Recent Charm Results at Belle

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Charm results achieved at Belle since CHARM2018.

BF and A_{CP} in $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$	preliminary result (to be submitted)
Search for $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+(\overline{K}\Xi)^-$	preliminary result (to be submitted)
BF and asymmetry parameters for $\Xi_c^0 \to (\Lambda, \Sigma^0)\overline{K}^{*0}$, and Σ^+K^{*-}	arXiv:2104.10361 [hep-ex], accepted by JHEP
BF and A_{CP} for $D_s^+ \to K^+\pi^0/\eta$ and $\pi^+\pi^0/\eta$	arXiv:2103.09969 [hep-ex], accepted by PRD
BF of $\Xi_c^0 \to \Xi^-\ell^+\nu_\ell$ and asymmetry parameter $\alpha(\Xi_c^0 \to \Xi^-\pi^+)$	arXiv:2103.06496 [hep-ex]
Amplitude analysis for $\Xi_c^0 \to \Xi^0 K^+K^-$	arXiv:2012.05607 [hep-ex], accepted by PRD
Determine spin-parity of $\Xi_c(2970)^+$	arXiv:2007.14700 [hep-ex], accepted by PRD
BF of $\Lambda_c^+ \to p\pi^0$ and $p\eta$	PRD 103, 072004 (2021)
BF of $\Lambda_c^+ \to \Lambda\eta\pi^+$, $\Sigma^0\eta\pi^+$, $\Lambda(1670)\pi^+$, and $\eta\Sigma(1385)$	PRD 103, 052005 (2021)
Search for $\Xi_c(2815, 2790)^{0,+} \to \Xi_c^{0,+}\gamma$	PRD 102, 071103(R) (2020)
Mixing parameter y_{CP} in $D^0 \to K_S^0\omega$	PRD 102, 071102(R) (2020)
Dalitz-plot analysis of $D^0 \to K^-\pi^+\eta$	PRD 102, 012002 (2020)
Absolute BF for Ξ_c^+ decays	PRD 100, 031101 (2019)
Absolute BF for Ξ_c^0 decays	PRL 122, 082001 (2019)
CP violation in $D^0 \to K^+K^-\pi^+\pi^-$	PRD 99, 011104(R) (2019)

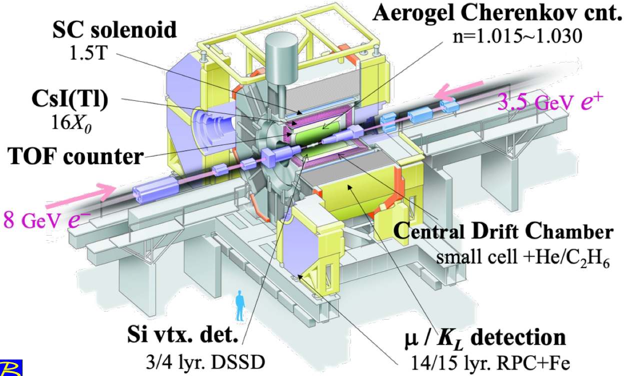
- Fruitful Charm results are lasting to produce, although the accumulation of final data set finished >10 years ago.
- Because of the time limit for this talk, I will select some recent results and present them here.

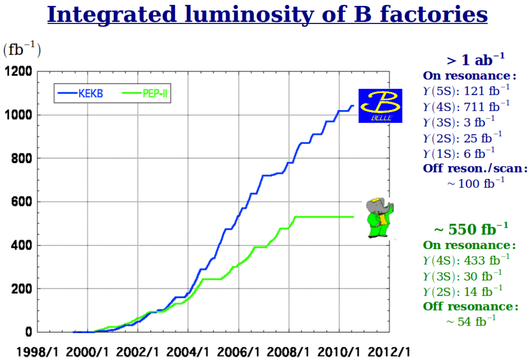
Outline

Outline

Belle experiment at KEKB

- KEKB is an asymmetric-energy e^+e^- collider operating near $\Upsilon(4S)$ mass peak (~ 10.58 GeV$/c^2$, $> B\bar{B}$ threshold).
- Belle detector has good performances on momentum/vertex resolution; particle identification, etc.
- Accumulated data set of ~ 1 ab^{-1}: not only including a large $B\bar{B}$ sample as a B-factory; but also providing us a large charm sample to study charm physics.



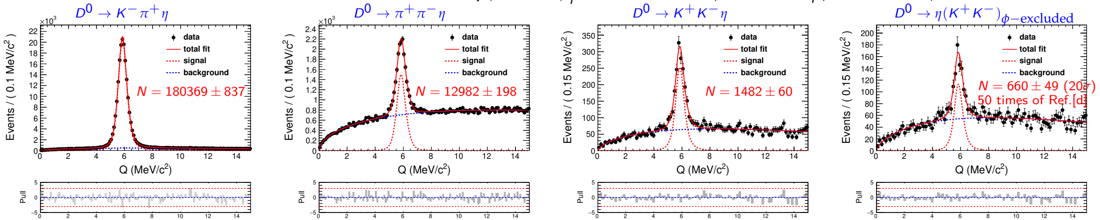


> 10 years ago

Outline

Branching fractions and CP asymmetries for $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$ Preliminary result

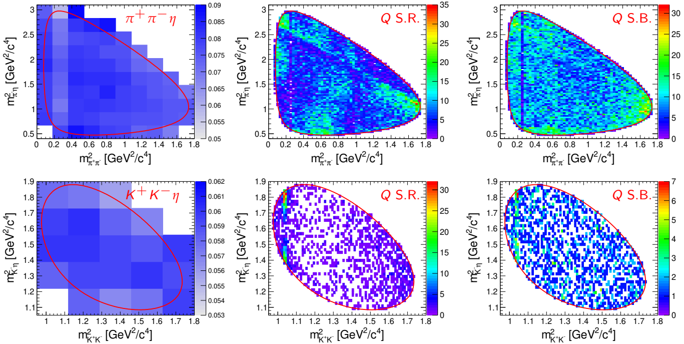
- The first and only observation of charm CP violation is achieved at LHCb: $\Delta A_{CP}(D^0 \to K^+K^-, D^0 \to \pi^+\pi^-)$[a].
- Here we extend these singly Cabibbo-suppressed (SCS) decays with an additional η meson in the final state, to measure their time-integrated CP asymmetries and branching fractions ($\mathcal{B}$).
  - For $D^0 \to \pi^+\pi^-\eta$: $\delta\mathcal{B}/\mathcal{B} \sim 6\%$[b, c]; $A_{CP} = (-9.6 \pm 5.7)\%$[c].
  - For $D^0 \to K^+K^-\eta$: no total $\mathcal{B}$ result; $\delta\mathcal{B}/\mathcal{B}(D^0 \to \eta(K^+K^-)_{\text{non}-\phi}) \sim 35\%$[d]; $\delta\mathcal{B}/\mathcal{B}(D^0 \to \phi\eta) \sim 20\%$[e, f].
  - Reference Cabibbo-favored (CF) mode $D^0 \to K^-\pi^+\eta$ is well-measured with $\delta\mathcal{B}/\mathcal{B} \sim 2\%$[g, d] and Dalitz-plot analysis result[g].
- Based on 980 fb^{-1} data set, we fit the distributions of $Q = M(h^+h^-\eta\pi_s) - M(h^+h^-\eta) - m(\pi_s)$, to extract the signal yields for these decay channels and also for $D^0 \to \eta(K^+K^-)_{\phi-\text{excluded}}$ with $|M_{KK} - m_\phi| > 20$ MeV$/c^2$.



[a]LHCb, Phys. Rev. Lett. **122**, 211803 (2019)
[b]CLEO, Phys. Rev. D **77**, 002003 (2008)
[c]BESIII, Phys. Rev. D **101**, 052009 (2020)
[d]BESIII, Phys. Rev. Lett. **124**, 241803 (2020)
[e]Belle, Phys. Rev. Lett. **92**, 101803 (2004)
[f]BESIII, Phys. Lett. B **798**, 134017 (2019)
[g]Belle, Phys. Rev. D **102**, 012002 (2020)

Branching fractions and CP asymmetries for $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$ Preliminary result

- The efficiency-corrected yield on Dalitz-plot: $N^{\rm cor} = \sum_i \frac{N_i^{\rm tot} - N^{\rm bkg} f_i^{\rm bkg}}{\varepsilon_i}$ to consider bin-to-bin variations of ε, where ε_i is the efficiency in the $i^{\rm th}$-bin based on PHSP signal MC; $N^{\rm tot}$ is yield in Q signal region; and $N^{\rm bkg}$ is the fitted background yield in Q signal region; $f_i^{\rm bkg}$ is the fraction of background in the $i^{\rm th}$-bin, with $\sum_i f_i = 1$, obtaining from the Dalitz-plot in Q sideband.



S.R. = signal region;
S.B. = sideband region

A very clear $\phi(1020)$ structure

Then we have $\frac{\mathcal{B}(D^0\to h^+h^-\eta)}{\mathcal{B}(D^0\to K^-\pi^+\eta)} = \frac{N^{\rm cor}(D^0\to h^+h^-\eta)}{N^{\rm cor}(D^0\to K^-\pi^+\eta)}$

$$\frac{\mathcal{B}(D^0\to\pi^+\pi^-\eta)}{\mathcal{B}(D^0\to K^-\pi^+\eta)} = [6.49 \pm 0.09\,({\rm stat}) \pm 0.12\,({\rm syst})] \times 10^{-2}$$

$$\frac{\mathcal{B}(D^0\to K^+K^-\eta)}{\mathcal{B}(D^0\to K^-\pi^+\eta)} = [9.57^{+0.36}_{-0.33}\,({\rm stat}) \pm 0.20\,({\rm syst})] \times 10^{-3}$$

$$\frac{\mathcal{B}(D^0\to K^+K^-\eta)_{\rm ex.-\phi}}{\mathcal{B}(D^0\to K^-\pi^+\eta)} = [5.26^{+0.45}_{-0.38}\,({\rm stat}) \pm 0.11\,({\rm syst})] \times 10^{-3}$$

Using $\mathcal{B}(D^0 \to K^-\pi^+\eta) = (1.877 \pm 0.036)\%$[g,d], we have the absolute branching fractions of $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\eta(K^+K^-)_{\rm ex.-\phi}$, respectively:

$[1.22 \pm 0.02\,({\rm stat}) \pm 0.02\,({\rm syst}) \pm 0.02\,(\mathcal{B}_{\rm ref})] \times 10^{-3}$

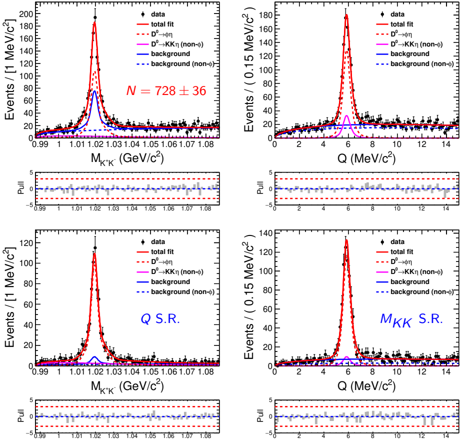
$[1.80^{+0.07}_{-0.06}\,({\rm stat}) \pm 0.04\,({\rm syst}) \pm 0.03\,(\mathcal{B}_{\rm ref})] \times 10^{-4}$

$[0.99^{+0.08}_{-0.07}\,({\rm stat}) \pm 0.02\,({\rm syst}) \pm 0.02\,(\mathcal{B}_{\rm ref})] \times 10^{-4}$.

the last one is somewhat higher (but more precise) than a similar measurement by BESIII[d] $(0.59 \pm 0.19) \times 10^{-4}$.

Branching fractions and CP asymmetries for $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$ Preliminary result

- To extract the yield of this SCS and color-suppressed decay $D^0 \to \phi\eta$, we perform M_{KK}-Q 2D fit instead of Q 1D fit, considering there is a Q-peaking background from non-ϕ $D^0 \to K^+K^-\eta$ component.



- The likelihood difference with and without including signal component $\Delta \ln \mathcal{L} = 464.8$ corresponds to a very high statistical significance (31σ) $\Rightarrow$ First observation.
- Based on $N_{sig} = 600 \pm 29$ and $\varepsilon = (5.262 \pm 0.021)\%$ in signal region, the relative branching fraction is determined.
$$\frac{\mathcal{B}(D^0\to\phi\eta,\phi\to K^+K^-)}{\mathcal{B}(D^0\to K^-\pi^+\eta)} = [4.82 \pm 0.23\,(\text{stat}) \pm 0.16\,(\text{syst})] \times 10^{-3}.$$
- using $\mathcal{B}(D^0 \to K^-\pi^+\eta)$[g,d] and $\mathcal{B}_{\rm PDG}(\phi \to K^+K^-)$, we have
$$\mathcal{B}(D^0 \to \phi\eta) = [1.84 \pm 0.09\,(\text{stat}) \pm 0.06\,(\text{syst}) \pm 0.04\,(\mathcal{B}_{\rm ref})] \times 10^{-4},$$
which is consistent, but notably more precise than, previous results at Belle[e] and BESIII[f].
- As a consistency check, we calculate $\mathcal{B}(D^0 \to K^+K^-\eta)_{\text{non}-\phi}$ by $\mathcal{B}(D^0 \to K^+K^-\eta) - \mathcal{B}(D^0 \to \phi\eta, \phi \to K^+K^-) = (0.90 \pm 0.08) \times 10^{-4}$ which is very close to our measurement of $\mathcal{B}(D^0 \to K^+K^-\eta)_{\text{ex.}-\phi}$.

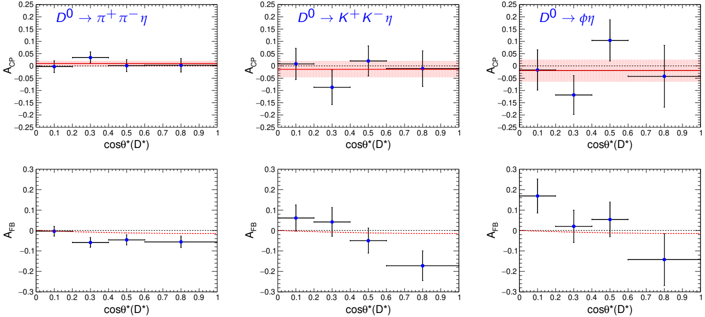
Branching fractions and CP asymmetries for $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$ Preliminary result

Introduction to time-integrated CP asymmetry

- Time-integrated CP asymmetry for $D \to f$ decays: $A_{CP} = \frac{\mathcal{B}(D\to f)-\mathcal{B}(\bar{D}\to\bar{f})}{\mathcal{B}(D\to f)+\mathcal{B}(\bar{D}\to\bar{f})}$
- Taking D^0 decays for example, for the decay chain $e^+e^- \to c\bar{c} \to D^{*+}X$, $D^{*+} \to [D^0 \to f]\pi_s^+$, the raw asymmetry:
$$A_{\rm raw} = \frac{N_{\rm rec}(D^{*+}) - N_{\rm rec}(D^{*-})}{N_{\rm rec}(D^{*+}) + N_{\rm rec}(D^{*-})} = A_{\rm FB}^{D^{*+}} + A_{CP}^{D^0\to f} + A_{\varepsilon}^{f} + A_{\varepsilon}^{\pi_s},$$
where forward-backward asymmetry $A_{\rm FB}$ is arising from γ-Z^0 interference and higher-order QED effects.
- Method (1): reference mode (CF or A_{CP} well-measured mode) to cancel same asymmetry sources, e.g. $\Delta A_{CP} = A_{CP}(D_s^+ \to \pi^0\pi^+) - A_{CP}(D_s^+ \to \phi\pi^+)$ where the latter one is well-measured.
- Method (2): correction method for the charged track detection asymmetry. e.g. in our decays, we weight events to correct the slow pion asymmetry: $w_{D^0,\bar{D}^0} = 1 \mp A_{\varepsilon}^{\pi_s}[\cos\theta(\pi_s), p_T(\pi_s)]$
- In our decay ($A_{\varepsilon}^{f} = 0$), our weighted samples have the corrected raw asymmetry: $\boxed{A_{\rm corr} = A_{CP} + A_{\rm FB}(\cos\theta^*)}$.
- Since A_{CP} is independent on any kinematic variable and $A_{\rm FB}(\cos\theta^*) = -A_{\rm FB}(-\cos\theta^*)$, we determine the asymmetries in multiple symmetric bins of $\cos\theta^*$:
$$A_{CP}(\cos\theta^*) = \frac{A_{\rm corr}(\cos\theta^*) + A_{\rm corr}(-\cos\theta^*)}{2}, \qquad A_{\rm FB}(\cos\theta^*) = \frac{A_{\rm corr}(\cos\theta^*) - A_{\rm corr}(-\cos\theta^*)}{2}.$$
Finally, fitting these A_{CP} values to a constant gives the final measurement of $A_{CP}^{D^0\to f}$ that we are interested in.

Branching fractions and CP asymmetries for $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$ Preliminary result

- To correct for an asymmetry in $\pi_s^\pm$ reconstruction efficiencies, we weight events according to $A_\varepsilon^{\pi_s}(\cos\theta,\, p_T)$-map. Then the weighted samples are divided into eight bins of $\cos\theta^*$.
- We perform a simultaneous fit on the Q or M_{KK}-Q distributions for D^0 and $\bar{D}^0$ samples in each $\cos\theta^*$ bin, to extract the corrected raw asymmetry $A_{\rm corr}$: $N_{\rm sig}(D^0, \bar{D}^0) = N_{\rm sig}/2 \cdot (1 \pm A_{\rm corr})$.
- Then, using the formula in previous slide, we calculate four A_{CP} values and four $A_{\rm FB}$ values, as plotted in below figures.



Fitting these A_{CP} values to a constant gives:

$$A_{CP}(D^0 \to \pi^+\pi^-\eta) = [0.9 \pm 1.2\,(\text{stat}) \pm 0.5\,(\text{syst})]\%,$$
$$A_{CP}(D^0 \to K^+K^-\eta) = [-1.4 \pm 3.3\,(\text{stat}) \pm 1.1\,(\text{syst})]\%,$$
$$A_{CP}(D^0 \to \phi\eta) = [-1.9 \pm 4.4\,(\text{stat}) \pm 0.6\,(\text{syst})]\%,$$

where the first result represents a significant improvement in precision over previous result[c]; the later two are the first such measurements.

No evidence for CP violation is found.

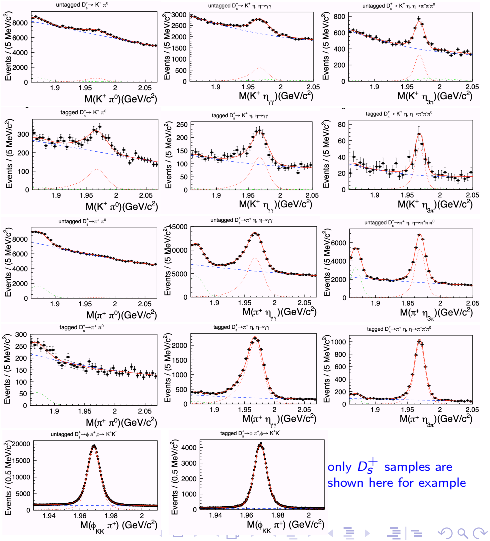
Branching fractions and A_{CP} for $D_s^+ \to K^+(\pi^0,\eta)$ and $\pi^+(\pi^0,\eta)$

arXiv:2103.09969 [hep-ex], accepted by PRD

- We use D_s^{*+}-tagged and untagged $D_s^{\pm}$ samples from 921 fb^{-1} data set, and measure the $\mathcal{B}$'s relative to $D_s^+ \to [\phi \to K^+K^-]\pi^+$.
- To suppress backgrounds, we use a neural network (NN) based on input variables: $p(D_s^+)$, $|dl_{xy}|$ or dr, $\theta_{hel}(h^+)$, $N(K)$, $\theta^{\rm thrust}$, and $\theta(p(D_s^+), \vec{r}_{\rm vtx})$. The NN output is required to be greater than some minimum value, which is determined optimally.
- Simultaneous fit on tagged and untagged samples for $M_{D_s^+}$ distribution to extract signal yield, and $\mathcal{B}_{\rm sig} = N_{\rm sig}/N_{\phi\pi} \cdot \varepsilon_{\phi\pi}/\varepsilon_{\rm sig} \cdot \mathcal{B}_{\phi\pi}$.

Decay mode	ε (%)	Fitted yield	$\mathcal{B}/\mathcal{B}_{\phi\pi^+}$ (%)	$\mathcal{B}$ (10^{-3})
$D_s^+ \to K^+\pi^0$	8.10 ± 0.04	11978 ± 846	$3.28 \pm 0.23 \pm 0.13$	$0.735 \pm 0.052 \pm 0.030 \pm 0.026$
$D_s^+ \to K^+\eta_{\gamma\gamma}$	7.42 ± 0.05	10716 ± 429	$8.04 \pm 0.32 \pm 0.35$	$1.80 \pm 0.07 \pm 0.08 \pm 0.06$
$D_s^+ \to K^+\eta_{3\pi}$	4.04 ± 0.02	3175 ± 121	$7.62 \pm 0.29 \pm 0.33$	$1.71 \pm 0.07 \pm 0.08 \pm 0.06$
$D_s^+ \to K^+\eta$	–	–	$7.81 \pm 0.22 \pm 0.24$	$1.75 \pm 0.05 \pm 0.05 \pm 0.06$
$D_s^+ \to \pi^+\pi^0$	6.63 ± 0.04	491 ± 734	$0.16 \pm 0.25 \pm 0.09$	$0.037 \pm 0.055 \pm 0.021 \pm 0.001$
$D_s^+ \to \pi^+\eta_{\gamma\gamma}$	10.84 ± 0.02	166696 ± 1173	$85.54 \pm 0.64 \pm 3.32$	$19.16 \pm 0.14 \pm 0.74 \pm 0.68$
$D_s^+ \to \pi^+\eta_{3\pi}$	6.50 ± 0.03	56132 ± 407	$83.55 \pm 0.64 \pm 4.37$	$18.72 \pm 0.14 \pm 0.98 \pm 0.67$
$D_s^+ \to \pi^+\eta$	–	–	$84.80 \pm 0.47 \pm 2.64$	$19.00 \pm 0.10 \pm 0.59 \pm 0.68$
$D_s^+ \to \phi\pi^+$	22.05 ± 0.13	1005688 ± 2527	1	–

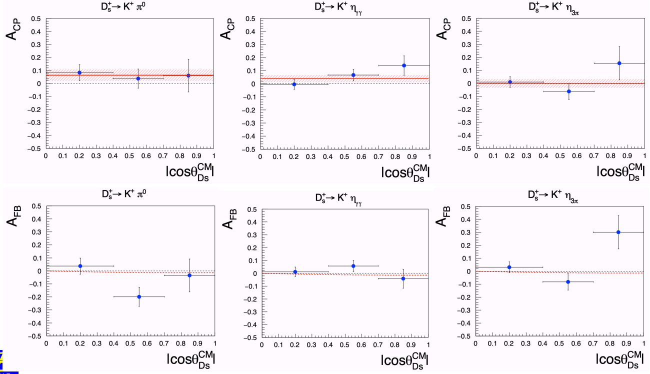
- No significant signal for $D_s^+ \to \pi^+\pi^0$ is observed, thus, an upper limit is set: $\mathcal{B}(D_s^+ \to \pi^+\pi^0) < 1.2 \times 10^{-4}$ at 90% C.L., which is the most stringent constraint to date.



only D_s^+ samples are shown here for example

Branching fractions and A_{CP} for $D_s^+ \to K^+(\pi^0,\eta)$ and $\pi^+(\pi^0,\eta)$ arXiv:2103.09969 [hep-ex], accepted by PRD

- Simultaneous fit on four $M(D_s^+)$ distributions from D_s^+ and D_s^- tagged and untagged samples to extract the raw asymmetry $A_{\rm raw}$.
- For $D_s^+ \to \pi^+\eta$, we use reference mode $D^0 \to \phi\pi$ which is well-measured: $A_{CP}^{\phi\pi} = -0.0038 \pm 0.0026 \pm 0.0008$ from PDG: $\Delta A_{\rm raw} = A_{\rm raw}^{\pi\eta} - A_{\rm raw}^{\phi\pi} = A_{CP}^{\pi\eta} - A_{CP}^{\phi\pi} \Rightarrow \boxed{A_{CP}^{\pi\eta} = \Delta A_{\rm raw} + A_{CP}^{\phi\pi}}$.
- For $D_s^+ \to K^+(\pi^0,\eta)$, we firstly perform simultaneous fit for six bins of $\cos\theta^*$, individually, to obtain $A_{\rm raw}$; and add a correction for K^+ asymmetry with $A_\varepsilon^K(\cos\theta, p)$ 2D map. Then, a similar method as previous analysis is used to obtain A_{CP} and $A_{\rm FB}$.



Finally, fitting these A_{CP} values to a constant gives the final measurements of A_{CP}:

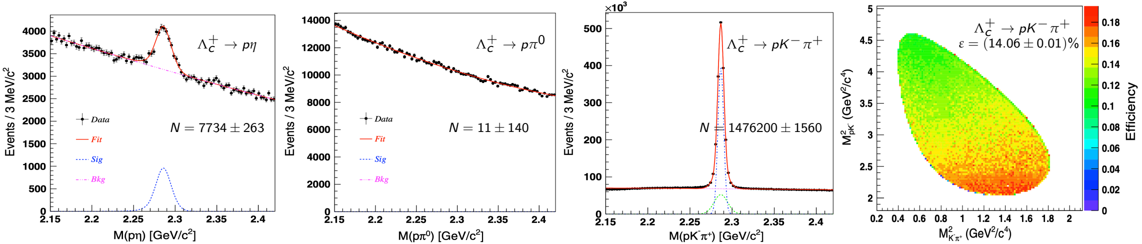
Decay mode	$A_{\rm raw}$	A_{CP}
$D_s^+ \to K^+\pi^0$	0.115 ± 0.045	$0.064 \pm 0.044 \pm 0.011$
$D_s^+ \to K^+\eta_{\gamma\gamma}$	0.046 ± 0.027	$0.040 \pm 0.027 \pm 0.005$
$D_s^+ \to K^+\eta_{3\pi}$	-0.011 ± 0.033	$-0.008 \pm 0.034 \pm 0.008$
$D_s^+ \to K^+\eta$	–	$0.021 \pm 0.021 \pm 0.004$
$D_s^+ \to \pi^+\eta_{\gamma\gamma}$	0.007 ± 0.004	$0.002 \pm 0.004 \pm 0.003$
$D_s^+ \to \pi^+\eta_{3\pi}$	0.008 ± 0.006	$0.002 \pm 0.006 \pm 0.003$
$D_s^+ \to \pi^+\eta$	–	$0.002 \pm 0.003 \pm 0.003$
$D_s^+ \to \phi\pi^+$	0.002 ± 0.001	–

These results are the most precise and show no evidence of CP violation. (PS: nearly at same time, LHCb reported A_{CP} results for these decays with competitive precision in arXiv:2103.11058.)

Outline

Branching fractions of SCS decays $\Lambda_c^+ \to p(\pi^0, \eta)$ PRD 103, 072004 (2021)

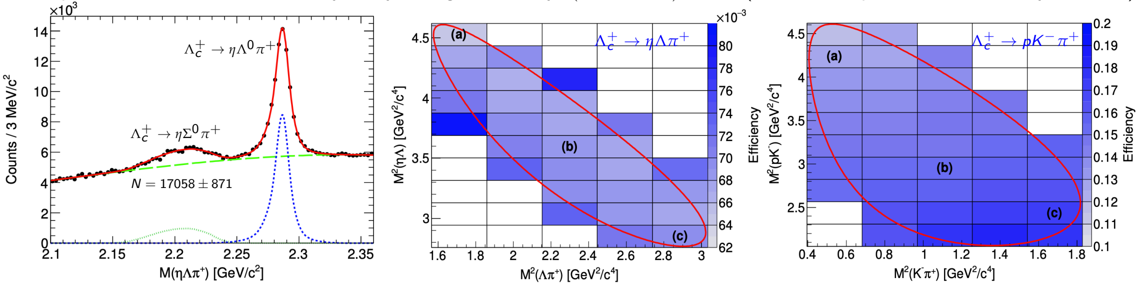
- In theory, SCS decays $\Lambda_c^+ \to p(\pi^0, \eta)$ proceed predominantly through internal W emission and W exchange. The theoretical calculations predict $\mathcal{B}(\Lambda_c^+ \to p\eta)$ to be at least an order of magnitude greater than that of $\Lambda_c^+ \to p\pi^0$.
- BESIII: first evidence (4.2σ): $\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.30) \times 10^{-3}$; and $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$ at 90% C.L.
- Using Belle 980 fb^{-1} data sets, we measure $\frac{\mathcal{B}(SCS)}{\mathcal{B}(CF)} = \frac{N^{obs}(SCS)}{\varepsilon(SCS)\mathcal{B}(\pi^0,\eta\to\gamma\gamma)} / \frac{N^{obs}(CF)}{\varepsilon(CF)}$ with reference CF mode $\Lambda_c^+ \to pK^-\pi^+$.



- We have $\frac{\mathcal{B}(\Lambda_c^+\to p\eta)}{\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)} = [2.258 \pm 0.077(\text{stat}) \pm 0.122(\text{syst})] \times 10^{-2}$, and $\frac{\mathcal{B}(\Lambda_c^+\to p\pi^0)}{\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)} < 1.273 \times 10^{-3}$ at 90% C.L.
- Using W.A. $\mathcal{B}(CF)$, we obtain $\mathcal{B}(\Lambda_c^+ \to p\eta) = [1.42 \pm 0.05(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-3}$, consistent with and more precise than both the latest published results, and consistent with theoretical predictions; $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0 \times 10^{-5}$. Their ratio of these two branching fractions is consistent with the theoretical prediction.

Branching fractions of CF decays $\Lambda_c^+ \to (\Lambda,\Sigma^0)\pi^+\eta$ PRD 103, 052005 (2021)

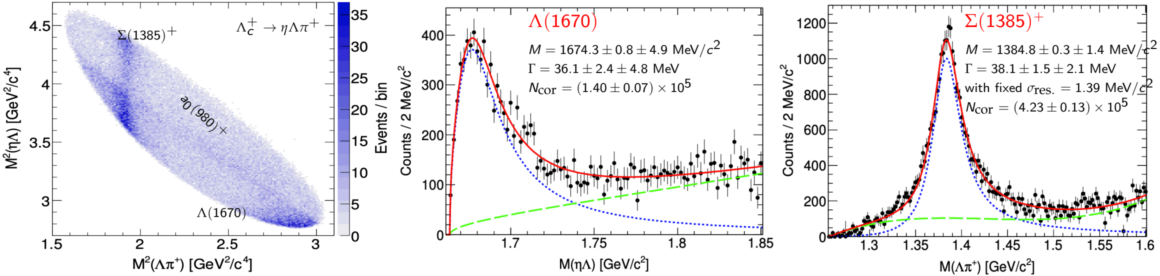
- The $\Lambda_c^+ \to \eta\Lambda\pi^+$ is an ideal mode to study $\Lambda(1670)$ because the isospin is fixed for any combination of two particles in final state.
- Based on 980 fb^{-1} Belle data set, a large sample of $\Lambda_c^+ \to \eta\Lambda\pi^+$ is obtained. Meanwhile, $\Lambda_c^+ \to \eta\Sigma^0\pi^+$ is observed as a feed-down component, which has the corrected yield by averaged efficiency: $(3.05 \pm 0.16) \times 10^5$. (intermediate process is dominant syst. source)



- Both $\Lambda_c^+ \to \eta\Lambda\pi^+$ and $pK^-\pi^+$ have sufficiently large statistics to extract yield in individual bins of Dalitz plots, to consider the bin-to-bin variations of efficiencies. The total yields are $N_{\rm cor}(\eta\Lambda\pi) = (7.41 \pm 0.07) \times 10^5$ and $N_{\rm cor}(pK\pi) = (1.005 \pm 0.001) \times 10^7$.
- We have $\frac{\mathcal{B}(\Lambda_c^+ \to \eta\Lambda\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.293 \pm 0.003 \pm 0.014$ and $\frac{\mathcal{B}(\mathcal{B}(\Lambda_c^+ \to \eta\Sigma^0\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.120 \pm 0.006 \pm 0.010$.
- Finally, $\boxed{\mathcal{B}(\Lambda_c^+ \to \eta\Lambda\pi^+) = (1.84 \pm 0.02 \pm 0.09 \pm 0.09)\%}$ and $\boxed{\mathcal{B}(\Lambda_c^+ \to \eta\Sigma^0\pi^+) = (7.56 \pm 0.39 \pm 0.62 \pm 0.39) \times 10^{-3}}$.

Study of $\Lambda_c^+ \to \Lambda(1670)\pi^+$, $\eta\Sigma(1385)^+$ in $\Lambda_c^+ \to \eta\Lambda\pi^+$

PRD 103, 052005 (2021)



- On Dalitz plot, bands corresponding to $\Lambda_c^+ \to \Lambda(1670)\pi^+/\eta\Sigma(1385)^+$ resonant subchannels are seen, along with $\Lambda_c^+ \to \Lambda a_0(980)^+$.
- For every 2 MeV/c^2 bin of $M_{\eta\Lambda}$ and $M_{\Lambda\pi}$ distributions, Λ_c^+ signal yield is obtained by fitting $M_{\eta\Lambda\pi}$. Then, a relativistic Breit-Wigner (mass-dependent width) is used to describe (S-wave) $\Lambda(1670)$ and (P-wave) $\Sigma(1385)$
- The results are $\frac{\mathcal{B}(\Lambda_c^+ \to [\Lambda(1670) \to \eta\Lambda]\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (5.54 \pm 0.29 \pm 0.73) \times 10^{-2}$ and $\frac{\mathcal{B}(\Lambda_c^+ \to \eta\Sigma(1385)^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.192 \pm 0.006 \pm 0.016$.
- Finally, using W.A. $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$, we have $\boxed{\mathcal{B}(\Lambda_c^+ \to [\Lambda(1670) \to \eta\Lambda]\pi^+) = (3.48 \pm 0.19 \pm 0.46 \pm 0.18) \times 10^{-3}}$, and $\boxed{\mathcal{B}(\Lambda_c^+ \to \eta\Sigma(1385)^+) = (1.21 \pm 0.04 \pm 0.46 \pm 0.10 \pm 0.06)\%}$. (Besides the mass and width of $\Lambda(1670)$ and $\Sigma(1385)^+$ are presented.)

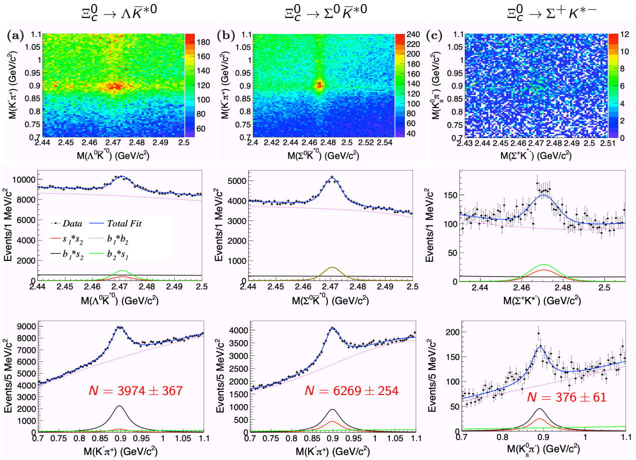
BF and asymmetry parameters for $\Xi_c^0 \to (\Lambda, \Sigma^0)\bar{K}^{*0}$ and $\Sigma^+ K^{*-}$ arXiv:2104.10361 [hep-ex], accepted by JHEP

- BF measurements help to distinguish different theoretical models; the asymmetry parameter α of Ξ_c^0 decays are still not well measured, which is important to test parity violation in charmed baryon sectors.
- We measure BF and α for three CF Ξ_c^0 decays relative to $\Xi_c^0 \to \Xi^- \pi^+$ based on 980 fb^{-1} data sets.
- The signal yields are extracted via $M_{\Xi_c^0}$-M_{K^*} 2D fit. See the figures with achieved signal yields.
- Then we have relative BF after efficiency correction:

$$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = 0.18 \pm 0.02 \pm 0.01$$
$$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = 0.69 \pm 0.03 \pm 0.03$$
$$\mathcal{B}(\Xi_c^0 \to \Sigma^+ K^{*-})/\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = 0.34 \pm 0.06 \pm 0.02$$

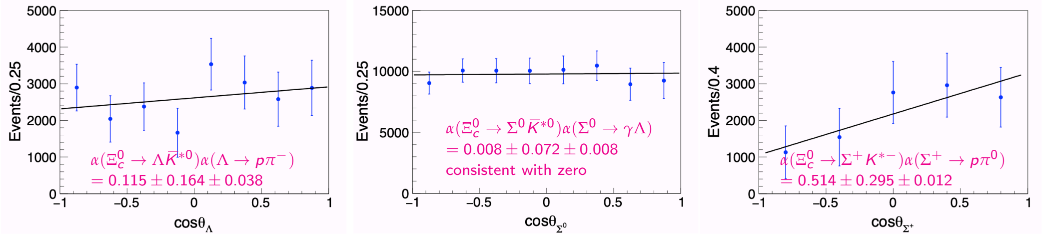
- Finally, using $\mathcal{B}_{\text{PDG}}(\Xi_c^0 \to \Xi^-\pi^+)$, we have absolute BFs below for the first time:

$$\mathcal{B}(\Xi_c^0 \to \Lambda\bar{K}^{*0}) = (3.3 \pm 0.3 \pm 0.2 \pm 1.0(\mathcal{B}_{\text{ref}})) \times 10^{-3}$$
$$\mathcal{B}(\Xi_c^0 \to \Sigma^0\bar{K}^{*0}) = (12.4 \pm 0.5 \pm 0.5 \pm 3.6(\mathcal{B}_{\text{ref}})) \times 10^{-3}$$
$$\mathcal{B}(\Xi_c^0 \to \Sigma^+ K^{*-}) = (6.1 \pm 1.0 \pm 0.4 \pm 1.8(\mathcal{B}_{\text{ref}})) \times 10^{-3}$$



BF and asymmetry parameters for $\Xi_c^0 \to (\Lambda, \Sigma^0)\bar{K}^{*0}$ and $\Sigma^+ K^{*-}$ arXiv:2104.10361 [hep-ex], accepted by JHEP

- Taking $\Xi_c^0 \to \Lambda \bar{K}^{*0}$ for example, the differential decay rate[a] $\frac{dN}{d\cos\theta_\Lambda} \propto 1 + \alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0})\alpha(\Lambda \to p\pi^-)\cos\theta_\Lambda$ where α is the asymmetry parameter, θ_Λ is the helicity angle between the proton momentum and $\bar{K}^{*0}$ momentum in the Λ rest frame.
- This measurement is insensitive to production polarization of Ξ_c^0 in B-factory[b].
- The $\alpha(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})$ can not be measured since $\alpha(\Sigma^0 \to \gamma\Lambda) = 0$ for an electromagnetic decay. So we measure $\alpha(\Xi_c^0 \to \Sigma^0\bar{K}^{*0})\alpha(\Sigma^0 \to \gamma\Lambda)$ just to validate no bias in the measurement.



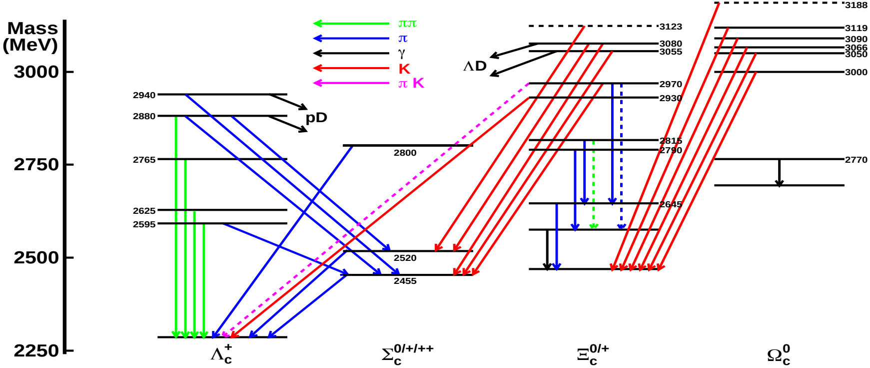
- Using $\alpha_{\rm PDG}(\Lambda \to p\pi^-) = 0.747 \pm 0.010$ and $\alpha_{\rm PDG}(\Sigma^+ \to p\pi^0) = -0.980 \pm 0.017$, we finally have $\alpha(\Xi_c^0 \to \Lambda\bar{K}^{*0}) = 0.15 \pm 0.22 \pm 0.05$ and $\alpha(\Xi_c^0 \to \Sigma^+ K^{*-}) = -0.52 \pm 0.30 \pm 0.02$ for the first time.

[a] Phys. Rev. D **101**, 053002 (2020)
[b] Phys. Rev. D **63**, 111102 (2001)

Outline

Electromagnetic decays of $\Xi_c(2790, 2815)^{0,+} \to \Xi_c^{0,+}\gamma$ PRD 102, 071103(R) (2020)

- Different observed transitions processes of excited charmed baryons referred to HFLAV



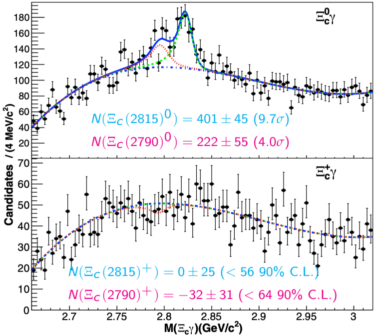
- In general, the decays of excited charmed baryons proceed via strong interactions; the only electromagnetic decays observed so far are $\Xi_c' \to \Xi_c\gamma$ and $\Omega_c(2770) \to \Omega_c\gamma$, since in these two transitions the mass difference is not sufficient for a strong decay.
- Here I present our search for four new electromagnetic decays $\Xi_c(2790, 2815)^{+,0} \to \Xi_c^{+,0}\gamma$ at Belle.

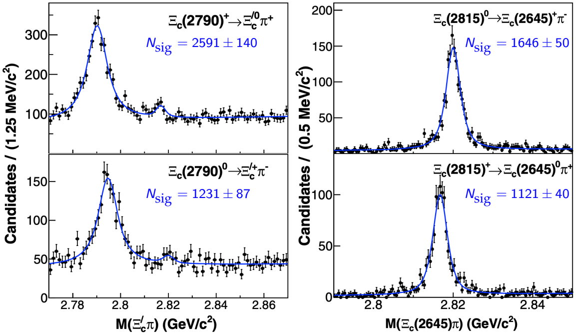
Electromagnetic decays of $\Xi_c(2790, 2815)^{0,+} \to \Xi_c^{0,+}\gamma$ PRD 102, 071103(R) (2020)

- Firstly, large $\Xi_c^{0(+)}$ samples are obtained using ten (seven) decay modes: $N_{\rm sig}(\Xi_c^0) = 142k$ and $N_{\rm sig}(\Xi_c^+) = 79k$.
- Then we fit the $M(\Xi_c\gamma)$ distributions with a Breit-Wigner⊗Crystal Ball for signal; a polynomial for background.
- The first observation/evidence of an electromagnetic decay of an orbitally-excited neutral charmed baryons with branching ratios using normalization modes. No evidence of the analogous decays for charged charmed baryons (set upper limits at 90% C.L).

$$\frac{\mathcal{B}(\Xi_c(2815)^{0(+)} \to \Xi_c^{0(+)}\gamma)}{\mathcal{B}(\Xi_c(2850)^{0(+)} \to \Xi_c(2645)^{+(0)}\pi^- \to \Xi_c^{0(+)}\pi^+\pi^-)} = 0.41 \pm 0.05 \pm 0.03, \ (<0.09)$$

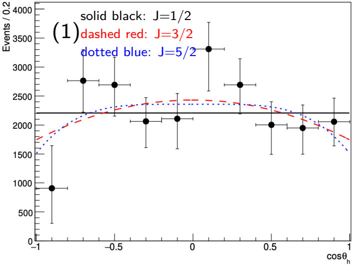
$$\frac{\mathcal{B}(\Xi_c(2790)^{0(+)} \to \Xi_c^{0(+)}\gamma)}{\mathcal{B}(\Xi_c(2790)^{0(+)} \to \Xi_c'^{+(0)}\pi^- \to \Xi_c^{+(0)}\gamma\pi^-)} = 0.13 \pm 0.03 \pm 0.02, \ (<0.06)$$

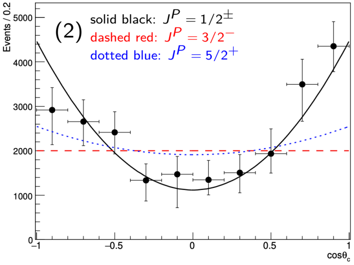


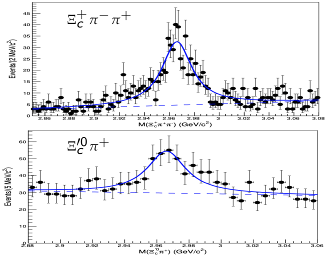


First determination of J^P of a charmed-strange baryon, $\Xi_c(2970)^+$ arXiv:2007.14700 [hep-ex], accepted by PRD

- The unclear theoretical situation motivates this experimental determination of spin-parity of charmed-strange baryon: $J^P(\Xi_c(2970)^+)$, which provides important information to test predictions and help decipher its nature.
- Spin is determined by angular analysis of $\Xi_c(2970)^+ \to \Xi_c(2645)^0\pi^+ \to \Xi_c^+\pi^-\pi^+$.
  - (1) helicity angle θ_h of $\Xi_c(2970)^+$: the background-subtracted and efficiency-corrected yields distribution is fitted with expected decay-angle distribution W_J for different spin hypotheses. $\Rightarrow$ the best fit is for $J = 1/2$ but this is inconclusive, since others are excluded with small significance.
  - (2) helicity angle θ_c of $\Xi_c(2645)^0$: the expected angular correlation $W(\theta_c)$ with an assumption that lowest partial wave dominates, is used to to fit. $\Rightarrow$ the $J^P = 1/2^{\pm}$ hypothesis over the $3/2^-$ ($5/2^+$) one at the level of 5.1σ (4.0σ).







- Parity is established from $\mathcal{B}(\Xi_c(2970)^+ \to \Xi_c(2645)^0\pi^+)/\mathcal{B}(\Xi_c(2970)^+ \to \Xi_c'^0\pi^+) = 1.67 \pm 0.29(\text{stat})^{+0.15}_{-0.09}(\text{syst}) \pm 0.25(\text{IS})$. This result favors $J^P = 1/2^+$ with the spin of the light-quark degrees of freedom $s_l = 0$.

Outline

Summary

- Lots of charm results at Belle are achieved since CHARM2018 workshop. Here selected recent ones are presented.
  - BF and CP asymmetry for charm mesons decays: $D^0 \to \pi^+\pi^-\eta$, $K^+K^-\eta$, and $\phi\eta$; $D_s^+ \to K^+(\pi^0, \eta)$ and $\pi^+(\pi^0, \eta)$.
  - BF of Λ_c^+ decays: $\Lambda_c^+ \to \pi^+\eta(\Lambda, \Sigma^0)$, $\Lambda_c^+ \to \Lambda(1670)\pi^+$ and $\eta\Sigma(1385)^+$; $\Lambda_c^+ \to p(\pi^0, \eta)$.
  - BF and decay parameters for Ξ_c^0 decays: $\Xi_c^0 \to (\Lambda, \Sigma^0)\bar{K}^{*0}$, and Σ^+K^{*-}; $\Xi_c^0 \to \Xi^-\ell^+\nu_\ell$ and $\Xi_c^0 \to \Xi^-\pi^+$.
  - spectroscopy and properties of excited charmed baryons: $\Xi_c(2790, 2815)^{0,+} \to \Xi_c^{0,+}\gamma$; $J^P(\Xi_c(2970)^+)$.
  - D^0-$\bar{D}^0$ mixing and CP violation: y_{cp} in $D^0 \to K_S^0\omega$, $D^0 \to K^+K^-\pi^+\pi^-$.
  - amplitude analysis: $D^0 \to K^-\pi^+\eta$; $\Xi_c^0 \to \Xi^0K^+K^-$.
  - absolute BF for $\Xi_c^{0,+}$ using B decays.
  - charm rare and forbidden decays: recent BaBar results on LFV and LNV decays $D^0 \to X^0e^\pm\mu^\mp$, $h'^-h^-\ell'^+\ell^+$, and $h'^-h^+\ell'^\pm\ell^\mp$.
  - ......
- More charm results from Belle are on the road, e.g., T-odd asymmetry in multi-body decays, etc.
- For recent charmonium(-like) and XYZ results at Belle, please see Robert's talk tomorrow [link]
- As a summary, I would like to say, "Our Belle is not only keeping alive but still keeping energetic with fruitful charm results, although its final full data set was achieved more than 10 years ago"

Back up

Thank you for your attentions.

谢谢！

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