最新Belle实验成果和Belle II实验介绍

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研究支撑：大科学装置高能物理实验

1 北京谱仪合作组 (BES合作组)

2 日本B介子工厂实验 (Belle合作组)

3 日本超级B介子工厂实验(Belle II合作组)

4 欧洲核子中心大强子对撞机实验(CMS合作组)

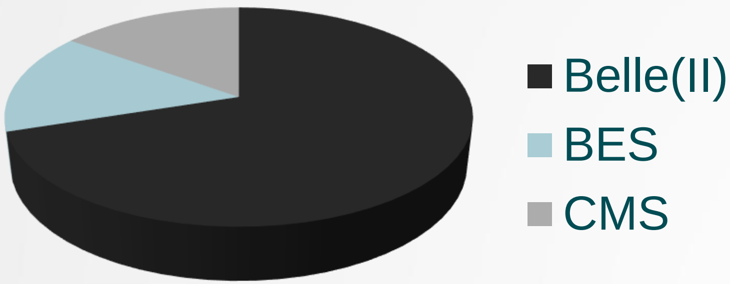
Belle合作组： 为世界上两大B介子工厂之一，其对电荷-宇称对称性破坏的研究对2008年诺贝尔物理学奖的得主扮演关键的角色。

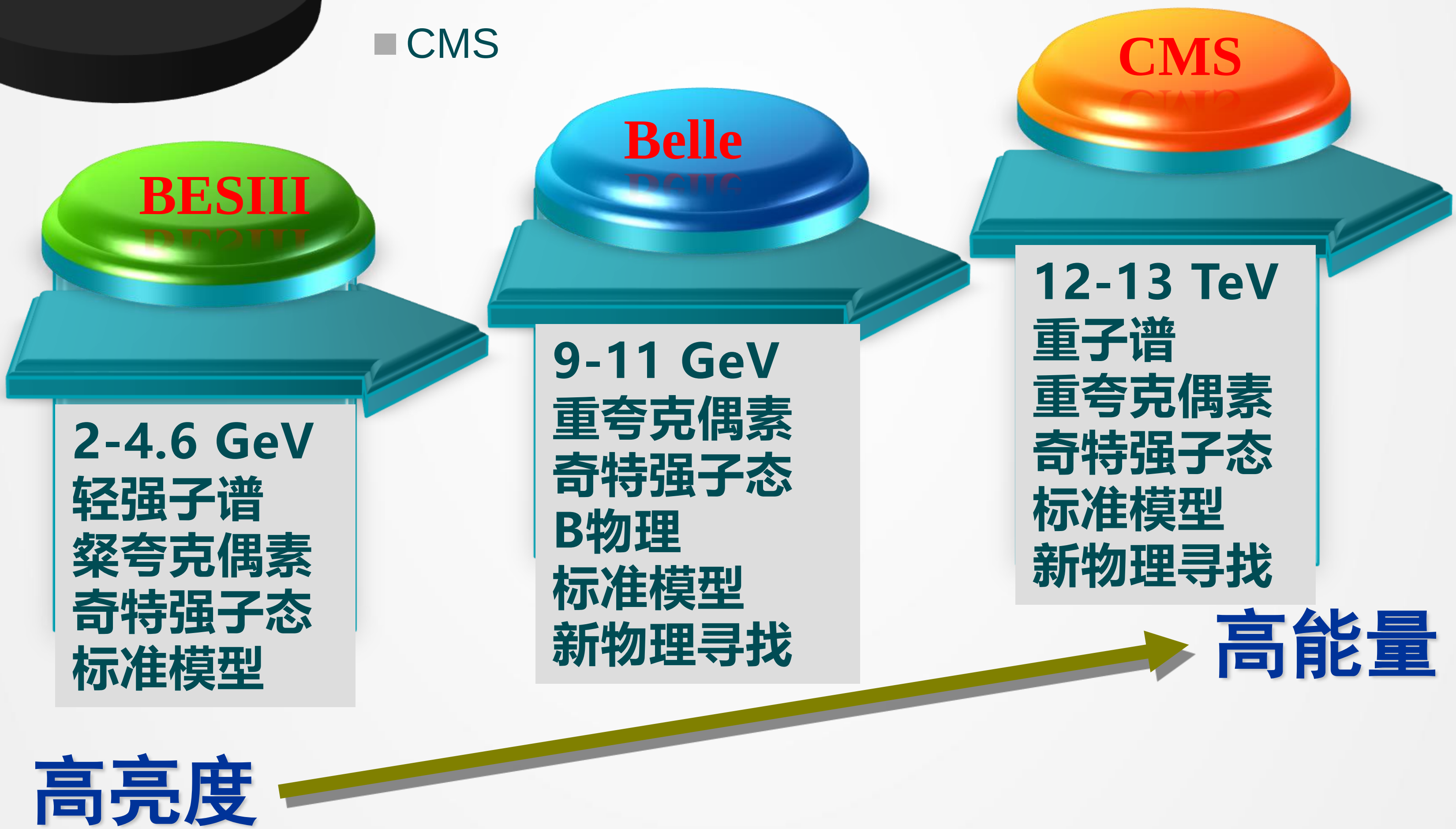
CMS实验： 上帝粒子粒子的研究对2012年诺贝尔物理学奖的得主扮演重要且关键的角色。

三者实验之间的关系

在实验方面利用BESIII、Belle、Belle II和CMS实验寻找超出标准模型的新物理和研究新强子态，同时积极参加Belle II、希格斯工厂的软硬件建设；
理论方面通过微扰量子色动力学、格点量子色动力学等理论工具研究新强子态、希格斯粒子的性质

时间分配





团队建设和依托平台

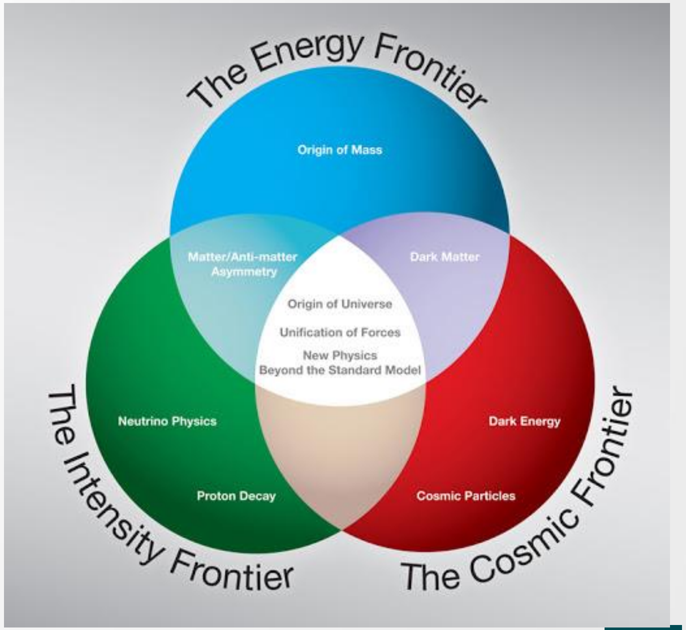
实验	人员规模	研究的课题	基金的支持
BESIII	1名教授，4名青年研究员	奇特强子态研究、稀有衰变寻找、轻强子谱和重子谱以及粲偶素产生与衰变机制、D/Ds介子的纯轻和半轻衰变等	973子课题、自然科学基金大科学装置联合面上项目、青年项目
Belle	1名教授，3名青年研究员	奇特强子态研究、粲/底偶素的产生与衰变机制、(粲)重子谱及衰变等	自然科学基金面上项目、国际交流合作项目
Belle II	1名教授，3名青年研究员	奇特强子态研究、粲/底偶素的产生与衰变机制、B介子的纯轻和半轻衰变、B介子中的CP破坏、τ轻子物理等 KLM子探测器系统升级	自然科学基金面上项目、国际交流合作项目
CMS	2名教授	希格斯粒子的性质，深入检验标准模型；寻找ZZ和WW新的共振态，以直接寻找新物理	国家重点研发计划、自然科学基金国际交流项目

*** 团队主要成员：沈成平、王小龙、罗涛、郭玉萍、严亮、Hideki okawa**

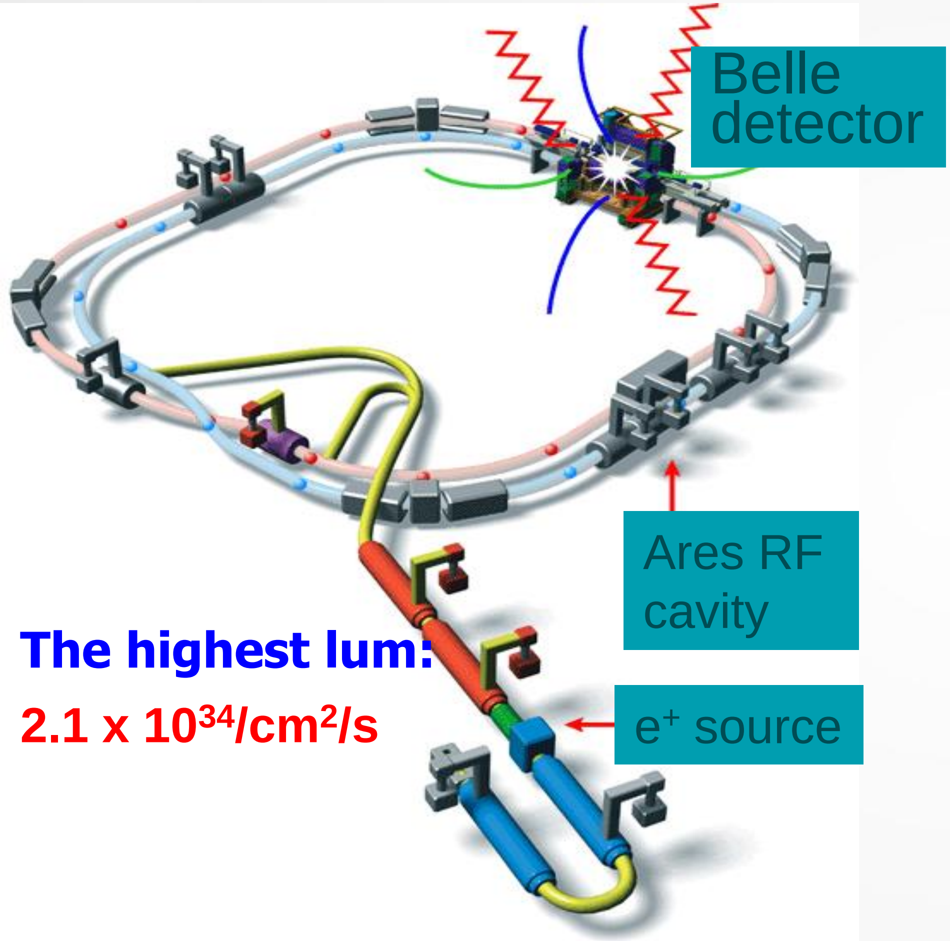
*** 复旦现在是国内Belle/Belle II合作组最大成员单位，也是BESIII合作组国内最重要的成员单位之一。**

粒子物理中亟待解决的重要问题

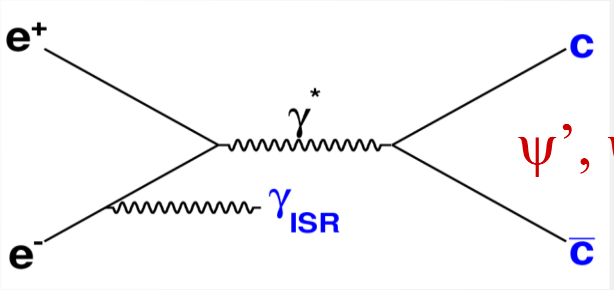
- 粒子物理标准模型成功地解释了绝大多数现有实验事实，但仍有几个重大问题亟需解答，味物理主要关注两个基本问题：
  - 是否存在新的电荷宇称（CP）破坏机制
  - 是否存在对味结构敏感的新粒子或新相互作用
- 两种回答方式：直接寻找和间接寻找，互为补充；历史上很多发现都由间接寻找给出
- 利用重味物理实验所采集的大统计量数据，通过精确测量，可以间接寻找高能标的新物理



Belle 实验



KEKB Collider

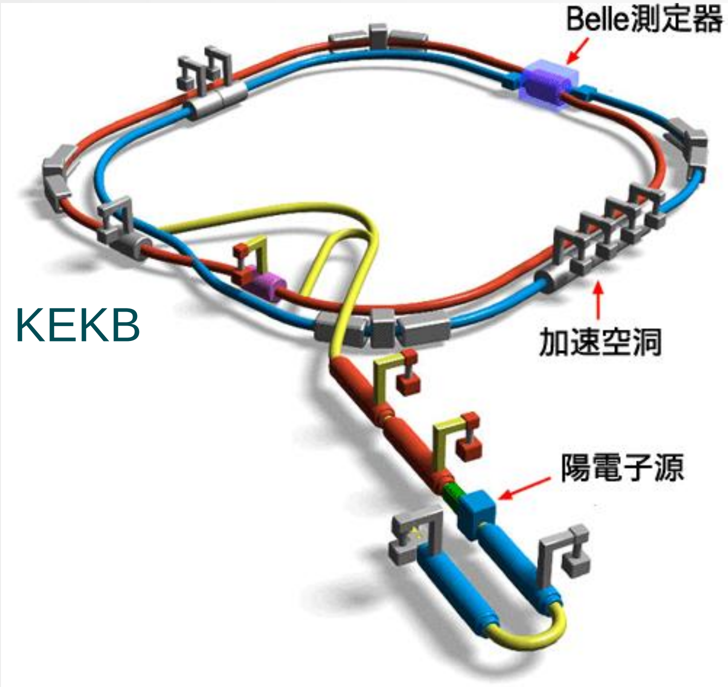


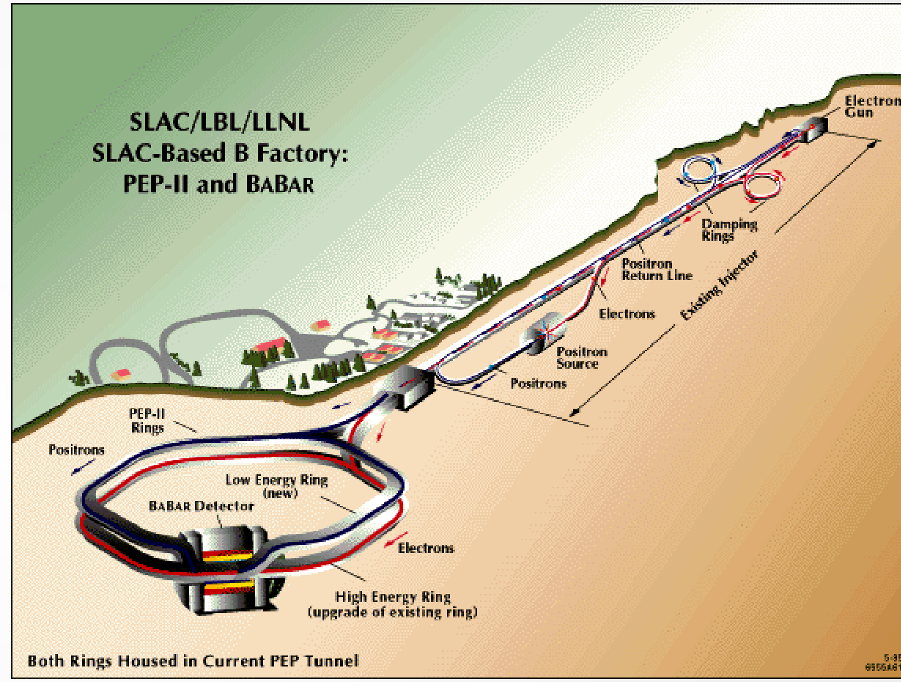
ψ', ψ'', Y…

CMS energy
10.58 GeV

Effective CMS
3-5 GeV

Asymmetric B factories: flavour physics at the luminosity frontier





$\sqrt{s}=10.58$ GeV

$e^+ \rightarrow \Upsilon(4s) \leftarrow e^-$

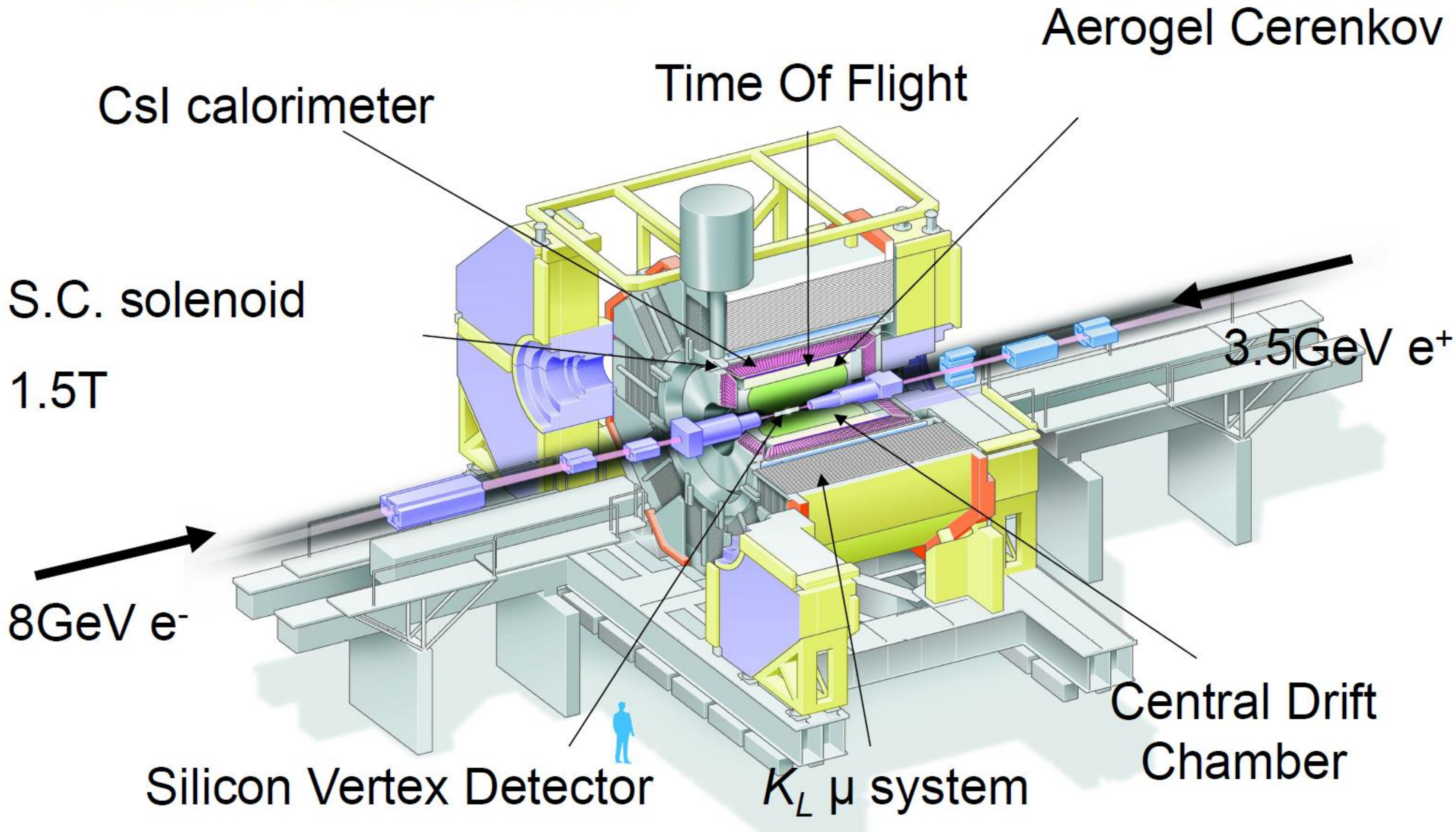
$\Upsilon(4s) \rightarrow B\,\bar{B}$

$\Delta z \sim c\beta\gamma\tau_B$
$\sim 200\mu m$

BaBar $p(e^-)=9$ GeV $p(e^+)=3.1$ GeV $\beta\gamma=0.56$

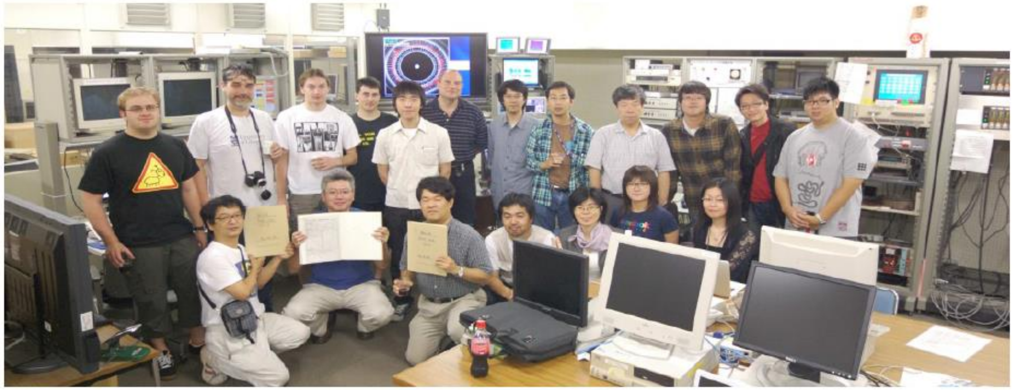
Belle $p(e^-)=8$ GeV $p(e^+)=3.5$ GeV $\beta\gamma=0.42$

Belle detector



High resolution, general purpose 4π spectrometer with particle-id

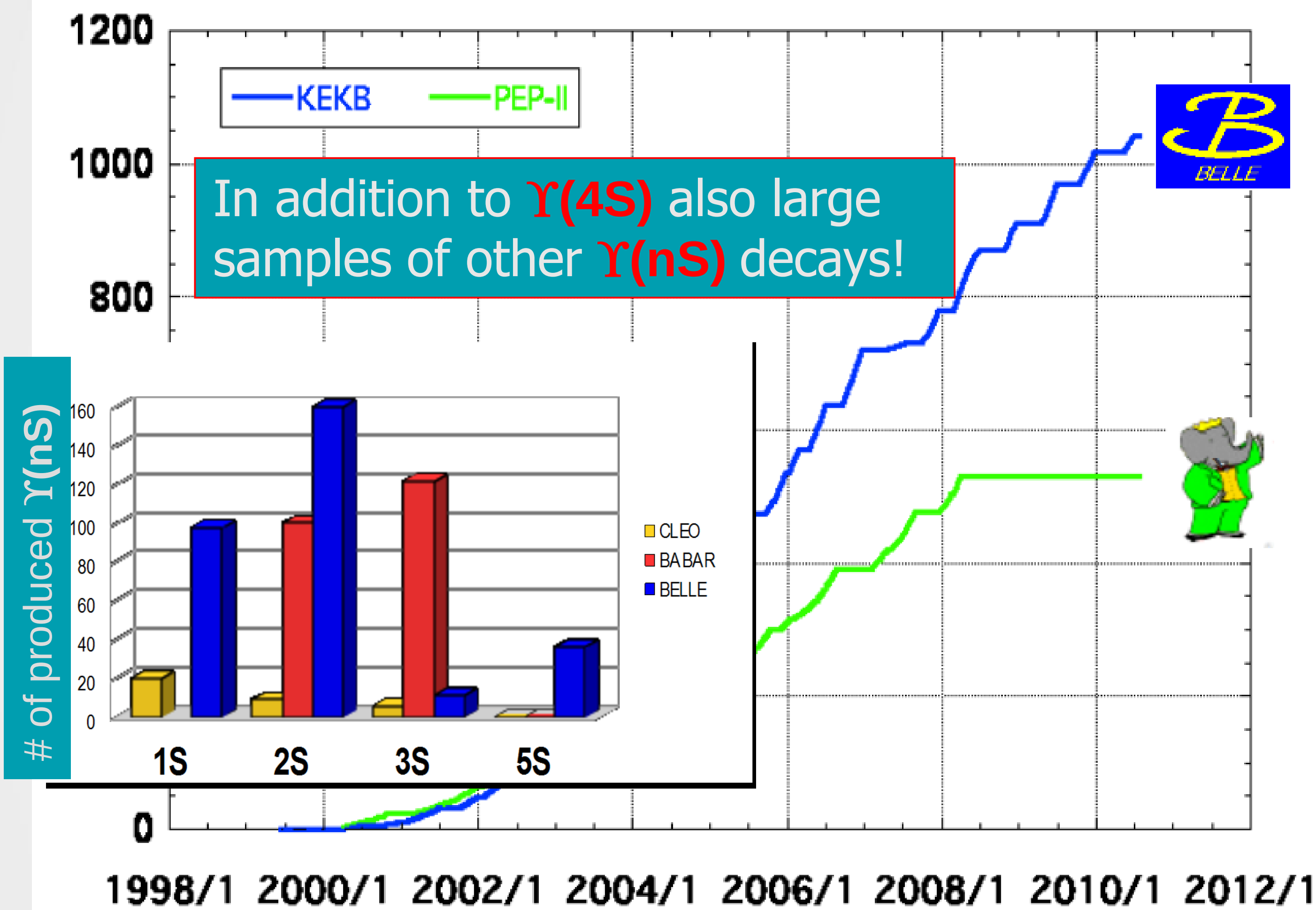
The last beam abort of KEKB on June 30, 2010



First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1 \times 10^{34}/cm^2/s$
$L > 1ab^{-1}$

Integrated luminosity of B factories

Fantastic performance far beyond design values!



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

~ 54 fb^{-1}

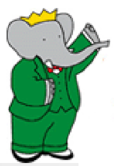
Time Dependent CPV – Success! (2001)

VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

Observation of Large CP Violation in the Neutral B Meson System

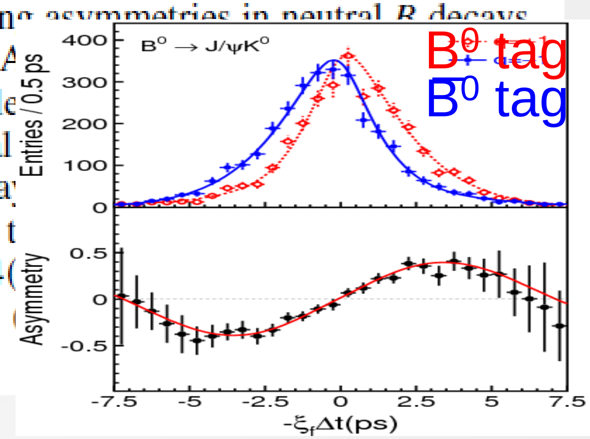
We present a measurement of the standard model CP violation parameter $\sin 2\phi_1$ based on a 29.1 fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. One neutral B meson is fully reconstructed as a $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$, $J/\psi K_L$, or $J/\psi K^{*0}$ decay and the flavor of the accompanying B meson is identified from its decay products. From the asymmetry in the distribution of the time intervals between the two B meson decay points, we determine $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$. We conclude that we have observed CP violation in the neutral B meson system.

VOLUME 87, NUMBER 9 PHYSICAL REVIEW LETTERS 27 AUGUST 2001

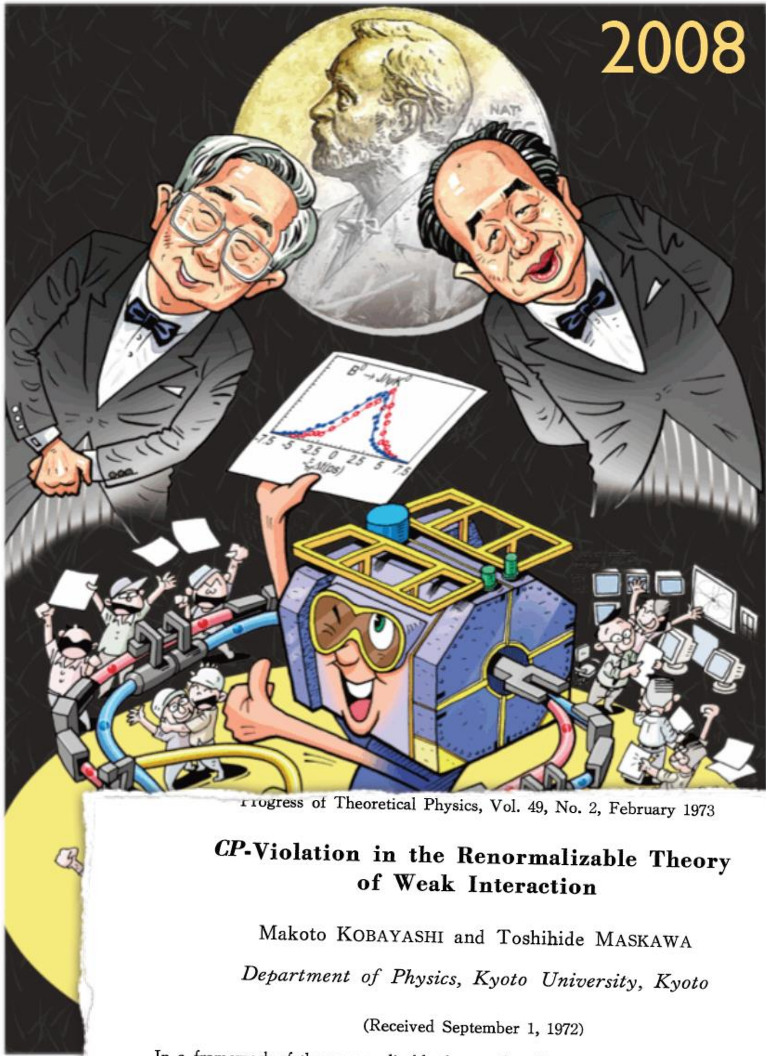


Observation of CP Violation in the B^0 Meson System

We present an updated measurement of time-dependent CP-violatin
with the *BABAR* detector at the PEP-II asymmetric B Factory at SLA
sample of $\Upsilon(4S)$ decays collected in 2001, bringing the data available
events in which one neutral B meson is fully reconstructed in a final
the flavor of the other neutral B meson is determined from its deca
CP-violating asymmetry, which in the standard model is proportional t
time distributions in such events. The result $\sin 2\beta = 0.59 \pm 0.14($
violation in the B^0 meson system. We also determine $|\lambda| = 0.93 \pm$
with no direct CP violation.



CPV is due to an irreducible phase in the unitary quark mixing matrix in 3 generations



Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

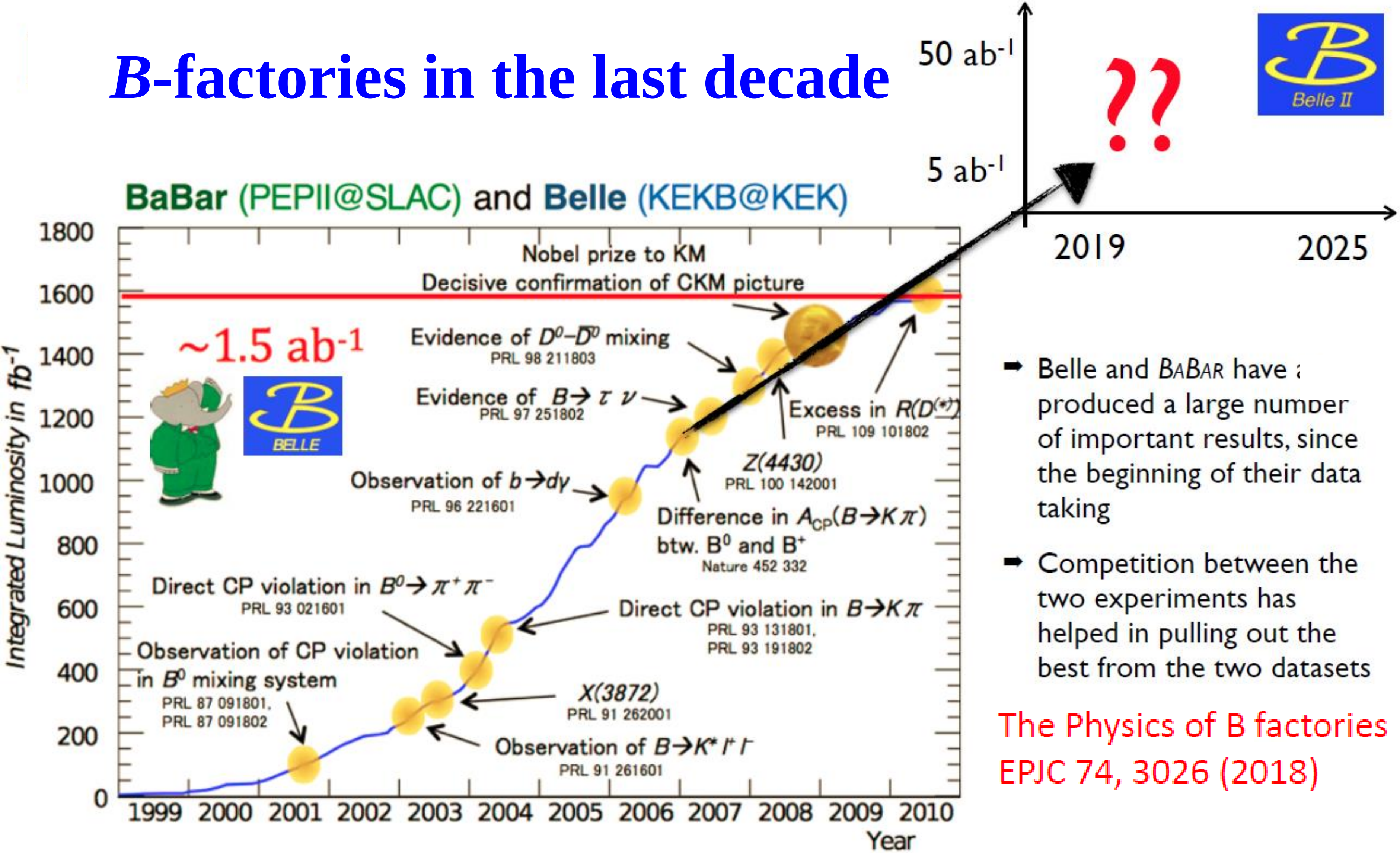
(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system, ...

- Critical role of the *B*-factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation
- A single irreducible phase in the weak int. matrix accounts for most of the *CP* violation observed in the K's and in the B's
- *CP*-violating effects in the B sector are $\mathcal{O}(1)$ rather than $\mathcal{O}(10^{-3})$ as in the K^0 system.

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

Book: The Physics of the B factories

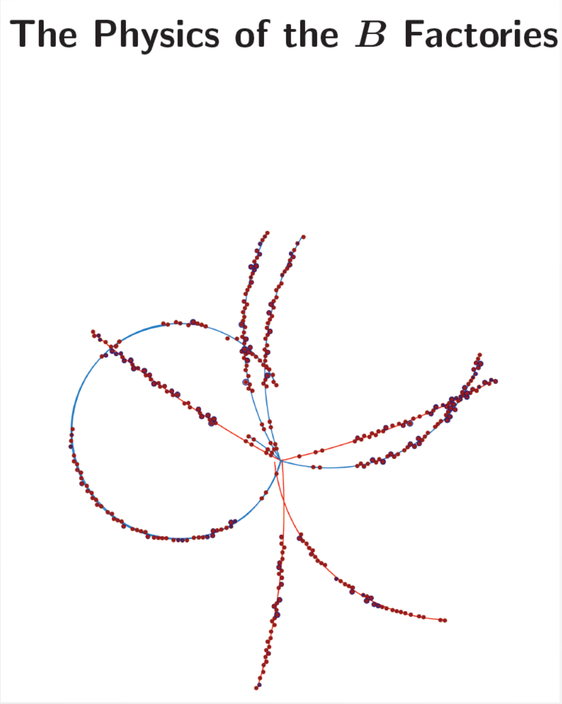
- Released on 2013.7.8
- Efforts from both of BaBar and Belle
- More than four years to finish it !

Foreword

Makoto Kobayashi
Honorary Professor Emeritus
KEK

2008 诺贝尔奖写序

Toshihide Maskawa
Director General
Kobayashi-Maskawa Institute for the Origin of Particles and the Universe
Nagoya University



Press Release

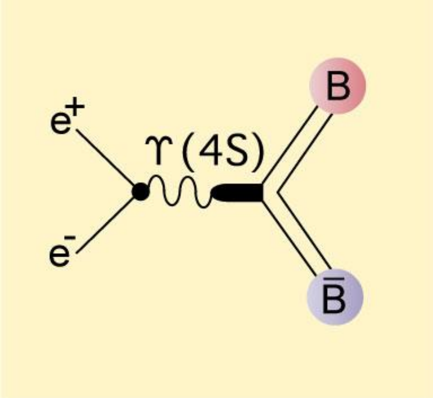
50 years from the Discovery of "CP-violation"

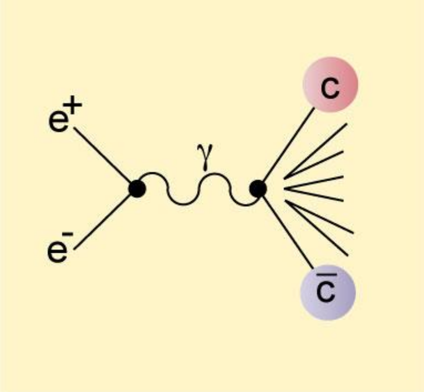
- Belle and Babar complete the Joint Book on their experimental work to prove the Kobayashi-Maskawa theory of CP-violation -

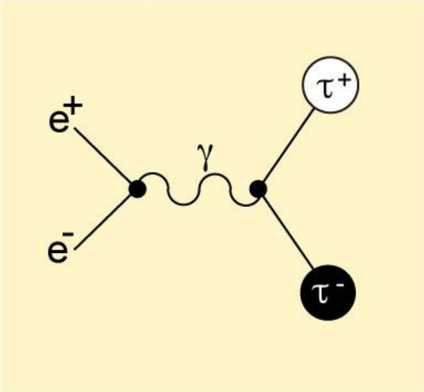
July 11, 2014

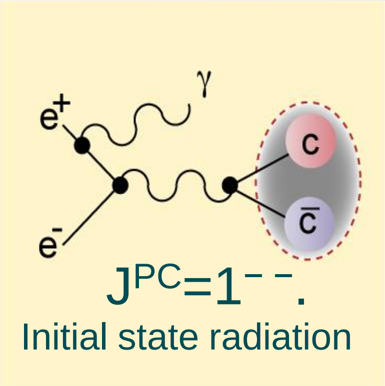
arXiv:1406.6311
EPJC 74, 3026 (2014)
Book: ~900 pages

The Physics Program



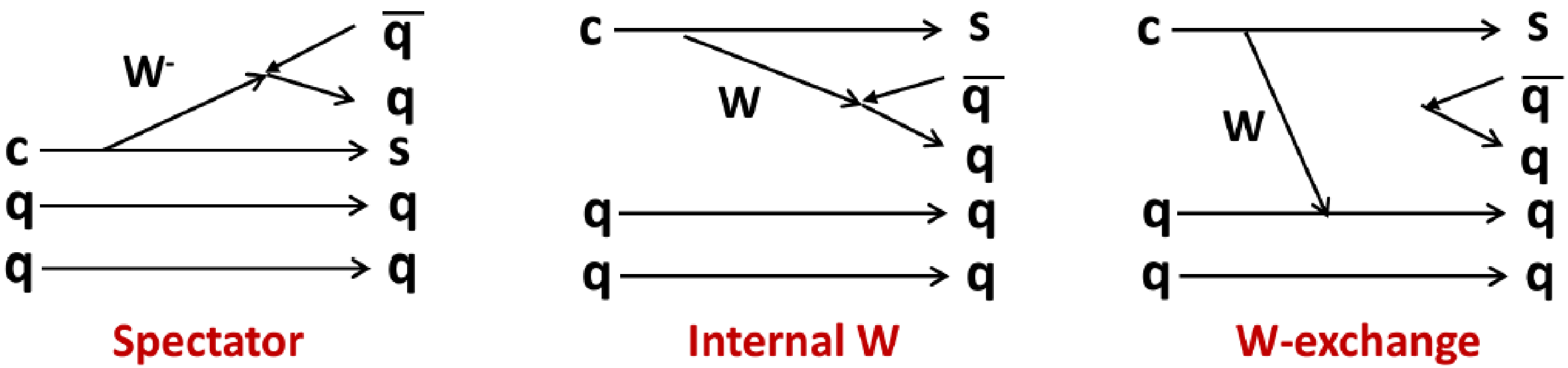






- a (Super) B-factory (~1.1 x 10^9 $B\bar{B}$ pairs per ab^{-1});
- a (Super) charm factory (~1.3 x 10^9 $c\bar{c}$ pairs per ab^{-1});
- a (Super) τ factory (~0.9 x 10^9 $\tau^+\tau^-$ pairs per ab^{-1});
- thanks to the Initial State Radiation, we can effectively scan the range [0.5 – 10] GeV and measure 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, …

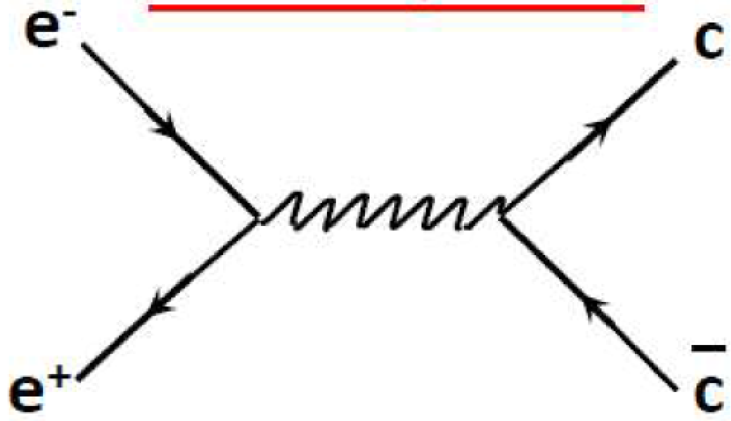
The Charmed Baryon Physics



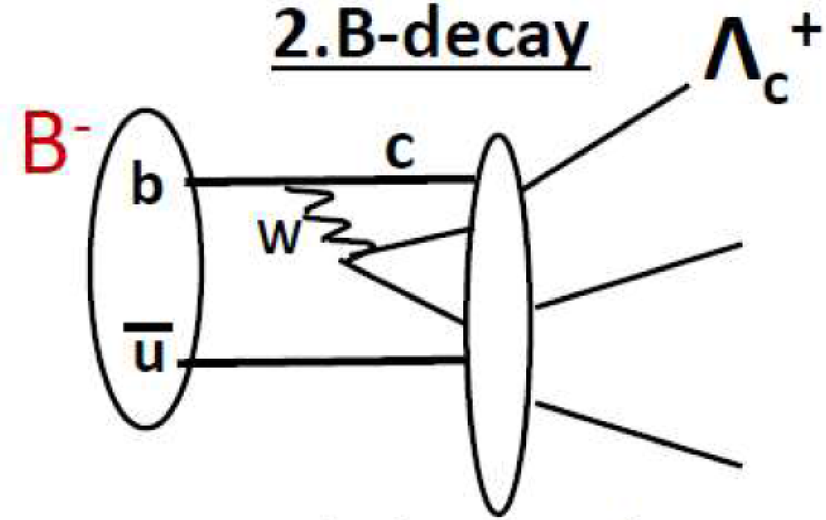
- The weak decay of charmed baryon has not been understood well.
- Three diagrams contribute in the tree level, but their strengths are not known.
- Ground state charm baryon is a good laboratory for studying strange baryons as decay proceed via $c \to s$ transition.
- Belle has collected $\sim 1\ \mathrm{ab}^{-1}\ \mathrm{e}^{+}\mathrm{e}^{-}$ 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.

Baryon production at B-factory

1. $e^+e^- \rightarrow c c^{bar}$



2. B-decay



Baryons produced via fragmentation

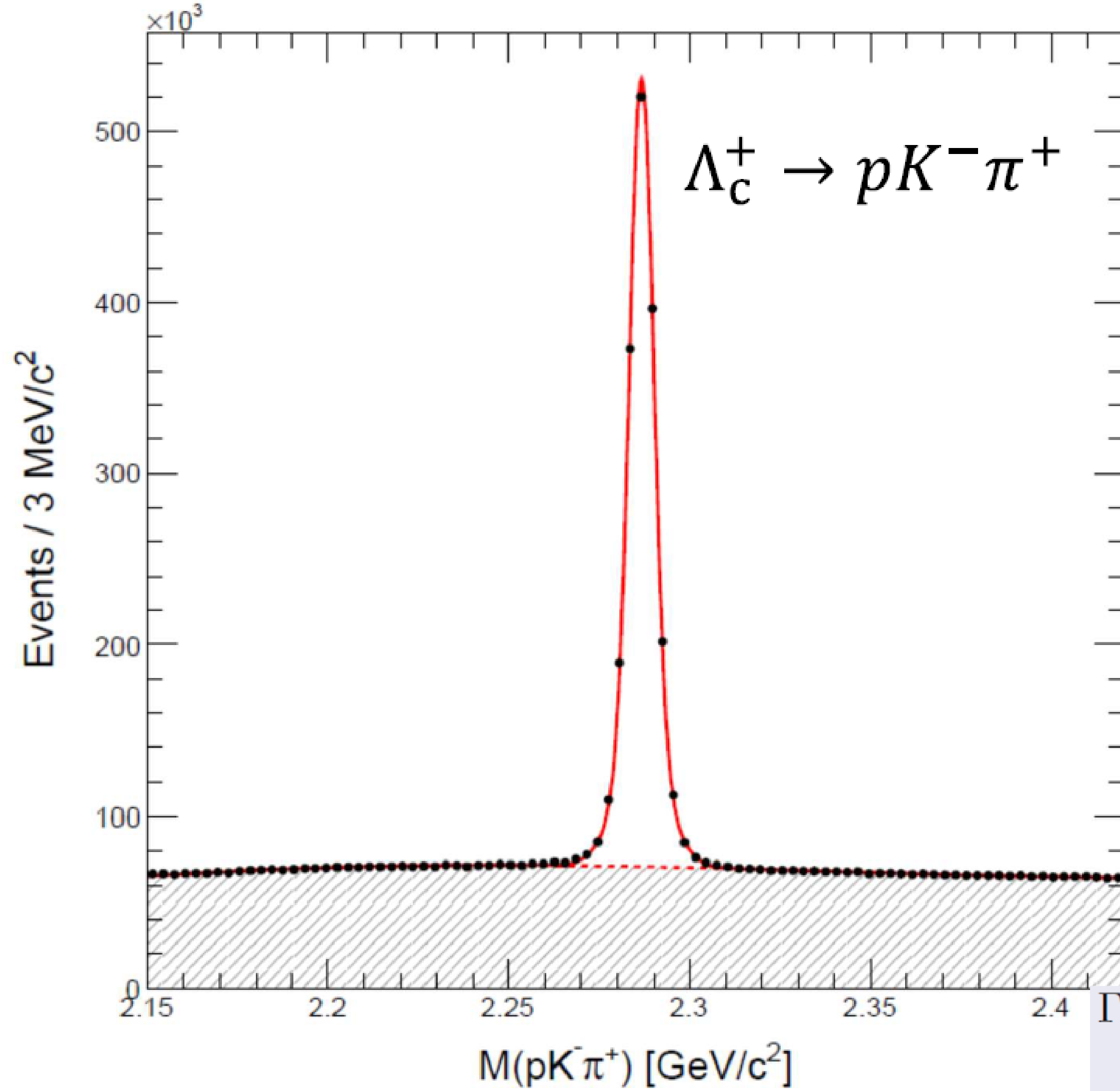
- Charmed baryons – rather direct
- Hyperons – later stage of fragmentation

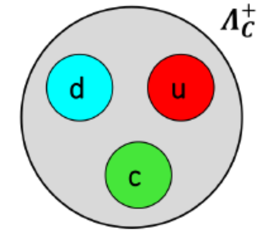
Huge statistics

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

Once bottom is produced, it favorably decays into charm.

Huge statistics, good quality





> 1 M events reconstructed

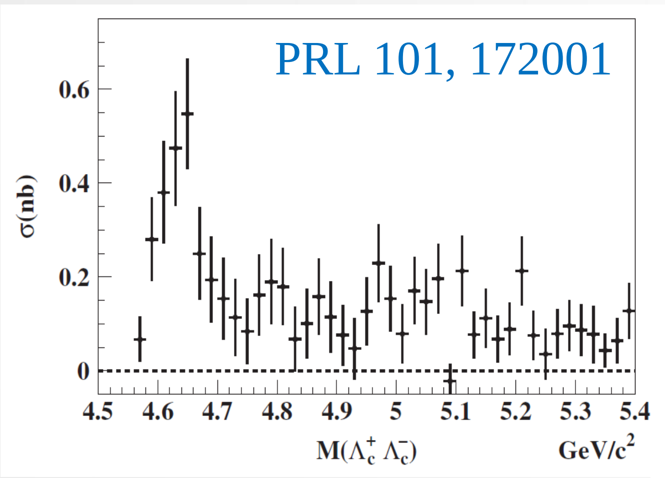
Resolution:
< 10 MeV FWHM

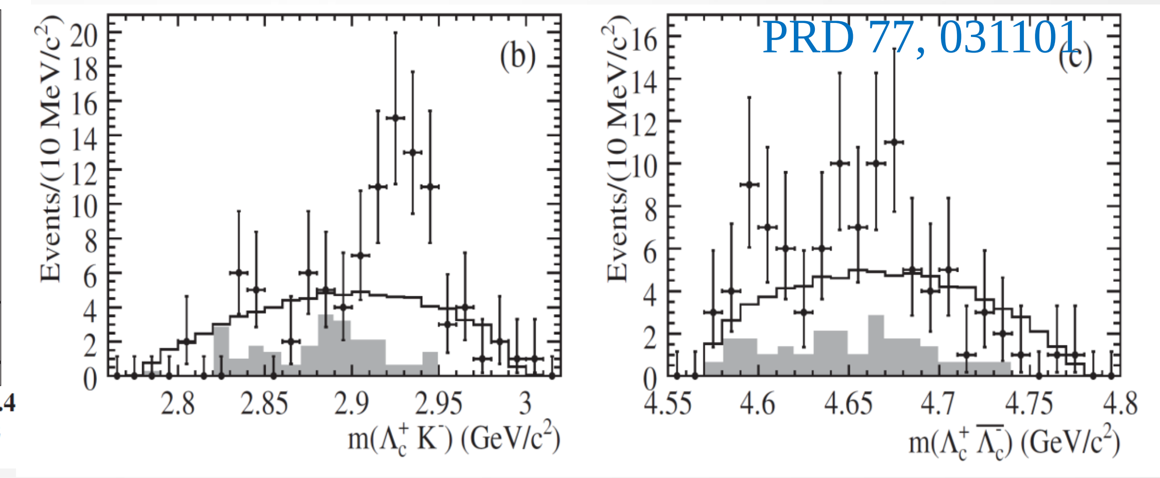
S/N ~ 10

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

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

- Belle reported a structure, called X(4630), in the $\Lambda_c^+\overline{\Lambda}_c^-$ invariant mass distribution in $e^+e^- \to \gamma_{ISR}\Lambda_c^+\overline{\Lambda}_c^-$ PRL 101, 172001
- BarBar once studied $B^+ \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ and found two small peaks in $M_{\Lambda_c^+\overline{\Lambda}_c^-}$ 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 $\Lambda_c^+\overline{\Lambda}_c^-$ and it's isospin partner Y(4616) is predicted. PRD 82, 094008; PRL102, 242004





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

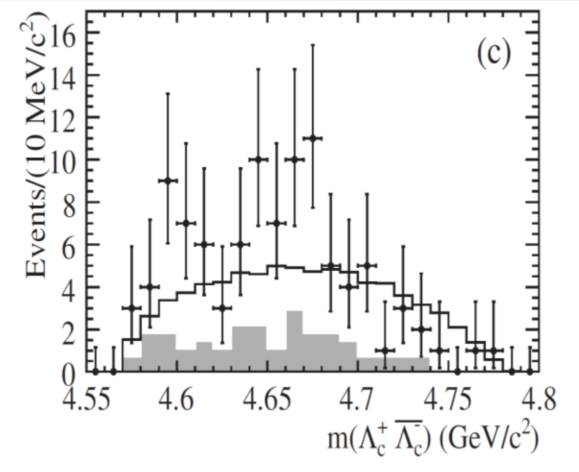
$\Xi_c(2930)$ *

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

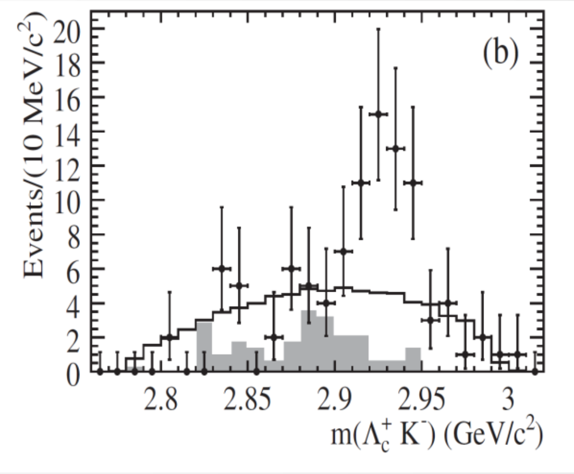
$\Xi_c(2930)$ $\quad$ $I(J^P) = ?(?^?)$

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

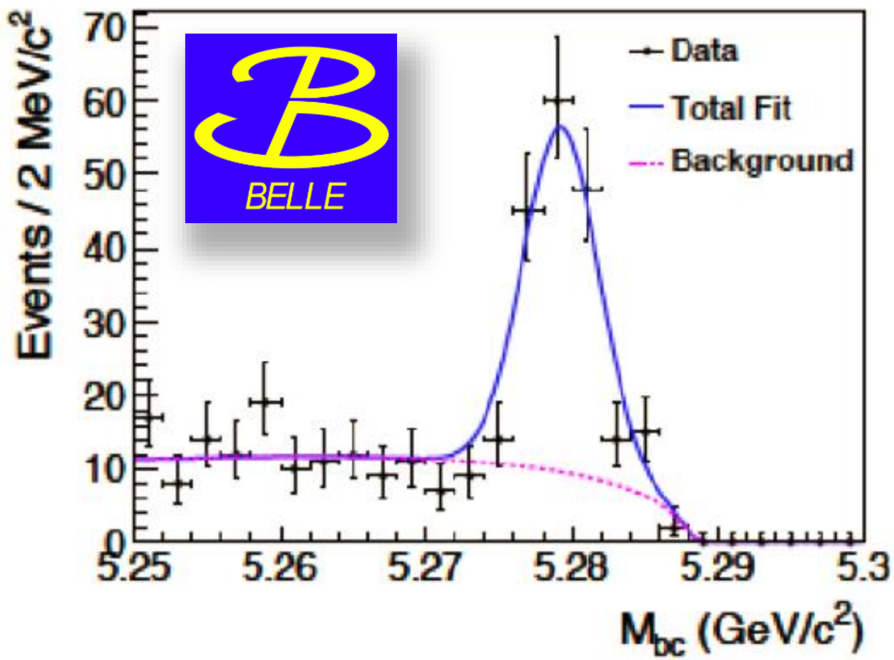


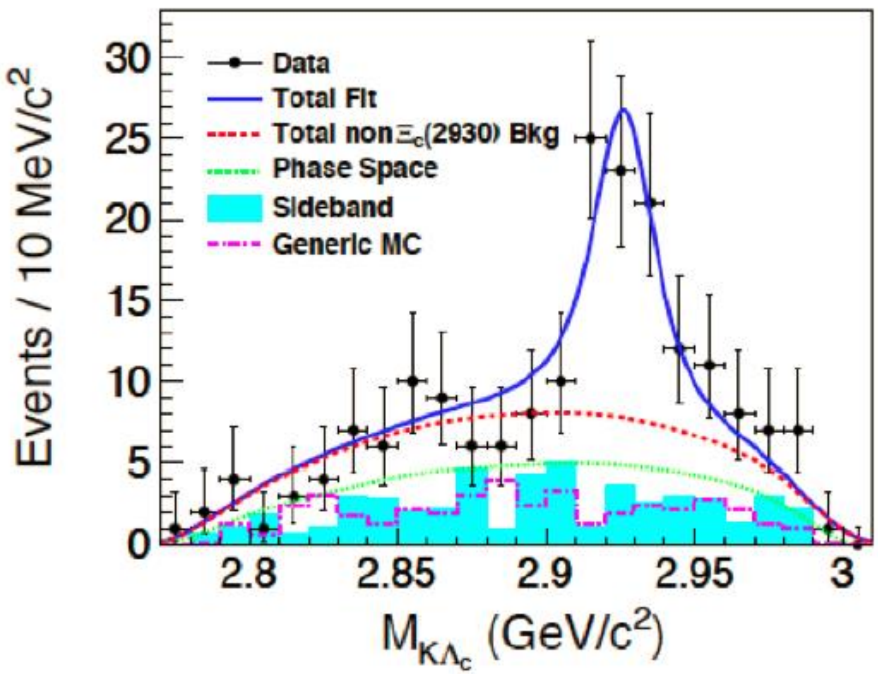
tion for experimental resolution, we obtain $m = 2931 \pm 3(\mathrm{stat}) \pm 5(\mathrm{syst})\ \mathrm{MeV}/c^2$ and $\Gamma = 36 \pm 7(\mathrm{stat}) \pm 11(\mathrm{syst})$ MeV. We do not see any such structure in the m_{ES} sideband region. This description is in good agreement with the data (χ^2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

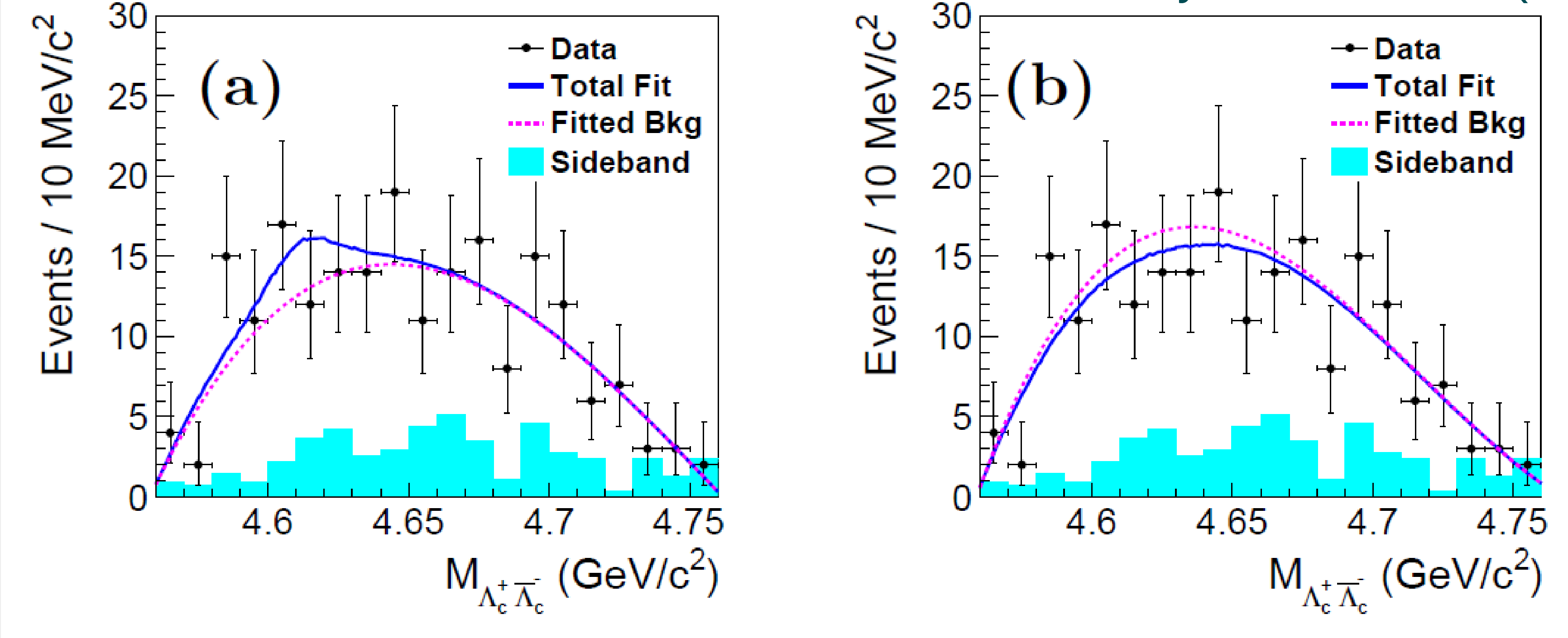
5.1σ significance

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)

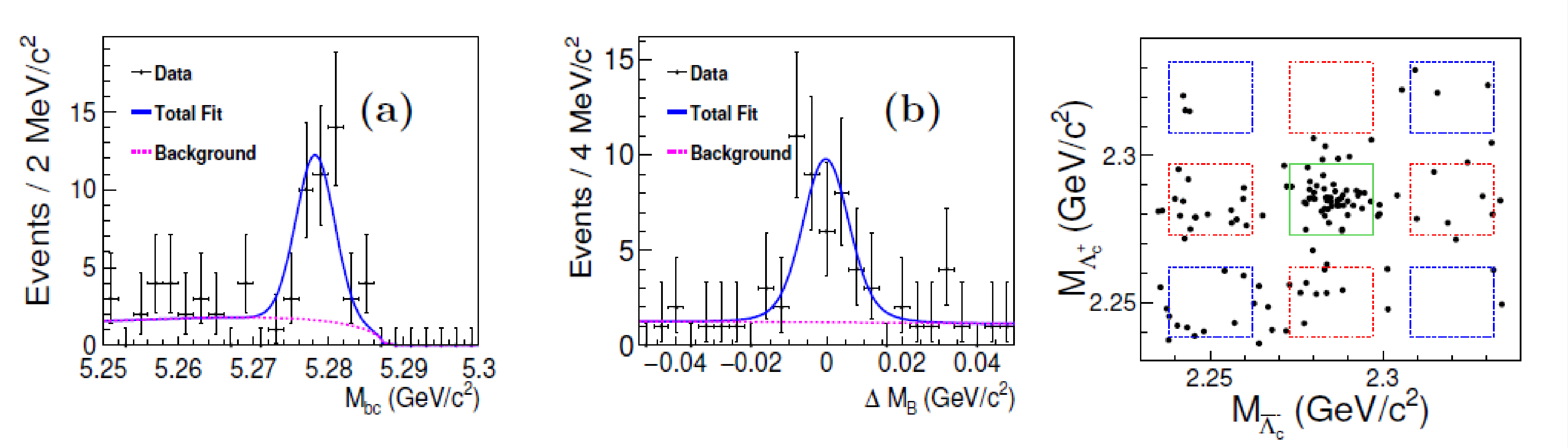


- No Y(4660) and its spin partner Y_η were observed. in the $\Lambda_c^+\overline{\Lambda}_c^-$ invariant mass distribution
- 90% C.L. upper limits of $B^+ \to K^+Y(4660) \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ and $B^+ \to K^+Y_\eta \to K^+\Lambda_c^+\overline{\Lambda}_c^-$ are 1.2×10^{-4} and 2.0×10^{-4}.

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

Eur. Phys. J. C78, 928 (2018)

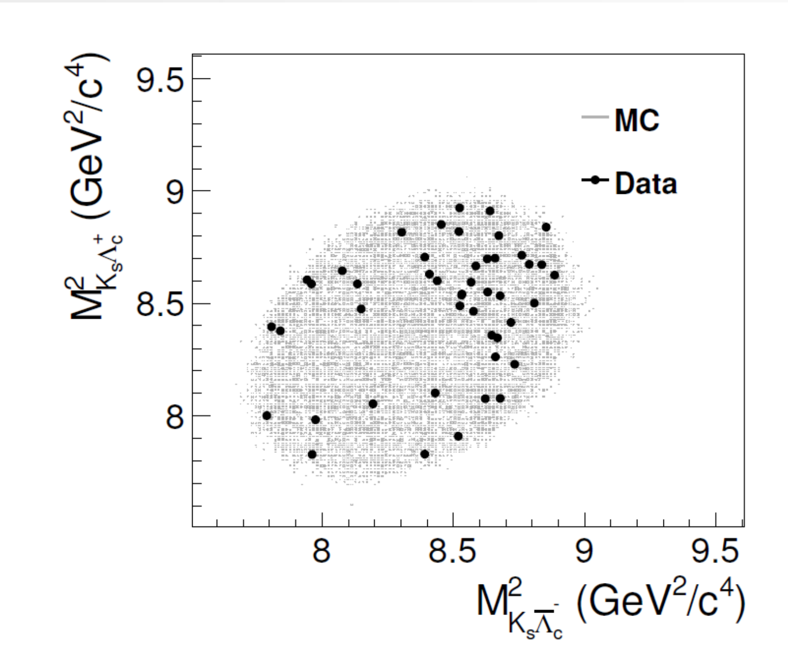
- Based on full $\Upsilon(4S)$ data set (772 M $B\bar{B}$ pairs) at Belle
- Three Λ_c decay channels:
  $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to pK_s(\pi^+\pi^-)$ and $\Lambda_c^+ \to \Lambda(p\pi^-)\pi^+$.
- B candidates extracted via 2D fit to M_{bc} and ΔM_B

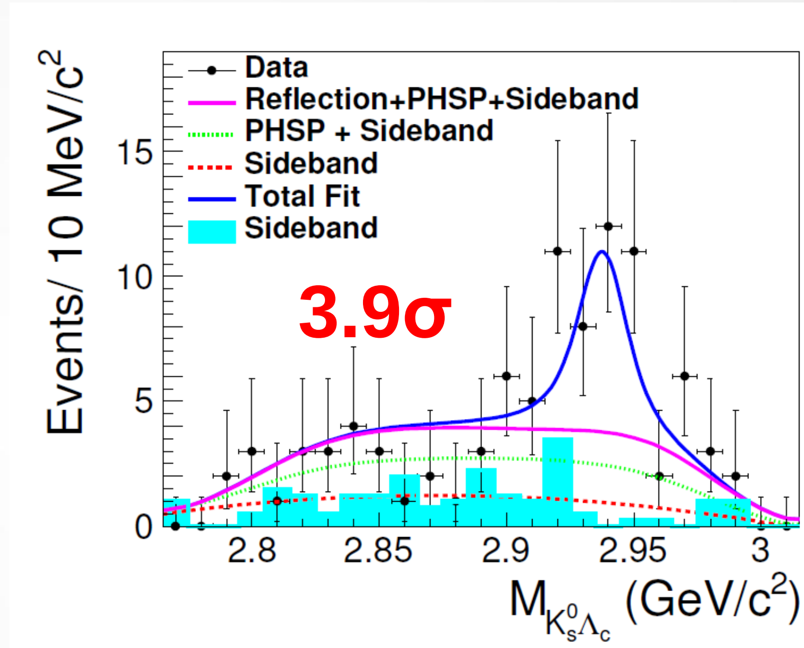


- Quite clear $\Lambda_c^+\bar{\Lambda}_c^-$ signals and B^0 signals.
  - $N^{\rm sig} = 34.9 \pm 6.6$ with a statistical signal significance above 8.3σ
  - $\mathcal{B}(\bar{B}^0 \to \bar{K}^0 \Lambda_c^+ \bar{\Lambda}_c^-) = [3.99 \pm 0.76(\text{stat.}) \pm 0.51(\text{syst.})] \times 10^{-4}$

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

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

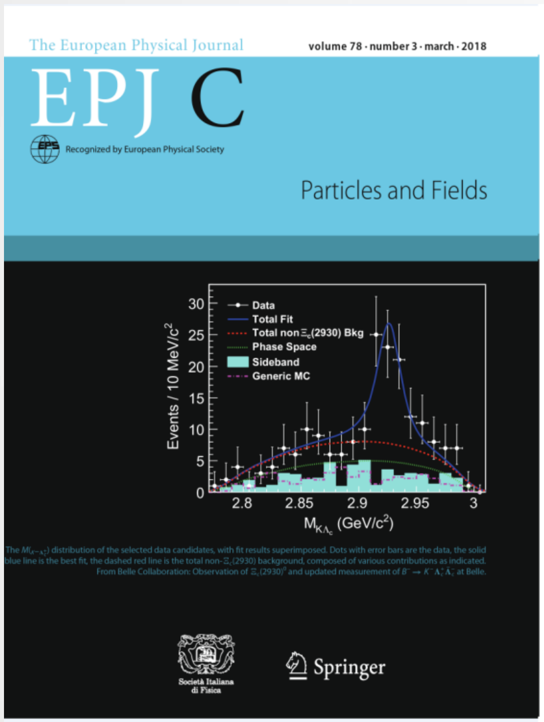


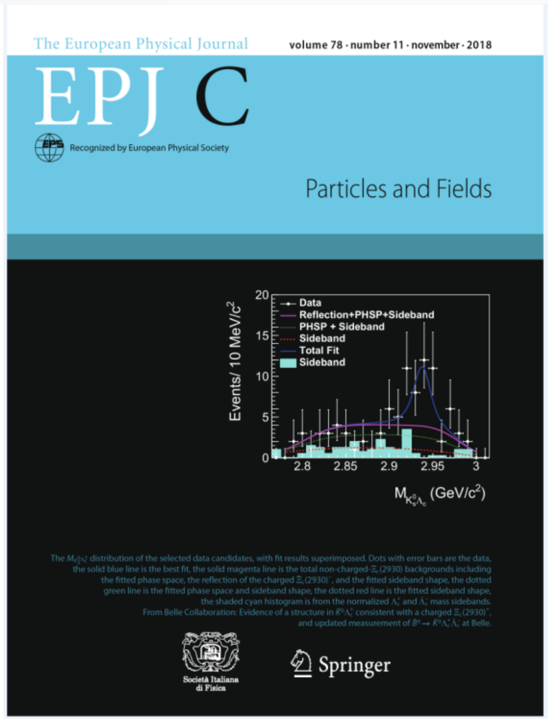


- $N_{\Xi_c^\pm} = 21.2 \pm 4.6$, stat. significance 4.1σ
- $M_{\Xi_c^\pm(2930)} = 2942.3 \pm^{1.5} \pm 1.6$ MeV$/c^2$
- $\Gamma_{\Xi_c^\pm(2930)} = 14.8 \pm^{2.5} \pm 7.1$ MeV

发现了新粲重子激发态$\Xi_c(2930)$

- 相继发现带电的和中性的$\Xi_c(2930)$，具有奇特性质：唯一在B介子衰变过程中发现，但未在正负电子直接对撞过程中观测到的Ξ_c激发态，引起广泛关注。





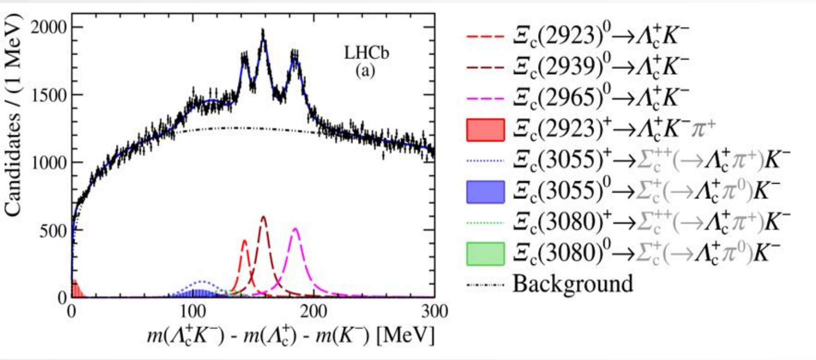
两篇论文均被选为EPJC封面论文。

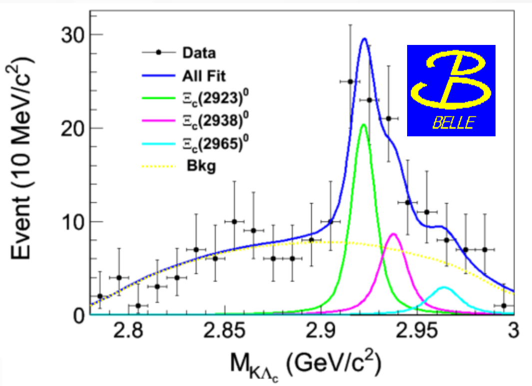
理论解释：
普通的Ξ_c激发态
$\Lambda_c\bar{K}$分子态
。。。。

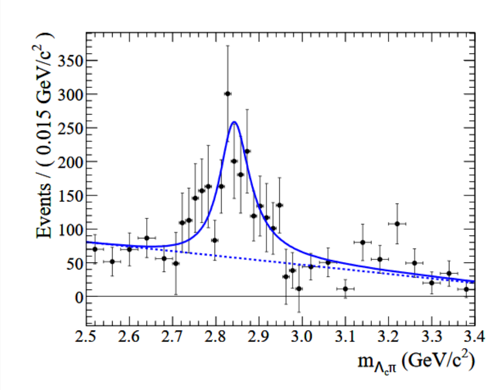
Y.B.Li, *C.P.Shen *et al* (Belle) EPJC 78, 928 (2018)；
Y.B.Li, *C.P.Shen *et al* (Belle) EPJC 78, 252 (2018)

Charmed baryon spectra at BelleII

- LHCb recently reconstructed $\mathrm{K}^{+}\Lambda_{c}^{-}$ and found $\Xi_c(2923)^0$, $\Xi_c(2939)^0$ and $\Xi_c(2965)^0$
- $\Xi_c(2930)^0$ is the sum of them ?







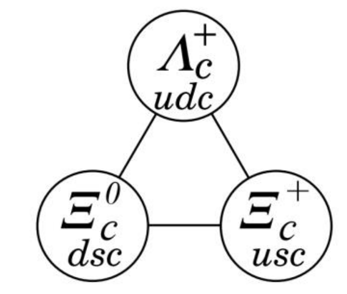
PRD.78.112003

Phys. Rev. Lett. 124, 222001

- We use LHCb's results as input, refit our plot and find the fit result is good
  - ➢ More data needed to extract signal yield with low uncertainty
  - ➢ Notice $\Xi_c(2923)^+ \to \Lambda_c^+ K^- \pi^+$, can we find more decay channel?
  - ➢ How about $\Sigma_c(2800)$? Is $\Sigma_c(2800)$ the overlap of several Σ_c?
  - ➢ …….

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: $B(\Xi_c^0 \to \Xi^-\pi^+)$~1.12% or 0.74% [PRD48, 4188 (1993)], (2.24±0.34)% [JHEP03, 66(2018)], (1.91±0.17)% [1811.07265]
- 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 !

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

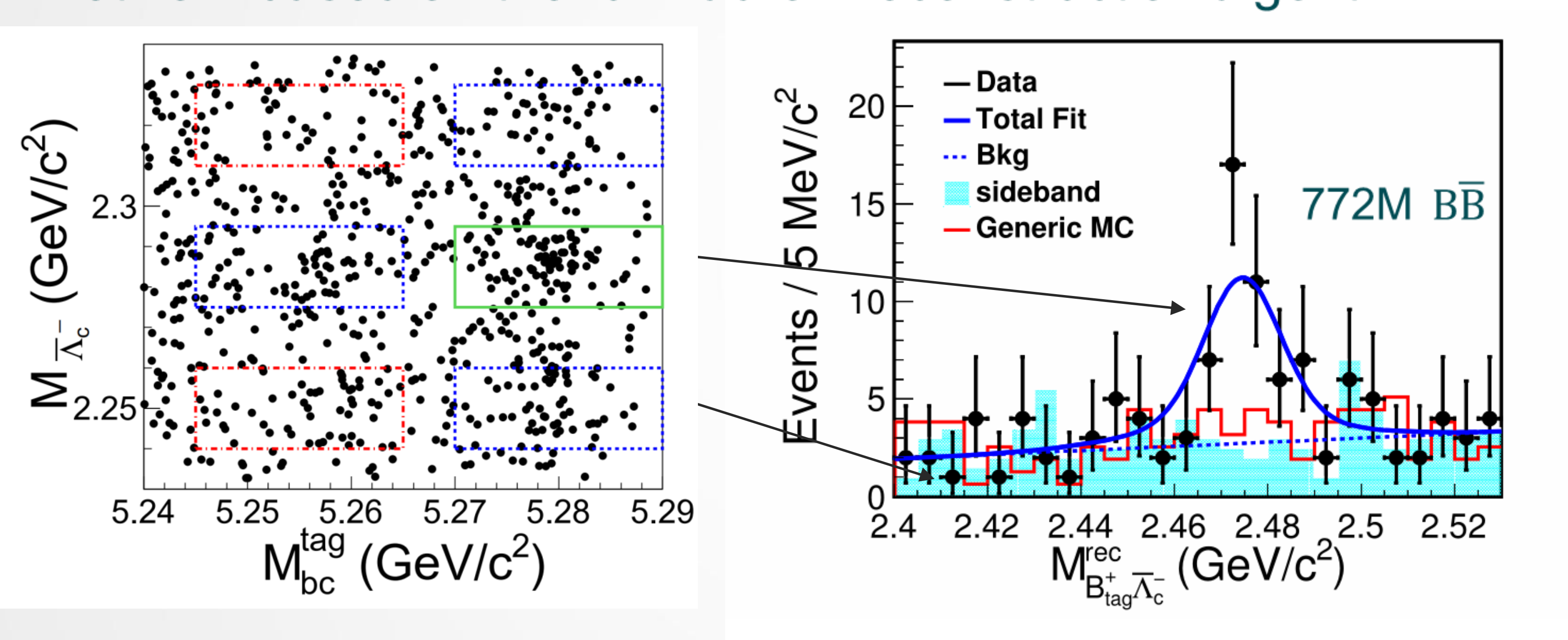
$$\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+) \equiv \frac{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+)}{\mathcal{B}(B^- \to \bar{\Lambda}_c^-\Xi_c^0)}.$$

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

- For inclusive $\boldsymbol{B^-} \to \boldsymbol{\bar{\Lambda}_c^-}\Xi_c^0$, Ξ_c^0 →anything, never measured before.
- For exclusive $B(\boldsymbol{B^-} \to \boldsymbol{\bar{\Lambda}_c^-}\Xi_c^0)$ $B(\Xi_c^0 \to \Xi^-\pi^+)$; $B(\boldsymbol{B^-} \to \boldsymbol{\bar{\Lambda}_c^-}\Xi_c^0)$ $B(\Xi_c^0 \to \Lambda K^-\pi^+)$, 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$, $\Xi_c^0 \to$anything)= $(9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$ for the first time

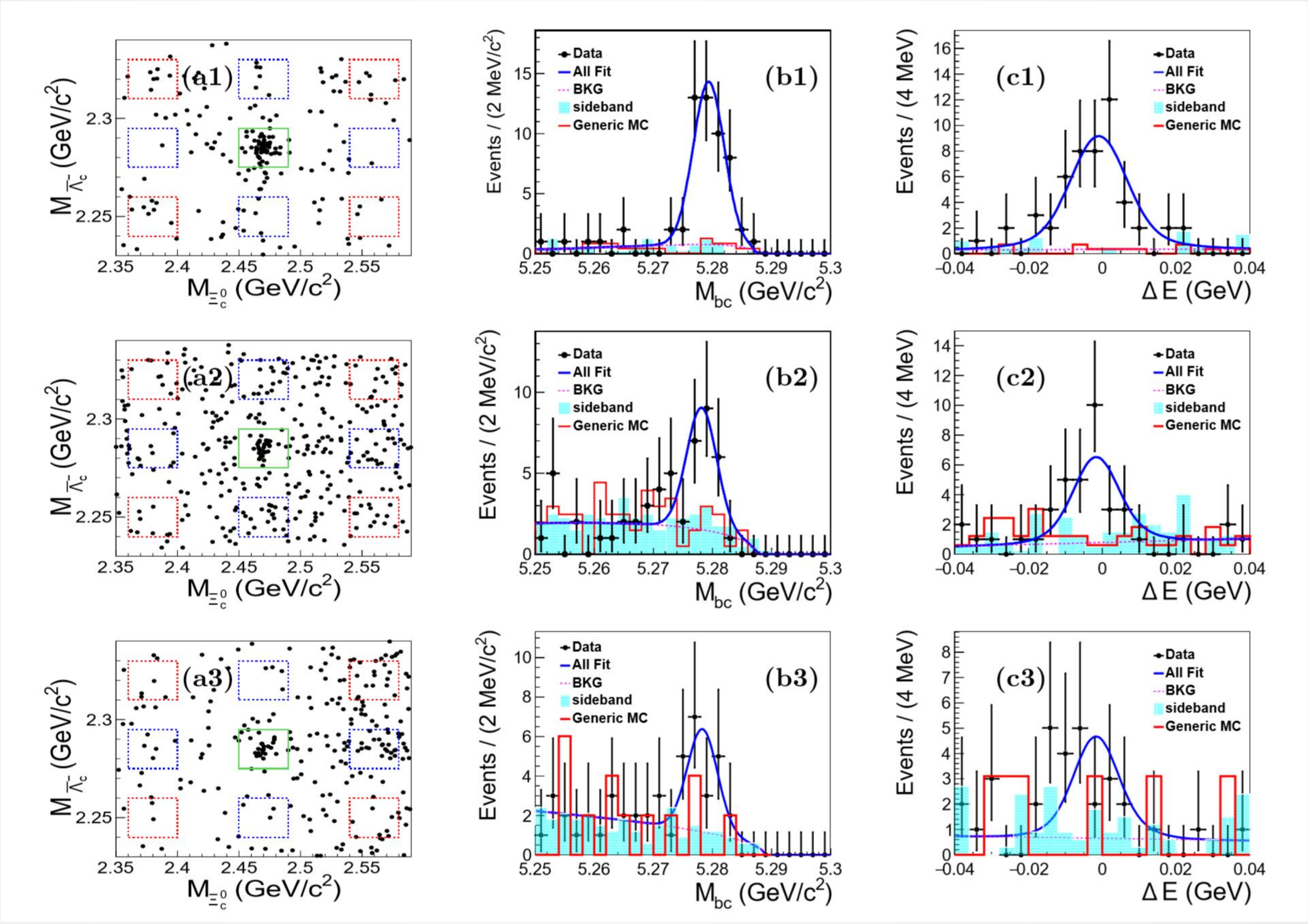
Y.B.Li, C.P.Shen et al. (Belle)
PRL122, 082001 (2019)

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

$\Xi^-\pi^+$
44.8 ± 7.3
9.5σ

$\Lambda K^-\pi^+$
24.1 ± 5.5
6.8σ

$pK^-K^-\pi^+$
16.6 ± 5.4
4.6σ



Y.B.Li, C.P.Shen et al (Belle) PRL122, 082001 (2019)

Measurements of absolute Brs of Ξ_c^0

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

Y.B.Li, C.P.Shen et al (Belle) PRL122, 082001 (2019)

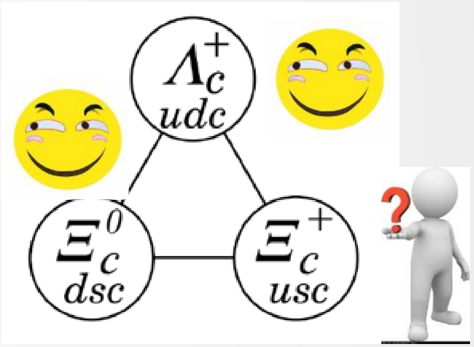
BF	Result	Theory	PDG
$\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)$	$(9.51 \pm 2.10 \pm 0.88) \times 10^{-4}$	$\sim 10^{-3}$	
$\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$(1.71 \pm 0.28 \pm 0.15) \times 10^{-5}$		$(2.4 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)$	$(1.11 \pm 0.26 \pm 0.10) \times 10^{-5}$		$(2.1 \pm 0.9) \times 10^{-5}$
$\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^0)\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+)$	$(5.47 \pm 1.78 \pm 0.57) \times 10^{-6}$		
$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$(1.80 \pm 0.50 \pm 0.14)\%$	1.12% or 0.74%	
$\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)$	$(1.17 \pm 0.37 \pm 0.09)\%$		
$\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+)$	$(0.58 \pm 0.23 \pm 0.05)\%$		
$\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$	$0.65 \pm 0.18 \pm 0.04$		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 $B^- \to \bar{\Lambda}_c^- \Xi_c^0$ inclusively and exclusively
- First model-independent measurement of absolute Brs of Ξ_c^0 decays
- The branching fraction $B(B^- \to \bar{\Lambda}_c^- \Xi_c^0)$ is measured for the first time
- The $B(\Xi_c^0 \to \Xi^- \pi^+)$ can be used to determine the BR of other Ξ_c^0 decays.

Measurements of absolute Brs of Ξ_c^+

- The decays of charmed baryons in experiment are needed to extract the non-perturbative contribution thus important to constrain phenomenological models of strong interaction.

- For the SU(3) anti-triplet charmed baryons the branching fractions of $\boldsymbol{\Lambda_c^+}$ [PRL 113,042003(2014); PRL 116,052001(2016)] and Ξ_c^0 [PRL 122,082001(2019)] has been measured.



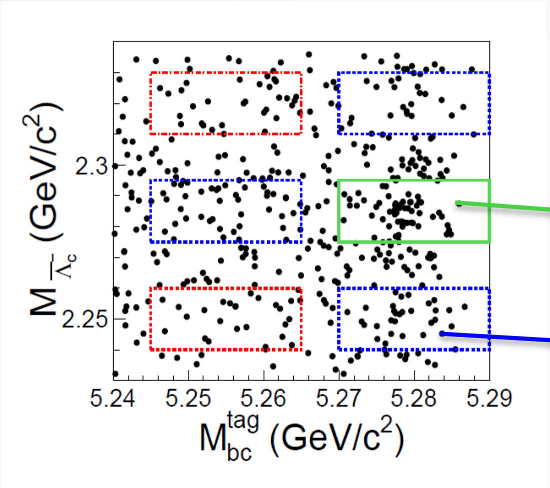
- The Brs of remaining Ξ_c^+ are all measured with ratio to the $\Xi_c^+ \to \boldsymbol{\Xi^- \pi^+ \pi^+}$

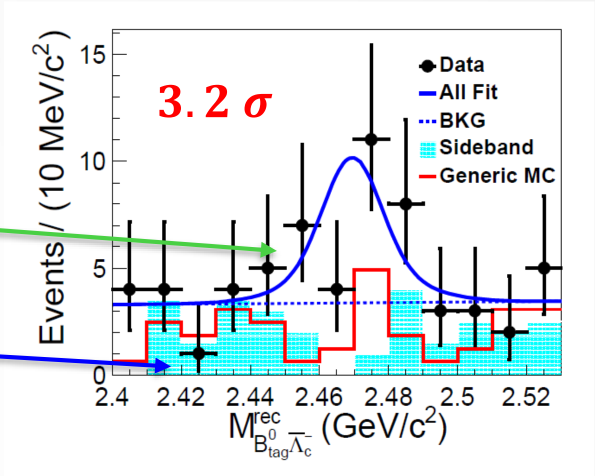
- The comparison of Ξ_c^+ decays with those of Λ_c^+ and and Ξ_c^0 can also provide an important test of SU(3) flavor symmetry.

$\Xi_c^+ \to p\, K^- \pi^+$ is a particularly important decay mode as it is the one most often used to reconstruct Ξ_c^+ candidates at hadron collider experiments, such as LHCb. Theory predicts the B($\Xi_c^+ \to p\, K^- \pi^+$)=(2.2±0.8)% [EPJC 78, 224 (2018); Chin. Phys. C 42, 051001 (2018)].

Measurement of Ξ_c^+ absolute BRs

Measurement $\mathcal{B}(\bar{B}^0 \to \overline{\Lambda}_c^- \Xi_c^+)$ with $\Xi_c^+ \to anythings$





- reconstruct $\overline{\Lambda}_c^-$ via $\bar{p}K^+\pi^-$ decay mode

Y.B.Li, C.P.Shen et al (Belle)
PRD 100, 031101 (2019)

- tag a B^0 with neural network based Full-Reconstruction algorithm.
- An unbinned maximum likelihood fit: $N(\Xi_c^+) = 18.8 \pm 6.8$
- $\mathcal{B}(\bar{B}^0 \to \overline{\Lambda}_c^- \Xi_c^+) = [1.16 \pm 0.42(stat.) \pm 0.15(syst.)] \times 10^{-3}$

Measurement of Ξ_c^+ absolute BRs

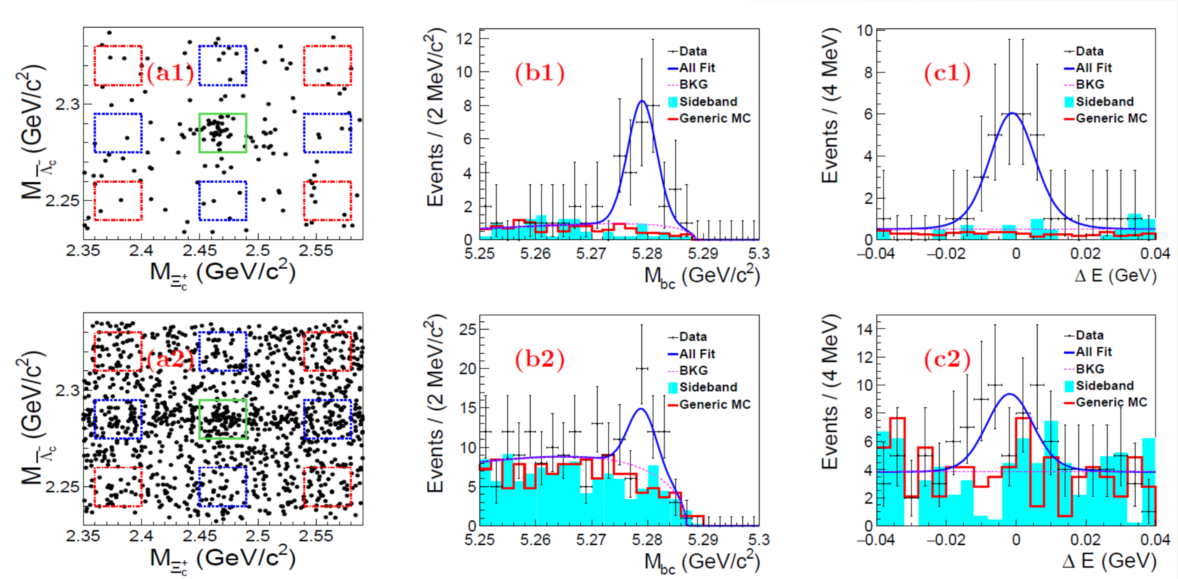
Measurement $\mathcal{B}\left(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+\right)$
with $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ or $pK^- \pi^+$

$\Xi_c^+ \to \Xi^- \pi^+ \pi^+$
$N = 24.2 \pm 5.4$

6.9σ

$\Xi_c^+ \to pK^- \pi^+$
$N = 24.0 \pm 6.9$

4.5σ



Y. B. Li. C. P. Shen et al (Belle) PRD 100, 031101 (2019)

Measurement of Ξ_c^+ absolute BRs

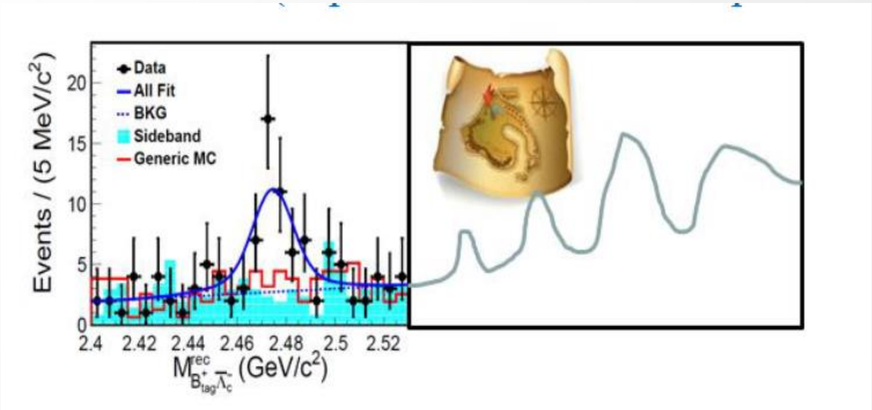
Y. B. Li. C. P. Shen et al (Belle) PRD 100, 031101 (2019)

BF	Result	Theory	PDG
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$	$(1.16 \pm 0.42 \pm 0.15) \times 10^{-3}$	$\sim 10^{-3}$	
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+))\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$(3.32 \pm 0.74 \pm 0.33) \times 10^{-5}$		$(1.8 \pm 1.8) \times 10^{-5}$
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)$	$(5.27 \pm 1.51 \pm 0.69) \times 10^{-5}$		
$\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$(2.86 \pm 1.21 \pm 0.38)\%$	$(1.47 \pm 0.84)\%$	
$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)$	$(0.45 \pm 0.21 \pm 0.07)\%$	$(2.2 \pm 0.8)\%$	
$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+)/\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$	$0.16 \pm 0.06 \pm 0.02$		0.21 ± 0.04

- First model –independent $\mathcal{B}\left(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+\right)$ measurement
- $\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$ can be used to determine the BR of other Ξ_c^+ decay

Measurements of the branching fractions of $B^- \to \bar{\Lambda}_c^- \Xi_c^{*0}$

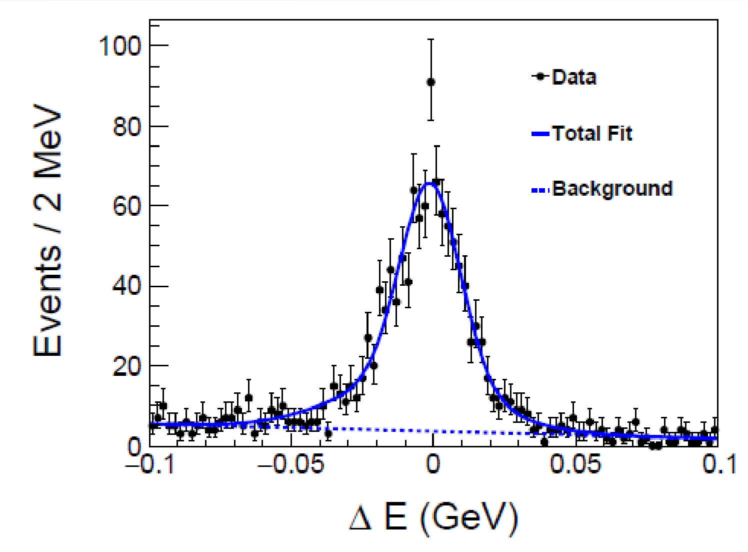
- Branching fractions of $B^{-/0} \to \bar{\Lambda}_c^- \Xi_c^{0/+}$ as well as the absolute branching fractions of $\Xi_c^{+/0}$ were measured by Belle. [PRL 122, 082001 (2019)] [PRD 100, 031101(R) (2019)]
- In those works, only $\Xi_c^{+/0}$ signal region of $\bar{\Lambda}_c^-$ recoil mass spectrum is focused on.
- A nature question is: can we observe the excited Ξ_c states in the higher region of the $\bar{\Lambda}_c^-$ recoil mass spectrum.
- In this analysis, we checked the higher region of the $\bar{\Lambda}_c^-$ recoil mass spectrum.
- We present the first measurements of branching fractions of the decays $B^- \to \bar{\Lambda}_c^- \Xi_c^{\prime 0}$, $B^- \to \bar{\Lambda}_c^- \Xi_c(2645)^0$, and $B^- \to \bar{\Lambda}_c^- \Xi_c(2790)^0$, using a missing-mass technique.



Measurements of the branching fractions of $B^- \to \bar{\Lambda}_c^- \Xi_c^{*0}$

$\Delta E = E_{B_{tag}^{C.M.}} - E_{beam}$

$M_{bc}^{tag} = \sqrt{E_{beam}^2 - p_{B_{tag}^{C.M.}}^2}$



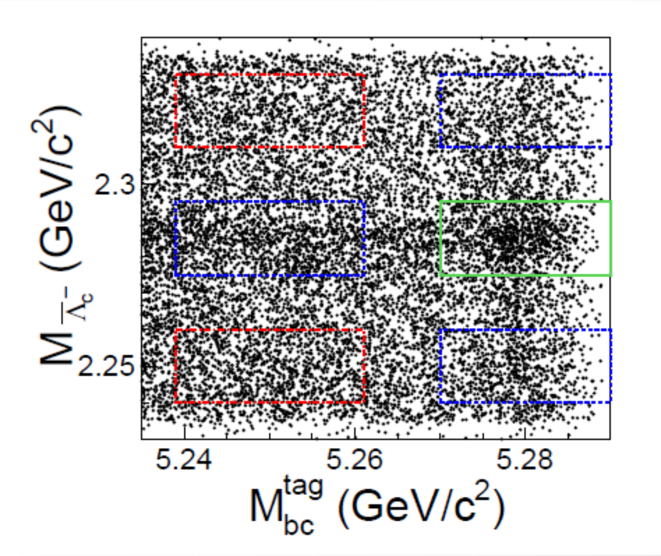


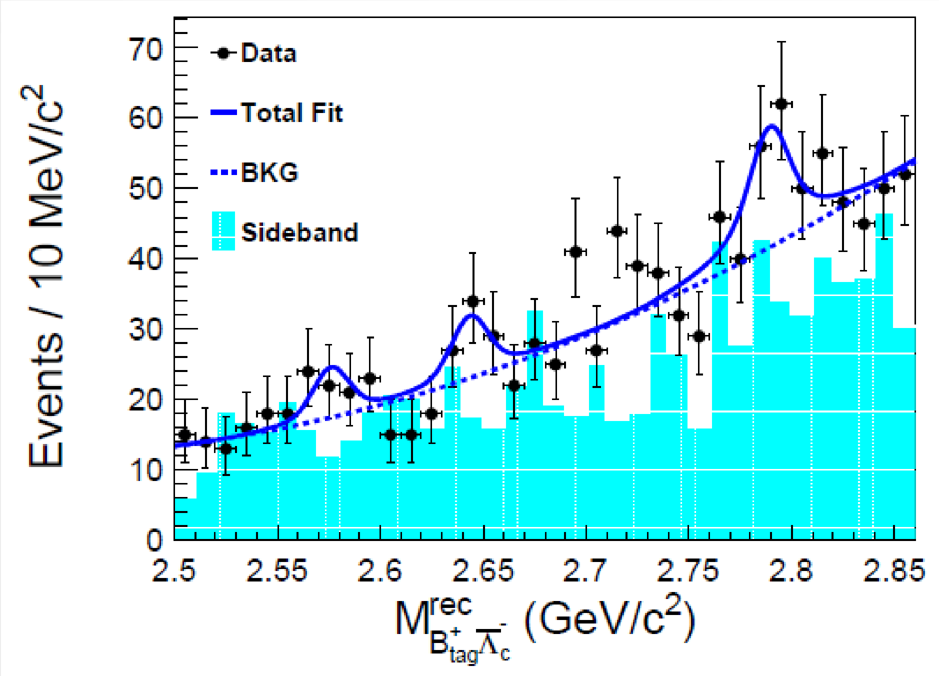
Figure: ΔE distributions and the scatter plot of M_{bc} of B_{tag}^+ versus of $M_{\bar{\Lambda}_c^-}$of signal side in the Ξ_c^{*0}signal region, $i.e.$, 2.5 GeV/c^2<$M_{B_{tag}^+ \bar{\Lambda}_c^-}^{rec}$<2.86 GeV/$c^2$.

- We take $|\Delta E| < 0.04$ GeV (~3σ) as ΔEsignal region.
- The normalized contribution from M_{bc} and $M_{\bar{\Lambda}_c^-}$ sidebands is estimated using the half the number of events in blue dashed boxed, minus one-fourth the number of events in the red dashed boxed.

Measurements of the branching fractions of $B^- \to \bar{\Lambda}_c^- \Xi_c^{*0}$

Recoil mass spectrum from data:

[PRD 100, 112010 (2019)]



- The empty space between the fitted background level and the normalized sideband is the contribution from other multi-body $B^- \to \bar{\Lambda}_c^- + anything$ decays.

- Since the statistical significances of $\Xi_c'^0$ and $\Xi_c(2645)^0$ are less than 3σ, the 90% C.L. upper limits on the numbers of $\Xi_c'^0$ and $\Xi_c(2645)^0$ signal events are determined.

	$N_{\rm sig}$	$\mathcal{B}(B^- \to \bar{\Lambda}_c^- \Xi_c^{*0})$ [Upper Limit]	Significance (σ)
$\Xi_c'^0$	18 ± 10	$(3.4 \pm 2.0 \pm 0.4) \times 10^{-4}$ $[6.5 \times 10^{-4}]$	1.7
$\Xi_c(2645)^0$	24 ± 13	$(4.4 \pm 2.4 \pm 0.5) \times 10^{-4}$ $[7.9 \times 10^{-4}]$	1.9
$\Xi_c(2790)^0$	60 ± 22	$(1.1 \pm 0.4 \pm 0.2) \times 10^{-3}$	3.1

Ξ_c worklist:

1. Measurement of absolute decay branching fractions

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.80 \pm 0.52)\%$$ PRL 122 082001

$$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.27)\%$$ PRD 100 031101

μ?

$$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (1.8 \pm 1.2)\%$$ PDG

$$\mathcal{B}(\Xi_c^+ \to \Xi^0 e^+ \nu_e) = (1.8^{+0.7}_{-0.8})\%$$ PDG, ratios to $\Xi^- 2\pi^+$

Need updated

2. Find more decay modes:

PRD 101, 053002

CF (%)

$\Xi_c^+ \to \Sigma^+ \bar{K}^{*0}$	1.40 ± 0.69[a]
$\Xi_c^+ \to \Xi^0 \rho^+$	14.48 ± 2.44[a]
$\Xi_c^0 \to \Lambda^0 \bar{K}^{*0}$	1.37 ± 0.26
$\Xi_c^0 \to \Sigma^0 \bar{K}^{*0}$	0.42 ± 0.23
$\Xi_c^0 \to \Sigma^+ K^{*-}$	0.24 ± 0.17
$\Xi_c^0 \to \Xi^0 \rho^0$	0.88 ± 0.22
$\Xi_c^0 \to \Xi^0 \omega$	2.78 ± 0.45
$\Xi_c^0 \to \Xi^0 \phi$	0.14 ± 0.13
$\Xi_c^0 \to \Xi^- \rho^+$	8.98 ± 0.55

SCS (10^{-3})

$\Xi_c^+ \to \Lambda^0 \rho^+$	1.52 ± 0.57
$\Xi_c^+ \to p \bar{K}^{*0}$	4.71 ± 1.22[a]
$\Xi_c^+ \to \Sigma^0 \rho^+$	11.45 ± 1.52
$\Xi_c^+ \to \Sigma^+ \rho^0$	2.85 ± 0.81
$\Xi_c^+ \to \Sigma^+ \omega$	4.11 ± 0.77
$\Xi_c^+ \to \Sigma^+ \phi$	1.82 ± 0.40[a]
$\Xi_c^+ \to \Xi^0 K^{*+}$	4.28 ± 1.64
$\Xi_c^0 \to \Lambda^0 \rho^0$	0.13 ± 0.11
$\Xi_c^0 \to \Lambda^0 \omega$	1.51 ± 0.20
$\Xi_c^0 \to \Lambda^0 \phi$	0.44 ± 0.08[a]
$\Xi_c^0 \to p K^{*-}$	0.19 ± 0.14
$\Xi_c^0 \to n \bar{K}^{*0}$	2.52 ± 0.79
$\Xi_c^0 \to \Sigma^0 \rho^0$	0.11 ± 0.10
$\Xi_c^0 \to \Sigma^0 \omega$	0.70 ± 0.13
$\Xi_c^0 \to \Sigma^0 \phi$	0.30 ± 0.07
$\Xi_c^0 \to \Sigma^+ \rho^-$	0.19 ± 0.13
$\Xi_c^0 \to \Sigma^- \rho^+$	5.56 ± 0.34
$\Xi_c^0 \to \Xi^0 K^{*0}$	0.79 ± 0.23
$\Xi_c^0 \to \Xi^- K^{*+}$	3.36 ± 0.23

DCS (10^{-4})

$\Xi_c^+ \to \Lambda^0 K^{*+}$	$0.34^{+0.37}_{-0.34}$
$\Xi_c^+ \to p \rho^0$	0.22 ± 0.17
$\Xi_c^+ \to p \omega$	1.66 ± 0.70
$\Xi_c^+ \to p \phi$	2.29 ± 0.39
$\Xi_c^+ \to n \rho^+$	0.43 ± 0.33
$\Xi_c^+ \to \Sigma^0 K^{*+}$	3.08 ± 0.20
$\Xi_c^+ \to \Sigma^+ K^{*0}$	0.40 ± 0.08
$\Xi_c^0 \to \Lambda^0 K^{*0}$	0.28 ± 0.13
$\Xi_c^0 \to p \rho^-$	0.15 ± 0.11
$\Xi_c^0 \to n \rho^0$	0.07 ± 0.06
$\Xi_c^0 \to n \omega$	0.56 ± 0.24
$\Xi_c^0 \to n \phi$	0.77 ± 0.13
$\Xi_c^0 \to \Sigma^0 K^{*0}$	0.07 ± 0.01
$\Xi_c^0 \to \Sigma^- K^{*+}$	2.08 ± 0.14

Semileptonic

$10^3 \mathcal{B}(\Xi_c^+ \to \Sigma^0 e^+ \nu_e)$	3.1 ± 0.4
$10^4 \mathcal{B}(\Xi_c^+ \to \Lambda e^+ \nu_e)$	10.3 ± 1.5
$10^4 \mathcal{B}(\Xi_c^0 \to \Sigma^- e^+ \nu_e)$	15.7 ± 2.2

PLB792, 214

3.Decay parameter measurement:

Ξ_c^0 DECAY PARAMETERS

α FOR $\Xi_c^0 \to \Xi^- \pi^+$ $\quad \boxed{-0.6 \pm 0.4}$

The only measurement with large error

4. Form factors

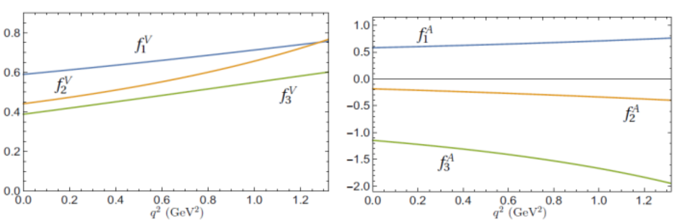


FIG. 1: Form factors of the weak $\Xi_c \to \Xi$ transitions.

EPJC 79 695

Plentiful physics parameters need to be measured !

Measurements of Brs and asymmetry parameters of $\Xi_c^0 \to \Lambda \overline{K}^{*0}$, $\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+ K^{*-}$ arXiv:2104.10361

- There are some difficulties for the theoretical study in the non-leptonic decays of charmed baryons due to the failure of the factorization approach.
- Branching fraction measurements help to distinguish different theoretical models.
- The asymmetry parameters of Ξ_c^0 are still not well measured, which is important to test parity violation in charmed-baryon sectors.

Decay branching fractions (%) and asymmetry parameters of the Cabibbo favored $B_c \to B_n + V$ decays in QCD and $SU(3)_F$ approach.

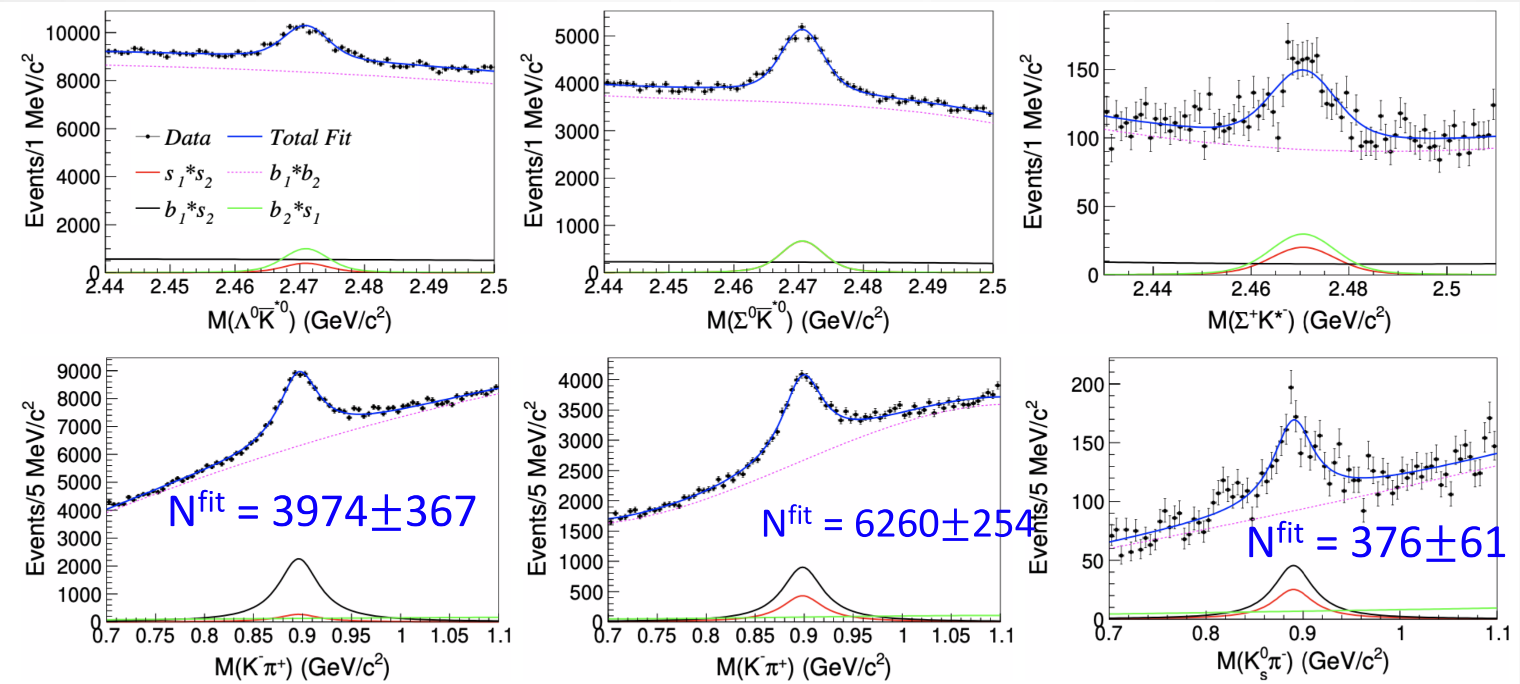
Branching fractions	KK [1]	Zen [2]	HYZ [3]	GLT [4]
$\Xi_c^0 \to \Lambda^0 \overline{K}^{*0}$	1.55	1.15	0.46±0.21	1.37±0.26
$\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}$	0.85	0.77	0.27±0.22	0.42±0.23
$\Xi_c^0 \to \Sigma^+ K^{*-}$	0.54	0.37	0.93±0.29	0.24±0.17

Asymmetry parameters	KK [1]	Zen [2]	GLT [4]
$\Xi_c^0 \to \Lambda^0 \overline{K}^{*0}$	0.58	+0.49	-0.67±0.24
$\Xi_c^0 \to \Sigma^0 \overline{K}^{*0}$	-0.87	+0.25	-0.42±0.62
$\Xi_c^0 \to \Sigma^+ K^{*-}$	-0.60	+0.51	$-0.76^{+0.64}_{-0.24}$

[1] Z. Phys. C 55, 659 (1992) [2] Phys. Rev. D 50, 5787 (1994) [3] Phys. Lett. B 792, 35 (2019)
[4] Phys. Rev. D 101, 053002 (2020)

Measurements of Brs $\Xi_c^0 \to \Lambda\bar{K}^{*0}$, $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+K^{*-}$

$\Xi_c^0 \to \Lambda^0\bar{K}^{*0}$ $\Xi_c^0 \to \Sigma^0\bar{K}^{*0}$ $\Xi_c^0 \to \Sigma^+K^{*-}$ arXiv:2104.10361



$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.18 \pm 0.02(\text{stat.}) \pm 0.01(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.69 \pm 0.03(\text{stat.}) \pm 0.03(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Sigma^+K^{*-})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+)$	$0.34 \pm 0.06(\text{stat.}) \pm 0.02(\text{syst.})$
$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})$	$(3.3 \pm 0.3(\text{stat.}) \pm 0.2(\text{syst.}) \pm 1.0(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})$	$(12.4 \pm 0.5(\text{stat.}) \pm 0.5(\text{syst.}) \pm 3.6(\text{ref.})) \times 10^{-3}$
$\mathcal{B}(\Xi_c^0 \to \Sigma^+K^{*-})$	$(6.1 \pm 1.0(\text{stat.}) \pm 0.4(\text{syst.}) \pm 1.8(\text{ref.})) \times 10^{-3}$

By using the reference mode $\Xi_c^0 \to \Xi^-\pi^+$ [arXiv: 2103.06496 (2021)], we calculate the absolute branching fractions with signal yields between reference and signal channels after efficiency corrections.

Asymmetry parameter extractions

arXiv:2104.10361

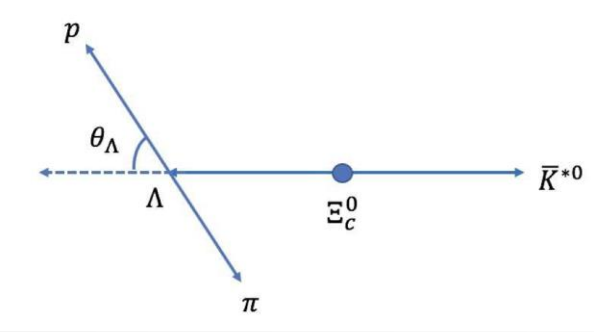
For $\Xi_c^0 \to \Lambda^0\overline{K}^{*0}$, $\Xi_c^0 \to \Sigma^0\overline{K}^{*0}$, and $\Xi_c^0 \to \Sigma^+K^{*-}$, the differential decay rates [PRD 101, 053002 (2020)] are given by:

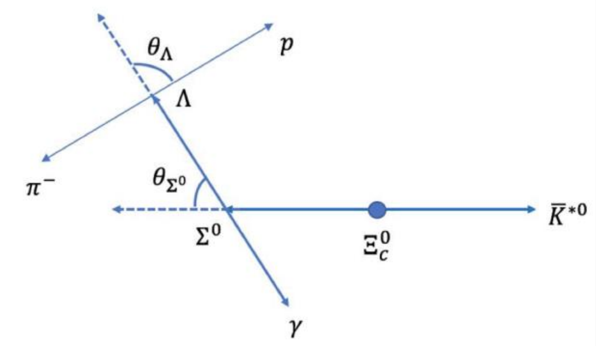
$$\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha(\Xi_c^0 \to \Lambda\overline{K}^{*0})\alpha(\Lambda \to p\pi^-)\cos\theta_\Lambda,$$

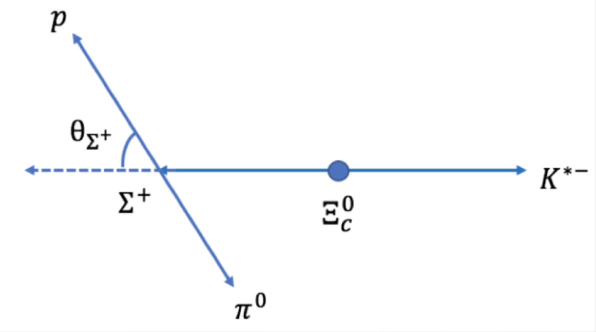
$$\frac{dN}{d\cos\theta_{\Sigma^0}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^0\overline{K}^{*0})\alpha(\Sigma^0 \to \Lambda\gamma)\cos\theta_{\Sigma^0}, \text{ and}$$

$$\frac{dN}{d\cos\theta_{\Sigma^+}} \propto 1 + \alpha(\Xi_c^0 \to \Sigma^+K^{*-})\alpha(\Sigma^+ \to p\pi^0)\cos\theta_{\Sigma^+}.$$

Definitions of θ_Λ, θ_{Σ^0}, and θ_{Σ^+}:



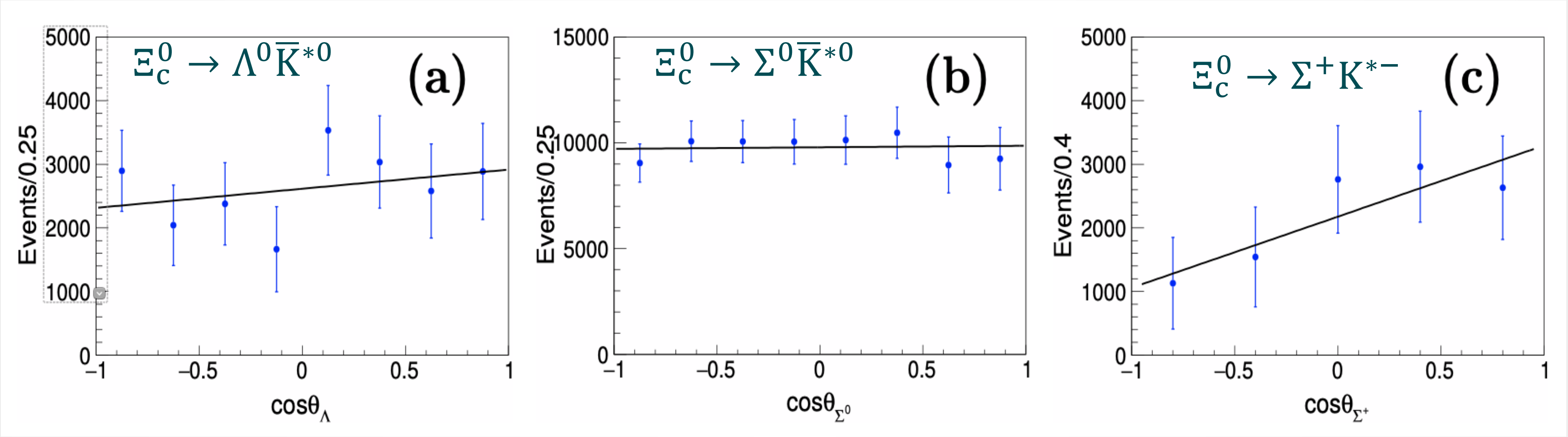




- This measurement is insensitive to production polarization of Ξ_c^0 in B-factory [PRD 63, 111102 (2001)].
- The asymmetry parameter $\alpha(\Sigma^0 \to \Lambda\gamma)$ is expected to be zero due to the case of parity conservation for an electromagnetic decay of $\Sigma^0 \to \Lambda\gamma$.

Asymmetry parameters

arXiv:2104.10361



Note that $\alpha(\Lambda \to p\pi^-) = 0.747 \pm 0.010$ and $\alpha(\Sigma^+ \to p\pi^0) = -0.980 \pm 0.017$ from PDG.

$\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})\alpha(\Lambda \to p\pi^-)$	$0.115 \pm 0.164(\text{stat.}) \pm 0.038(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})\alpha(\Sigma^0 \to \gamma\Lambda)$	$0.008 \pm 0.072(\text{stat.}) \pm 0.008(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^+K^{*-})\alpha(\Sigma^+ \to p\pi^0)$	$0.514 \pm 0.295(\text{stat.}) \pm 0.012(\text{syst.})$
$\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})$	$0.15 \pm 0.22(\text{stat.}) \pm 0.05(\text{syst.})$
$\alpha(\Xi_c^0 \to \Sigma^+K^{*-})$	$-0.52 \pm 0.30(\text{stat.}) \pm 0.02(\text{syst.})$

Ξ_c semileptonic decay

- BESIII measured the $\mathcal{B}(\Lambda_c^+ \to \Lambda l^+ \nu)$ PRL 115, 221805(2015) & PLB 767, 42 (2017)

$\Lambda e^+ \nu_e$	$(3.6 \pm 0.4)\%$
$\Lambda \mu^+ \nu_\mu$	$(3.5 \pm 0.5)\%$

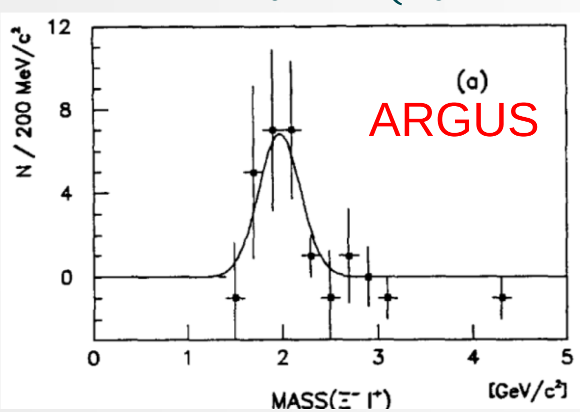
- $\mathcal{B}(\Xi_c \to \Xi\, l^+ \nu)$ was measured by ARGUS and CLEOII
  - ARGUS: $495.0\ \mathrm{pb}^{-1}$ at $\Upsilon(1S, 2S, 3S)$ and off_res energy points; **18 events;** PLB 303, 368(1993)

$$\sigma\left(e^+e^- \to \Xi_c^0 X\right)\mathcal{B}\left(\Xi_c^0 \to \Xi^- l^+ \nu_l\right) = 0.74 \pm 0.24 \pm 0.09\ \mathrm{pb}\quad l^+ = \mu^+\ or\ e^+$$

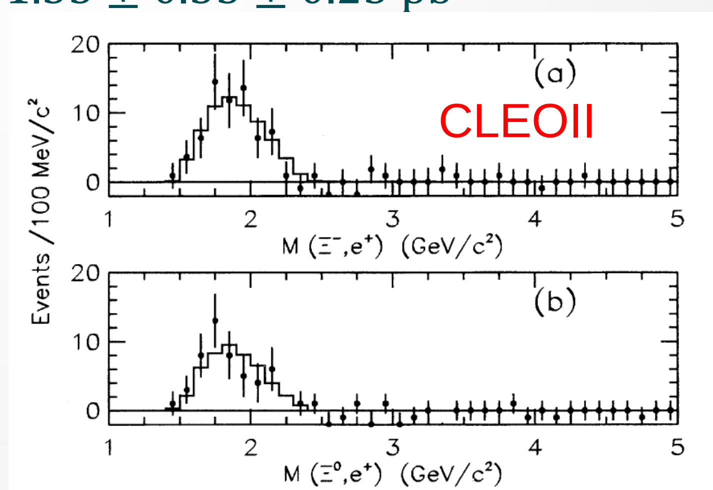
  - CLEOII: $2.1\mathrm{fb}^{-1}$ at and bellow $\Upsilon(4S)$ energy point; **54 signal events**; PRL 74 16(1995)

$$\sigma\left(e^+e^- \to \Xi_c^0 X\right)\mathcal{B}\left(\Xi_c^0 \to \Xi^- e^+ \nu_e\right) = 0.63 \pm 0.12 \pm 0.10\ \mathrm{pb}$$

$$\sigma\left(e^+e^- \to \Xi_c^+ X\right)\mathcal{B}\left(\Xi_c^+ \to \Xi^0 e^+ \nu_e\right) = 1.55 \pm 0.33 \pm 0.25\ \mathrm{pb}$$



$$\frac{\mathrm{BR}\left(\Xi_c^0 \to \Xi^- l^+ X\right)}{\mathrm{BR}\left(\Xi_c^0 \to \Xi^- \pi^+\right)} = 0.96 \pm 0.43 \pm 0.18$$

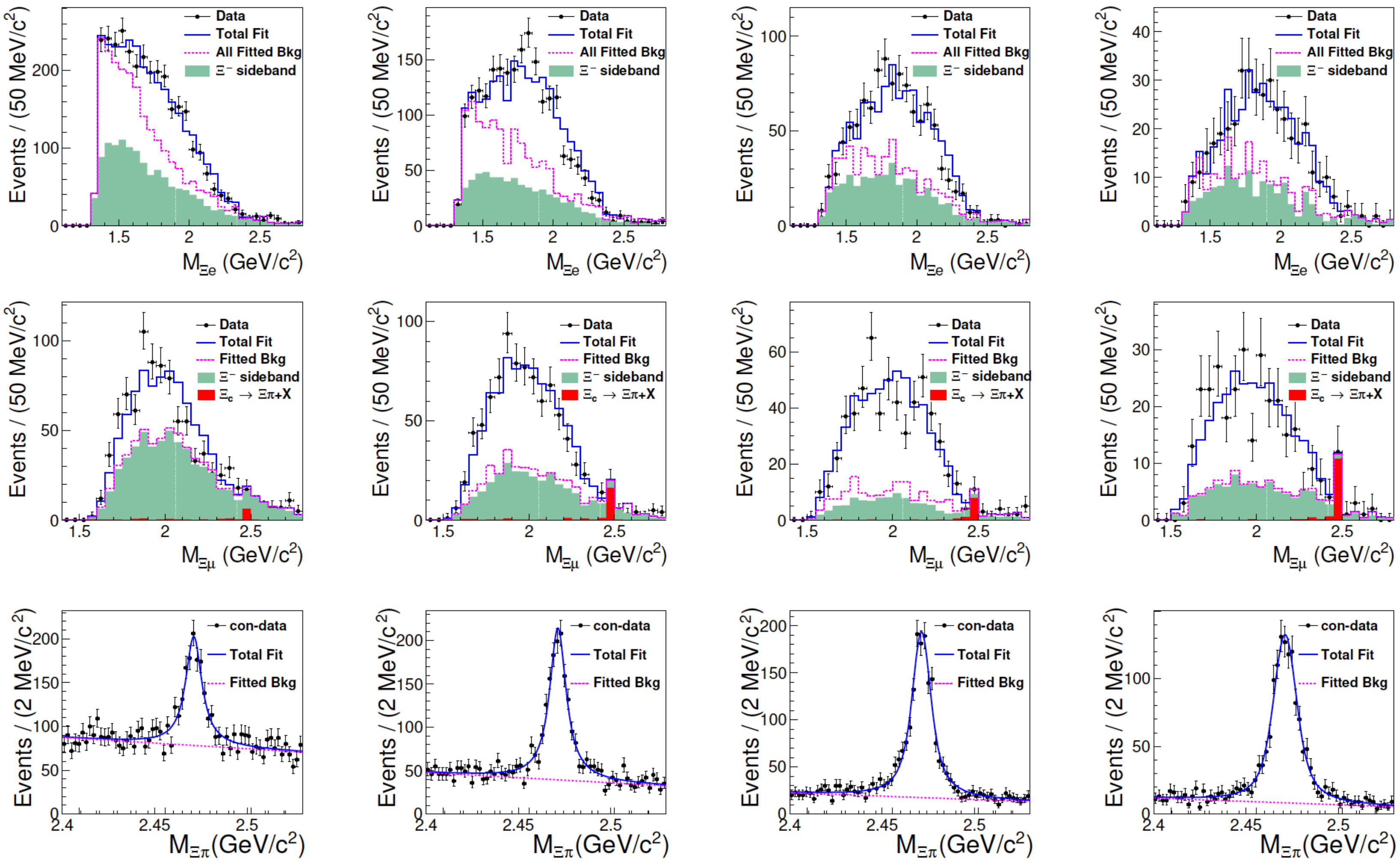


$$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)/\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = 0.32 \pm 0.10^{+0.05}_{-0.03}$$

Measurements of $\mathcal{B}(\Xi_c^0 \to \Xi^- l \nu)$

89.454 fb^{-1} continuum data below $\Upsilon(4S)$

arXiv:2103.06496



$\frac{p^*_{\Xi\ell(\pi)}}{p^*_{max}}$ [0.45, 0.55) [0.55, 0.65) [0.65, 0.75) ≥ 0.75

$p^*_{\Xi\ell(\pi)}$ is the momentum of $\Xi\ell(\pi)$ in center of mass system , $p^*_{max} = \sqrt{E^2_{beam} - M^2_{\Xi_c^0}}$

Measurements of $\mathcal{B}(\Xi_c^0 \to \Xi^- l\, \nu\,)$

arXiv:2103.06496

$$\mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell) \equiv \frac{N_{\Xi_c^0} \cdot \mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell)}{N_{\Xi_c^0} \cdot \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)} \times \mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)$$

$p_f^*/p_{\max}^*$	$[0.45, 0.55)$	$[0.55, 0.65)$	$[0.65, 0.75)$	≥ 0.75	$\frac{\mathcal{B}(\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}$
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	$(8.71 \pm 0.74) \times 10^2/15.79\%$	$(9.15 \pm 0.77) \times 10^2/18.87\%$	$(5.13 \pm 0.56) \times 10^2/21.60\%$	$(2.13 \pm 0.30) \times 10^2/22.54\%$	0.954 ± 0.055
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	$(3.10 \pm 0.72) \times 10^2/6.43\%$	$(5.24 \pm 0.64) \times 10^2/10.47\%$	$(4.34 \pm 0.44) \times 10^2/14.37\%$	$(2.05 \pm 0.40) \times 10^2/17.81\%$	0.952 ± 0.094
$\Xi_c^0 \to \Xi^- \pi^+$	$(9.41 \pm 0.07) \times 10^2/23.36\%$	$(1.29 \pm 0.07) \times 10^3/24.71\%$	$(1.51 \pm 0.06) \times 10^3/25.91\%$	$(1.22 \pm 0.06) \times 10^3/27.13\%$	$\cdots$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\, e^+ \nu_e) = (1.72 \pm 0.10(stat.) \pm 0.12(syst.) \pm 0.50)\%$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\, \mu^+ \nu_\mu) = (1.71 \pm 0.17(stat.) \pm 0.13(syst.) \pm 0.50)\%$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\, e^+ \nu_e)\,/\,\mathcal{B}(\Xi_c^0 \to \Xi^-\, \mu^+ \nu_\mu) = 1.00 \pm 0.11 \pm 0.09$$

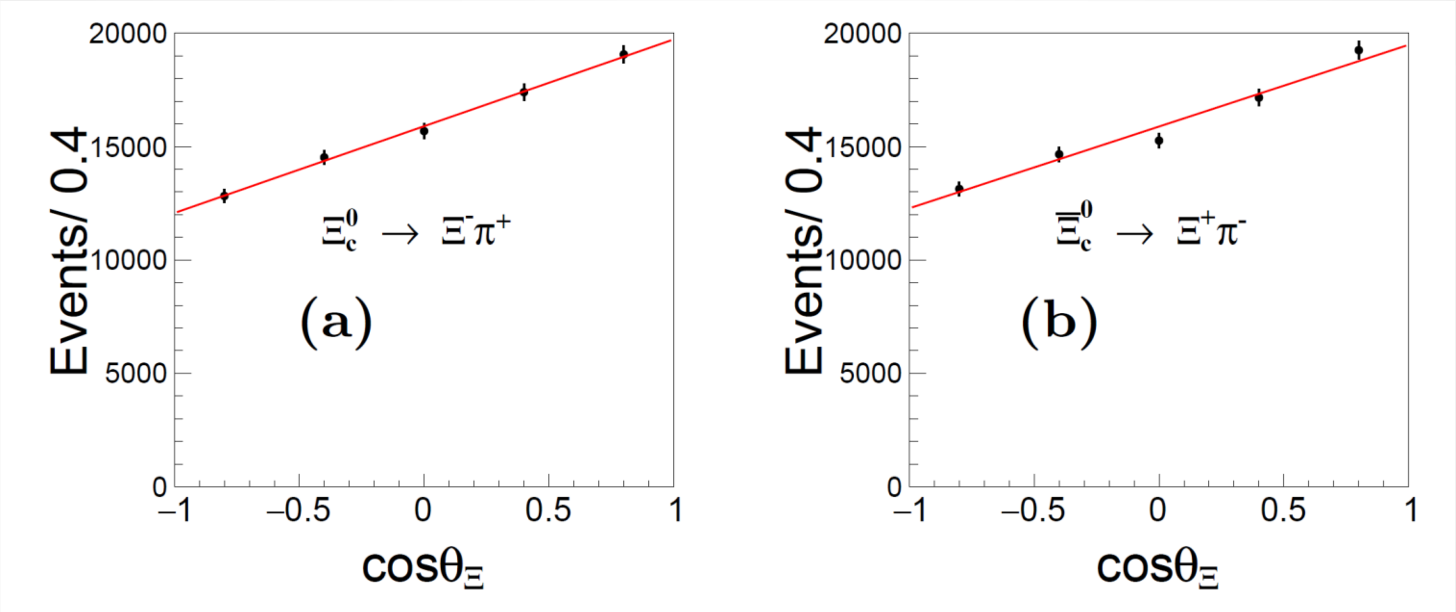
The result is consistent with the expectation of LFU.

Measurements of $\mathcal{A}_{cp}$ of $\Xi_c^0 \to \Xi^-\pi^+$

arXiv:2103.06496

$$\frac{dN}{d\cos\theta_\Xi} \propto 1 + \alpha_{\Xi^-\pi^+}\alpha_{\Xi^-}\cos\theta_\Xi$$

θ_Ξ: angle between the $\vec{p}_\Lambda$ and $-\vec{p}_{\Xi_c^0}$ in the Ξ^- rest frame



$$\alpha_{\Xi^-\pi^+} = -0.60 \pm 0.04 \pm 0.02$$

$$\alpha_{\Xi^+\pi^-} = 0.58 \pm 0.04 \pm 0.02$$

$$\mathcal{A} = \frac{\alpha_{\Xi^-\pi^+} - \alpha_{\Xi^+\pi^-}}{\alpha_{\Xi^-\pi^+} + \alpha_{\Xi^+\pi^-}} = 0.015 \pm 0.052 \pm 0.017.$$

The result is consistent with no *CP* violation.

Measurements of Branching Fractions of $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ decays at Belle

Motivation:

- **The weak decay of charmed baryons is very useful for testing many contradictory theoretical models and methods**. However, the cognition and exploration of charmed baryon goes pretty slowly.

- The precision of measurement of the decay branching fraction remains poor for many Cabibbo-favored (CF) decays and even worse for some decays dominated by Cabibbo-suppressed even though many different experiments like Belle and BESIII have hard work on improving the measurement results of charmed baryons.

- In theory, the singly Cabibbo-suppressed (SCS) decays $\boldsymbol{\Lambda_c^+ \to p\pi^0}$ and $\boldsymbol{\Lambda_c^+ \to p\eta}$ proceed dominantly through internal W-emission and W-exchange. The measurement of these two decay branching fractions may **be interesting to study the underlying dynamic of charmed baryon decays.**

- In experiment, BESIII report the branching fractions of these two SCS decays, which are $\boldsymbol{B(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}}$ at 90% confidence level and $\boldsymbol{B(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.30) \times 10^{-3}}$.

- In this analysis, we utilize the much higher statistic sample of Λ_c^+ collected by Belle detector to improve the measurement precision.

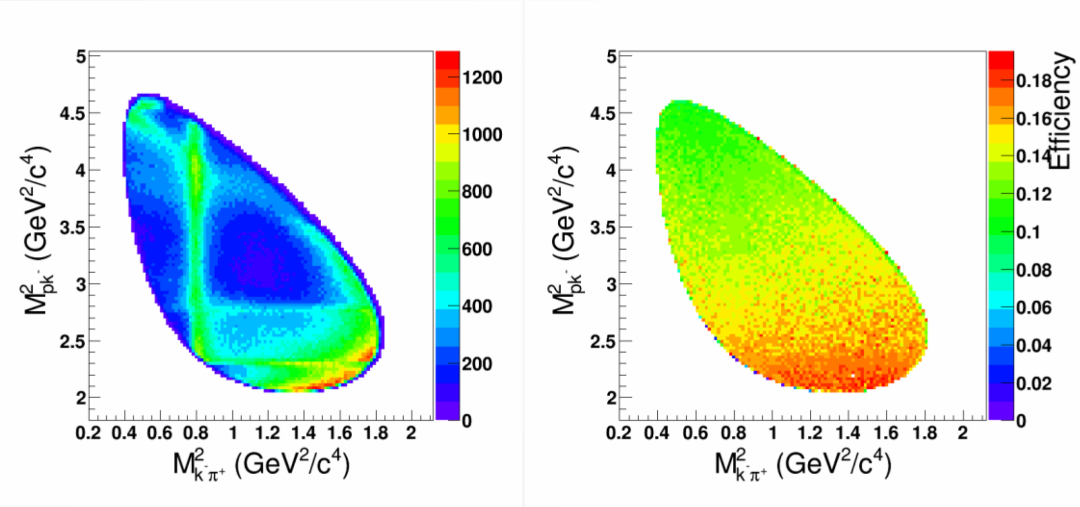
Measurement of $\Lambda_c^+ \to pK^-\pi^+$ decay

PRD103, 072004 (2021)

A method of branching ratio with respect to CF decay $\Lambda_c^+ \to pK^-\pi^+$ (reference mode) is applied to measure the branching fractions of two SCS decays.

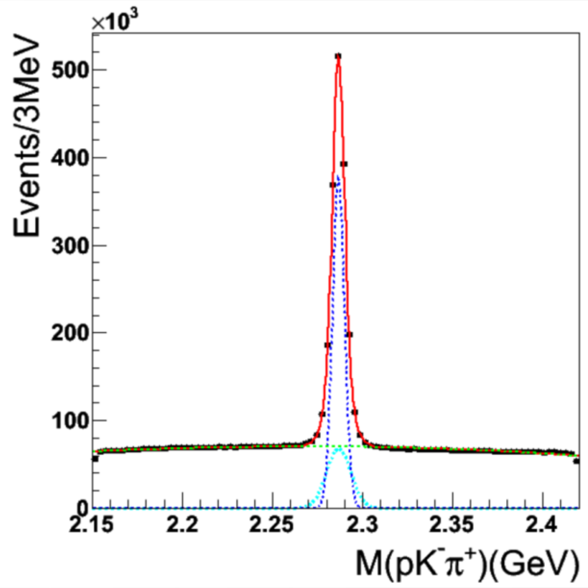
$$\frac{B(SCS)}{B(CF)} = \frac{N^{obs}(SCS)}{\epsilon^{MC}(SCS)} \times \frac{\epsilon^{MC}(CF)}{N^{obs}(CF)}$$

Signal efficiency estimation: Dalitz method.



Left: Dalitz plot from data; Right: Dalitz plot of efficiency from signal MC.

$$\varepsilon = \sum s_i / \sum_j (s_j/\varepsilon_j) = (14.06 \pm 0.01)\,\%.$$



Fit to M($pK^-\pi^+$) from data.

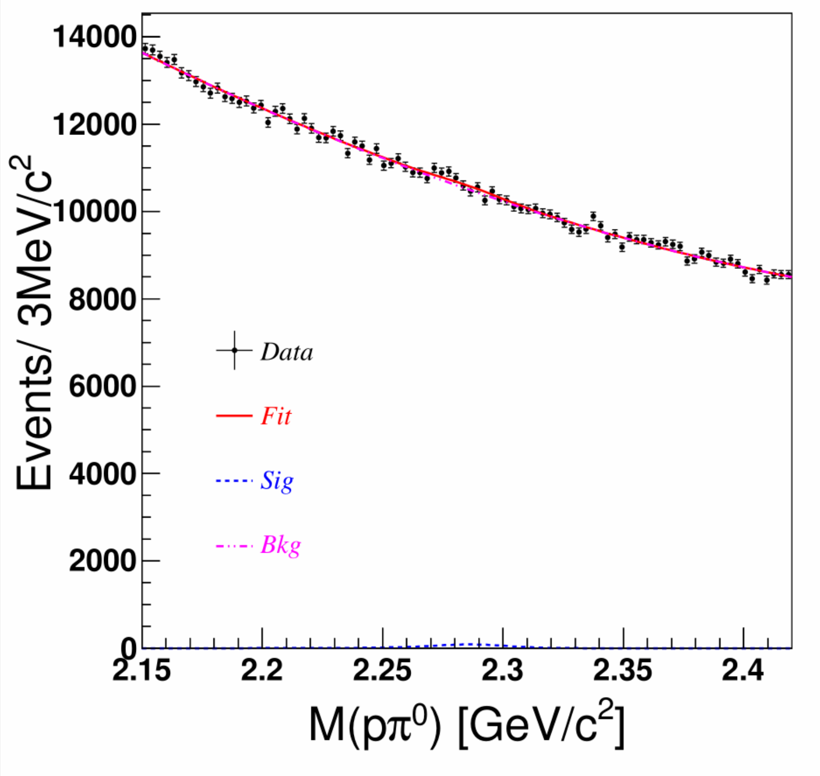
double Gaussian + second-order polynomial

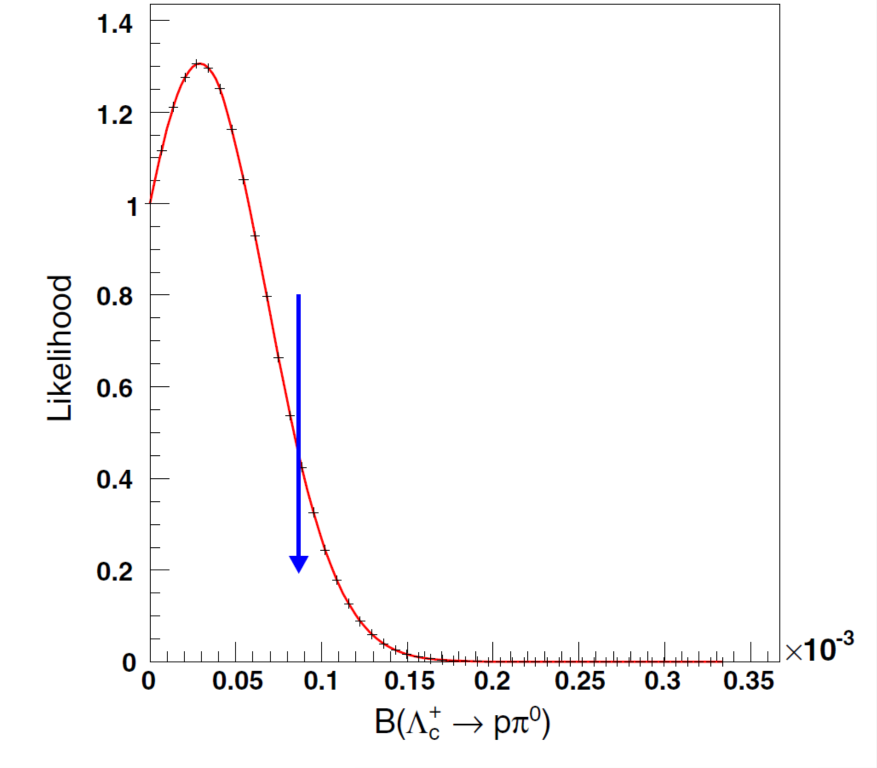
Yield: **1476200 ± 1560**
χ^2/ndf=1.06

Measurement of $\Lambda_c^+ \to p\pi^0$ ($\to \gamma\gamma$) decay

PRD103, 072004 (2021)

- The efficiency estimated from signal MC sample is $(\mathbf{8.891} \pm \mathbf{0.030})\%$.
- There is no obvious signal excess in M($\boldsymbol{p\pi^0}$) from data. We set an upper limit on branching fraction of $\boldsymbol{B(\Lambda_c^+ \to p\pi^0) < 8 \times 10^{-5}}$ at 90% C.L., reducing the value to more than half of the current best upper limit of 2.7×10^{-4}.



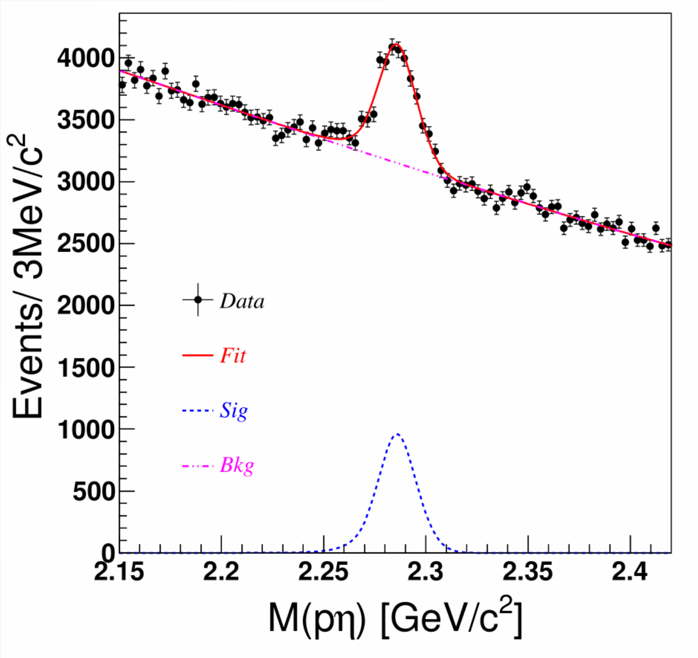


Left: fit to the invariant mass distribution of $p\pi^0$ with a fixed signal yield of **1269**. Right: The likelihood distribution changing with the branching fraction with the systematic uncertainty involved.

Measurement of $\Lambda_c^+ \to p\eta(\to \gamma\gamma)$decay

PRD103, 072004 (2021)

- The efficiency estimated from signal MC sample is $(\mathbf{8.279} \pm \mathbf{0.030})\%$.



Gaussian + CB for signal.
Second-order polynomial for background.

Yield: $\mathbf{7734 \pm 263}$
χ^2/ndf=1.23

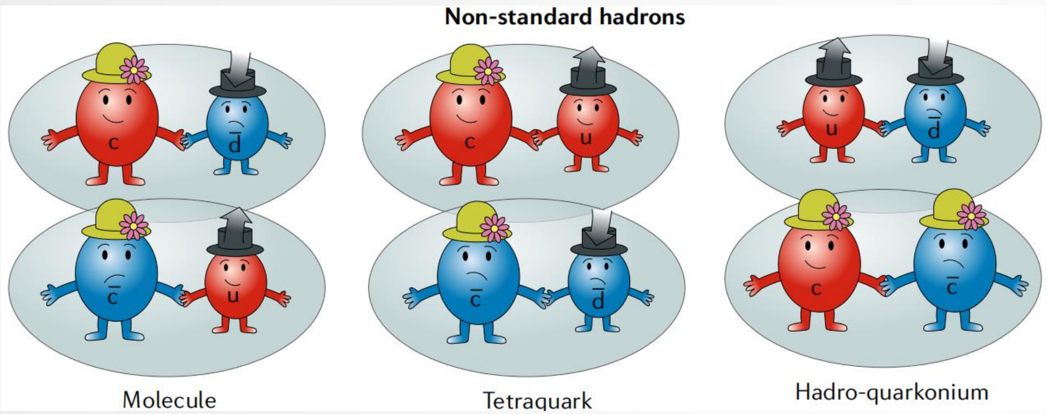
- A significant Λ_c^+ signal is observed in M($p\eta$) distribution from data. The branching fraction is $\boldsymbol{B(\Lambda_c^+ \to p\eta) = (1.42 \pm 0.05 \pm 0.11) \times 10^{-3}}$, which is consistent with the latest BESIII measured result of $(1.24 \pm 0.30) \times 10^{-3}$ with much improved precision.
- The measured $\boldsymbol{B(\Lambda_c^+ \to p\eta)}$ is at least an order of magnitude larger than $\boldsymbol{B\left(\Lambda_c^+ \to p\pi^0\right)}$, which is consistent with the theoretical prediction of an internal W-emission mechanism involving an s quark in $\boldsymbol{\Lambda_c^+ \to p\eta}$.

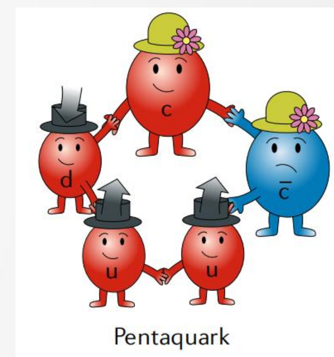
XYZ states

成功=X+Y+Z

Hadrons: normal & multiquarks (exotic)

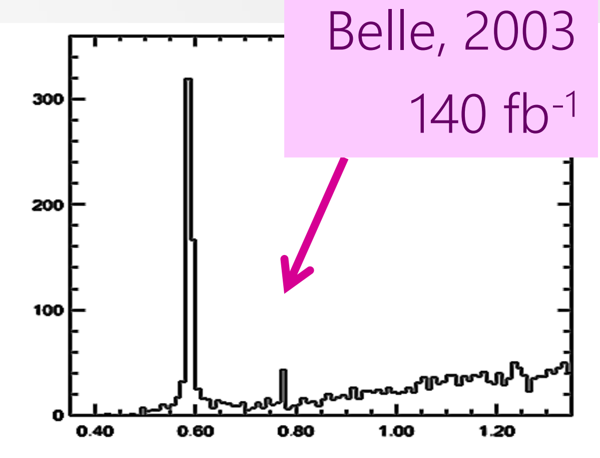
- Quark model: hadrons are composed from 2 (meson) quarks or 3 (baryon) quarks





- QCD does not forbid hadrons with $N_{quarks} \neq 2, 3$
  - Glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - Hybrid : $N_{quarks} = 2$ (or more) + excited gluon
  - Multiquark state : $N_{quarks} > 3$
  - Molecule : bound state of more than 2 hadrons
  - …

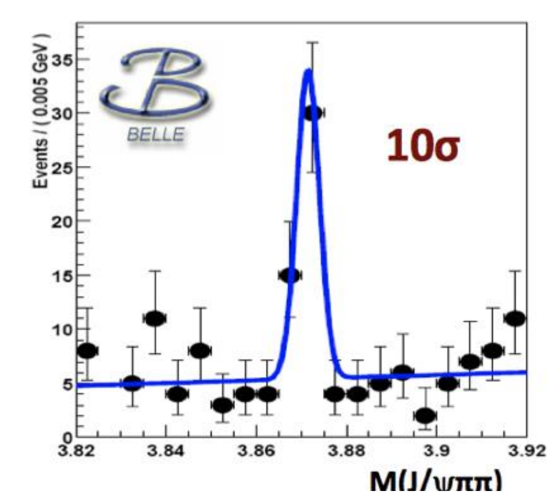
What is the X(3872)?



M(ππJ/ψ) –M(J/ψ) [GeV]

- Mass: Very close to $D^0\bar{D}^{*0}$ threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$
- Production
  - in $p\bar{p}/pp$ collision – rate similar to charmonia
  - In B decays – KX similar to $\bar{c}c$, K*X smaller than $\bar{c}c$
  - Y(4260)→γ+X(3872)
- Decay BR: open charm ~ 50%, charmonium~O(%)
- Nature (very likely exotic)
  - Loosely $\bar{D}^0D^{*0}$ bound state (like deuteron)?
  - Mixture of excited χ_{c1} and $\bar{D}^0D^{*0}$ bound state?

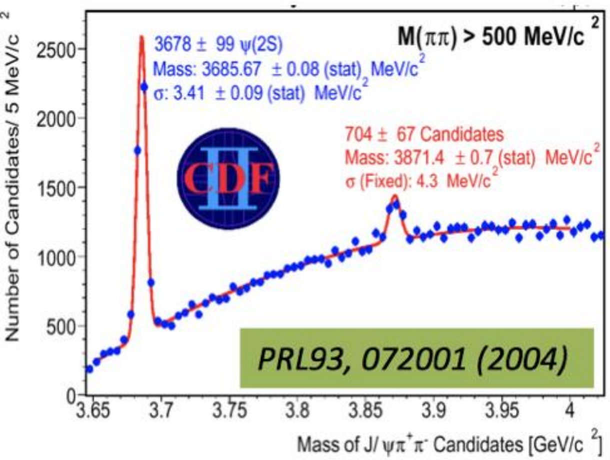
X(3872)→J/ψπ⁺π⁻

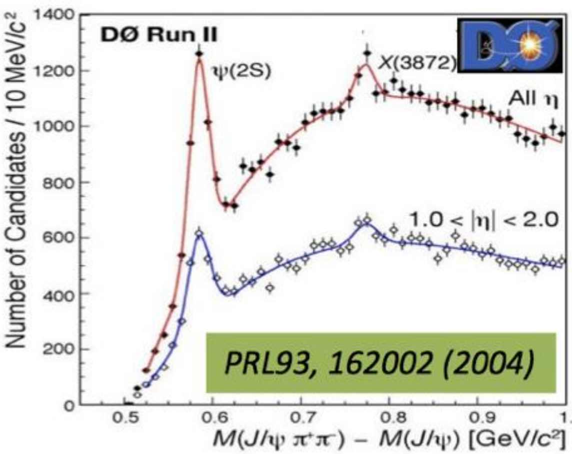


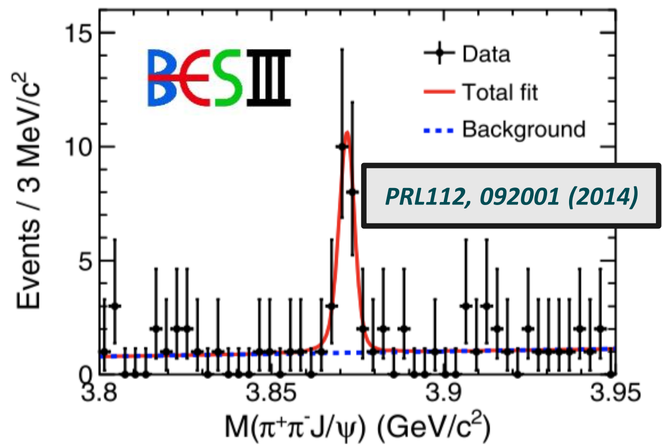
The most-cited article at Belle: 1900+

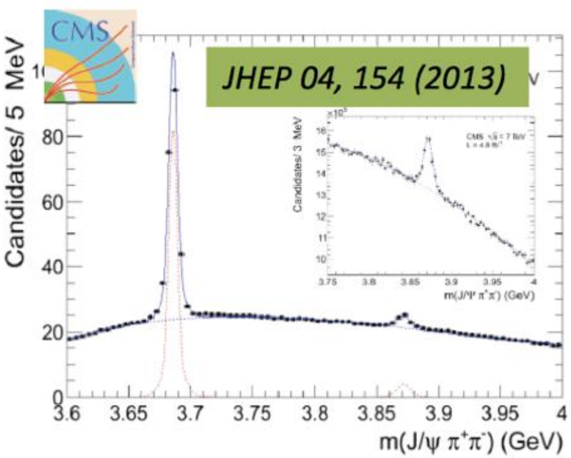
First observed by Belle in $\mathrm{B} \rightarrow \mathrm{K}\, \mathrm{J}/\psi\pi^{+}\pi^{-}$ ***PRL91, 262001 (2003)***

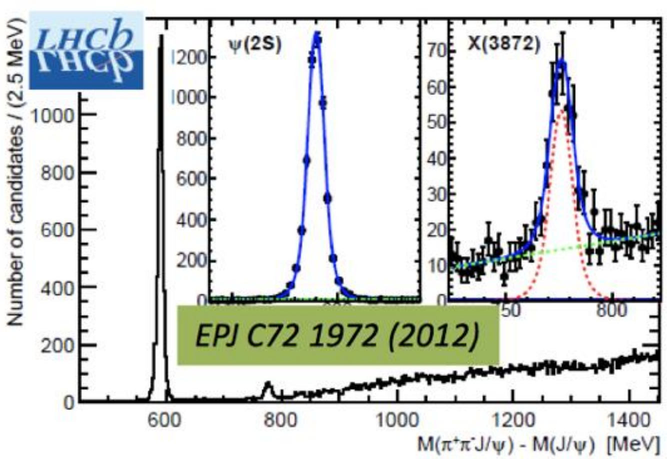
- $\mathrm{M_X}$ close to $\mathrm{D^0\overline{D}^{*0}}$ threshold M = (3871.68±0.17) MeV
- Surprisingly narrow: $\Gamma_{\mathrm{tot}} < 1.2$ MeV at 90% C.L.











X(3872)→J/ψγ: C-even

Angular analysis:

Belle 2006: $J^{PC} = 1^{++}$ or ≥2

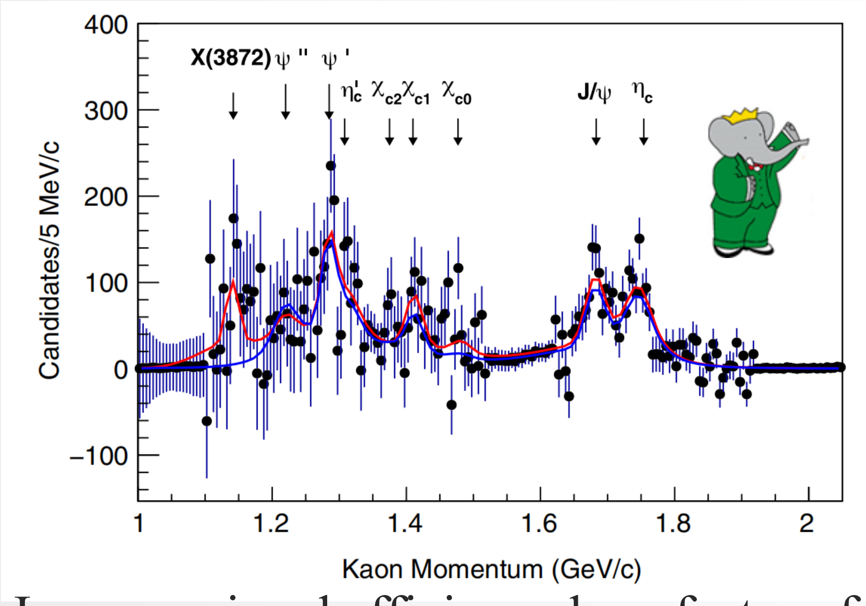
CDF 2008: $J^{PC} = 1^{++}$ or 2^{-+}

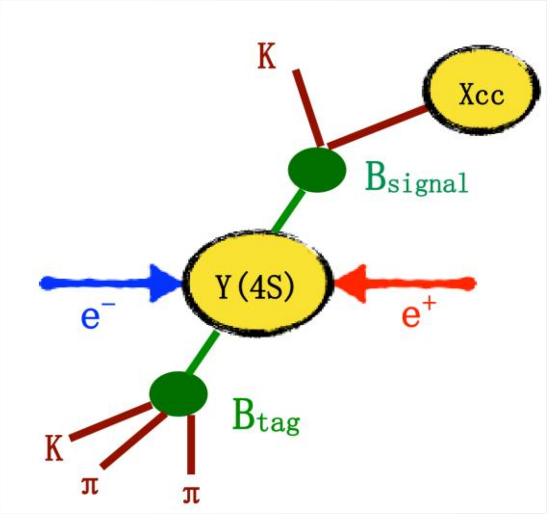
Belle 2011: $J^{PC} = 1^{++}$ or 2^{-+}

LHCb 2013: $J^{PC} = 1^{++}$

$B^{\pm}\rightarrow X(3872)K^{\pm}$

- The determination of the $\mathcal{B}(B^{\pm}\rightarrow X(3872)K^{\pm})$ leads to $\mathcal{B}(X(3872)\rightarrow J/\psi\pi^{+}\pi^{-})$, bringing useful information regarding the complex nature of the X(3872).
- The original tetraquark model [PRD **71**, 014028 (2005)] predicts it to be about 50%. Various molecular models [PRD **72**, 054022 (2005); PRD **69**, 054008 (2004)] predict it to be $\lesssim$10%.





BaBar, 424 fb^{-1}, PRL 124, 152001 (2020)

- Increase signal efficiency by a factor of 3 by retaining all B tag candidate instead of the best one.
- There is 3σ evidence of the decay $B^{\pm}\rightarrow X(3872)K^{\pm}$, detected for the first time using this recoil technique.
- $\mathcal{B}(B^{\pm}\rightarrow X(3872)K^{\pm}) = (2.1\pm0.6\pm0.3)\times10^{-4}$

Absolute branching fractions of X(3872) decays

- Globally analyzing the measurements by BESIII, Belle, Babar, LHCb
- The absolute branching fractions of X(3872) is free parameters in the fitting

$$\chi^2(x) = \sum_{i=1}^{25} \frac{(x_i - x)^2}{\sigma_i^2},$$

- Statistical uncertainties are dominant for most measurements.
- Possible correlation between the systematics of different measurements in an experiments is neglected.

C.H.Li, C.Z.Yuan, Phys.Rev. D100 (2019) 094003

Index (i)	Parameters	Values	Experiments
	$X(3872) \to \pi^+\pi^- J/\psi$	$(\times 10^{-6})$	
1	$B^+ \to X(3872)K^+$	$8.61 \pm 0.82 \pm 0.52$	Belle [14]
2		$8.4 \pm 1.5 \pm 0.7$	BaBar [15]
3	$B^0 \to X(3872)K^0$	$4.3 \pm 1.2 \pm 0.4$	Belle [14]
4		$3.5 \pm 1.9 \pm 0.4$	BaBar [15]
	$X(3872) \to \gamma J/\psi$	$(\times 10^{-6})$	
5	$B^+ \to X(3872)K^+$	$1.78^{+0.48}_{-0.44} \pm 0.12$	Belle [22]
6		$2.8 \pm 0.8 \pm 0.1$	BaBar [23]
7	$B^0 \to X(3872)K^0$	$1.24^{+0.76}_{-0.61} \pm 0.11$	Belle [22]
8		$2.6 \pm 1.8 \pm 0.2$	BaBar [23]
	$X(3872) \to \gamma\psi(3686)$	$(\times 10^{-6})$	
9	$B^+ \to X(3872)K^+$	$0.83^{+1.98}_{-1.83} \pm 0.44$	Belle [22]
10		$9.5 \pm 2.7 \pm 0.6$	BaBar [23]
11	$B^0 \to X(3872)K^0$	$1.12^{+3.57}_{-2.90} \pm 0.57$	Belle [22]
12		$11.4 \pm 5.5 \pm 1.0$	BaBar [23]
	$X(3872) \to D^{*0}\bar{D}^0 + c.c.$	$(\times 10^{-4})$	
13	$B^+ \to X(3872)K^+$	$0.77 \pm 0.16 \pm 0.10$	Belle [16]
14		$1.67 \pm 0.36 \pm 0.47$	BaBar [17]
15	$B^0 \to X(3872)K^0$	$0.97 \pm 0.46 \pm 0.13$	Belle [16]
16		$2.22 \pm 1.05 \pm 0.42$	BaBar [17]
	$X(3872) \to \omega J/\psi$	$(\times 10^{-6})$	
17	$B^+ \to X(3872)K^+$	$6 \pm 2 \pm 1$	BaBar [18]
18	$B^0 \to X(3872)K^0$	$6 \pm 3 \pm 1$	BaBar [18]
	Ratios		
19	$\frac{\mathcal{B}(X(3872)\to\gamma J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	0.79 ± 0.28	BESIII [19]
20	$\frac{\mathcal{B}(X(3872)\to D^{*0}\bar{D}^0+c.c.)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	14.81 ± 3.80	BESIII [19]
21	$\frac{\mathcal{B}(X(3872)\to\omega J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	$1.6^{+0.4}_{-0.3} \pm 0.2$	BESIII [20]
22	$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c1})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	$0.88^{+0.33}_{-0.27} \pm 0.10$	BESIII [21]
23	$\frac{\mathcal{B}(X(3872)\to\gamma\psi(3686))}{\mathcal{B}(X(3872)\to\gamma J/\psi)}$	$2.46 \pm 0.64 \pm 0.29$	LHCb [24]
	$B^+ \to X(3872)K^+$	$(\times 10^{-4})$	
24		$2.1 \pm 0.6 \pm 0.3$	BaBar [27]
25		$1.2 \pm 1.1 \pm 0.1$	Belle [26]

Absolute branching fractions of X(3872) decays

- Fitting results

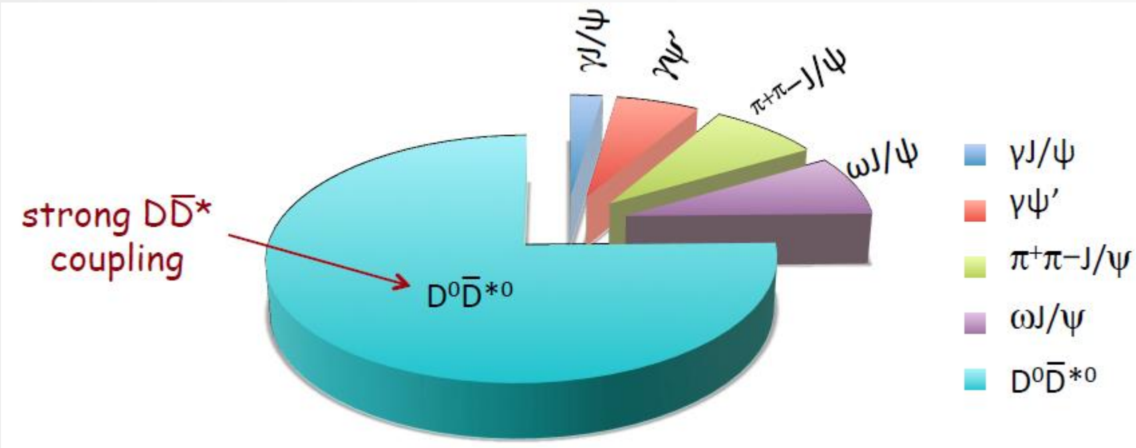
C.H.Li, C.Z.Yuan, Phys.Rev. D100 (2019) 094003

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + c.c.$	$(52.4^{+25.3}_{-14.3})\%$
3	$X(3872) \to \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
4	$X(3872) \to \gamma\psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
5	$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
6	$X(3872) \to \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
7	$B^+ \to X(3872)K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
	$X(3872) \to$ unknown	$(31.9^{+18.1}_{-31.5})\%$

- $X(3872) \to \pi^+\pi^- J/\psi \sim (4.1^{+1.9}_{-1.1})\%$
- $X(3872) \to D^0 D^{*0} \sim (52.4^{+25.3}_{-14.3})\%$
- Unknown decay ~ $(31.9^{+18.1}_{-31.5})\%$

- Statistical uncertainties are dominant.
- At Belle II, we need improve the measurements related with X(3872) decays

X(3872) decay channels



$\Gamma_{\text{“tot”}} \approx 15\ \Gamma(X(3872) \rightarrow \pi^+\pi^- J/\psi)$

$\Gamma(X(3872) \rightarrow \pi^+\pi^- J/\psi) < 80$ keV

D^0-$\bar{D}^{*0}$ molecule?

Lots of literature about this

QCD diquark-diantiquark?

Maiani et al. PRD 71, 014028 (2005)

Impossible to produce such an fragile extended object in prompt high energy hadron colliders at the rates reported by CDF & CMS

Predicts partner states (e.g., a nearby state with u→d) that have yet be seen.

no charged partners of the X(3872)

no nearby neutral X(3872) partners

X(3872) from Belle

. **Observation of a narrow charmonium - like state in exclusive B+- ---> K+- pi+ pi- J / psi decays**
Belle Collaboration (S.K. Choi (Gyeongsang Natl. U.) *et al.*). Sep 2003. 10 pp.
Published in **Phys.Rev.Lett. 91 (2003) 262001**
DOI: 10.1103/PhysRevLett.91.262001
e-Print: **hep-ex/0309032** | **PDF**

References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; ADS Abstract Service; Link to Press Release

2016 W.K.H. Panofsky Prize in Experimental Particle Physics Recipient

Stephen L Olsen
Institute for Basic Science

Citation:

"*For leadership in the BaBar and Belle Experiments, which established the violation of CP symmetry in B-meson decay, and furthered our understanding of quark mixing and quantum chromodynamics.*"

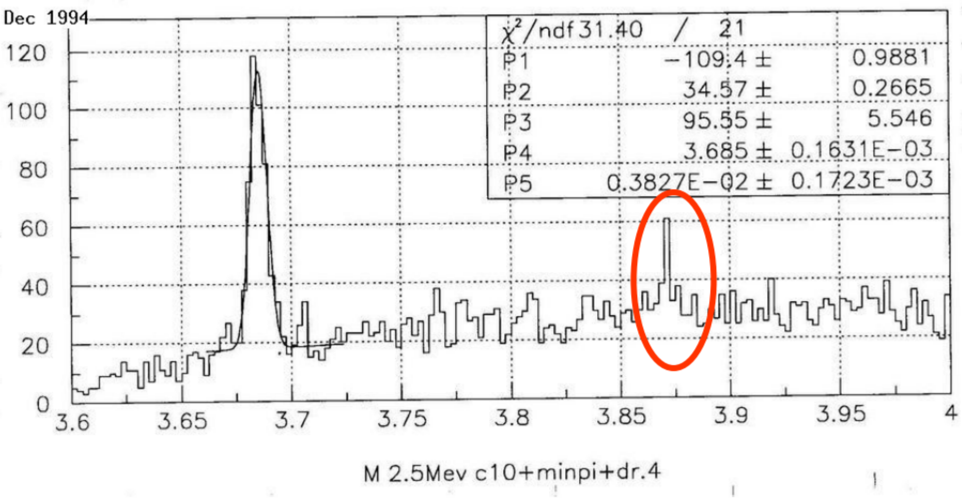
Background:

Stephen Lars Olsen received a B.S. from the City College of New York in 1963 and a Ph.D. in physics from the University of Wisconsin in 1970. He is currently an Emeritus Research Fellow at the Center for Underground Physics of the Institute for Basic Science in Korea. His research has concentrated mostly on studies of heavy quarks and their associated hadrons using CLEO at Cornell, AMY and Belle experiments at KEK in Japan, and the BES experiments at IHEP in Beijing. He currently participates in the KIMS dark matter and AMoRE neutrinoless double beta decay searches at the Yangyang Underground Laboratory in Korea. Olsen was an Alfred P. Sloan Fellow (1972-1977), a John Simon Guggenheim Fellow (1986-1987), a Japan Society for the Promotion of Science Fellow (1987-1988). He was awarded the University of Hawaii Regents Medal for Excellence inResearch in 2002 and was designated as a University of Wisconsin Distinguished Alumni in 2007. He was elected Fellow of the APS in 1984.

Hints before the discovery of $X(3872)\to J/\psi\pi^+\pi^-$

易凯

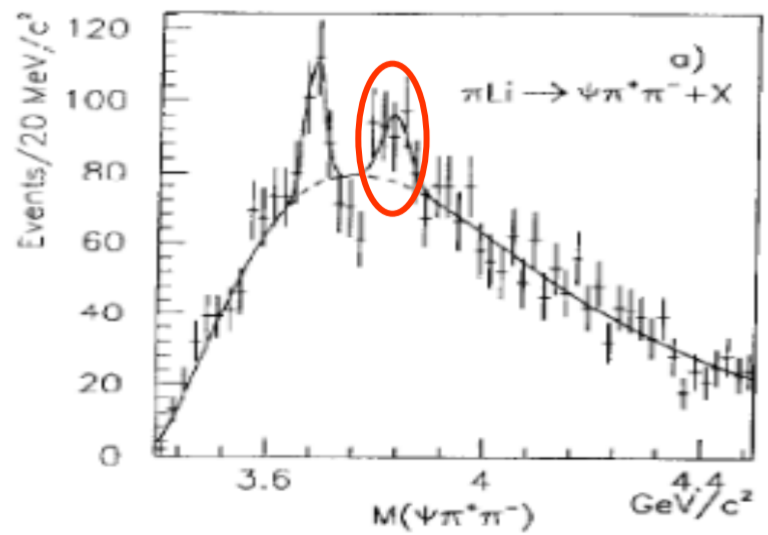
CDF internal, 1994



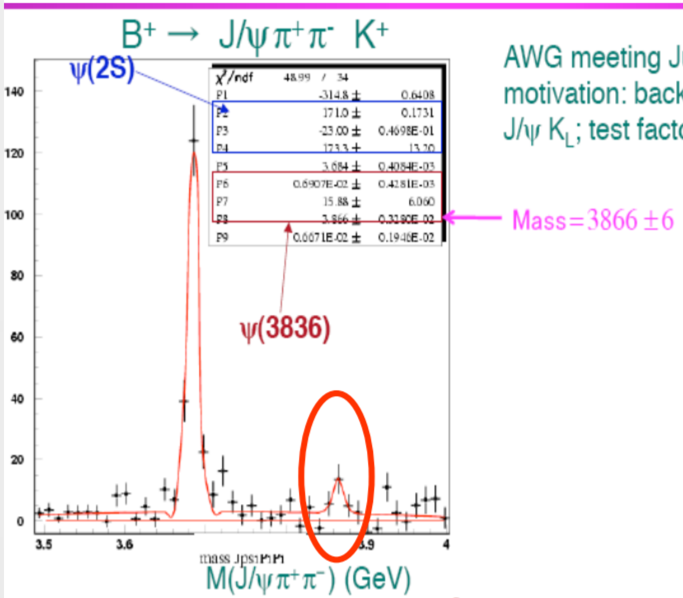
E705, PRD 50, 4258 (1994)

E705 saw $\psi(3836)$ (2^{--}) in 1994, 3.836 ± 0.013 GeV

PRL 115 011803, PRL 111 032001



BaBar internal, 2003



AWG meeting June 2003
motivation: background to
$J/\psi K_L$; test factorization…

From BaBar B-Factory Symposium (C. Hearty)

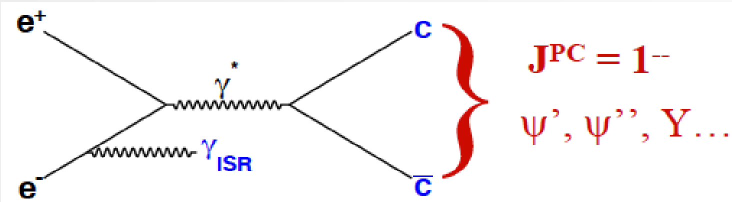
http://www-conf.slac.stanford.edu/b-factory-symposium/talks.asp

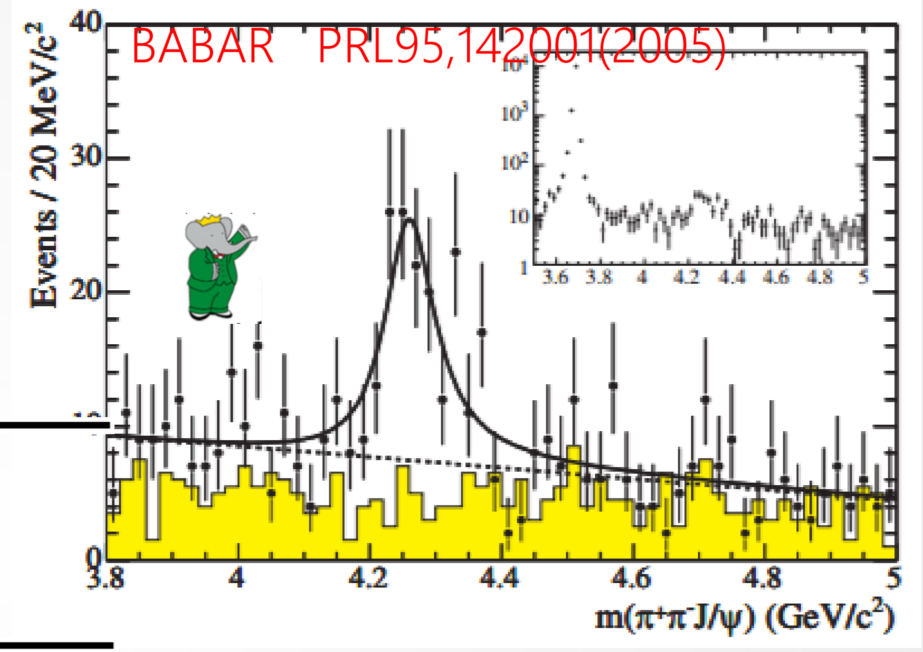
***CDF saw a hint in 1994**, unpublished*

***BaBar saw a hint in 2003**, unpublished*

Both CDF and Babar spotted hints of X(3872) before its discovery!

$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section

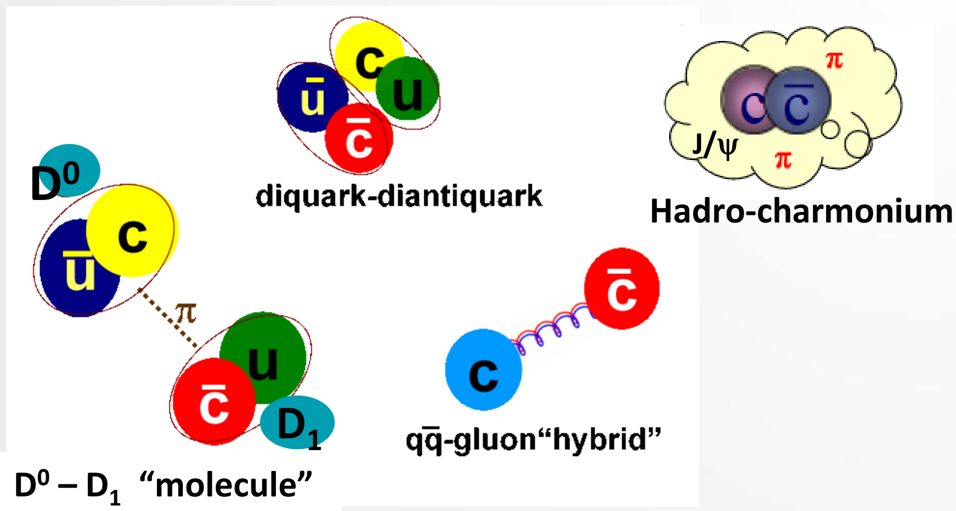




$X(4260)$

$$I^G(J^{PC}) = ?^?(1^{--})$$

$X(4260)$ MASS	4251 ± 9	PDG AVERAGE
$X(4260)$ WIDTH	120 ± 12	PDG AVERAGE

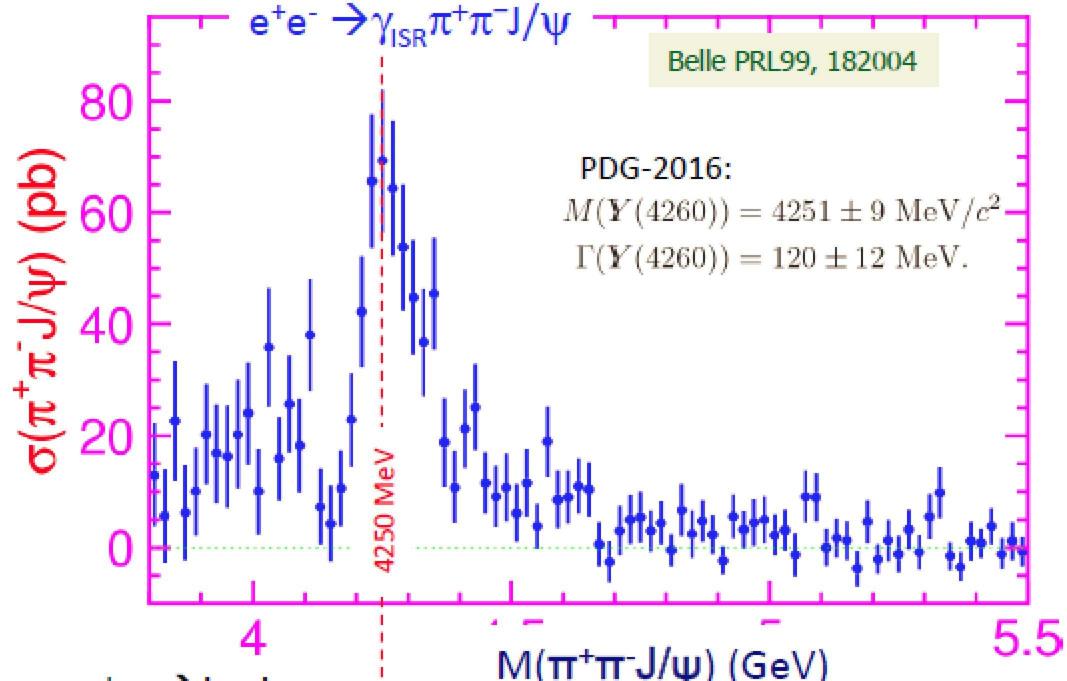


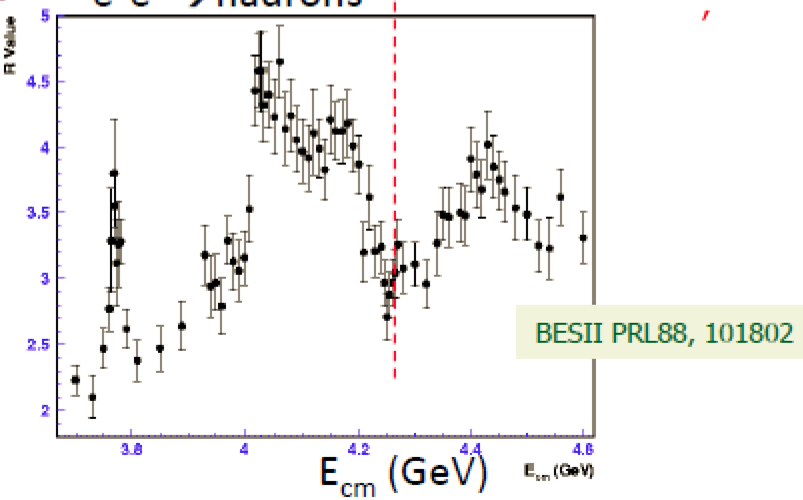
Y(4260) → $\pi^+\pi^- J/\psi$ confirmed by Belle

no sign of Y(4260) → $D^{(*)}\bar{D}^{(*)}$

Y(4260) peak in $\sigma(\pi^+\pi^- J/\psi)$ occurs at a dip in $\sigma(D^{(*)}\bar{D}^{(*)})$

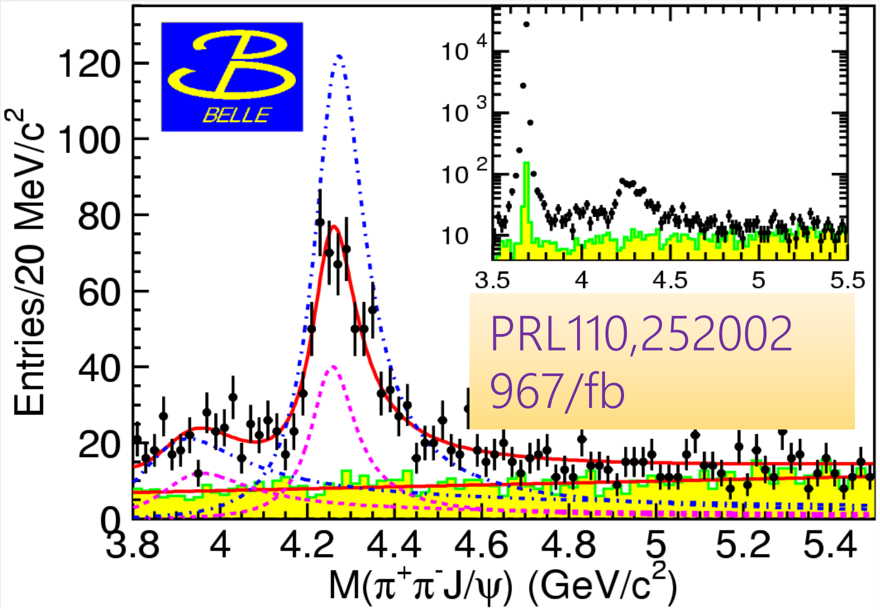
$\Gamma(\pi^+\pi^- J/\psi)$ is large, but should be OZI suppressed if $c\bar{c}$



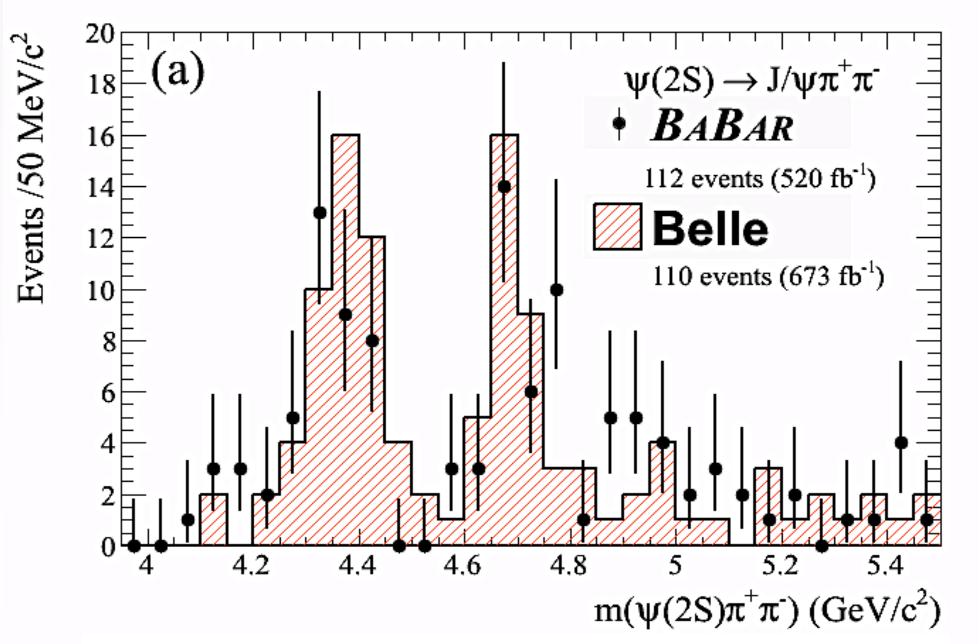


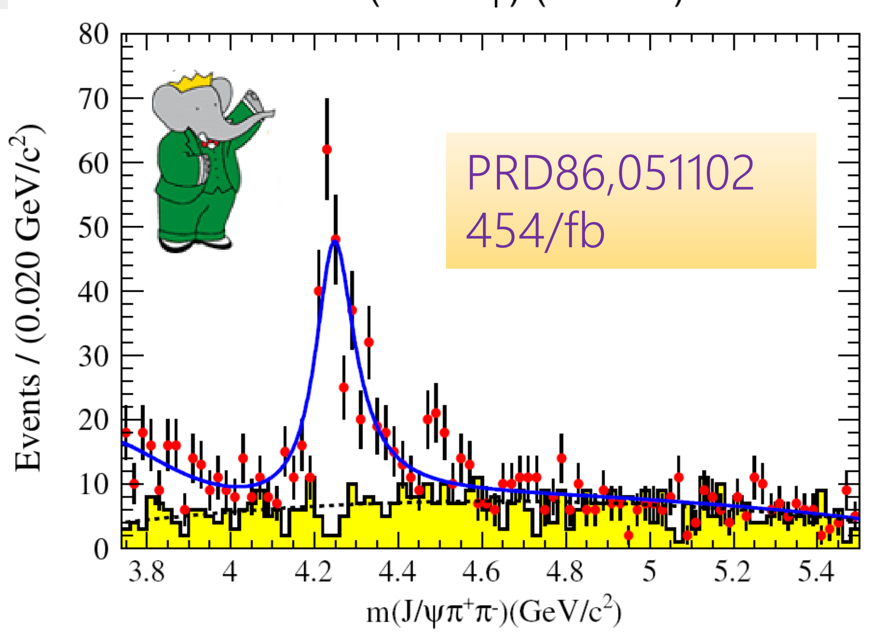
The Y states

Belle: PRL99,142002, 670/fb
BaBar: PRD89, 111103, 520/fb

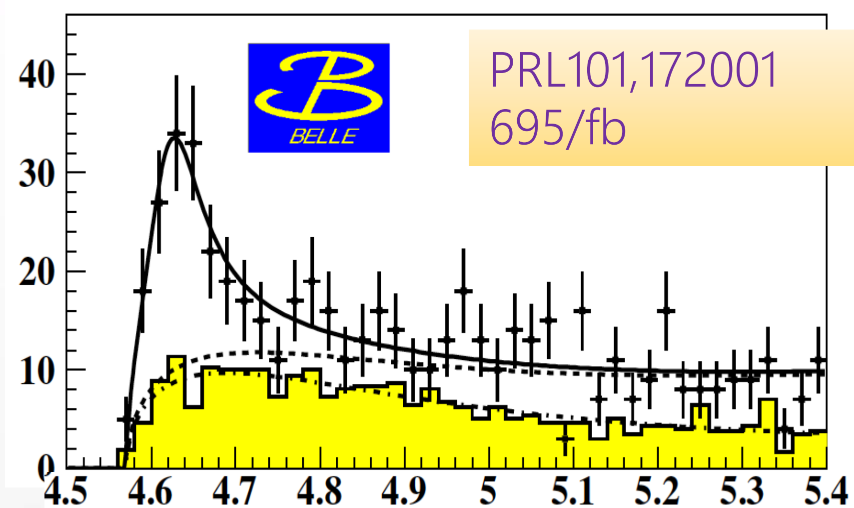


PRL110,252002
967/fb





PRD86,051102
454/fb

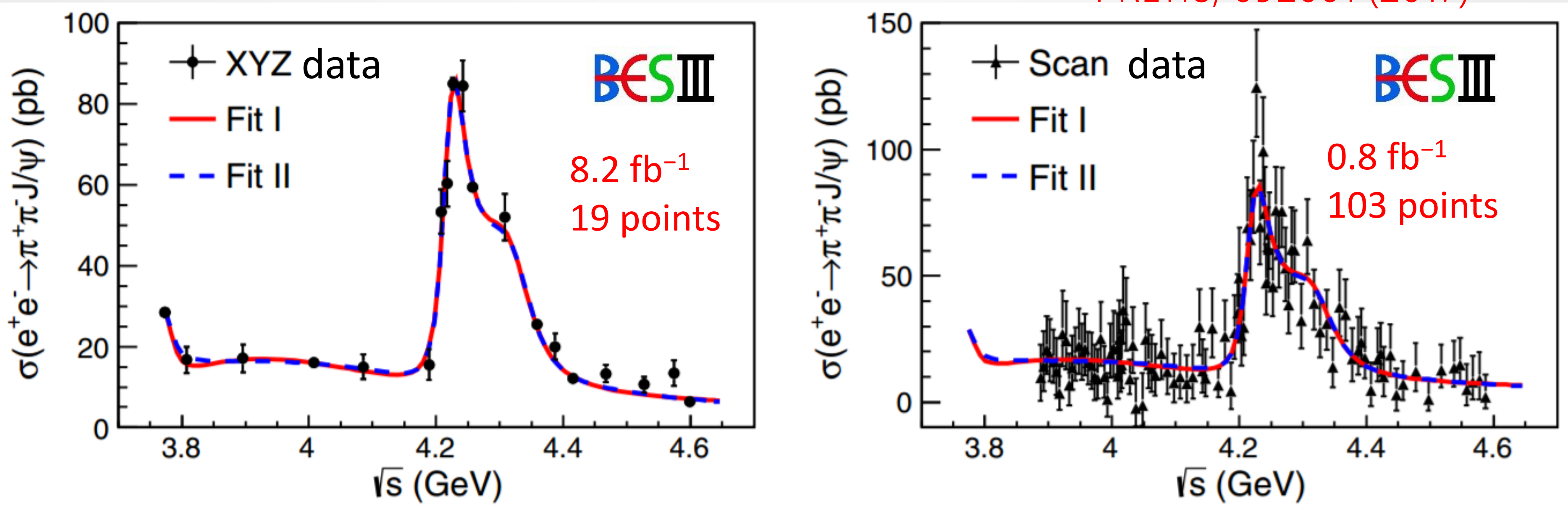


PRL101,172001
695/fb

M($\Lambda_c^+\Lambda_c^-$)

$e^+e^- \to \pi^+\pi^- J/\psi$ cross section

PRL118, 092001 (2017)



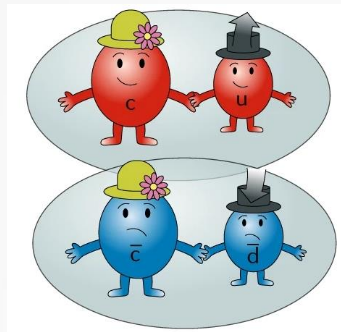
- Most precise cross section measurment to date from BESIII
- Fit I = $|BW_1+BW_2*e^{i\phi 2}+BW_3*e^{i\phi 3}|^2$ or Fit II = $|\exp+BW_2*e^{i\phi 2}+BW_3*e^{i\phi 3}|^2$ (other fits ruled out)
- M = 4222.0±3.1±1.4 MeV (lower)
- Γ = 44.1±4.3±2.0 MeV (narrower)
- A 2nd resonance Y_2 with M=4320.0±10.4±7.0 MeV/c^2

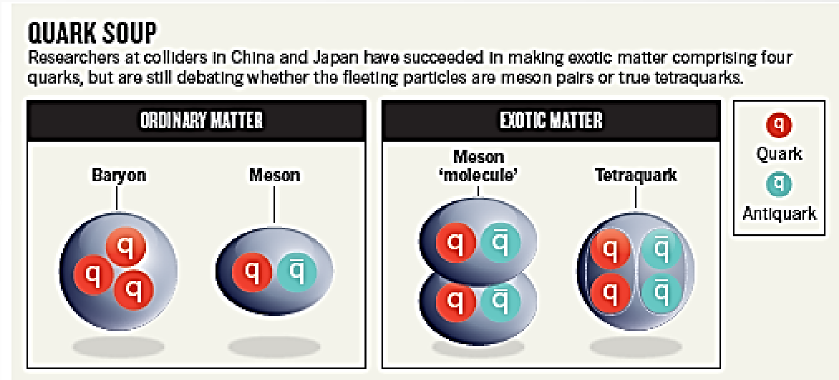
  Γ=$101.4^{+25.3}_{-19.7}$±10.2 MeV
- Observed for the first time, significance > 7.6σ

Observation of the $Z_c(3900)$
— a charged charmoniumlike structure —

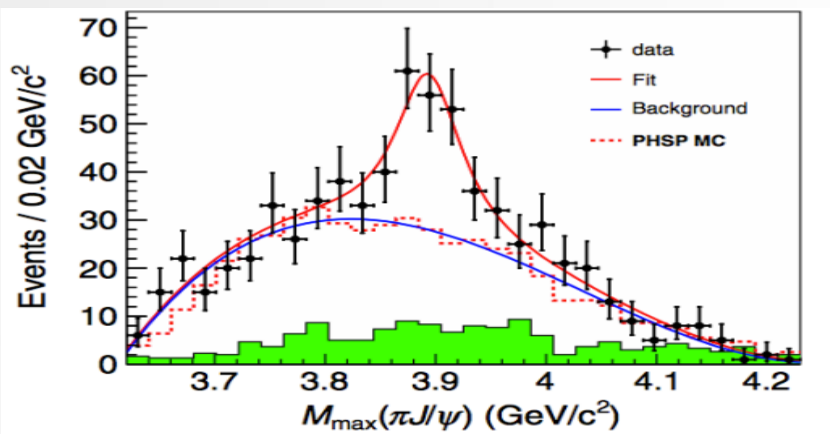
BESIII: 2013年3月24日
Belle： 3月30日
CLEOc：4月10日

Z_c established !





Belle with ISR data (PRL 110, 252002)



PARTICLE PHYSICS

Quark quartet opens fresh vista on matter

First particle containing four quarks is confirmed.

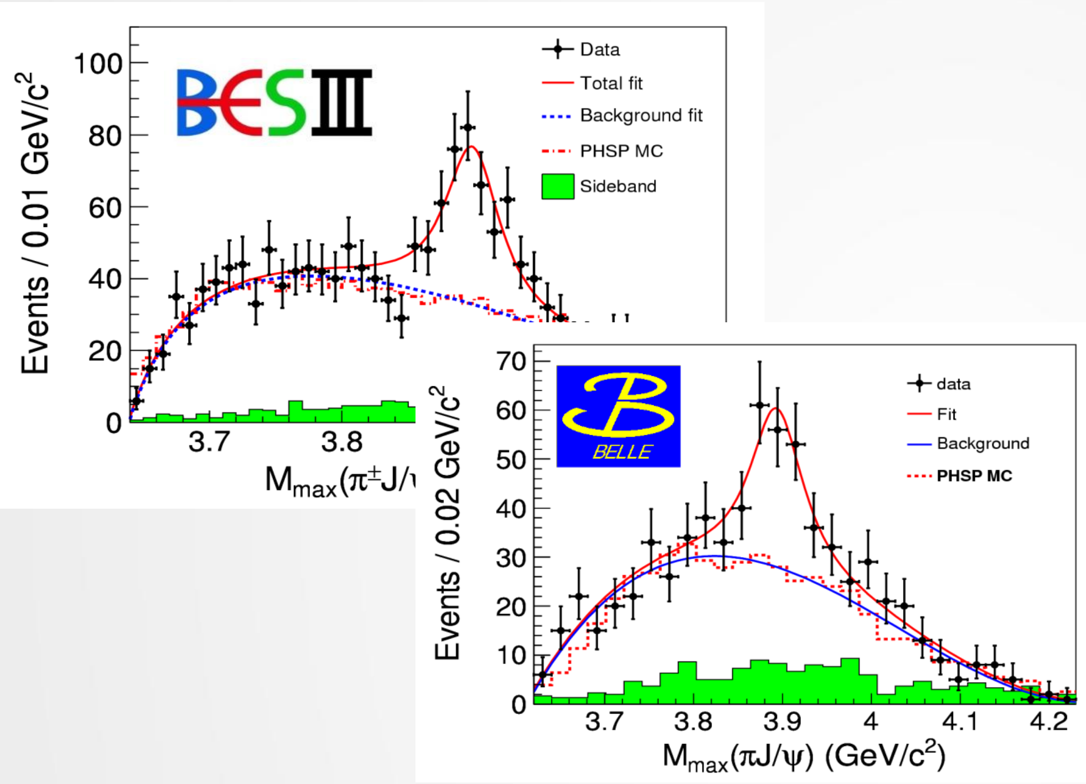
BY DEVIN POWELL

Physicists have resurrected a particle that may have existed in the first hot moments after the Big Bang. Arcanely called $Z_c(3900)$, it is the first confirmed particle made of four quarks, the building blocks of much of the Universe's matter.

Until now, observed particles made of quarks have contained only three quarks (such as protons and neutrons) or two quarks (such as the pions and kaons found in cosmic rays). Although no law of physics precludes larger antimatter counterparts, positrons. These crashes have one-thousandth the energy of those at the world's most powerful accelerator, the Large Hadron Collider (LHC) at CERN near Geneva, Switzerland, but they are still energetic enough to mimic conditions in the early Universe. Collision rates at KEK are more than twice those at the LHC, and they occasionally give birth to rare particles not found in nature today —

"They have clear evidence of a particle with four quarks."

发现带电类粲偶素粒子$Z_c(3900)$



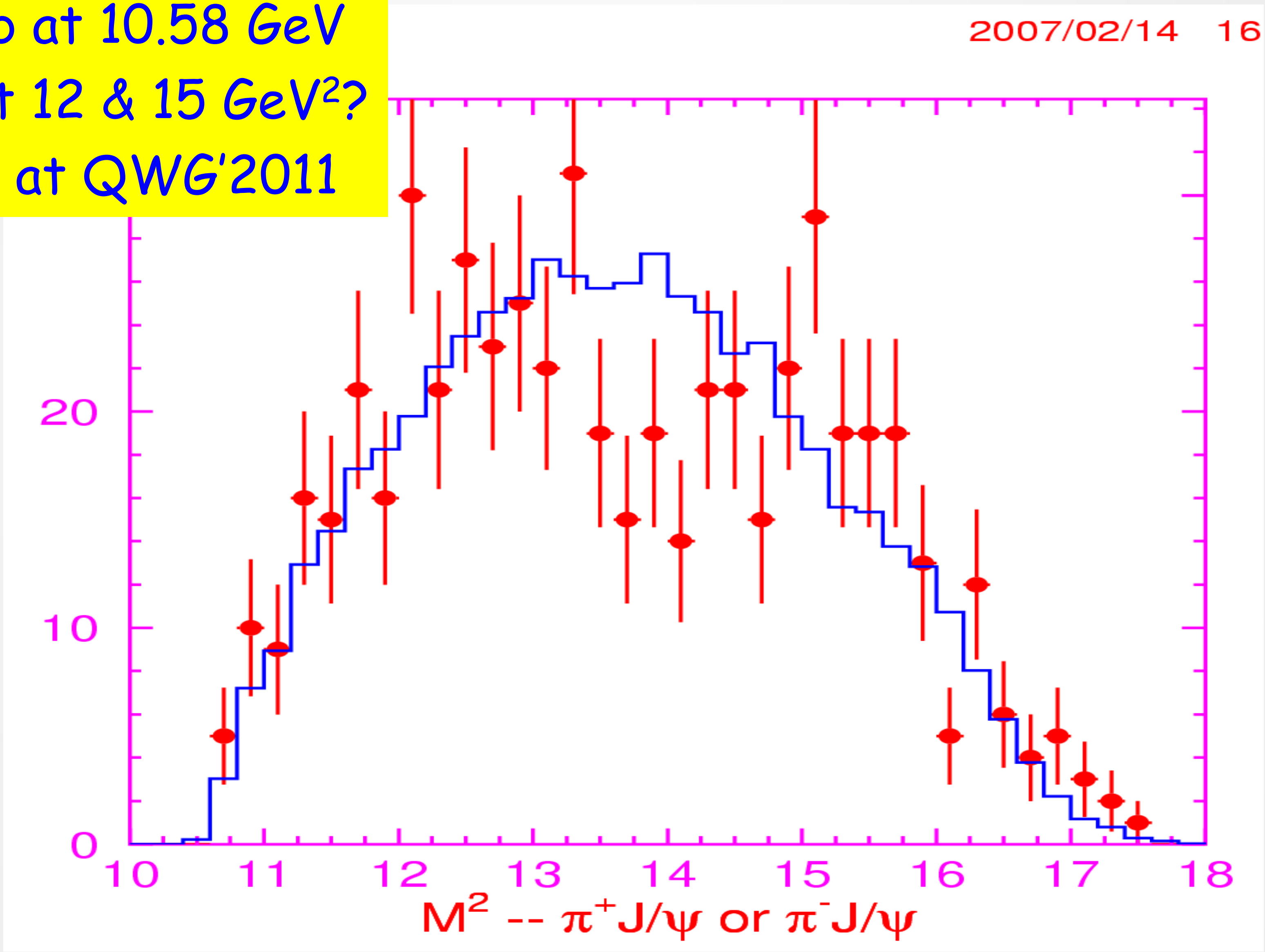
$Z_c(3900)$因其衰变产生$\pi^{\pm}$和J/ψ介子，组成中含有粲夸克和反粲夸克且带有和电子相同或相反的电荷，提示其中至少含有四个夸克，可能是科学家长期寻找的一种奇特强子。

6月17日，发现$Z_c(3900)$的论文在《物理评论快报》发表，杂志编辑推荐，并特别配发题为"新粒子暗示存在四夸克物质"的评论；《自然》杂志发表了题为"夸克'四重奏'开启物质世界的大门"的研究热点报道。

Belle: PRL110, 252002 (2013) **BESIII: PRL110, 252001 (2013)**

M(ππJ/ψ)∈[4.2, 4.4] GeV via ISR

548/fb at 10.58 GeV
Peaks at 12 & 15 GeV²?
Shown at QWG'2011



X+Y+Z

Phys. Rept. 873（2020） 1–154

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Physics Reports xxx (xxxx) xxx

Q3

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PHYSICS REPORTS

Q1 The *XYZ* states: Experimental and theoretical status and perspectives

Nora Brambilla [l,m], Simon Eidelman [b,k,h], Christoph Hanhart [f,*], Alexey Nefediev [h,i,j], Cheng-Ping Shen [e,a,**], Christopher E. Thomas [d], Q2 Antonio Vairo [l], Chang-Zheng Yuan [g,c]

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The XYZ states: experimental and theoretical status and perspectives #1

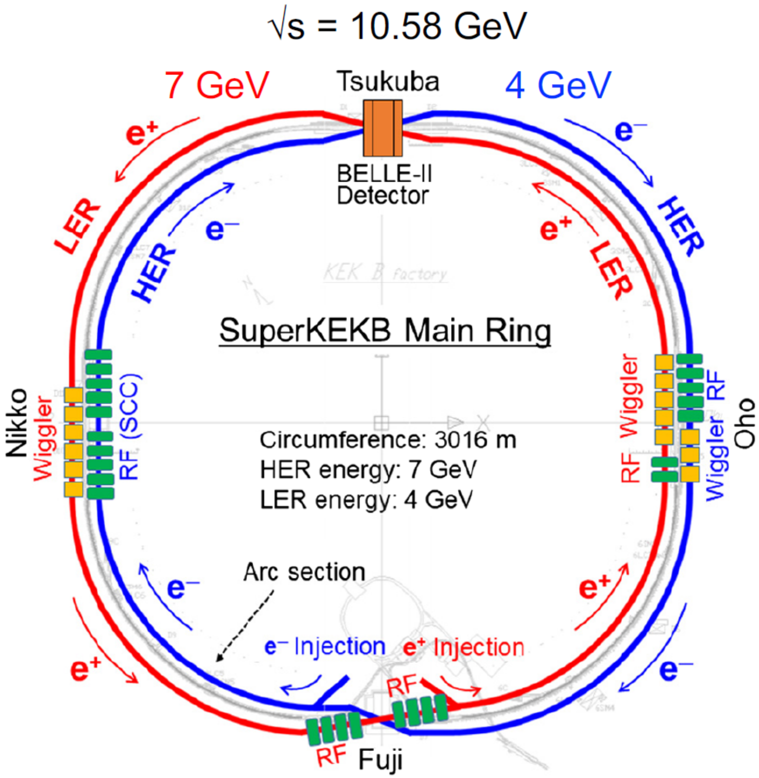
Nora Brambilla (Munich, Tech. U. and TUM-IAS, Munich), Simon Eidelman (Novosibirsk, IYF and Novosibirsk State U.), Christoph Hanhart (Julich, Forschungszentrum), Alexey Nefediev (Lebedev Inst. and Moscow, MIPT and Moscow Phys. Eng. Inst.), Cheng-Ping Shen (Fudan U., Shanghai and Beihang U.) et al. (Jul 17, 2019)

Published in: *Phys.Rept.* 873 (2020) 1-154 • e-Print: 1907.07583 [hep-ex]

Upgrade and Prospects

SuperKEKB Collider

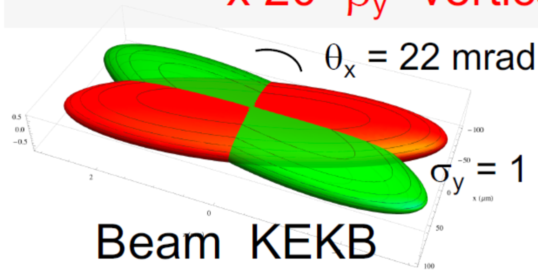
SuperKEKB is a new e^+e^- collider located at KEK (Tsukuba, Japan), it operates in the **intensity frontier** region with a target instantaneous luminosity of 6×10^{35} $cm^{-2} s^{-1}$ which is 30 times larger than that of the previous KEKB collider.

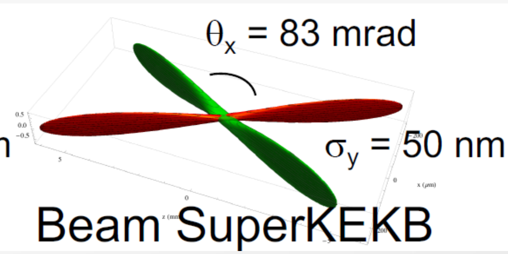


	Instantaneous luminosity ($cm^{-2} s^{-1}$)	Integrated recorded luminosity (ab^{-1})
Babar PEP-II	1×10^{34} $cm^{-2} s^{-1}$	0.55 0.43 Y(4S)
Belle KEKB	2.11×10^{34} $cm^{-2} s^{-1}$	1 0.71 (Y4S)
Belle II SuperKEKB	6×10^{35} $cm^{-2} s^{-1}$	50

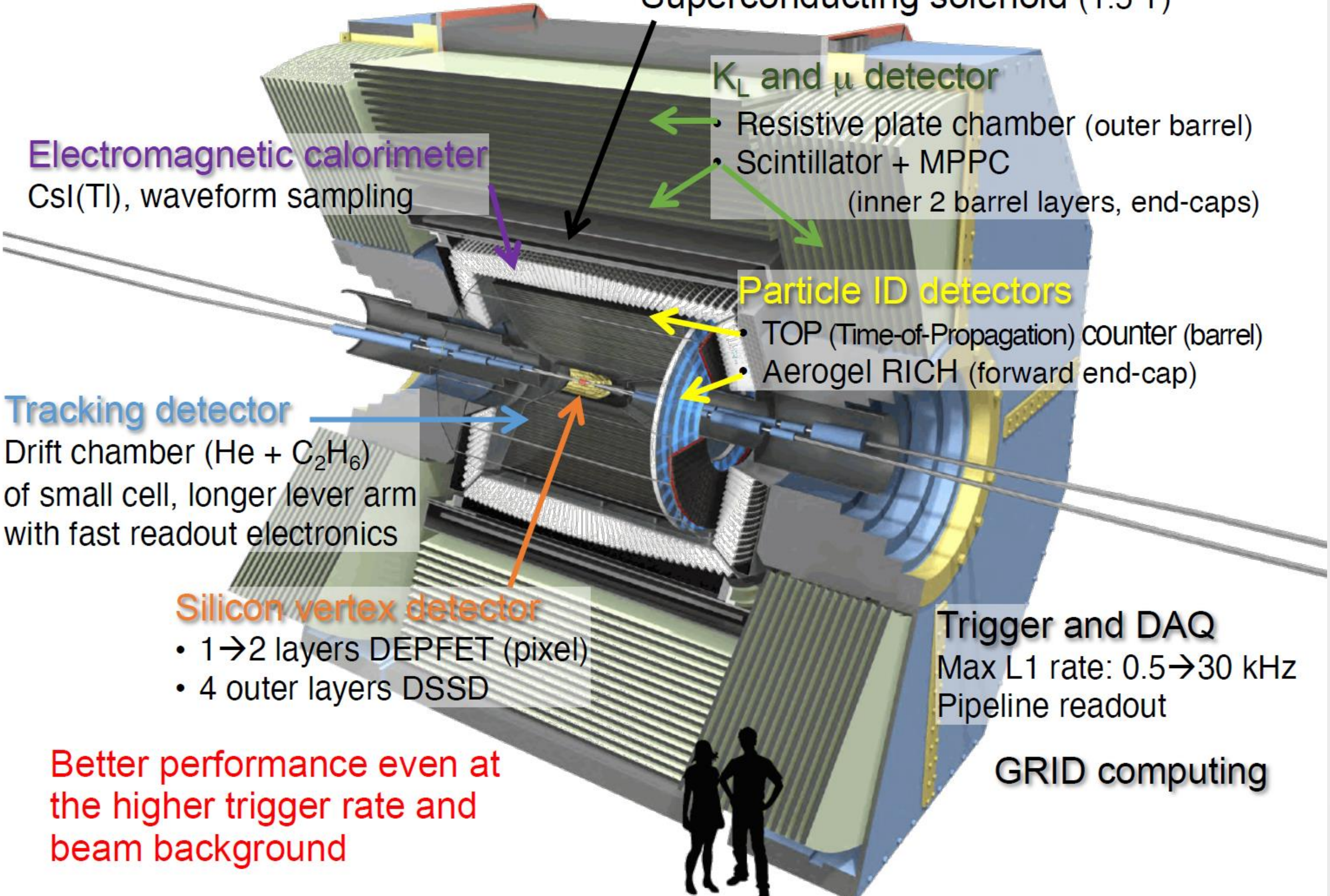
$\mathcal{L}$ x 30 : x1.5 current increase

x 20 β_y^* vertical beta function decrease





Belle II detector



Better performance even at the higher trigger rate and beam background

Belle II Physics Program

- Precision CKM
- CPV in b→s penguin decays
- Tauonic decays
- FCNC
- Charm decays
- LFV τ decays

+

- Hadron spectroscopy
- Dark sector

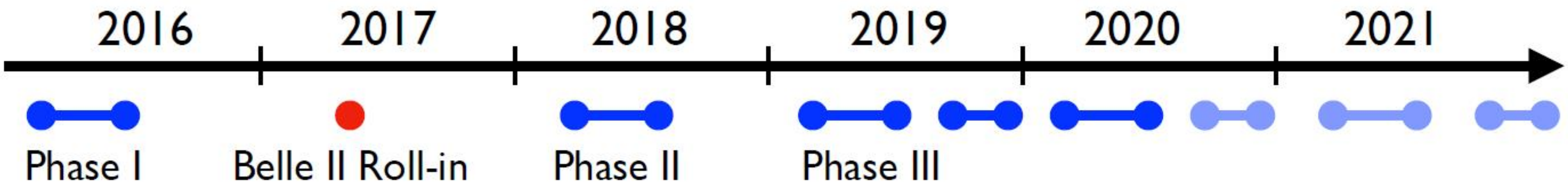
"Belle II Physics Book"
B2TIP (Belle II Theory Interface Platform)
PTEP 2019, no. 12, 123C01 (2019)

Observables	Expected the. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	1.0	Belle II
ϕ_3 [°]	***	1.0	LHCb/Belle II
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II *
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb
CP Violation			
$S(B \to \phi K^0)$	***	0.02	Belle II
$S(B \to \eta' K^0)$	***	0.01	Belle II
$\mathcal{A}(B \to K^0\pi^0)[10^{-2}]$	***	4	Belle II
$\mathcal{A}(B \to K^+\pi^-)$ $[10^{-2}]$	***	0.20	LHCb/Belle II
(Semi-)leptonic			
$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	**	3%	Belle II
$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	**	7%	Belle II
$R(B \to D\tau\nu)$	***	3%	Belle II
$R(B \to D^*\tau\nu)$	***	2%	Belle II/LHCb
Radiative & EW Penguins			
$\mathcal{B}(B \to X_s\gamma)$	**	4%	Belle II
$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	***	0.005	Belle II
$S(B \to K_S^0\pi^0\gamma)$	***	0.03	Belle II
$S(B \to \rho\gamma)$	**	0.07	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	**	0.3	Belle II
$\mathcal{B}(B \to K^*\nu\overline{\nu})$ $[10^{-6}]$	***	15%	Belle II
$\mathcal{B}(B \to K\nu\overline{\nu})$ $[10^{-6}]$	***	20%	Belle II
$R(B \to K^*\ell\ell)$	***	0.03	Belle II/LHCb
Charm			
$\mathcal{B}(D_s \to \mu\nu)$	***	0.9%	Belle II
$\mathcal{B}(D_s \to \tau\nu)$	***	2%	Belle II
$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	**	0.03	Belle II
$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	***	0.03	Belle II *
$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	***	4	Belle II
Tau			
$\tau \to \mu\gamma$ $[10^{-10}]$	***	< 50	Belle II
$\tau \to e\gamma$ $[10^{-10}]$	***	< 100	Belle II
$\tau \to \mu\mu\mu$ $[10^{-10}]$	***	< 3	Belle II/LHCb

* LHCb is now more competitive

Measurements with ultimate precisions down to theory errors !

SuperKEKB/Belle II Operation History



Phase 1 (w/o QCS/Belle II)

- Accelerator tuning w/ single beams

Phase 2 (w/ QCS/Belle II but w/o VXD)

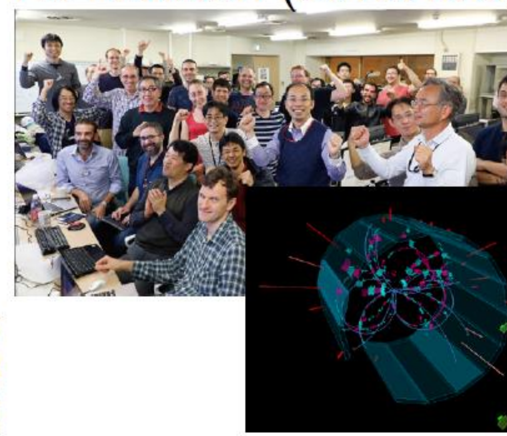
- Verification of nano-beam scheme
- Understand beam background
- Collision data w/o VXD

Phase 3 (w/ full detector)

- Production of physics data

Belle II roll-in (2017.4.17)

1st collision (2018.4.26)



Installation of VXD

Phase 3 physics run (2019.3.25~)

Current integrated luminosity

We kept SuperKEKB and Belle II running in 2020/2021 during the COVID-19 crisis, with extra effort from the local crew and the help of remote shifters

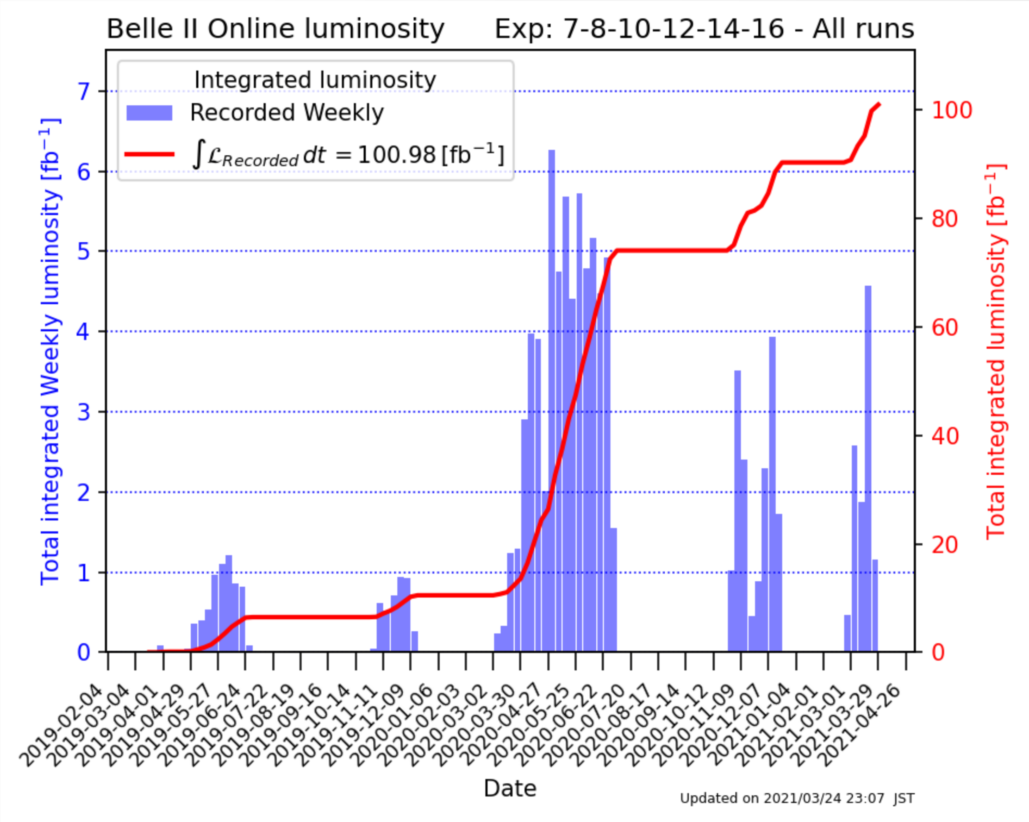
Luminosity world record

2.11×10^{34} $cm^{-2}s^{-1}$
(KEK June 2009)

2.14×10^{34} $cm^{-2}s^{-1}$
(LHC May 2018)

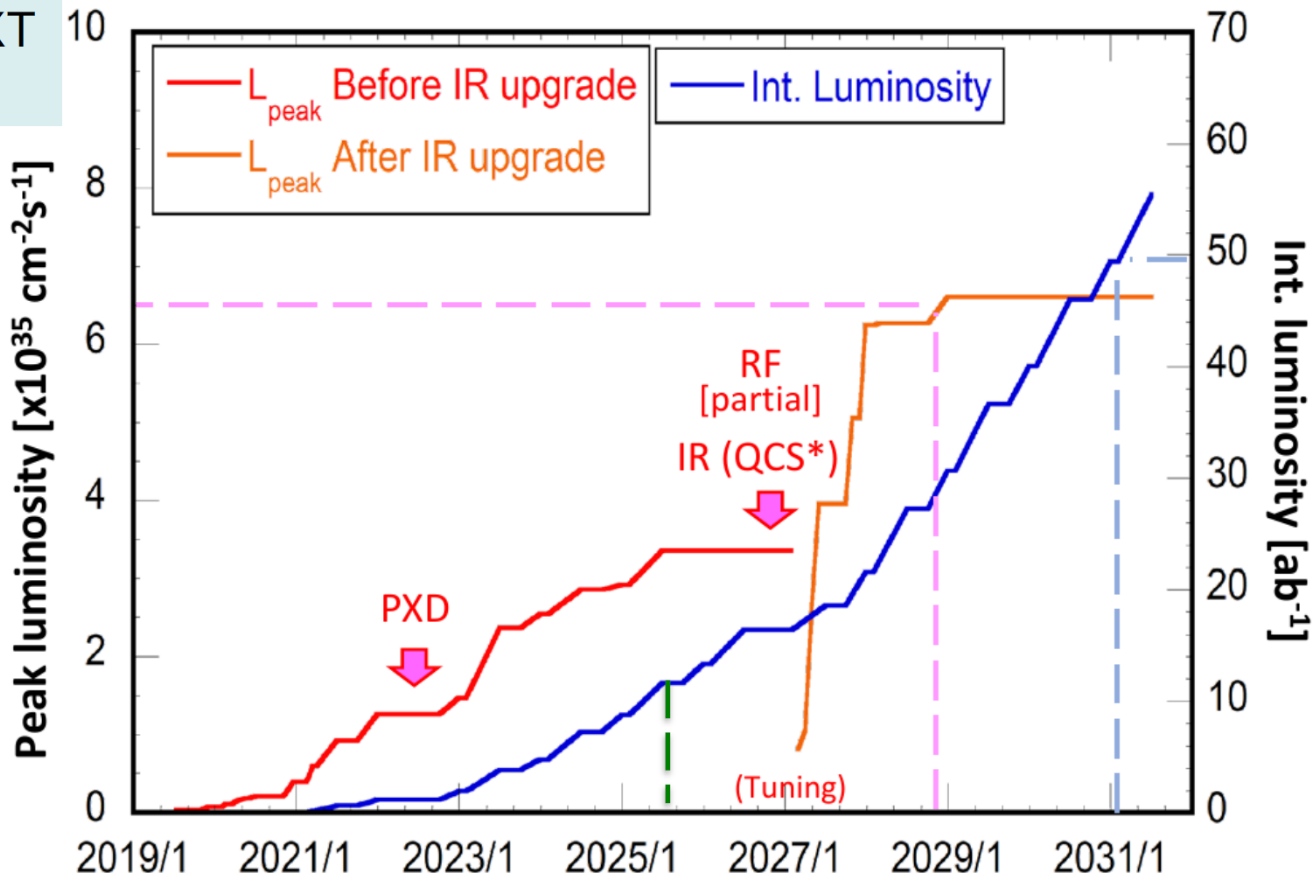
2.4×10^{34} $cm^{-2}s^{-1}$
(SuperKEKB June 2020)

$$\int \mathcal{L}_{Recorded}\, dt = 100.98\,[\mathrm{fb}^{-1}]$$



Luminosity Plan

Submitted to MEXT roadmap 2020



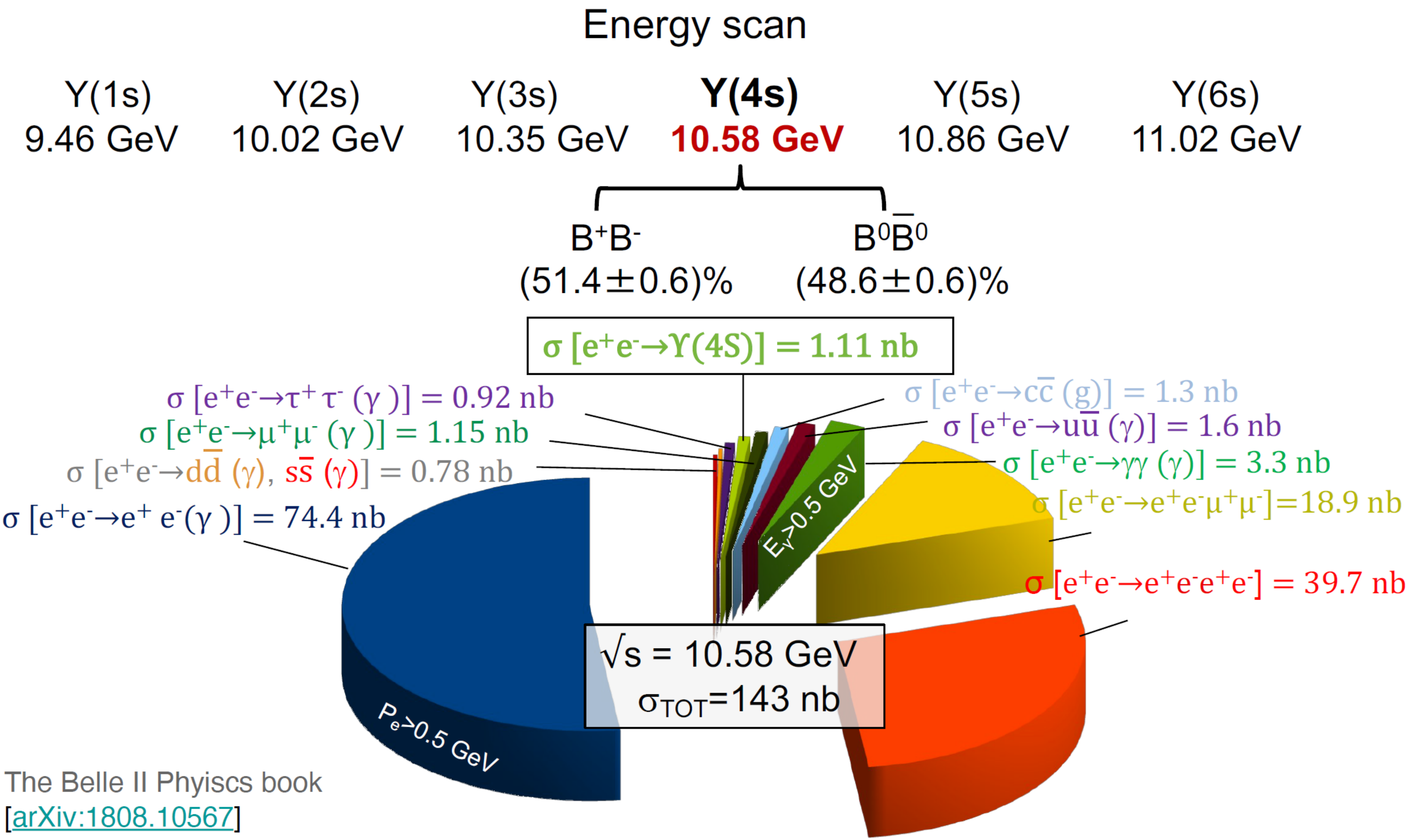
$\int \mathcal{L} = 0.5 \div 1\ ab^{-1}$ in 2022

$\int \mathcal{L} = 10\ ab^{-1}$ in 2026

$\mathcal{L}_{peak} = 6\ 10^{35}\ cm^{-2}\ s^{-1}$ in 2029

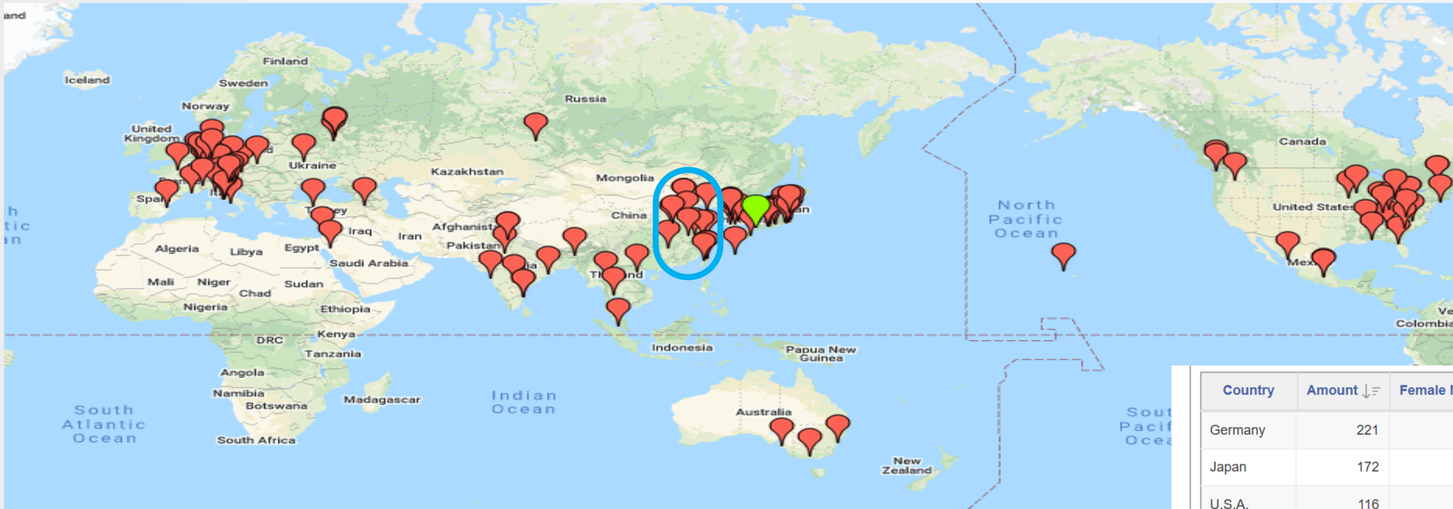
$\int \mathcal{L} = 50\ ab^{-1}$ in 2031

Belle II energy points



The Belle II Phyiscs book
[arXiv:1808.10567]

Belle II国际合作组与中国组



- 规模排第五，但是竞争很激烈。
- 需要考虑更多的研究内容！
- 需要更多的国内支持！

Country	Amount	Female Members	Male Members	Other Members	No Gender Set
Germany	221	41	175		
Japan	172	31	141		
U.S.A.	116	8	108		
Italy	90	14	75		
China	61	15	46	-	-
India	49	18	31	-	-
Russia	47	8	39	-	-
France	47	5	42	-	-

61名成员！

- 合作组规模: 26个国家和地区，>120个研究单位, >1000名成员。
  - 50%为博士后及以上。
  - 众多实验室：KEK, IHEP(Beijing), BNL, SLAC, TRIUMF, DESY, LAL, INFN, BINP, …
- 中国组： 复旦，高能所，中科大、河南师大等12个单位。
- 技术支持：
  - 网页: https://napp.fudan.edu.cn/belle2/ （复旦）
  - Indico: https://indico.ihep.ac.cn/category/109/ （高能所），https://napp.fudan.edu.cn/indico/ （复旦）

- 参与内容:
  - 物理分析：传统强项，但需要拓展研究领域
  - 硬件：高能所，复旦
  - 计算：高能所，复旦，北航；+科大，山大，南师
  - DAQ和触发：高能所，辽师，+山大
  - 探测器刻度：复旦，高能所，
  - 数据检查：中科大，北航

The first Belle II collaboration paper has been submitted to arXiv and “Chinese Physics C”

(https://arxiv.org/abs/1910.05365)

Cornell University

arXiv.org > hep-ex > arXiv:1910.05365

Search...

Help | Adva

High Energy Physics - Experiment

Measurement of the integrated luminosity of the Phase 2 data of the Belle II experiment

Belle II Collaboration: F. Abudinén, I. Adachi, P. Ahlburg, H. Aihara, N. Akopov, A. Aloisio, L. Andricek, N. Anh Ky, D. M. Asner, H. Atmacan, T. Aushev, V. Aushev, K. Azmi, V. Babu, S. Baehr, S. Bahinipati, A. M. Bakich, P. Bambade, Sw. Banerjee, S. Bansal, V. Bansal, M. Barrett, J. Baudot, A. Beaulieu, J. Becker, P. K. Behera, J. V. Bennett, E. Bernieri, F. U. Bernlochner, M. Bertemes, M. Bessner, S. Bettarini, V. Bhardwaj, F. Bianchi, T. Bilka, S. Bilokin, D. Biswas, G. Bonvicini, A. Bozek, M. Bračko, P. Branchini, N. Braun, T. E. Browder, A. Budano, S. Bussino, M. Campajola, L. Cao, G. Casarosa, C. Cecchi, D. Červenkov, M.-C. Chang, P. Chang, R. Cheaib, V. Chekelian, Y. Q. Chen, Y.-T. Chen, B. G. Cheon, K. Chilikin, H.-E. Cho, K. Cho, S. Choudhury, D. Cinabro, L. Corona, L. M. Cremaldi, S. Cunliffe, T. Czank, F. Dattola, E. De La Cruz-Burelo, G. De Nardo, M. De Nuccio, G. De Pietro, R. de Sangro, M. Destefanis, S. Dey, A. De Yta-Hernandez, F. Di Capua, S. Di Carlo, J. Dingfelder, Z. Doležal, I. Domínguez Jiménez, T. V. Dong, K. Dort, S. Dubey, S. Duell, S. Eidelman, M. Eliachevitch, T. Ferber, D. Ferlewicz, G. Finocchiaro, S. Fiore, A. Fodor, F. Forti, A. Frey, B. G. Fulsom, M. Gabriel, E. Ganiev, M. Garcia-Hernandez, A. Garmash, V. Gaur et al. (299 additional authors not shown)

(Submitted on 11 Oct 2019)

From April to July 2018, a data sample at the peak energy of the $\Upsilon(4S)$ resonance was collected with the Belle~II detector at the SuperKEKB electron-positron collider. This is the first data sample of the Belle~II experiment. Using Bhabha scattering events, we measure the integrated luminosity of the data sample to be $(496.7 \pm 0.3 \pm 3.5)$~pb^{-1}, where the first uncertainty is statistical and the second is systematic. A measurement with digamma events is performed as a cross-check, and the obtained result is in agreement with the nominal result. This work provides a basis for future luminosity measurements at Belle~II.

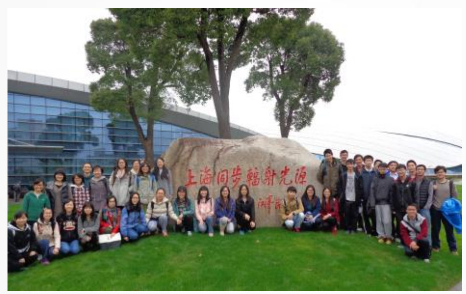
Comments: 12 pages, 2 figures, the first Belle II Collaboration paper

Subjects: **High Energy Physics - Experiment (hep-ex)**

X.Y.Zhou, S.X.Li, C.P.Shen et al (Belle II), CPC 44,021001(2020)

复旦大学
核科学与技术系/现代物理研究所

我系始建于1958年，曾用名原子能系、物理二系、原子核科学系。1997年，原子核科学系改建为现代物理研究所。2009年重建核科学与技术系并恢复本科教育。现有教师53人，其中正高级职称25人（4名外籍），含2名全职中科院院士、2名美国物理学会会士、5名国家杰出青年基金获得者、2名科技部科技创新万人计划领军人才及其他8名国家级人才。



全国首批原子核物理本科专业（1958年）之一、首批硕士点（含粒子物理与原子核物理、原子与分子物理、等离子体物理等三个专业，1962年）和博士点（含粒子物理与原子核物理、原子与分子物理两个专业，1981年）及物理学博士后站点之一（1985年）。目前建有核电子学、热工水力学等5个本科专业教学实验室，与中国工程物理研究院等单位建立实习实训基地10余个。在校本科生120余名、在校研究生130余名。

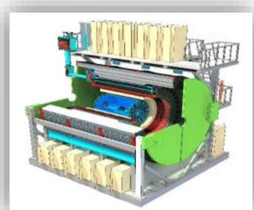
核物理与离子束应用教育部重点实验室　上海EBIT实验室　国家基金委创新研究群体　科技部重点领域创新团队　教育部重离子物理创新引智基地

主要研究领域：粒子物理与核物理
核技术及其应用
原子与分子物理
核相关理论与计算物理

主持纵向项目50余项，包括国家基金创新研究群体、重大项目、杰出青年基金、科技部重点研发计划、中科院战略性先导项目。

参与的部分国际合作组实验

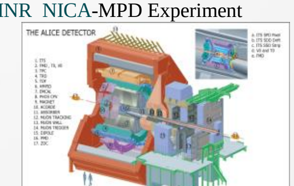
BNL RHIC-STAR Experiment


BNL RHIC-sPHENIX Experiment

JINR NICA-MPD Experiment

KEK Belle II Experiment


GSNL CUORE Experiment



CERN LHC-ALICE Experiment

Summary

- Although Belle has stopped data taking for >10 years ago, we are still producing exciting results [China group has made great contributions].
- Belle II started data taking on 25 March 2019 with its full detector.
- The Belle II experiment at SuperKEKB aims to find New Physics beyond the SM with ultimate precision measurement (a few %, typically) of heavy flavor decays.
- SuperKEKB has achieved Lpeak =2.4 x $10^{34}cm^{-2}s^{-1}$ (world highest luminosity)
- Belle II is performing as expected, and obtained early physics results.
- SuperKEKB/Belle II aims at accumulate $50ab^{-1}$ by ~2030, by further improving the luminosity performance.

感谢您的批评指正

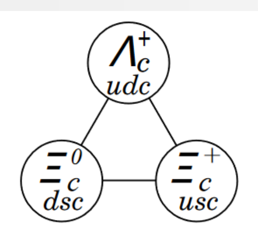
沈成平 shencp@fudan.edu.cn

BackUp : Semileptonic decays

Semileptonic decays of charmed baryons:

- be calculated with QCD factorization approach
- The cleanest processes among charm decays
- Decay rate depend on CKM matrix element $|V_{cq}|$ and strong interaction (form factor)
- Verify lepton universality.

$$\mathcal{A}(\mathbf{B_c} \to \mathbf{B_n} \ell^+ \nu_\ell) = \frac{G_F}{\sqrt{2}} V_{cq} \langle \mathbf{B_n} | J_\mu^{(V-A)} | \mathbf{B_c} \rangle \bar{u}_\nu \gamma^\mu \frac{(1-\gamma_5)}{2} v_\ell$$



$$\mathrm{B_c} = (\Xi_c^0, -\Xi_c^+, \Lambda_c)\,,$$

$$\mathrm{B}_n = \begin{pmatrix} \frac{1}{\sqrt{6}}\Lambda + \frac{1}{\sqrt{2}}\Sigma^0 & \Sigma^+ & p \\ \Sigma^- & \frac{1}{\sqrt{6}}\Lambda - \frac{1}{\sqrt{2}}\Sigma^0 & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{pmatrix}$$

$$J_\mu^{(V-A)} = \bar{q}\gamma_\mu(1-\gamma_5)/2c$$

$\bar{u}_\nu$ and v_ℓ: Dirac bispinors $q = s, d$

G_F: Fermi constant

BackUp: $\Xi_c \rightarrow \Xi\ (\Lambda) l\ \nu$

$\Xi_c \rightarrow \Xi\ (\Lambda) l\ \nu$ have been well studied theoretically.

- Total branching fraction($\mathcal{B}$),
- forward-backward asymmetries($\mathcal{A}_{FB}$),
- differential decay rates($\mathrm{d}\Gamma/dq^2$)

are observable values that uncover the underline dynamics of QCD.

Theories such as:

SU(3) symmetry arXiv:1901.05610 PRD, 97, 073006 (2018) PLB, 792, 214 (2019); Quasipotential approach relativistic quark model EPJC, 79, 695 (2019); light-front quark modelCPC, 42,093101(2018); light-cone QCD sum rules EPJC, 79, 695 (2019)

calculated:

$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^- l^+ \nu_e) = 1.35\sim7.26\%$ $\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 l^+ \nu_e) = 3.3\sim28.6\%$

$\mathcal{B}(\Xi_c^+ \rightarrow \Lambda l^+ \nu_e) = 0.082\sim0.17\%$

Also EPJC, 79, 695 (2019) predict: $$\frac{6\Gamma(\Xi_c \rightarrow \Lambda e \nu_e)}{|V_{cd}|^2} = \frac{\Gamma(\Xi_c \rightarrow \Xi e \nu_e)}{|V_{cs}|^2}$$

BackUp: Excited states:

By John Yelton

https://hflav-eos.web.cern.ch/hflav-eos/charm/baryons/Excited_Apr19/baryons_April19.html

Charmed Baryon Excited State	Mode	Mass (MeV/c^2)	Natural Width (MeV/c^2)	J^P	Status and Comments
$\Lambda_c(2595)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$	2592.25 ± 0.28	$2.59 \pm 0.30 \pm 0.47$	$1/2^-$	well established, most precise mmeasurement by CDF [1]
$\Lambda_c(2625)^+$	$\Lambda_c^+\pi^+\pi^-$	2628.11 ± 0.19	< 1.9	$3/2^-$	well established, most precise measurements by CDF [1]
$\Lambda_c(2765)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$	2766.6 ± 2.4	50	??	discovered by CLEO, seen by Belle, but parameters not measured [2]
$\Lambda_c(2880)^+$	$\Lambda_c^+\pi^+\pi^-$, $\Sigma_c\pi$, $\Sigma_c(2520)\pi$, D^0p	2881.53 ± 0.35	5.8 ± 1.1	$5/2^+$ (experimental evidence)	well established and seen in more than one mode [2] [4]
$\Lambda_c(2940)^+$	D^0p, $\Sigma_c\pi$	$2939.3^{+1.4}_{-1.5}$	17^{+8}_{-6}	??	Seen by both BaBar [4] and BelleMizuk
$\Sigma_c(2455)^{++}$	$\Lambda_c^+\pi^+$	167.510 ± 0.17	$1.89 \pm^{+0.09}_{-0.18}$	$1/2^+$	well established, most precise measurements by Belle [5]
$\Sigma_c(2455)^+$	$\Lambda_c^+\pi^+$	166.4 ± 0.4	< 4.6 @ 90% CL	$1/2^+$	well established, but parameters not measured precisely
$\Sigma_c(2455)^0$	$\Lambda_c^+\pi^+$	167.29 ± 0.17	$1.83^{+0.11}_{-0.19}$	$1/2^+$	well established, most precise measurements by Belle [5]
$\Sigma_c(2520)^{++}$	$\Lambda_c^+\pi^+$	$231.95^{+0.17}_{-0.12}$	$14.78 \pm +0.30_{-0.40}$	$3/2^+$	well etablished, most precise measurements by Belle [5]
$\Sigma_c(2520)^+$	$\Lambda_c^+\pi^+$	231.0 ± 2.3	< 17 @ 90% CL	$3/2^+$	fairly well established, awaits precise measurement
$\Sigma_c(2520)^0$	$\Lambda_c^+\pi^+$	$232.02^{+0.15}_{-0.14}$	$15.3^{+0.4}_{-0.5}$	$3/2^+$	well established, most precise measurements by Belle [5]
$\Sigma_c(2800)^{++}$	$\Lambda_c^+\pi^+$	514^{+4}_{-6}	75^{+18+12}_{-13-11}	tentatively identified	observed by Belle [6] - should be confirmed
$\Sigma_c(2800)^+$	$\Lambda_c^+\pi^0$	505^{+15}_{-5}	62^{+37+52}_{-23-38}	as members of the predicted	
$\Sigma_c(2800)^0$	$\Lambda_c^+\pi^-$	519^{+5}_{-7}	72^{+22}_{-15}	Σ_{c2} $3/2^-$ isospin triplet?	same states as that below?
	$\Lambda_c^+\pi^-$	$560 \pm 8 \pm 10$	86^{+33}_{-22}		seen by Babar [7] in resonant substructure of B decays - needs confirmation
$\Xi_c'^+$	$\Xi_c^+\gamma$	110.5 ± 0.4		$1/2^+$	well established
$\Xi_c'^0$	$\Xi_c^0\gamma$	108.3 ± 0.4		$1/2^+$	well established
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	178.5 ± 0.1	2.1 ± 0.2	$3/2^+$	well established, widths recently measured by Belle [8]
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	174.7 ± 0.1	2.4 ± 0.2	$3/2^+$	
$\Xi_c(2790)^+$	$\Xi_c'^0\pi^+$	320.7 ± 0.5	9 ± 1	$1/2^-$	well established, widths recently measured by Belle [8]
$\Xi_c(2790)^0$	$\Xi_c'^+\pi^-$	323.8 ± 0.5	10 ± 1	$1/2^-$	
$\Xi_c(2815)^+$	$\Xi_c(2645)^0\pi^+$	348.8 ± 0.1	2.43 ± 0.23	$3/2^-$	well established, widths recently measured by Belle [8]
$\Xi_c(2815)^0$	$\Xi_c(2645)^+\pi^-$	349.4 ± 0.1	2.54 ± 0.23	$3/2^-$	
$\Xi_c(2930)^+$	$\Lambda_c^+K_S^0$	$2942.3 \pm 4.4 \pm 1.5$	$14.8 \pm 8.8 \pm 2.5$	??	"evidence" recently reported by Belle [9]
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	$2928.9 \pm 3.0^{+0.9}_{-12.0}$	$19.5 \pm 8.4^{+5.9}_{-7.9}$	??	originally reported by BaBar [11], confirmed by Belle [10]
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$	2967.2 ± 0.8	21 ± 3	??	well established, but parameters in different modes and experiments differ
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-$	2970.4 ± 0.8	28 ± 3	??	well established, but parameters in different modes and experiments differ
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$,ΛD	3055.7 ± 0.4	8.0 ± 1.9	??	seen by Belle and BaBar [12] [14]
$\Xi_c(3055)^0$	ΛD	3059.0 ± 0.8	6.2 ± 2.4	??	newly observed by Belle [14]
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Sigma_c(2520)^{++}K^-$, ΛD	3077.8 ± 0.3	3.6 ± 0.7	??	seen by Belle and BaBar [12] [15]
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-$, $\Sigma_c^0K_S^0$, $\Sigma_c(2520)^0K_S^0$	3079.9 ± 1.0	5.6 ± 2.2	??	seen by Belle and BaBar [12] [14] [15]
$\Omega_c(2770)^0$	$\Omega_c^0\gamma$	2765.9 ± 2.0	0	$3/2^+$	seen by BaBar [16] and Belle [17]
$\Omega_c(3000)^0$	$\Xi_c^+K^-$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	??	LHCb [18]
$\Omega_c(3050)^0$	$\Xi_c^+K^-$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$< 1.2, 95\%$CL	??	LHCb [18]
$\Omega_c(3066)^0$	$\Xi_c^+K^-$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	??	LHCb [18]
$\Omega_c(3090)^0$	$\Xi_c^+K^-$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	??	LHCb [18]
$\Omega_c(3119)^0$	$\Xi_c^+K^-$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	??	LHCb [18]
$\Omega_c(3118)^0$	$\Xi_c^+K^-$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	??	Reported by LHCb [18], not clear if it is several resonances

BackUp: Current charmed baryon status

Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$ or $\Sigma_c(2765)$		*
$\Lambda_c(2860)^+$	$3/2^+$	***
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$	$3/2^-$	***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	****
$\Xi_c^{\prime +}$	$1/2^+$	***
$\Xi_c^{\prime 0}$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		**
$\Xi_c(2970)$ was $\Xi_c(2980)$		***
$\Xi_c(3055)$		***
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	$1/2^+$	***
$\Omega_c(2770)^0$	$3/2^+$	***
$\Omega_c(3000)^0$		***
$\Omega_c(3050)^0$		***
$\Omega_c(3065)^0$		***
$\Omega_c(3090)^0$		***
$\Omega_c(3120)^0$		***

****:Existence is certain, properties fairly explored.

***:Existence is very likely or certain, further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined.

**:Evidence of existence is only fair.

*:Evidence of existence is poor.

Only Λ_c^+, Ξ_c^0 and $\Sigma_c(2455)$ in ** status**