}^0 \to K_S^0)$	6.5%	279	-
$\Xi^0 K^-$	4.0%	$\mathcal{B}(\pi^0 \to \gamma\gamma)$	7.8%	242	
$\Xi^- K^- \pi^+$	9.4%	-	28.6%	-	**2091**
$\Xi^- K_S^0 \pi^0$	1.5%	$\mathcal{B}(K_S^0 \to \pi^+\pi^-) \times \mathcal{B}(\pi^0 \to \gamma\gamma) \times \mathcal{R}(\bar{K}^0 \to K_S^0)$	14.3%	-	**55**
$\Xi^0 K_S^0 \pi^-$	2.3%	$\mathcal{B}(\pi^0 \to \gamma\gamma) \times \mathcal{B}(K_S^0 \to \pi^+\pi^-) \times \mathcal{R}(\bar{K}^0 \to K_S^0)$	28.6%	-	**177**
$\Xi^0 K^- \pi^0$	0.8%	$\mathcal{B}(\pi^0 \to \gamma\gamma) \times \mathcal{B}(\pi^0 \to \gamma\gamma)$	14.3%	-	**82**

- $\mathcal{B}(\Omega(2012) \to K\Xi)$: $\mathcal{B}(\Omega(2012) \to K\Xi\pi)$ = 14.3 : 85.7 in Ref.[arxiv:1807.00997].
- $\mathcal{T}[\Xi^- \bar{K}^0]$: $\mathcal{T}[\Xi^0 K^-]$ = 1 : 1.2 from PRL121, 052003 (2018)
- The isospin analysis shows $\mathcal{T}[\Xi^- K^- \pi^+]$: $\mathcal{T}[\Xi^- \bar{K}^0 \pi^0]$: $\mathcal{T}[\Xi^0 \bar{K}^0 \pi^-]$: $\mathcal{T}[\Xi^0 K^- \pi^0]$ = 2:1:2:1
- In the calculation of $\mathcal{B}^{\text{decay}}$, the common $\mathcal{B}$, e.g., $\mathcal{B}(\Lambda \to p\pi^-)$ is cancelled. $\mathcal{R}(\bar{K}^0 \to K_S^0)$ = 0.5
- If theoretical predictions are correct, we will most likely observe $\Omega(2012)$ in mode $\Omega(2012) \to \Xi^- K^- \pi^+$.

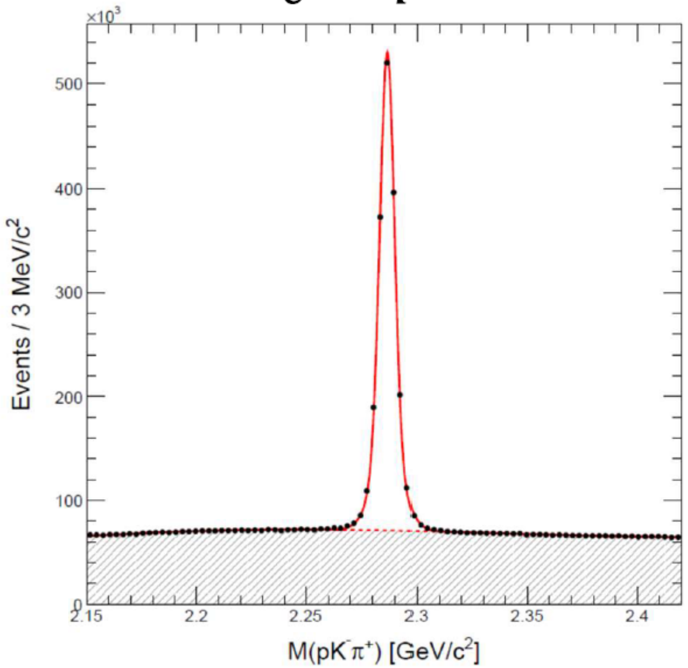
Double-Cabibbo suppressed decay $\Lambda_c^+ \to p\, K^+\pi^-$

- Weak decay amplitude of a charm quark
  - c → s: $\cos\theta_c$ ~ 1
    d: $\sin\theta_c$ ~ 0.23 ← Cabibbo suppression
  - At the same time, emitted W decays into a qqbar pair
    $u\bar{d}$: $\cos\theta_c$
    $u\bar{s}$: $\sin\theta_c$
- So, the decay $c \to d(u\bar{s})$ is twice suppressed
  → Doubly Cabibbo-suppressed decay
  - Naively, decay branch is $O(\tan^4\theta_c)$ ~ 0.28% smaller compared to counterpart ($c \to s(\bar{d}u)$)



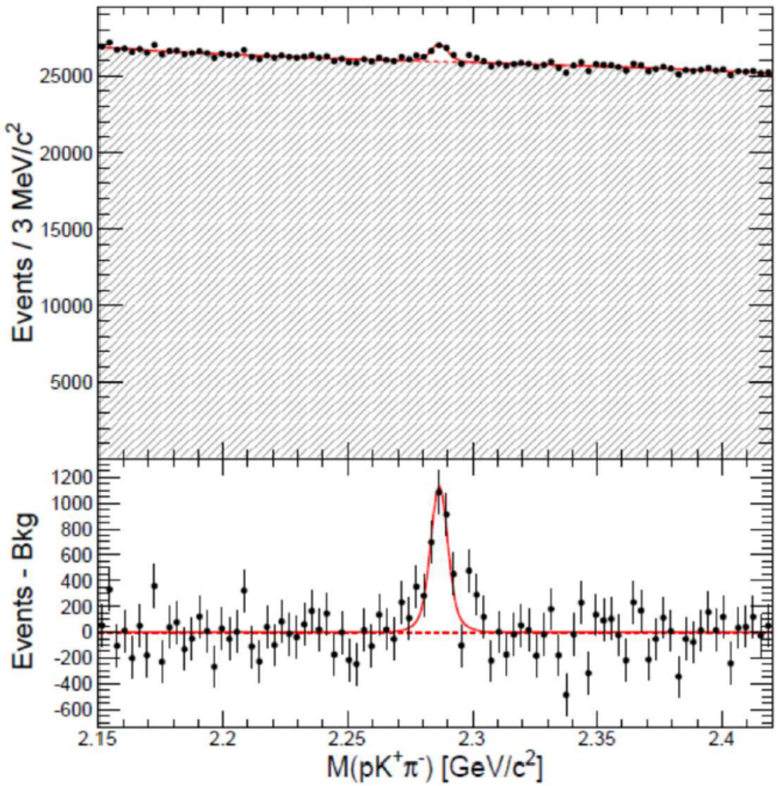
DCS decay $\Lambda_c^+ \to p\,K^+\pi^-$

CF: $\Lambda_c^+ \to pK^-\pi^+$



$(1.452 \pm 0.015) \times 10^6$ events

DCS: $\Lambda_c^+ \to pK^+\pi^-$



3587±380 events

Significant signal observed!

(significance 9.4σ)

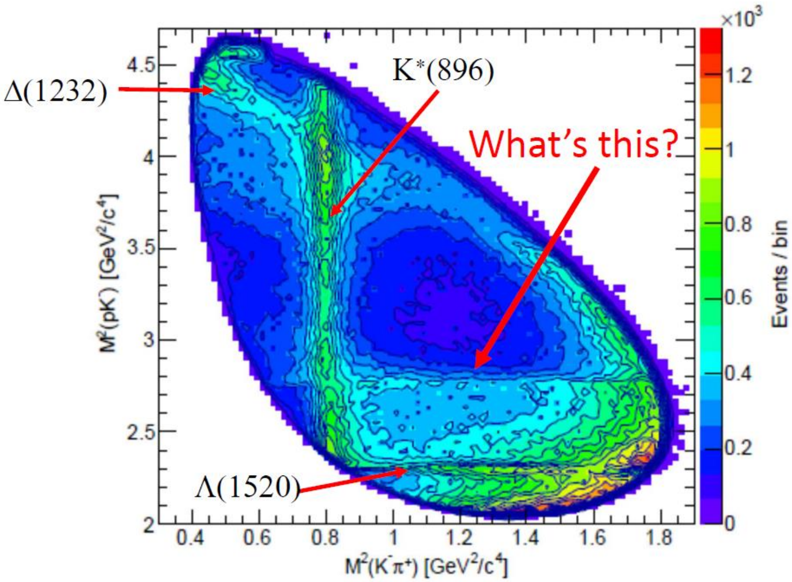
[PRL117, 011801]

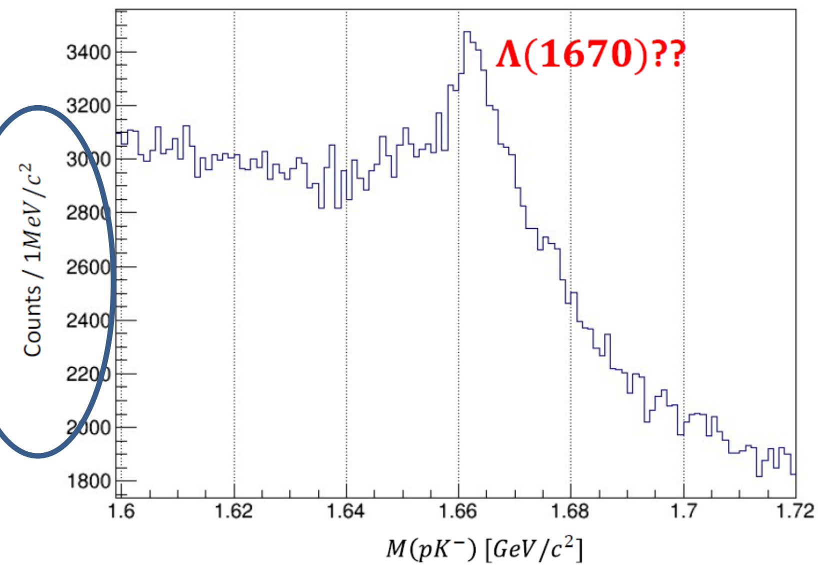
$$BR(\Lambda_c^+ \to pK^+\pi^-) = (1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$$

The first observation of DCS decay in Baryon

A new Λ excited states ?

Dalitz plot: $\Lambda_c^+ \to pK^-\pi^+$ [PRL117.011801]





- The peak position is ~1663 MeV, near the $\Lambda\eta$ threshold (1663.5 MeV)
- Width is ~10 MeV, significantly narrower than Λ, Σ resonances in this region
  - $\Lambda(1670)$: 25-50 MeV
  - $\Sigma(1660)$: 40-200 MeV
  - $\Sigma(1670)$: 40-80 MeV
  - $\Lambda(1690)$: ~60 MeV
- 2 independent groups claim there is a new narrow Λ^* resonance at this energy with J=3/2
  - Kamano et al. [PRC90.065204, PRC92.025205]
    $J^P=3/2^+$ (P_{03}), M=1671+2-8 MeV, Γ=10+22-4 MeV
  - Liu & Xie [PRC85.038201, PRC86.055202]
    $J^P=3/2^-$ (D_{03}), M=1668.5±0.5 MeV, Γ=1.5±0.5 MeV
- The reason is the same
  - From $K^-p \to \Lambda\eta$ measurement near the threshold by Crystal Ball collaboration at BNL [PRC64.055205]
  - Especially the angular distribution → Model independent
- There is no state in quark models
  - It must be an exotic
  - $uds s\bar{s}$ pentaquark??

Observation of Pc states at LHCb

LHCb: PRL115, 072001 (2015)

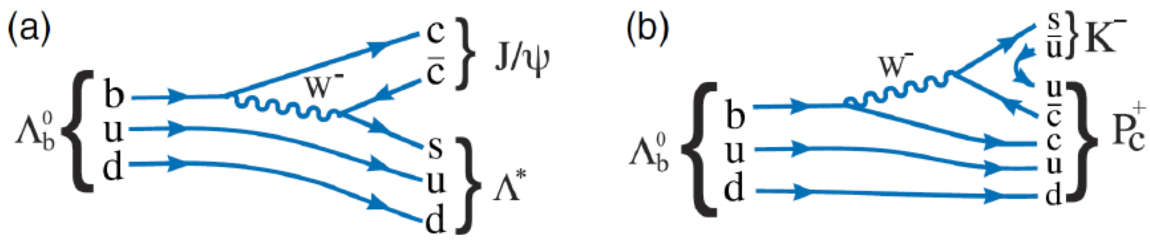
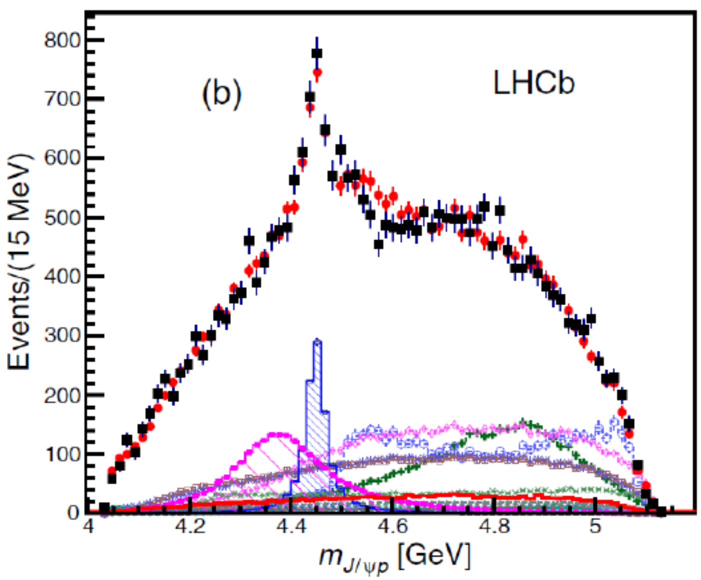
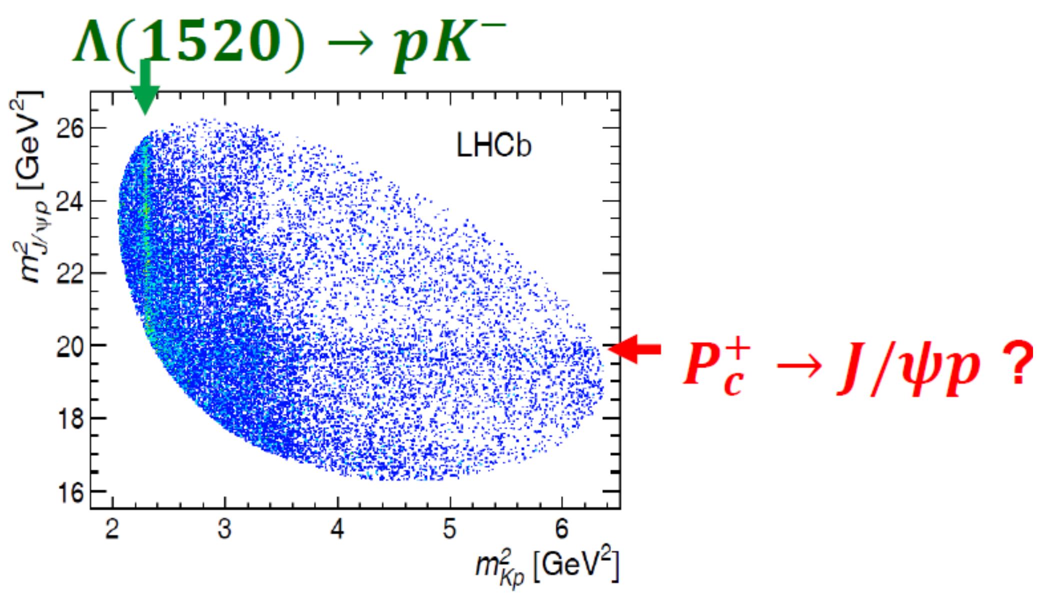


FIG. 1 (color online). Feynman diagrams for (a) $\Lambda_b^0 \to J/\psi \Lambda^*$ and (b) $\Lambda_b^0 \to P_c^+ K^-$ decay.

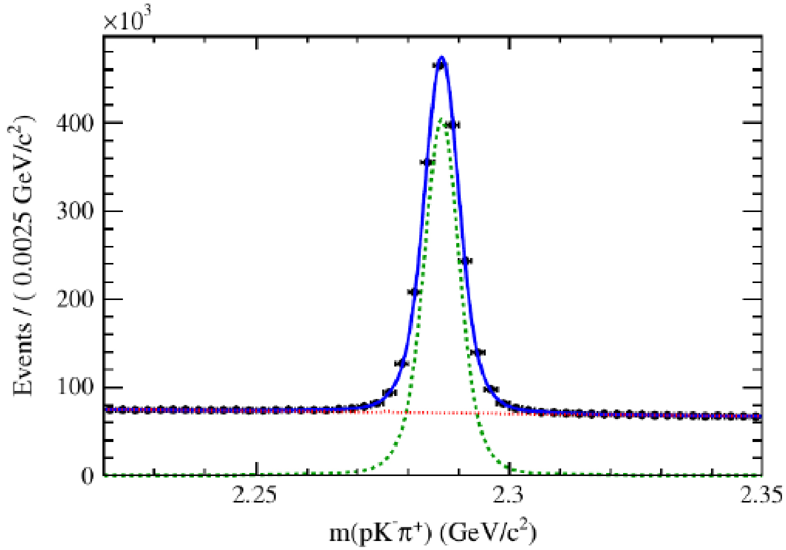


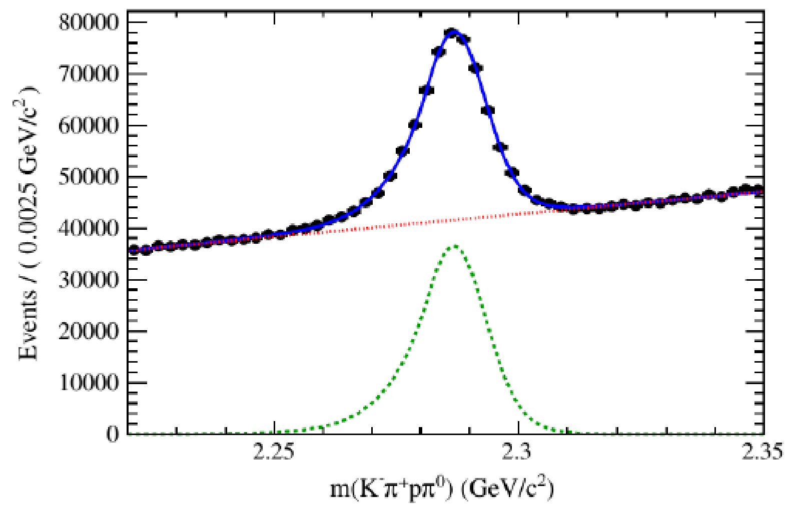


- Analogue search for hidden-strange pentaquark by switching $b \to c(\Lambda_b^0 \to \Lambda_c^+)$, $c \to s(J/\psi \to \phi)$: $\Lambda_c^+ \to \pi^0 P_s^+ \to \pi^0(\phi p)$.

Reference modes

- $\Lambda_c^+ \to \phi p \pi^0$ is Cabibbo-suppressed decay.
- $\Lambda_c^+ \to p K^- \pi^+$ is used for reference, and the Cabibbo-favored decay $\Lambda_c^+ \to K^- \pi^+ p \pi^0$ is measured.





- $\frac{\mathcal{B}(\Lambda_c^+ \to K^- \pi^+ p \pi^0)}{\mathcal{B}(\Lambda_c^+ \to K^- \pi^+ p)} = (0.685 \pm 0.007 \pm 0.018)$
- Most precise measurement: $\mathcal{B}(\Lambda_c^+ \to K^- \pi^+ p \pi^0) = (4.42 \pm 0.05 \pm 0.12 \pm 0.16)\%$
- Previous measurement from BESIII: $(4.53 \pm 0.23 \pm 0.30)\%$

B. Pal *et al.*, Phys.Rev.D96, 051102(R)(2017)

Search for Ps states at Belle

Phys.Rev.D96, 051102(R)(2017)

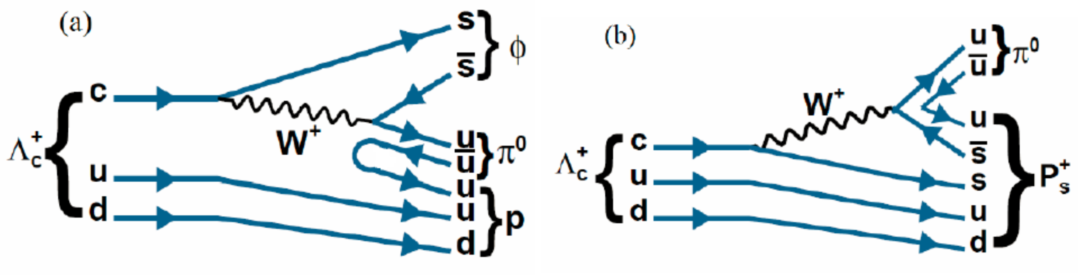
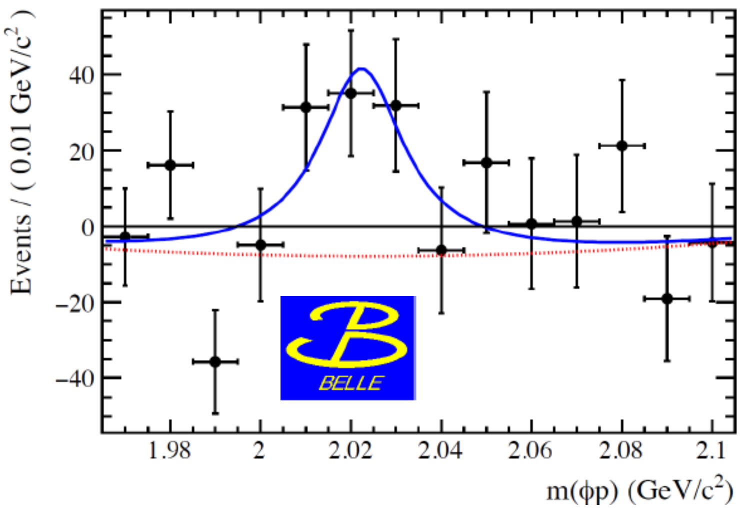


FIG. 1. Feynman diagram for the decay (a) $\Lambda_c^+ \to \phi p \pi^0$ and (b) $\Lambda_c^+ \to P_s^+ \pi^0$.



Perform 2D fit to $M_{K^+K^-p\pi^0}$ vs $M_{K^+K^-}$ plane.

$\Sigma^+ \to p\pi^0$ vetoed

- **No significant Ps signal**
- **Best fit yields a peak at M=(2025±5) MeV/c^2 and Γ=(22±12) MeV**

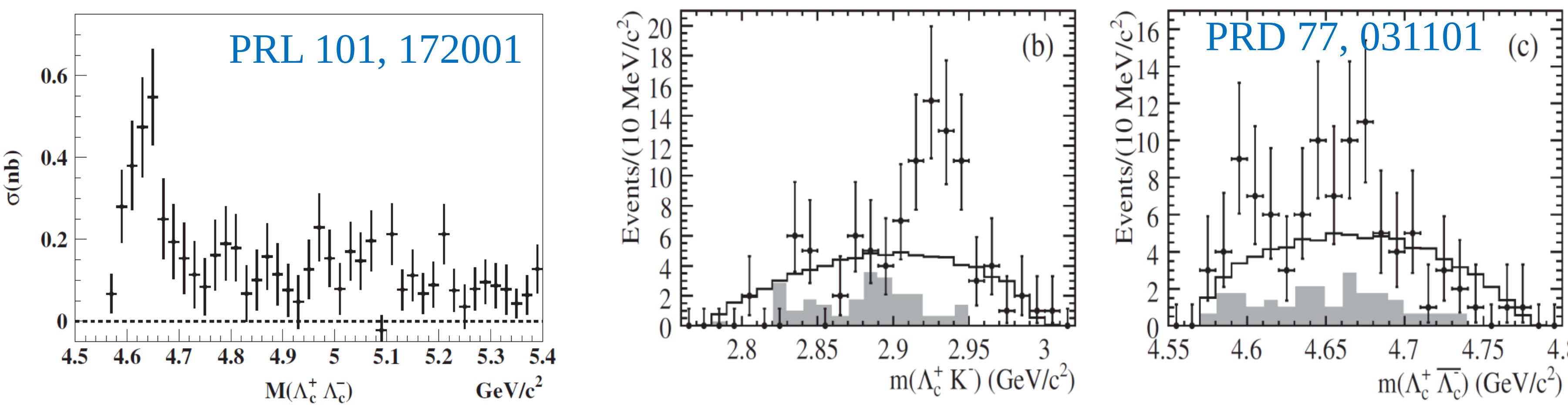
PRD96, 051102(R) (2017); 915fb^{-1}

Number of candidate $\Lambda_c \to P_s\pi^0 \to \phi p\pi^0$ events: 77.6±28.1

$B(\Lambda_c \to P_s\pi^0) \times B(P_s \to \phi p) < 8.3\times10^{-5}$ @90% C.L.

$\Xi_c(2930)^0$ in $B^+ \to K^+\Lambda_c^+\bar{\Lambda}_c^-$

- Belle reported a structure, called X(4630), in the $\Lambda_c^+\bar{\Lambda}_c^-$ invariant mass distribution in $e^+e^- \to \gamma_{ISR}\Lambda_c^+\bar{\Lambda}_c^-$ PRL 101, 172001
- BarBar once studied $B^+ \to K^+\Lambda_c^+\bar{\Lambda}_c^-$ and found two small peaks in $M_{\Lambda_c^+\bar{\Lambda}_c^-}$ spectrum and a vague structure named $\Xi_c(2930)$ is seen in the distribution of $M_{K\,\Lambda_c}$. Larger data is needed to verify them. PRD 77, 031101
- Also, some theory explained that Y(4660) has a large partial decay width to $\Lambda_c^+\bar{\Lambda}_c^-$ and it's isospin partner Y(4616) is predicted. PRD 82, 094008; PRL102, 242004



$\Xi_c(2930)^0$ in $B^+ \to K^+ \Lambda_c^+ \overline{\Lambda}_c^-$

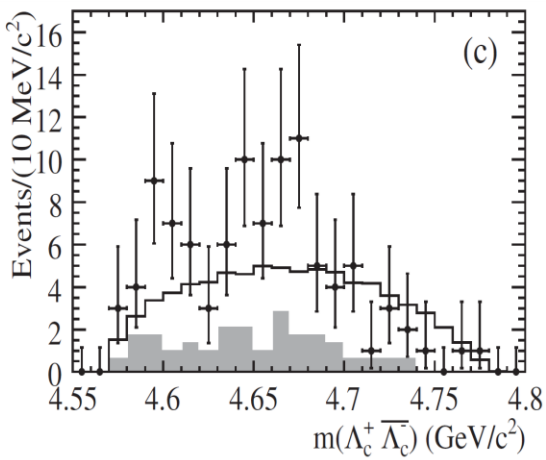
$\Xi_c(2930)$ *

CHARMED BARYONS
($C = +1$)
$\Lambda_c^+ = udc$, $\Sigma_c^{++} = uuc$, $\Sigma_c^+ = udc$, $\Sigma_c^0 = ddc$, $\Xi_c^+ = usc$, $\Xi_c^0 = dsc$, $\Omega_c^0 = ssc$

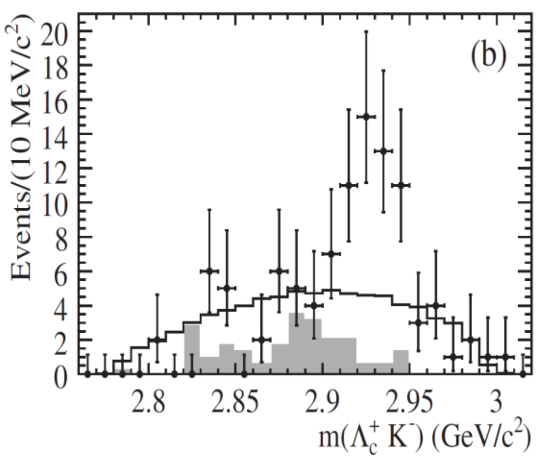
$\Xi_c(2930)$ $\quad I(J^P) = ?(?^?)$

A peak seen in the $\Lambda_c^+ K^-$ mass projection of $B^- \to \Lambda_c^+ \overline{\Lambda}_c K^-$ events.

$\Xi_c(2930)$ MASS	2931 ± 6 MeV
$\Xi_c(2930)$ WIDTH	36 ± 13 MeV

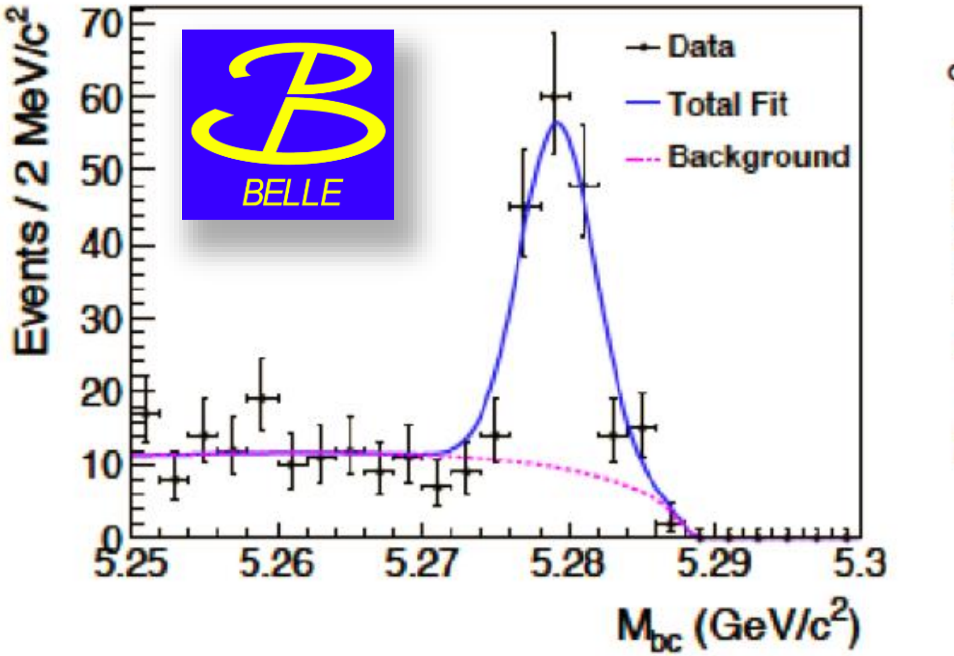


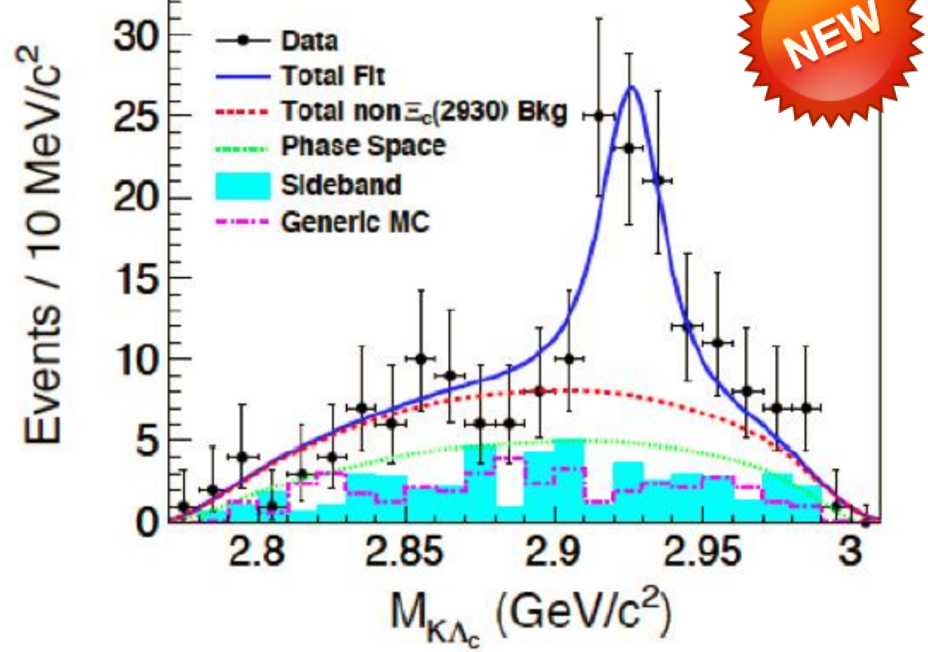
tion for experimental resolution, we obtain $m = 2931 \pm 3(\mathrm{stat}) \pm 5(\mathrm{syst})\ \mathrm{MeV}/c^2$ and $\Gamma = 36 \pm 7(\mathrm{stat}) \pm 11(\mathrm{syst})$ MeV. We do not see any such structure in the m_{ES} sideband region. This description is in good agreement with the data (χ^2 probability of 22%) and could be interpreted as a single Ξ_c^0 resonance with those parameters, though a more complicated explanation (e.g. two narrow resonances in close proximity) cannot be excluded.



Observation of $\Xi_c(2930)^0$ in $B^+ \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ at Belle

Eur. Phys. J. C78, 252 (2018)





153±14 B decay signal events.
$Br(B^+ \to \Lambda_c^+ \Lambda_c^- K^+) = (4.80 \pm 0.43 \pm 0.68) \times 10^{-4}$

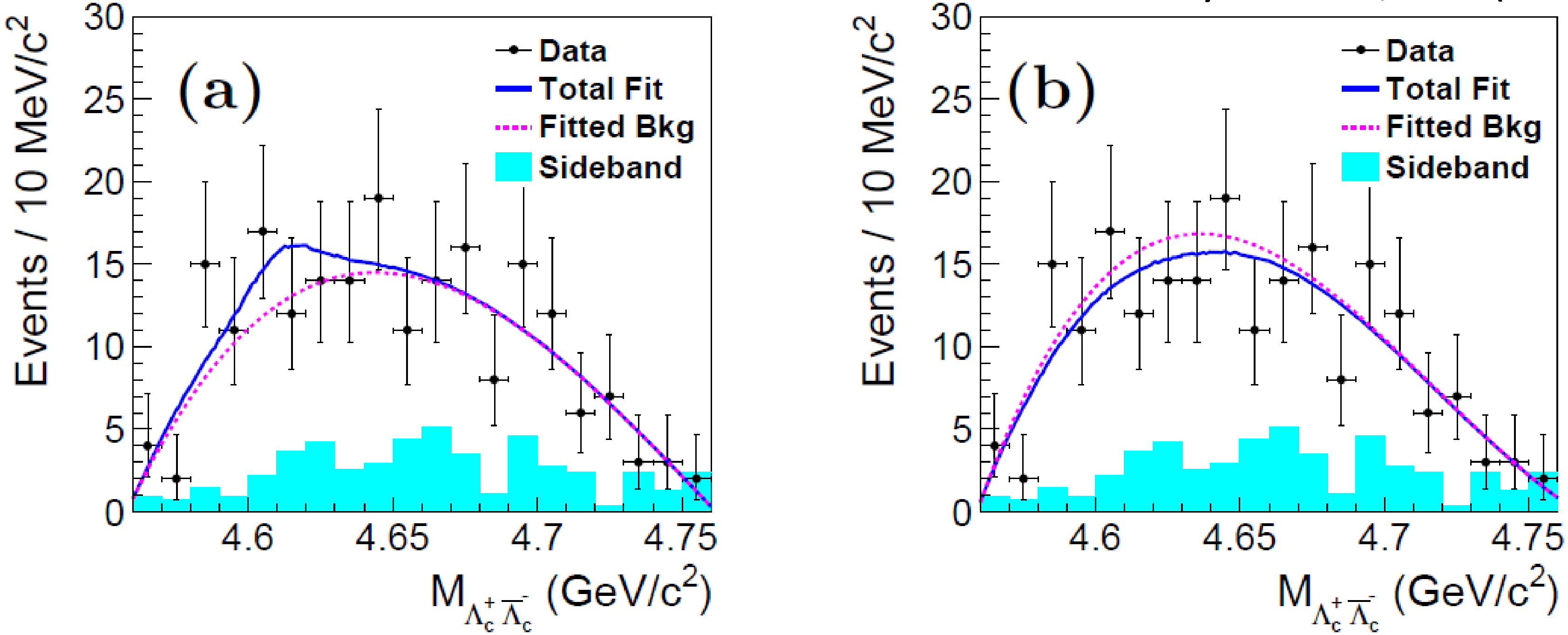
$\Xi_c(2930)^0 \to \Lambda_c^+ K^-$ 61±16 events
5.1σ significance

Clear confirmation for the BaBar claim, PRD77,031101(2008) and much more precise M=2928.9±3.0 +0.8/-12.0 MeV, Γ=19.5±8.4 +5.4/-7.9 MeV

- $\Xi_c(2930)^0 = csd$ is the first charmed-strange baryon established in B decay.

Search for Y(4660) and its spin part in $B^+ \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ at Belle

Eur. Phys. J. C78, 252 (2018)

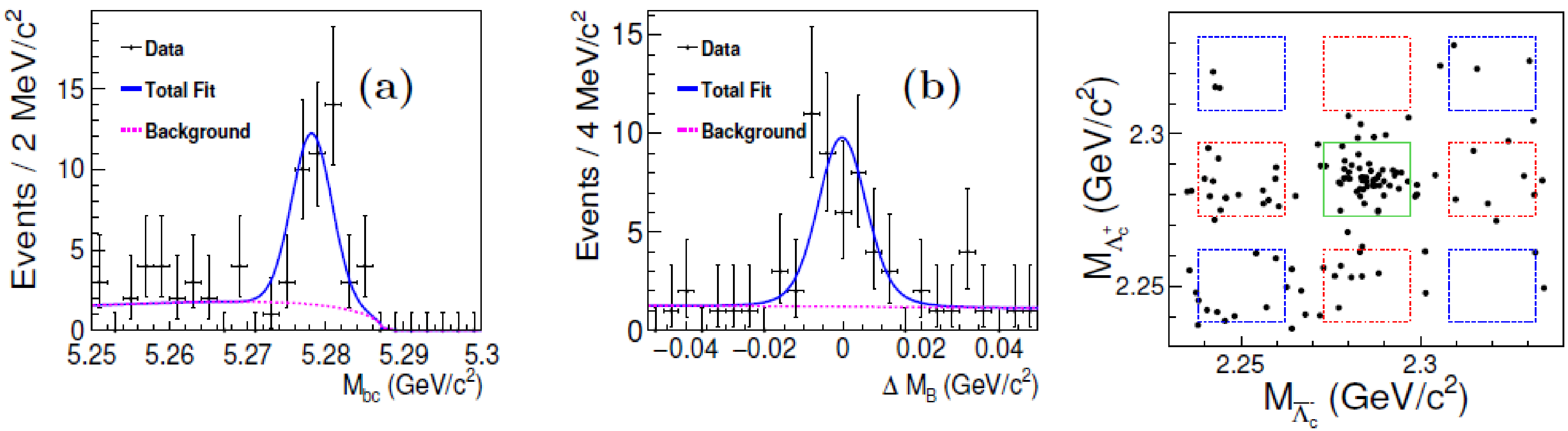


- No Y(4660) and its spin partner Y_η were observed. in the $\Lambda_c^+\overline{\Lambda}_c^-$ invariant mass distribution
- 90% C.L. upper limits of $B^+ \to K^+Y(4660) \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ and $B^+ \to K^+Y_\eta \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ are 1.2×10^{-4} and 2.0×10^{-4}.

Evidence of charged $\Xi_c(2930)$ in $B^0 \to K^0 \Lambda_c^+ \bar{\Lambda}_c^-$

arXiv:1806.09182

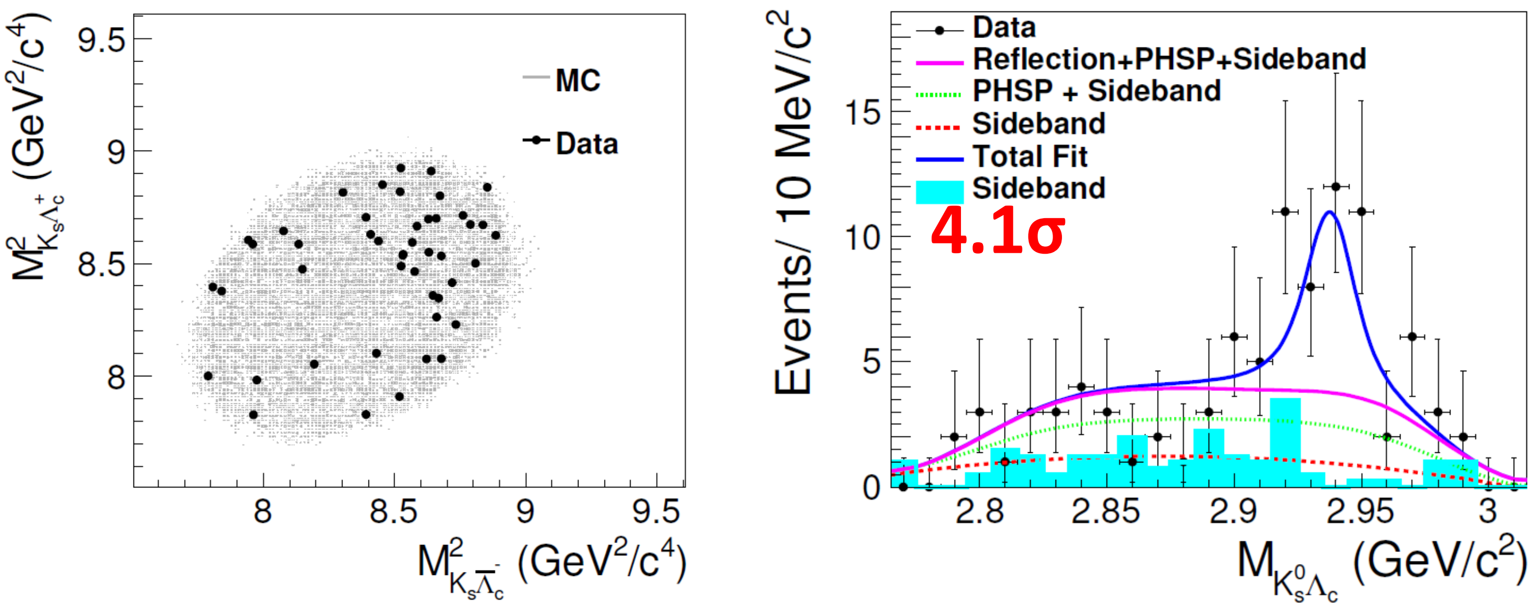
- Based on full $\Upsilon(4S)$ data set (772 M $B\bar{B}$ pairs) at Belle
- Three Λ_c decay channels:
  $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to pK_s(\pi^+\pi^-)$ and $\Lambda_c^+ \to \Lambda(p\pi^-)\pi^+$.
- B candidates extracted via 2D fit to M_{bc} and ΔM_B



- Quite clear $\Lambda_c^+\bar{\Lambda}_c^-$ signals and B^0 signals.
  - $N^{\rm sig} = 34.9 \pm 6.6$ with a statistical signal significance above 8.3σ
  - $\mathcal{B}(B^0 \to K^0\Lambda_c^+\bar{\Lambda}_c^-) = (3.84 \pm 0.73 \pm 0.48) \times 10^{-4}$

Evidence of charged $\Xi_c(2930)$ in $B^0 \to K^0 \Lambda_c^+ \bar{\Lambda}_c^-$

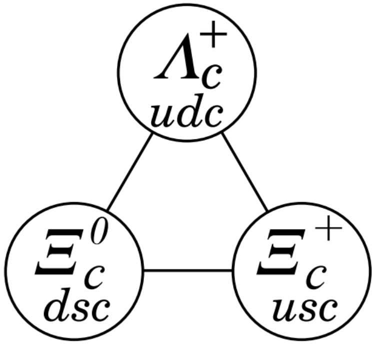
- Charged $\Xi_c(2930)$ extracted by fitting $M_{K_S^0 \Lambda_c}$



- $N_{\Xi_c^\pm} = 21.2 \pm 4.6$, stat. significance 4.1σ
- $M_{\Xi_c^\pm(2930)} = 2942.3 \pm 4.4 \pm 1.6\ \mathrm{MeV}/c^2$
- $\Gamma_{\Xi_c^\pm(2930)} = 14.8 \pm 8.8 \pm 7.1\ \mathrm{MeV}$

Measurements of absolute Brs of Ξ_c^0

- Weak decays of charmed hadrons play an unique role in the study of strong interaction； the charmed-baryon sector also offers an unique and excellent laboratory for testing heavy-quark symmetry and light-quark chiral symmetry.
- For the charmed baryons of the SU(3) anti-triplet, only Λ_c absolute Brs were measured by Belle [PRL113,042002(2014), first time] and BESIII [PRL116,052001(2016)]
- Since Ξ_c^0 [PRL62,863(1989)] and Ξ_c^+[PLB122,455 (1983)] were discovered ~30 years ago, no absolute Brs could be measured.



- For Ξ_c^0, the Brs are all measured with ratios to the $\Xi^-\pi^+$, the so called reference mode.

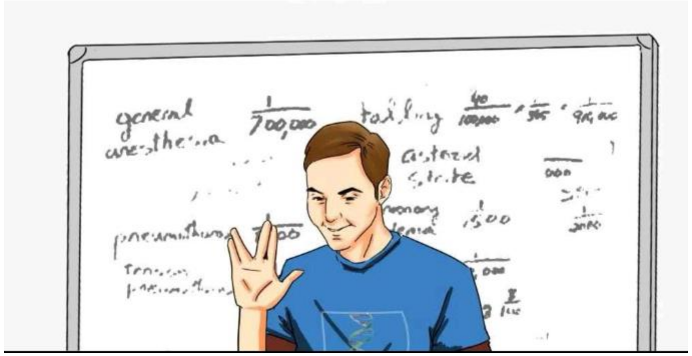
Measurements of absolute Brs of Ξ_c^0

- Theory: $B(\Xi_c^0 \to \Xi^-\pi^+)$~1.3% [PRD48, 4188 (1993)], (2.24±0.34)% [JHEP03, 66(2018)].
- The $B(\Xi_c^0 \to \Lambda K^-\pi^+)$/ $B(\Xi_c^0 \to \Xi^-\pi^+)$ = 1.07 ± 0.12± 0.07 and $B(\Xi_c^0 \to pK^-K^-\pi^+)$/ $B(\Xi_c^0 \to \Xi^-\pi^+)$= 0.33 ± 0.03±0.03 [PLB 605,237]
- $\Xi_c^0 \to pK^-K^-\pi^+$ plays a fundamental role in lots of bottom baryons study at LHCb .
- How to measure Ξ_c^0 absolute Brs ? Model Independent !

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)},$$

$$\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)}.$$

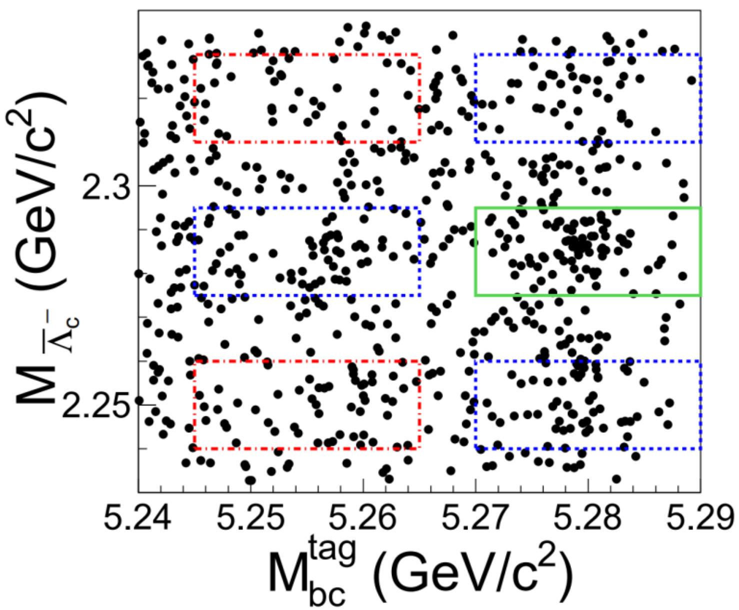
$$\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)}.$$

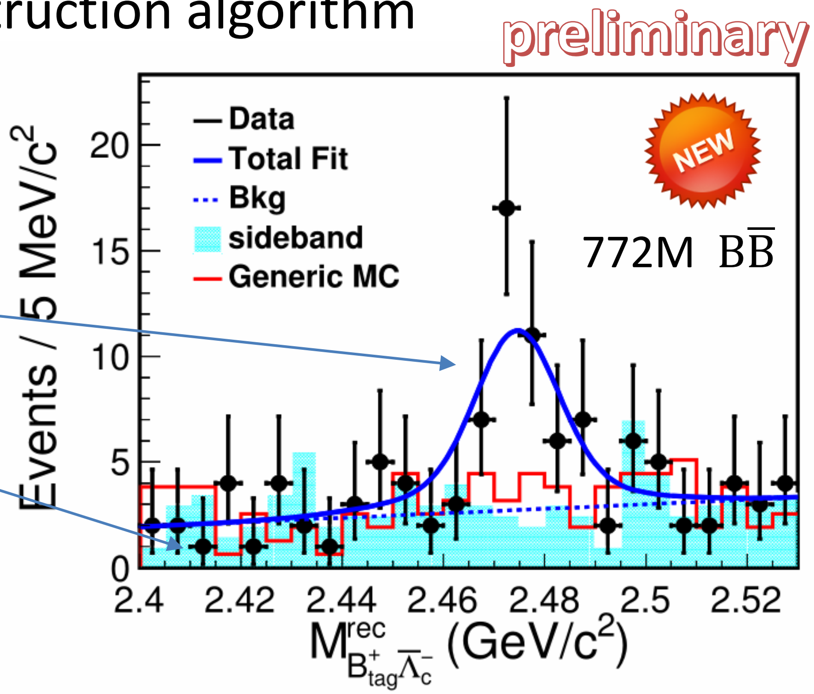


- For inclusive $B^- \to \bar{\Lambda}_c^-\Xi_c^0$, $\Xi_c^0 \to$anything, never measured before.
- For exclusive $B(B^- \to \bar{\Lambda}_c^-\Xi_c^0)$ $B(\Xi_c^0 \to \Xi^-\pi^+)$; $B(B^- \to \bar{\Lambda}_c^-\Xi_c^0)$ $B(\Xi_c^0 \to \Lambda K^-\pi^+)$, measured by Belle and BaBar with large errors.

Measurements of Br of $B^- \to \bar{\Lambda}_c^- \Xi_c^0$, $\Xi_c^0 \to$anything

- The $\bar{\Lambda}_c^-$ reconstructed via its $\bar{p}K^+\pi^-$ and $\bar{p}K_s^0$ decays
- A tagged B meson candidate, B_{tag}^+, is reconstructed using a neural network based on the full hadron-reconstruction algorithm





- An unbinned maximum likelihood fit: N(Ξ_c^0)=40.9 $\pm$9.0, 5.5σ(stat.)
- B($B^- \to \bar{\Lambda}_c^- \Xi_c^0$, Ξ_c^0 →anything)= $(9.51\pm2.10\pm0.88)\times10^{-4}$ for the first time

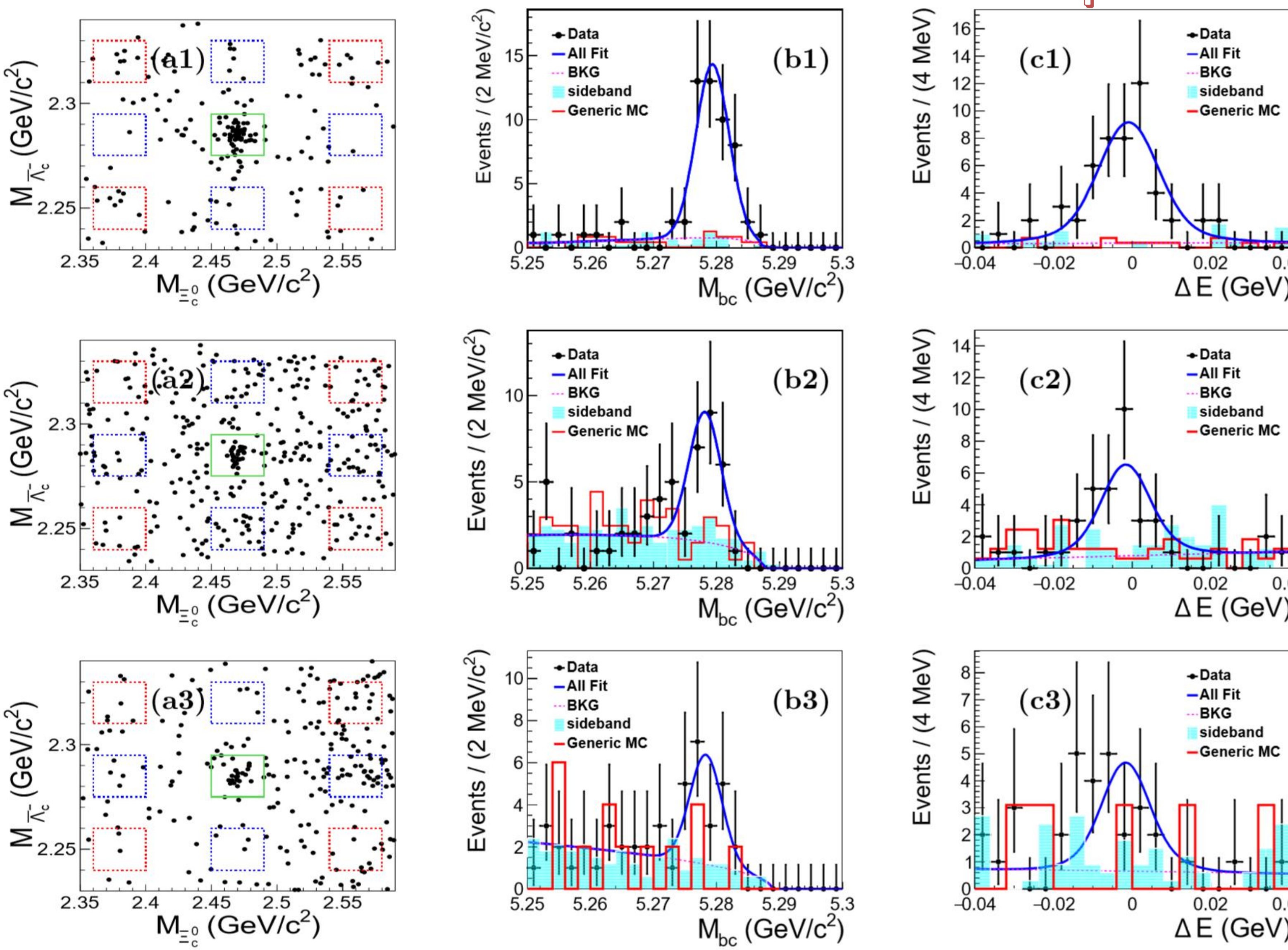
Measurements of Brs of $B^- \to \overline{\Lambda}_c^- \Xi_c^0$, with $\Xi_c^0 \to \Xi^-\pi^+$; $\Xi_c^0 \to \Lambda K^-\pi^+$; $\Xi_c^0 \to pK^-K^-\pi^+$

preliminary

$\Xi^-\pi^+$
44.8 ± 7.3
9.5σ

$\Lambda K^-\pi^+$
24.1 ± 5.5
6.8σ

$pK^-K^-\pi^+$
16.6 ± 5.4
4.6σ



Measurements of absolute Brs of Ξ_c^0

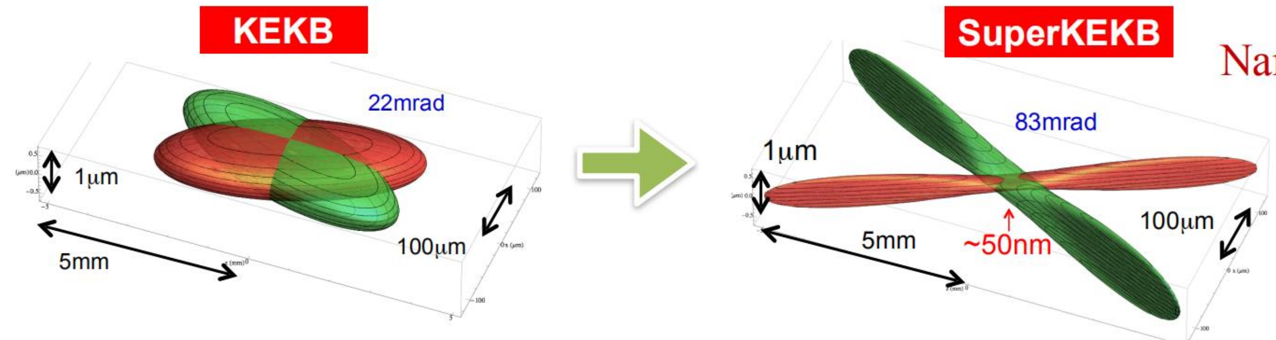
Summary of the measured branching fractions and the ratios of Ξ_c^0 decays

preliminary

Channel	Br/Ratio	PDG
$\mathcal{B}(\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0)$	$(9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$	
$\mathcal{B}(\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0)\,\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$(1.71 \pm 0.28 \pm 0.15) \times 10^{-5}$	$(2.4 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0)\,\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)$	$(1.11 \pm 0.26 \pm 0.10) \times 10^{-5}$	$(2.1 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0)\,\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+)$	$(5.47 \pm 1.78 \pm 0.57) \times 10^{-6}$	
$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$	
$\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$	
$\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$	
$\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$0.65 \pm 0.18 \pm 0.04$	1.07 ± 0.14
$\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$0.32 \pm 0.12 \pm 0.07$	0.34 ± 0.04

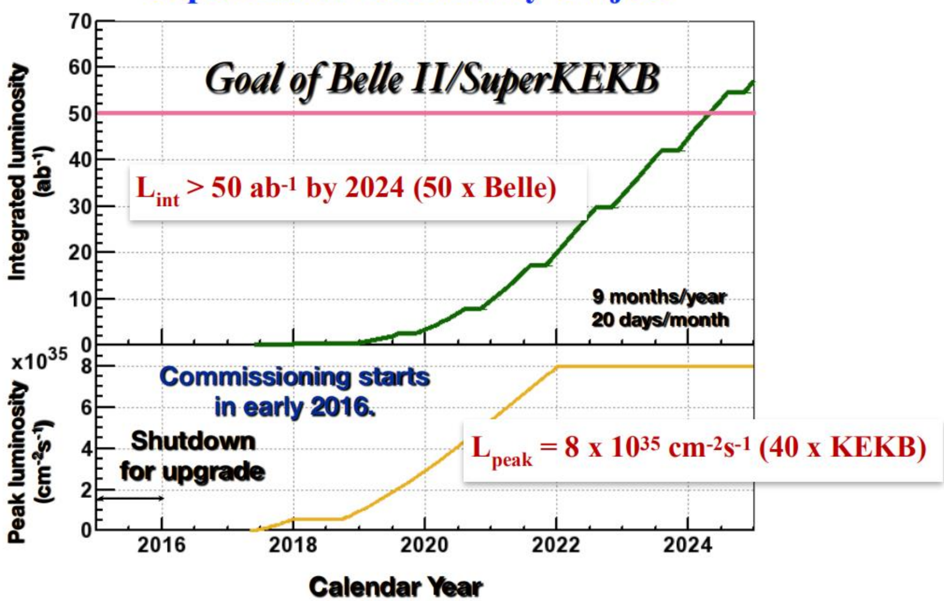
- We have performed an analysis of $\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0$ inclusively and exclusively
- First model-independent measurement of absolute Brs of Ξ_c^0 decays
- The branching fraction $\mathcal{B}(\boldsymbol{B}^- \to \overline{\boldsymbol{\Lambda}}_c^- \Xi_c^0)$ is measured for the first time
- The measured $\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$ can be used to determine the BR of other Ξ_c^0 decays.

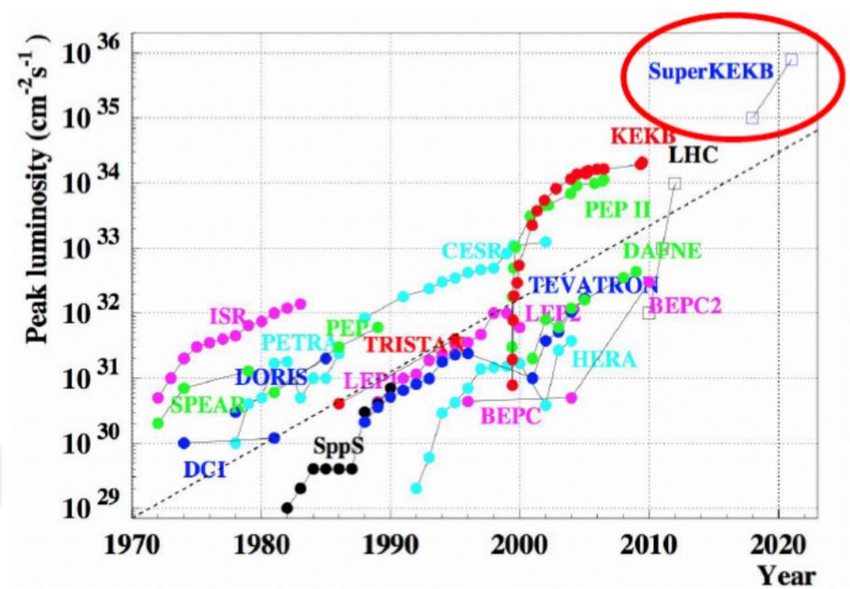
SuperKEKB



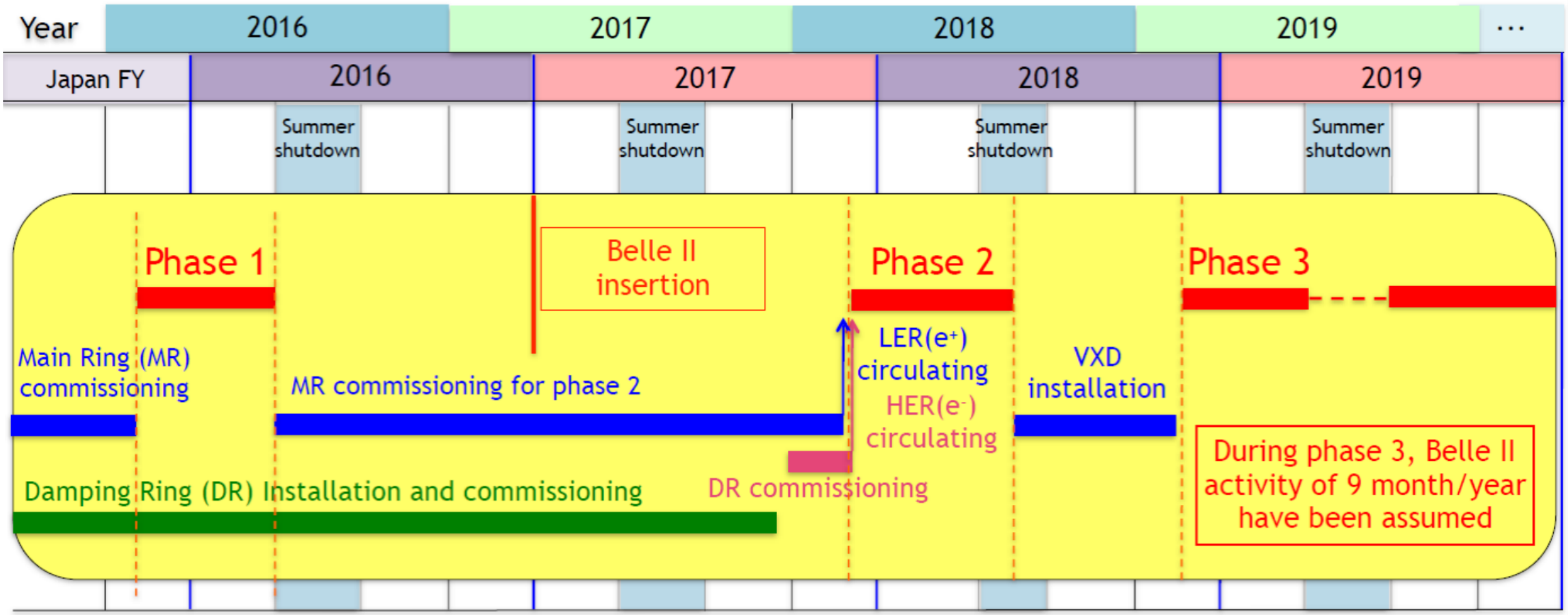
Nano-Beam Scheme

SuperKEKB Luminosity Project



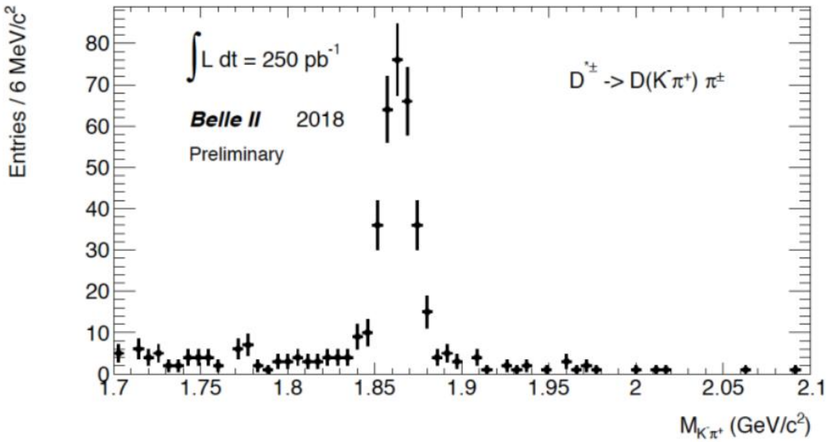


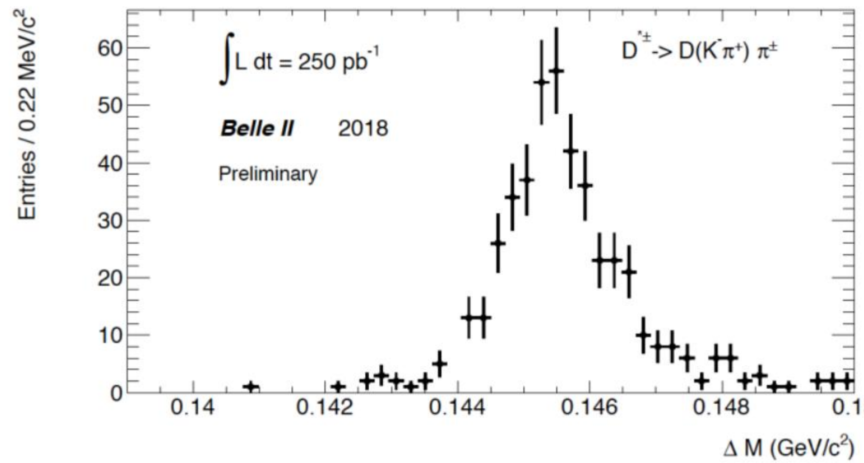
SuperKEKB and Belle II Schedule

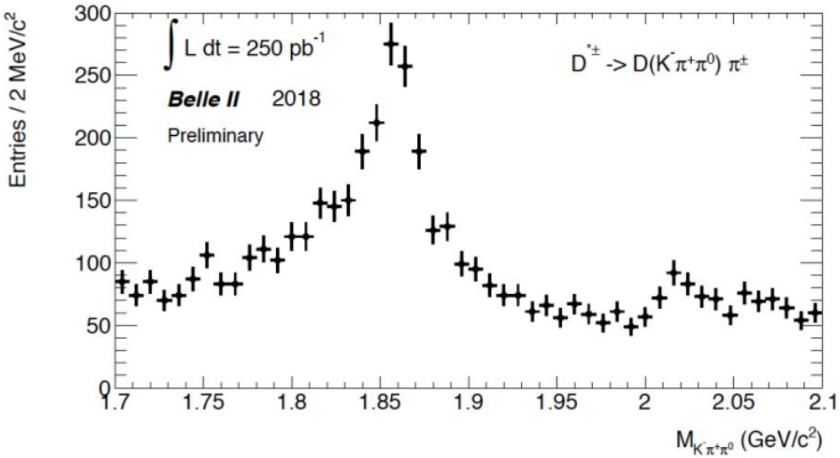


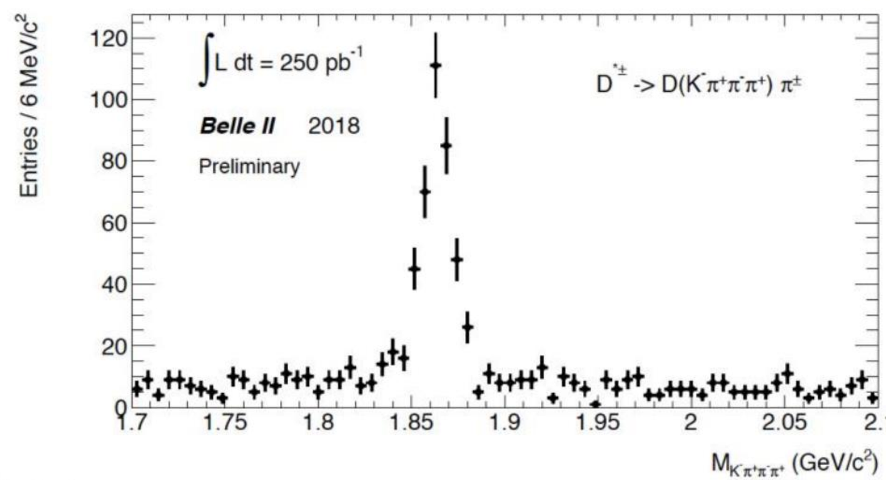
- ✅ **Phase1, Feb.-June, 2016**
  - **Accelerator commissioning, no collision**
- ✅ **Phase2, Feb.-July 17, 2018**
  - **Collision w/o vertex detectors**
  - **Understand background and detector performance**
  - **Instantaneous luminosity reach ~0.5×10^{34} cm^{-2}s^{-1}**
  - **~0.5 fb^{-1} data at the Υ(4S) resonance was collected**

Belle II Performance





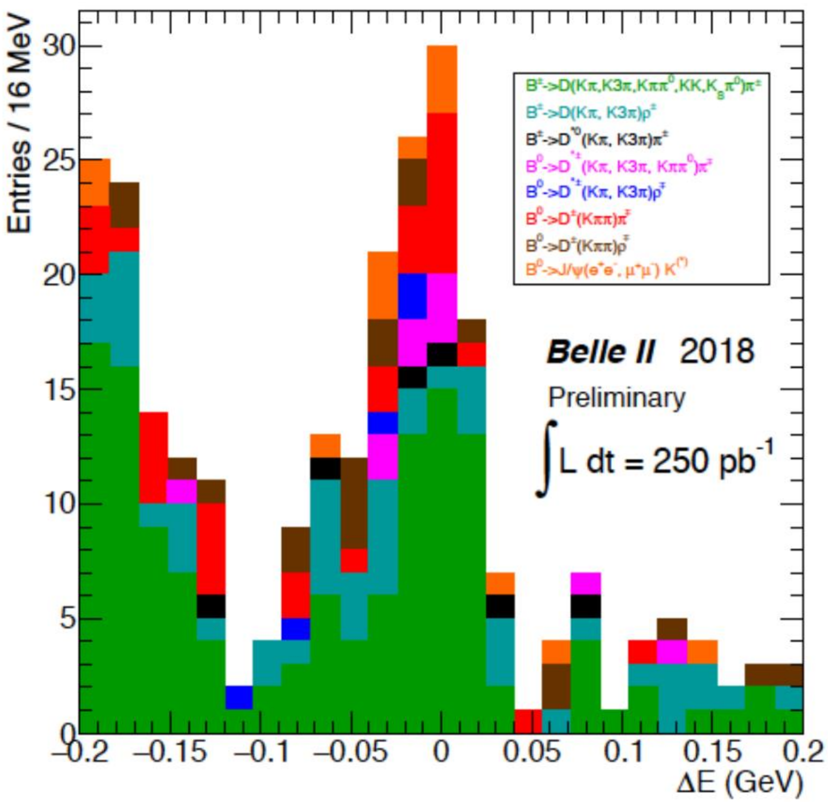


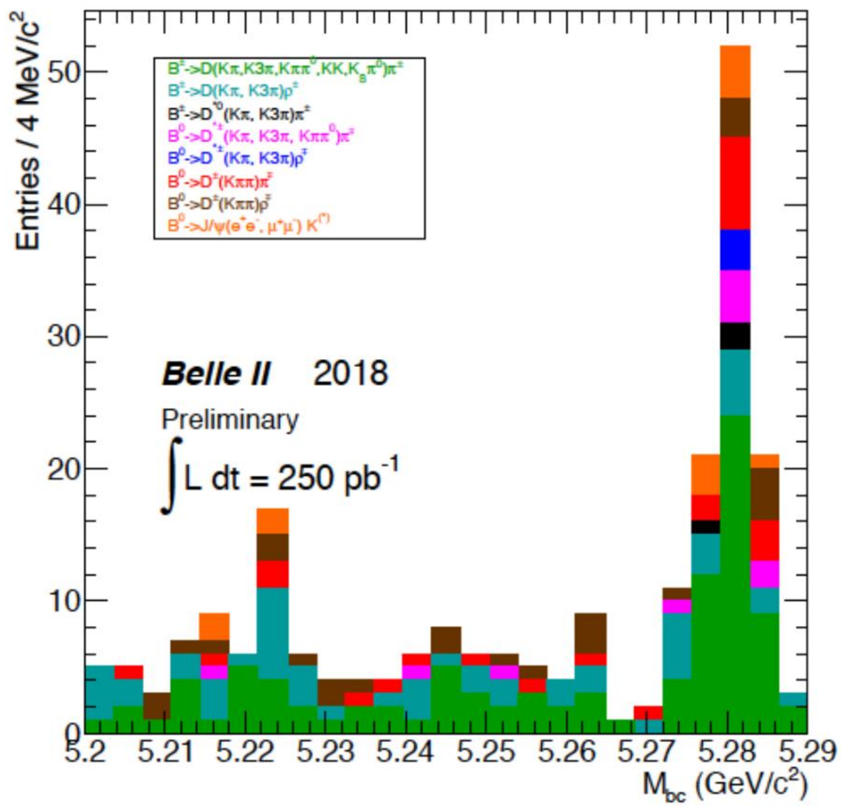


Clear charm signals e+e- → ccbar
Belle II detector is working well!

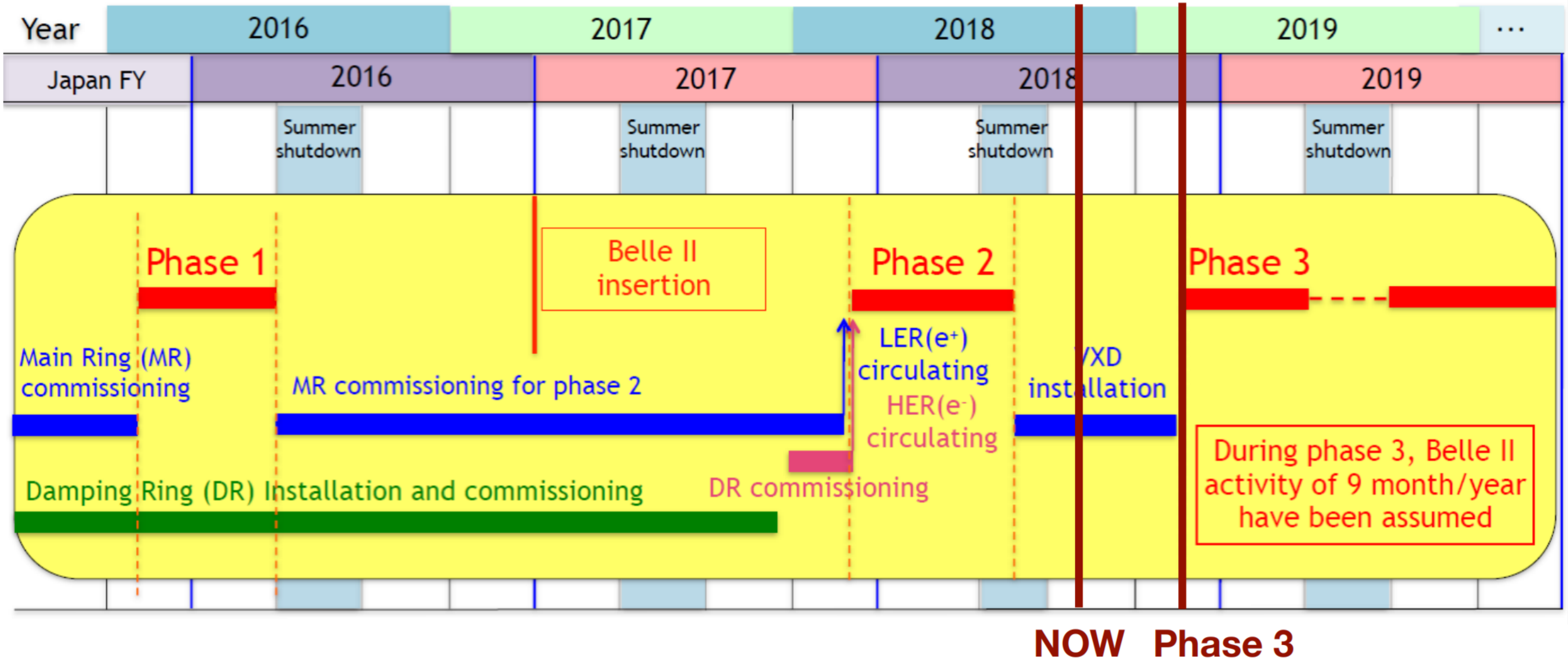
Belle II Performance

We are seeing B signals!





Belle II in future



Phase 3

- **Installation of VXD**
- **Start physics run with full detectors in Spring 2019**
- **Operate 9 months per year**

Belle II possibilities

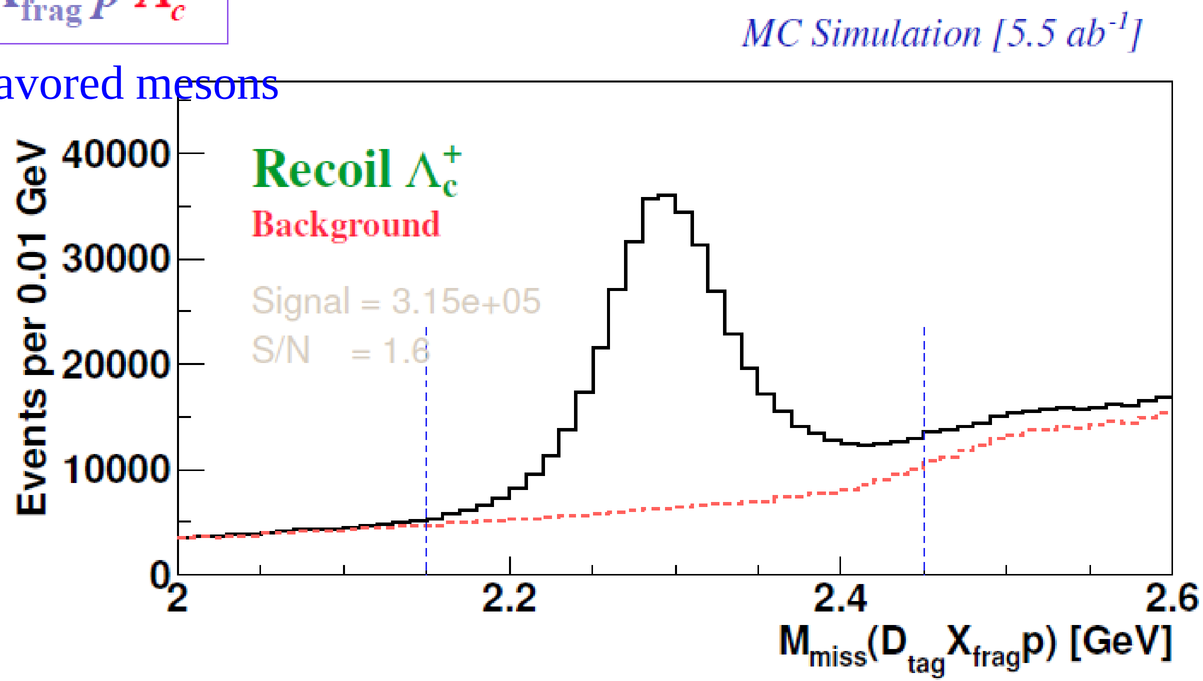
- Many things, but some of them can be done in Belle, too
  - We have not used the full potential of Belle data
- Examples include:
  - Search for more Y_c resonances in unsearched modes; e.g., $\Lambda_c \eta$
  - J^P measurements for Λ_c^*, Ξ_c^*, Ω_c^* ...; Partial wave analysis.
    → We can determine J^P of most of presently known states
    → Comprehensive list of charmed baryons
  - Search for $\Xi*$ and $\Omega*$ resonances in the decay of Λ_c and Ξ_c.
  - Weak decay branches and decay asymmetry parameters
  - Exotic search: pentaquarks, dibaryons, ...
    e.g., ND, $N\overline{D}$(or Θ_c), H, H_c, $\Lambda_c N$, ...

....

Inclusive $\Lambda_c^+ \rightarrow X$

$e^+e^- \rightarrow D_{tag} X_{frag}\, p\, \Lambda_c^+$

X_{frag} : a few unflavored mesons



⇒ *Belle II yield in 50 ab^{-1}:* ***2.8 x 10^6 inclusive***

Unique sample:

- *allows measurement of Λ_c absolute branching fractions*
- *allows measurement of semileptonic Λ_c decays*
- *allows searches for Λ_c rare decays with missing energy*

Summary

- Belle data taking is over, but still actively publishing results. Many interesting results are from (charmed)baryon spectroscopy.

  --Observation of an excited Ω^- baryon: $\Omega^*(2012)$

  -- First observation of doubly Cabibbo-suppressed decay in $\Lambda_c^+ \to p\, K^+\pi^-$

  -- First observation of $\Xi_c^0(2930)$ and evidence of $\Xi_c^{+-}(2930)$ in B decays

  -- Search for Ps in $\Lambda_c^+ \to p\phi\pi^0$ decay

  -- Measurements of absolute Brs of Ξ_c^0

- Interesting results are expected at Belle II, where 50 times more statistics than Belle.

  --Spin-parity determination of most (charmed)baryons and hyperons.

  --Search for new (charmed)baryon/hyperon resonances

  -- And more …