# Hadronic decays of charmed hadrons at BESIII

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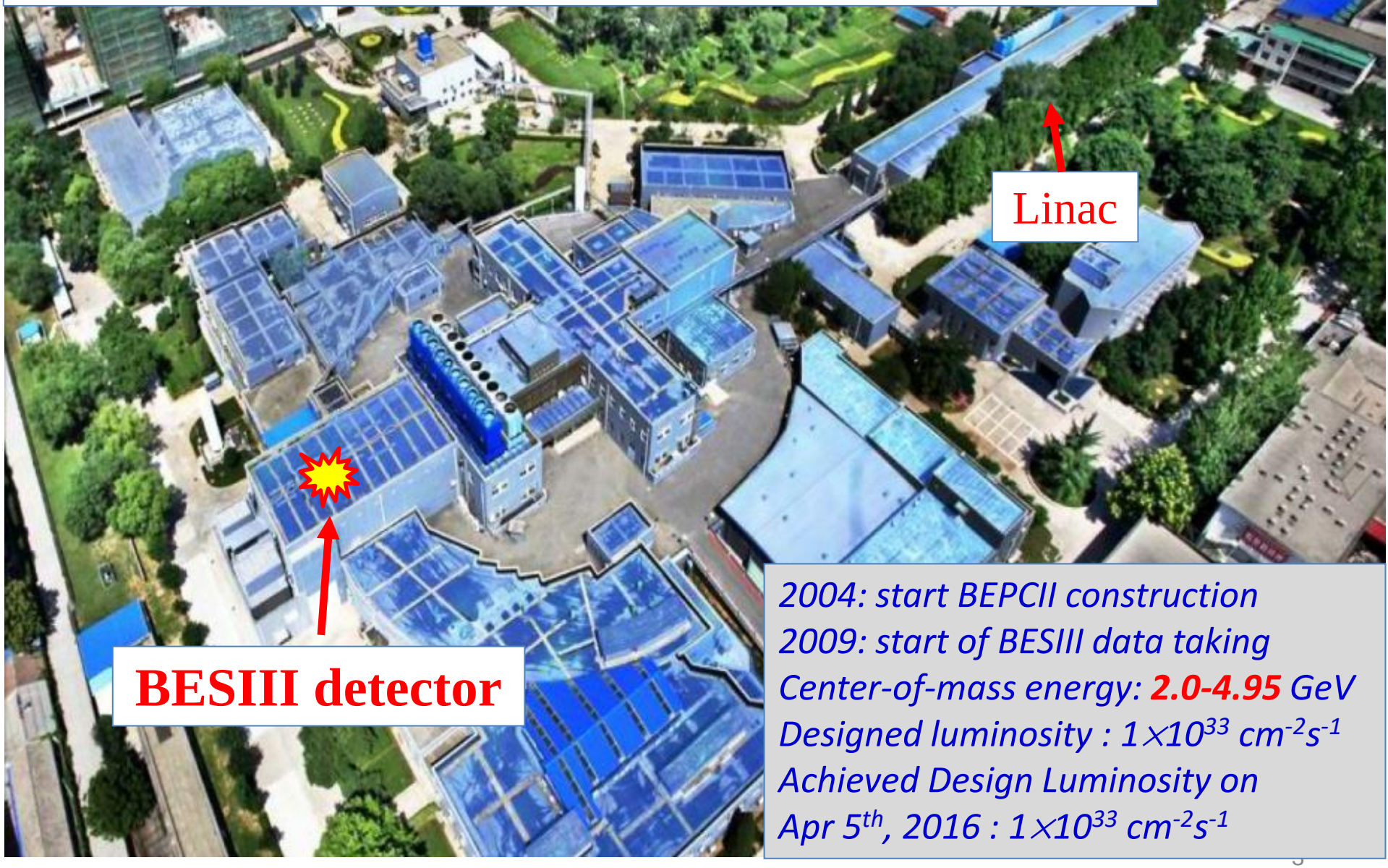
# Outline

- **BEPCII/BESIII**
- **Hadronic decays of charmed hadrons**
  - Measurements of strong-phase parameters
  - Amplitude analysis for $D_s^+$ decays
- **Summary**

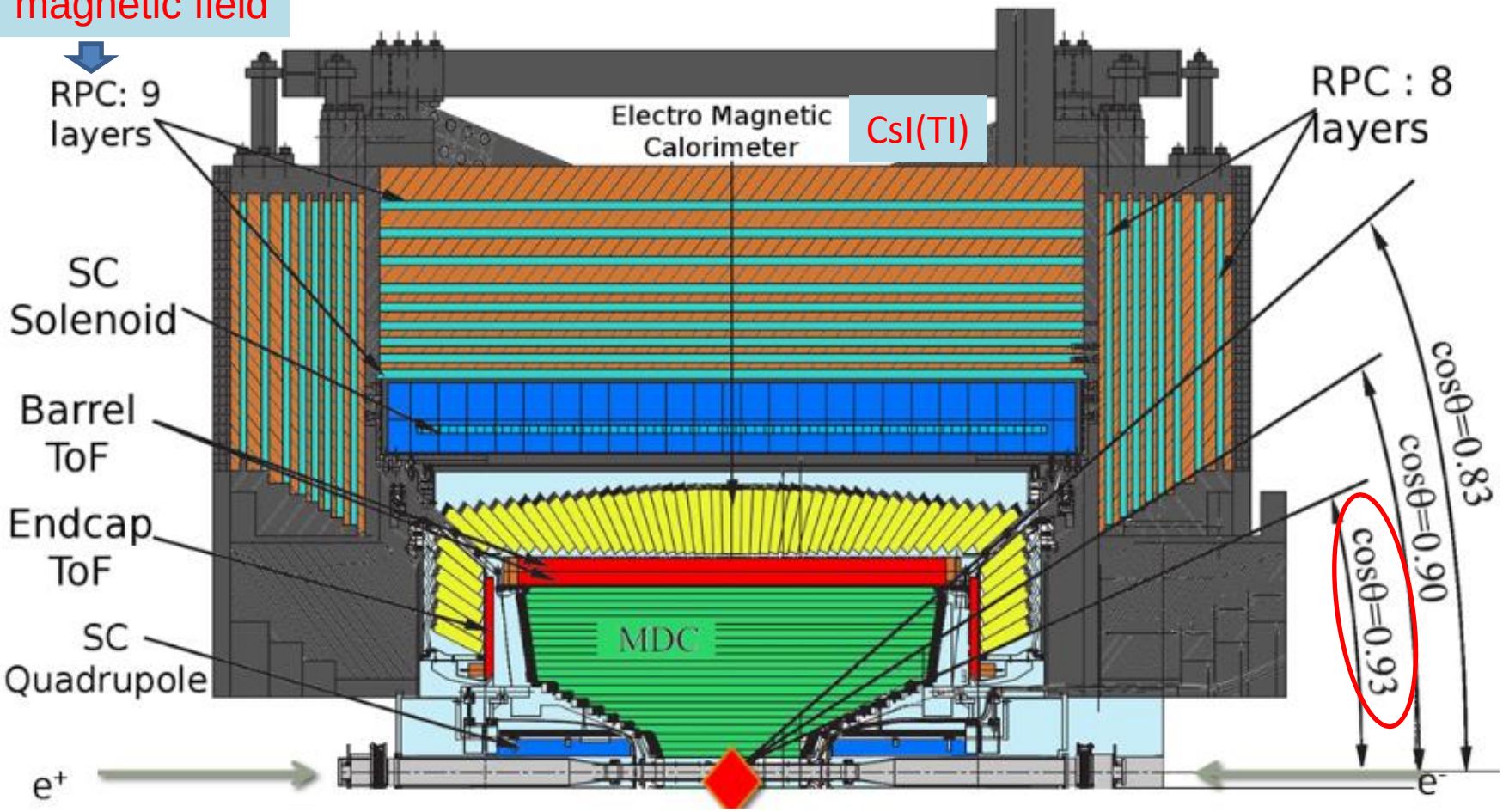
# Beijing Electron Positron Collider (BEPC)




*2004: start BEPCII construction*
*2009: start of BESIII data taking*
*Center-of-mass energy:* ***2.0-4.95*** *GeV*
*Designed luminosity : $1\times10^{33}$ $cm^{-2}s^{-1}$*
*Achieved Design Luminosity on*
*Apr 5th, 2016 : $1\times10^{33}$ $cm^{-2}s^{-1}$*

# BESIII Detector

1 T magnetic field




- MDC:
  - $\sigma p/p$: 0.5%@1GeV/c
  - $\sigma_{dE/dx}$: 6% for electrons
- TOF:
  - $\sigma_T$: 68 ps (Barrel)
  - 110 ps (Endcap)
- EMC:
  - $\sigma E/\sqrt{E}$: 2.5(5.0)%@1GeV for barrel(endcap)

# BESIII Collaboration

## Europe (17)

Germany: Bochum Ruhr Univ., GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg Univ. of Mainz, Justus-Liebig-Univ. Giessen, Univ. of Münster, Univ. of Giessen; Russia: Budker Institute of Nuclear Physics, Joint Institute for Nuclear Research; Italy: Ferrara Univ., INFN Laboratori Nazionali di Frascati, Univ. of Turin; The Netherlands : KVI-CART Univ. of Groningen; Sweden: Uppsala Univ.,

Turkey: *Turkish Accelerator Center Particle Factory Group; UK: Univ. of Oxford, Univ. of Manchester.*

## USA (5)

Carnegie Mellon Univ.,

Indiana Univ.,

Univ. of Hawaii,

Univ. of Minnesota,

Univ. of Rochester,

## China (48)

IHEP, Beihang Univ., *Beijing Institute of Petrochemical Technology*, CCAST, Fudan Univ., Guangxi Normal Univ., Guangxi Univ., Hangzhou Normal Univ., Henan Normal Univ., Henan Univ. of Science and Technology, Huazhong Normal Univ., Huangshan College, Hunan Univ., Hunan Univ., Hunan Normal Univ., Institute of modern Physics, Jilin Univ., Lanzhou Univ., Liaoning Normal Univ., Liaoning Univ., Nanjing Normal Univ., Nanjing Univ., Nankai Univ., Peking Univ., Qufu Normal Univ., North China Electric Power Univ., Shanxi Univ., Shanxi Normal Univ., Shandong Normal Univ., Shandong Univ., Shanghai Jiao Tong Univ., Soochow Univ., South China Normal Univ., Southeast Univ., Sun Yat-Sen Univ., Tsinghua Univ., Univ. of Chinese Academy of Sciences , Univ. of Jinan, Univ. of Science and Technology of China, Univ. of Sciences and Technology Liaoning, Univ. of South China, Wuhan Univ., Xinyang Normal Univ., Zhejiang Univ., Zhengzhou Univ.

## Others In ASIA(9)

COMSATS Institute of Information Technology, Pakistan,

Indian Institute of Technology, Madras, India

Institute of Physics and Technology Mongolia,

Seoul National Univ., Korea,

Tokyo University, Japan

Univ. of Punjab, Pakistan

*Suranaree Univ. of Technology, Thailand*

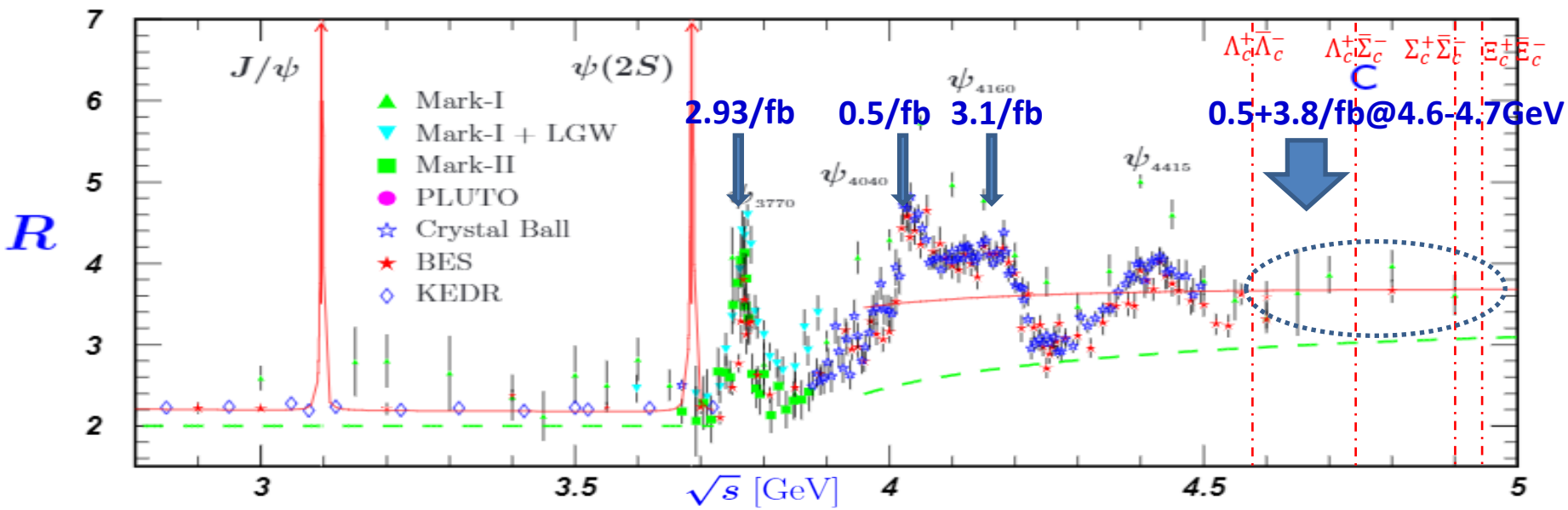
*University of Lahore, Pakistan*

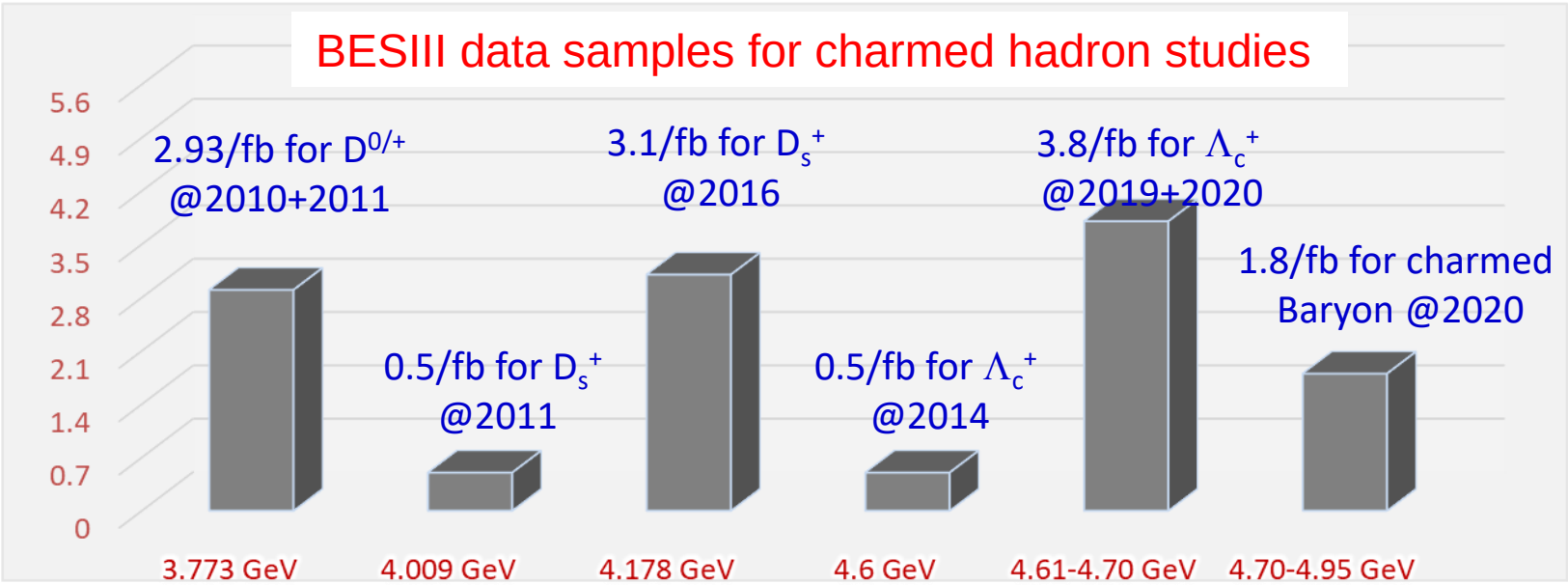
## South America (1)

University of Tarapaca

BESIII: ~500 members from 80 institutes in 17 countries.

# Data for charm hadron studies at BESIII

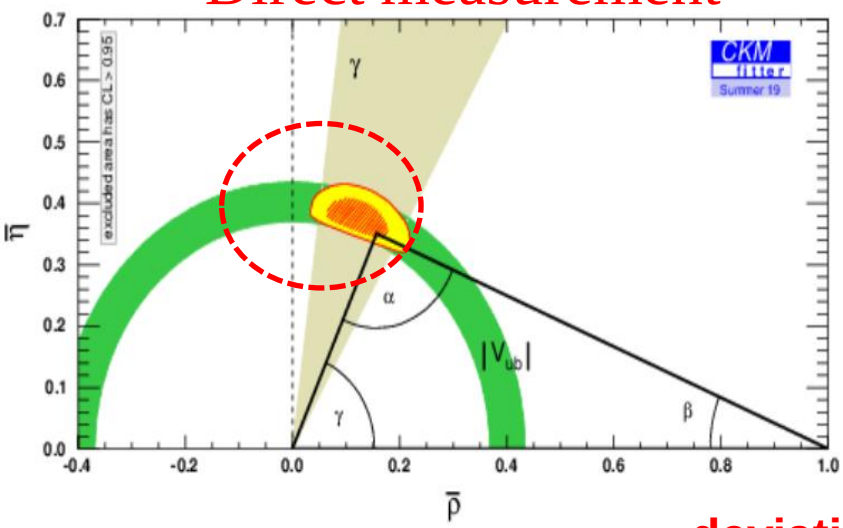


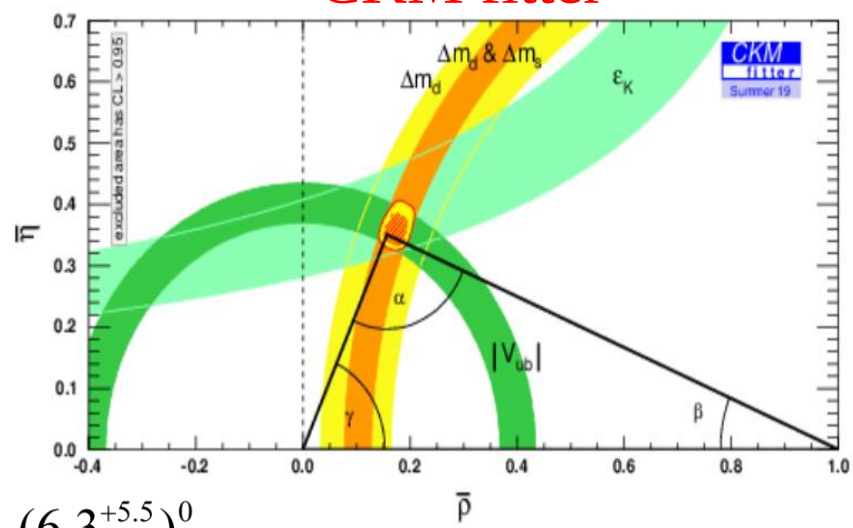
# Measurements of strong-phase parameters

- Phase angle $\gamma/\phi_3$ is the only CKM angle that can be measured in tree-level processes, in which the contribution of non-SM effects is expected to be small [JHEP 01(2014)051].
- Measurement of $\gamma$ provides a benchmark of the SM with negligible theoretical uncertainty.

Direct measurement




CKM fitter

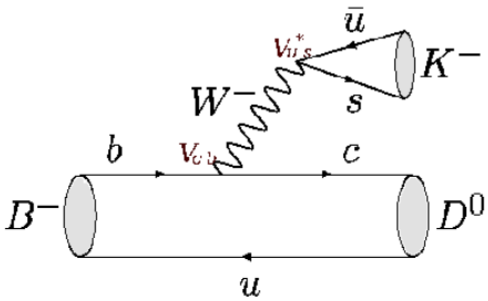


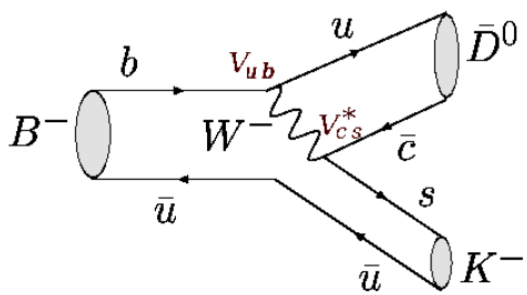

$(72.1^{+5.4}_{-5.7})^0$ ⟷ **deviation:** $(6.3^{+5.5}_{-5.8})^0$ ⟷ $(65.8^{+0.9}_{-1.3})^0$

- An improved knowledge of the measurement of $\gamma$ (precision: ~1°, >5σ) is important to further test the SM and probe for new physics.

# Measurements of strong-phase parameters

- Phase angle $\gamma/\phi_3$ can be measured by studying the interference between $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow \bar{D}^0 K^-$.




$$A(B^- \rightarrow D^0 K^-) = A_B A_D$$

$$A(B^- \rightarrow \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)} A_{\bar{D}}$$

*where $r_B$ is ratio of suppressed to favored amplitudes, $\delta_B$ is the strong-phase difference between the favoured and suppressed amplitudes.*

- Generally, three methods were proposed to measure $\gamma/\phi_3$:
  - ✓ GLW [1]: via $D^0 \rightarrow$ CP eigenstate, $K^+K^-$, $\pi^+\pi^-$, $K_S^0\pi^0$ etc.
  - ✓ ADS [2]: via $D^0 \rightarrow$ CF and DCS, such as $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^+$ etc.
  - ✓ GGSZ [3]: via with $D^0 \rightarrow$ Multi-body self-conjugate decays, $K_s^0\pi^+\pi^-$ etc.

Strong-phase are key inputs.


*[1] M. Gronau, D. London, Phys. Lett. B 253, 483 (1991); M. Gronau, D. Wyler, Phys. Lett. B 265, 172 (1991).*
*[2] D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett. 78, 3257 (1997).*
*[3] A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D 68, 054018 (2003).*

- **ADS approach** [D. Atwood, I. Dunietz and A. Soni, Phys. Rev. Lett. 78, 3257 (1997) ] :

  $B^- \to DK^-$ with $D \to Kn\pi$, such as: $D \to K3\pi$, $K\pi\pi^0$ etc.

$$\Gamma(B^- \to (K^+3\pi)_D K^-) \propto r_B^2 + (r_D^{K3\pi})^2 + 2R_{K3\pi} r_B r_D^{K3\pi} \cdot \cos(\delta_B + \delta_D^{K3\pi} - \gamma)$$

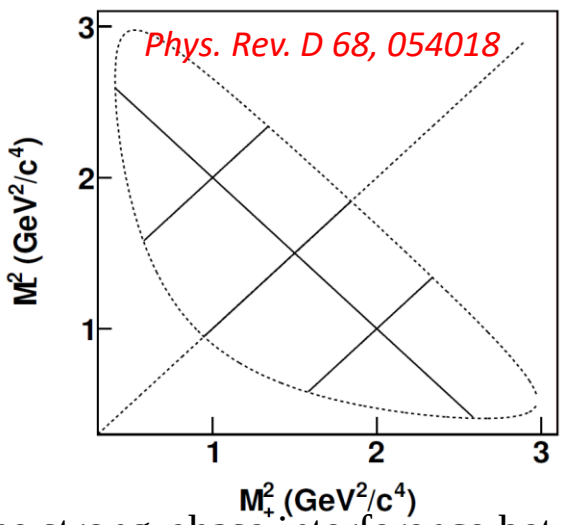
  where $R_{K3\pi}$ is coherence factor, and $\delta_D^{K3\pi}$ is averaged strong-phase difference.

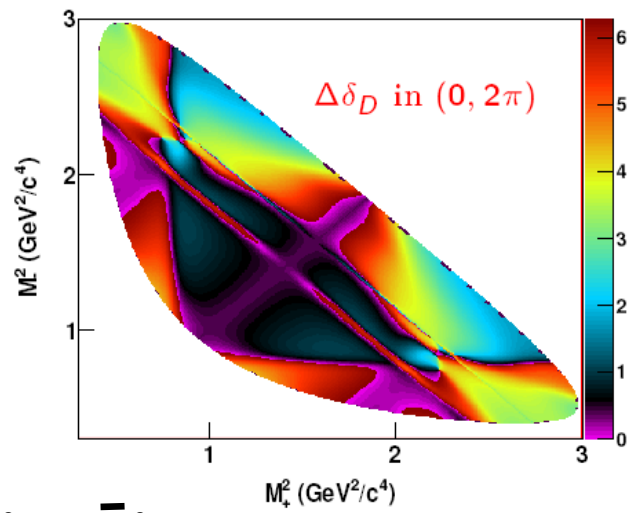
- **GGSZ approach** [A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D 68, 054018] :

  $B^- \to DK^-$ with $D \to$ Multi-body self-conjugate decays, $K_{s/L}^0\pi^+\pi^-$, $K_{s/L}^0K^+K^-$ etc.

  Amplitude:

$$d\Gamma(B^\pm \to \tilde{D}^0 K^\pm) = |f_D(m_\pm^2, m_\mp^2)|^2 + r_B^2|f_D(m_\mp^2, m_\pm^2)|^2 + 2r_B|f_D(m_\pm^2, m_\mp^2)||f_D(m_\mp^2, m_\pm^2)| \times [\cos\Delta\delta_D \cos(\delta_B \pm \phi_3) + [\sin\Delta\delta_D \sin(\delta_B \pm \phi_3)],$$




*The strong-phase difference ($\Delta\delta_D$) calculated based on "Babar 2008" Model.*

The strong-phase interference between $D^0$ and $\bar{D}^0$ can be parameterized as:

$$c_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i |f_D(m_+^2, m_-^2)||f_D(m_-^2, m_+^2)| \cos[\Delta\delta_D(m_+^2, m_-^2)] dm_+^2 dm_-^2$$

$$s_i = \frac{1}{\sqrt{F_i F_{-i}}} \int_i |f_D(m_+^2, m_-^2)||f_D(m_-^2, m_+^2)| \sin[\Delta\delta_D(m_+^2, m_-^2)] dm_+^2 dm_-^2$$

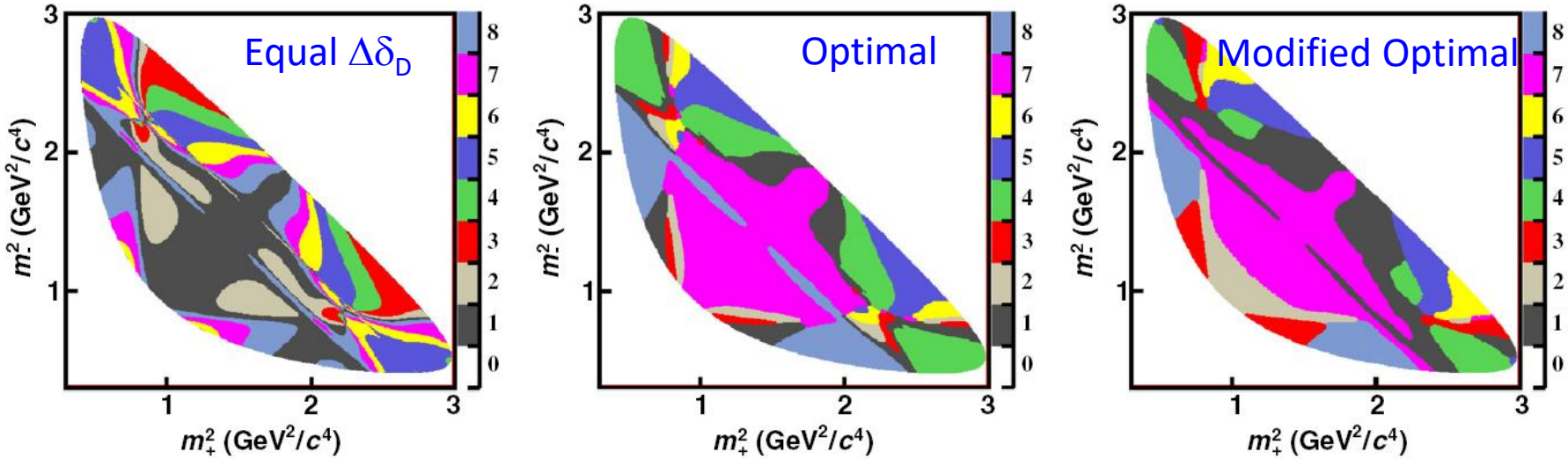
*strong-phase difference:*

$$\Delta\delta_D = \delta_D(m_+^2, m_-^2) - \delta_D(m_-^2, m_+^2)$$

where $c_i$ and $s_i$ are the amplitude-weighted averages of $\cos\Delta\delta_D$ and $\sin\Delta\delta_D$ over each Dalitz-plot bin.

# Strong-phase parameters in $D \rightarrow K_S^0\pi^+\pi^-$

- **Three typical binning schemes [Phys. Rev. D 82, 112006 (2010)]**




**DD-mixing[1], β measurements[2]** — [minimum variation in $\Delta\delta_D$]

**γ measurements[3,4]** — [Optimized sensitivity, no background included]

**γ in Low yields** — [Optimization including backgrounds]

- ✓ "BaBar K-matrix" $D^0 \rightarrow K_S^0\pi^+\pi^-$ model as in Ref. [Phys. Rev. D 78, 034023 (2008)].
- ✓ It should be noted that although the choice of binning is model-dependent, however, a poor choice of model results only in a loss of precision, instead of bias in measuring $\gamma/\phi_3$.


[1] R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 122, 231802 (2019); JHEP 04(2016) 033.
[2] V. Vorobyev et al. (Belle Collaboration), Phys. Rev. D 94, 052004 (2016).
[3] R. Aaij et al. (LHCb Collaboration), Phys. Lett. B 718, 43 (2012); JHEP 10 (2014) 097; JHEP 06 (2016) 131; JHEP 08 (2018) 176.
[4] H. Aihara et al. (Belle Collaboration), Phys. Rev. D 85, 112014 (2012).

# The Quantum Correlated $D\bar{D}$ meson pairs

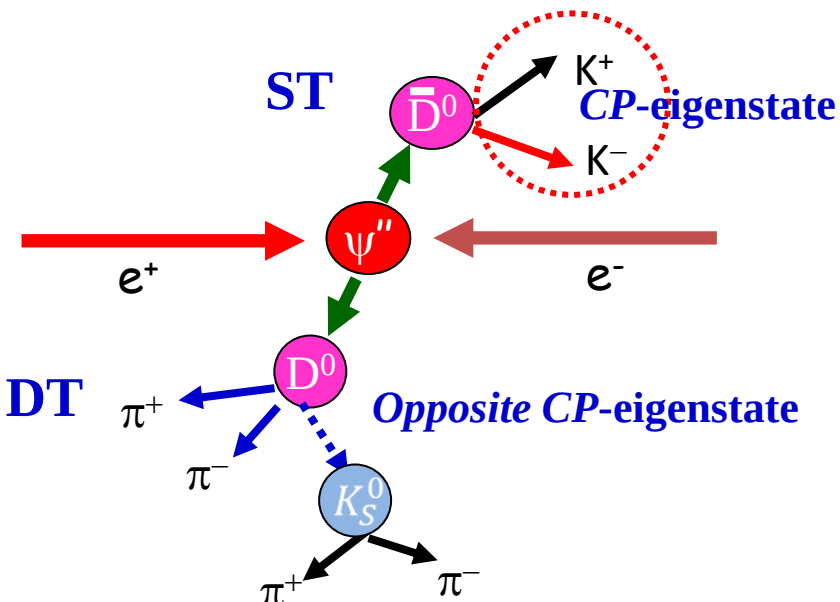
- $\psi(3770)$ is a spin –1 state and therefore the amplitude of $\psi(3770) \rightarrow D^0\bar{D}^0$:

$$(|D^0\rangle|\bar{D}^0\rangle - |\bar{D}^0\rangle|D^0\rangle)/\sqrt{2}$$ [anti-symmetric wave function]

The amplitude for two D mesons to decay to states ***F*** and ***G*** is [PRD68, 033003 (2003)]:

$$\Gamma(F|G) = \Gamma_0\,[A_F^2\bar{A}_G^2 + \bar{A}_F^2 A_G^2 - 2R_F R_G A_F \bar{A}_F A_G \bar{A}_G \cos[\delta_D^F - \delta_D^G]]$$

- Hence, the coherence factors $R_F$, the strong-phase difference $\delta_D^F$, can be extracted based on the study of the quantum correlated DD meson pairs.




The DT mode $K^+K^-$ *vs.* $K_S^0\pi^+\pi^-$ is selected as an example.

- ✓ **Single tag (ST) samples:**
  decay products of only one D meson are reconstructed
- ✓ **Double tag (DT) samples:**
  decay products of both D mesons are reconstructed
- ✓ **Some typical reconstructed D decay modes**

| Tag group | |
|---|---|
| Flavor | $K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^-\pi^+, K^+e^-\bar{\nu}_e$ |
| $CP$-even | $K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0, K_L^0\pi^0, \pi^+\pi^-\pi^0$ |
| $CP$-odd | $K_S^0\pi^0, K_S^0\eta, K_S^0\omega, K_S^0\eta', K_L^0\pi^0\pi^0$ |
| Mixed-$CP$ | $K_S^0\pi^+\pi^-$ |

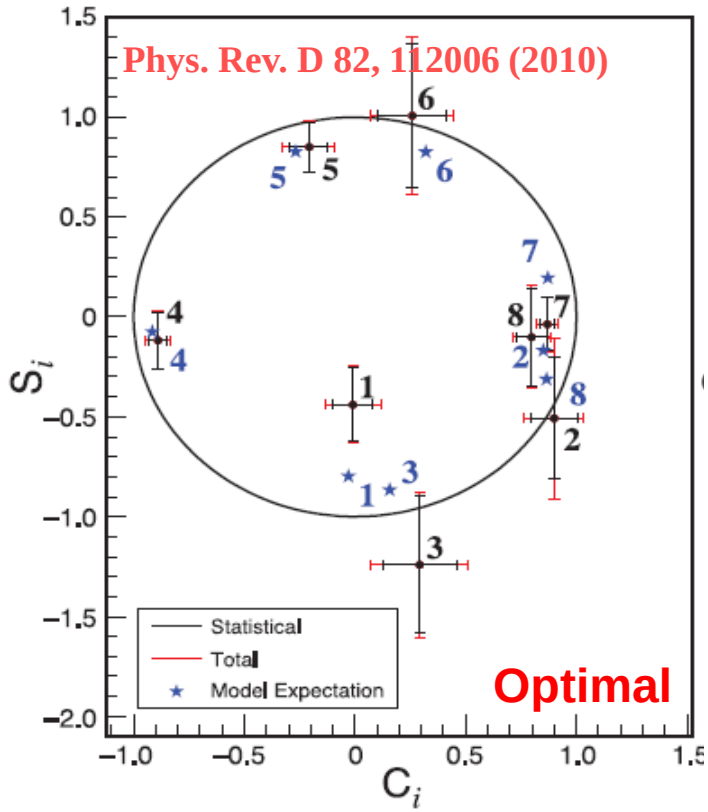
- ✓ **Expected events for $K_S\pi^+\pi^-$ .vs. CP-eigenstate:**

$$f_{CP\pm} = \frac{1}{\sqrt{2}}[f_D(m_+^2, m_-^2) \pm f_D(m_-^2, m_+^2)]$$

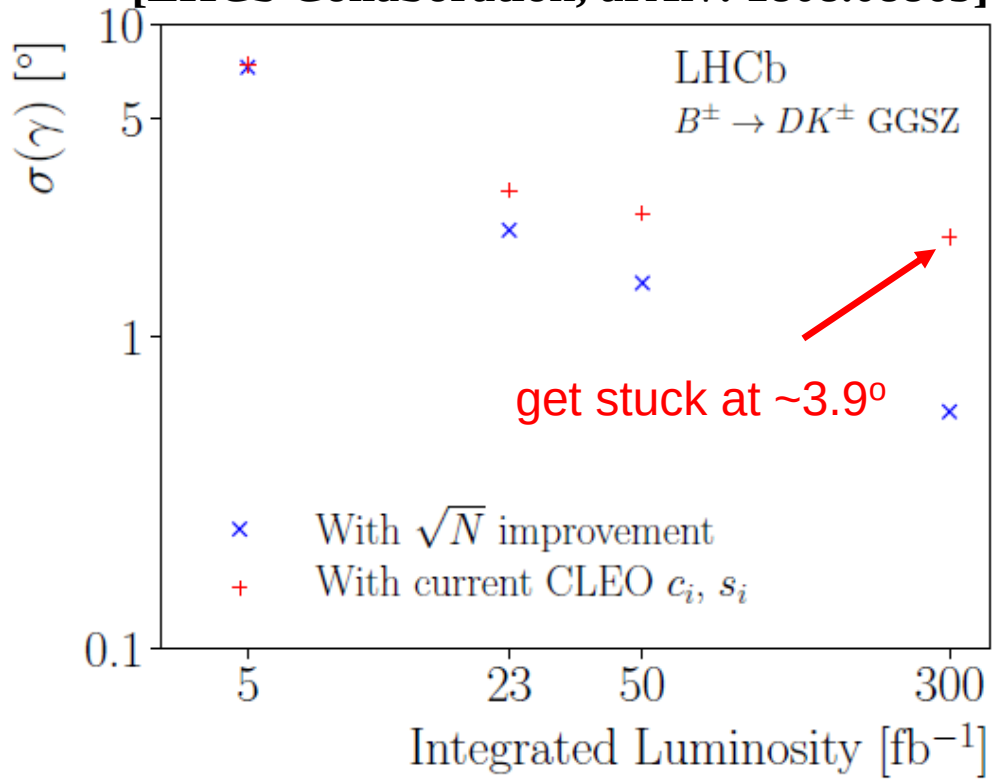
$$M_i^{\pm} = h_{CP\pm}(K_i \pm 2c_i\sqrt{K_i K_{-i}} + K_{-i})$$

# Strong-phase parameters in $D \rightarrow K_S^0 \pi^+ \pi^-$

✓ **Results of $c_i$ and $s_i$ in optimal binning from CLEO experiments.**




**[LHCb Collaboration, arXiv: 1808.08865]**




✓ The systematic uncertainty in measurement of $\gamma$ due to the input of strong-phase parameters is 3.9° for optimal binning. The overall sensitivity of $\gamma$ is systematically limited to ~3.9° for model-independent GGSZ approach.

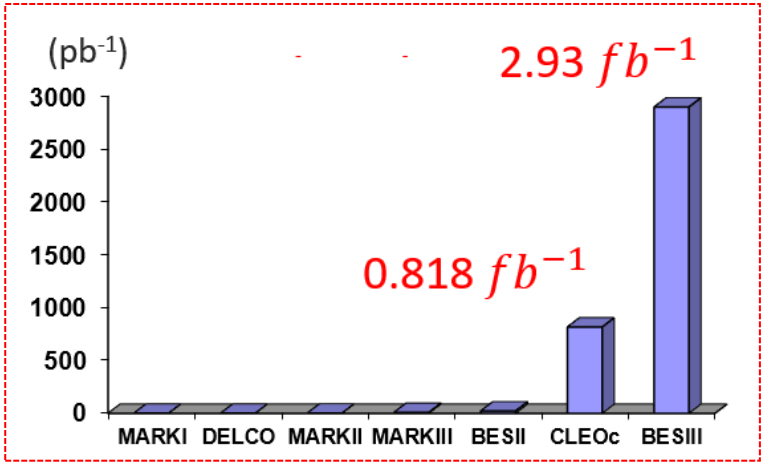
✓ *Therefore, improved measurements in $c_i$ & $s_i$ from BESIII are essential for degree-level precision of measuring $\gamma$ via model-independent GGSZ approach.*

# $\psi(3770) \rightarrow D^0\bar{D}^0$ samples at BESIII

- BESIII is the only machine running at $\tau$-charm energy region. The quantum-correlated studies are key to constrain the $\gamma/\phi_3$ measurement at LHCb upgrades 1(2) and Belle II experiments.

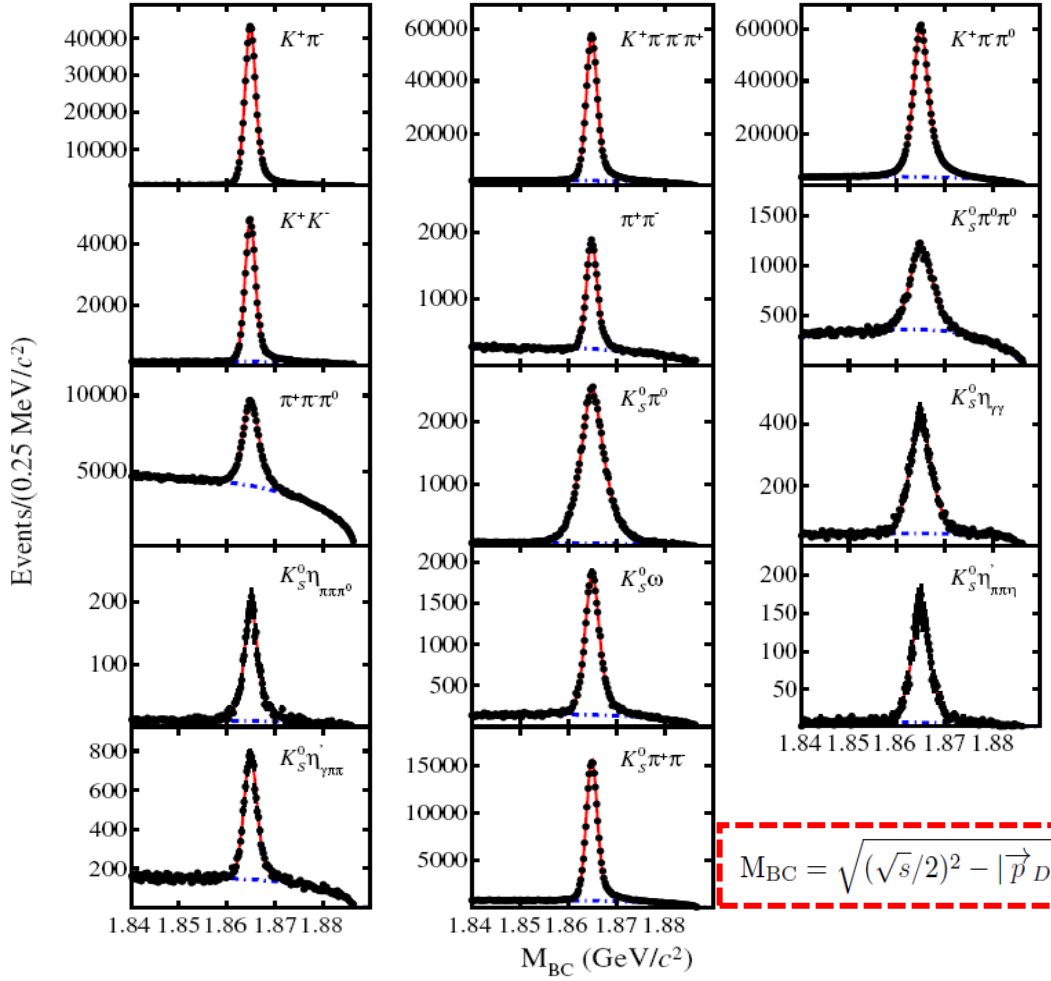
**2.93/fb @ 3.773 GeV**

The largest $\psi(3770)$ data sample



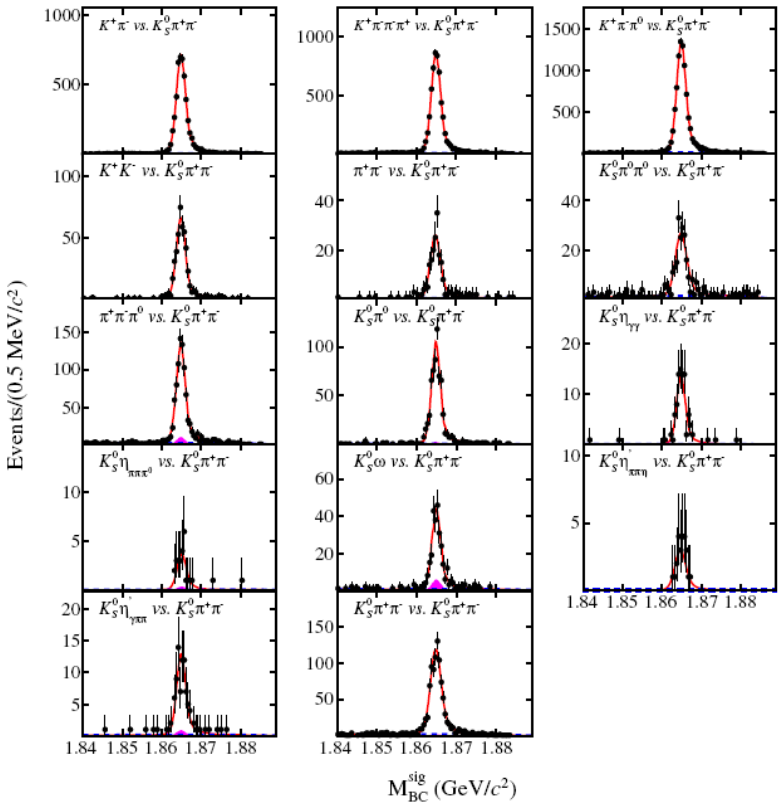

- ✓ Good performance of BESIII detector: high tracking & PID efficiencies; high purity samples.

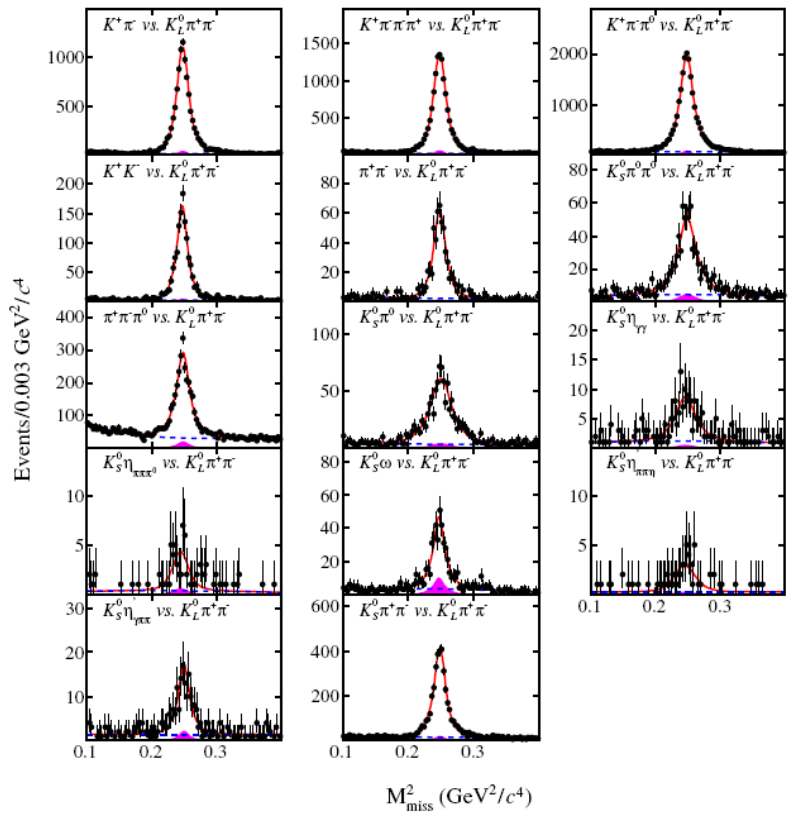
**beam-constrained mass distributions in data**

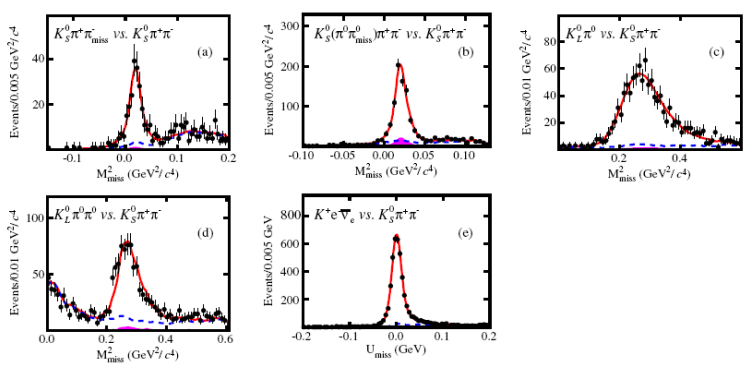



$$M_{BC} = \sqrt{(\sqrt{s}/2)^2 - |\vec{p}_{D_{tag}}|^2}$$

# DT events for $D \rightarrow K_{S/L}{}^{0}\pi^{+}\pi^{-}$ in data



*DT events at BESIII:*

$CP-eigenstate\ vs. K_S^0\pi^+\pi^-$: 5.3×CLEO

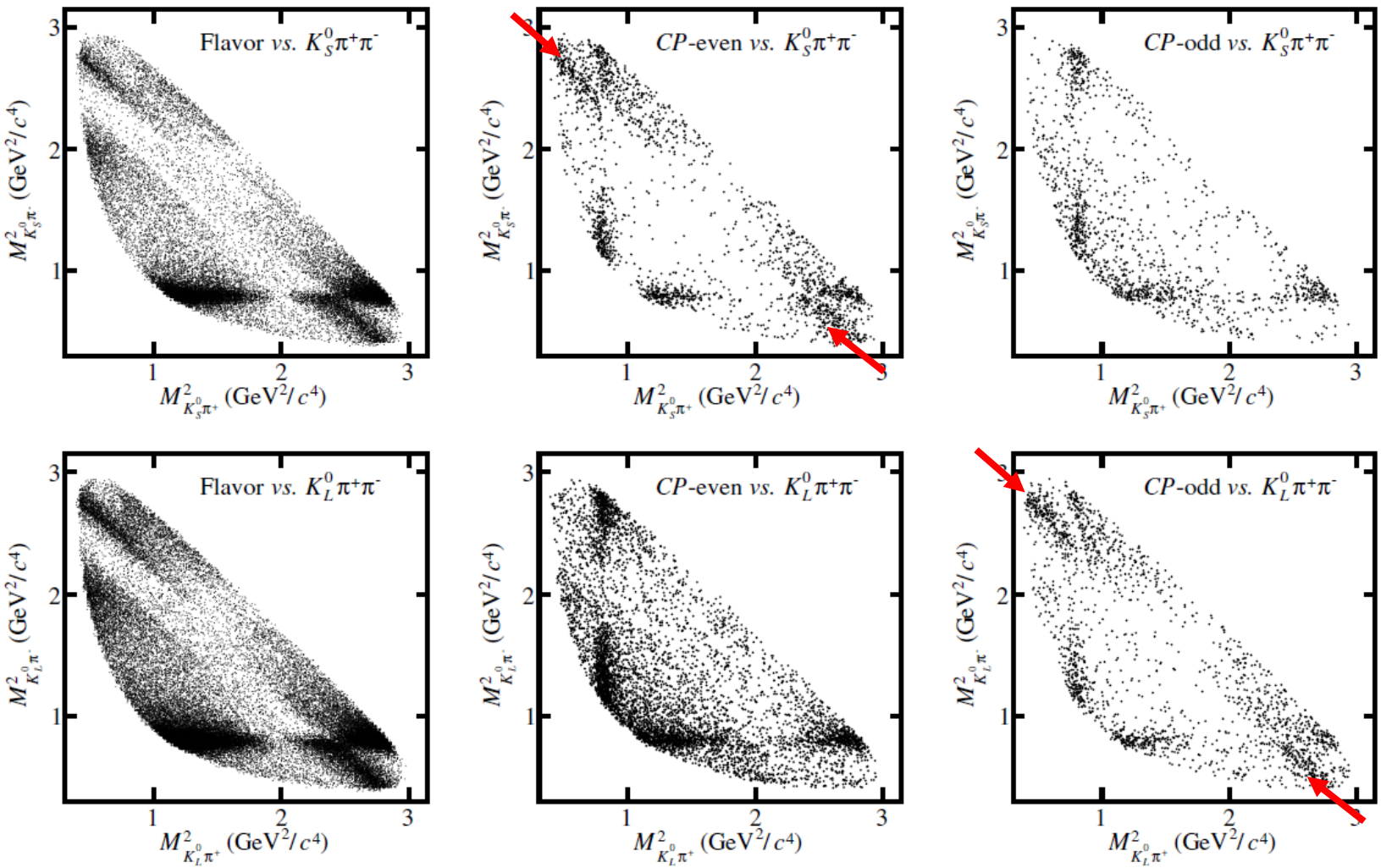
$CP-eigenstate\ vs. K_L^0\pi^+\pi^-$: 9.2×CLEO

$K_S^0\pi^+\pi^-\ vs. K_S^0\pi^+\pi^-$: 3.9×CLEO

$K_L^0\pi^+\pi^-\ vs. K_S^0\pi^+\pi^-$ : 2.9×CLEO

# Dalitz plots for $D \rightarrow K_{S/L}\pi^+\pi^-$ observed in data

- Effect of quantum correlation is immediately seen in Dalitz plots.

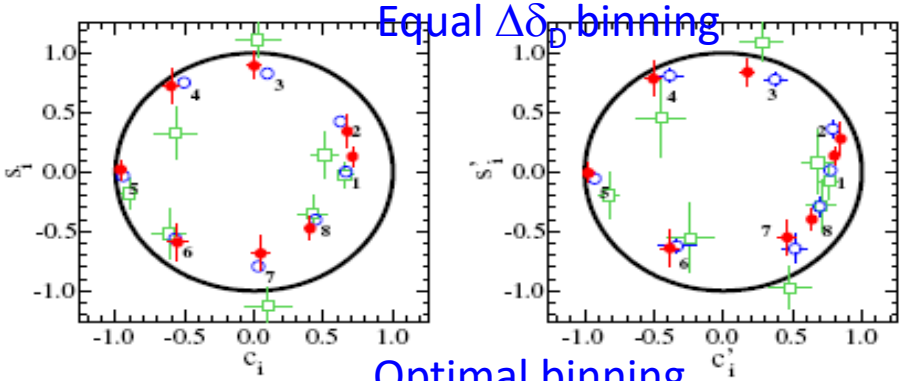



The CP-odd component $K_S^0\rho(770)^0$ is visible in CP-even tagged $K_S^0\pi^+\pi^-$ decays, but is absent in CP-odd tagged $K_S^0\pi^+\pi^-$ decays.

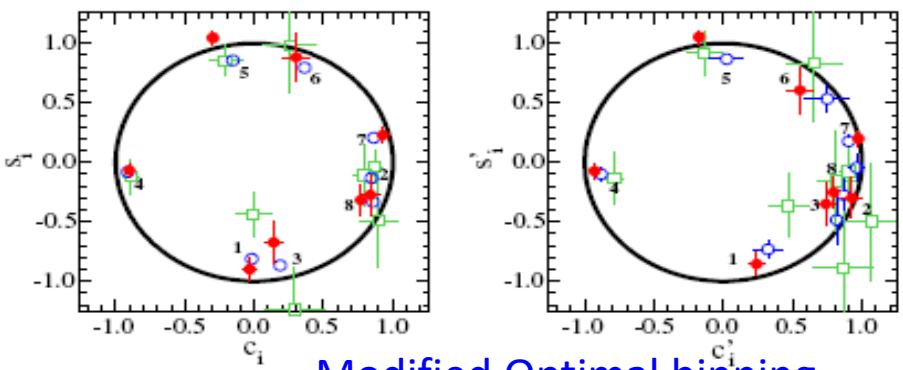
# The strong-phase parameters ($c_i^{(\prime)}$, $s_i^{(\prime)}$) in $D \to K_{S/L}^0 \pi^+\pi^-$

✓ The $c_i^{(\prime)}$ and $s_i^{(\prime)}$ measured in this work, the expected results and the CLEO results.

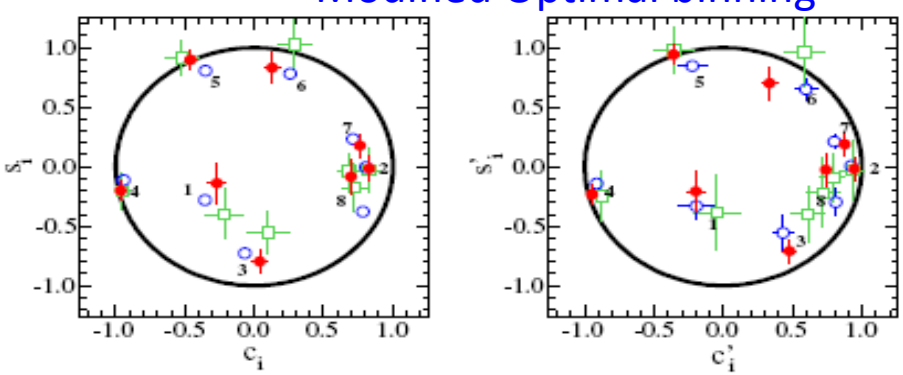
Equal $\Delta\delta_D$ binning



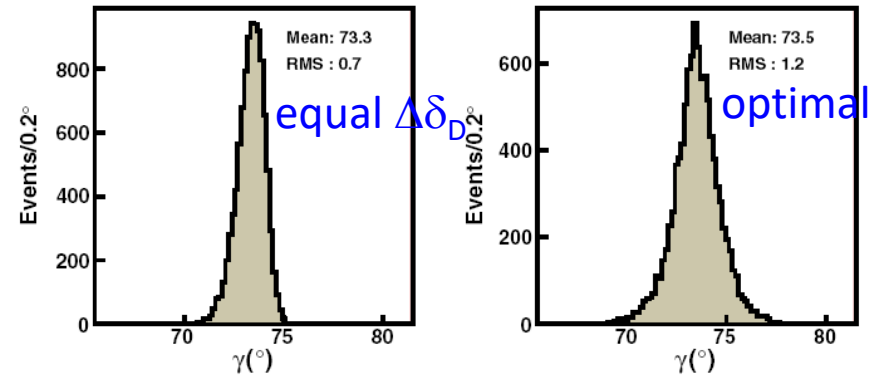

Optimal binning




Modified Optimal binning




✓ The expected uncertainty for $\gamma$ with $B^- \to DK^-$, $D \to K_S^0 \pi^+\pi^-$.




✓ Limited by statistical errors, especially for $s_i$ and $s_i'$.

✓ On average a factor of ~2.5 (2.0) more precise for $c_i$ ($s_i$) and ~2.8 (2.2) more precise for $c'_i$ ($s'_i$) than CLEO.

✓ The associated uncertainty on $\gamma/\phi_3$ is expected to be roughly a factor of three smaller than that from CLEO analysis.

✓ The improved precision on $c'_i$ and $s'_i$ are important for Belle-II in $\gamma/\phi_3$ measurement with $B^- \to DK^-$, $D \to K_L^0 \pi^+\pi^-$.

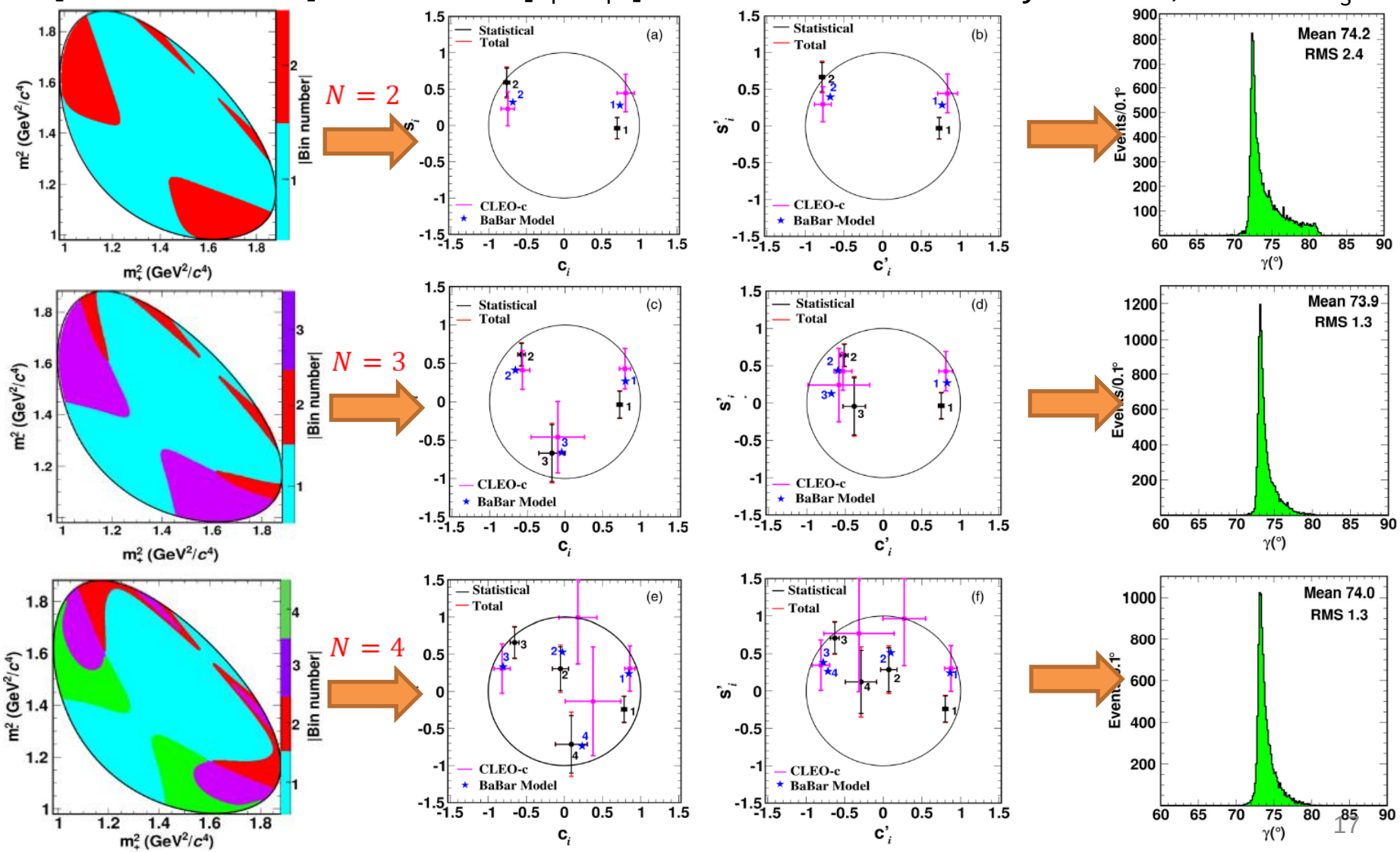
# The strong-phase parameters in $D \to K_{S/L}^0 K^+ K^-$

[Phys. Rev. D 102, 152008(2020)]

Equal $\Delta\delta_D$ binning [PRD78,034023(2008)]

Strong-phase parameters $[c_i^{(\prime)}, s_i^{(\prime)}]$ measured in data

expected uncertainties on $\gamma$ by $B^- \to DK^-$, with $D \to K_S K^+ K^-$



# Measurements of coherence factors in $D \to K^-\pi^+\pi^+\pi^-$ and $D \to K^-\pi^+\pi^0$

[JHEP05(2021)164]

- For $D \to K^- n\pi$, the coherence factor $R_S$, the amplitude ratio $r_D$ and strong-phase difference $\delta_D$ between the CF and DCS amplitude averaged over phase space:

$$R_S e^{-i\delta_D^S} = \frac{\int \mathcal{A}_S^\star(\mathrm{x})\mathcal{A}_{\bar{S}}(\mathrm{x})\mathrm{dx}}{A_S A_{\bar{S}}} \quad \text{and} \quad r_D^S = A_{\bar{S}}/A_S$$

*$A(s)$ is the decay amplitude of $D \to K^- n\pi$.*

- The amplitude for two D mesons decay to states S(single tag) and T(double tag):

$$\Gamma(S|T) = A_S^2 A_T^2 \left[(r_D^S)^2 + (r_D^T)^2 - 2R_S R_T r_D^S r_D^T \cos(\delta_D^T - \delta_D^S)\right]$$

| | | |
|---|---|---|
| Flavour | Like sign | $K^-\pi^+\pi^+\pi^-$, $K^-\pi^+\pi^0$, $K^-\pi^+$ |
| | Opposite sign | $K^+\pi^-\pi^-\pi^+$, $K^+\pi^-\pi^0$, $K^+\pi^-$ |
| $CP$ | Even | $K^+K^-$, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$, $K_L^0\pi^0$, $K_L^0\omega$, $\pi^+\pi^-\pi^0$ |
| | Odd | $K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$, $K_S^0\eta'$, $K_S^0\phi$, $K_L^0\pi^0\pi^0$ |
| Self-conjugate | | $K_S^0\pi^+\pi^-$ |

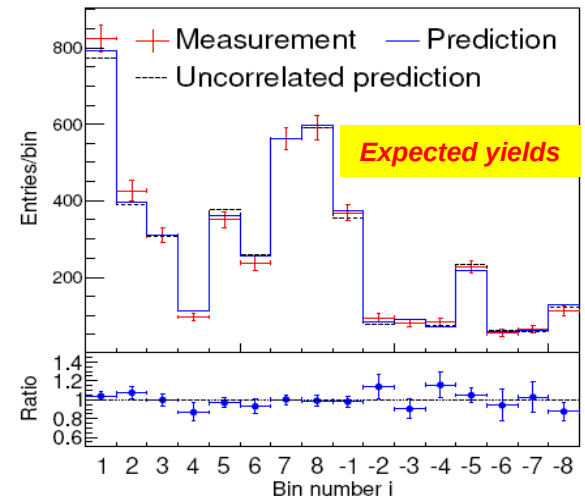
- ✓ *For CP tags:* $\Gamma(S|CP) = A_S^2 A_{CP}^2 \left(1 + (r_D^S)^2 - 2\lambda R_S r_D^S \cos\delta_D^S\right)$
- ✓ *For Like-sign tags:* $\Gamma(S|S) = A_S^2 A_{\bar{S}}^2 \left[1 - R_S^2\right]$
- ✓ *For Like-sign tags:* $Y_i^S = H\left(K_i + \left(r_D^S\right)^2 K_{-i} - 2r_D^S R_S \sqrt{K_i K_{-i}}\left[c_i \cos\delta_D^S - s_i \sin\delta_D^S\right]\right)$

# Measurements of coherence factors in $D \to K^-\pi^+\pi^+\pi^-$ and $D \to K^-\pi^+\pi^0$

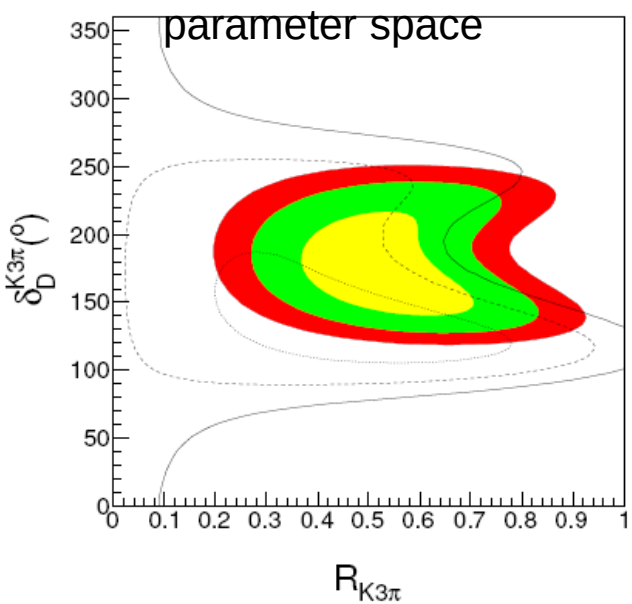
[JHEP05(2021)164]

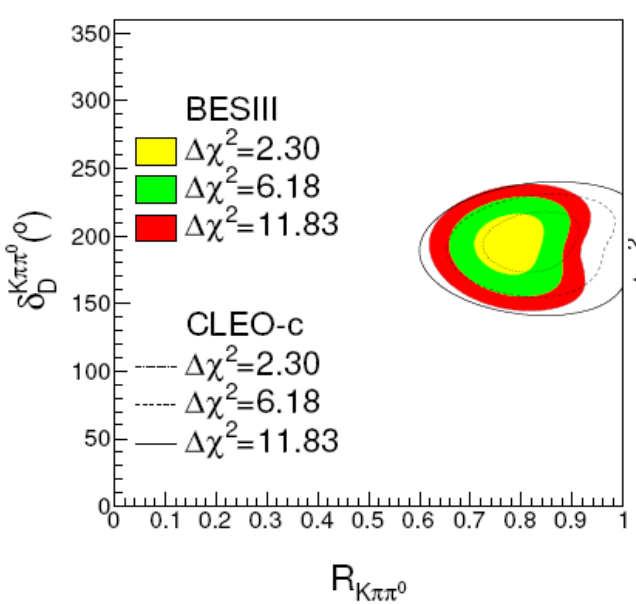
- Fitted central values for strong-phase parameters.

| Parameter | Global fit | Binned fit | | | |
|---|---|---|---|---|---|
| | | Bin 1 | Bin 2 | Bin 3 | Bin 4 |
| $R_{K3\pi}$ | $0.52^{+0.12}_{-0.10}$ | $0.58^{+0.25}_{-0.33}$ | $0.78^{+0.50}_{-0.21}$ | $0.85^{+0.15}_{-0.12}$ | $0.45^{+0.33}_{-0.37}$ |
| $\delta_D^{K3\pi}$ | $\left(167^{+31}_{-19}\right)^\circ$ | $\left(131^{+124}_{-16}\right)^\circ$ | $\left(150^{+37}_{-39}\right)^\circ$ | $\left(176^{+57}_{-21}\right)^\circ$ | $\left(274^{+19}_{-30}\right)^\circ$ |
| $r_D^{K3\pi}$ $(\times 10^{-2})$ | $5.46 \pm 0.09$ | $5.44^{+0.45}_{-0.14}$ | $5.80^{+0.14}_{-0.13}$ | $5.75^{+0.41}_{-0.14}$ | $5.09^{+0.14}_{-0.14}$ |
| $R_{K\pi\pi^0}$ | $0.78 \pm 0.04$ | $0.80 \pm 0.04$ | | | |
| $\delta_D^{K\pi\pi^0}$ | $\left(196^{+14}_{-15}\right)^\circ$ | $(200 \pm 11)^\circ$ | | | |
| $r_D^{K\pi\pi^0}$ $(\times 10^{-2})$ | $4.40 \pm 0.11$ | $4.41 \pm 0.11$ | | | |

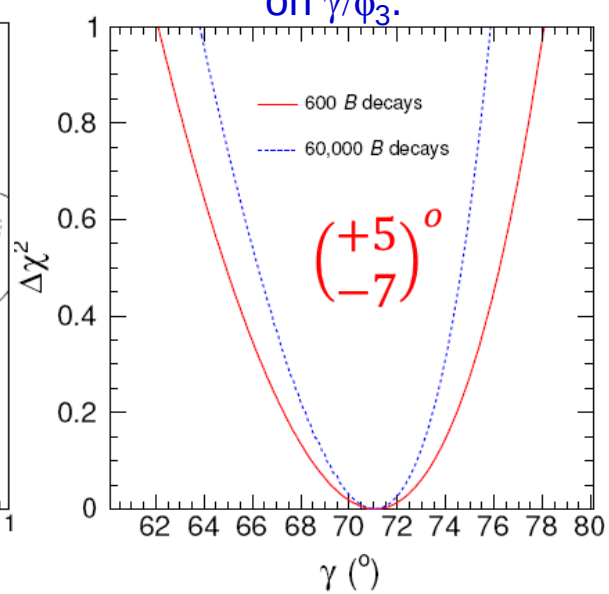



- ✓ Scans of $\Delta\chi^2$ in the global ($R^{K3\pi}$, $\delta_D^{K3\pi}$) and ($R_{K\pi\pi0}$, $\delta_D^{K\pi\pi0}$) parameter space




- ✓ Expected uncertainty on $\gamma/\phi_3$.



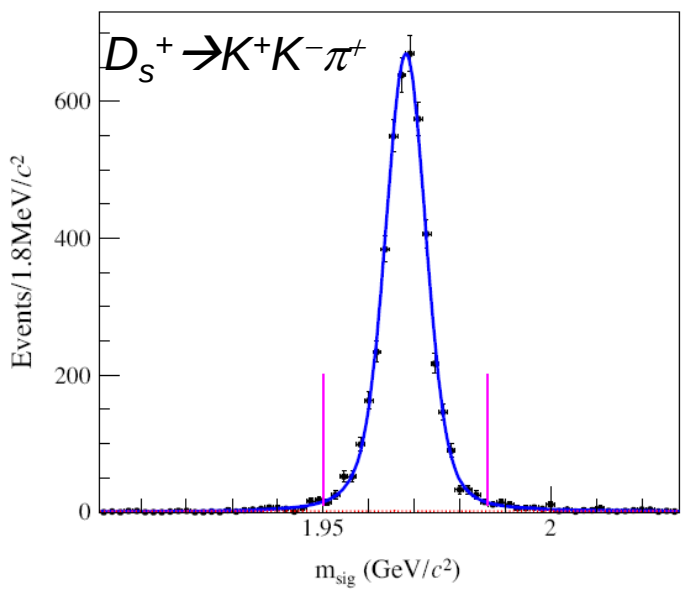
# Amplitude analysis of $D_s^+ \to K^+K^-\pi^+$

- Hadronic decay $D_s^+ \to K^+K^-\pi^+$ is usually used as the reference mode (Large BF). The improvement BF measurement is also important for $D_s^+$ decay channels.
- Knowledge of the decay amplitudes can reduce the systematic uncertainties related to the substructures.
- The BFs of $D_s^+ \to \bar{K}^*(892)^0 K^+$ and $D_s^+ \to \varphi(1020)\,\pi^+$ measured in this analysis can help to refine theoretical models.

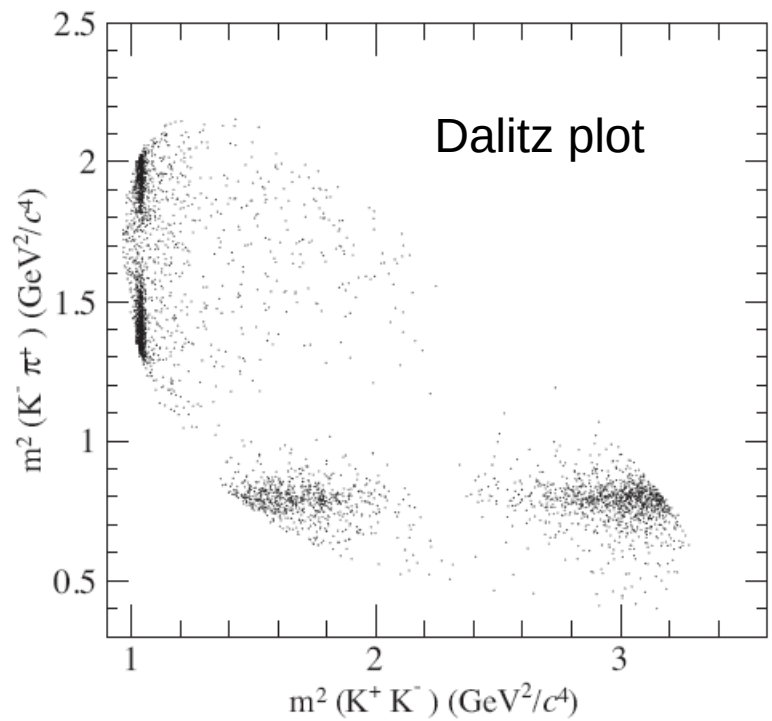
3.19/fb@4.178 GeV

- DT method, recoiling against eight ST modes.

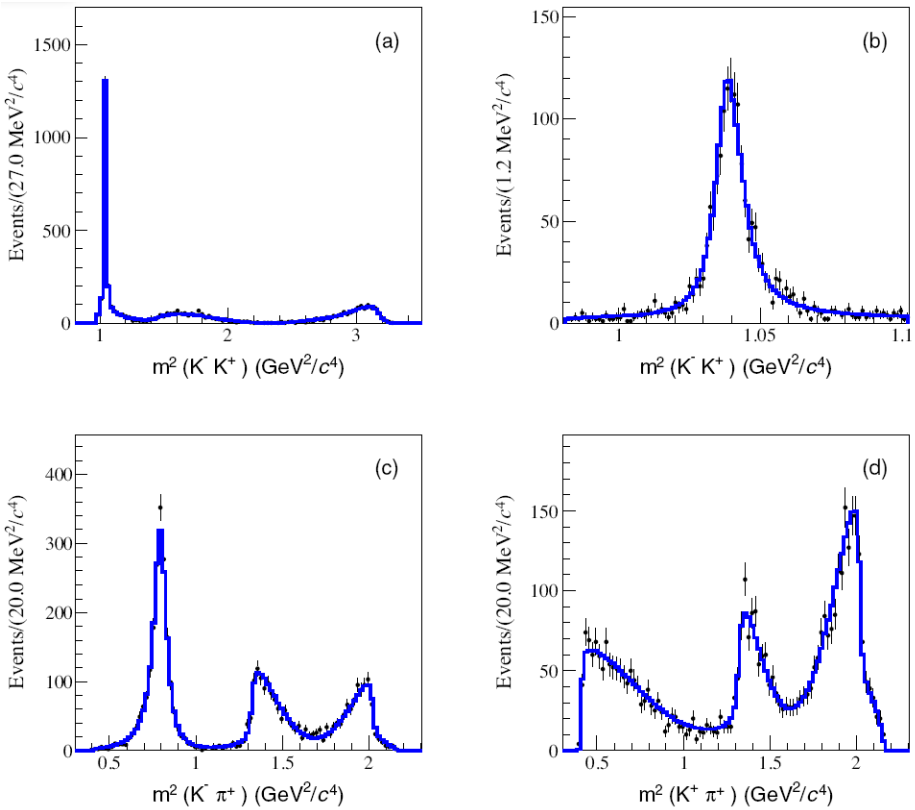
[Phys. Rev. D 104, 012016(2021)]




4399 signal events with purity 99.6%



## Amplitude results:




## Absolute branching fraction by DT:

$$\mathcal{B}_{\rm sig} = \frac{N_{\rm sig}^{\rm obsA} + 2N_{\rm sig}^{\rm obsB}}{\sum_\alpha Y_{\rm ST}^\alpha \epsilon_{\rm tag,sig}^\alpha / \epsilon_{\rm tag}^\alpha}$$

| $\mathcal{B}\ (D_s^+ \to K^+K^-\pi^+)$ (%) | Collaboration |
|---|---|
| $5.55 \pm 0.14_{\rm stat} \pm 0.13_{\rm sys}$ | CLEO [25] |
| $5.06 \pm 0.15_{\rm stat} \pm 0.21_{\rm sys}$ | Belle [26] |
| $5.78 \pm 0.20_{\rm stat} \pm 0.30_{\rm sys}$ | *BABAR* [27] |
| $5.47 \pm 0.08_{\rm stat} \pm 0.13_{\rm sys}$ | BESIII(this analysis) |

Input BF & amplitudes

| Process | BF<br>BESIII (this analysis) |
|---|---|
| $D_s^+ \to \bar{K}^*(892)^0K^+,\ \bar{K}^*(892)^0 \to K^-\pi^+$ | $2.64 \pm 0.06_{\rm stat} \pm 0.07_{\rm sys}$ |
| $D_s^+ \to \phi(1020)\pi^+,\ \phi(1020) \to K^+K^-$ | $2.21 \pm 0.05_{\rm stat} \pm 0.07_{\rm sys}$ |
| $D_s^+ \to S(980)\pi^+,\ S(980) \to K^+K^-$ | $1.05 \pm 0.04_{\rm stat} \pm 0.06_{\rm sys}$ |
| $D_s^+ \to \bar{K}_0^*(1430)^0K^+,\ \bar{K}_0^*(1430)^0 \to K^-\pi^+$ | $0.16 \pm 0.03_{\rm stat} \pm 0.03_{\rm sys}$ |
| $D_s^+ \to f_0(1710)\pi^+,\ f_0(1710) \to K^+K^-$ | $0.10 \pm 0.02_{\rm stat} \pm 0.03_{\rm sys}$ |
| $D_s^+ \to f_0(1370)\pi^+,\ f_0(1370) \to K^+K^-$ | $0.07 \pm 0.02_{\rm stat} \pm 0.01_{\rm sys}$ |
| $D_s^+ \to K^+K^-\pi^+$ total BF | $5.47 \pm 0.08_{\rm stat} \pm 0.13_{\rm sys}$ |

The best precision to data.

| Amplitude | Magnitude ($\rho$) | Phase ($\phi$) | FFs (%) | Significance ($\sigma$) |
|---|---|---|---|---|
| $D_s^+ \to \bar{K}^*(892)^0K^+$ | 1.0 (fixed) | 0.0 (fixed) | $48.3 \pm 0.9 \pm 0.6$ | $>20$ |
| $D_s^+ \to \phi(1020)\pi^+$ | $1.09 \pm 0.02 \pm 0.01$ | $6.22 \pm 0.07 \pm 0.04$ | $40.5 \pm 0.7 \pm 0.9$ | $>20$ |
| $D_s^+ \to S(980)\pi^+$ | $2.88 \pm 0.14 \pm 0.17$ | $4.77 \pm 0.07 \pm 0.07$ | $19.3 \pm 1.7 \pm 2.0$ | $>20$ |
| $D_s^+ \to \bar{K}_0^*(1430)^0K^+$ | $1.26 \pm 0.14 \pm 0.16$ | $2.91 \pm 0.20 \pm 0.23$ | $3.0 \pm 0.6 \pm 0.5$ | 8.6 |
| $D_s^+ \to f_0(1710)\pi^+$ | $0.79 \pm 0.08 \pm 0.14$ | $1.02 \pm 0.12 \pm 0.06$ | $1.9 \pm 0.4 \pm 0.6$ | 9.2 |
| $D_s^+ \to f_0(1370)\pi^+$ | $0.58 \pm 0.08 \pm 0.08$ | $0.59 \pm 0.17 \pm 0.46$ | $1.2 \pm 0.4 \pm 0.2$ | 6.4 |

# Amplitude analysis of $D_s^+ \to K_s^0\pi^+\pi^0$

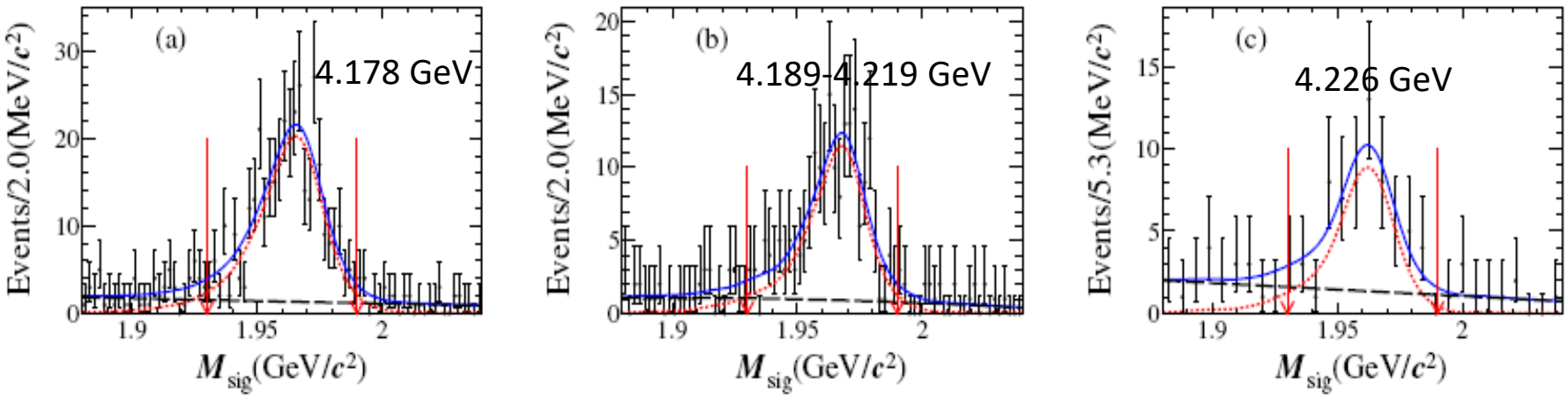
- Hadronic decay $D_s^+ \to K_s^0\pi^+\pi^0$ is usually used as the reference mode. Hence, the improvement BF measurement is also important for $D_s^+$ decay channels.
- Knowledge of the decay amplitudes can reduce the systematic uncertainties related to the substructures.
- The BFs of $D_s^+ \to K^*(892)^0\pi^+$ and $D_s^+ \to K^*(892)^+\pi^0$ measured in this analysis can help to refine theoretical models.

6.32/fb@4.178-4.226 GeV

- DT method, recoiling against eight ST modes.

[JHEP06(2021)181]

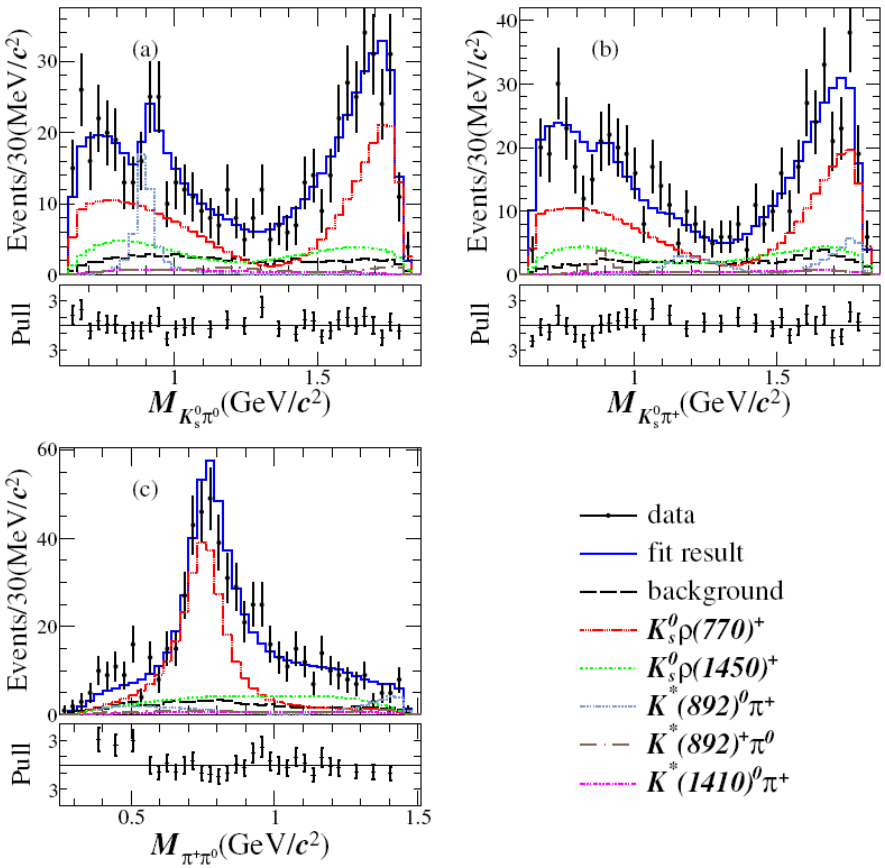
The signals for $D_s^+ \to K_s^0\pi^+\pi^0$ selected from data samples.




- ✓ Totally, about 600 signal events are observed from data.
- ✓ The purity of the selected data sample is roughly 86%.

# Amplitude analysis of $D_s^+ \to K_s^0 \pi^+ \pi^0$

- Amplitude results:




- Absolute branching fraction by DT:

$$\mathcal{B}_{\rm sig} = \frac{N^{\rm DT}_{\rm total}}{\mathcal{B}_{K^0_S\to\pi^+\pi^-}\mathcal{B}_{\pi^0\to\gamma\gamma}\sum_{\alpha,i} N^{\rm ST}_{\alpha,i}\epsilon^{\rm DT}_{\alpha,{\rm sig},i}/\epsilon^{\rm ST}_{\alpha,i}},$$

$$Br(D_s^+ \to K_S^0\pi^+\pi^0) = (5.43 \pm 0.30 \pm 0.15) \times 10^{-3}$$

Input BF & amplitudes

| Intermediate process | BF ($10^{-3}$) |
|---|---|
| $D_s^+ \to K_S^0\rho^+$ | $2.73 \pm 0.42 \pm 0.22$ |
| $D_s^+ \to K_S^0\rho(1450)^+$ | $1.11 \pm 0.24 \pm 0.24$ |
| $D_s^+ \to K^*(892)^0\pi^+$ | $0.45 \pm 0.12 \pm 0.05$ |
| $D_s^+ \to K^*(892)^+\pi^0$ | $0.25 \pm 0.08 \pm 0.02$ |
| $D_s^+ \to K^*(1410)^0\pi^+$ | $0.18 \pm 0.09 \pm 0.03$ |

| Amplitude | Magnitude ($\rho_n$) | Phase ($\phi_n$) | FF (%) | Significance ($\sigma$) |
|---|---|---|---|---|
| $D_s^+ \to K_S^0\rho^+$ | 1.0(fixed) | 0.0(fixed) | $50.2 \pm 7.2 \pm 3.9$ | >10 |
| $D_s^+ \to K_S^0\rho(1450)^+$ | $2.7 \pm 0.5$ | $2.2 \pm 0.2 \pm 0.1$ | $20.4 \pm 4.3 \pm 4.4$ | >10 |
| $D_s^+ \to K^*(892)^0\pi^+$ | $0.4 \pm 0.1$ | $3.2 \pm 0.2 \pm 0.1$ | $8.4 \pm 2.2 \pm 0.9$ | 5.0 |
| $D_s^+ \to K^*(892)^+\pi^0$ | $0.3 \pm 0.1$ | $0.2 \pm 0.2 \pm 0.2$ | $4.6 \pm 1.4 \pm 0.4$ | 4.0 |
| $D_s^+ \to K^*(1410)^0\pi^+$ | $0.8 \pm 0.2$ | $0.2 \pm 0.3 \pm 0.1$ | $3.3 \pm 1.6 \pm 0.5$ | 3.7 |

# Summary

- BESIII had collected the largest data samples for study of charmed hadrons, including $D^0$, $D^+$, $D_s^+$ and $\Lambda_c^+$ etc.
- A range of important and unique results had been published in recent years.
- BESIII will collected more 17/fb data at $\psi(3770)$ resonance peak.
- More important results are expected in charmed hadron decays at BESIII.

# Thanks!