Belle II实验粲物理近期成果介绍

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第八届粒子物理天问论坛

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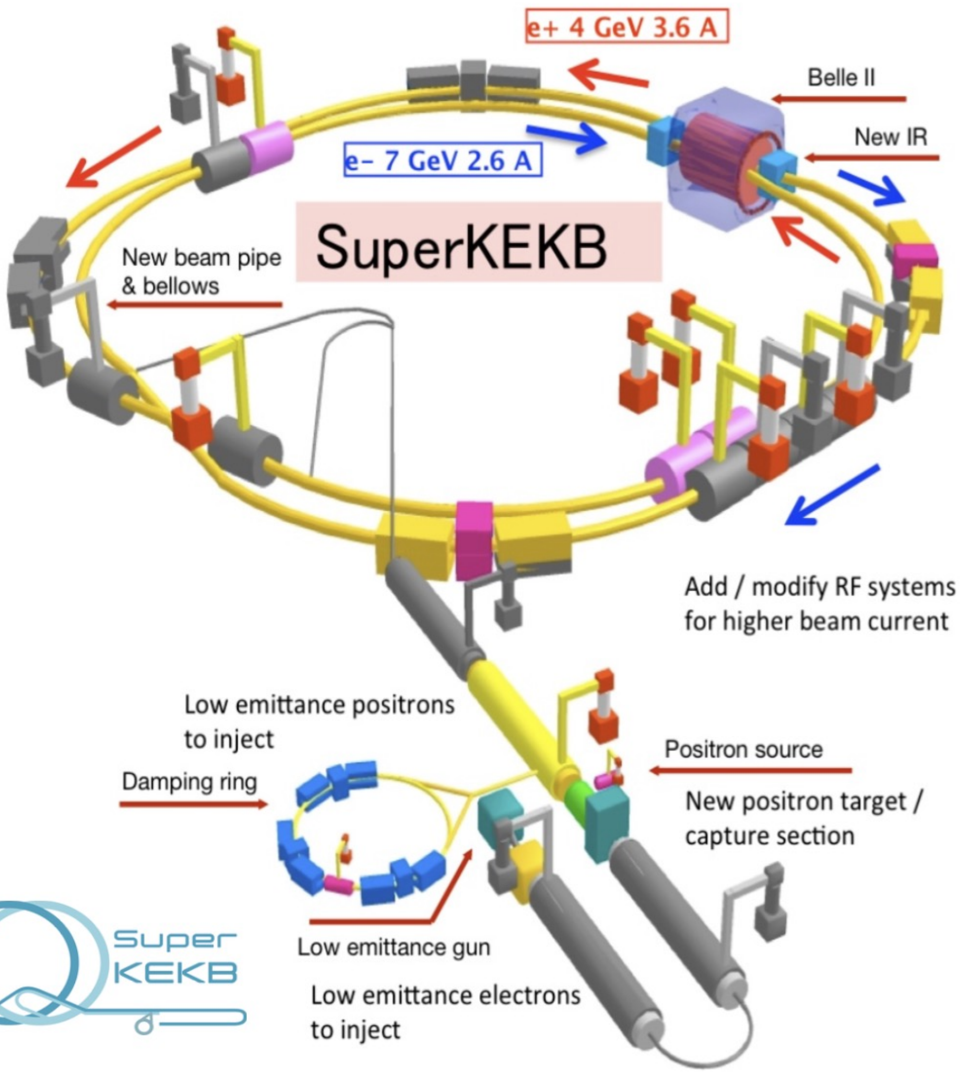
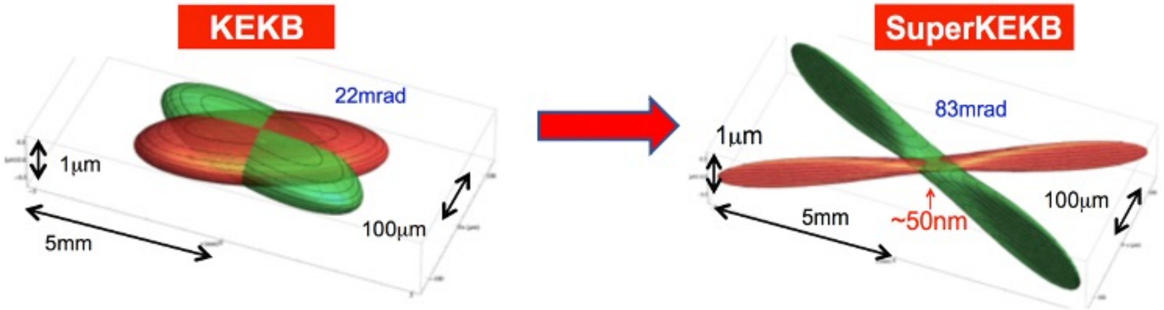
Belle-II实验近期粲物理结果

- Charm @ Belle II
- Radiative or rare charm decay:
  - $D_{s0}(2317)^+ \to D_s^{*+}\gamma$
  - $D^+ \to \pi^+ e^+ e^-$
- Charmed baryon hadronic decay:
  - $\Lambda_c^+ \to \Lambda K^+(\pi^0, \eta)$
  - $\Xi_c^0 \to \Lambda(\pi^0, \eta, \eta')$
- Charm CP violation:
  - $D_{(s)}^+ \to \eta h^+$
  - $\Lambda_c^+ \to p h^+ h^-, \Xi_c^+ \to \Sigma^+ h^+ h^-$

超级B介子工厂：SuperKEKB



加速器	KEKB	→ SuperKEKB
• 能量（物理尺度）	10.58 GeV	
• 亮度（测量精度）	2.1×10^{-34}	→ $6\times10^{-33}\ \mathrm{cm^{-2}s^{-1}}$



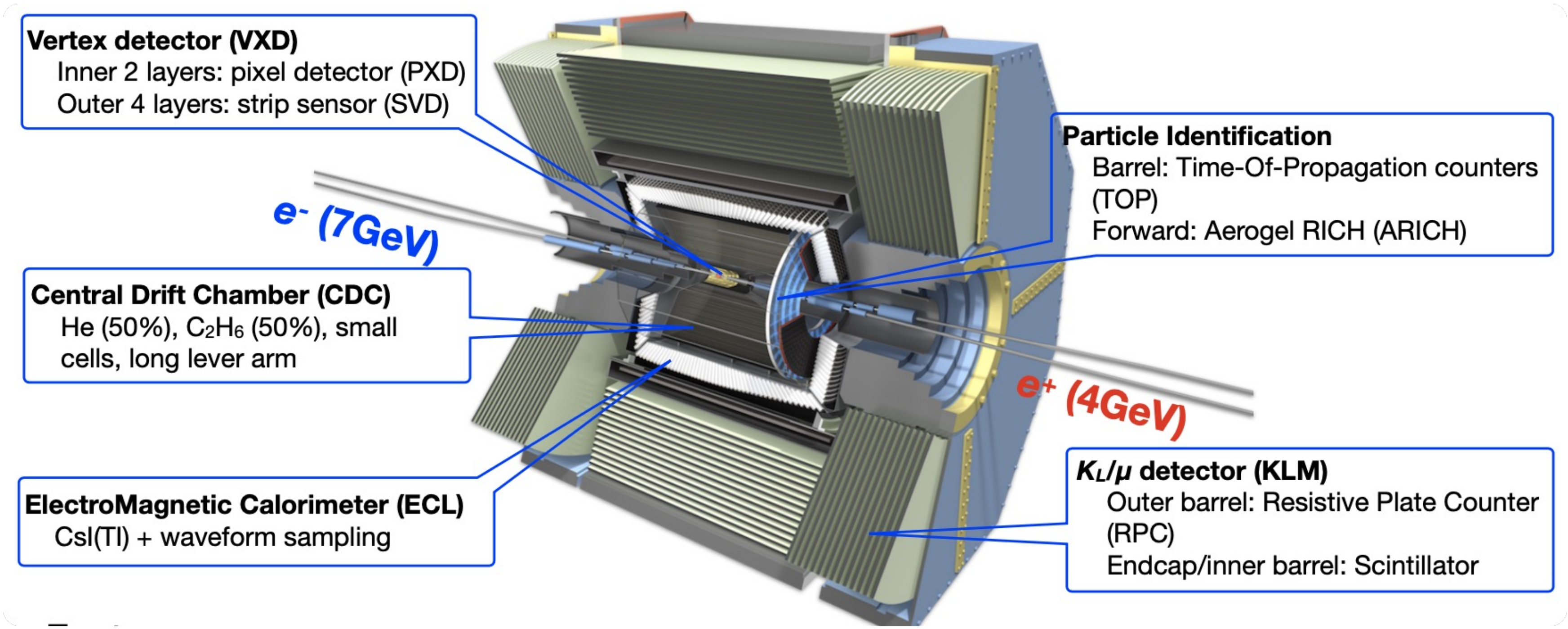
Beam current: KEKB x ~1.5

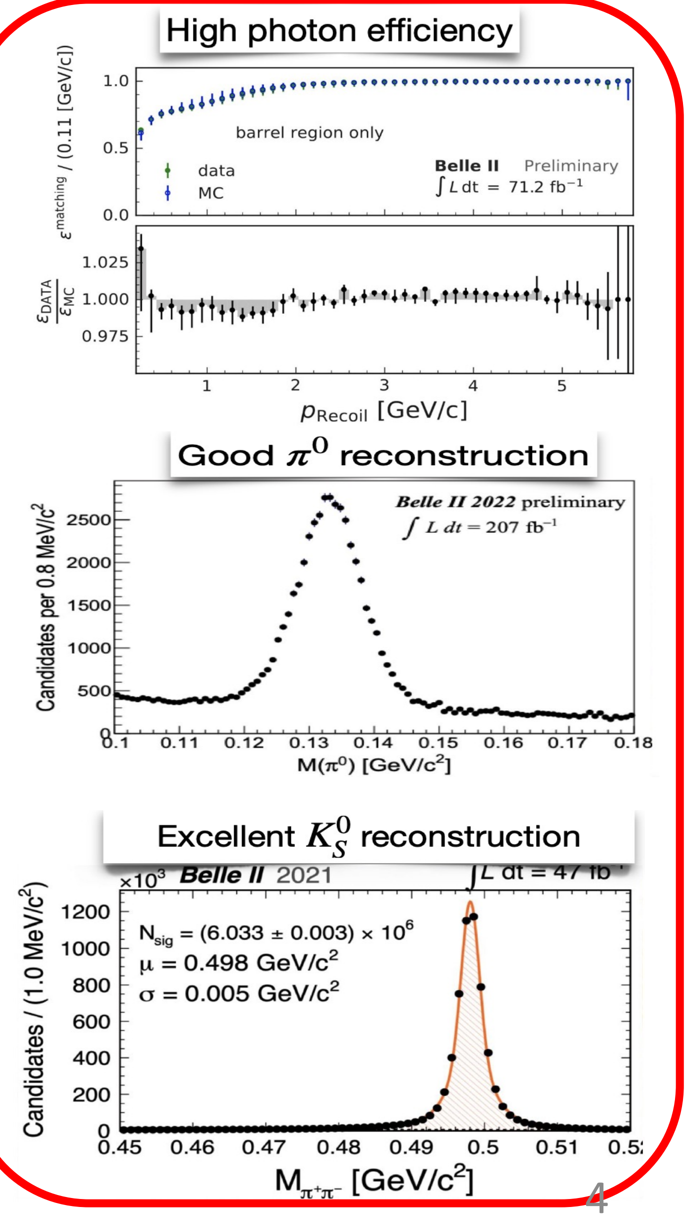
$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Beam squeeze: KEKB / ~20

共同实现高亮度的数据采集！

Belle II探测器和其性能





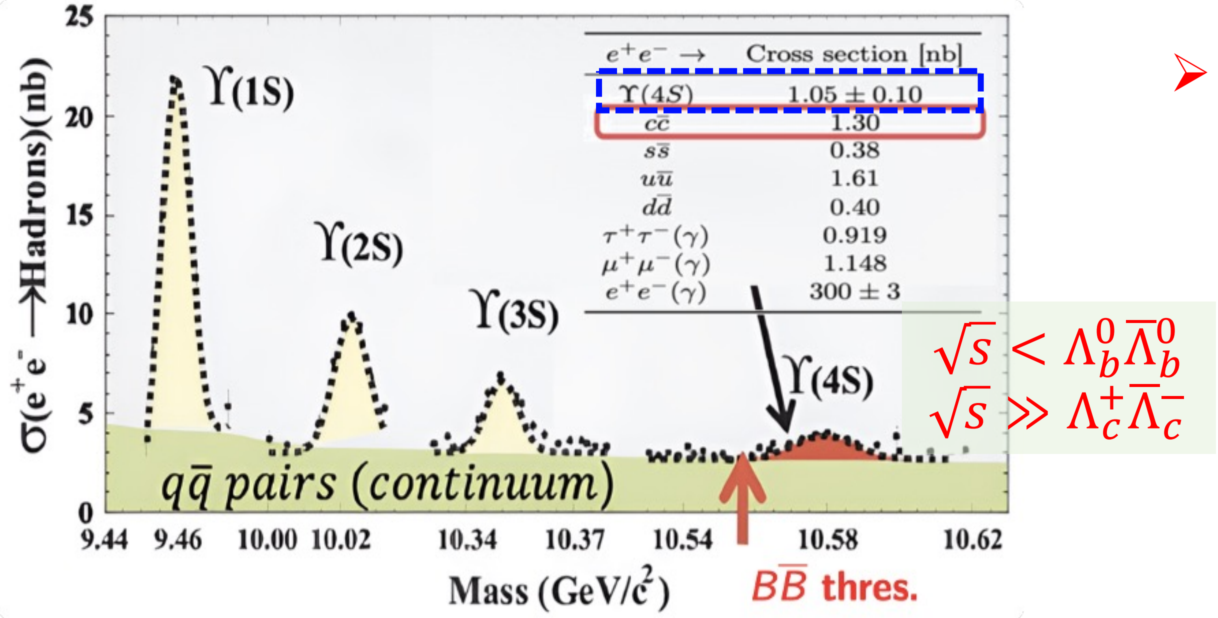
Belle II探测器的性能优势：

- 4π立体角：高接受度
- 顶点和径迹：高空间分辨率&粒子鉴别能力
- 事例触发：效率高；特殊触发（对低重数末态的事例）

中性/长寿命粒子
具有高重建效率

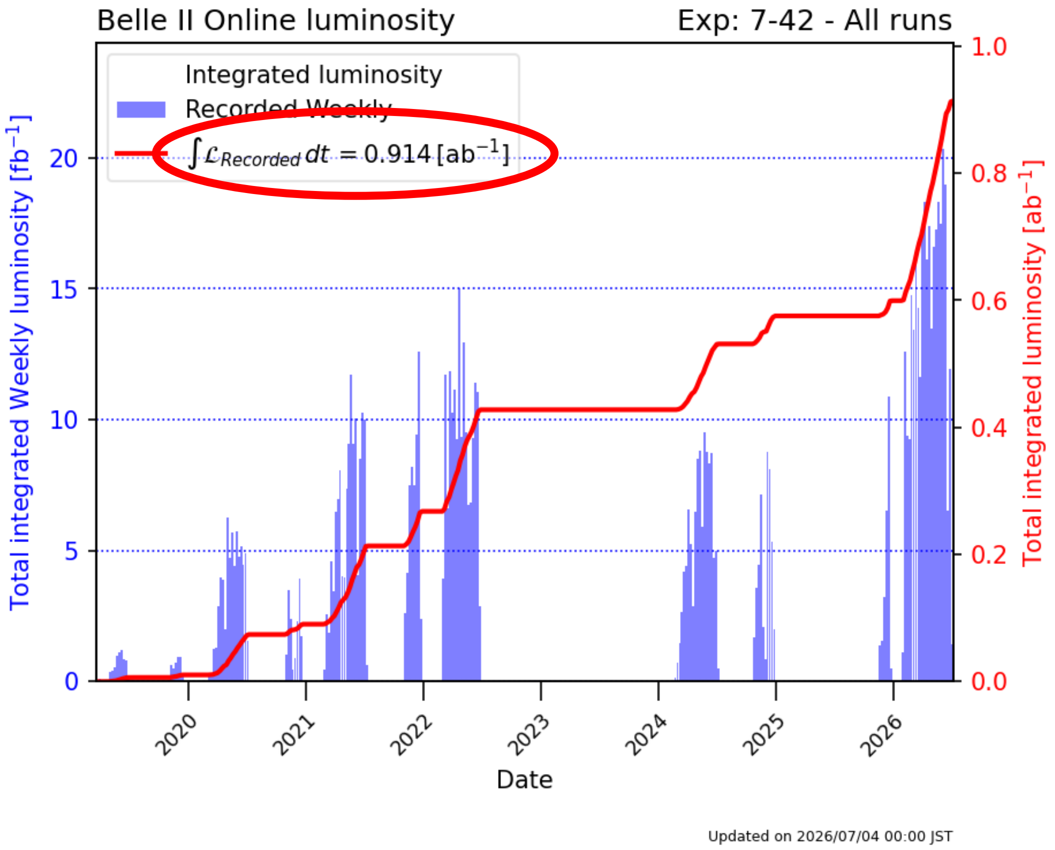
粲样本的产生@Belle II

- SuperKEKB: 超级B/陶/粲工厂

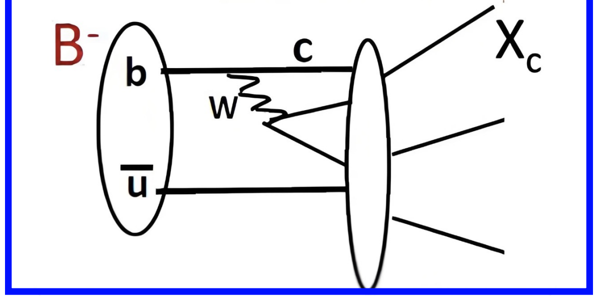


Belle II进入ab^{-1}亮度时期

- 已积累粲样本：$N(D^0)\sim O(10^9)$，$N(\Lambda_c^+)\sim O(10^8)$

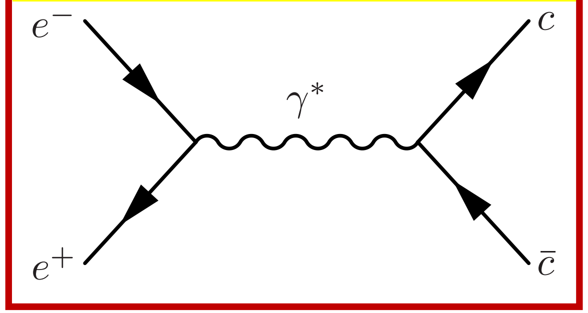


(1) BToCharm decay



产额可控

(2) $e^+e^- \to c\bar{c}$



产额巨大

Belle-II实验粲物理成果

~20% of all physics publications

Belle II

- Charm lifetimes:
  - $\tau(D^{0,+})$, PRL 127, 211801 (2021)
  - $\tau(\Lambda_c^+)$, PRL 130, 071802 (2023)
  - $\tau(\Omega_c^0)$, PRD 107, L031103 (2023)
  - $\tau(D_s^+)$, PRL 131, 171803 (2023)
- Charmed baryon:
  - $\Xi_c^0 \to \Xi^0(\pi^0, \eta, \eta')$, JHEP 10 (2024) 045
  - $\Lambda_c^+ \to pK_S^0\pi^0$ (B1), PRD 112, 012013 (2025)
  - $\Xi_c^+ \to pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$, JHEP 03 (2025) 061
  - $\Xi_c^+ \to \Sigma^+K_S^0, \Xi^0\pi^+, \Xi^0K^+$, JHEP 08 (2025) 195
  - $\Xi_c^0 \to \Lambda(\pi^0, \eta, \eta')$, PRD 113, 032015 (2026)
  - $\Lambda_c^+ \to \Lambda K^+(\pi^0, \eta)$, preliminary result
- Charm CPV:
  - $D_{(s)}^+ \to K_S^0K^-\pi^+\pi^+$, JHEP 04 (2025) 036
  - $D^0 \to K_S^0K_S^0$ (D^{*+}), PRD 111, 012015 (2025)
  - $D^0 \to \pi^0\pi^0$, PRD 112, 012006 (2025)
  - $D^0 \to K_S^0K_S^0$ (CFT), PRD 112, 012017 (2025)
  - $D^+ \to \pi^+\pi^0$, PRD 112, L031101 (2025)
  - $D^0 \to \pi^+\pi^-\pi^0$, PRD 113, 052006 (2026)
  - $\Xi_c^+ \to \Sigma^+h^+h^-, \Lambda_c^+ \to ph^+h^-$, PRD 113, 032017 (2026)
  - $D_{(s)}^+ \to \eta h^+$, preliminary result
- Charmed meson:
  - mixing in $D^0 \to K_S^0\pi^+\pi^-$, PRD 111, 112011 (2025)
  - $D^0 \to h^+h'^-e^+e^-$ (B1), PRD 112, L071101 (2025)
  - $D_{s0}(2317)^+ \to D_s^{*+}\gamma$, PRL 136, 241901 (2026)
  - $D^+ \to \pi^+e^+e^-$, preliminary result

Belle-II实验近期粲物理结果介绍

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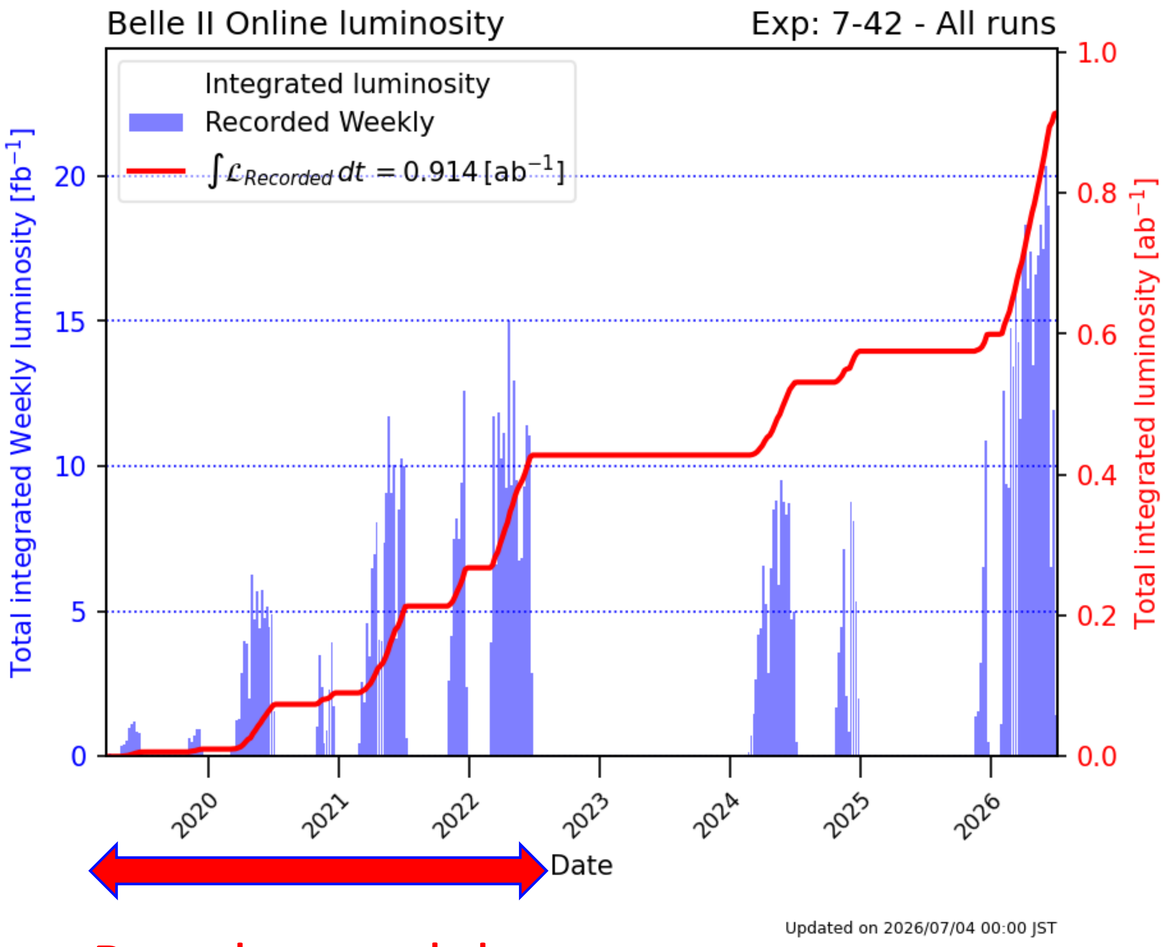
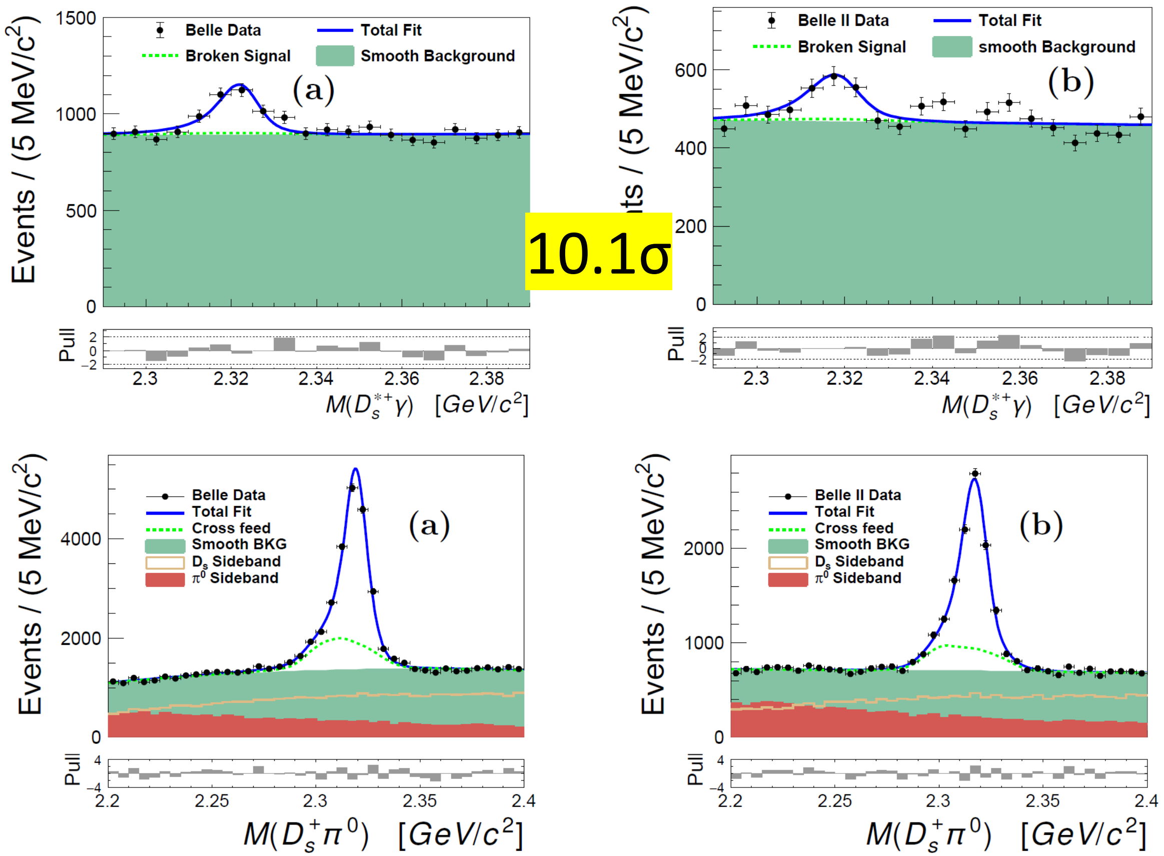


Based on real data before 2023 (428/fb)

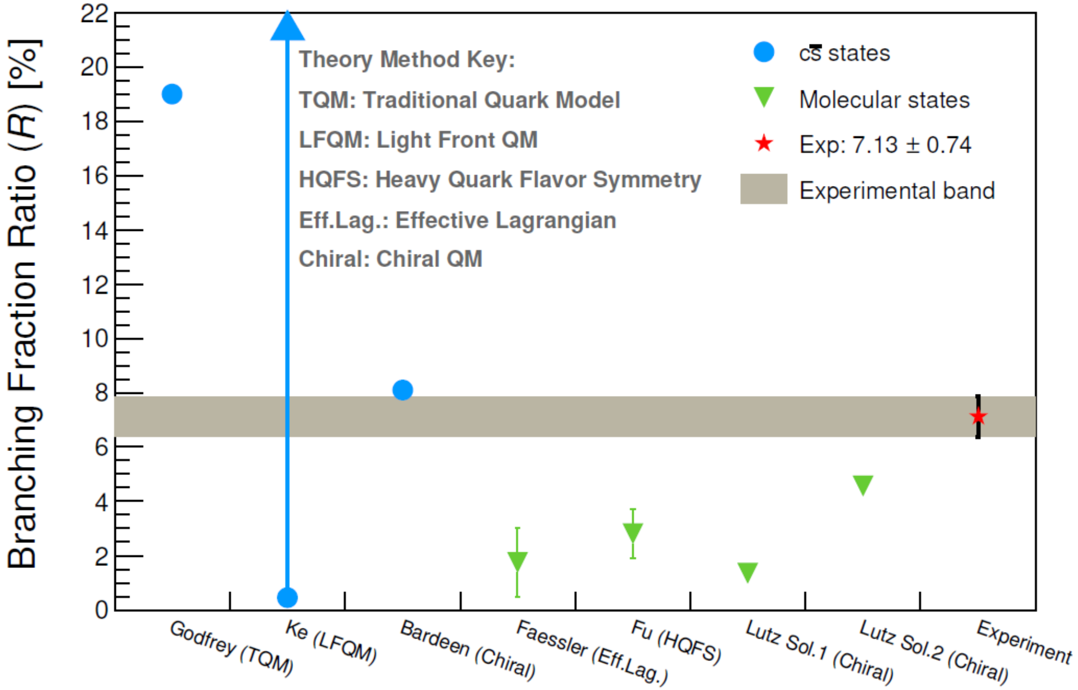
observation of $D_{s0}(2317)^+ \to D_s^{*+}\gamma$ PRL 136, 241901 (2026)

BELLE Belle II

- Precise nature of $D_{s0}^*(2317)^+$ remains unresolved, underscoring the need for new and improved data.
- The width of $D_s(2317)^+$ is unknown: $\Gamma(D_s(2317)^+) < 3.8$ MeV @95% CL.



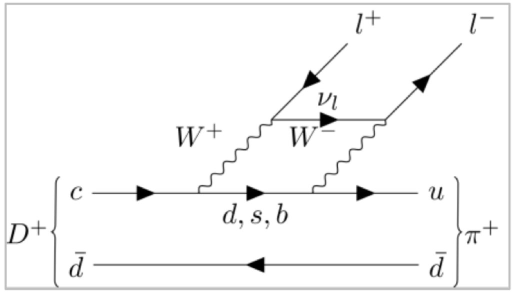
$$R = \frac{\mathcal{B}(D_s(2317)^+ \to D_s^{*+}\gamma)}{\mathcal{B}(D_s(2317)^+ \to D_s^+\pi^0)} = [7.14 \pm 0.70 \pm 0.23]\%$$

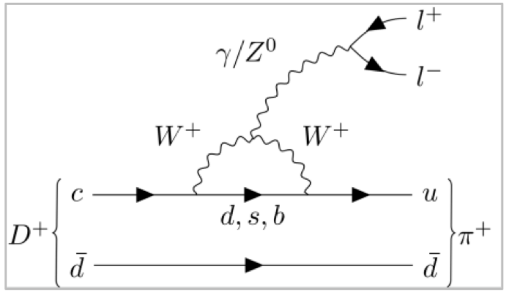


More radiative decays on the road. Stay tuned!

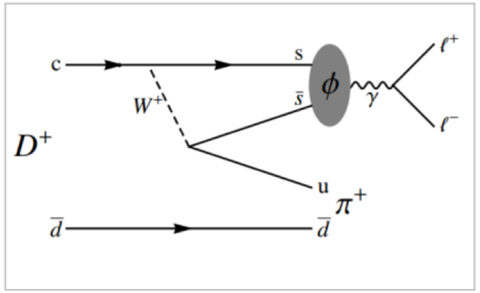
Charm rare decay: $D^+ \to \pi^+ e^+ e^-$

- Highly suppressed in the SM, making it sensitive to possible effects from physics beyond the SM.
- The total decay rate is dominated by long-distance contributions ($O(10^{-6})$ level), which can mask short-distance new physics effects.

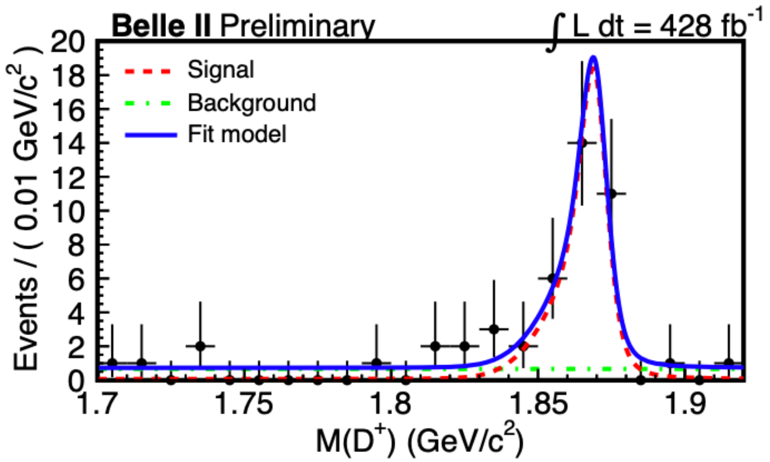


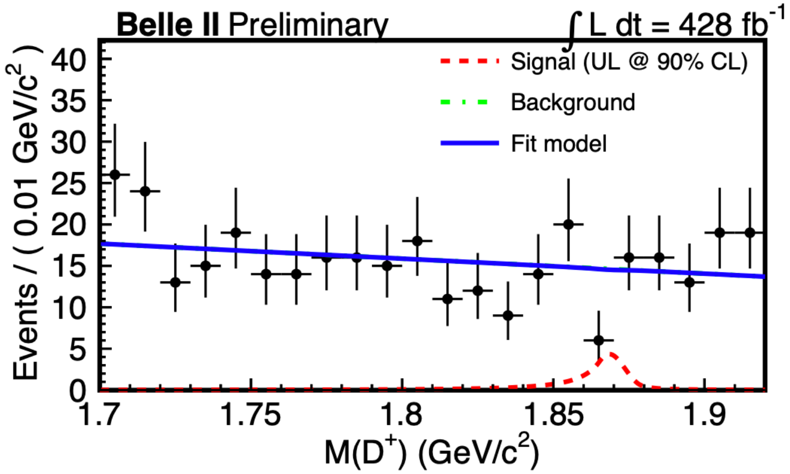


short-distance



long-distance





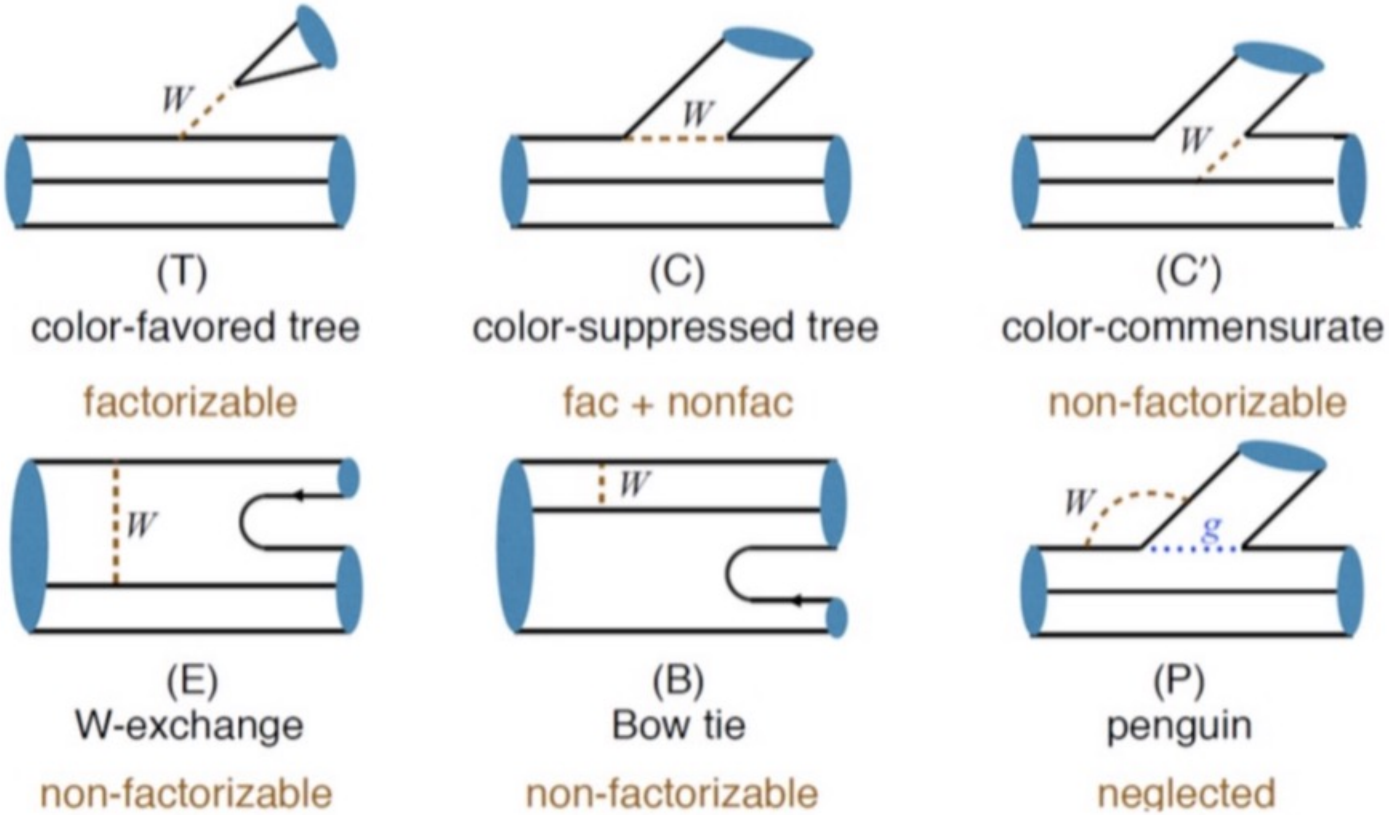
$M(e^+e^-)$ interval	Efficiency (%) Belle	Efficiency (%) Belle II	N_{sig} Belle	N_{sig} Belle II	$\mathcal{B}$ $(\times 10^{-7})$	UL $(\times 10^{-7})$
I_1	3.82 ± 0.04	4.73 ± 0.04	-1.7 ± 5.8	-1.0 ± 3.4	-0.6 ± 2.0	< 3.0
I_2	5.03 ± 0.03	6.14 ± 0.03	0.0 ± 6.0	0.0 ± 3.6	0.0 ± 2.1	< 3.3
I_3	5.94 ± 0.03	7.42 ± 0.03	-2.0 ± 5.8	-1.2 ± 3.4	-0.7 ± 2.0	< 2.9
I_{full}	5.29 ± 0.02	6.57 ± 0.02	-0.3 ± 9.6	-0.2 ± 5.7	-0.1 ± 3.3	< 4.7
$I_\phi^{\mathrm{Valid.}}$	4.75 ± 0.02	6.13 ± 0.02	$51 \pm 6 \pm 3$	$30 \pm 4 \pm 2$	$17.5 \pm 2.2 \pm 1.2$	-

$I_1 \in (0.20, 0.50)$ GeV$/c^2$
$I_2 \in (0.56, 0.95)$ GeV$/c^2$
$I_3 \in (1.05, 1.75)$ GeV$/c^2$

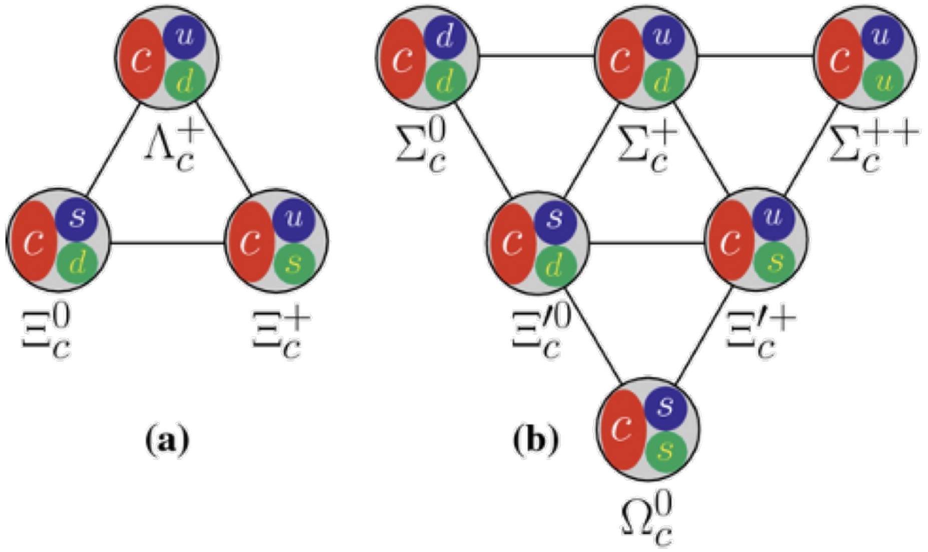
$I_\phi^{valid.} \in (0.995, 1.035)$ GeV$/c^2$

粲重子非轻衰变的测量

- In hadronic decay of charmed baryon, the nonfactorizable contributions from internal W-emission and W-exchange diagrams play an essential role and can not be neglected.



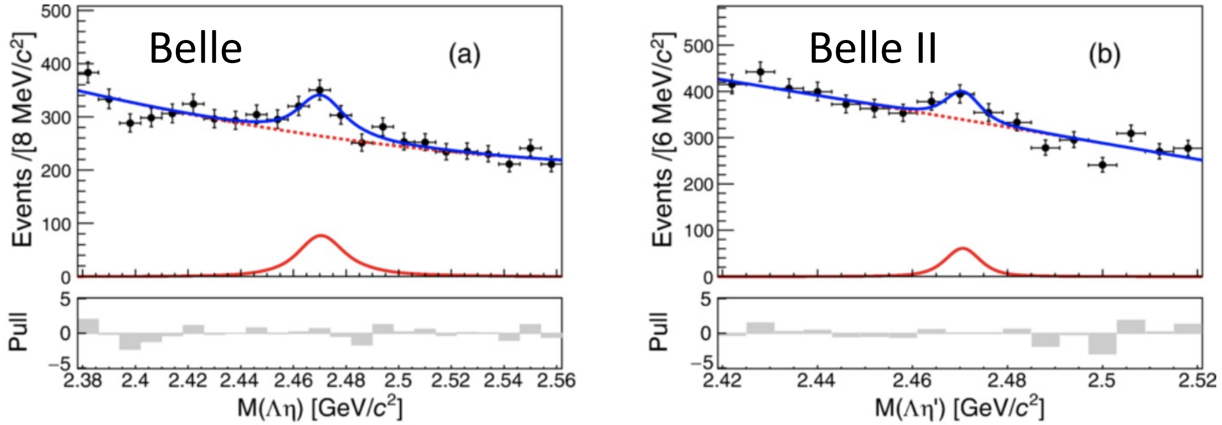
[Fig. in Chin. Phys. C 50, 022002 (2026)]



Belle II覆盖所有单味道粲重子

粲重子:两体非轻衰变的测量

- $\Xi_c^0 \to \Xi^0(\pi^0, \eta, \eta')$, JHEP 10 (2024) 045
- $\Xi_c^+ \to pK_S^0, \Lambda\pi^+, \Sigma^0\pi^+$, JHEP 03 (2025) 061
- $\Xi_c^+ \to \Sigma^+K_S^0, \Xi^0\pi^+, \Xi^0K^+$, JHEP 08 (2025) 195
- $\Xi_c^0 \to \Lambda(\pi^0, \eta, \eta')$, PRD 113, 032015 (2026)

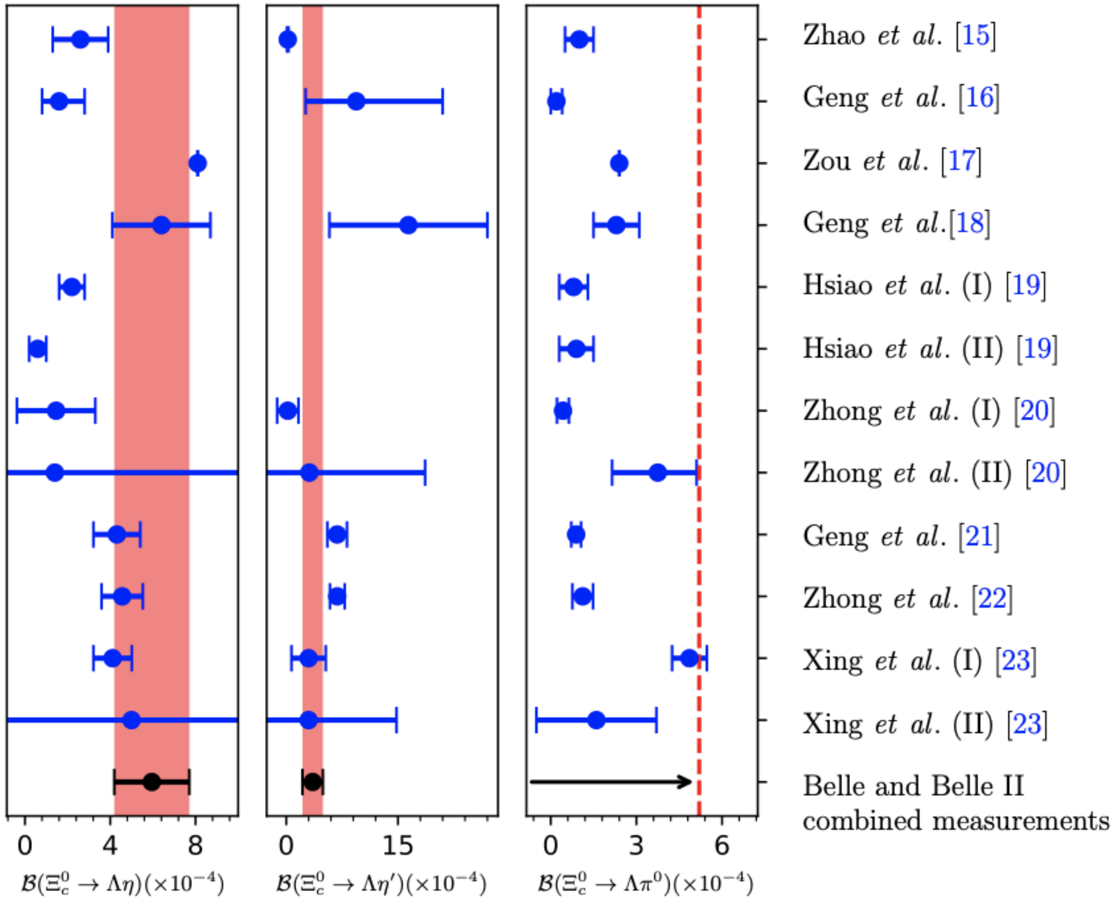


Based on B+B2 (1.4ab[-1]) dataset:

$$\frac{B(\Xi_c^0 \to \Lambda\eta)}{B(\Xi_c^0 \to \Xi^-\pi^+)} = (4.16 \pm 0.91 \pm 0.23)\%$$

$$\frac{B(\Xi_c^0 \to \Lambda\eta')}{B(\Xi_c^0 \to \Xi^-\pi^+)} = (2.48 \pm 0.82 \pm 0.12)\%$$

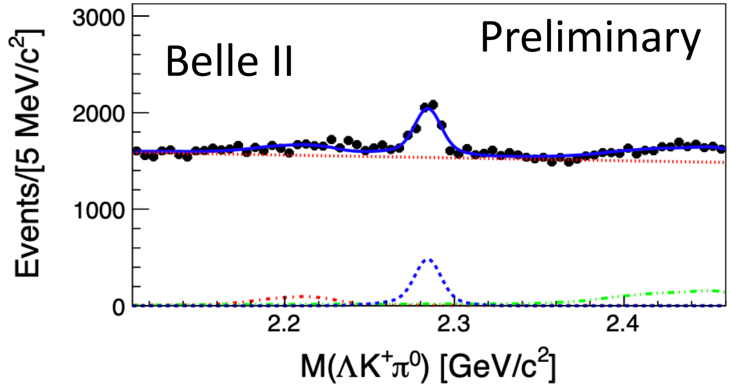
$$\frac{B(\Xi_c^0 \to \Lambda\pi^0)}{B(\Xi_c^0 \to \Xi^-\pi^+)} < 3.5\%$$

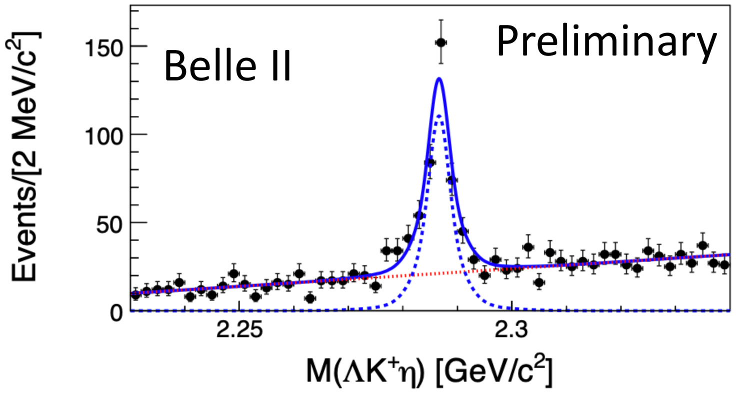


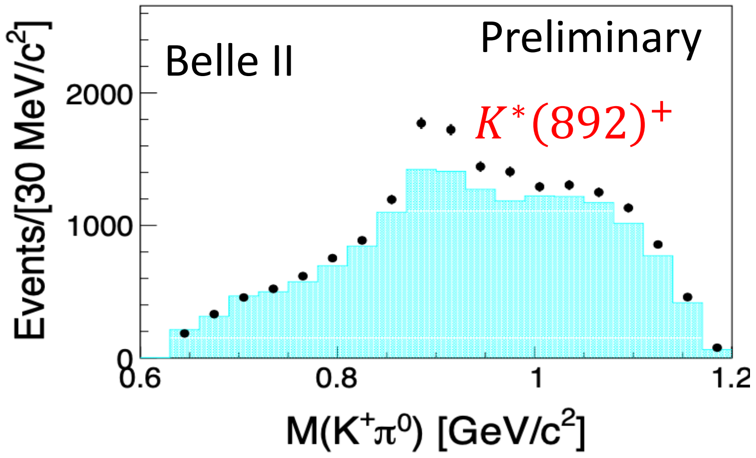
两体衰变分支比的精确结果：为理论研究提供了重要实验依据。

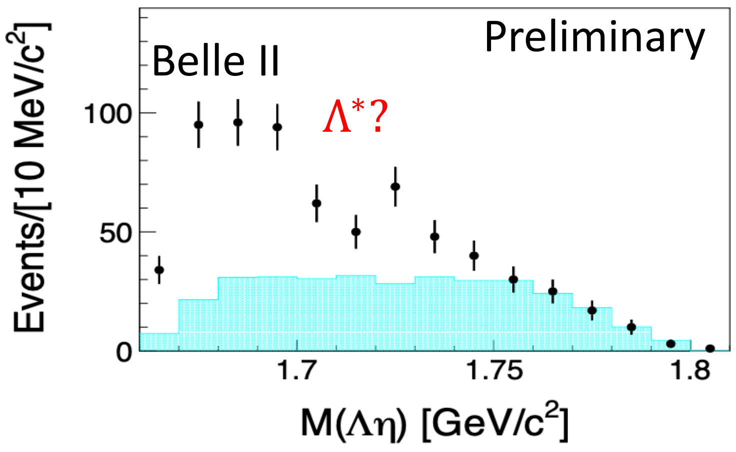
粲重子：SCS衰变的测量

- 粲重子单卡比玻压低（SCS）过程为CP破坏的敏感寻找提供了好的平台。
- 但目前还有大量的SCS过程有待被发现或精确测量。





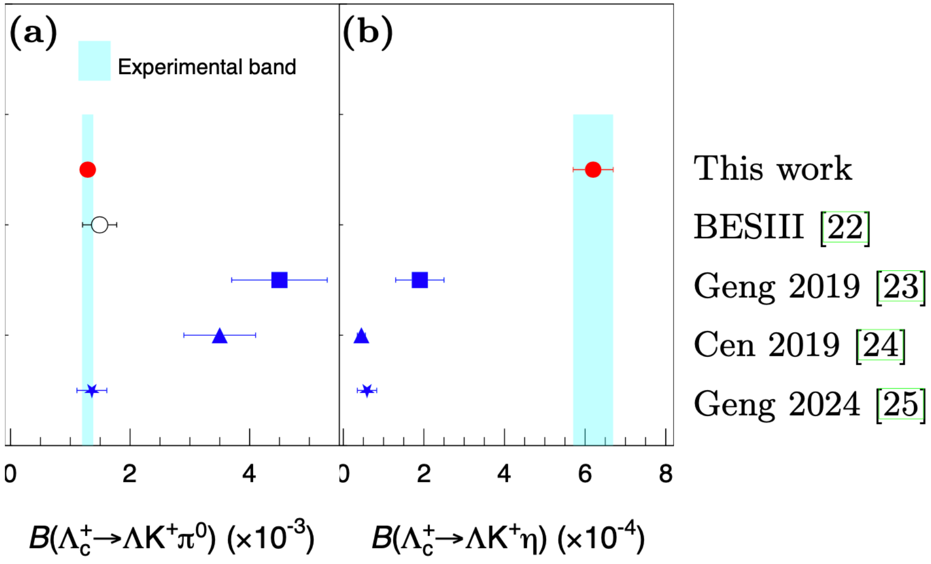




- 基于Belle+Belle-II的1.5/fb数据

$$\frac{\mathcal{B}(\Lambda_c^+\to\Lambda K^+\pi^0)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}=(1.82\pm0.07\pm0.07)\%$$

$$\frac{\mathcal{B}(\Lambda_c^+\to\Lambda K^+\eta)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)}=(8.73\pm0.35\pm0.43)\times10^{-3},$$



已经可看到一些共振态或结构。更多数据：振幅分析和CP破坏寻找。

粲重子非轻衰变：进行中的测量

Belle II

Λ_c^+非轻衰变：

- $\Lambda_c^+ \to \Lambda K_S^0\pi^+, \Lambda K_S^0 K^+, \Lambda K^+\pi^+\pi^-$
- $\Lambda_c^+ \to \Xi^0 K_S^0\pi^+, \Xi^0 K^{*+}$
- $\Lambda_c^+ \to \Sigma^+K^+\pi^-, \Sigma^+K_S^0K_S^0, \Sigma^+K^+K^-$
- $\Lambda_c^+ \to \Xi^0 K^+$ $(B\ \&\ \alpha)$
- $\Lambda_c^+ \to \Sigma^+K_S^0$ $(B\ \&\ \alpha\ \&\ A_{CP}^{\alpha})$
- $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ (PWA)
- ....

基于570/fb（≲2025）的测量结果正如火如荼开展中（中国组为主导），

敬请期待！

$\Xi_c^{0,+}$非轻衰变：

- $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ (PWA)
- $\Xi_c^+ \to \Lambda K_S^0\pi^+, pK_S^0K_S^0$
- $\Xi_c^+ \to \Lambda K_S^0K^+, \Xi^-K^+\pi^+, \Omega^-K^+\pi^+$
- $\Xi_c^+ \to \Xi^0\pi^+\pi^+\pi^-, \Sigma^+K^-\pi^+$
- $\Xi_c^+ \to \Xi^0K_S^0\pi^+, \Xi_c^0 \to \Xi^-K_S^0\pi^+, \Xi^0K^+\pi^-$

- $\Xi_c^0 \to \Omega^-K^+$ $(B\ \&\ \alpha)$
- $\Xi_c^0 \to pK_S^0K^-, \Sigma^+K_S^0\pi^-, \Lambda K^-\pi^+$
- $\Xi_c^0 \to \Xi^-K^+, \Lambda K_S^0, \Sigma^+K^-$ $(B\ \&\ \alpha)$
- $\Xi_c^0 \to \Xi^-h^+\pi^0, \Xi^-h^+\eta$
- $\Xi_c^0 \to \Xi(1530)^{-,0}\pi^{+,0}$

- absolute $B(\Xi_c^+ \to f)$
- ......

近期粲物理结果介绍

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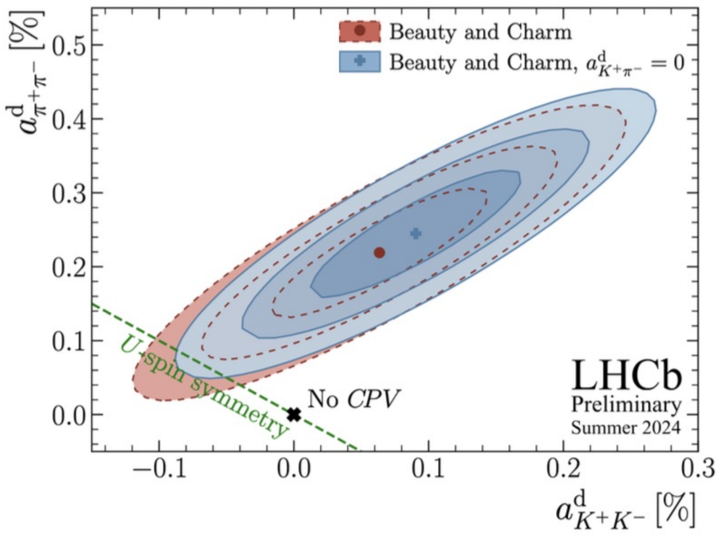
  - $D^+ \to \pi^+ e^+ e^-$
- Charmed baryon hadronic decay:
  - $\Lambda_c^+ \to \Lambda K^+(\pi^0, \eta)$
  - $\Xi_c^0 \to \Lambda(\pi^0, \eta, \eta')$
- Charm CP violation:
  - $D_{(s)}^+ \to \eta h^+$
  - $\Lambda_c^+ \to p h^+ h^-, \Xi_c^+ \to \Sigma^+ h^+ h^-$

粲强子CP破坏的现状

- 粲强子衰变中CP破坏效应：标准模型预期很小[1, 2]，因此是新物理的敏感探针。

- 粲介子衰变CP破坏：
  - 2019年LHCb测 $\Delta A_{CP}(D^0 \to K^+K^-, \pi^+\pi^-) = (-1.54 \pm 0.29)\times 10^{-3}$ 。首次发现粲CP破坏[3]，入选“物理十大突破”。后续研究发现其主要来自$D^0 \to \pi^+\pi^-$过程[4]。目前理论上并不能很好的解释此CP破坏的来源。因此实验需要更多“发现”和更精确测量。

LHCb-CONF-2024-004



- 粲重子衰变CP破坏：
  - 2025年，LHCb在底味重子衰变中首次发现重子CP破坏[5]，入选“物理十大突破”。
  - 粲重子CP破坏：尚未发现的任何实验迹象。

[1] H.-n. Li, et al. PRD 86, 036012 (2012)
[2] H.-Y. Cheng et al. PRD 104, 073003 (2021)
[3] (LHCb) Phys. Rev. Lett. 122, 211803 (2019)
[4] (LHCb) Phys. Rev. Lett. 131, 091802 (2023)
[5] (LHCb) Nature 643 (2025) 8074

Charm CPV: $A_{CP}(D^+_{(s)} \to \pi^+\eta)$

- Belle II has high efficiencies on $\gamma, \pi^0/\eta$ (and long-lived particle: K^0_S and hyperons).
- Better vertex fitter w.r.t Belle: treeFit (simultaneous fit of all vertices in a decay chain).

Belle II (428/fb , $\eta \to \gamma\gamma, \pi^+\pi^-\pi^0$) using reference mode $D^+ \to K^0_S\pi^+$:

$A_{CP}(D^+ \to \pi^+\eta) = (-0.07 \pm 0.52 \pm 0.02)\%$

$A_{CP}(D^+_s \to \pi^+\eta) = (-0.32 \pm 0.38 \pm 0.02)\%$

the most precise results.

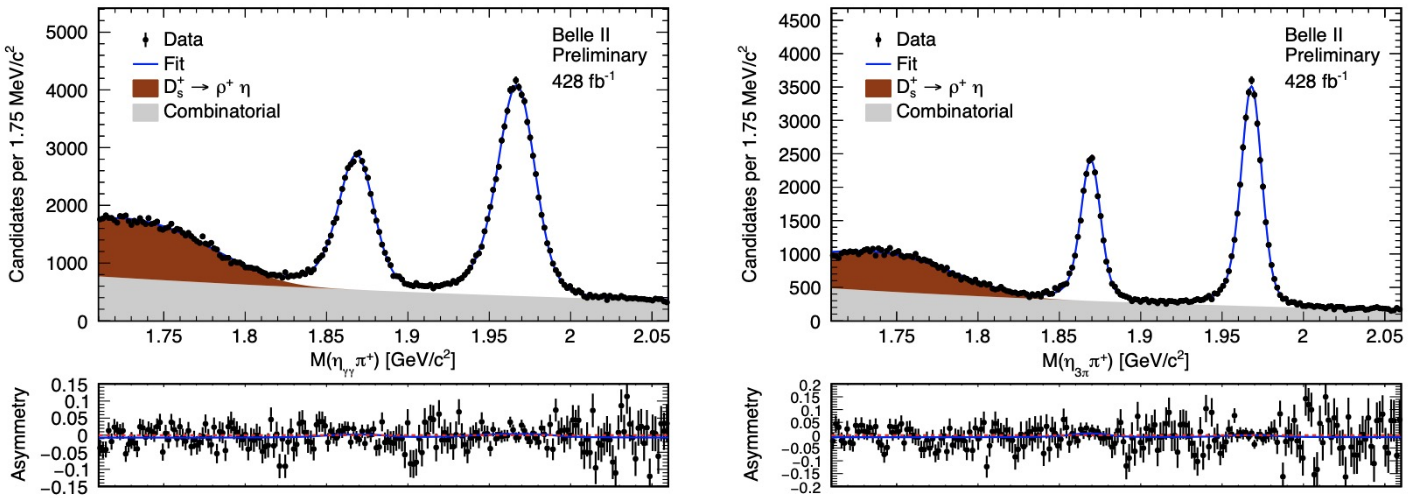
Vs. previous $A_{CP}(D^+ \to \pi^+\eta)$ results:

Belle (791 fb^{-1}, $\eta \to \pi^+\pi^-\pi^0$):
$\sigma = 1.1\%$ [PRL 107, 221801 (2011)]

LHCb (6 fb^{-1}, $\eta \to \pi^+\pi^-\gamma$):
$\sigma = 0.7\%$ [JHEP 04 (2023) 081]

LHCb (6 fb^{-1}, $\eta \to e^+e^-\gamma$):
$\sigma = 0.8\%$ [JHEP 06 (2021) 019]

$\eta \to \gamma\gamma$ $\quad$ $\eta \to \pi^+\pi^-\pi^0$



- Belle II shows a better sensitivity per luminosity.
- The σ_{stat} is dominated: very promising with higher luminosity.

$A_{CP}(\Lambda_c^+ \to ph^+h^-, \Xi_c^+ \to \Sigma^+h^+h^-)$

PRD 113, 032017 (2026)

Belle II

- LHCb reported [1]: $\Delta A_{CP}^{wgt} = A_{CP}(\Lambda_c^+ \to pK^+K^-) - A_{CP}^{wgt}(\Lambda_c^+ \to p\pi^+\pi^-) = (0.30 \pm 0.91 \pm 0.61)\%$
- U-spin symmetry [2,3]: $A_{CP}(\Lambda_c^+ \to pK^+K^-) + A_{CP}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) = 0$

$$A_{CP}(\Lambda_c^+ \to p\pi^+\pi^-) + A_{CP}(\Xi_c^+ \to \Sigma^+K^+K^-) = 0$$

- Using sample of $e^+e^- \to c\bar{c} \to (\Lambda_c^+ \to f) + X$, raw asymmetry:

$$A_{raw} = \frac{N_{obs}(\Lambda_c^+ \to f) - N_{obs}\left(\overline{\Lambda}_c^- \to \bar{f}\right)}{N_{obs}(\Lambda_c^+ \to f) - N_{obs}\left(\overline{\Lambda}_c^- \to \bar{f}\right)} = A_{FB}^{\Lambda_c^+} + A_{CP}(\Lambda_c^+ \to f) + A_{\varepsilon}^{f}$$

- **Control samples**: to remove the common A_{ε}^{f}:
  - $\Xi_c^+ \to \Sigma^+h^+h^-$: $\Lambda_c^+ \to \Sigma^+h^+h^-$
  - $\Lambda_c^+ \to ph^+h^-$: $\Lambda_c^+ \to p\pi^+K^-, D^0 \to K^-\pi^+\pi^+\pi^-$ (not $D^0 \to K^-\pi^+$ due to kinematic region)

[1] A. Raij et al. (LHCb Collaboration) JHEP 03 (2018) 182. [2] Y. Grossman and S. Schacht, PRD 99 (2019) 033005; [3] D. Wang, EPJC 79 (2019) 429.

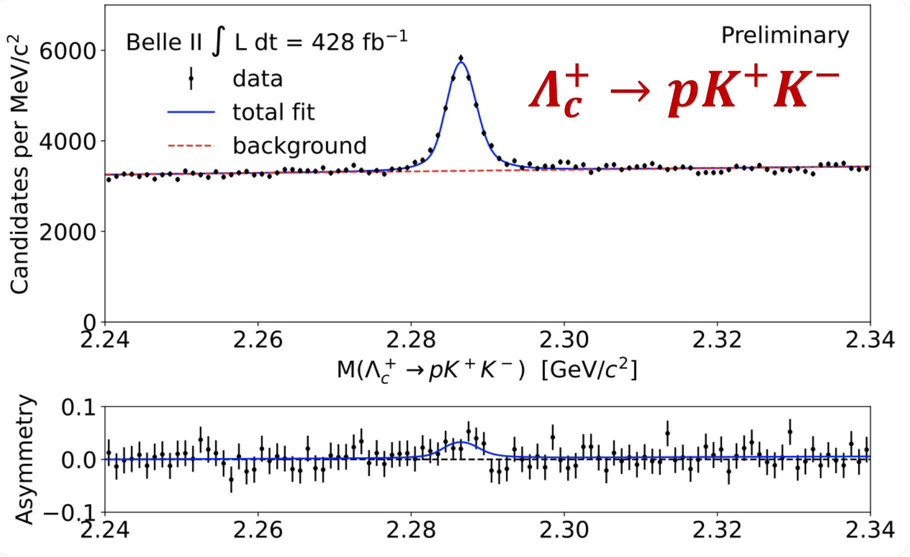
$A_{CP}(\Lambda_c^+ \to p h^+ h^-, \Xi_c^+ \to \Sigma^+ h^+ h^-)$

PRD 113, 032017 (2026)

- Belle II (428/fb) result:

$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) = (3.7 \pm 6.6 \pm 0.6)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) = (9.5 \pm 6.8 \pm 0.5)\%,$$
$$A_{CP}(\Lambda_c^+ \to p K^+ K^-) = (3.9 \pm 1.7 \pm 0.7)\%,$$
$$A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-) = (0.3 \pm 1.0 \pm 0.2)\%,$$

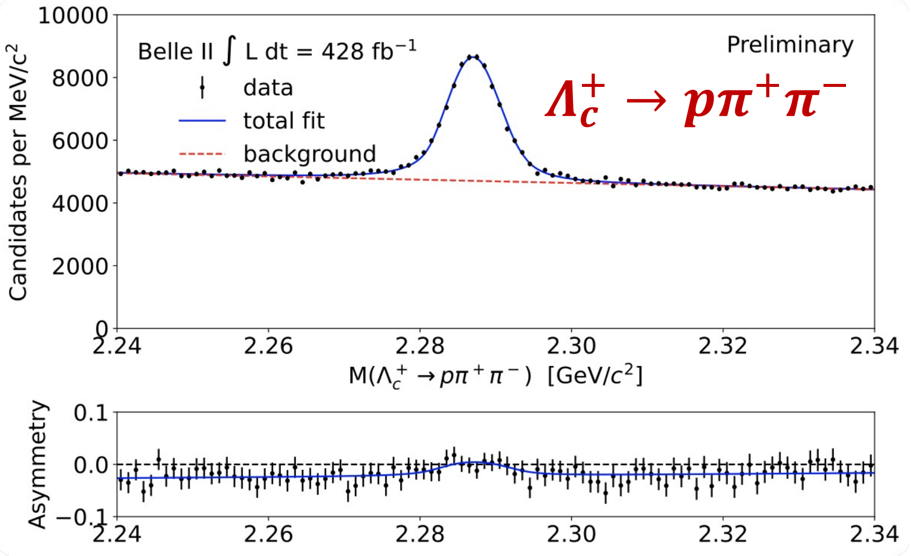
first A_{CP} for 3-body SCS decays of charmed baryons



- Testing U-spin sum rules:

$$A_{CP}(\Xi_c^+ \to \Sigma^+ \pi^+ \pi^-) + A_{CP}(\Lambda_c^+ \to p K^+ K^-)$$
$$= (13.4 \pm 7.0 \pm 0.9)\%,$$
$$A_{CP}(\Xi_c^+ \to \Sigma^+ K^+ K^-) + A_{CP}(\Lambda_c^+ \to p \pi^+ \pi^-)$$
$$= (\ 4.0 \pm 6.6 \pm 0.7)\%,$$

σ_{stat} dominated; at few percent level;
→ more data desired.



总结和展望

- Belle实验对粲物理的研究具有巨大潜力，尤其对于末态包含中性粒子或不可见粒子的衰变过程。性能显著提升的探测器+更先进的软件/方法也提供重要保障。

- 基于428/fb数据，近期取得了最新的成果：
  - 辐射衰变&稀有衰变： $D_{s0}(2317)^+ \to D_s^{*+}\gamma, D^+ \to \pi^+ e^+ e^-$
  - 粲重子非轻衰变： $\Lambda_c^+ \to \Lambda K^+(\pi^0,\eta), \Xi_c^0 \to \Lambda(\pi^0,\eta,\eta')$ ......
  - 粲强子CP破坏： $D^0 \to K_S^0 K_S^0;\ D_{(s)}^+ \to \eta h^+; \Lambda_c^+ \to p h^+ h^-, \Xi_c^+ \to \Sigma^+ h^+ h^-$ ...

- Belle II进入ab^{-1}时。基于B+B2（2ab^{-1}）数据正开展丰富的粲物理研究工作。
  - 更多粲强子辐射衰变、非轻衰变的精确测量；粲CP破坏。
  - 以及 PWA $\Xi_c^+ \to \Xi^-\pi^+\pi^+, \Lambda_c^+ \to \Lambda\pi^+\pi^0, \Lambda_c^+ \to \Sigma^+\pi^+\pi^-$； ···

- 快马加鞭，未来可期。

谢谢您的聆听！

Back up

54th B2GM
2026.07.05@Vienna

CP破坏的测量@Belle II

物理量

$$A_{CP}(D\to f)=\frac{\Gamma(D\to f)-\Gamma(\bar{D}\to f)}{\Gamma(D\to f)+\Gamma(\bar{D}\to f)}$$

实验观测量

$$A_{raw}(D\to f)=\frac{N_{obs}(D\to f)-N_{obs}(\bar{D}\to f)}{N_{obs}(D\to f)+N_{obs}(\bar{D}\to f)}$$

- 例如：$e^+e^-\to c\bar{c}\to D^{*+}+\text{anything}$, 此单举过程中$D^{*+}\to[D^0\to f]\pi_s^+$味标记样本。
- 实验观测到信号数: $N_{\text{obs}}(D^{*+})=N_{prod}(D^{*+})\cdot B(D^{*+}\to D^0\pi_s^+)\cdot B(D^0\to f)\cdot\varepsilon_{det}$

$$N_{\text{obs}}(D^{*-})=N_{prod}(D^{*-})\cdot B(D^{*-}\to\bar{D}^0\pi_s^-)\cdot B(\bar{D}^0\to\bar{f})\cdot\bar{\varepsilon}_{det}$$

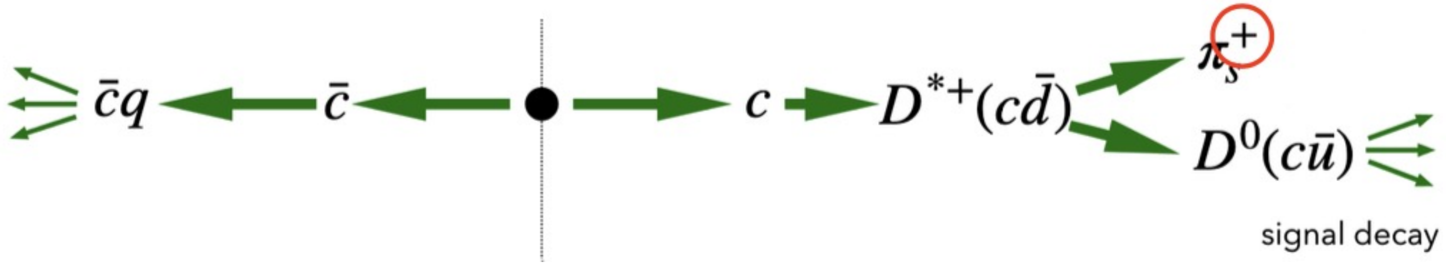
$$A_{\text{raw}}=\frac{N_{\text{obs}}(D^{*+})-N_{\text{obs}}(D^{*-})}{N_{\text{obs}}(D^{*+})+N_{\text{obs}}(D^{*-})}\approx A_{\text{prod}}^{D^{*+}}+A_{CP}^{D^{*+}\to D^0\pi_s^+}+A_{CP}^{D^0\to f}+A_\varepsilon^{\pi_s}+A_\varepsilon^{f}$$

- $A_{\text{prod}}^{D^{*+}}$: 是$\cos\theta^*$的奇函数。$A_{CP}^{D^{*+}\to D^0\pi_s^+}=0$（强衰变）；
- $A_{CP}^{D^0\to f}$: 所关心的 $D^0\to f$ 衰变CP破坏。
- $A_\varepsilon^{\pi_s,f}$: 末态粒子的探测不对称性；其值依赖动量和极角分布。利用控制样本可获得：

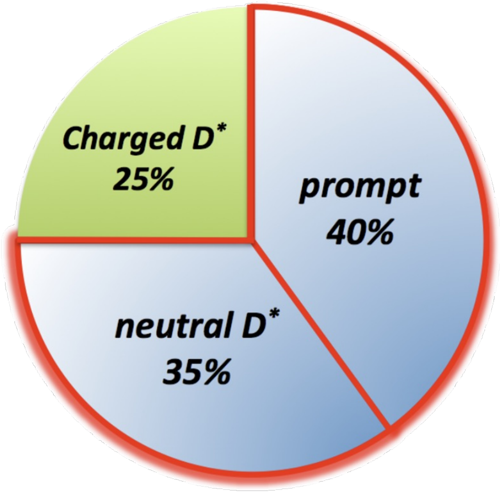
$$\mathcal{A}_{\text{raw}}^{\text{tagged}}\simeq\mathcal{A}_{\text{prod}}+\mathcal{A}_\varepsilon^{K\pi}+\mathcal{A}_\varepsilon^{\pi_{\text{tag}}}$$
$$\mathcal{A}_{\text{raw}}^{\text{untagged}}\simeq\mathcal{A}_{\text{prod}}+\mathcal{A}_\varepsilon^{K\pi},$$

charm flavor tagging for D^0

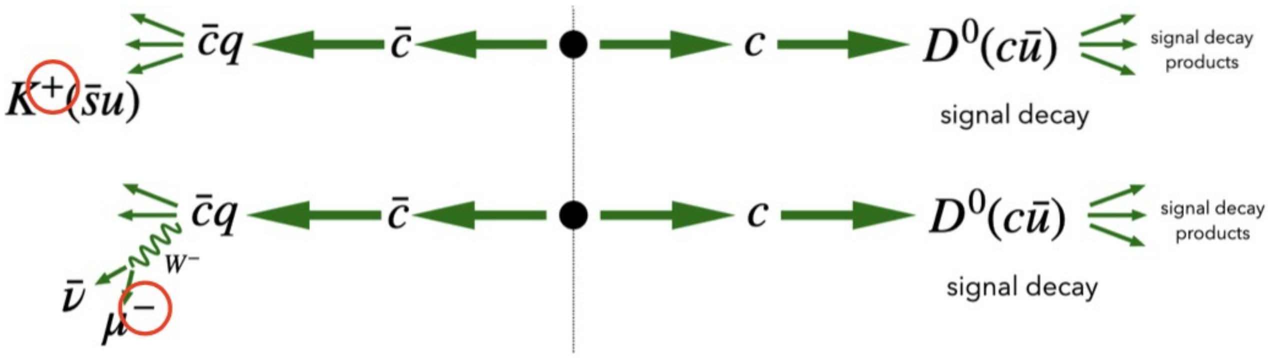
1) using $D^{*+} \to D^0\pi^+$ to tag the D flavor：



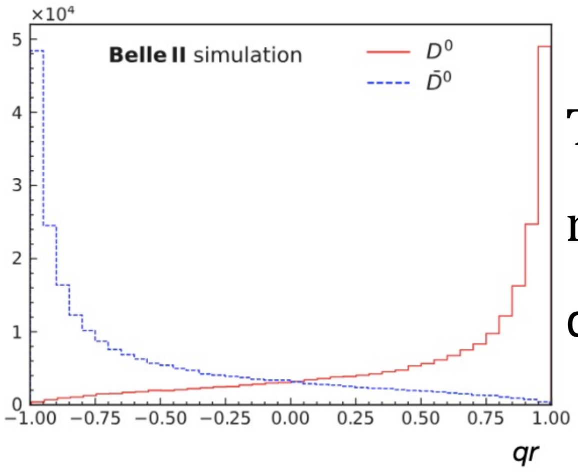
D^0 sources



2) opposite-side flavor tagging for $e^+e^- \to c\bar{c}$:



PRD 107, 112010 (2023)



This charm flag tag (CFT) method: adding ~50% more data to D*-tag sample.

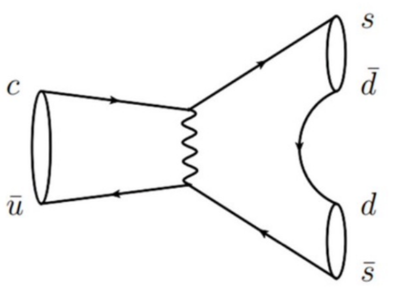
Charm CPV: $A_{CP}(D^0 \to K_S^0 K_S^0)$

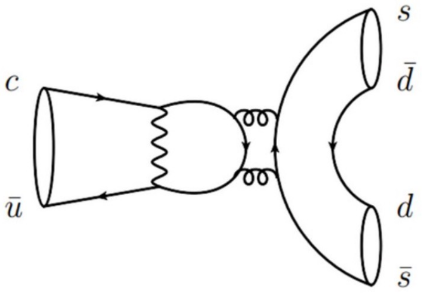
PRD 111, 012015 (2025)

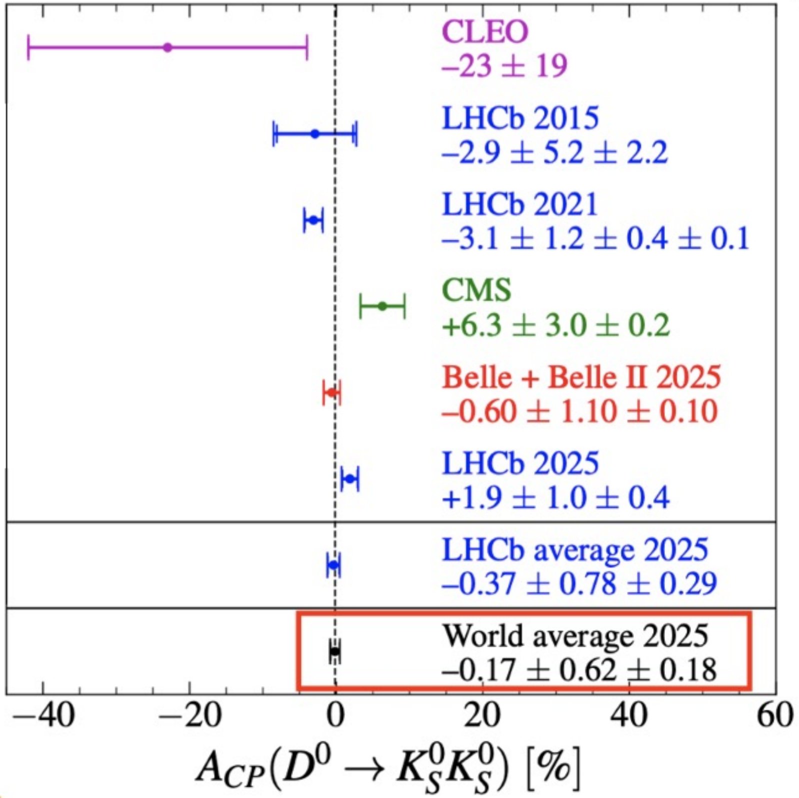
PRD 112, 012017 (2025)

$A_{CP}(D^0 \to K_S^0 K_S^0)$ may be enhanced to 1% level with the SM, by the interference of $c \to us\bar{s}$ and $c \to ds\bar{s}$ amplitudes.

[PRD 99, 113001 (2019), PRD 92, 054036 (2015)]

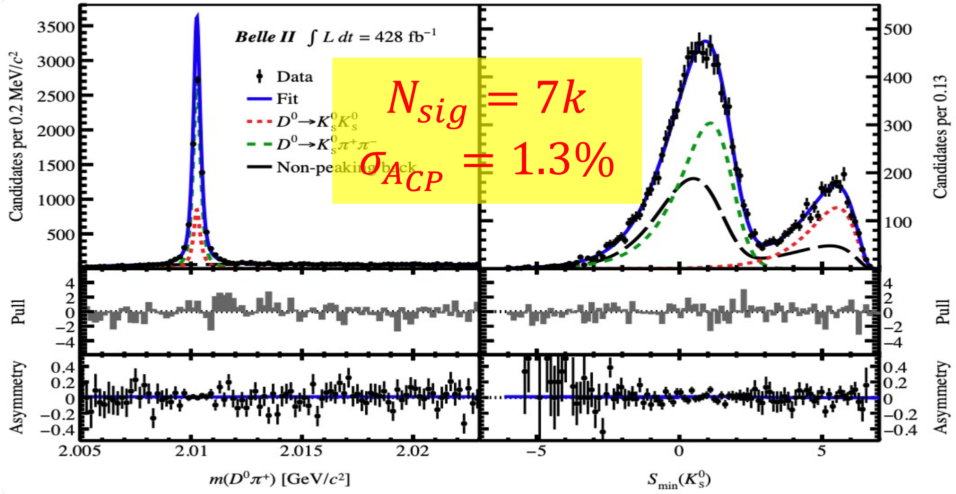






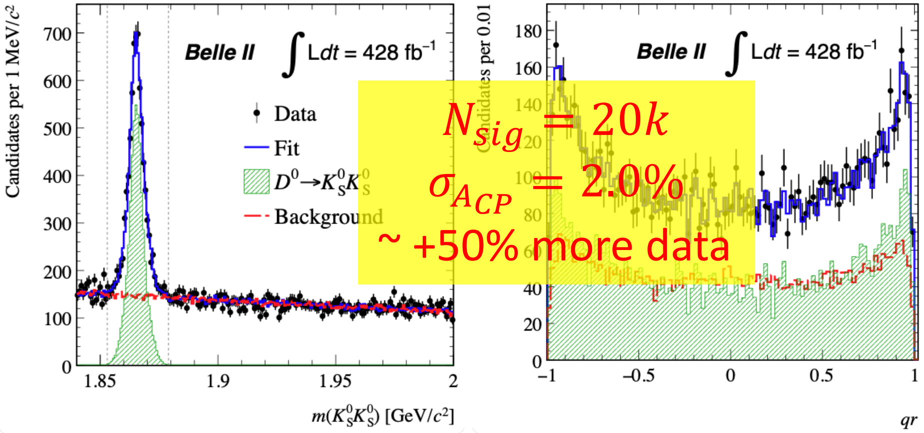
- No hints for CP violation!
- All experiments: σ_{stat} dominated

1) using $D^{*+} \to D^0\pi^+$ to tag the D flavor



2) using opposite-side flavor tagging for $e^+e^- \to c\bar{c}$

[PRD 107, 112010 (2023)] For more details, see backup.

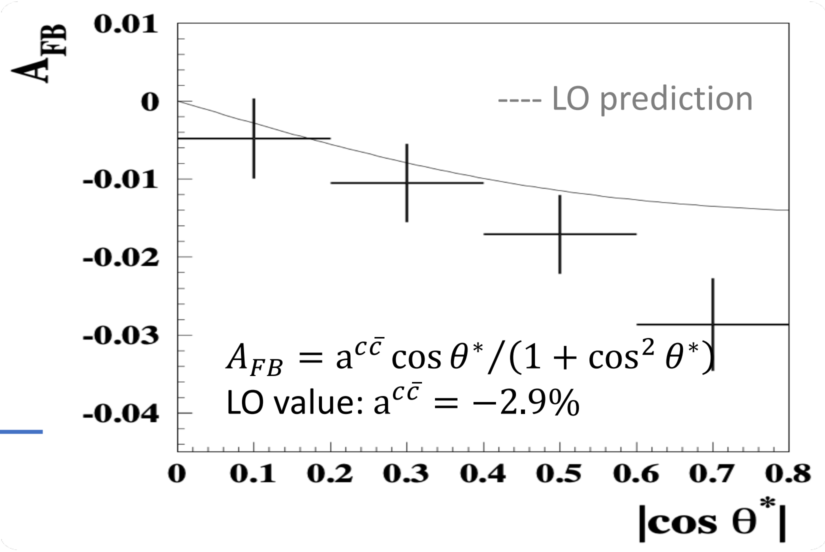


CP asymmetry using inclusive sample

- Using inclusive sample of $e^+e^- \to (\Lambda_c^+ \to f) + X$ (with total product yield $N_{\text{prod}}^{\Lambda_c^+}$), we have :
  - observed yields: $N_{obs}(\Lambda_c^+ \to f) = N_{\text{prod}}^{\Lambda_c^+} \cdot B(\Lambda_c^+ \to f) \cdot \varepsilon_{det}^{f}$
    $N_{obs}(\bar{\Lambda}_c^- \to \bar{f}) = N_{\text{prod}}^{\bar{\Lambda}_c^-} \cdot B(\bar{\Lambda}_c^- \to \bar{f}) \cdot \varepsilon_{det}^{\bar{f}}$
  - raw asymmetry: $A_{raw} = \frac{N_{obs}(\Lambda_c^+ \to f) - N_{obs}(\bar{\Lambda}_c^- \to \bar{f})}{N_{obs}(\Lambda_c^+ \to f) - N_{obs}(\bar{\Lambda}_c^- \to \bar{f})} = A_{FB}^{\Lambda_c^+} + A_{CP}(\Lambda_c^+ \to f) + A_{\varepsilon}^{p}$ (if asymmetries <<1)

- For e^+e^- collision, phase-space integrated product asymmetry $A_{FB}^{\Lambda_c^+} = 0$, but a function of $\cos\theta^*$ in e^+e^- CMS, which is induced by (1) interference by γ^* or Z^0 contributes at the percent level [4]; (2) higher-order QED effects to peak sharply in the forward and backward directions [5]. Following from CP conservation in the production, the FB asymmetry must be an anti-symmetric function of $\cos\theta^*$, i.e. $A_{FB}(\cos\theta^*) = -A_{FB}(-\cos\theta^*)$

A_{FB} in $D^0 \to K^+K^-.\pi^+\pi^+$ [6]



[1] (LHCb) JHEP 03 (2018) 182.
[2] Y. Grossman and S. Schacht, PRD 99 (2019) 033005;
[3] D. Wang, EPJC 79 (2019) 429.
[4] R.J. Cashmore et al. Z. Phys. C 30 (1986) 125.
[5] (BaBar) PRL 100, 061803 (2008)
[6] (Belle) PLB 670 (2008) 190-195.