北京航空航天大學
BEIHANG UNIVERSITY

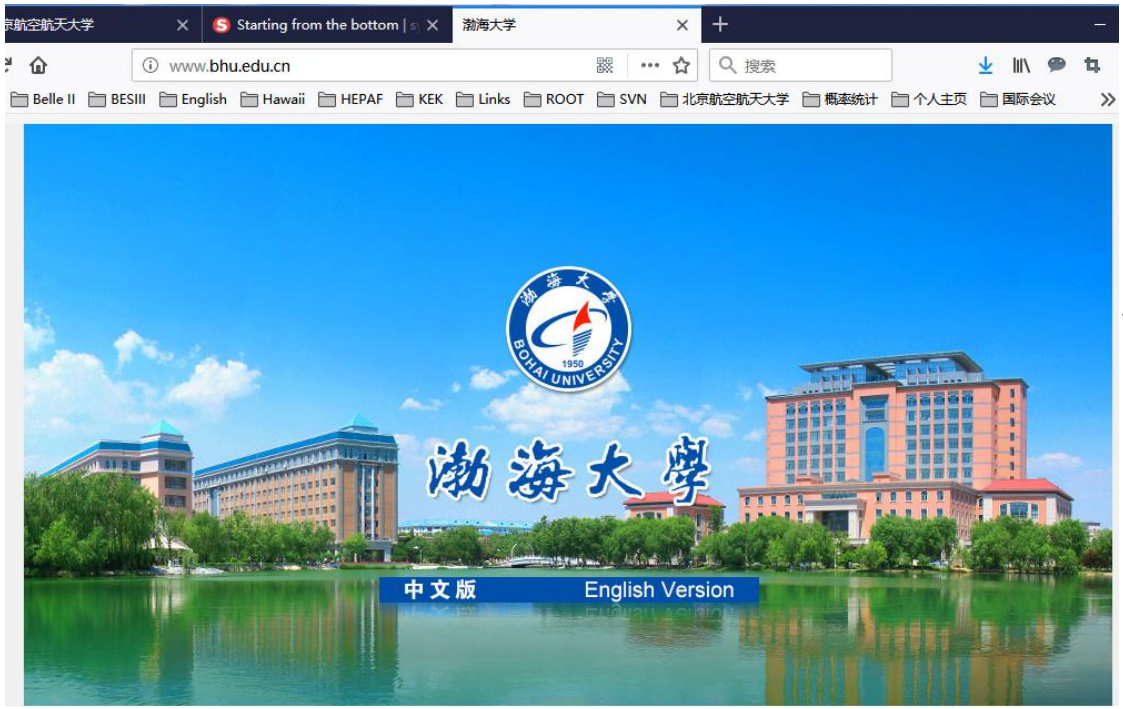
Recent Baryon Results at Belle and the prospect in the Belle II experiment

Chengping Shen

The Mini-workshop on Baryonic spectroscopy at e+e- colliders
IHEP, April 19-20, 2018

Beihang University=BHU ? NO !

08:30 - 12:00 , registration on site		
	Experimental Overview (Chair: 待定)	
09:00 - 09:10	Opening Speech	Xiaoyan Shen (IHEP)
09:10 - 09:20	Introduction to the workshop	Bin Wang (IHEP)
09:20 - 09:50	An overview of Baryon study at BESIII	Beijiang Liu (IHEP)
09:50 - 10:20	An overview of Baryon study at Belle/Belle II	Chengping Shen (BHU)



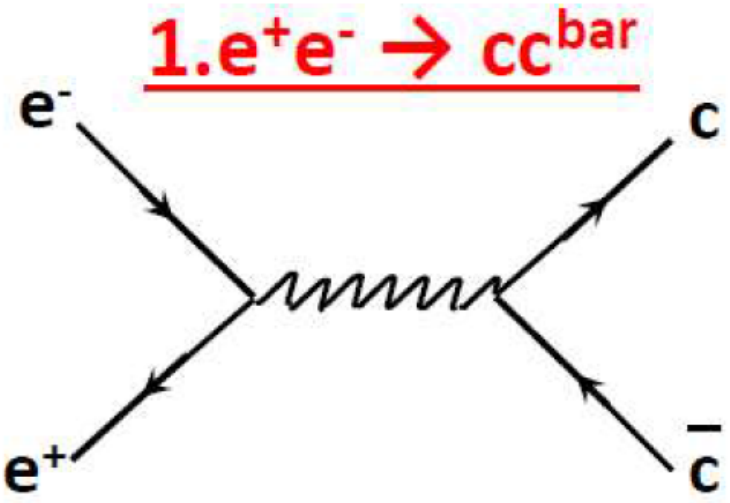
Beihang University (previously known as Beijing Univeristy of Aeronautics and Astronautics)

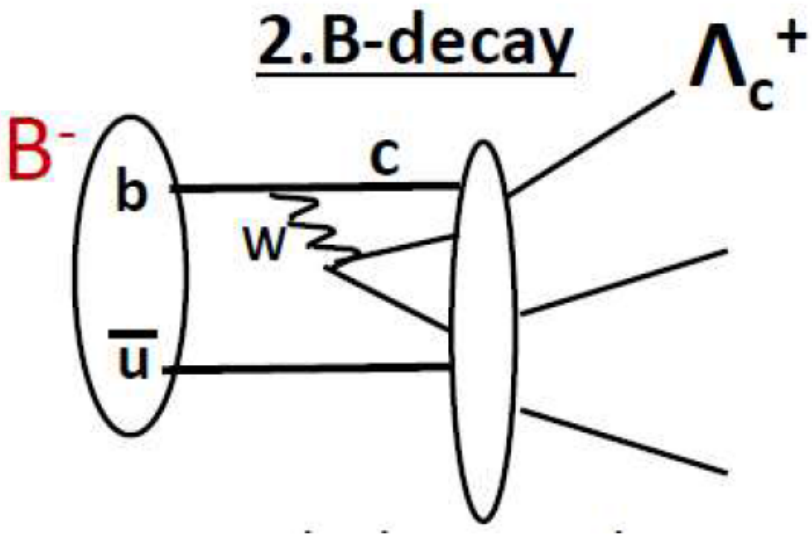
We are BUAA !

Outline

- Introduction
- Baryon results at Belle
- Belle II status
- Prospects of baryon study at Belle II
- Summary

Baryon production at B-factory





Baryons produced via fragmentation

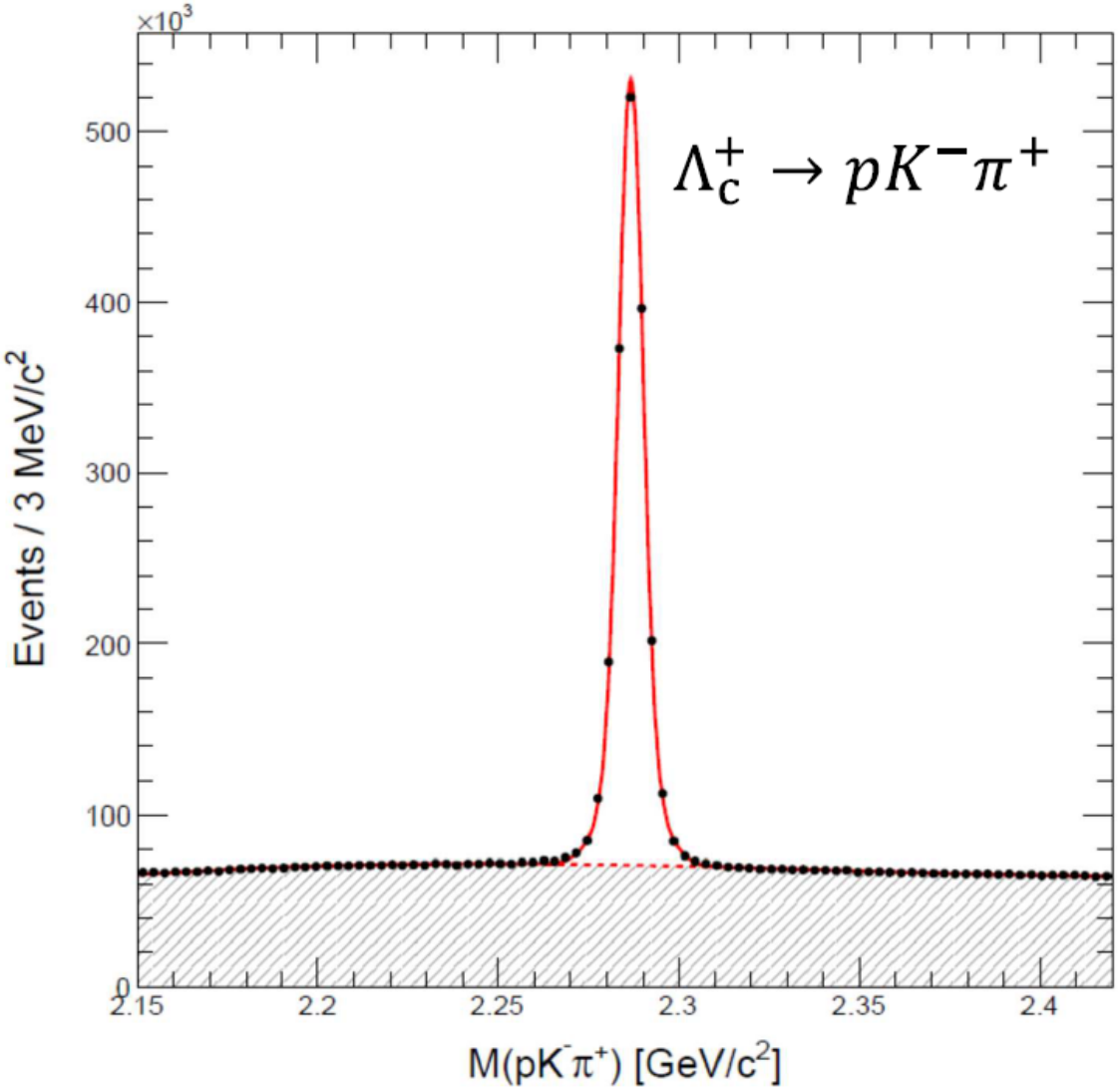
- Charmed baryons – rather direct
- Hyperons – later stage of fragmentation

Huge statistics

B is efficiently produced via $\Upsilon(4s)$

Once bottom is produced, it favorably decays into charm.

Huge statistics, good quality



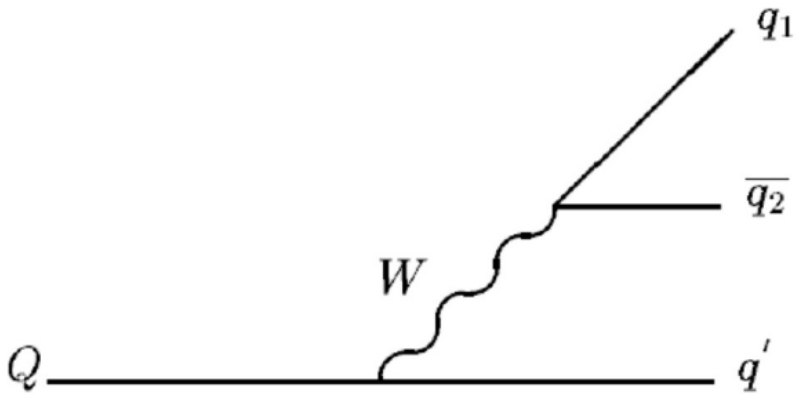
> 1 M events reconstructed

Resolution:
< 10 MeV FWHM

S/N ~ 10

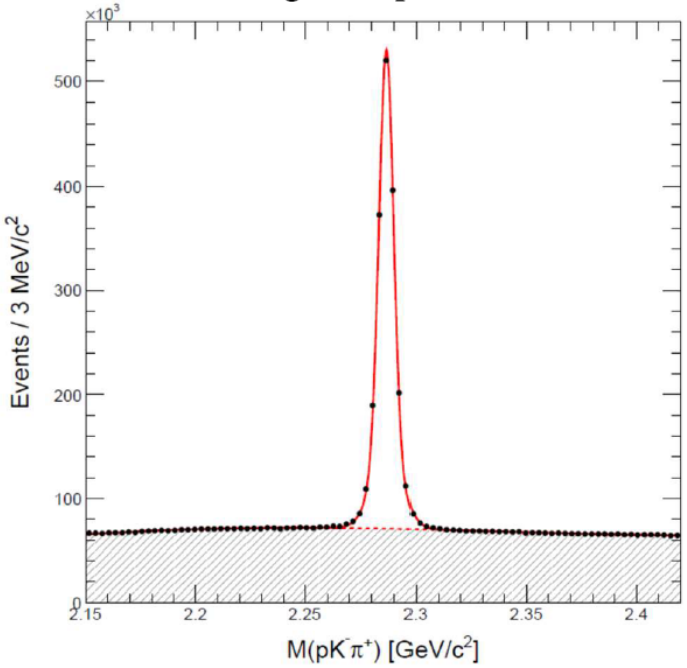
Double-Cabibbo suppressed decay
$\Lambda_c^+ \to p\, K^+ \pi^-$

- Weak decay amplitude of a charm quark
  - c → s: $\cos\theta_c \sim 1$
    d: $\sin\theta_c \sim 0.23$ ← 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 $O(\tan^4\theta_c) \sim 0.28\%$ smaller compared to counterpart $(c \to s(\bar{d}u))$



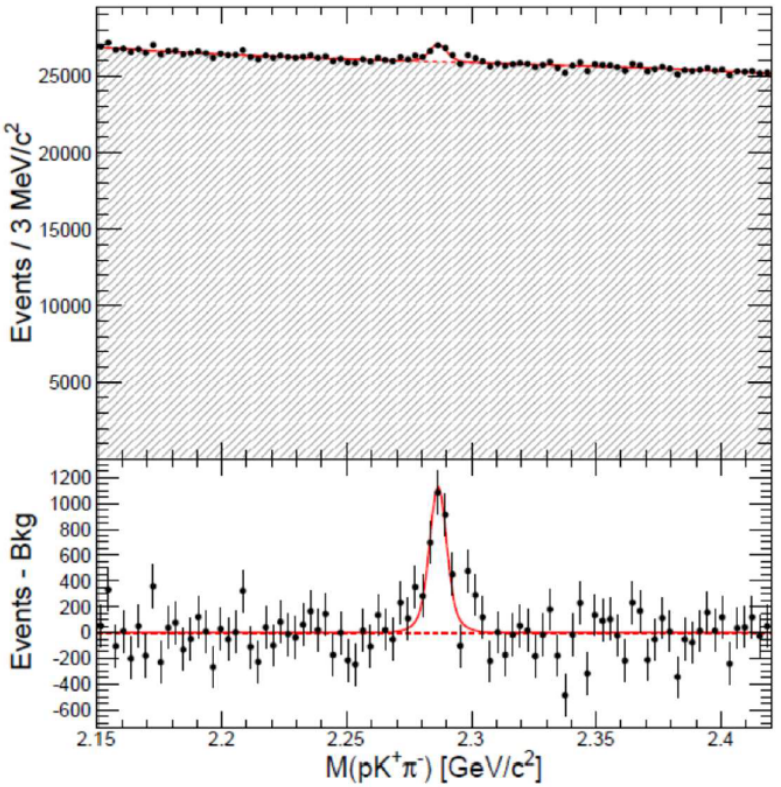
DCS decay $\Lambda_c^+ \to p\,K^+\pi^-$

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)

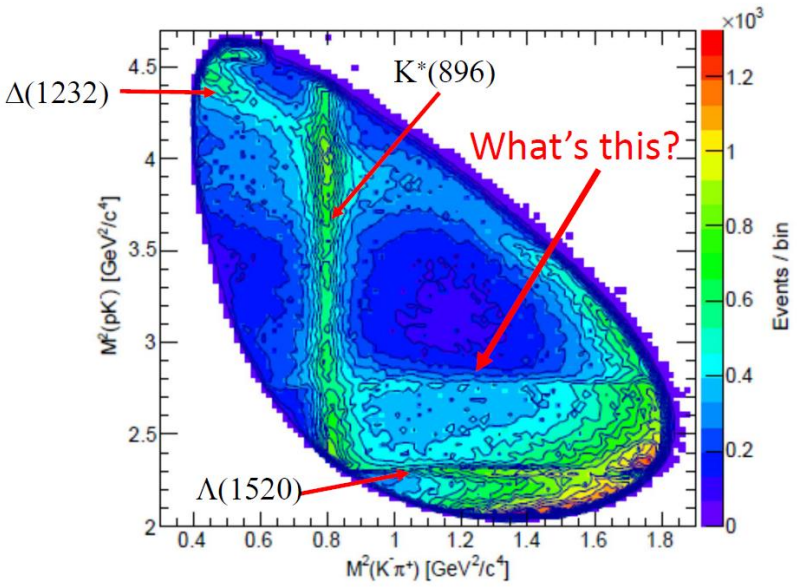
[PRL117, 011801]

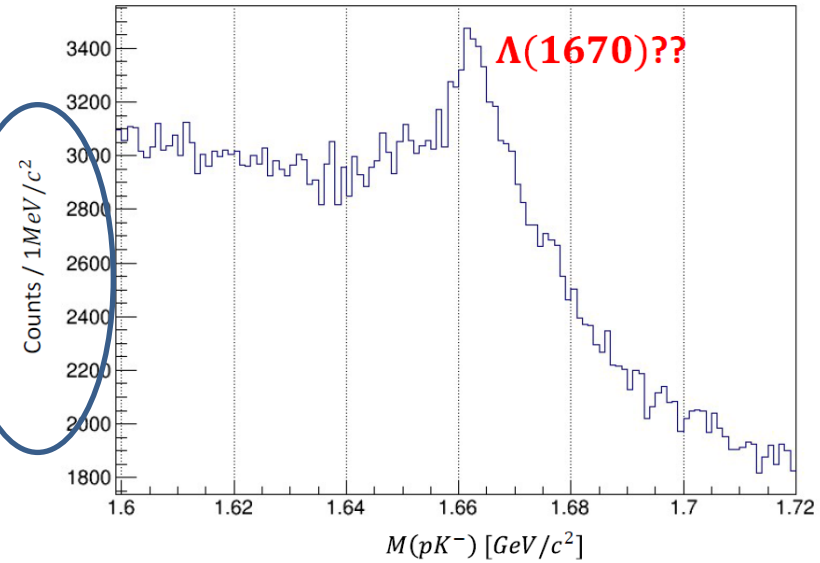
$$BR(\Lambda_c^+ \to pK^+\pi^-) = (1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$$

The first observation of DCS decay in Baryon

A new Λ excited states ?

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

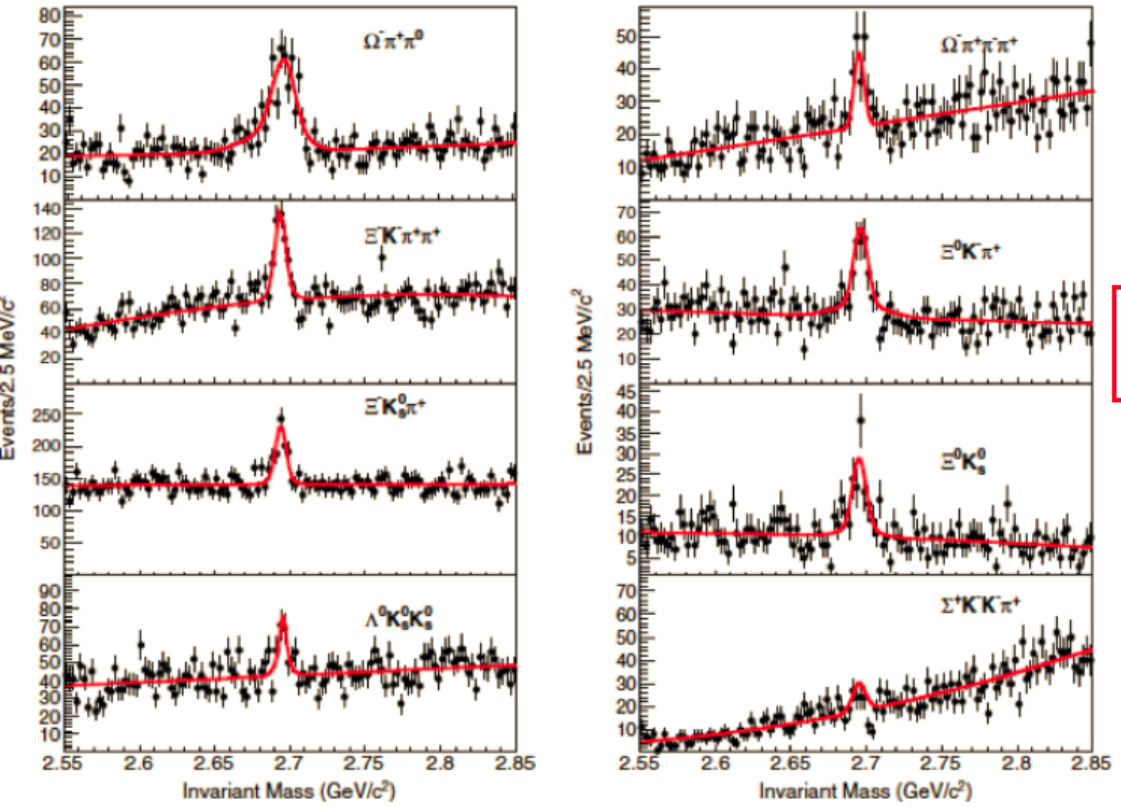




- The peak position is ~1663 MeV, near the $\Lambda\eta$ threshold (1663.5 MeV)
- Width is ~10 MeV, significantly narrower than Λ, Σ resonances in this region
  - $\Lambda(1670)$: 25-50 MeV
  - $\Sigma(1660)$: 40-200 MeV
  - $\Sigma(1670)$: 40-80 MeV
  - $\Lambda(1690)$: ~60 MeV
- 2 independent groups 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
  - $udss\bar{s}$ pentaquark??

Ω_c branching fractions

PRD97,032001(2018)



Mode	Signal yield	Order of polynomial	Resolution (MeV/c^2)	Efficiency (%)
$\Omega^-\pi^+$	691 ± 29	1	5.1	10.08
$\Omega^-\pi^+\pi^0$	403 ± 31	2	13.3	2.95
$\Omega^-\pi^+\pi^-\pi^+$	108 ± 16	1	4.4	5.23
$\Xi^-K^-\pi^+\pi^+$	278 ± 27	2	4.3	5.98
$\Xi^0K^-\pi^+$	168 ± 21	1	7.8	2.09
$\Xi^-K^0_S\pi^+$	349 ± 36	1	4.6	4.81
$\Xi^0K^0_S$	98 ± 15	2	7.0	1.73
$\Lambda K^0_SK^0_S$	95 ± 18	1	3.7	3.22
$\Sigma^+K^-K^-\pi^+$	17 ± 8	2	3.8	2.00

Three modes are new measurements.

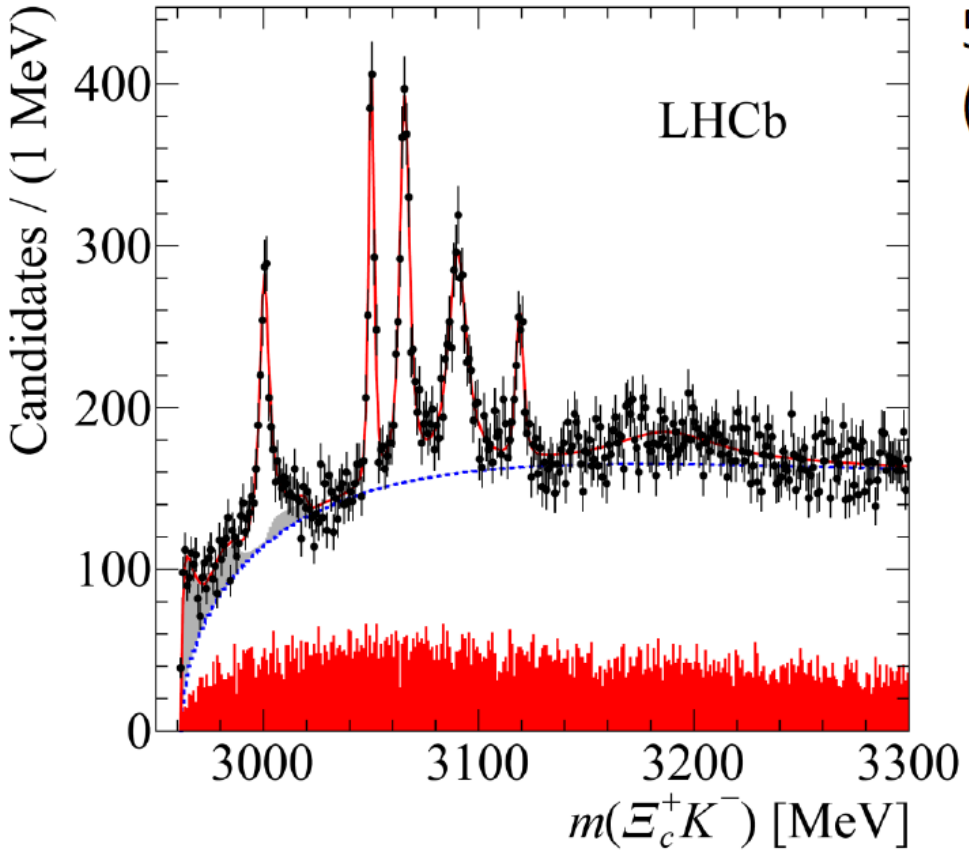
Eight Ω_c^+ decay modes considered.

Observation of excited Ωc states at LHCB

Orbitally excited Ω_c cannot decay to $\Omega^-\pi+$, therefore $\Xi_c^+K^-$ is a good place to look.

Earlier this year, LHCb did exactly that:

PRL118, 182001(2017)



5 Narrow states
(+ possibly one wide one)

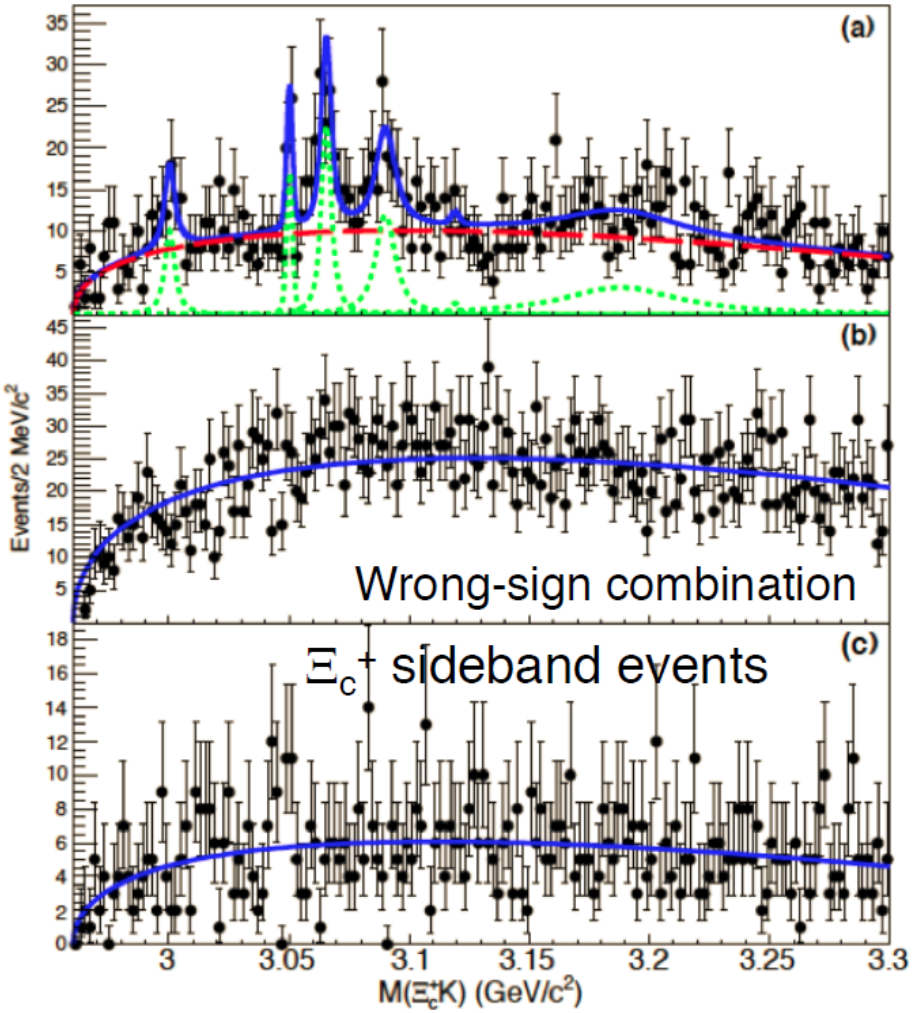
BELLE can do the same!

We can identify kaons with good efficiency. Cut at high momentum ($x_p > 0.75$)

Confirmation of excited Ωc states at Belle

PRD97, 051102 (2018)

arXiv:1711.07927, submitted to PRD.



In $\Xi_c^+ K^-$ mass spectrum, peaks at 3000, 3050, 3066 and 3090 MeV, 3119 MeV is not significant.

Four narrow states out of five reported from LHCb confirmed.

Confirmation of excited Ωc states at Belle

PRD97, 051102 (2018)

- The masses and intrinsic widths of all six are fixed to the values given by LHCb
- Strong confirmation of $\Omega_c^0(3066)$ and $\Omega_c^0(3090)$
- confirmation of $\Omega_c^0(3000)$ and $\Omega_c^0(3050)$
- No confirmation of $\Omega_c^0(3119)$ (but no disagreement due to the small statistics)
- confirmation of wide excess at higher mass.

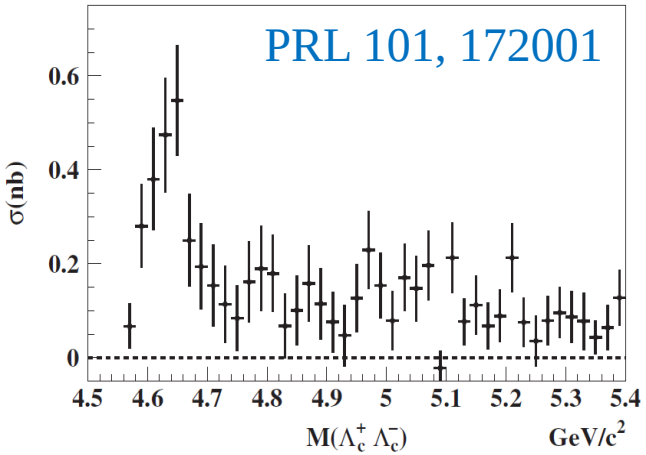
Unit: MeV/c^2

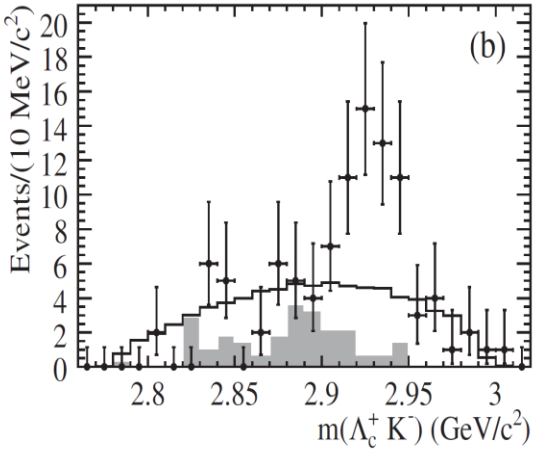
Ω_c Excited State	3000	3050	3066	3090	3119	3188
Yield	37.7 ± 11.0	28.2 ± 7.7	81.7 ± 13.9	86.6 ± 17.4	3.6 ± 6.9	135.2 ± 43.0
Significance	3.9σ	4.6σ	7.2σ	5.7σ	0.4σ	2.4σ
LHCb Mass	$3000.4 \pm 0.2 \pm 0.1$	$3050.2 \pm 0.1 \pm 0.1$	$3065.5 \pm 0.1 \pm 0.3$	$3090.2 \pm 0.3 \pm 0.5$	$3119 \pm 0.3 \pm 0.9$	$3188 \pm 5 \pm 13$
Belle Mass (with fixed Γ)	$3000.7 \pm 1.0 \pm 0.2$	$3050.2 \pm 0.4 \pm 0.2$	$3064.9 \pm 0.6 \pm 0.2$	$3089.3 \pm 1.2 \pm 0.2$	-	$3199 \pm 9 \pm 4$

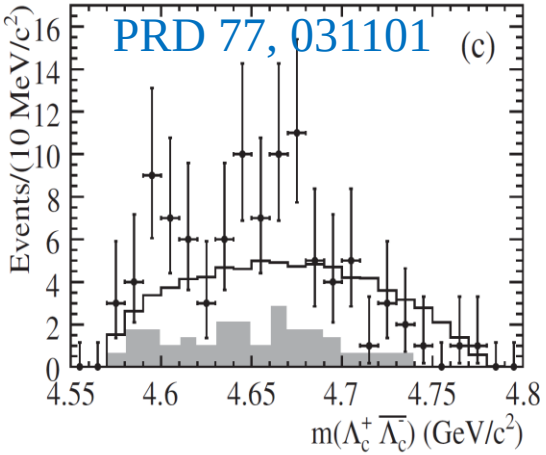
- Alternatively, the masses of the five signals are measured by fitting the same distribution without constraining the masses.
- In all cases, the results are consistent with the LHCb values.

$\Xi_c(2930)^0$ 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

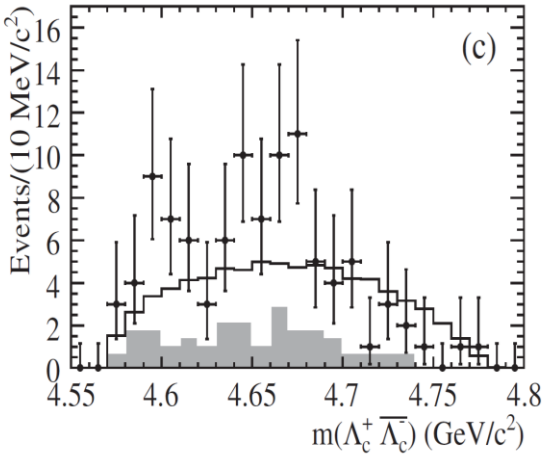
($C = +1$)

$\Lambda_c^+ = udc$, $\Sigma_c^{++} = uuc$, $\Sigma_c^+ = udc$, $\Sigma_c^0 = ddc$, $\Xi_c^+ = usc$, $\Xi_c^0 = dsc$, $\Omega_c^0 = ssc$

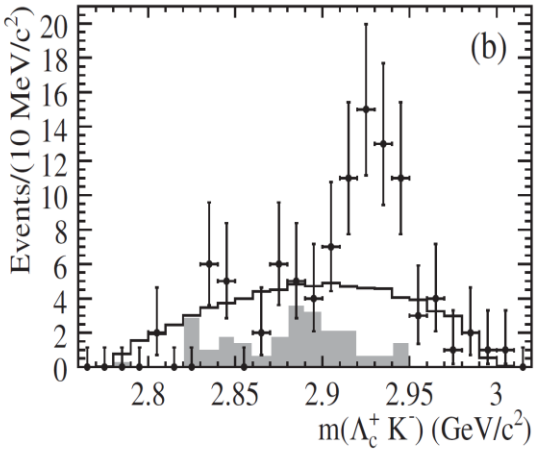
$\Xi_c(2930)$ $I(J^P) = ?(?^?)$

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

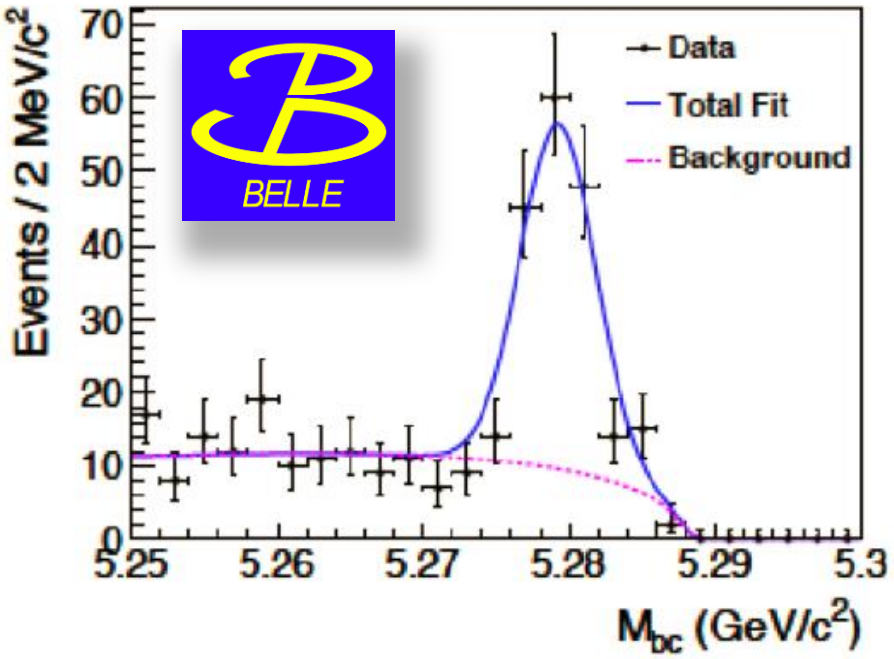


tion for experimental resolution, we obtain $m = 2931 \pm 3(\text{stat}) \pm 5(\text{syst})$ MeV/c^2 and $\Gamma = 36 \pm 7(\text{stat}) \pm 11(\text{syst})$ MeV. We do not see any such structure in the m_{ES} sideband region. This description is in good agreement with the data (χ^2 probability of 22%) 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.

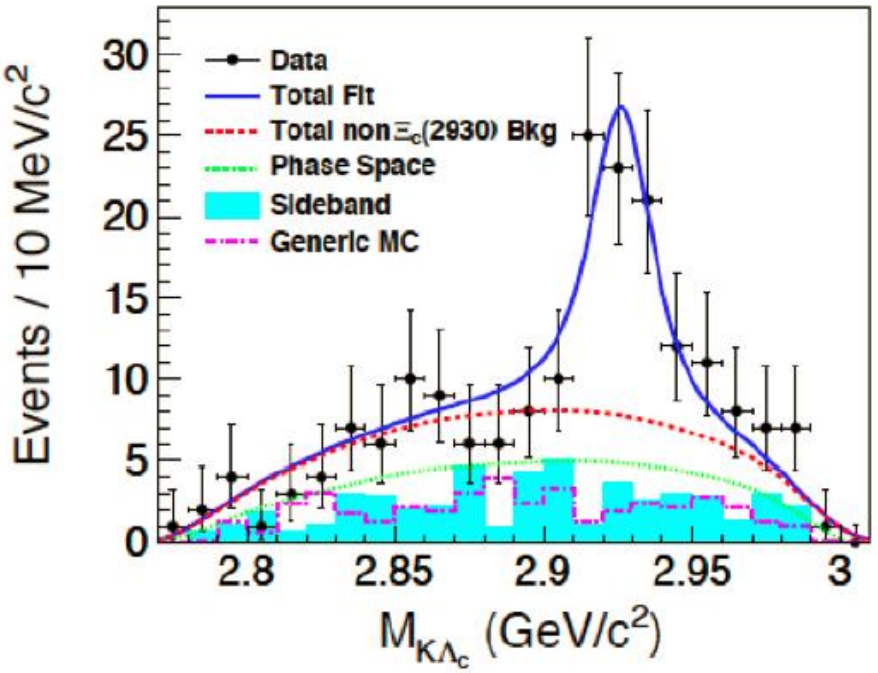


Observation of $\Xi_c(2930)^0$ in $B^+ \to K^+ \Lambda_c^+ \bar{\Lambda}_c^-$ at Belle

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



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

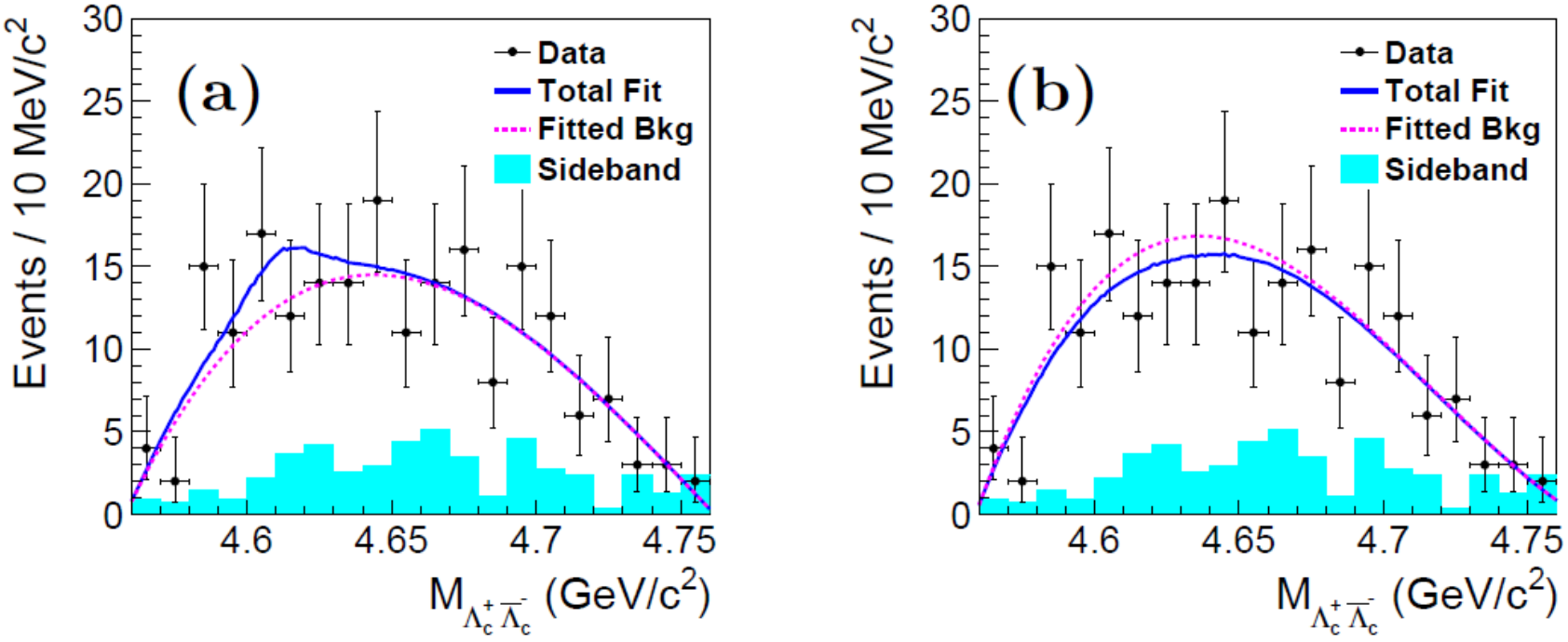


$\Xi_c(2930)^0 \to \Lambda_c^+ K^-$ 61±16 events
5.1σ significance

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

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}.

Observation of Pc states at LHCb

LHCb: PRL115, 072001 (2015)

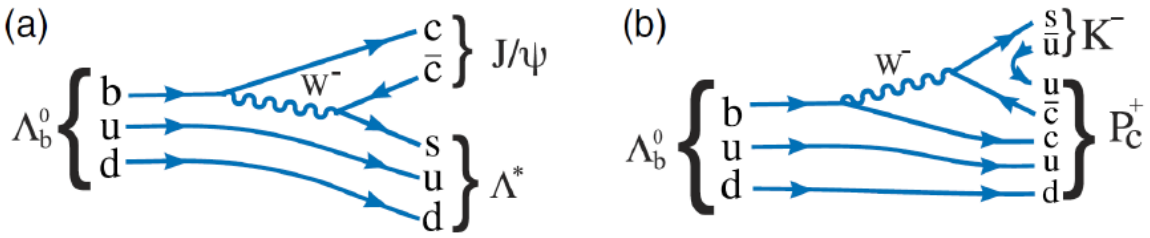
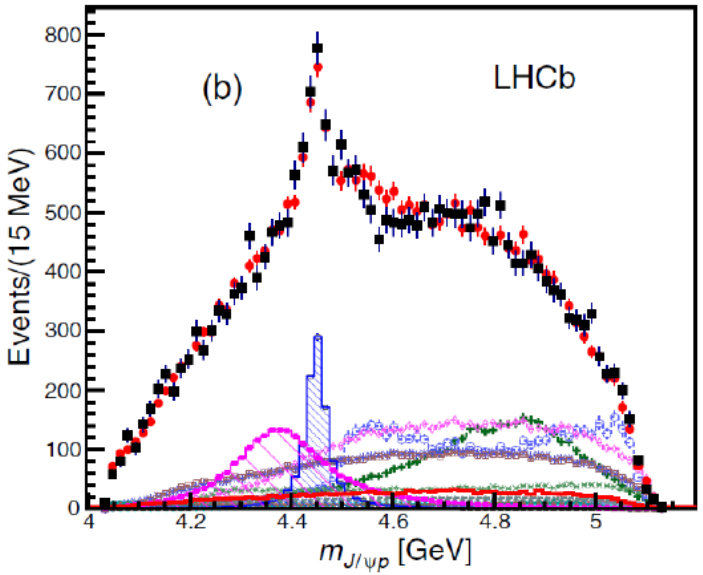
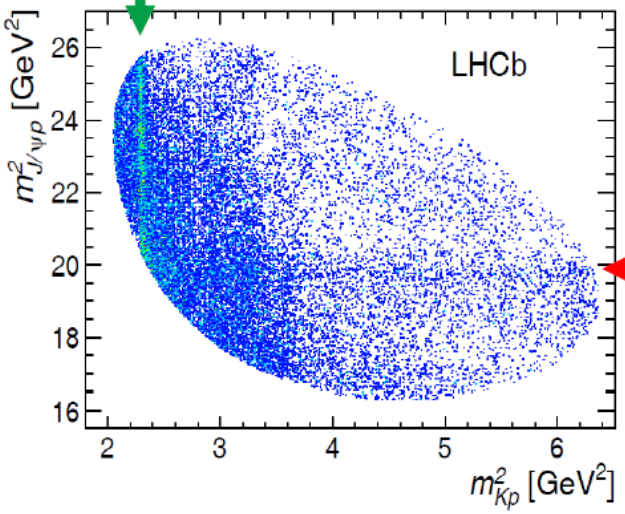


FIG. 1 (color online). Feynman diagrams for (a) $\Lambda_b^0 \to J/\psi\Lambda^*$ and (b) $\Lambda_b^0 \to P_c^+ K^-$ decay.



$\Lambda(1520) \to pK^-$



$P_c^+ \to J/\psi p$?

Search for Ps states at Belle

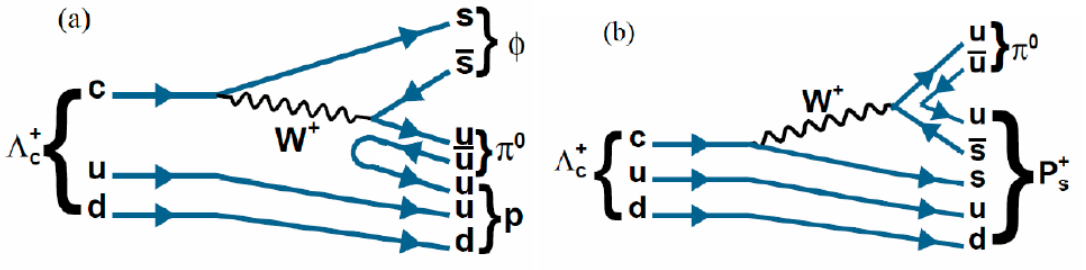
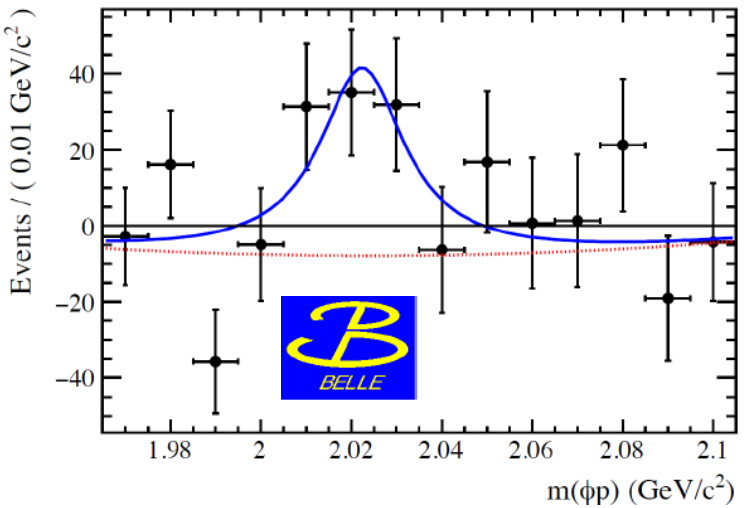


FIG. 1. Feynman diagram for the decay (a) $\Lambda_c^+ \to \phi p \pi^0$ and (b) $\Lambda_c^+ \to P_s^+ \pi^0$.



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

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

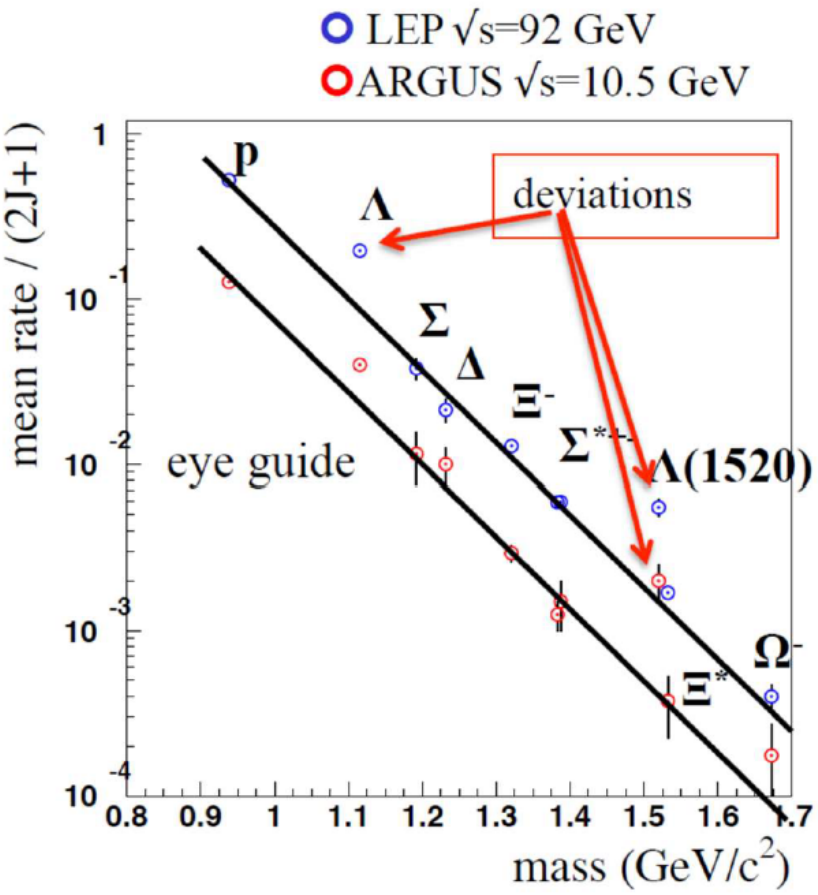
PRD96, 051102(R) (2017); 915fb^{-1}

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

$B(\Lambda_c \to P_s\pi^0) \times B(P_s \to \phi p) < 8.3 \times 10^{-5}$ @90% C.L.

Production rates of charmed baryon and hyperons

- Inclusive $e^+e^- \rightarrow h$ (+X) cross section
  $\sigma \propto (2J+1)\exp(-\alpha m)$
- Deviation for Λ and Λ(1520) in previous measurements
  - J=0, light (ud) di-quark in Λ?
- Need correction for feed-down
- How about charmed baryons?

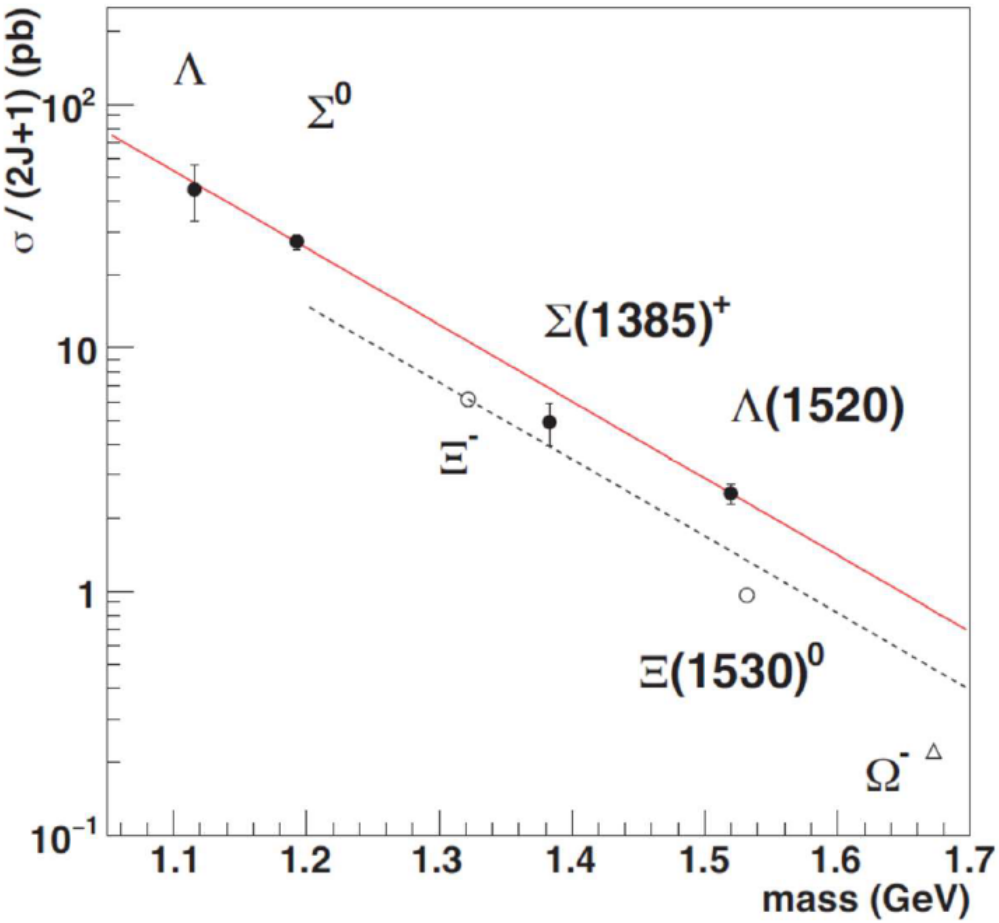


- New measurement in Belle

Result1 -- hyperons

[arXiv:1706.06791]

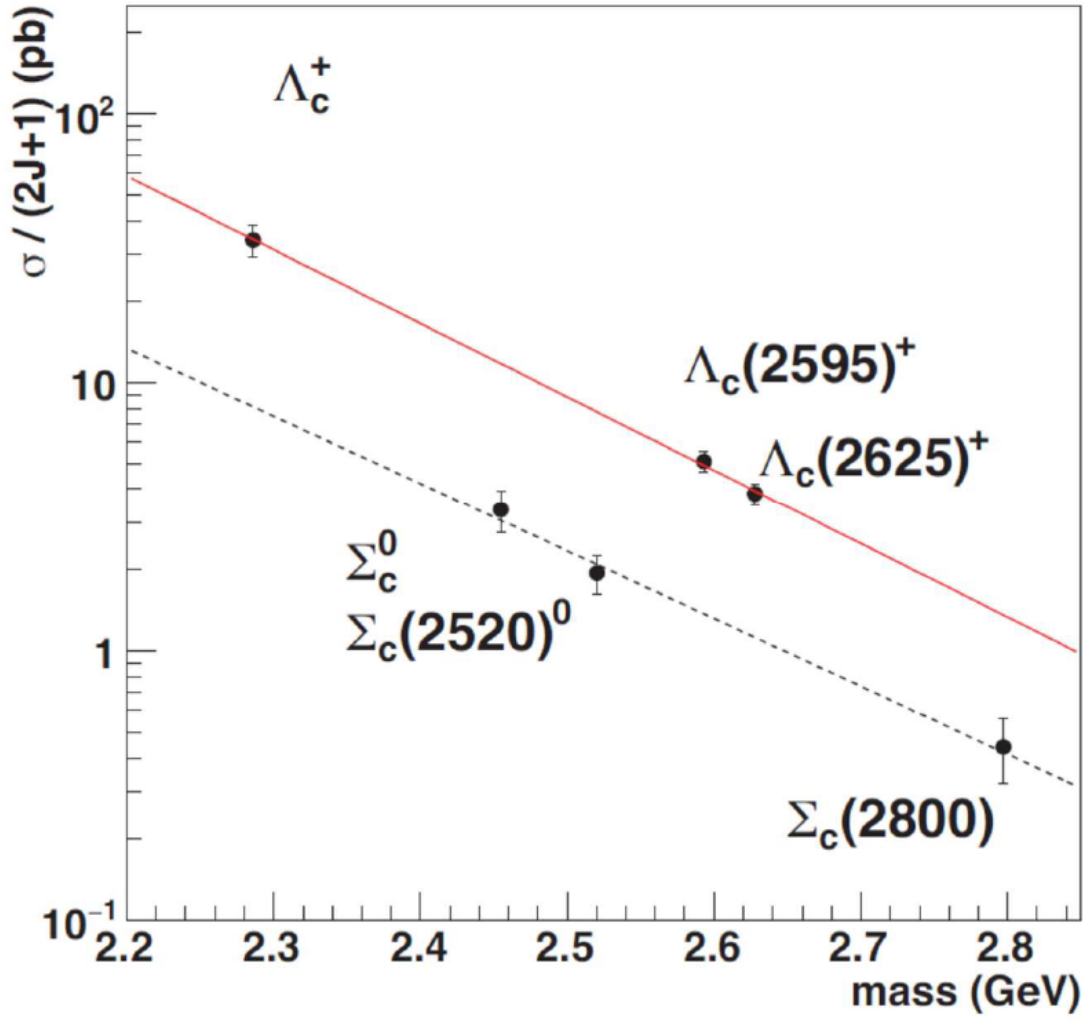
- Slope parameter
  $\alpha = -7.3 \pm 0.3$ GeV^{-1}
- Enhancement of Λ and Λ(1520) is not observed
- Suppression for "bad diquark"?
- Suppression of multi-strangeness baryons
  - g → ss suppress



Result2 – charm baryons

[arXiv:1706.06791]

- Λ_c line is siginificantly above the Σ_c line
  - By factor ~4
- Slope
  $\alpha = -6.3 \pm 0.5$ GeV^{-1} for Λ_c
  $\alpha = -5.8 \pm 1.0$ GeV^{-1} for Σ_c
- "Good diquarks" are preferably produced



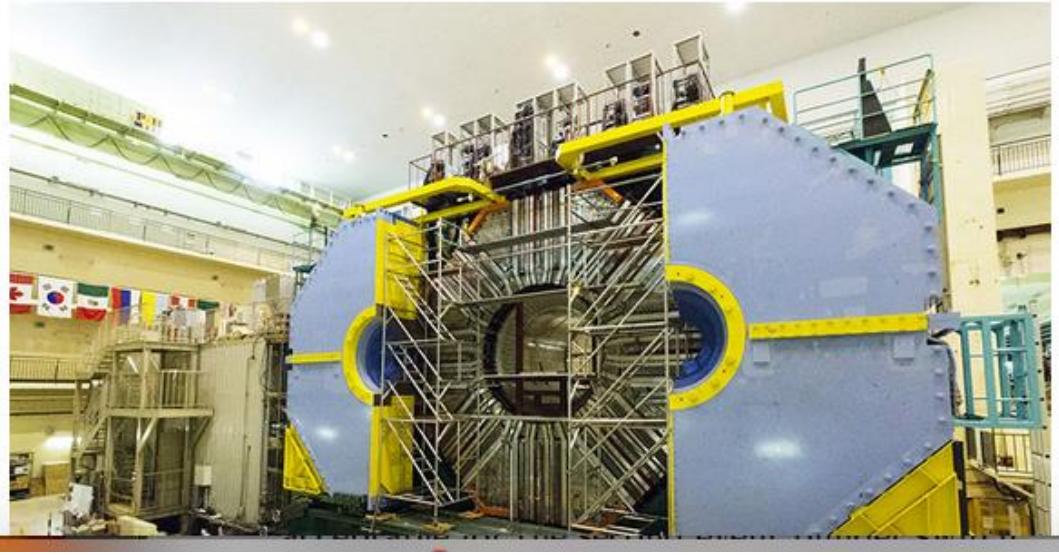
The world is waiting for us

NEWS · 12 JANUARY 2018

Revamped collider hunts for cracks in the fundamental theory of physics

Experiment smashes electrons into positrons to search for unseen particles and problems with overarching physics framework.

Elizabeth Gibney



PDF version

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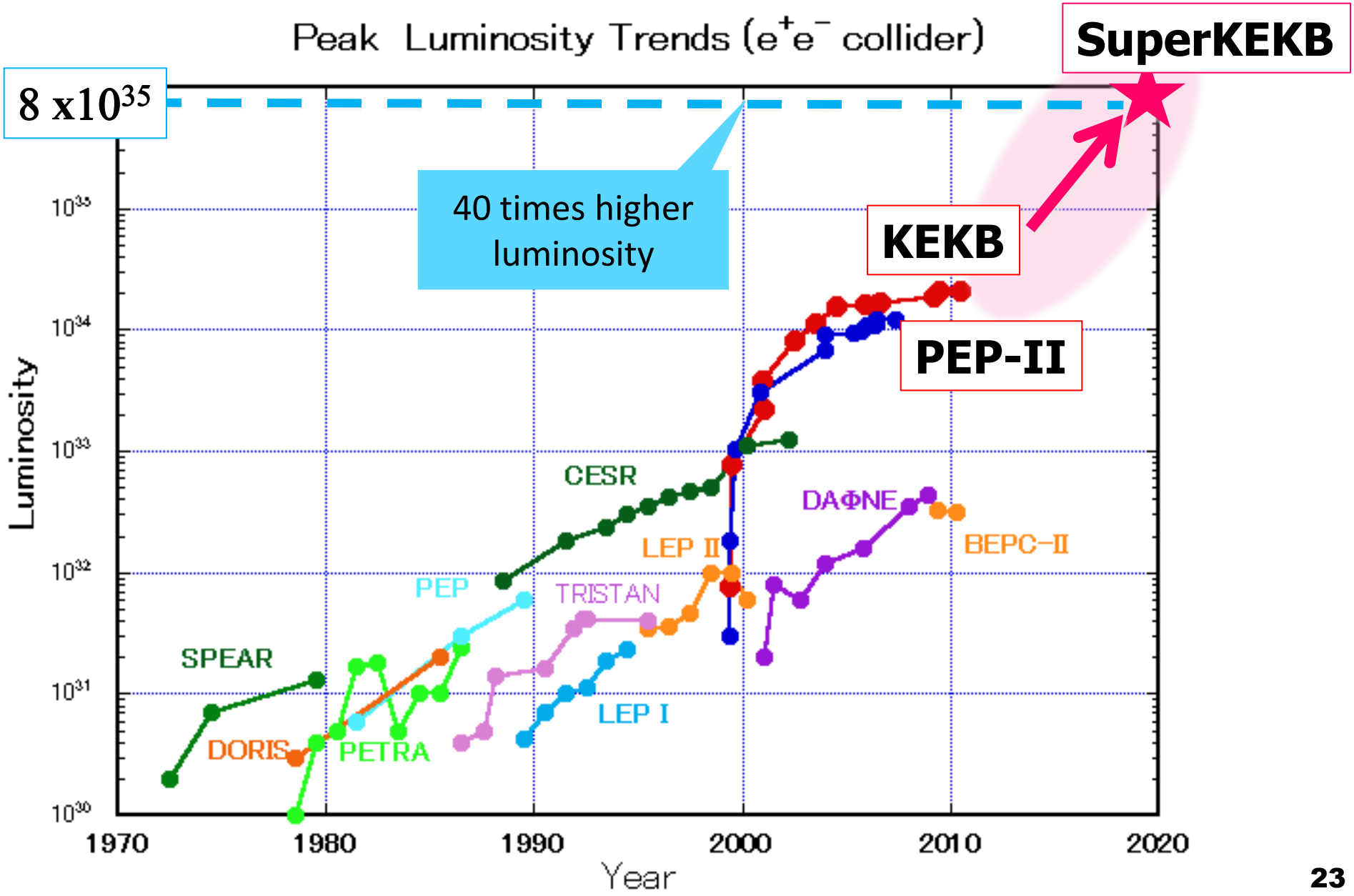
Physicists excited by latest LHC anomaly

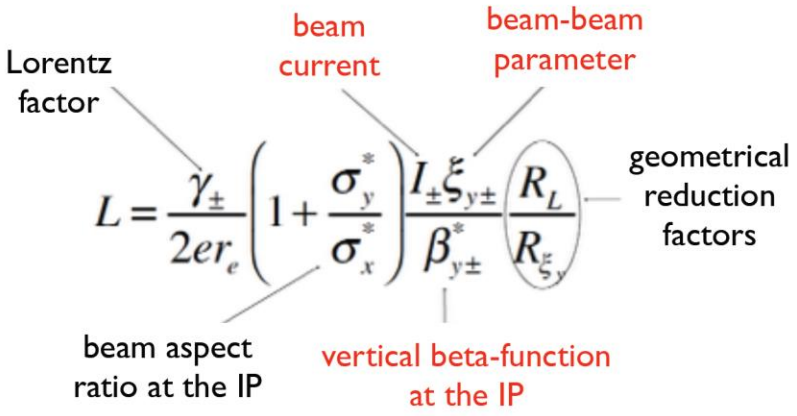
https://www.nature.com/articles/d41586-018-00162-x

Need O(100x) more data →Next generation B-factories



High-Luminosity Asymmetric B Factory

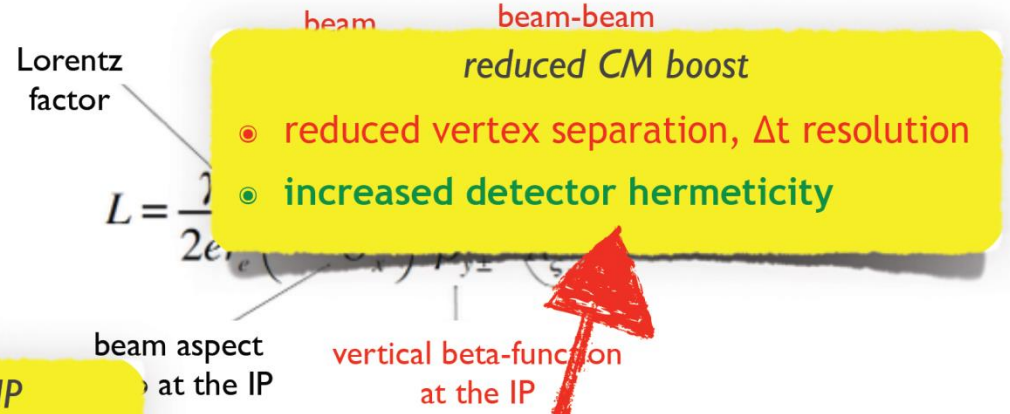
- Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @ IP by 1/20



parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
half crossing angle	φ	11		41.5		mrad
horizontal emittance	ε_x	18	24	3.2	4.6	nm
emittance ratio	κ	0.88	0.66	0.37	0.40	%
beta-function at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	129	90	0.0881	0.0807	
beam size at IP	σ_x^*/σ_y^*	100/2		10/0.059		μm
Luminosity	$\mathscr{L}$	2.1x10		8x10^{35}		cm^{-2}s^{-1}

High-Luminosity Asymmetric B Factory

- Target luminosity is $\mathscr{L}$ = 8x10^{35} cm^{-2}s^{-1} (x40 w.r.t. BELLE)
- Achievable in the *nano-beam scheme* (P. Raimondi for SuperB)
  - double beam currents
  - squeeze beams @



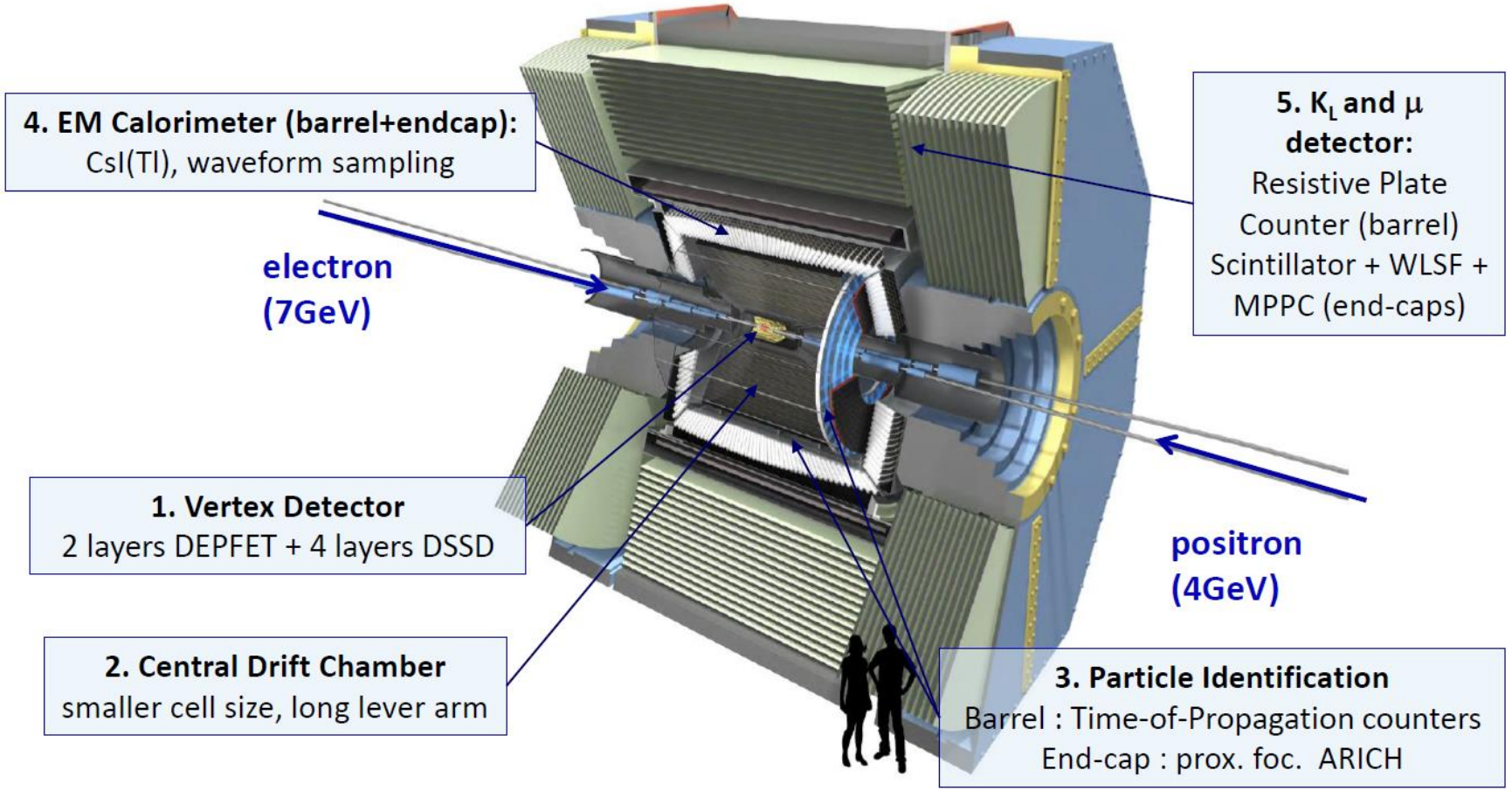
reduced CM boost
- reduced vertex separation, Δt resolution
- increased detector hermeticity

squeezed beams @ IP
- greatly improved constraint for decay chain vertex fitting

parameters		LER		SuperKEKB LER	SuperKEKB HER	units
beam energy	E_b	3.5	8	4	7	GeV
CM boost	$\beta\gamma$	0.425		0.28		
h				41.5		mrad
ho			24	3.2	4.6	nm
			0.66	37	0.40	%
b			5.9	32/0.27	25/0.30	mm
			1.19	3.6	2.6	A
bea			90	0.0881	0.0807	
			2	10/0.059		μm
			0	8x10^{35}		cm^{-2}s^{-1}

x40 luminosity
- higher background rates (~10-20x)
  - detectors occupancy, radiation damage, fake hits, pile-up noise in the calorimeter
- higher event rate
  - higher trigger rate, DAQ, computing
- x40 produced signal events

Belle II Detector



- All sub-detectors are upgraded from Belle II:
  - Except for ECL crystals and a part of Barrel KLM

- Improved IP and secondary vertex resolution
- Better K/π separation and flavor tagging
- Higher Ks, π^0 and slow pion reconstruction efficiency

Transitions to Operations

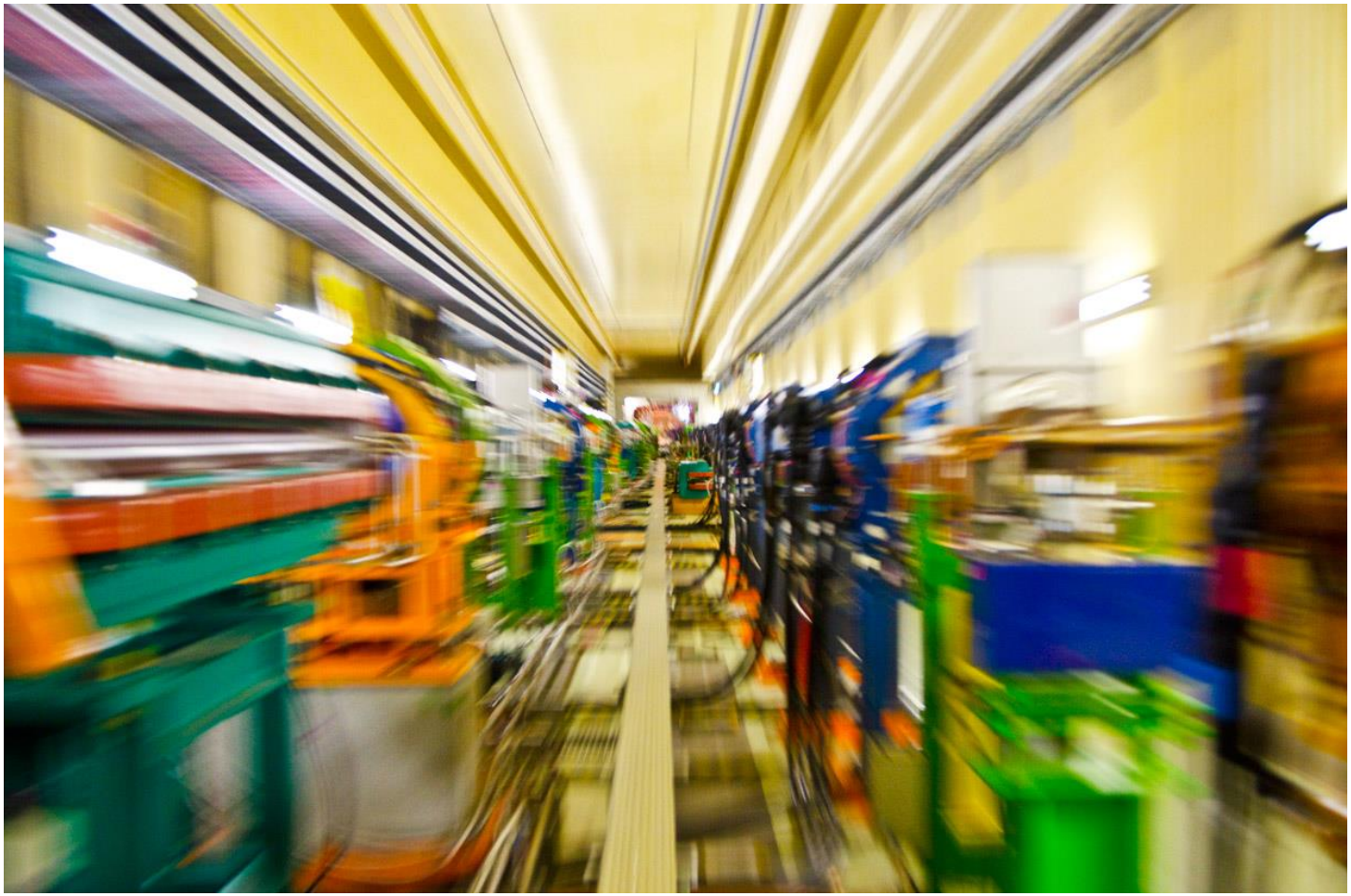
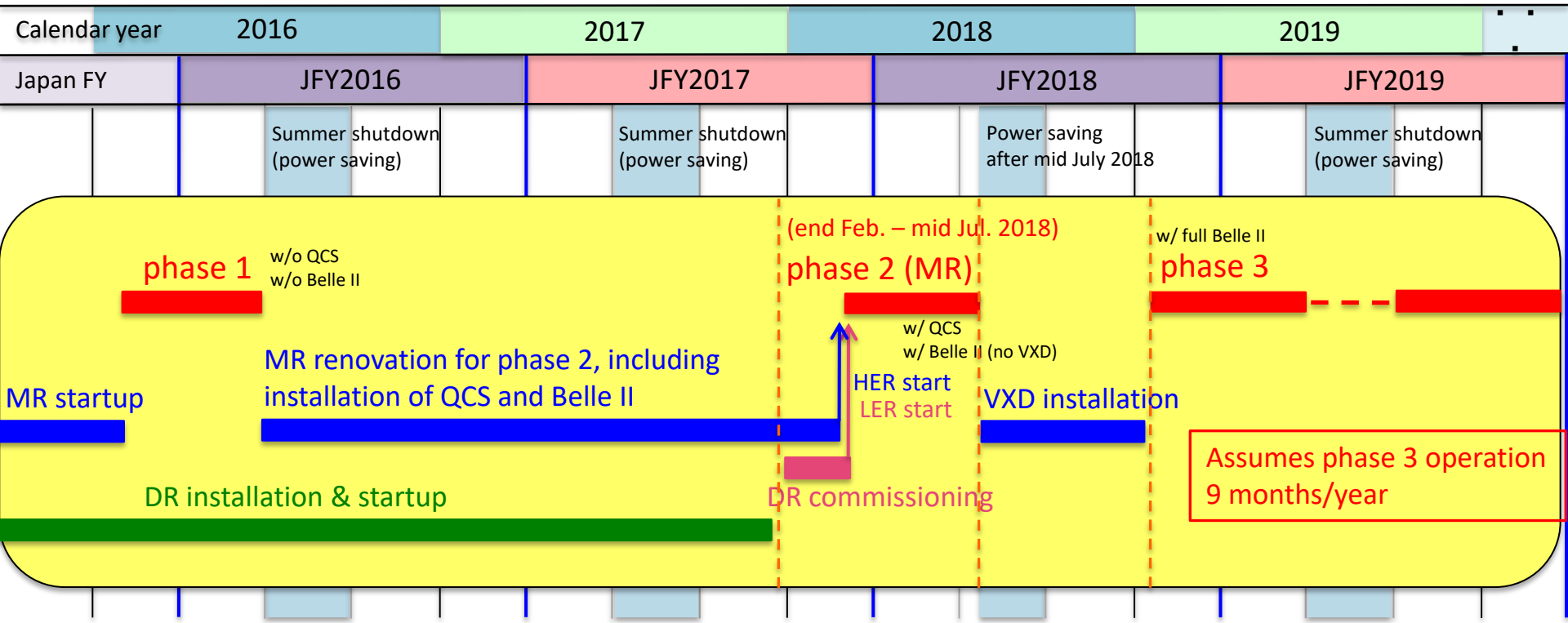


Photo credit: M. Friedl

SuperKEKB/Belle II schedule

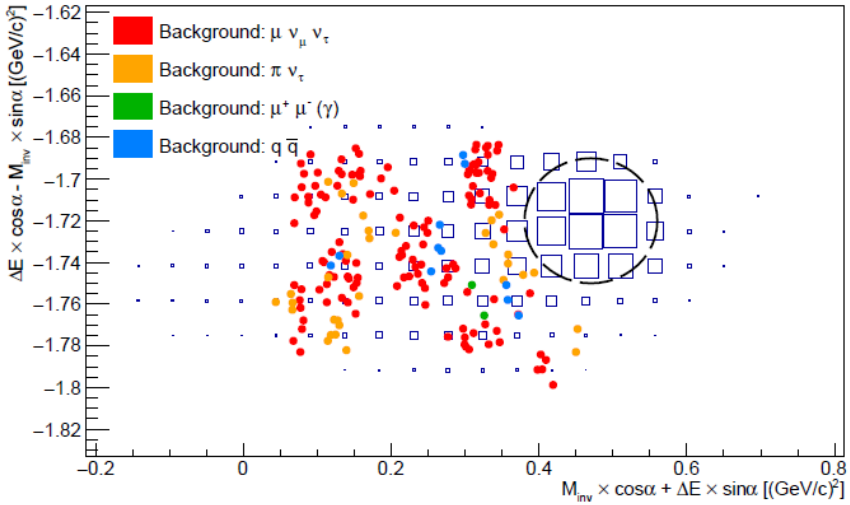
Oct. 2017



- Phase I: commissioning of the main ring; installation of outer detectors; vacuum scrubbing and beam bkg. studies
- Phase 2: start of the collisions, detector commissioning without vertex detector; first physics runs on Y(4S) and Y(6S) (~20±20 fb^{-1}) [now- July 2018]
- Phase 3: full detector operation in the end of 2018

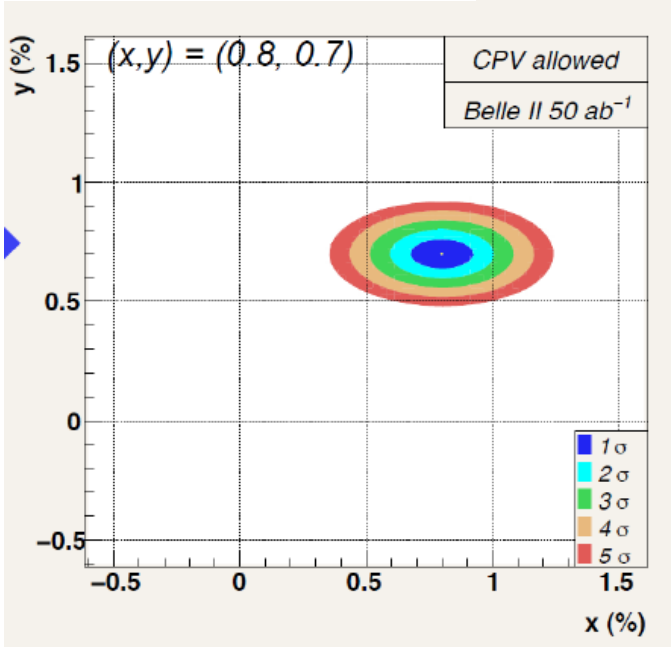
Status of Belle II Physics Book

- Belle II physics book (>630 pages), to be printed by PTEP very soon
  https://confluence.desy.de/display/BI/B2TiP+ReportStatus
- The contents include Belle II detector, simulation, reconstruction. analysis software, B decays, CKM angles, charm, quarkonium(-like), τ, new physics, ….
- Some golden channels are given with Belle II MC simulations, theoretical discussions, sensitivity and systematic estimates



MC signal and background estimates for $\tau \to \gamma\mu$

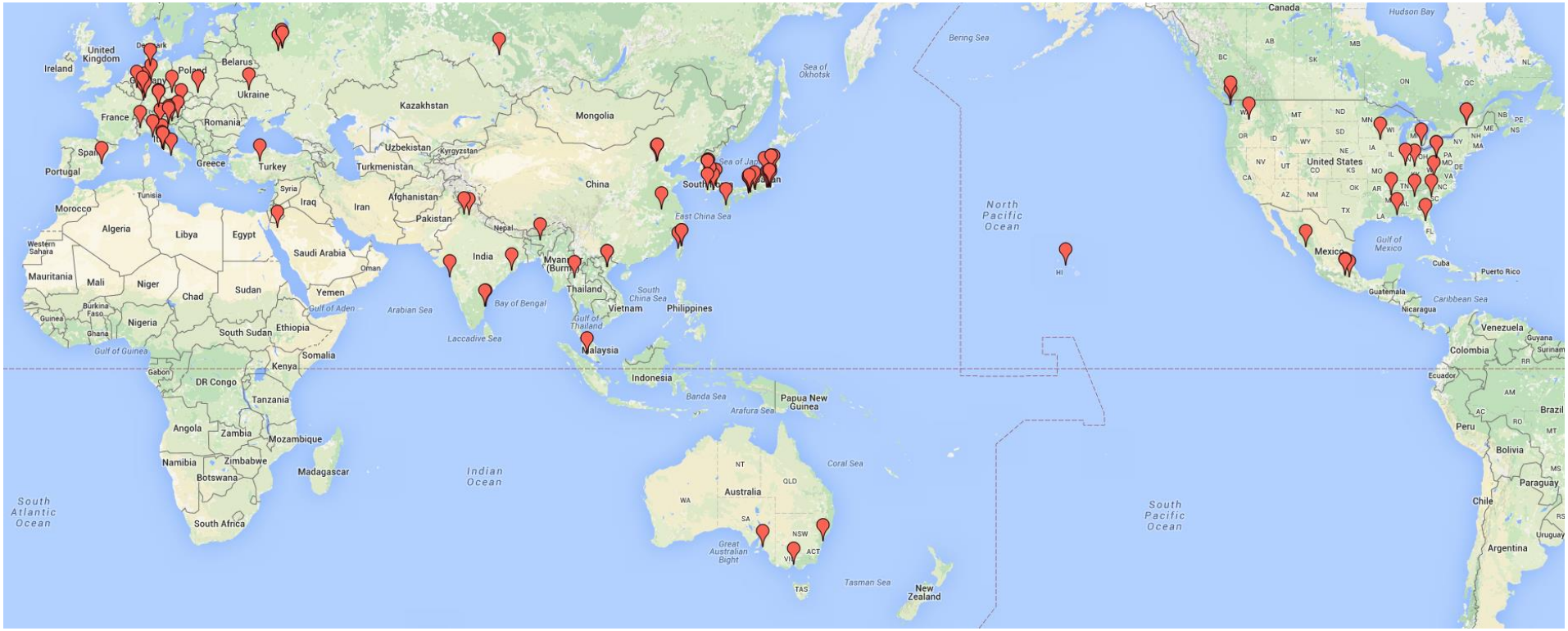
50 ab^{-1}:



Mixing constraints $D^0 - \overline{D}^0$ system

- $\gg 11.5\sigma$ to exclude no mixing (x,y)=(0,0) with CPV-allowed

Belle II Collaboration



750 colleagues, 101 institutions, 23 countries/regions

国内单位：北航、北大、高能所、中科大、复旦

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 Ξ^* and Ω^* resonances in the decay of Λ_c and Ξ_c.
  - Weak decay branches and decay asymmetry parameters
  - Exotic search: pentaquarks, dibaryons, …
    e.g., ND, $N\bar{D}$(or Θ_c), H, H_c, $\Lambda_c N$, …

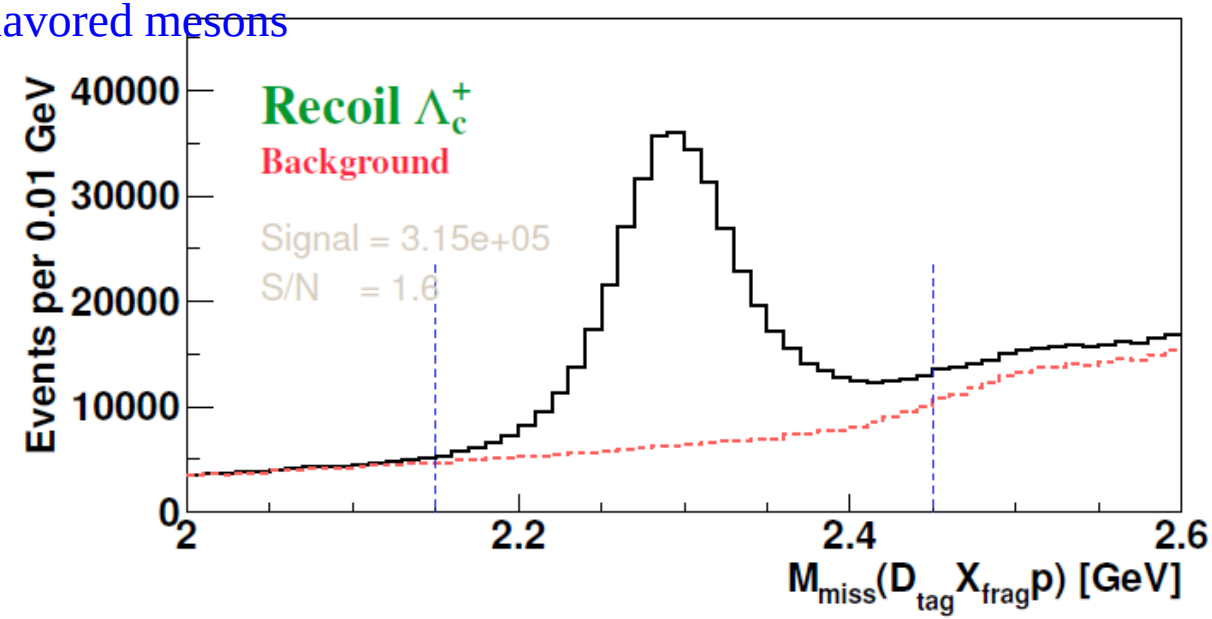
……

Inclusive $\Lambda_c^+ \to X$

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

X_{frag} : a few unflavored mesons

MC Simulation [5.5 ab^{-1}]



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

Unique sample:

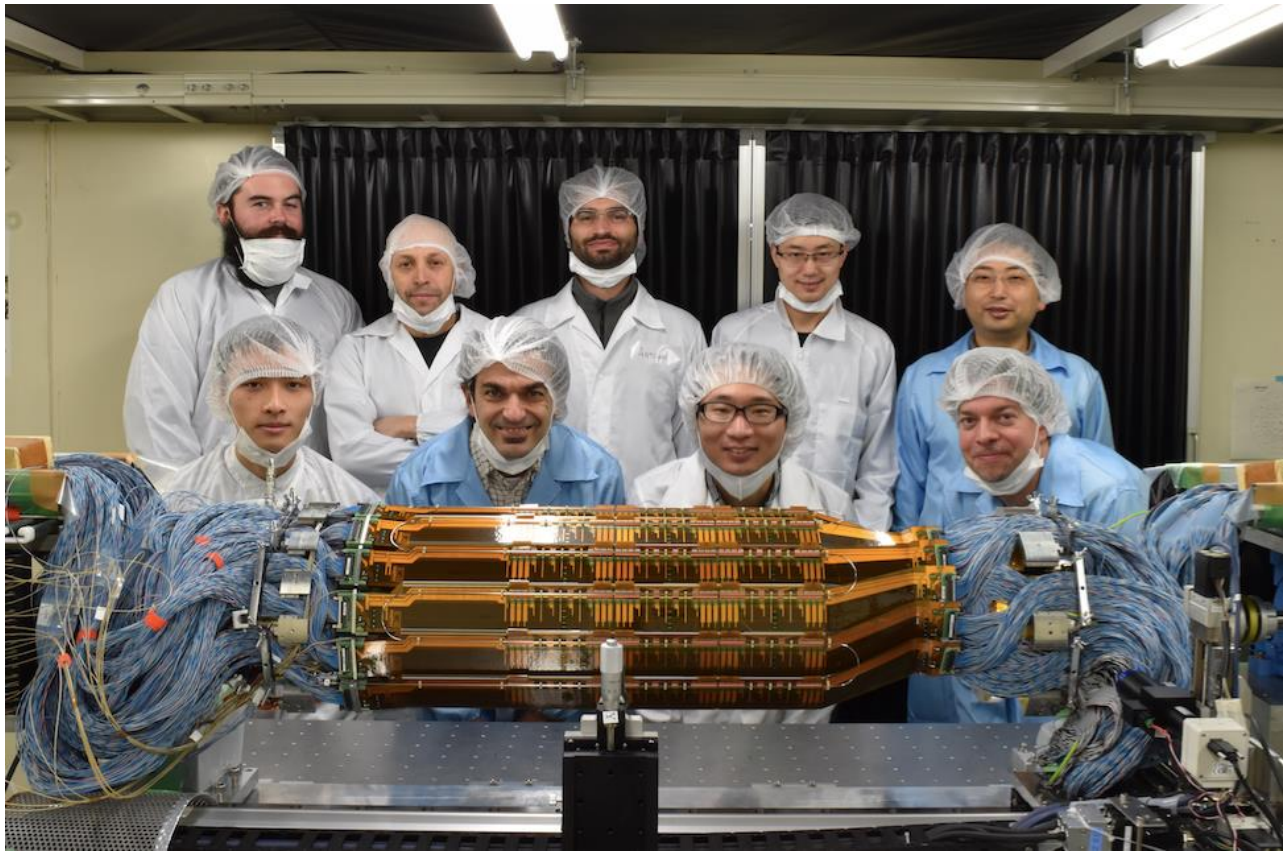
- *allows measurement of Λ_c absolute branching fractions*
- *allows measurement of semileptonic Λ_c decays*
- *allows searches for Λ_c rare decays with missing energy*

Summary

- Belle data taking is over, but still actively publishing results. Many interesting results are from baryon spectroscopy.
  - -- First observation of doubly Cabibbo-suppressed decay in $\Lambda_c^+ \to p\, K^+\pi^-$
  - -- Ω_c and excited Ω_c studies
  - -- First observation of $\Xi_c^0(2930)$ in B decays
  - -- Search for Ps in $\Lambda_c \to p\phi\pi^0$ decay
  - -- Production rates of charmed baryon and hyperons
- Interesting results are expected at Belle II, where 50 times more statistics than Belle.
  - --Spin-parity determination of most baryons and hyperons.
  - --Search for new baryon/hyperon resonances
  - -- And more …

thank you!

SVD ladder mount



- Jan 2018: Mount of the +X half shell was successfully completed

Beam Background Group

- *First Measurements of Beam Backgrounds at SuperKEKB*, submitted to NIMA, 101 pages
- Final experiment/simulation

$$LER\ beam\text{-}gas: 2.8^{+3.4}_{-2.3}$$

$$LER\ Touschek: 1.4^{+1.8}_{-1.1}$$

$$HER\ beam\text{-}gas: 108^{+180}_{-64}$$

$$HER\ Touschek: 4.8^{+8.2}_{-2.8}$$

- Phase 2 dedicated beam background detectors installed
  - VXD Volume: FANGS,CLAWS,PLUME
  - VXD dock space: TPCs, He-3 tubes
  - On QCS: PIN diodes, scintillators
- Next challenge: Phase 2 integration of DAQ and simulation

S. Vahsen, H. Nakayama et al

Photo credit: Carlos Marinas

Phase III:

Milestone: Completion of +X clam-shell of the SVD on Jan 18, 2018