



Belle (II) 实验上粲重子的近期研究

李素娴

复旦大学

第七届全国重味物理与量子色动力学研讨会
南京师范大学, 2025/04/18-22

Belle/Belle II实验介绍

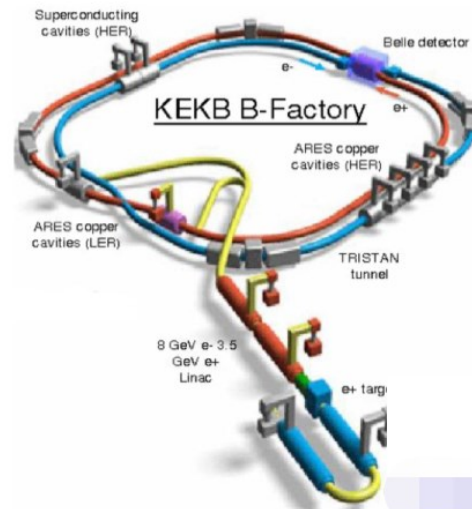
- 不对称能量的正负电子对撞机
- 对撞能量主要在10.58 GeV [Y(4S)能量点]

正负电子加速器 (KEKB)

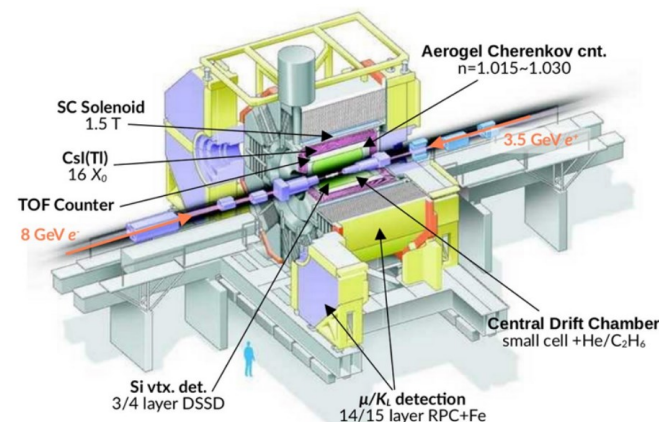
1999-2010

$$\Rightarrow L_{peak}: 2.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-2}$$

$$\Rightarrow L_{int} \sim 1 \text{ ab}^{-1}$$



BELLE @ KEKB



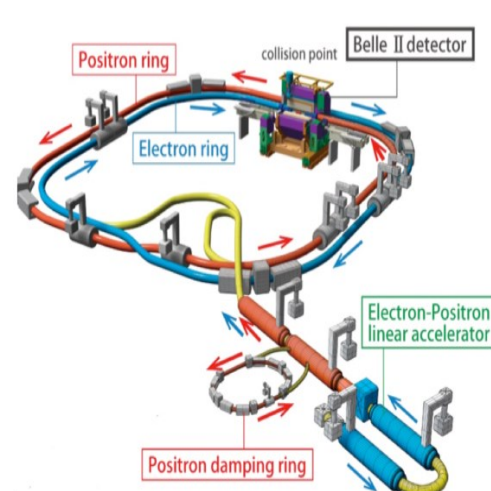
超级正负电子加速器 (SuperKEKB)

2019-至今

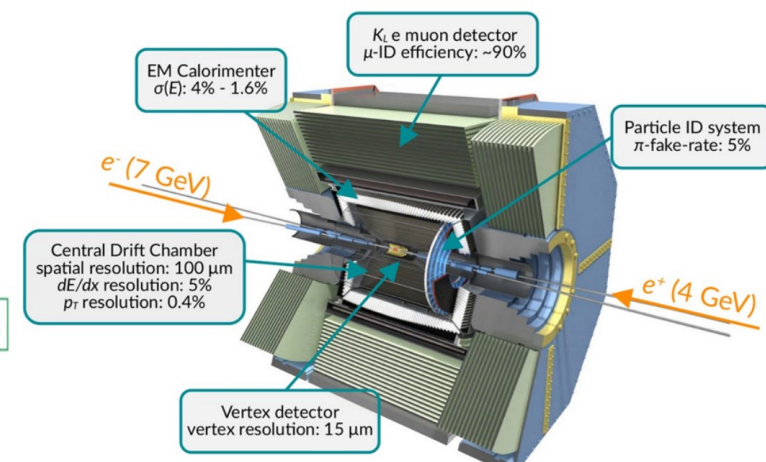
$$\Rightarrow L_{peak} = 5.1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-2}$$

$$\Rightarrow \text{Run1 (2019 - 2022): } L_{int} \sim 427 \text{ fb}^{-1}$$

$$\Rightarrow \text{Run2 (2024 -): } L_{int} \sim 150 \text{ fb}^{-1}$$



Belle II @ SuperKEKB



Belle/Belle II实验上的粲物理

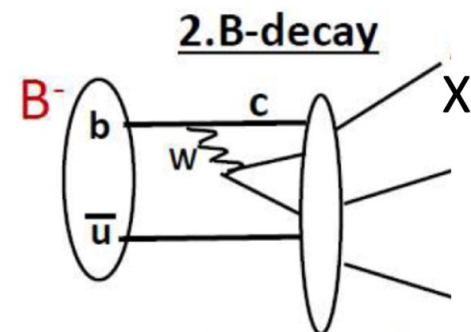
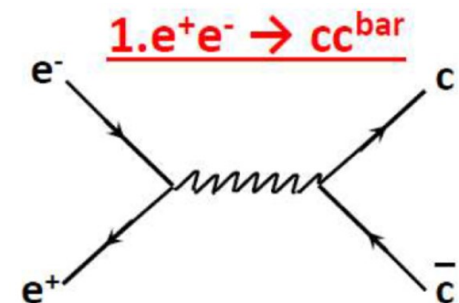
Belle/Belle II实验上粲物理的两种主要产生机制:

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

- 需要参考道，只能进行相对分支比的测量
- 大部分的粲物理分析都用到这种产生机制，因为比 $B\bar{B}$ 过程简单

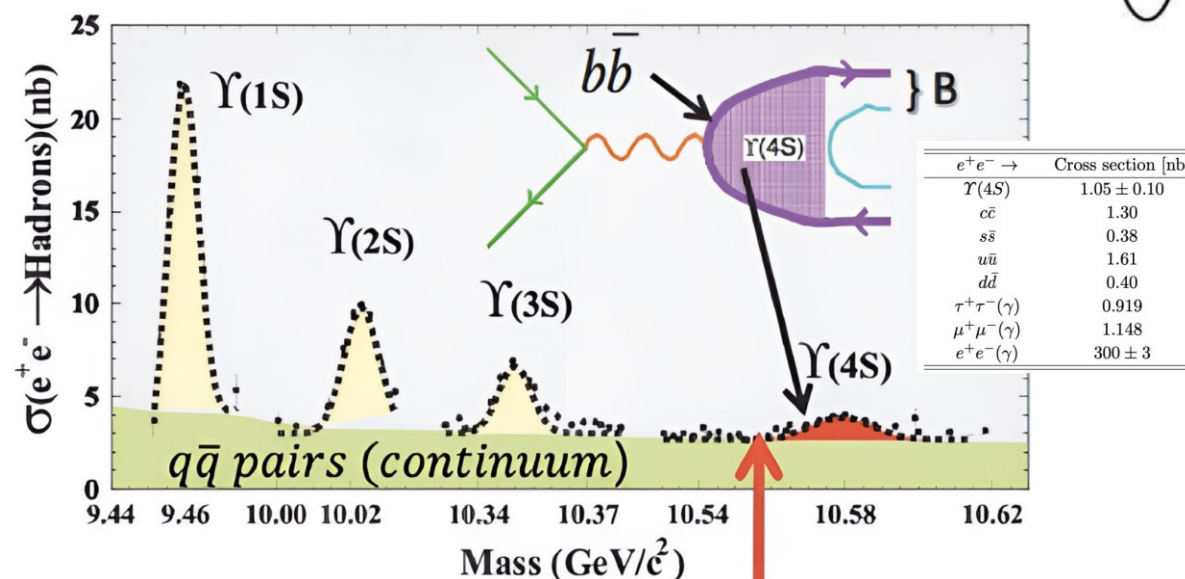
2. $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B} \rightarrow X_c$

- 精确的 $B\bar{B}$ 产生截面，可以进行绝对分支比的测量
- 信号产额小



粲物理的研究课题:

- $D^0 - \bar{D}^0$ 混合
- 振幅分析
- 寿命
- CP破缺
- 稀有衰变
- 粲重子



Belle/Belle II实验上粲重子的近期研究

- 粲重子能谱:

- 在 $\Lambda_c^+\eta, \Sigma_c(2455)\pi$ 等系统中寻找粲重子激发态

- 粲重子的强子衰变:

- $\Xi_c^0 \rightarrow \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta')$
- $\Lambda_c^+ \rightarrow \Sigma^+ \eta^{(\prime)}, \dots$

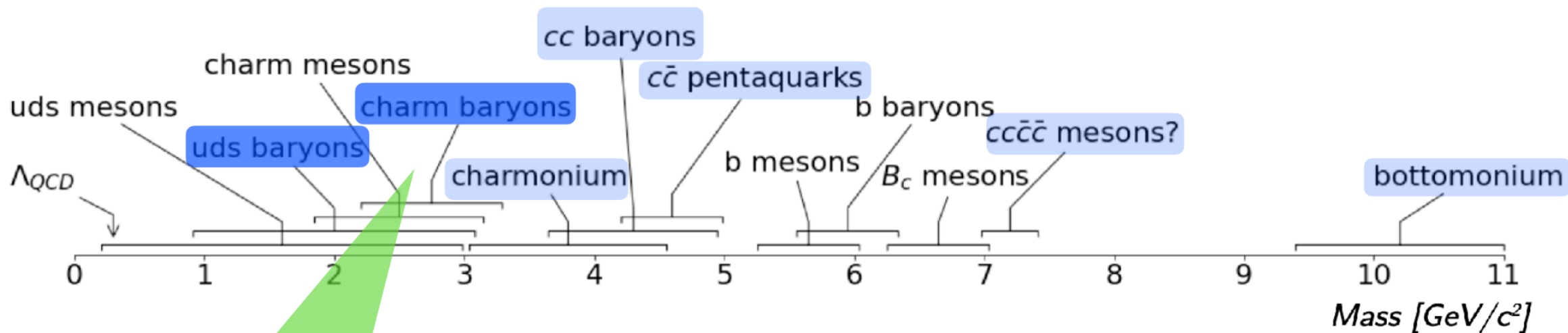
- 粲重子的半轻衰变:

- $\Xi_c^0 \rightarrow \Xi^0 l^+ l^-$

- 粲重子寿命测量

粲重子能谱

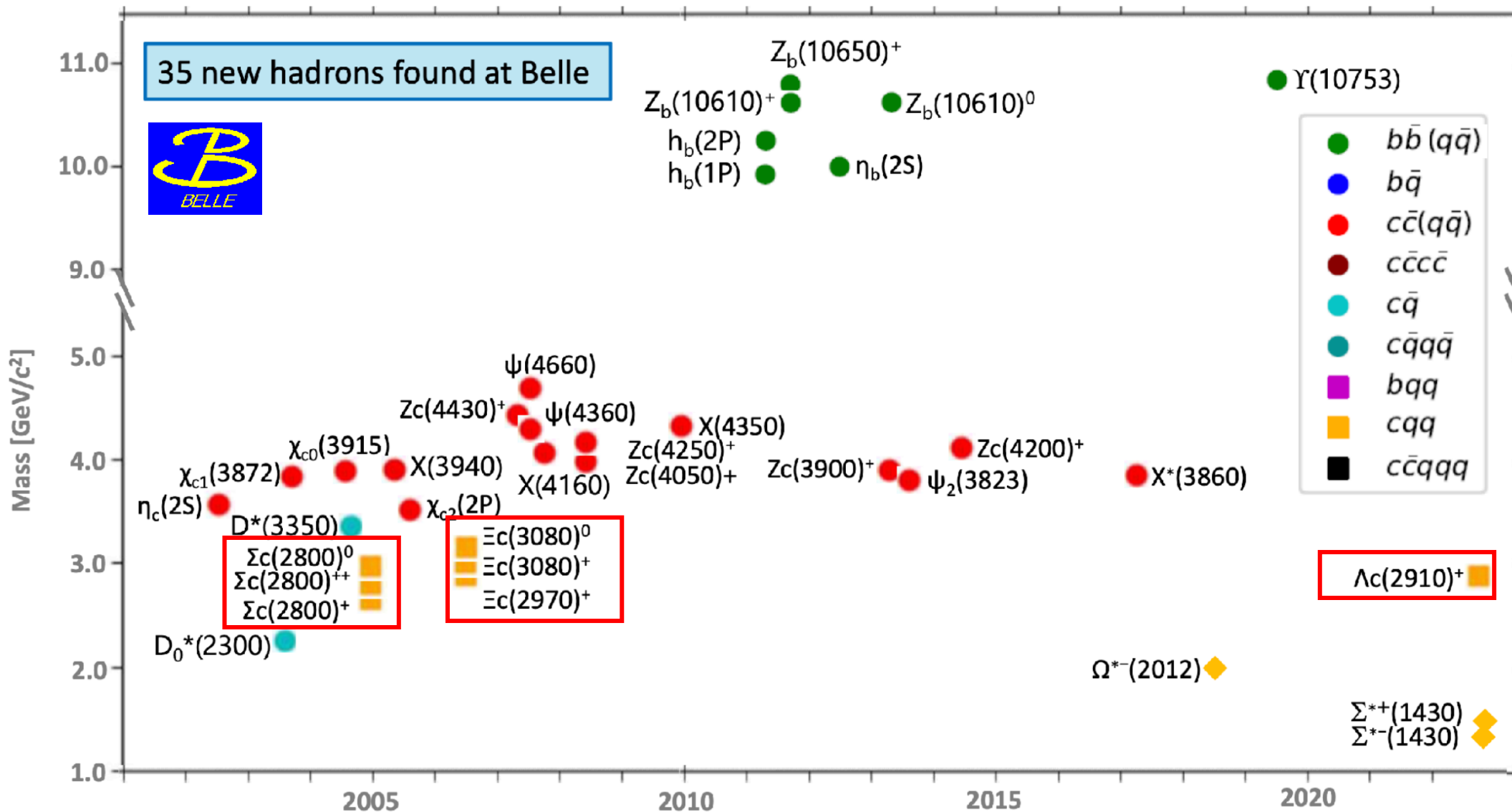
Belle/Belle II上能谱分析：从轻强子谱到底偶素谱



- Spectroscopy
- Decays

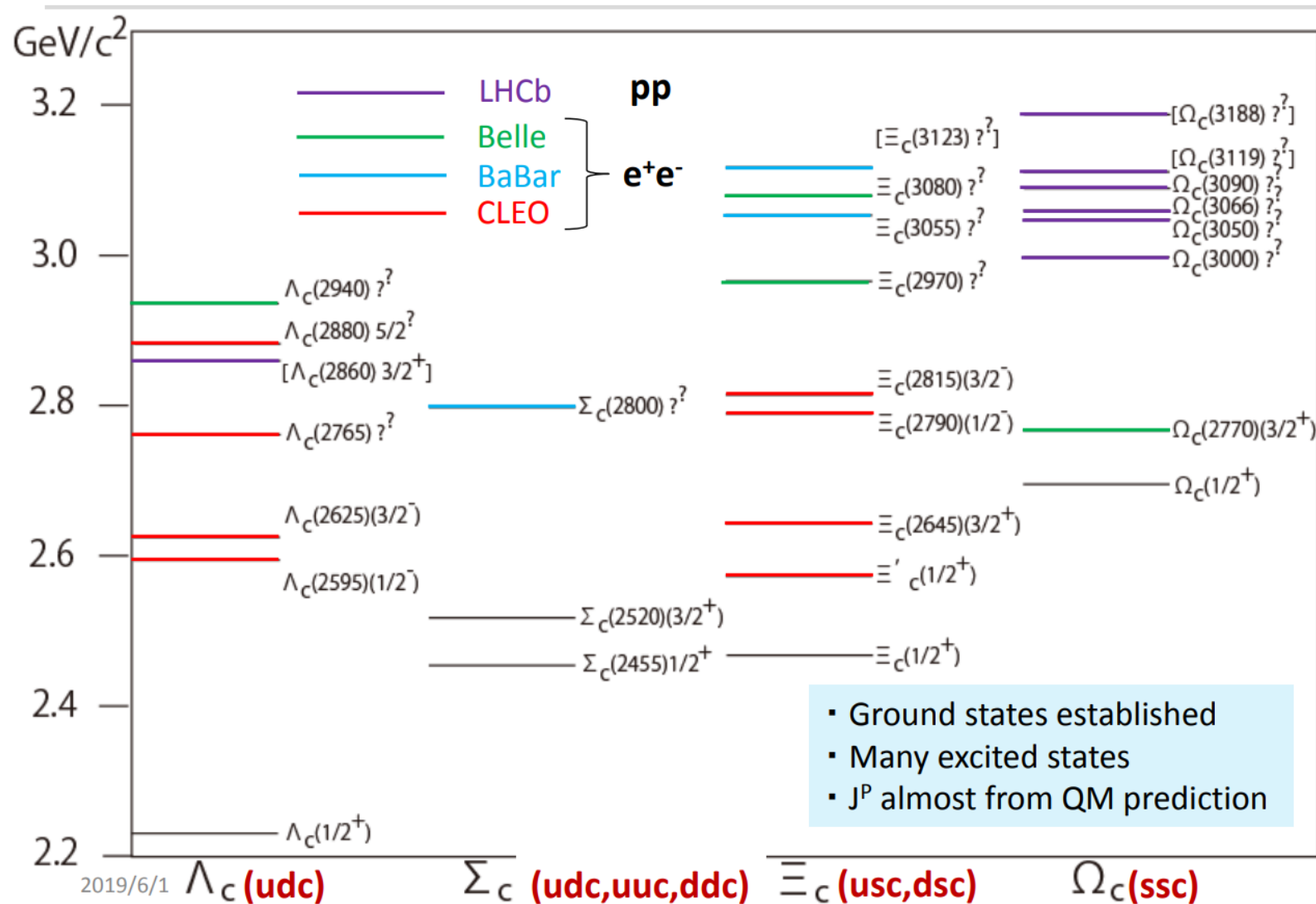
粲重子能谱

Belle上总共发现了35个强子，其中4个粲重子



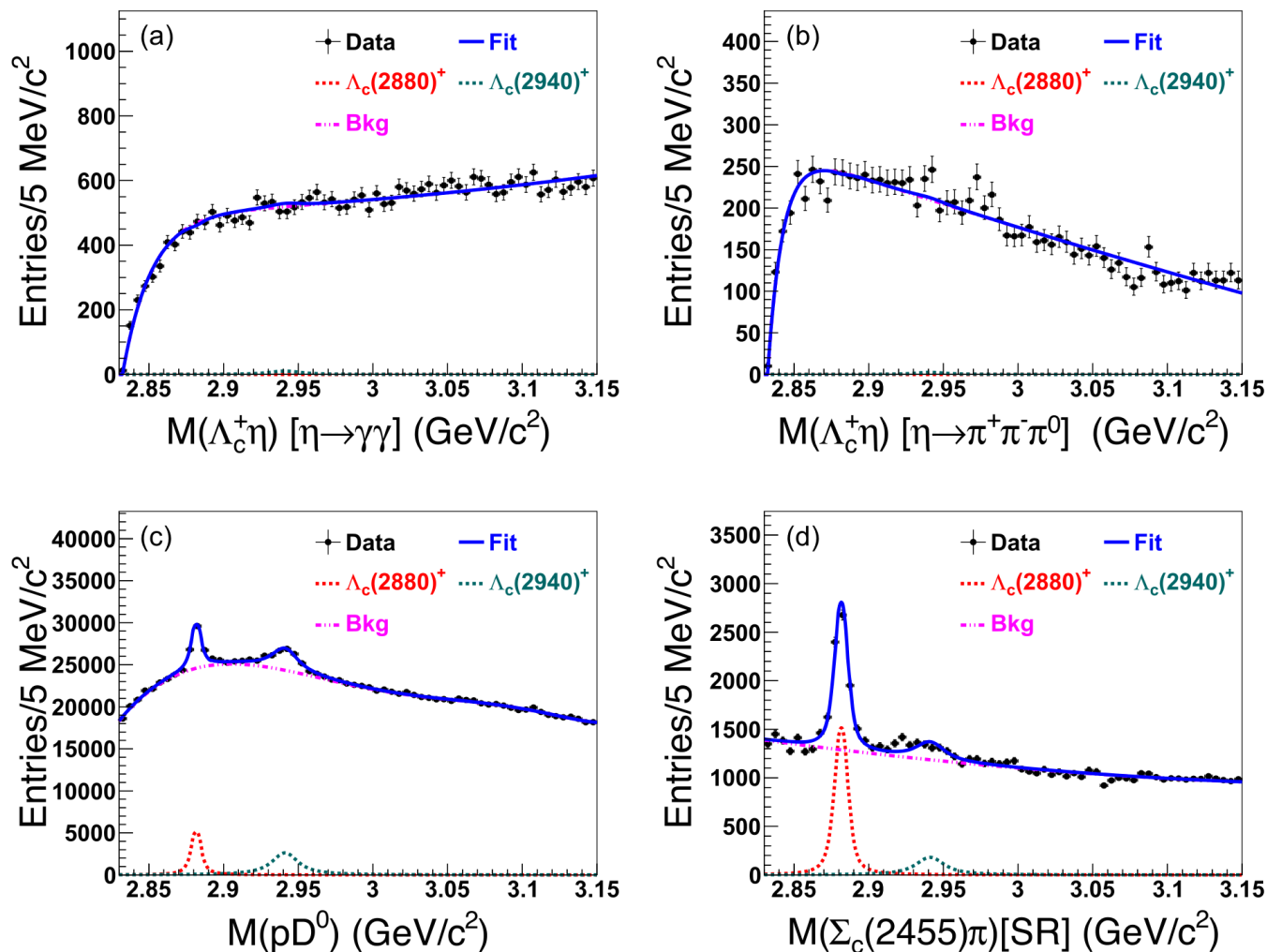
粲重子能谱

Belle, Babar, CLEO, LHCb实验上发现的粲重子激发态:



- 粲重子基态已经全部建立
- 实验上发现了很多的激发态
- 只有少数态的自旋宇称确立，大部分是来自夸克模型的预言

在 $\Lambda_c^+\eta$ 系统中寻找 Λ_c^+ 激发态



- 在 $\Lambda_c^+\eta$ 的质量谱上没有观测到任何预期的信号，如 $\Lambda_c(2880)$ 和 $\Lambda_c(2940)$ ，也没有看到任何新的信号。
- 在 pD^0 的质量谱上看到了显著的 $\Lambda_c(2880)$ 和 $\Lambda_c(2940)$ 信号。
- 首次测量了 $\Lambda_c^+\eta$ 和 pD^0 过程相对 $\Sigma_c\pi$ 的分支比：

$$R_{pD^0}(2880) = 0.75 \pm 0.03 \pm 0.07,$$

$$R_{pD^0}(2940) = 3.59 \pm 0.21 \pm 0.56,$$

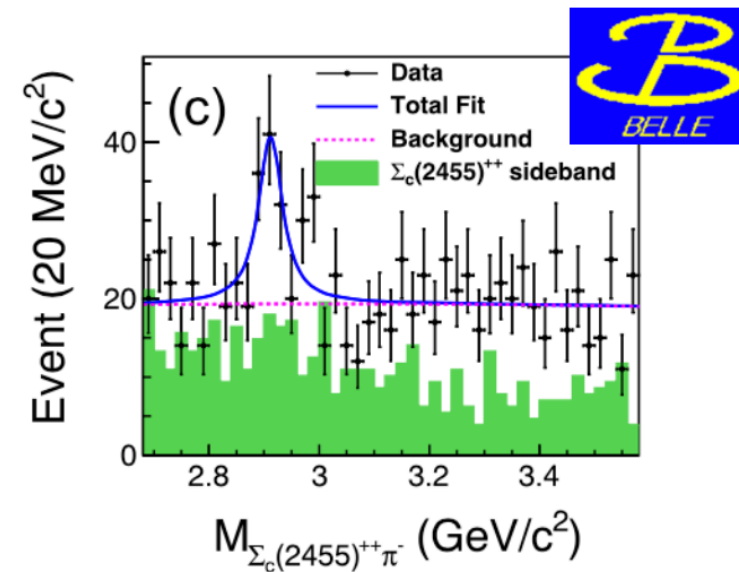
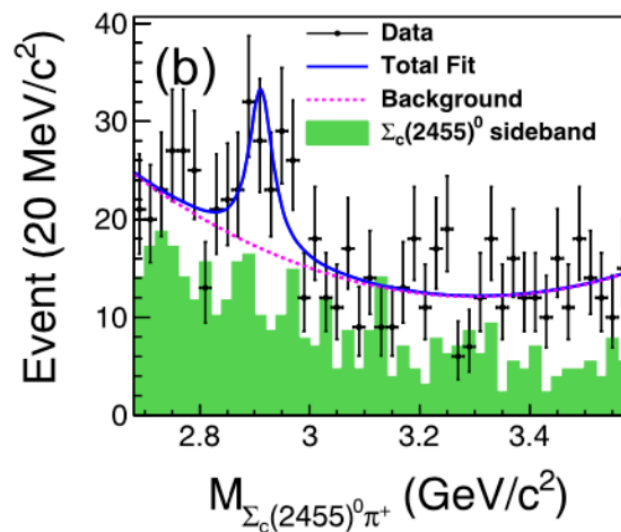
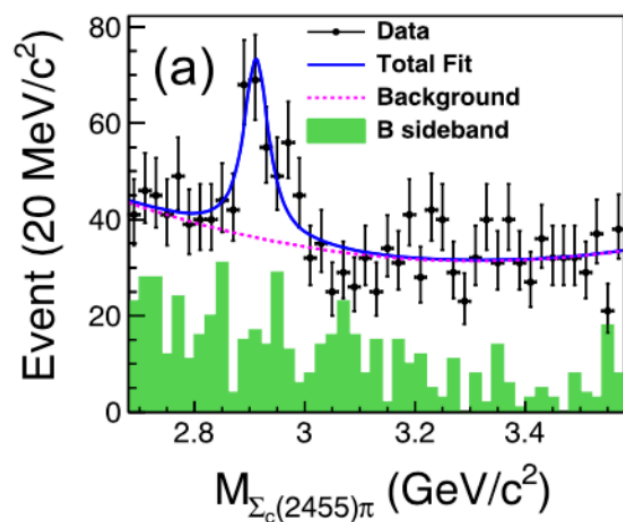
$$R_{\Lambda_c^+\eta}(2880) < 0.13,$$

$$R_{\Lambda_c^+\eta}(2940) < 1.11.$$

粲重子能谱

$\Lambda_c(2910)$ in $B^0 \rightarrow \Sigma_c(2455)^{0,-} \pi^\mp p$

PRL 130, 031901 (2023)



- 在 $\Sigma_c(2455)\pi$ 的质量谱上2.91GeV处看到一个窄的共振态，质量和宽度分别：

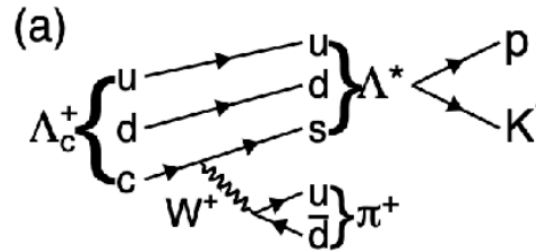
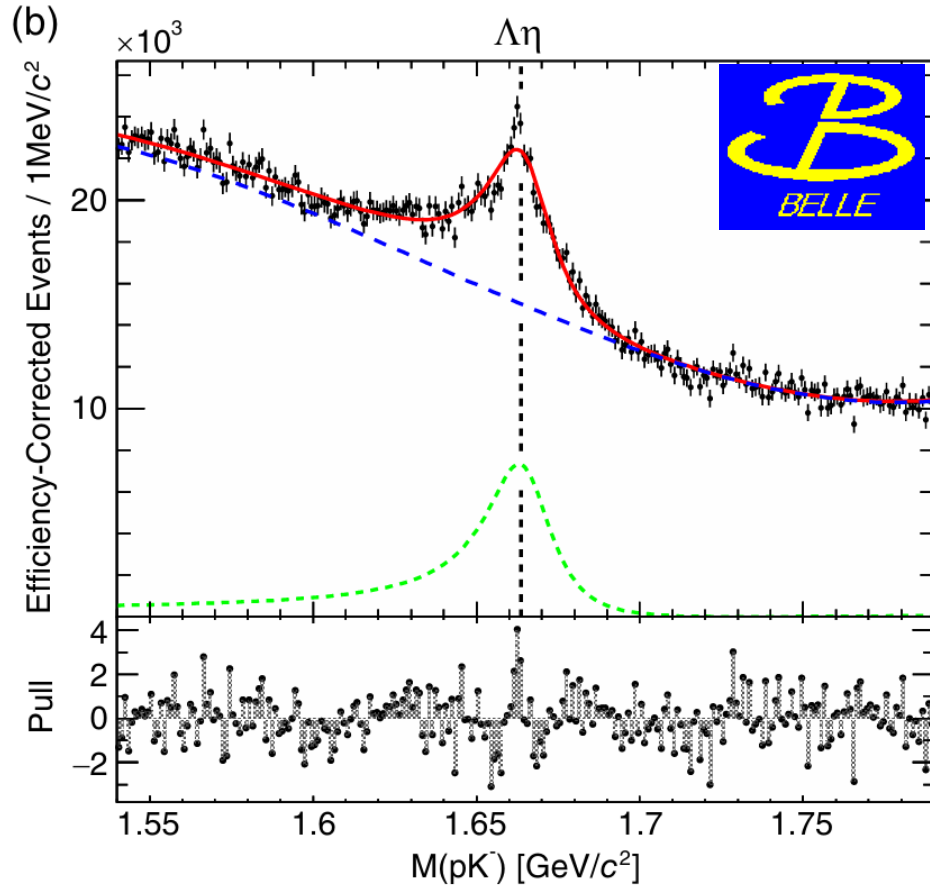
$$M = (2914.7 \pm 5.6) \text{ MeV}/c^2 \text{ and } \Gamma = (50.1 \pm 20.5) \text{ MeV}.$$

- 统计显著性 6.1σ ，拟合中考虑 $\Lambda_c(2880)^+$ 和 $\Lambda_c(2940)^+$ 后，显著性为 4.2σ
- 命名为 $\Lambda_c(2910)^+$ ，很可能是一个 $1/2^-$ 的 Λ_c^+ 激发态

粲重子能谱

Cusp effect on pK^- near $\Lambda\eta$ in $\Lambda_c^+ \rightarrow pK^- \pi^+$

PRD 108, L031104 (2023)



- 如果是一个新的共振态，用BW函数拟合

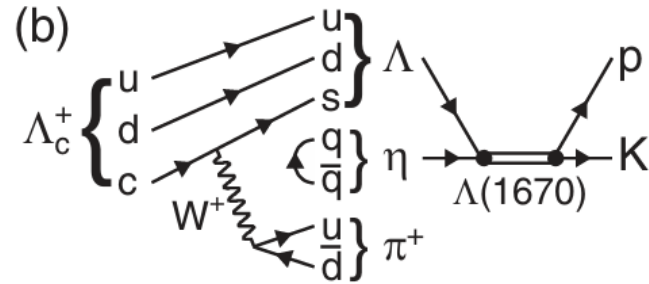
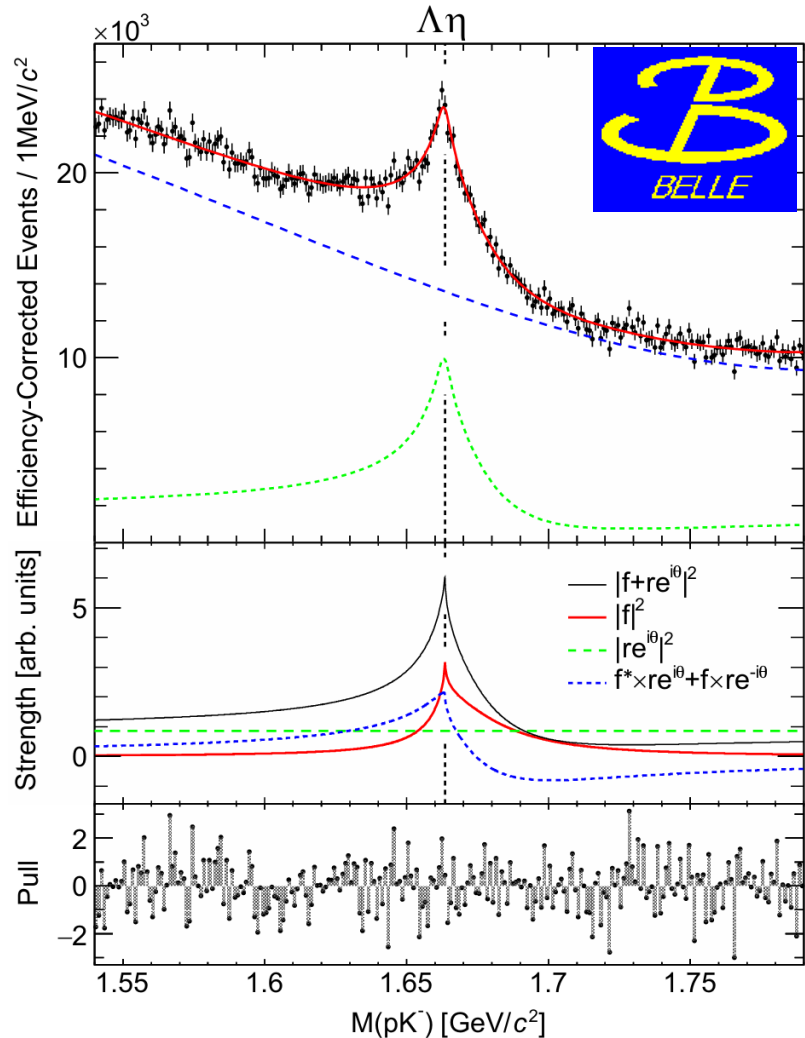
$$\frac{dN}{dm} \propto |\text{BW}(m)|^2 = \left| \frac{1}{(m - m_0) + i\frac{\Gamma_0}{2}} \right|^2,$$

- $M = (1665.4 \pm 0.5) \text{ MeV}/c^2$
- $\Gamma = (23.8 \pm 1.2) \text{ MeV}$
- 很明显不能很好地描述峰结构， $\chi^2 = 1.27$

粲重子能谱

Cusp effect on pK^- near $\Lambda\eta$ in $\Lambda_c^+ \rightarrow pK^- \pi^+$

PRD 108, L031104 (2023)



- 如果是 $\Lambda\eta$ 处的阈值效应，用Flatte函数拟合

$$\frac{dN}{dm} \propto |f(m)|^2 = \left| \frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta}k)} \right|^2,$$

- $m_f = 1674.4 \text{ MeV}/c^2$ fixed.
- 可以很好地描述峰结构， $\chi^2 = 1.06$
- Rejecting the hypothesis of a new resonance by 7σ

Belle/Belle II实验上粲重子的近期研究

- 粲重子能谱:

- 在 $\Lambda_c^+\eta, \Sigma_c(2455)\pi$ 等系统中寻找粲重子激发态

- 粲重子的强子衰变:

- $\Xi_c^0 \rightarrow \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta')$
- $\Lambda_c^+ \rightarrow \Sigma^+ \eta^{(\prime)}, \dots$

- 粲重子的半轻衰变:

- $\Xi_c^0 \rightarrow \Xi^0 l^+ l^-$

- 粲重子寿命测量

粲重子的强子衰变

JHEP 10 (2024) 045
Belle + Belle II 1.4/ab

$\Xi_c^0 \rightarrow \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta')$ 的分支比

- 首次测量下列过程的衰变分支比:

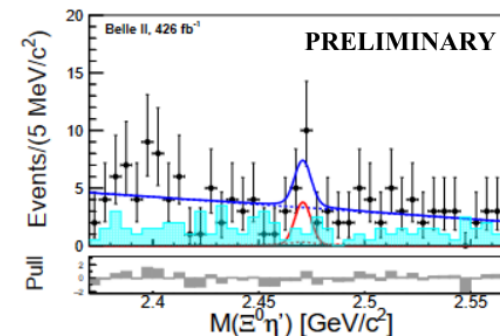
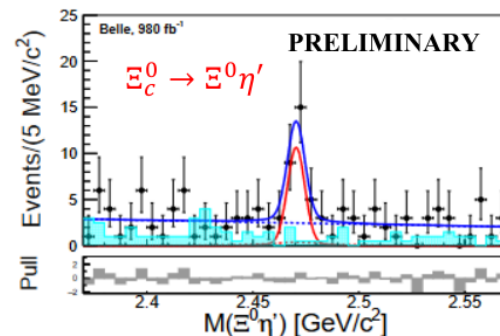
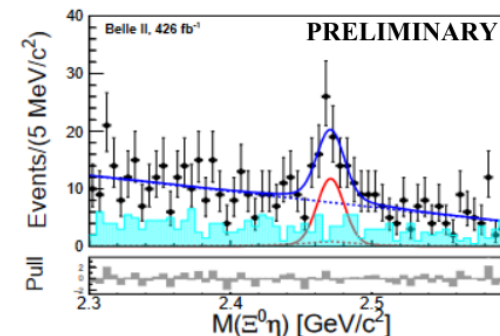
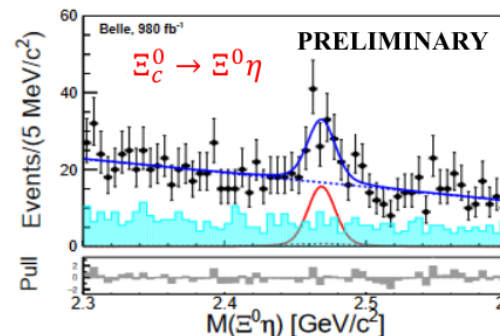
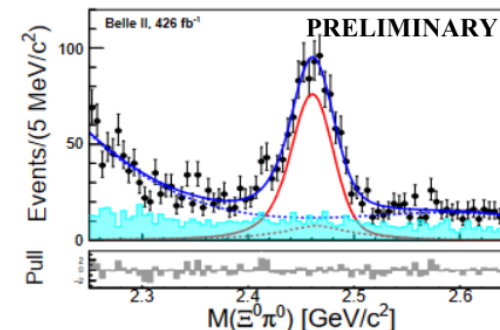
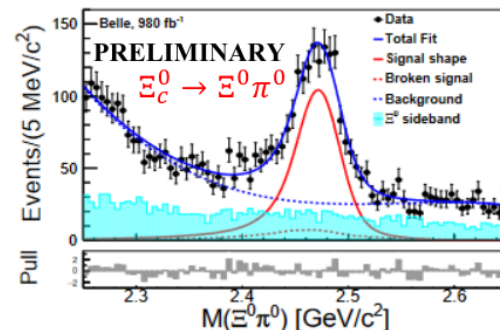
$$B(\Xi_c^0 \rightarrow \Xi^0 \pi^0) = (6.9 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.5(\text{norm.})) \times 10^{-3}$$

$$B(\Xi_c^0 \rightarrow \Xi^0 \eta) = (1.6 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.4(\text{norm.})) \times 10^{-3}$$

$$B(\Xi_c^0 \rightarrow \Xi^0 \eta') = (1.2 \pm 0.3(\text{stat.}) \pm 0.1(\text{syst.}) \pm 0.3(\text{norm.})) \times 10^{-3}$$

- 其中 $\Xi_c^0 \rightarrow \Xi^- \pi^+$ 是参考道
- 测量结果与SU(3)味对称模型预言符合[JHEP 02, 235 (2023)].

首个结合Belle和Belle II数据的粲物理分析。



粲重子的强子衰变

JHEP 10 (2024) 045
Belle + Belle I 1.4/ab

$\Xi_c^0 \rightarrow \Xi^0 \pi^0$ 的衰变不对称参数 α

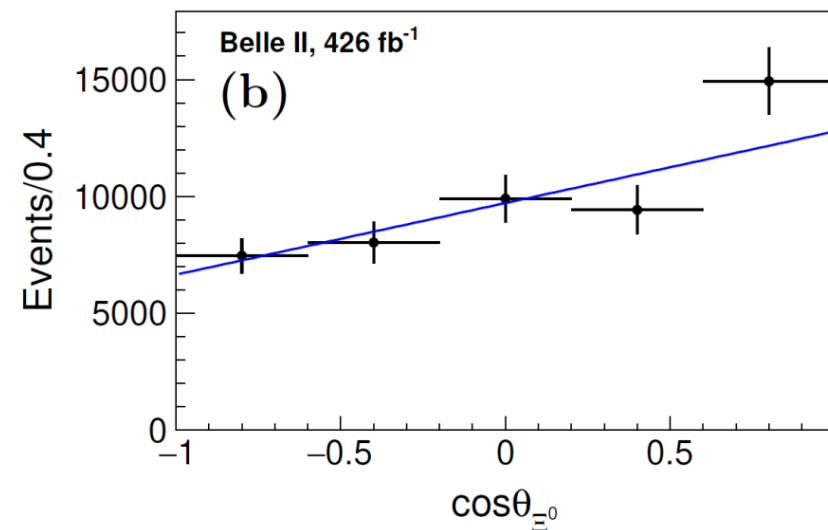
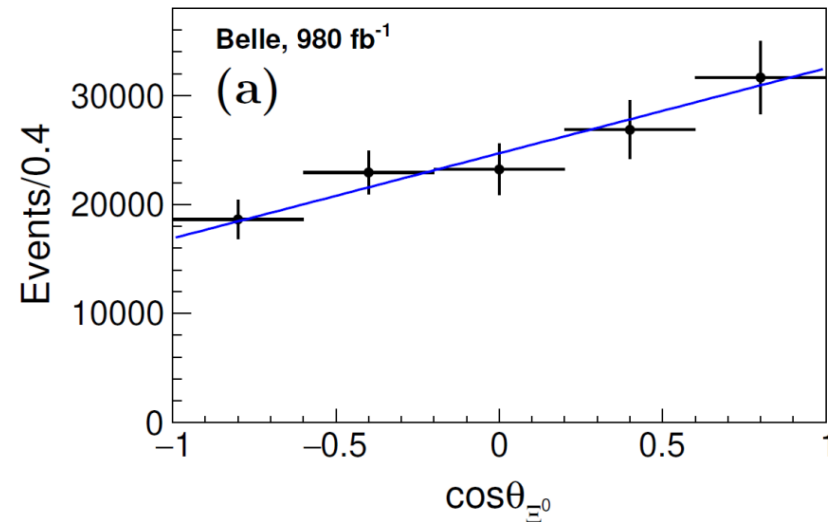
- P宇称破缺振幅和P宇称守恒振幅之间的干扰会导致角分布的不对称性，这种不对称性用参数 α 来量化：

$$\frac{dN}{d\cos\theta_{\Xi^0}} \propto 1 + \alpha(\Xi_c^0 \rightarrow \Xi^0 h^0)\alpha(\Xi^0 \rightarrow \Lambda\pi^0)\cos\theta_{\Xi^0}$$

- 通过拟合数据中的角分布，得到 $\Xi_c^0 \rightarrow \Xi^0 \pi^0$ 的 α 值：

$$\alpha(\Xi_c^0 \rightarrow \Xi^0 \pi^0) = -0.90 \pm 0.15(\text{stat.}) \pm 0.23(\text{syst.})$$

- 实验上首次测量
- 和理论预言一致[PRD 48, 4188(1993); PRD 101,014011 (2020)]



$\Xi_c^+ \rightarrow pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$ 的衰变分支比

- 采用 $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ 作为参考道，测量三个单卡比玻压制过程的相对衰变分支比：

$$\frac{\mathcal{B}(\Xi_c^+ \rightarrow pK_S^0)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (2.47 \pm 0.16 \pm 0.07)\%$$

$$\frac{\mathcal{B}(\Xi_c^+ \rightarrow \Lambda\pi^+)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (1.56 \pm 0.14 \pm 0.09)\%$$

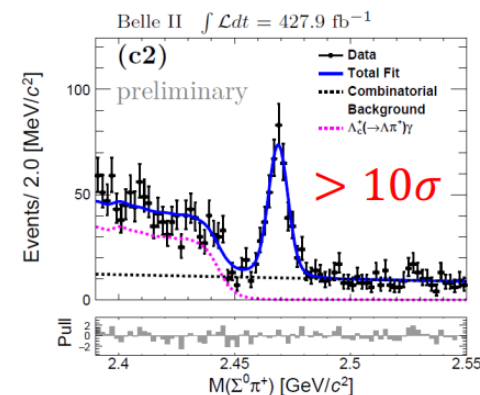
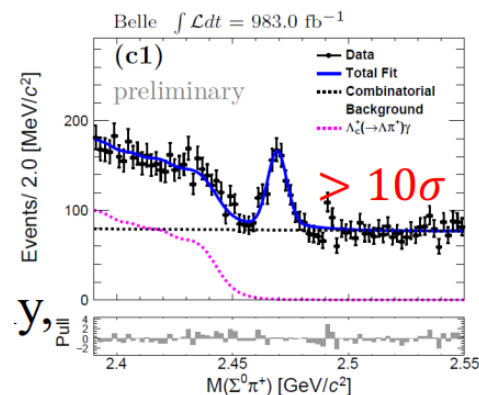
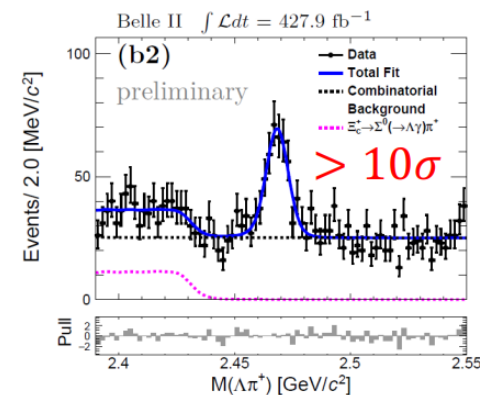
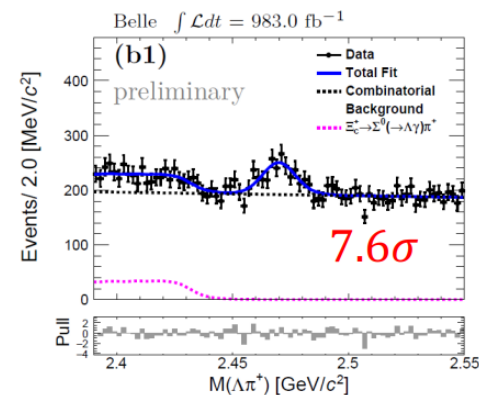
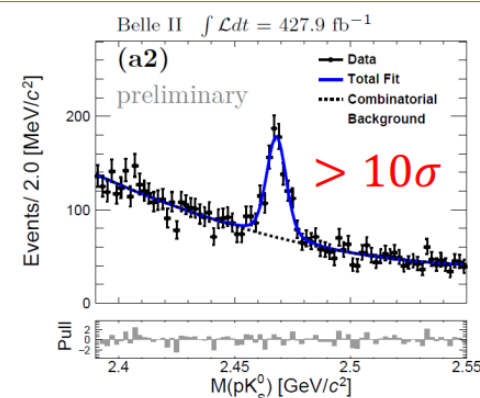
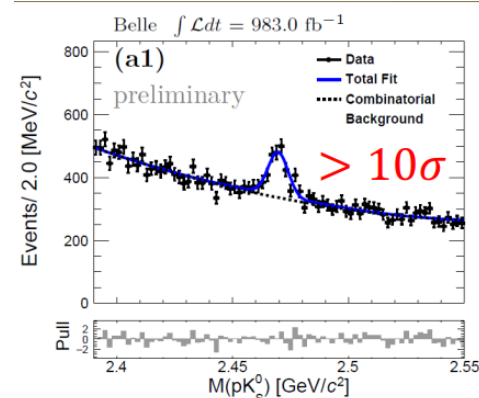
$$\frac{\mathcal{B}(\Xi_c^0 \rightarrow \Sigma^0\pi^+)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (4.13 \pm 0.26 \pm 0.22)\%$$

- 利用 $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ 的分支比，计算得到：

$$\mathcal{B}(\Xi_c^+ \rightarrow pK_S^0) = (7.16 \pm 0.46 \pm 0.20 \pm 3.21) \times 10^{-4}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow \Lambda\pi^+) = (4.52 \pm 0.41 \pm 0.26 \pm 2.03) \times 10^{-4}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^0\pi^+) = (1.20 \pm 0.08 \pm 0.07 \pm 0.54) \times 10^{-3}$$



粲重子的强子衰变

$\Xi_c^+ \rightarrow \Sigma^+ K_S^0, \Xi^0 K^+, \Xi^0 \pi^+$ 的衰变分支比

- 采用 $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ 作为参考道，测量三个单卡比玻过程的相对衰变分支比：

$$\frac{\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ K_S^0)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (6.4 \pm 0.7 \pm 0.3)\% \text{ [for the first time]}$$

$$\frac{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 K^+)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (1.6 \pm 0.2 \pm 0.1)\% \text{ [for the first time]}$$

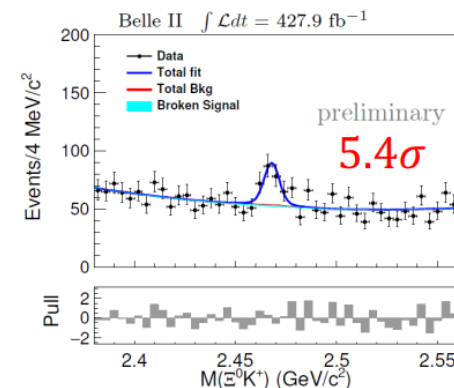
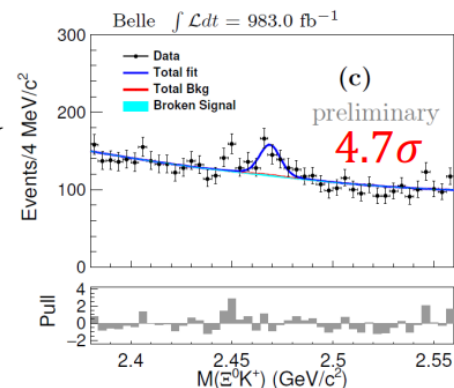
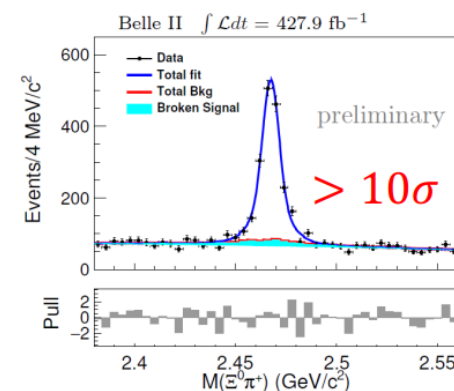
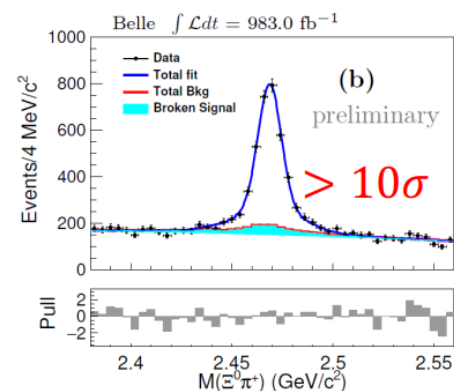
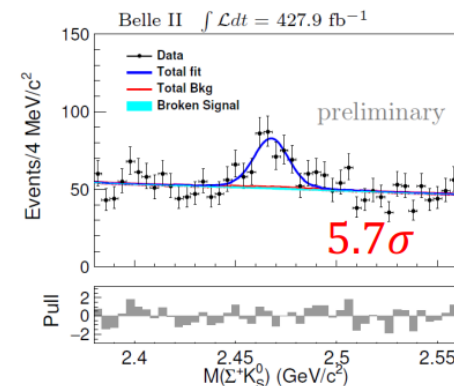
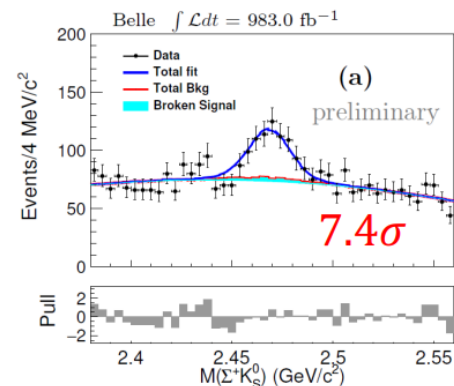
$$\frac{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 \pi^+)}{\mathcal{B}(\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+)} = (23.3 \pm 0.8 \pm 1.0)\%$$

- 利用 $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ 的分支比，计算得到：

$$\mathcal{B}(\Xi_c^+ \rightarrow \Sigma^+ K_S^0) = (1.86 \pm 0.20 \pm 0.08 \pm 0.83) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 K^+) = (0.46 \pm 0.07 \pm 0.02 \pm 0.21) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^+ \rightarrow \Xi^0 \pi^+) = (6.77 \pm 0.24 \pm 0.30 \pm 3.03) \times 10^{-3}$$



Belle/Belle II实验上粲重子的近期研究

- 粲重子能谱:

- 在 $\Lambda_c^+\eta, \Sigma_c(2455)\pi$ 等系统中寻找粲重子激发态

- 粲重子的强子衰变:

- $\Xi_c^0 \rightarrow \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta'), \dots$
- $\Lambda_c^+ \rightarrow \Sigma^+ \eta^{(\prime)}, \dots$

- 粲重子的半轻衰变:

- $\Xi_c^0 \rightarrow \Xi^0 l^+ l^-, \dots$

- 粲重子寿命测量

$\Xi_c^0 \rightarrow \Xi^0 l^+ l^-$ 的首次寻找

[PRD 109, 052003 (2024)]

- 对于末态中不含中微子的稀有半轻衰变，在轻重子和底重子系统中均观测到：

$$\Xi^0 \rightarrow \Lambda^0 e^+ e^-, \Sigma^+ \rightarrow p \mu^+ \mu^-, \text{ and } \Lambda_b \rightarrow \Lambda \mu^+ \mu^-$$

- 但在粲重子领域，实验上目前还没有观测到任何信号。
- Babar和LHCb实验都曾经寻找过 $\Lambda_c^+ \rightarrow p l^+ l^-$ ，没有看到显著的信号，给出了分支比上限。

$$B(\Lambda_c^+ \rightarrow p e^+ e^-) < 5.5 \times 10^{-6}$$

$$B(\Lambda_c^+ \rightarrow p \mu^+ \mu^-) < 7.7 \times 10^{-8}$$

- 理论上对于这种半轻衰变过程的计算也是存在重重困难

寻找和测量粲重子的稀有半轻衰变的分支比，对于测试和理解轻味普适性十分重要。

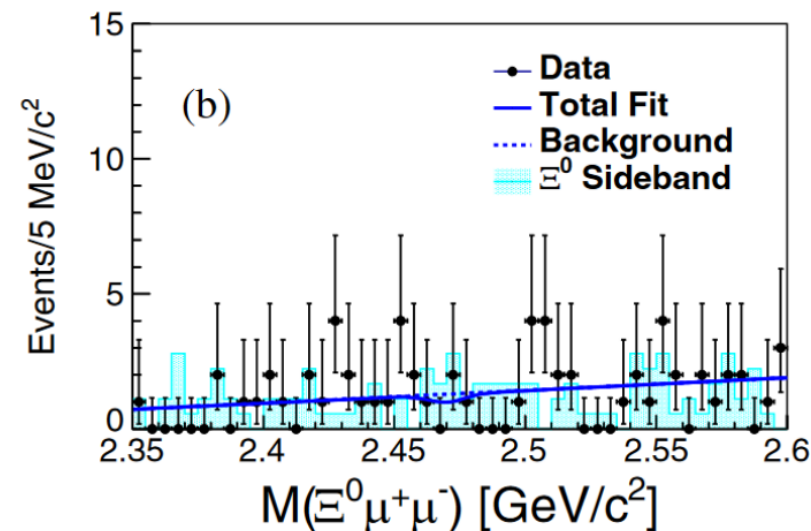
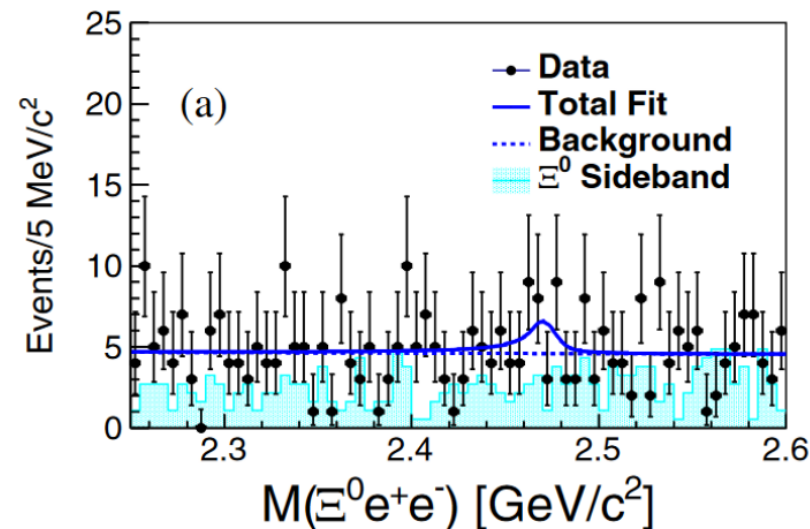
$\Xi_c^0 \rightarrow \Xi^0 l^+ l^-$ 的首次寻找

[PRD 109, 052003 (2024)]

- 在 $\Xi^0 l^+ l^-$ 的质量谱上没有看到任何信号!
- 给出两个模式的分支比上限, 和标准模型预言一致

	Measured	SM prediction
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0 e^+ e^-)$	$< 9.9 \times 10^{-5}$	$< 2.35 \times 10^{-6}$
$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0 \mu^+ \mu^-)$	$< 6.5 \times 10^{-5}$	$< 2.25 \times 10^{-6}$

SM prediction: PRD 103, 013007 (2021)



Belle/Belle II实验上粲重子的近期研究

- 粲重子能谱:

- 在 $\Lambda_c^+\eta, \Sigma_c(2455)\pi$ 等系统中寻找粲重子激发态

- 粲重子的强子衰变:

- $\Xi_c^0 \rightarrow \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta')$
- $\Lambda_c^+ \rightarrow \Sigma^+ \eta^{(\prime)}, \dots$

- 粲重子的半轻衰变:

- $\Xi_c^0 \rightarrow \Xi^0 l^+ l^-$

- 粲重子寿命测量

粲重子寿命测量

- 重夸克展开 (HQE) 用于确定具有重夸克的强子的寿命。
- 根据HQE的预期, 早期四个粲重子寿命的排序是:

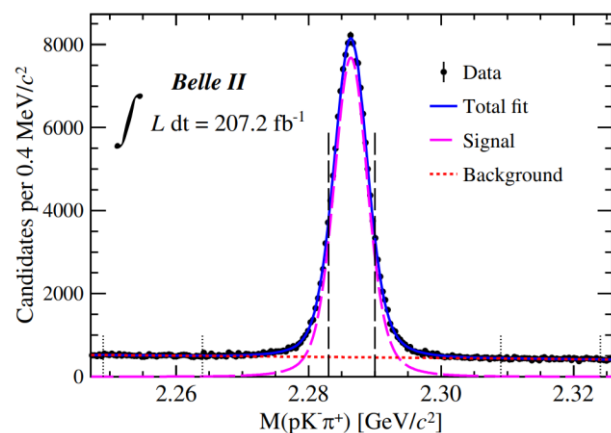
$$\tau(\Xi_c^+) > \tau(\Lambda_c^+) > \tau(\Xi_c^0) > \tau(\Omega_c^0)$$

- 2018年, LHCb实验更新了 Ω_c 寿命的测量 (PRL 121 (2018), 092003), 排序变成:

$$\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$$

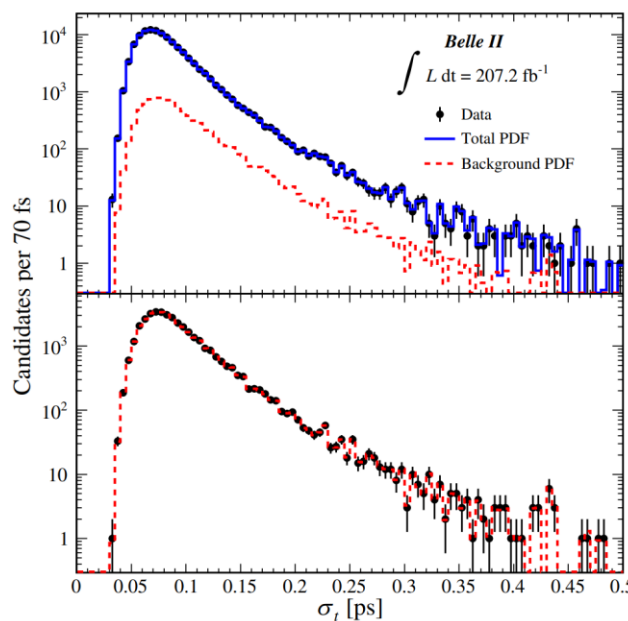
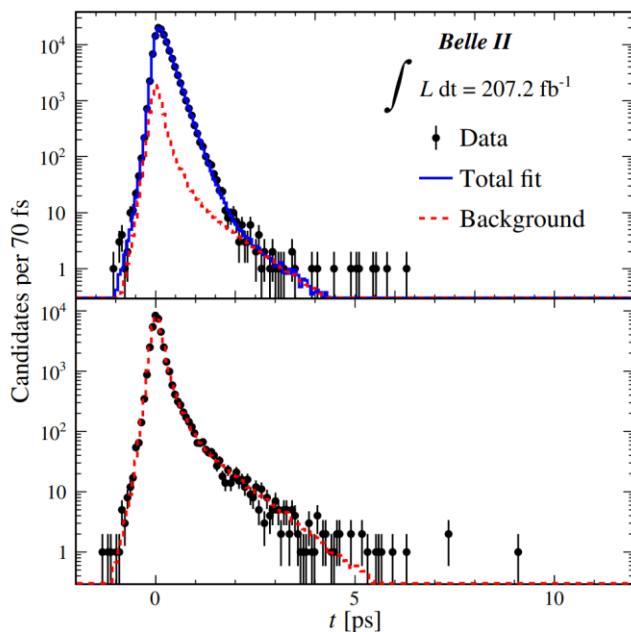
- 2023年, Belle II实验证实了LHCb实验的结果 (PRD 107, L031103 (2023))。

Λ_c^+ 的寿命测量



- 对衰变时间 (t) 和衰变时间误差 (σ_t) 进行二维联合拟合:

$$\text{PDF}(t, \sigma_t) = (1 - f_b) \int_0^\infty e^{-t_{\text{true}}/\tau} R(t - t_{\text{true}} | b, s\sigma_t) dt_{\text{true}} \text{PDF}_{\text{sig}}(\sigma_t) + f_b \text{PDF}_{\text{bkg}}(t, \sigma_t)$$



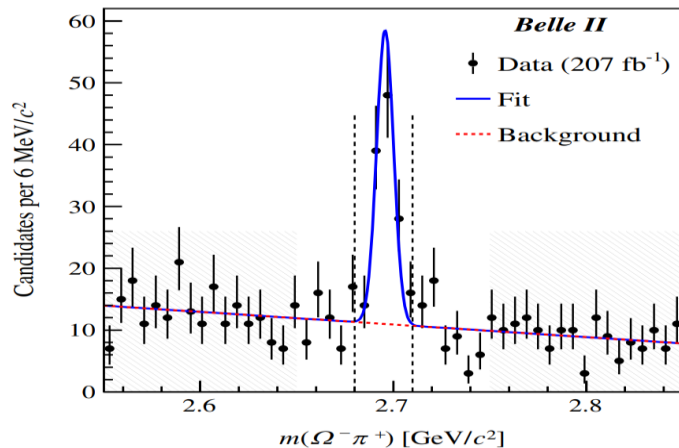
- 拟合得到寿命:

$$\tau(\Lambda_c^+) = 203.20 \pm 0.89 \pm 0.77 \text{ fs}$$

迄今为止最精确的测量结果，
与之前的测量结果一致。

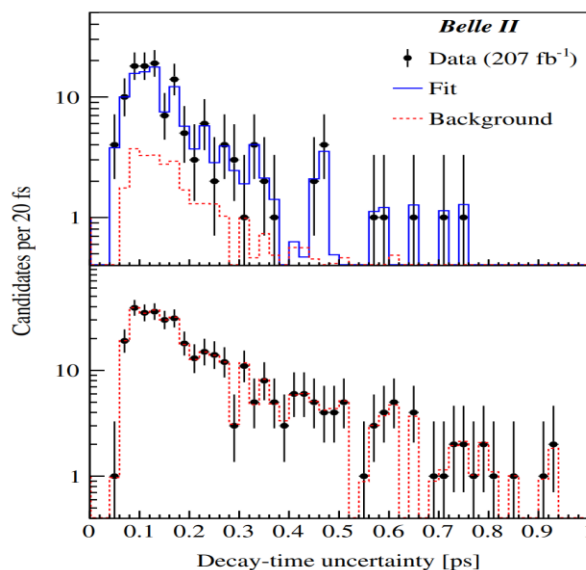
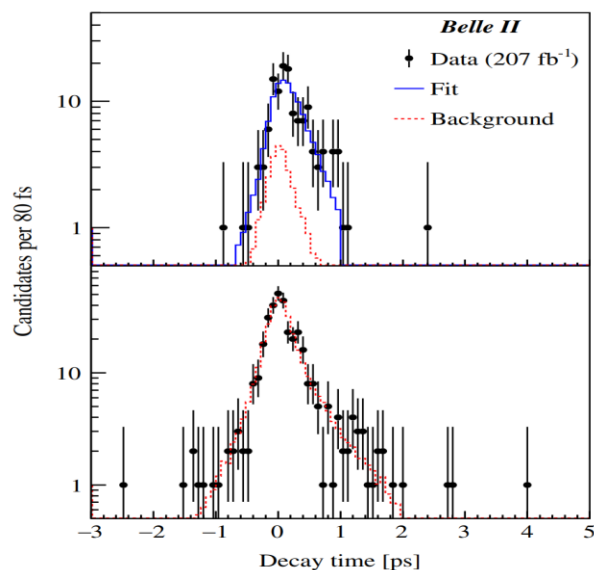
Ω_c^0 的寿命测量

[PRD 107, L031103 (2023)]



- 对衰变时间 (t) 和衰变时间误差 (σ_t) 进行二维联合拟合:

$$\text{PDF}(t, \sigma_t) = (1 - f_b) \int_0^\infty e^{-t_{\text{true}}/\tau} R(t - t_{\text{true}} | b, s\sigma_t) dt_{\text{true}} \text{PDF}_{\text{sig}}(\sigma_t) + f_b \text{PDF}_{\text{bkg}}(t, \sigma_t)$$



- 拟合得到寿命:

$$\tau(\Omega_c^0) = 243 \pm 48 \pm 11 \text{ fs}$$

和LHCb最新测量结果一致，测量结果证实 Ω_c^0 不是寿命最短的弱衰变粲重子！

总结

- Belle/Belle II实验是研究粲重子非常好的平台，
- 虽然Belle实验已经停止取数超过10年时间，它仍然在产出一些很好的物理结果，特别是在粲重子的研究方面
- Belle II实验开始了Run 2的取数，随着数据量的增加，未来结合Belle和Belle II实验的数据可以做更多更重要的粲重子的分析工作！

谢谢!

Theoretical Predictions for $\Xi_c^0 \rightarrow \Xi^0 h^0$

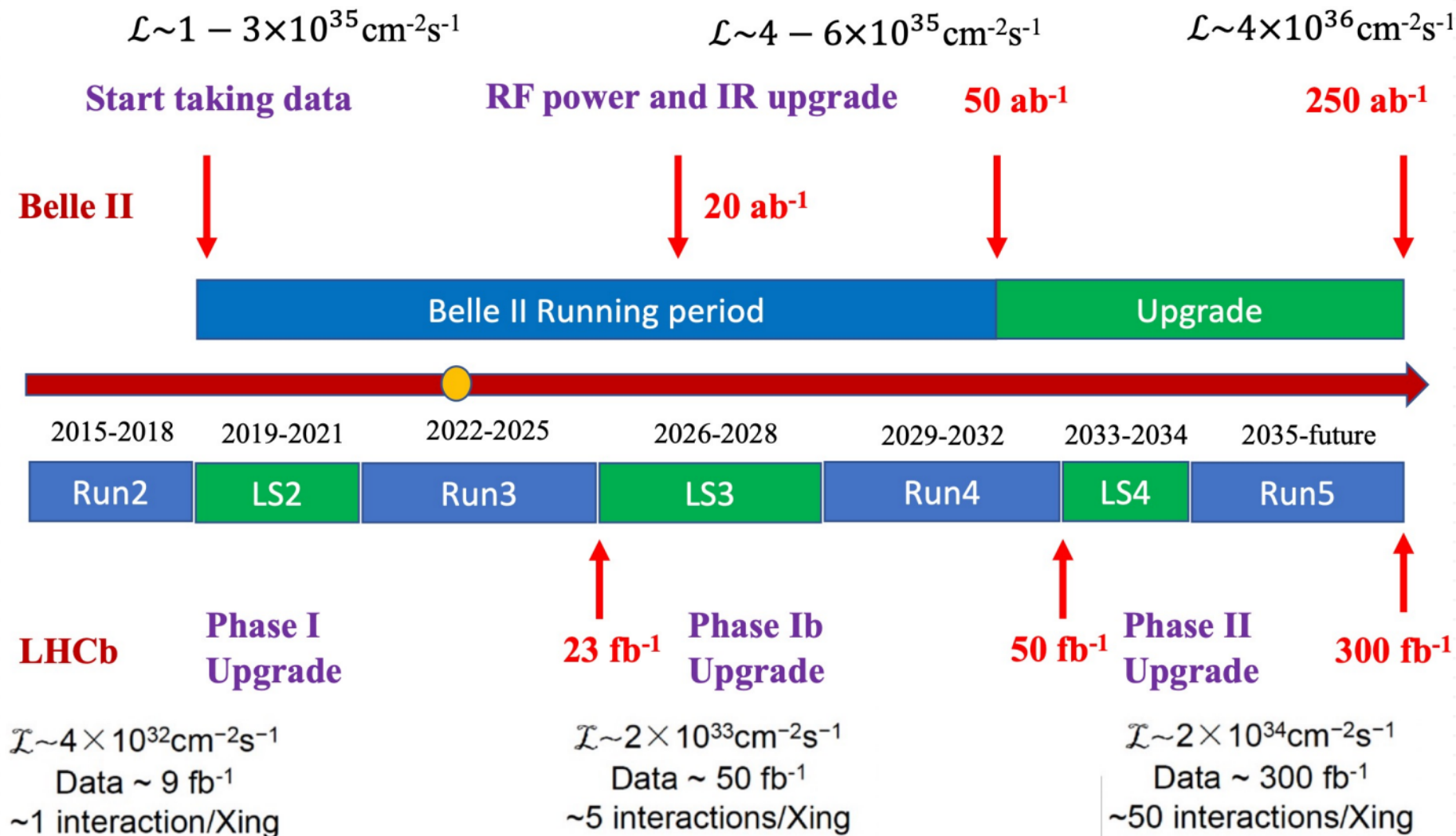
Table 1. Theoretical predictions for the branching fractions and decay asymmetry parameters for $\Xi_c^0 \rightarrow \Xi^0 h^0$ decays. Branching fractions are given in units of 10^{-3} .

Reference	Model	$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0 \pi^0)$	$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0 \eta)$	$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0 \eta')$	$\alpha(\Xi_c^0 \rightarrow \Xi^0 \pi^0)$
Körner, Krämer [5]	quark	0.5	3.2	11.6	0.92
Ivanov <i>et al.</i> [6]	quark	0.5	3.7	4.1	0.94
Xu, Kamal [7]	pole	7.7	-	-	0.92
Cheng, Tseng [8]	pole	3.8	-	-	-0.78
Żenczykowski [9]	pole	6.9	1.0	9.0	0.21
Zou <i>et al.</i> [10]	pole	18.2	26.7	-	-0.77
Sharma, Verma [11]	CA	-	-	-	-0.8
Cheng, Tseng [8]	CA	17.1	-	-	0.54
Geng <i>et al.</i> [12]	SU(3) _F	4.3±0.9	1.7 ^{+1.0} _{-1.7}	8.6 ^{+11.0} _{-6.3}	-
Geng <i>et al.</i> [13]	SU(3) _F	7.6±1.0	10.3±2.0	9.1±4.1	-1.00 ^{+0.07} _{-0.00}
Zhao <i>et al.</i> [14]	SU(3) _F	4.7±0.9	8.3±2.3	7.2±1.9	-
Huang <i>et al.</i> [15]	SU(3) _F	2.56±0.93	-	-	-0.23 ± 0.60
Hsiao <i>et al.</i> [16]	SU(3) _F	6.0±1.2	4.2 ^{+1.6} _{-1.3}	-	-
Hsiao <i>et al.</i> [16]	SU(3) _F -breaking	3.6±1.2	7.3±3.2	-	-
Zhong <i>et al.</i> [17]	SU(3) _F	1.13 ^{+0.59} _{-0.49}	1.56±1.92	0.683 ^{+3.272} _{-3.268}	0.50 ^{+0.37} _{-0.35}
Zhong <i>et al.</i> [17]	SU(3) _F -breaking	7.74 ^{+2.52} _{-2.32}	2.43 ^{+2.79} _{-2.90}	1.63 ^{+5.09} _{-5.14}	-0.29 ^{+0.20} _{-0.17}
Xing <i>et al.</i> [18]	SU(3) _F	1.30±0.51	-	-	-0.28 ± 0.18

- [5] J. G. Körner and M. Krämer, *Exclusive non-leptonic charm baryon decays*, Z. Phys. C **55** (1992) 659.
- [6] M. A. Ivanov, J. G. Korner, V. E. Lyubovitskij, and A. G. Rusetsky, *Exclusive nonleptonic decays of bottom and charm baryons in a relativistic three-quark model: Evaluation of nonfactorizing diagrams*, Phys. Rev. D **57** (1998) 5632.
- [7] Q. P. Xu and A. N. Kamal, *Cabibbo-favored nonleptonic decays of charmed baryons*, Phys. Rev. D **46** (1992) 270.
- [8] H. Y. Cheng and B. Tseng, *Cabibbo-allowed nonleptonic weak decays of charmed baryons*, Phys. Rev. D **48** (1993) 4188.
- [9] P. Żenczykowski, *Nonleptonic charmed-baryon decays: Symmetry properties of parity-violating amplitudes*, Phys. Rev. D **50** (1994) 5787.
- [10] J. Q. Zou, F. R. Xu, G. B. Meng, and H. Y. Cheng, *Two-body hadronic weak decays of antitriplet charmed baryons*, Phys. Rev. D **101** (2020) 014011.
- [11] K. K. Sharma and R. C. Verma, *A study of weak mesonic decays of Λ_c and Ξ_c baryons on the basis of HQET results*, Eur. Phys. J. C **7** (1999) 217.
- [12] C. Q. Geng, Y. K. Hsiao, C. W. Liu, and T. H. Tsai, *Antitriplet charmed baryon decays with SU(3) flavor symmetry*, Phys. Rev. D **97** (2018) 073006.
- [13] C. Q. Geng, C. W. Liu, and T. H. Tsai, *Asymmetries of anti-triplet charmed baryon decays*, Phys. Lett. B **794** (2019) 19.
- [14] H. J. Zhao, Y. L. Wang, Y. K. Hsiao, and Y. Yu, *A Diagrammatic Analysis of Two-Body Charmed Baryon Decays with Flavor Symmetry*, JHEP **02** (2020) 165.
- [15] F. Huang, Z. P. Xing, and X. Z. He, *A global analysis of charmless two body hadronic decays for anti-triplet charmed baryons*, JHEP **03** (2022) 143.
- [16] Y. K. Hsiao, Y. L. Wang, and H. J. Zhao, *Equivalent SU(3)_f approaches for two-body anti-triplet charmed baryon decays*, JHEP **09** (2022) 35.
- [17] H. Zhong, F. Xu, Q. Wen and Y. Gu, *Weak decays of antitriplet charmed baryons from the perspective of flavor symmetry*, JHEP **02** (2023) 235.
- [18] Z. P. Xing, *et al.*, *Global analysis of measured and unmeasured hadronic two-body weak decays of antitriplet charmed baryons*, Phys. Rev. D **108** (2023) 053004.

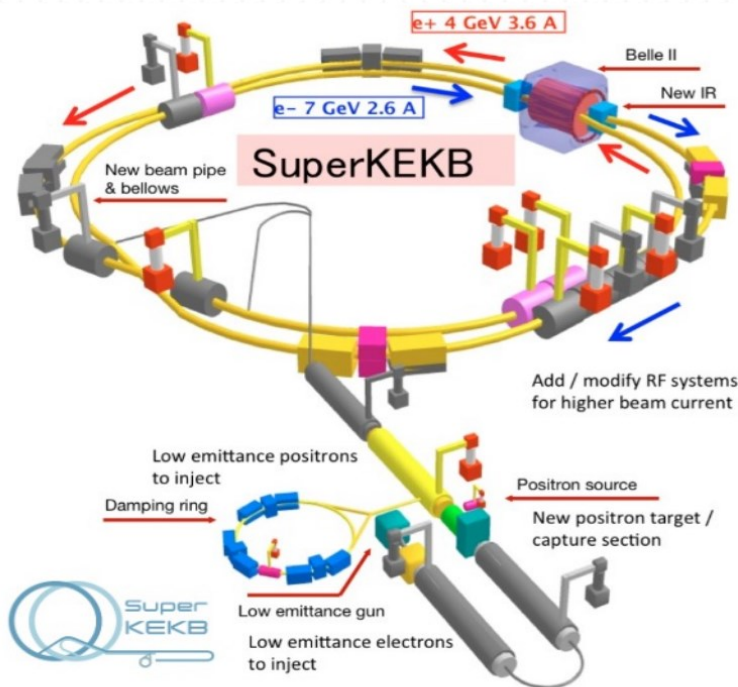
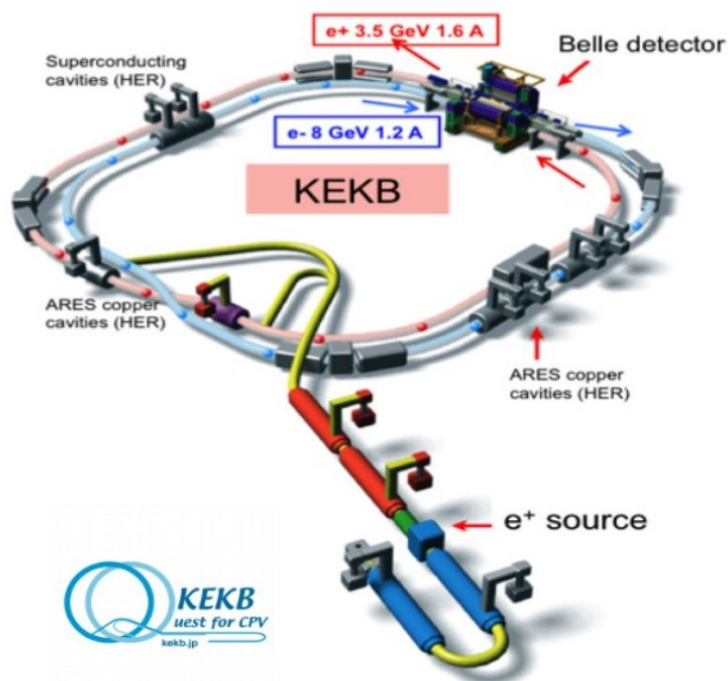
- Ref. [17] with breaking scenario suits best for \mathcal{B} measurements

Future



The more we know, the more we do not know!

Belle → Belle II: 加速器升级改造



- 质心能量提升, Belle II可以采集 $\Upsilon(6S)$ 的数据
- Belle II更高的束流强度
- Belle II采用nano beam方案, 在y轴方向压缩束流至纳米级别, 从而提高瞬时亮度
- Belle II的瞬时亮度预期提高30倍。

	E_{\pm} (GeV)	Cross Angle (mrad)	I_{\pm} (A)	β_y^* (mm)	\mathcal{L}
	LER/HER	(mrad)	LER/HER	LER/HER	($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	22	1.64/1.19	5.9/5.9	2.1×10^{34}
SuperKEKB	4.0/7.0	83	3.60/2.60	0.27/0.31	80×10^{34}
	$\beta\gamma \sim 2/3$		$\times 2$	$\times 20$	$\times 40$

luminosity

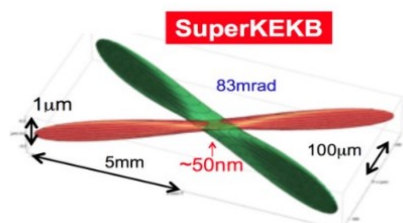
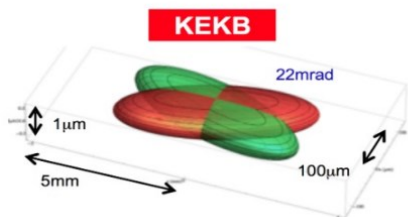
$$\mathcal{L} = \frac{\gamma_{\pm}}{2e r_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \frac{I_{\pm} \zeta_{y\pm}}{\beta_{y\pm}^*} \left(\frac{R_L}{R_{\zeta_y}} \right)$$

beam size: σ^* , beam-beam par.: ζ_{\pm} ,
beam current: I_{\pm} , beta function: β^*

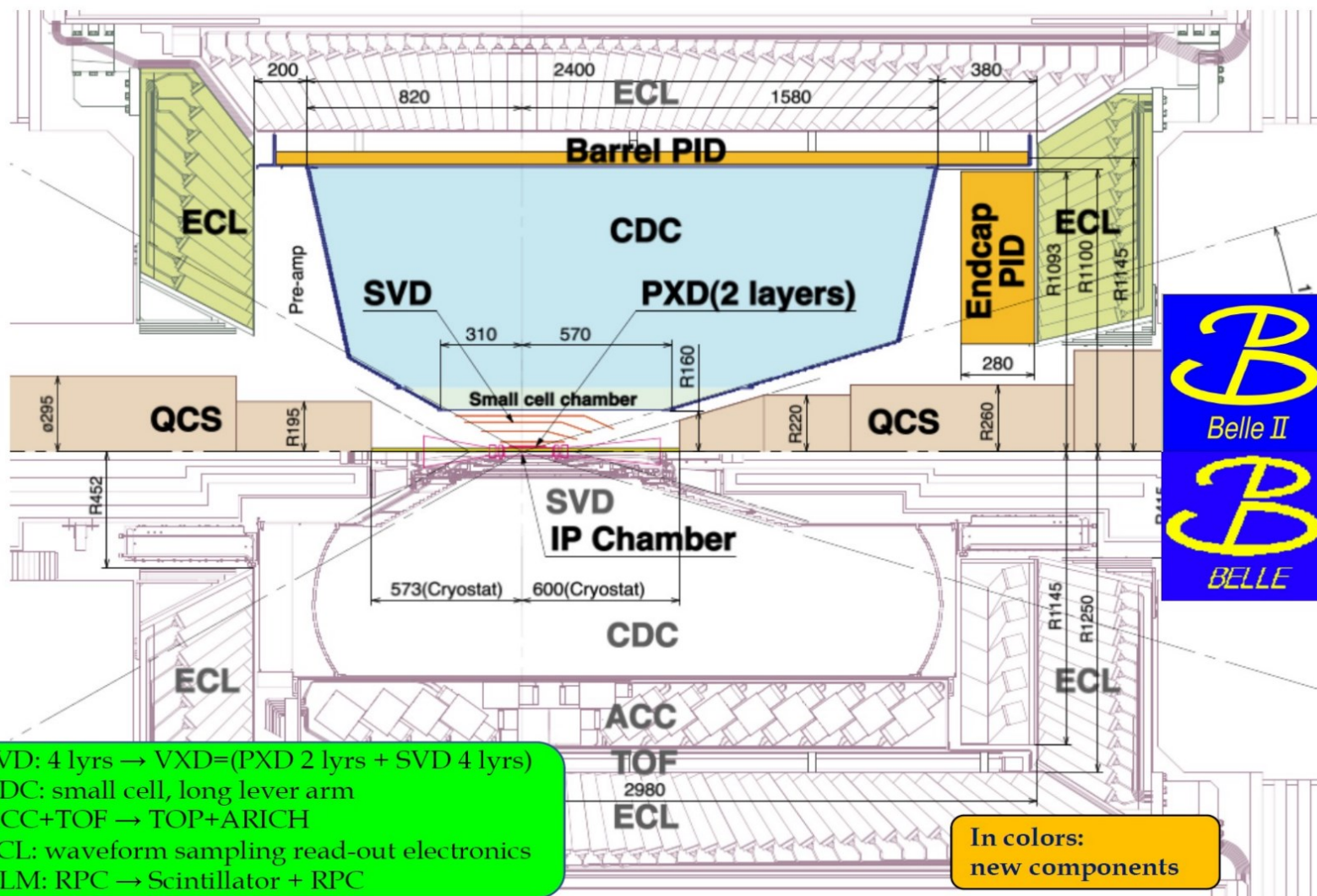
$$\mathcal{L}_{II}^{\text{peak}} \approx 30 \times \mathcal{L}_I^{\text{peak}}$$

$$\int^{\text{goal}} \mathcal{L}_{II} dt = 50 \text{ ab}^{-1} \approx 50 \int \mathcal{L}_I dt$$

Nano beam: small beamspot







Belle → Belle II: 探测器升级改造



- 4层SVD → 2层PXD+4层SVD: 提高B介子的空间分辨率
- CDC: 更小的探测单元
- ACC+TOF → TOP + ARICH
- ECL: 更好的电子学读出
- KLM: RPC → 闪烁体+ RPC

各实验粲物理样本的比较

Experiment	Machine	C.M.	Luminosity(fb^{-1})	N_{prod}	Efficiency	Characters
	BEPC-II (e^+e^-)	3.77 GeV	20	$D^{0,+}: 10^8$	~ 10-30%	☺ extremely clean environment ☺ quantum coherence ☹ no boost, no time-dept analysis
		4.18-4.23 GeV	7.3	$D_s^+: 5 \times 10^6$		
		4.6-4.7 GeV	4.5	$\Lambda_c^+: 0.8 \times 10^6$		
				☆☆	★★★	
	SuperKEKB (e^+e^-)	10.58 GeV	500 ($\rightarrow 50000$)	$D^0: 10^9 (\rightarrow 10^{11})$	$\mathcal{O}(1-10\%)$	☺ high-efficiency detection of neutrals ☺ good trigger efficiency ☺ time-dependent analysis ☹ smaller cross-section than LHCb
				$D_{(s)}^+: 10^8 (\rightarrow 10^{10})$		
	KEKB (e^+e^-)	10.58 GeV	1000	$\Lambda_c^+: 10^7 (\rightarrow 10^9)$	★★★	
				$D^{0,+}, D_s^+: 10^9$		
				$\Lambda_c^+: 10^8$	★★	
	LHC (pp)	7+8 TeV	1+2	5×10^{12}	$\mathcal{O}(0.1\%)$	☺ very large production cross-section ☺ large boost, excellent time resolution ☺ more charm sources ☹ dedicated trigger required
		13 TeV	6+9	10^{13}		
			($\rightarrow 23 \rightarrow 50$)			
				★★★★	★	

- **BESIII:** 本底干净，没有boost，不能做含时分析。粲重子产额低，但效率高
- **Belle/Belle II:** 中性粒子探测效率高，可做含时分析，粲重子产额中等，效率中等
- **LHCb:** 大的产生截面，优于含时分析，粲重子产额高，但效率低

三个实验在粲重子方面各有优势！