Charm hadron decay @ BESIII

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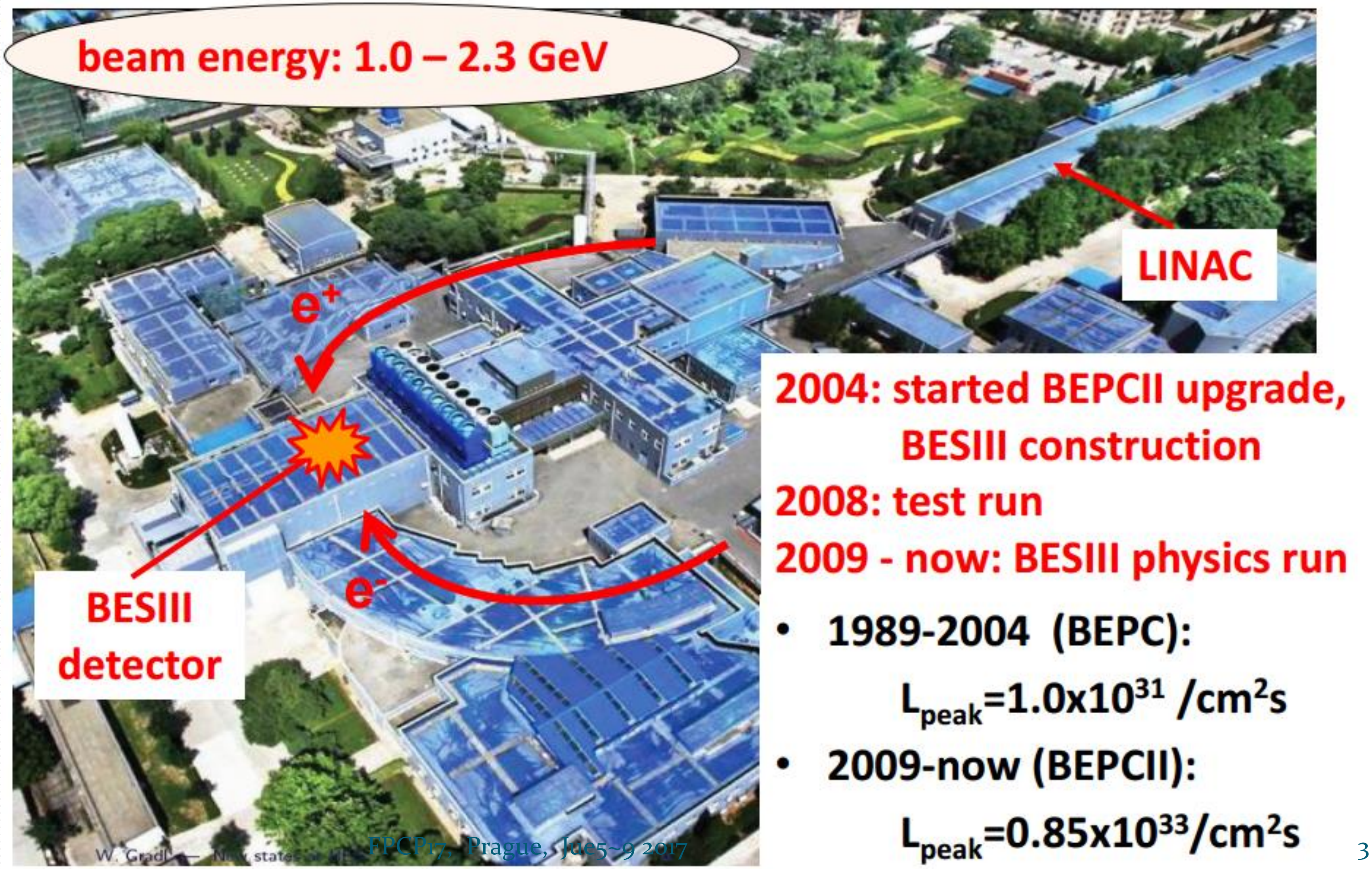
Outline

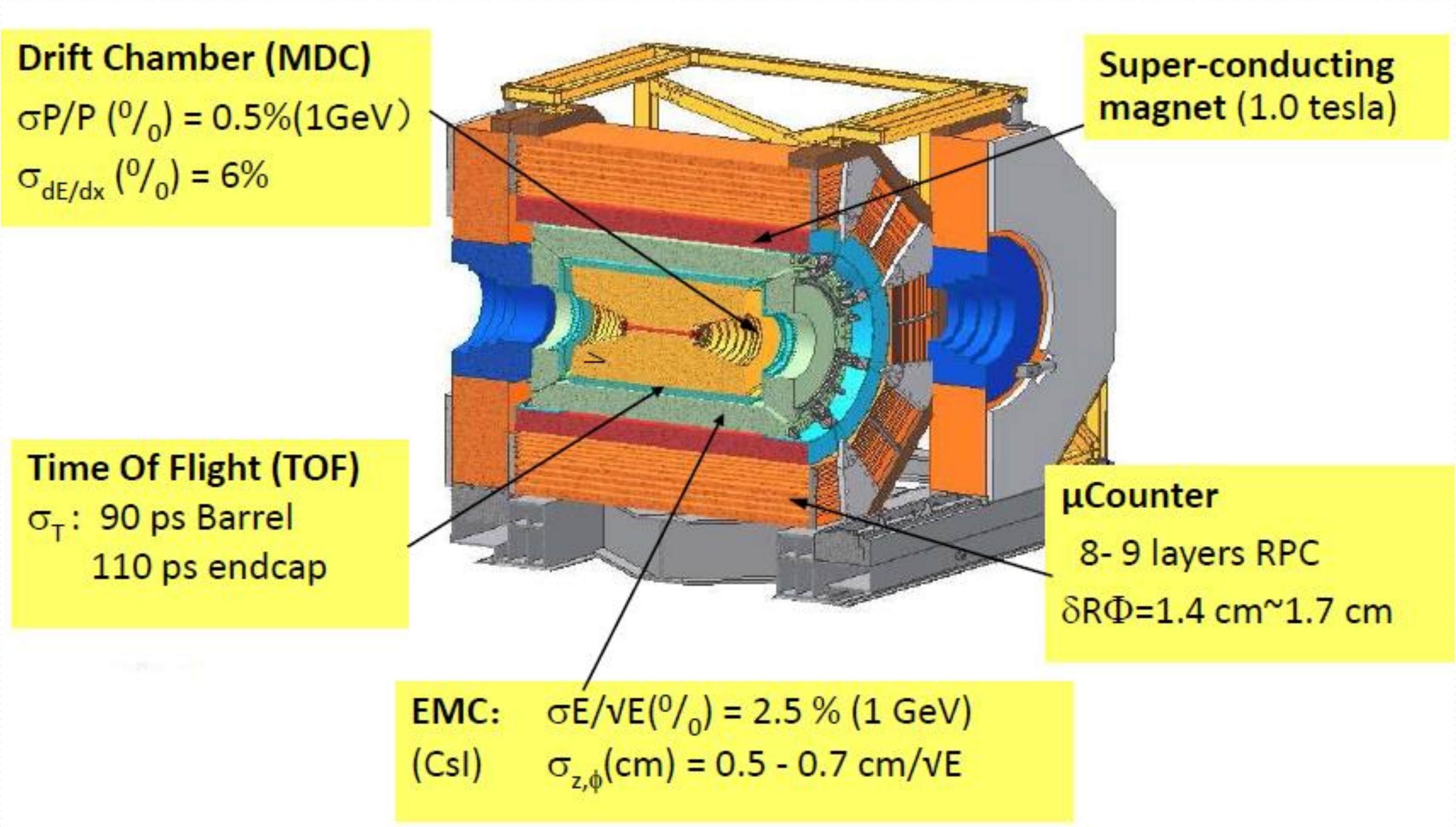
- **Introduction**
- **D hadronic decays**
  - **Absolute BR of $D^0 \to K_S/K_L\pi^0(\pi^0)$**
  - **y_{CP} Measurement from $D^0 \to K_S/K_L\pi^0$**
  - **BF measurements of some $D^{0(+)} \to PP$**
  - **BF measurements of $D^{0(+)} \to 2K_S+X$**
- **Λ_C hadronic decays**
  - **BRs of $\Lambda_C^+ \to \Sigma^-\pi^+\pi^+$ and $\Lambda_C^+ \to \Sigma^-\pi^+\pi^+\pi^0$**
  - **$\Lambda_C^+ \to p\pi^+\pi^+$ and $\Lambda_C^+ \to pK^+K^-$**
  - **$\Lambda_C^+ \to p\eta$ and $\Lambda_C^+ \to p\pi^0$**
  - **Measurement of $\Lambda_C^+ \to \Lambda+X$**
- **Summary**

I **will briefly go through some high lights of the recent experimental results today. (Will not cover most of the results, which had presented in the previous FPCP meetings.)**

Beijing Electron Positron Collider

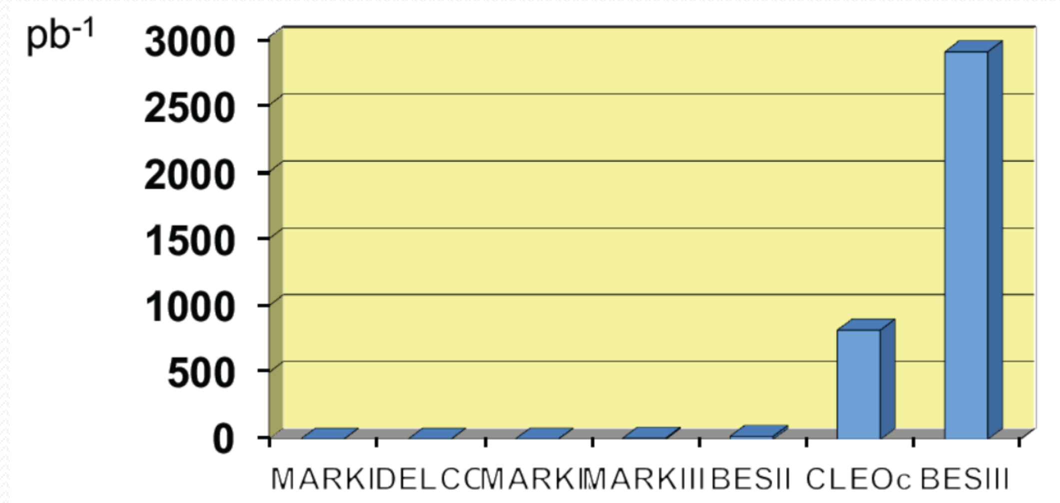


The BESIII detector

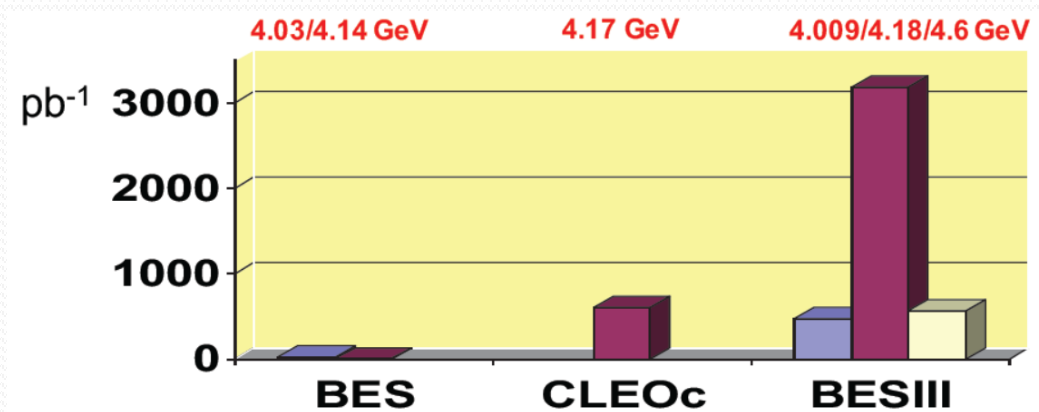


Charm data @BESIII

- ~2.92fb^{-1} $\psi(3770)$@3.773GeV

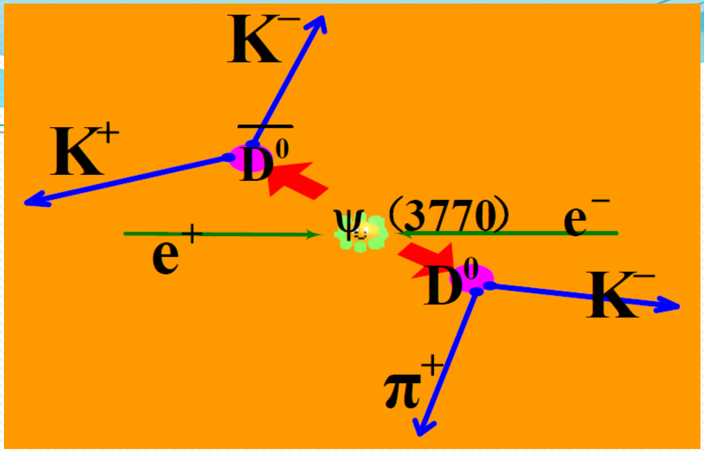


- ~0.48fb^{-1} $\psi(4040)$@4.009GeV
- ~3.16fb^{-1}@4.180GeV
- ~0.57fb^{-1}$\Lambda_c\Lambda_c$@4.600GeV



Tag technique

- Threshold production
  - Only D meson pairs
  - Quantum Correlations (QC)
  - Systematic uncertainties cancellations while applying double tag technique
- D tagging method
  - Single tag (higher eff, larger bg)
  - Double tag (lower eff, smaller bg)



$$M_{\rm BC} = \sqrt{E_{\rm beam}^2 - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$$

$$\Delta E = E - E_{\rm beam}$$

D^-

$$D^- \to K^+\pi^-\pi^-$$
$$D^- \to K^+\pi^-\pi^-\pi^0$$
$$D^- \to K_S^0\pi^-$$
$$D^- \to K_S^0\pi^-\pi^0$$
$$D^- \to K_S^0\pi^-\pi^+\pi^-$$
$$D^- \to K^+K^-\pi^-$$

D^0

$$D^0 \to K^-\pi^+$$
$$D^0 \to K^-\pi^+\pi^0$$
$$D^0 \to K^-\pi^+\pi^+\pi^-$$

$$K_S^0 \to \pi^+\pi^-$$
$$\pi^0 \to \gamma\gamma$$

D_s^-

$$D_s^- \to K_S^0 K^-$$
$$D_s^- \to K^+K^-\pi^-$$
$$D_s^- \to K^+K^-\pi^-\pi^0$$
$$D_s^- \to K_s K^+\pi^-\pi^-$$
$$D_s^- \to \pi^+\pi^-\pi^-$$
$$D_s^- \to \pi^-\eta$$
$$D_s^- \to \pi^-\eta'(\eta' \to \pi^+\pi^-\eta)$$
$$D_s^- \to \pi^-\eta'(\eta' \to \rho^0\gamma)$$
$$D_s^- \to \pi^-\pi^0\eta$$

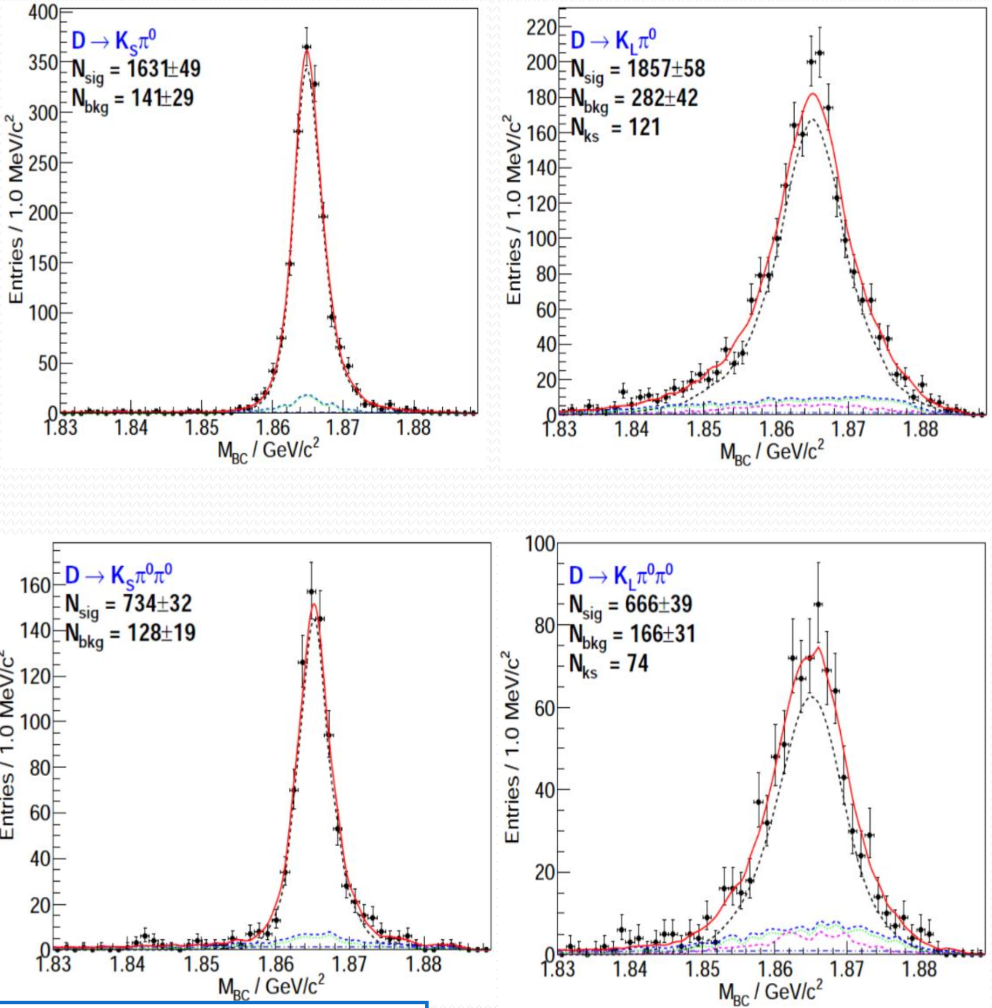
~1.5M D^+D^-, 2.2M D^0D^0

Absolute BR of $D^0 \to K_S/K_L\pi^0(\pi^0)$

- Interference $D \to K^0\pi$'s with (DCS) $D \to \bar{K}^0\pi$'s component:

  $Br(D \to K_S\pi) \neq Br(D \to K_L\pi)$
- Measure absolute branching fractions: $D^0 \to K_S\pi^0$, $D^0 \to K_S\pi^0\pi^0$, $D^0 \to K_L\pi^0$ and $D^0 \to K_L\pi^0\pi^0$
- K_L reconstruction
  - EMC neutral cluster $\to K_L$ position
  - Fix $\Delta E=0 \to K_L$ momentum

BESIII preliminary



$D \to K^0_{S,L}\pi^0$			
	$BR_{K_S\pi^0}(\%)$	$BR_{K_L\pi^0}(\%)$	$R(D \to K_{S,L}\pi^0)$
$K\pi$	1.209±0.041	1.044±0.038	0.0731±0.0245
$K3\pi$	1.205±0.035	0.946±0.033	0.1207±0.0225
$K\pi\pi^0$	1.237±0.028	0.939±0.028	0.1373±0.0184
All	1.221±0.019	0.967±0.019	0.1163±0.0123

$D \to K^0_{S,L}\pi^0\pi^0$			
	$BR_{K_S 2\pi^0}(\%)$	$BR_{K_L 2\pi^0}(\%)$	$R(D \to K_{S,L}2\pi^0)$
$K\pi$	1.028±0.048	1.257±0.075	-0.1001±0.0374
$K3\pi$	0.873±0.040	1.002±0.060	-0.0689±0.0376
$K\pi\pi^0$	1.004±0.036	1.156±0.062	-0.0703±0.0320
All	0.965±0.023	1.123±0.037	-0.0755±0.0204

BESIII preliminary

$$\mathcal{R}(D \to K^0_{S,L}\pi^0(\pi^0)) = \frac{\mathcal{B}_{K^0_S\pi^0(\pi^0)} - \mathcal{B}_{K^0_L\pi^0(\pi^0)}}{\mathcal{B}_{K^0_S\pi^0(\pi^0)} + \mathcal{B}_{K^0_L\pi^0(\pi^0)}}$$

y_{cp} measurement from $D^0 \rightarrow K_S/K_L\pi^0$

- Single Tag decay rate (CP tags)

$$\Gamma_{CP\pm} \propto 2|A_{CP\pm}|^2(1 \mp y)$$

- Double Tag decay rate (Flavor tags+)

$$\Gamma_{l;CP\pm} \propto |A_l|^2|A_{CP\pm}|^2$$

- Neglect term y^2 or higher order

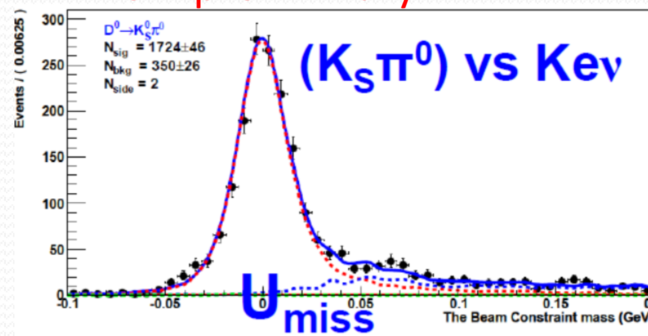
$$y_{CP} \approx \frac{1}{4}\left(\frac{\Gamma_{l;CP+}\Gamma_{CP-}}{\Gamma_{l;CP-}\Gamma_{CP+}} - \frac{\Gamma_{l;CP-}\Gamma_{CP+}}{\Gamma_{l;CP+}\Gamma_{CP-}}\right)$$

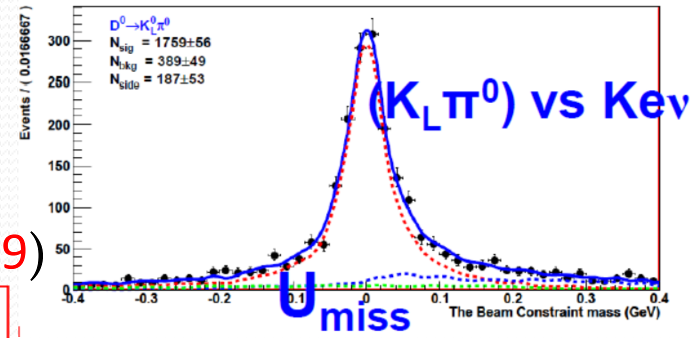
- BESIII previous measurement(PLB744(2015)339)
  - Flavor tags: $Ke\nu_e$, $K\mu\nu_\mu$
  - CP+ tags (3 modes): K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$
  - CP- tags (3 modes): $K_S\pi^0$, $K_S\eta$, $K_S\omega$

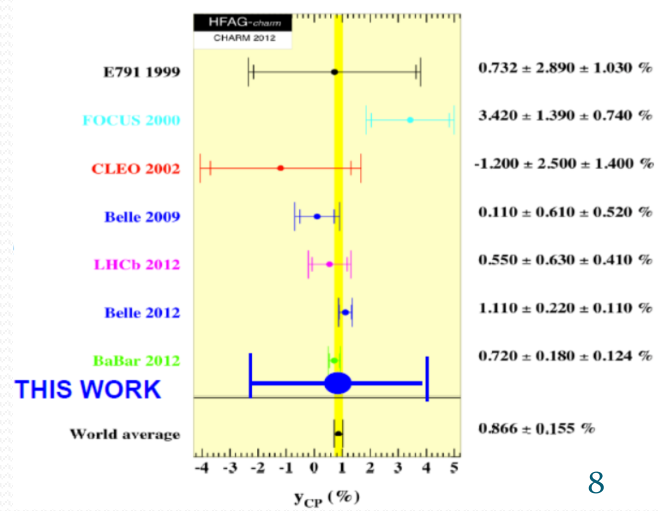
y_{CP}=(-2.0±1.3±0.7)%

- For this analysis
  - CP+ tag: $K_L\pi^0$; CP- tag: $K_S\pi^0$; Flavor tag: $Ke\nu_e$
  - Double tag yields are from U_{miss} fit
  - y_{CP} = (0.98±2.43)% (Statistical error only)

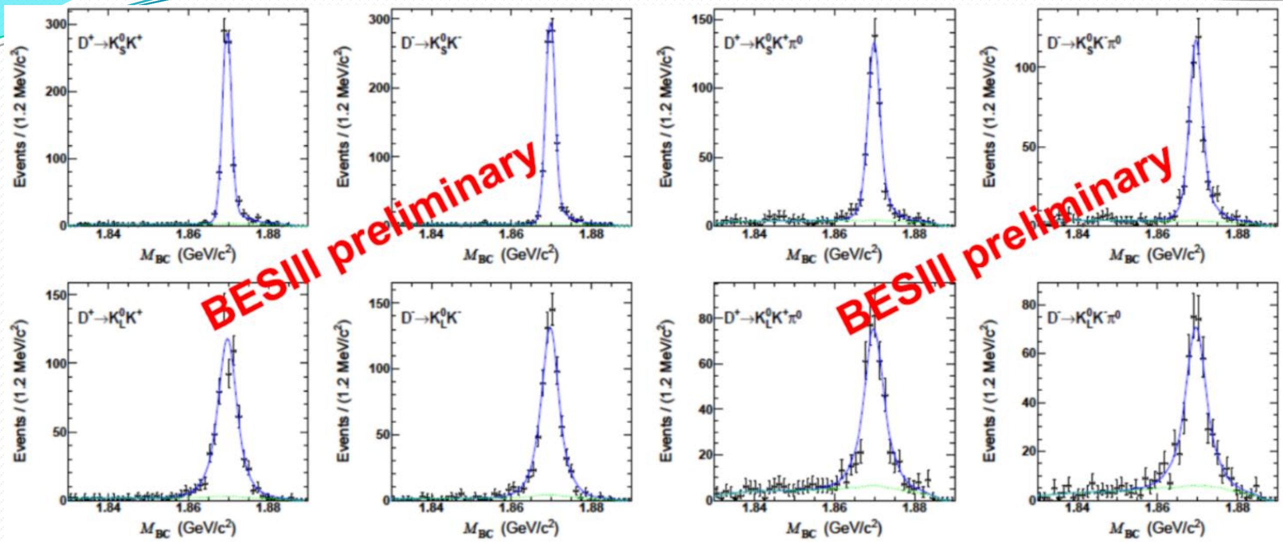
BESIII preliminary







$D^+ \to K_S K^+(\pi^0)$ and $D^+ \to K_L K^+(\pi^0)$



$$\mathcal{A}_{CP} = \frac{\mathcal{B}(D^+) - \mathcal{B}(D^-)}{\mathcal{B}(D^+) + \mathcal{B}(D^-)}$$

Signal mode	$\mathcal{B}(D^+)\,(\times 10^{-3})$	$\mathcal{B}(D^-)\,(\times 10^{-3})$	$\overline{\mathcal{B}}\,(\times 10^{-3})$	$\mathcal{B}$ (PDG) $(\times 10^{-3})$	$\mathcal{A}_{CP}$ (%)
$K^0_S K^\pm$	$3.01 \pm 0.12 \pm 0.08$	$3.10 \pm 0.12 \pm 0.08$	$3.06 \pm 0.09 \pm 0.08$	2.95 ± 0.15	$-1.5 \pm 2.8 \pm 1.6$
$K^0_S K^\pm \pi^0$	$5.23 \pm 0.28 \pm 0.24$	$5.09 \pm 0.29 \pm 0.22$	$5.16 \pm 0.21 \pm 0.23$	-	$1.4 \pm 4.0 \pm 2.4$
$K^0_L K^\pm$	$3.13 \pm 0.14 \pm 0.10$	$3.32 \pm 0.15 \pm 0.11$	$3.23 \pm 0.11 \pm 0.11$	-	$-3.0 \pm 3.2 \pm 1.2$
$K^0_L K^\pm \pi^0$	$5.17 \pm 0.30 \pm 0.21$	$5.26 \pm 0.30 \pm 0.21$	$5.22 \pm 0.22 \pm 0.21$	-	$-0.9 \pm 4.1 \pm 1.6$

- Agree with CLEO-c result

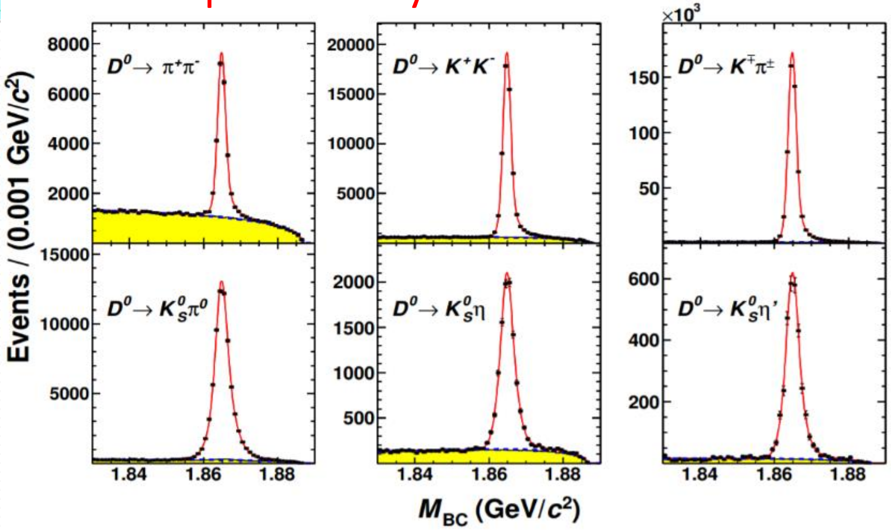
	$\mathcal{B}(D^+ \to K^0_S K^+)$
CLEO	$(3.14 \pm 0.09 \pm 0.08)\times 10^{-3}$

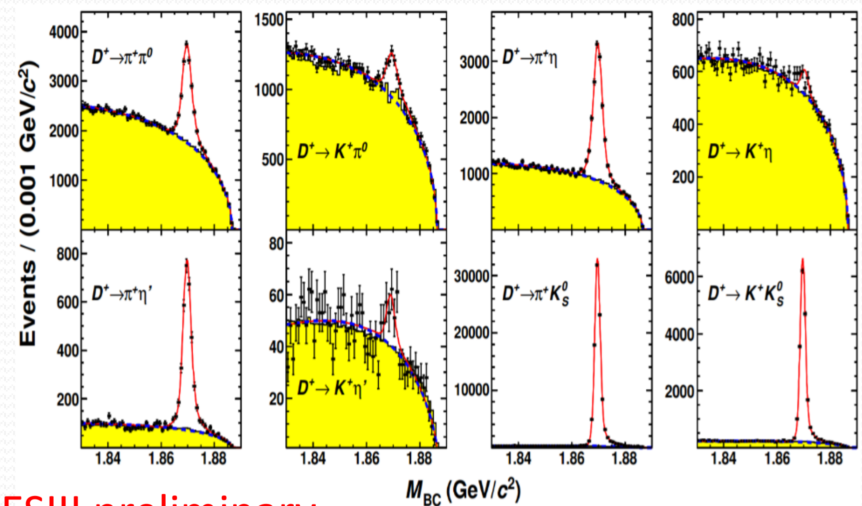
Phys. Rev. D77, 091106(R) (2008)
Single tag method

- Br of $D^+ \to K_S K^+ \pi^0$, $D^+ \to K_L K^+$ and $D^+ \to K_L K^+ \pi^0$ are measured for the first time
- No evidence for CP asymmetry in the 4 SCS decays

$D^{0(+)}\rightarrow PP$ (P=pseudoscalar)

BESIII preliminary





BESIII preliminary

Single tag method:

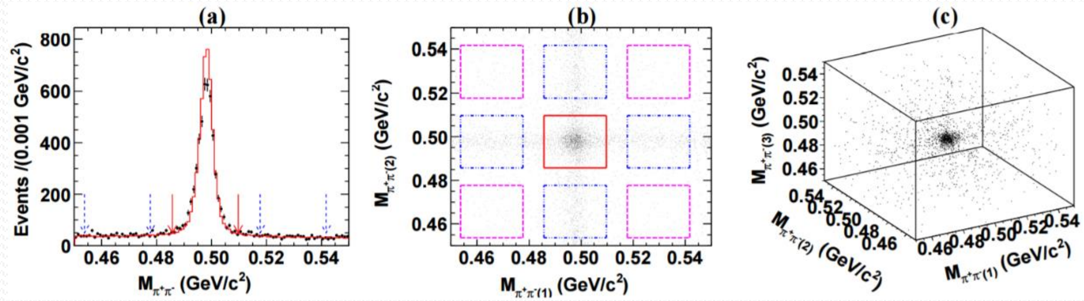
$$\mathcal{B}(D^{+(0)} \to P_1P_2) = \frac{N_{\rm net}}{2 \times N^{\rm tot}_{D^+D^-\ (D^0\bar{D}^0)} \times \varepsilon(\times\mathcal{B}_i)}$$

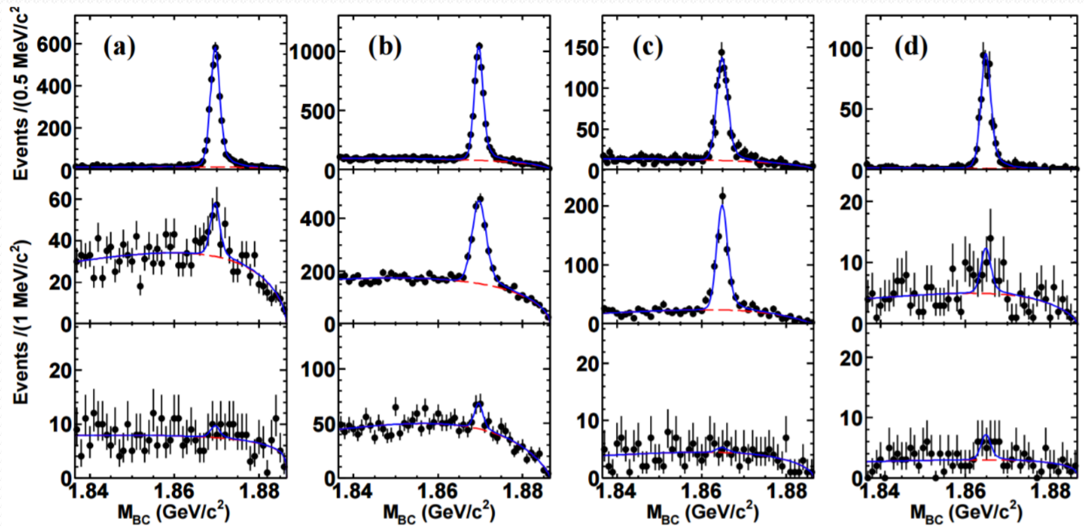
Mode	$\mathcal{B}_{\rm This\ work}$ $(\times10^{-3})$	$\mathcal{B}_{\rm PDG}$ $(\times10^{-3})$
$D^+\to\pi^+\pi^0$	$1.259\pm0.033\pm0.025$	1.24 ± 0.06
$D^+\to K^+\pi^0$	$0.231\pm0.021\pm0.006$	0.189 ± 0.025
$D^+\to\pi^+\eta$	$3.790\pm0.070\pm0.076$	3.66 ± 0.22
$D^+\to K^+\eta$	$0.151\pm0.025\pm0.014$	0.112 ± 0.018
$D^+\to\pi^+\eta'$	$5.12\pm0.14\pm0.21$	4.84 ± 0.31
$D^+\to K^+\eta'$	$0.164\pm0.051\pm0.025$	0.183 ± 0.023
$D^+\to K^0_S\pi^+$	$15.91\pm0.06\pm0.33$	15.3 ± 0.6
$D^+\to K^0_SK^+$	$3.183\pm0.029\pm0.067$	2.95 ± 0.15
$D^0\to\pi^+\pi^-$	$1.508\pm0.018\pm0.027$	1.421 ± 0.025
$D^0\to K^+K^-$	$4.233\pm0.021\pm0.076$	4.01 ± 0.07
$D^0\to K^\mp\pi^\pm$	$38.98\pm0.06\pm0.62$	39.4 ± 0.4
$D^0\to K^0_S\pi^0$	$12.39\pm0.06\pm0.30$	12.0 ± 0.4
$D^0\to K^0_S\eta$	$5.13\pm0.07\pm0.12$	4.85 ± 0.30
$D^0\to K^0_S\eta'$	$9.49\pm0.20\pm0.37$	9.5 ± 0.5

- BR results consistent with other measurement and have similar precisions with the existing best measurements

BF measurements of $D^{0(+)} \rightarrow 2K_S+X$

- Comprehensive or improved measurements of 3-body decays benefit the understanding of the interplay between weak and strong interactions in multi-body decays, where theory is poor than 2-body decays
- BF of $D^0 \rightarrow K_S K_S$ will be helpful to explore the SU(3) symmetry breaking in D decays
- Subtract the peaking background by sideband





$$N_{\rm net} = N_{K_S^0{\rm sig}} - \frac{1}{2}N_{\rm sb1} + \frac{1}{4}N_{\rm sb2} - N^{\rm b}_{\rm other}$$

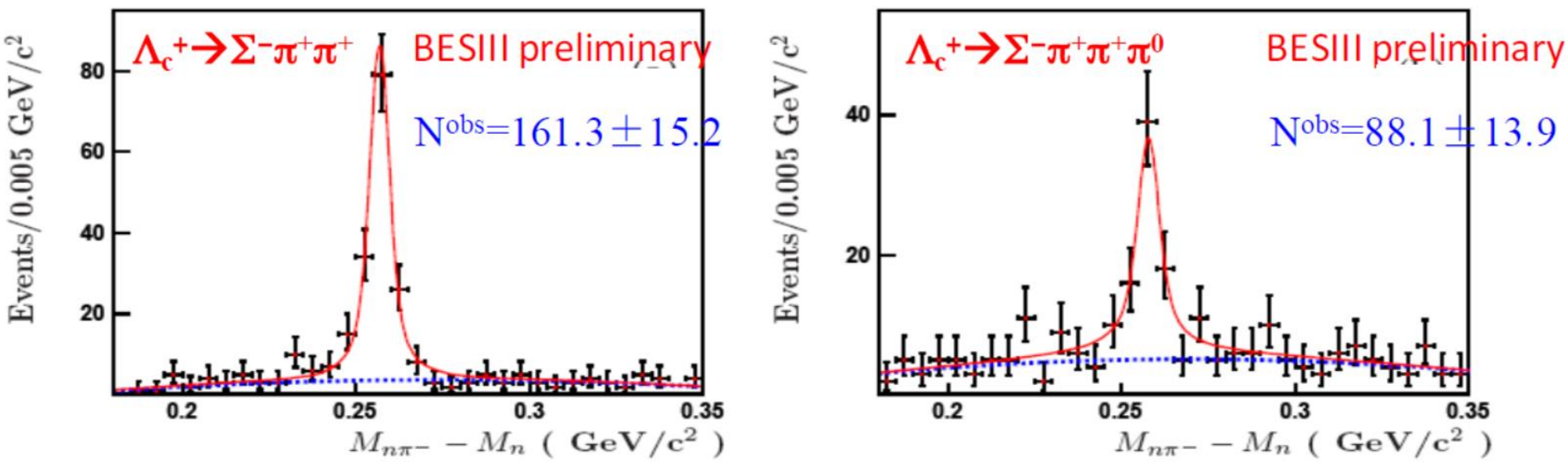
$$N_{\rm net} = N_{K_S^0{\rm sig}} - \frac{1}{2}N_{\rm sb1} + \frac{1}{4}N_{\rm sb2} - \frac{1}{8}N_{\rm sb3} - N^{\rm b}_{\rm other}$$

$$\mathcal{B}(D^{+(0)} \to f) = \frac{N_{\rm net}}{2 \cdot \sigma_{D^+D^-\ (D^0\bar{D}^0)} \cdot \mathcal{L} \cdot \epsilon}$$

Decay modes	This work	PDG
$D^+ \to K_S^0 K_S^0 K^+$	$25.4 \pm 0.5 \quad \pm 1.2$	45 ± 20
$D^+ \to K_S^0 K_S^0 \pi^+$	$27.0 \pm 0.5 \quad \pm 1.2$	–
$D^0 \to K_S^0 K_S^0$	$1.67 \pm 0.11 \pm 0.11$	1.7 ± 0.4
$D^0 \to K_S^0 K_S^0 K_S^0$	$7.21 \pm 0.33 \pm 0.44$	9.1 ± 1.3

PLB765,231(2017)

BRs of $\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+$ and $\Lambda_c^+ \rightarrow \Sigma^-\pi^+\pi^+\pi^0$

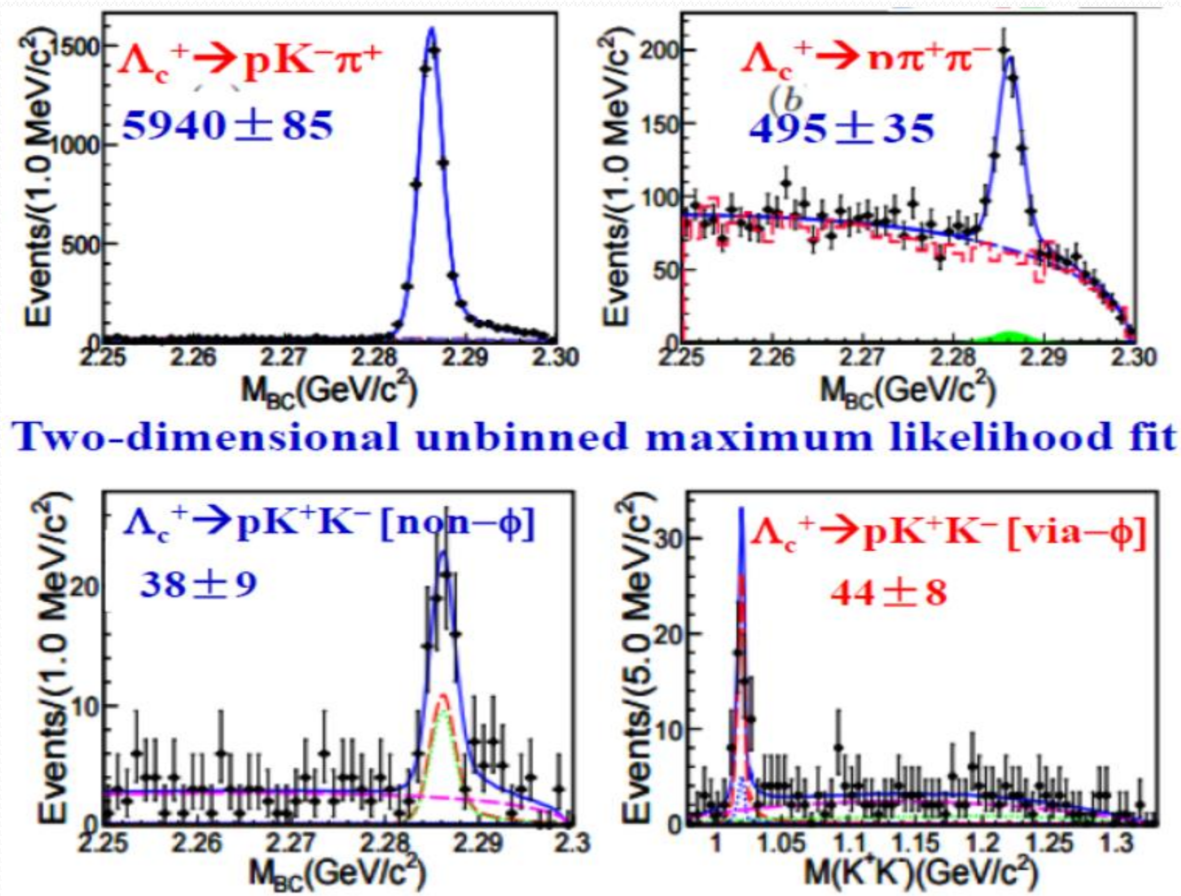


- The total measured Λ_C^+ decays BR < 65%
- PDG2017: $B(\Lambda_C^+ \rightarrow \Sigma^-\pi^+\pi^+) = (2.1 \pm 0.4)\%$(Large error)
- Preliminary results(statistical errors only):
  - **$B(\Lambda_C^+ \rightarrow \Sigma^-\pi^+\pi^+) = (1.81 \pm 0.17 \pm 0.09)\%$**
  - **$B(\Lambda_C^+ \rightarrow \Sigma^-\pi^+\pi^+\pi^0) = (2.11 \pm 0.33 \pm 0.14)\%$** (**First observation**)
- Consistent with PDG17 with better precision.

SCS decay of $\Lambda_c^+ \rightarrow p\pi^+\pi^-/K^+K^-$

PRL117,232002(2016)

- Study of SCS -Singly Cabibbo Suppressed decays can shed light on dynamics of Λ_c^+ decays
- $B(\Lambda_c^+ \rightarrow p\phi)$ is particular interest since it proceeds W-exchange only.



Green histogram: peaking background from $\Lambda_C^+ \rightarrow pK_S$ and $\Lambda_C^+ \rightarrow \Lambda\pi^+$

SCS decay of $\Lambda_c^+ \rightarrow p\pi^+\pi^-/K^+K^-$

PRL117,232002(2016)

- ST study, relative BFs to $\Lambda_c^+ \rightarrow pK^-\pi^+$ measured.
- Input BESIII measurement:

$$B[\Lambda_c^+ \rightarrow pK^-\pi^+]=(5.84\pm0.27\pm0.23)\%$$

–	$\mathcal{B}_{\rm mode}$	$\mathcal{B}$(PDG)	
$\Lambda_c^+ \rightarrow p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$	first observation
$\Lambda_c^+ \rightarrow p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$	improved precision
$\Lambda_c^+ \rightarrow pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$	improved precision

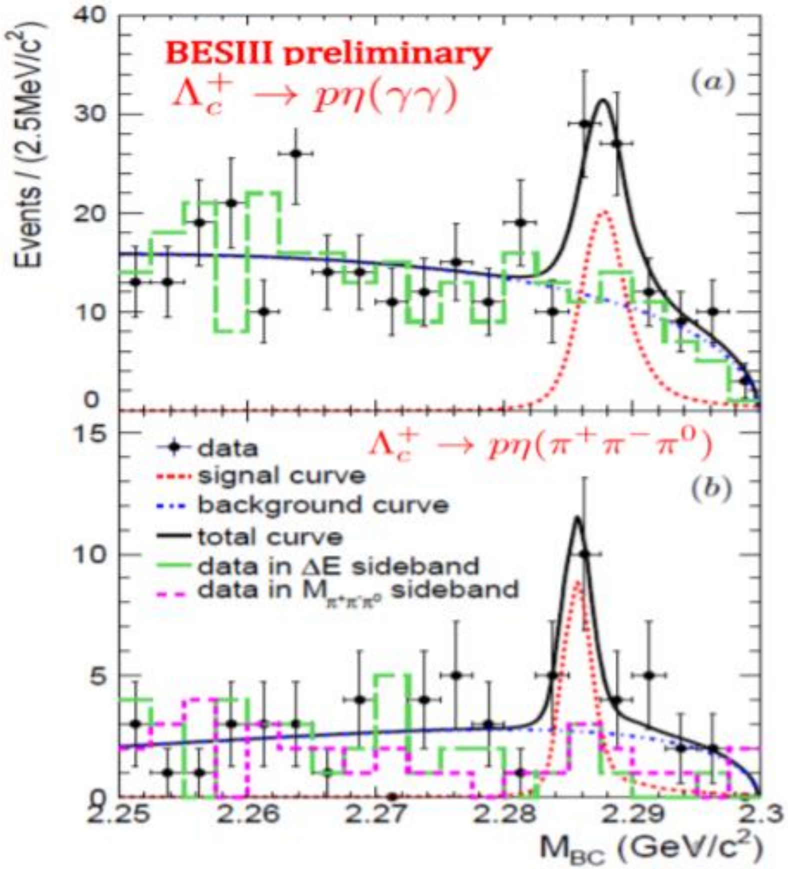
Uncertainties are statistical, systematic and reference mode uncertainty

- The result in this work:
  - investigate the dynamic of Λ_C^+ decays
  - distinguish the predictions from different theoretical models
  - Understand the contributions from the non-factorizable diagrams

SCS decay of $\Lambda_c^+ \rightarrow p\pi^0/p\eta$

Submit to PRL，arXiv:1702.05279

- $B(\Lambda_c^+ \rightarrow p\eta) >> B(\Lambda_c^+ \rightarrow p\pi^0)$ in the SU(3) flavor symmetry generated by u,d and s.
- Their relative size is essential to understand the interference of different non-factorizable diagrams



- Simultaneous fit:
  - $\eta \rightarrow \gamma\gamma$
  - $\eta \rightarrow \pi^+\pi^-\pi^0$
-

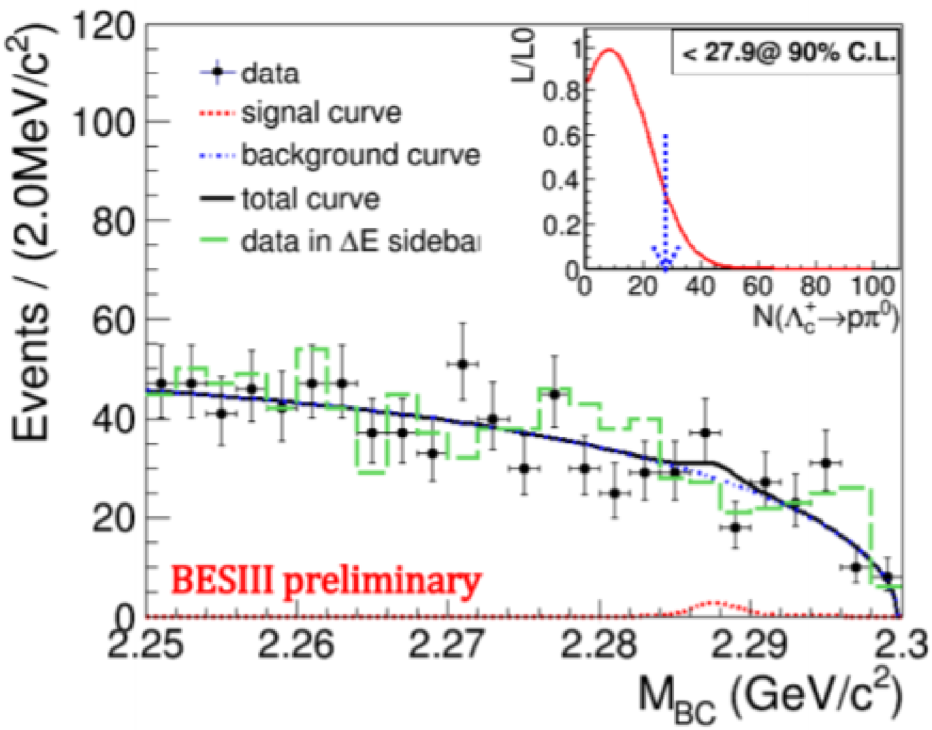
$$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta) = (1.24 \pm 0.28 \pm 0.1) \times 10^{-3}$$

First evidence for $\Lambda_c^+ \rightarrow p\eta$ with 4.2σ significance

SCS decay of $\Lambda_c^+ \to p\pi^0/p\eta$

Submit to PRL，arXiv:1702.05279

- $\Lambda_c^+ \to p\pi^0$：no obvious signal



- Fit to the M_{BC} distribution

Signal: MC shape ⊗ Gaussian

Background: Argus function

Upper limit:

$\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$

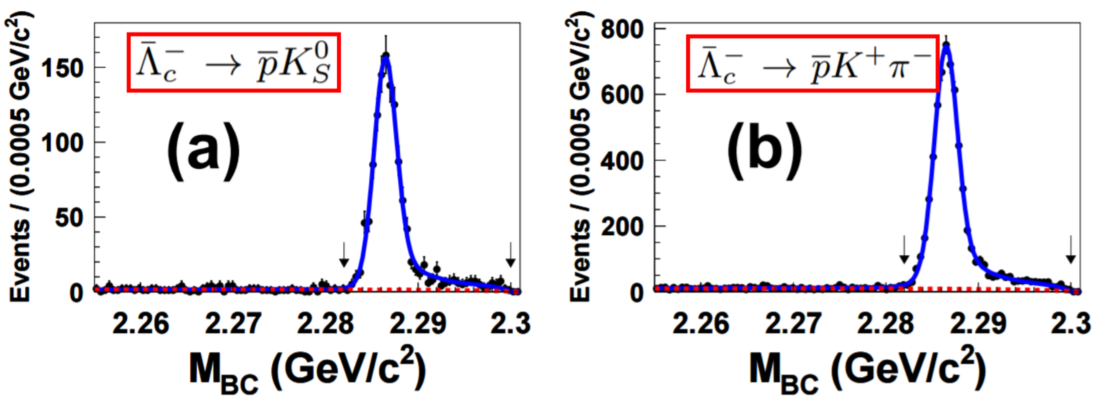
Compared with $\mathcal{B}(\Lambda_c^+ \to p\eta)$:

$\mathcal{B}(\Lambda_c^+ \to p\pi^0)/\mathcal{B}(\Lambda_c^+ \to p\eta)$<0.24

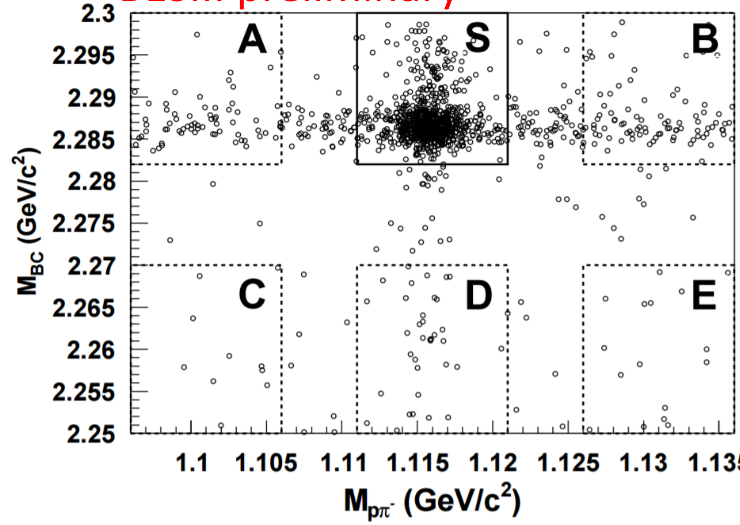
The measurement of $\Lambda_c \rightarrow \Lambda+X$

- The measurement is useful to test Heavy Quark Effect Theory(HQET)
- PDG2016: $B(\Lambda_c \rightarrow \Lambda+X) = 35 \pm 11\%$

BESIII preliminary



BESIII preliminary



$$N^{\rm sig} = N^{\rm S} - \frac{N^{\rm A} + N^{\rm B}}{2} - f \cdot (N^{\rm D} - \frac{N^{\rm C} + N^{\rm E}}{2})$$

Tagging mode i	ΔE (GeV)	$M_{\rm BC}$ (GeV/c^2)	$N_i^{\rm tag}$
$\bar{\Lambda}_c^- \rightarrow \bar{p}K_S^0$	$[-0.021, 0.019]$	$[2.282, 2.300]$	1220 ± 37
$\bar{\Lambda}_c^- \rightarrow \bar{p}K^+\pi^-$	$[-0.020, 0.015]$		6088 ± 85

$$\mathcal{A}_{\rm CP} \equiv \frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}$$

$B(\Lambda_C \rightarrow \Lambda+X) = (38.2^{+2.8}_{-2.2} \pm 0.6)\%$

Decay mode	Branching fraction(%)	$\mathcal{A}_{\rm CP}$
$\Lambda_c^+ \rightarrow \Lambda + X$	$39.3^{+4.6}_{-3.4} \pm 0.6$	$(2.1^{+7.0}_{-6.6} \pm 1.1)\%$
$\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X$	$37.7^{+3.8}_{-2.9} \pm 0.6$	

Summary

- BESIII released many new Charm results!
- Charm hadronic decays
  - Study DDbar mixing
  - The large ψ(3770) sample of BESIII allows to make measurements with improved precisions
- Charmed baryon
  - Precision measurements in Λ_c decays
  - Fill the unknown charts in the PDG
- In future
  - BESIII has collected 3.16fb^{-1} Ds data around Ecm=4.180GeV, expect new results on Ds decays in the near future
  - More Λ_c data taking proposed at BESIII→push the precisions to the level as we have in D/Ds

Thank you!

backup

SCS decay of $\Lambda_c^+ \rightarrow p\pi^+\pi^-/K^+K^-$

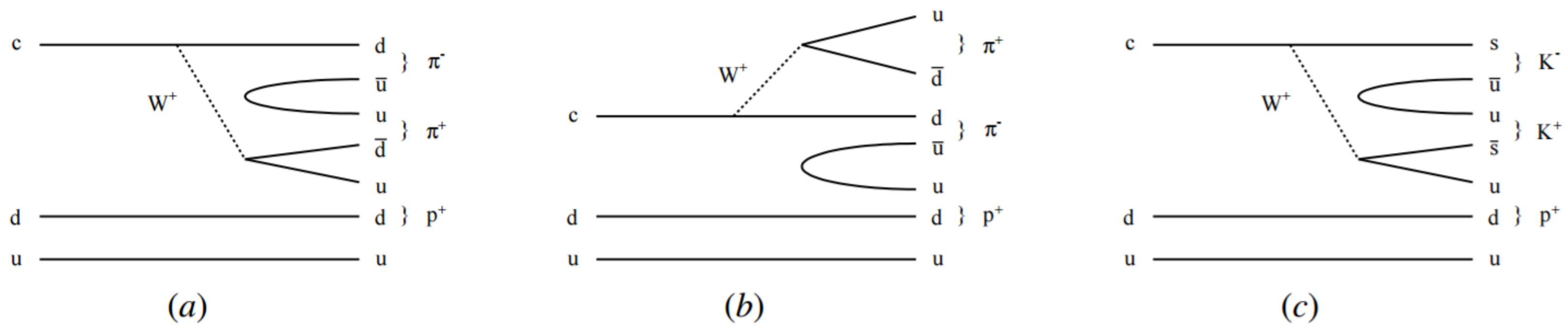


Figure 1: Feynman diagrams, (a) internal W-emission for $\Lambda_c^+ \rightarrow p\pi^+\pi^-$, (b) external W-emission for $\Lambda_c^+ \rightarrow p\pi^+\pi^-$, (c) internal W-emission for $\Lambda_c^+ \rightarrow pK^+K^-$

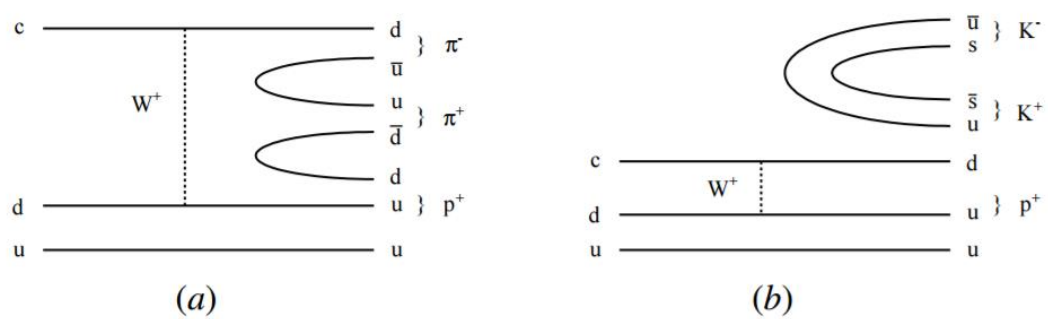
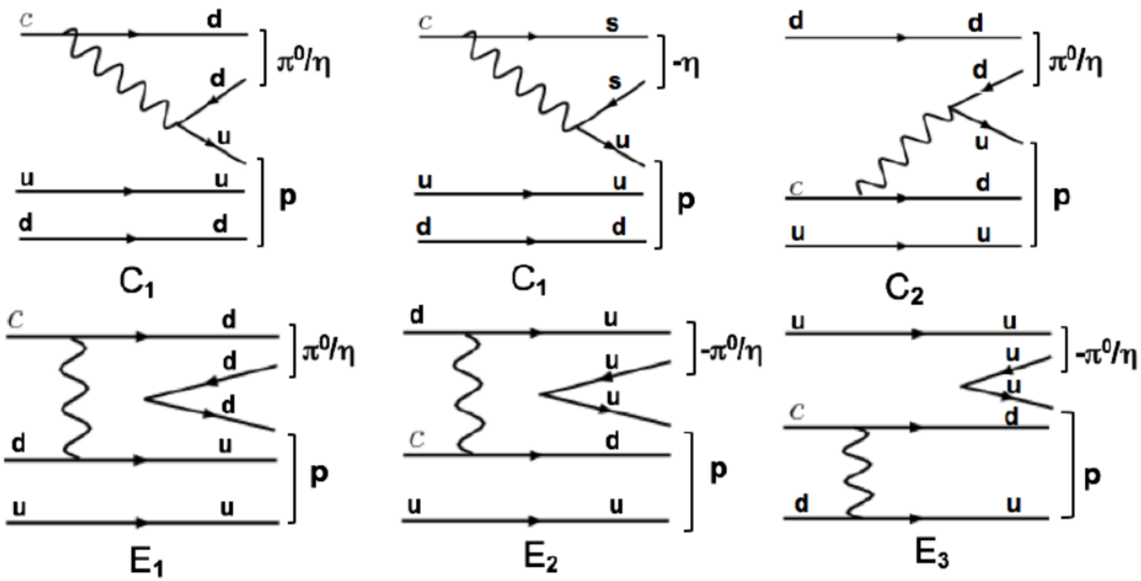


Figure 2: Feynman diagrams with W-exchange, (a) $\Lambda_c^+ \rightarrow p\pi^+\pi^-$ (b) $\Lambda_c^+ \rightarrow pK^+K^-$

SCS decay of $\Lambda_c^+ \rightarrow p\pi^0/p\eta$

Singly Cabibbo-suppressed modes: $\Lambda_c^+ \rightarrow p\pi^0, p\eta$



$\pi^0 = (d\bar{d} - u\bar{u})/\sqrt{2}$, $\eta = (d\bar{d} + u\bar{u} - s\bar{s})/\sqrt{3}$ for $\eta - \eta'$ mixing angle = 19.5^0

$A(\Lambda_c^+ \rightarrow p\pi^0) = (C_1 + C_2 + E_1 - E_2 - E_3)/\sqrt{2}$

$A(\Lambda_c^+ \rightarrow p\eta) = (2C_1 + C_2 + E_1 + E_2 + E_3)/\sqrt{3}$

It is most likely that

$\Gamma(\Lambda_c^+ \rightarrow p\eta) >> \Gamma(\Lambda_c^+ \rightarrow p\pi^0)$

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From Prof. Hai-Yang Cheng's report.

- More precise comparison of the two BFs are desired to explore the interference of different non-factorizable diagrams
- BESIII Preliminary result support the theoretic prediction.