Charm Physics at BESIII experiments

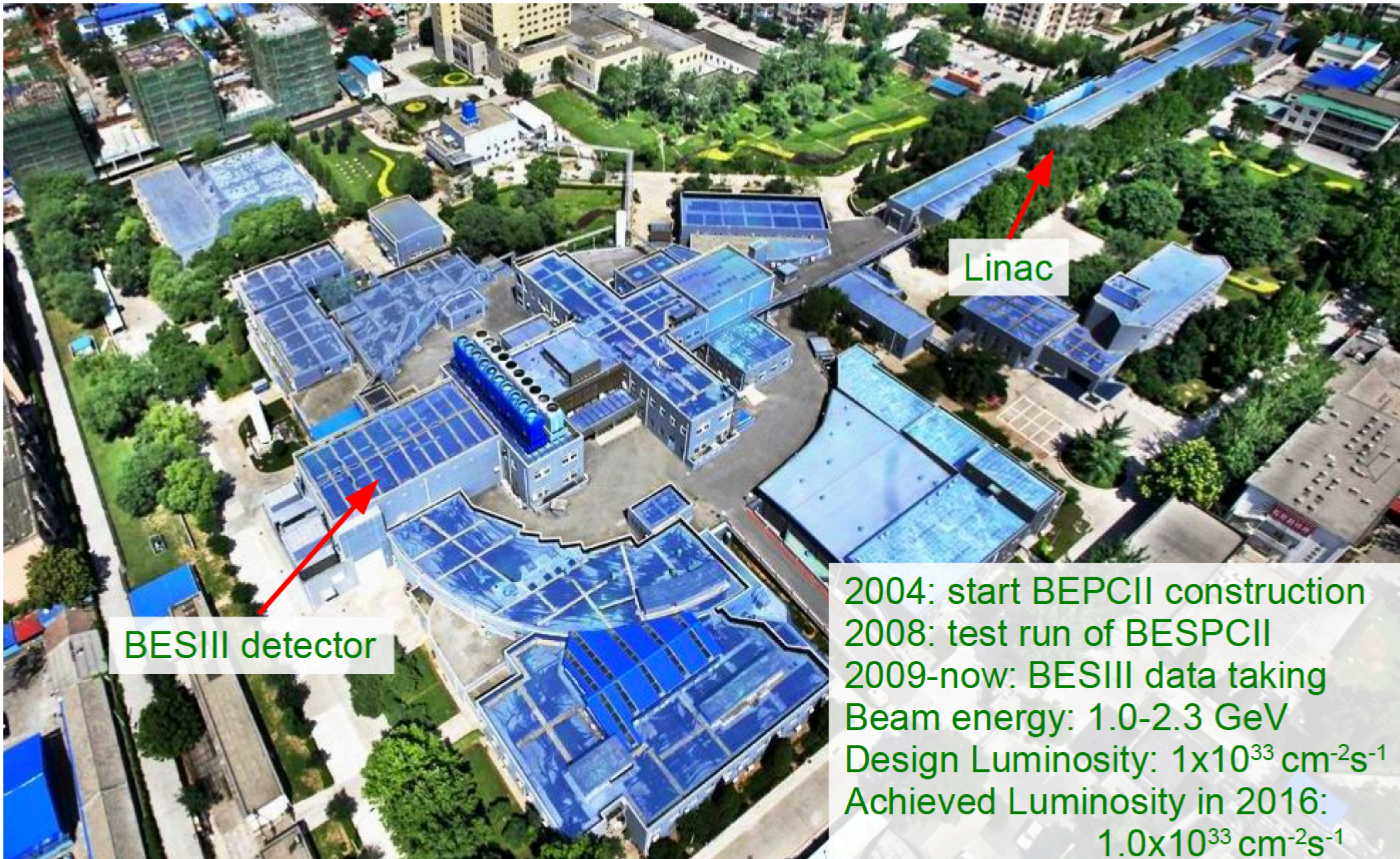
Bai-Cian Ke
IHEP

Outline

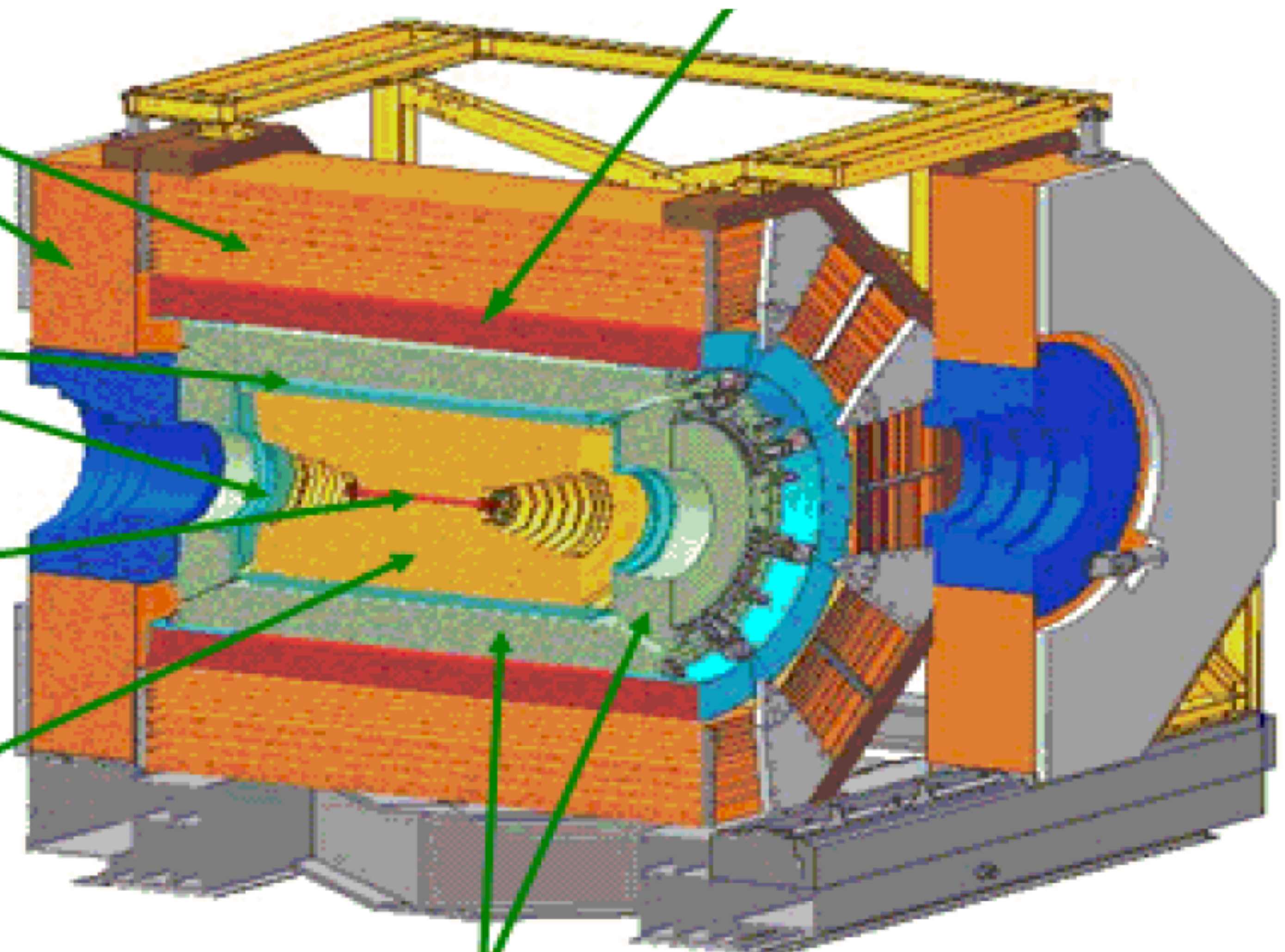
- **Introduction**
  - Important variables
  - D^0, D^+, D_s, and Λ_c^+ Dataset
  - DTag (Λ_cTag) and Branching Fraction
- **Branching Fraction Measurement**
  - D→omega π, hadronic and semileptonic decays of Λ_c, etc.
- **Amplitude Analysis**
  - D→$K^-\pi^+\pi^+\pi^-$, $K_S\pi^+\pi^+\pi^-$, $K^-\pi^+\pi^0\pi^0$, $\pi^+\pi^0\eta$, etc.
- **Summary**

Beijing Electron Positron Collider (BEPCII)

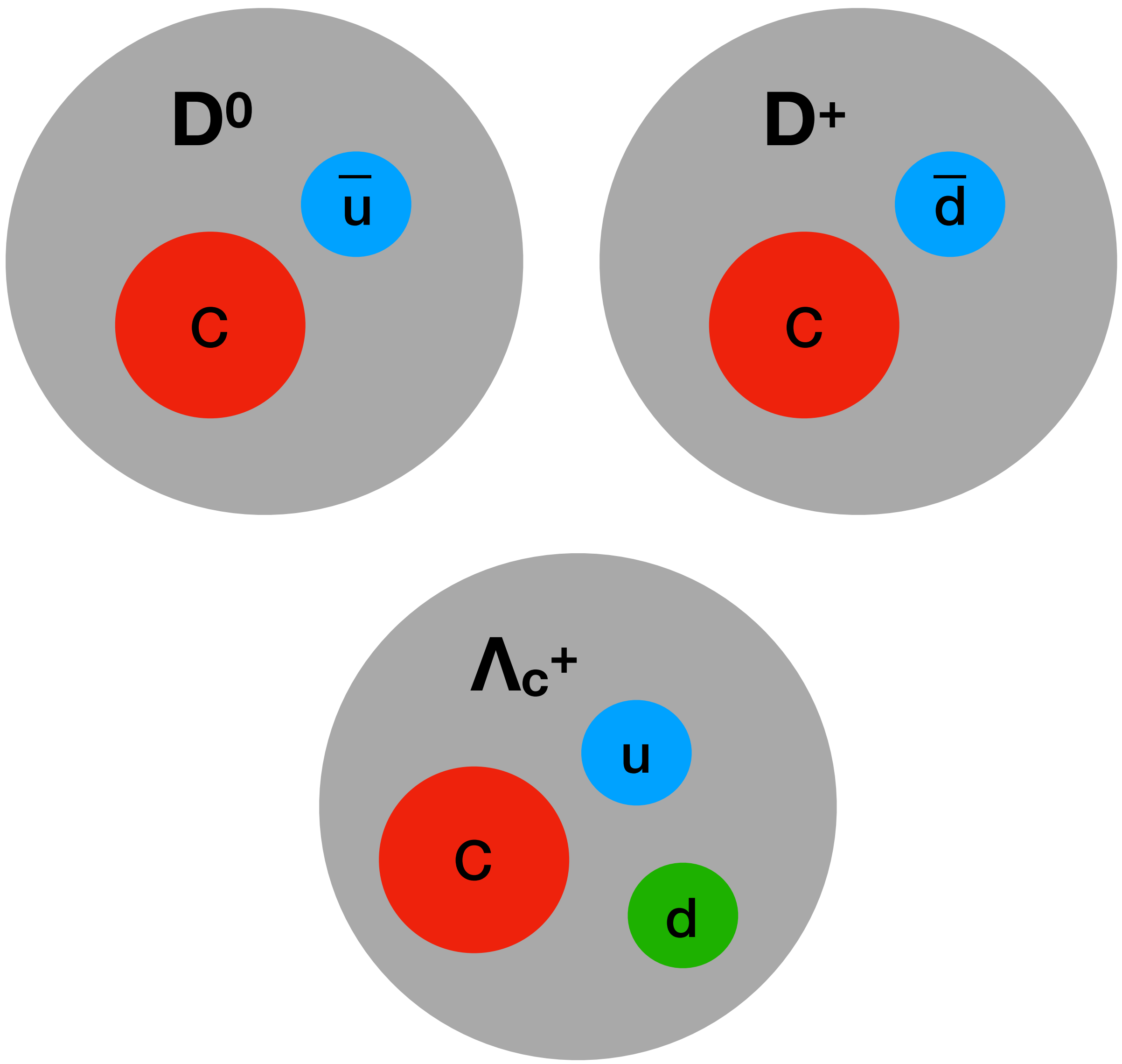
New Two-Ring Machine

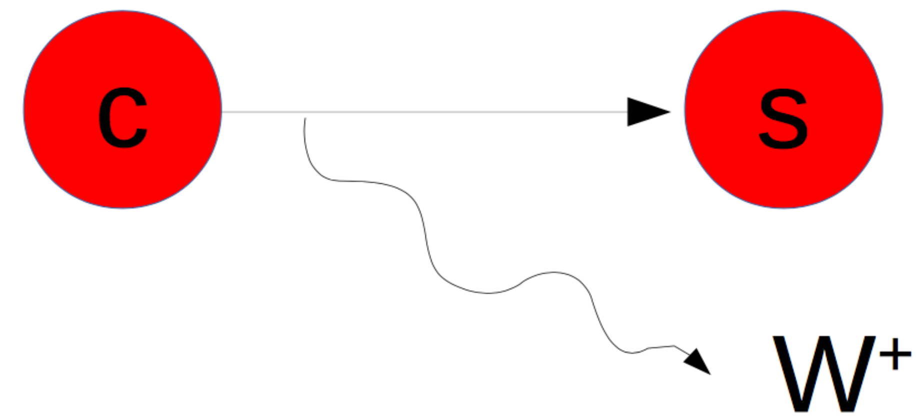


BESIII Detector



Physics of D and Λ_c





Cabibbo-favored decay

As the lightest and most common meson (baryon) containing a single charm quark, D (Λ_c) can only decay through the weak interaction and plays a key role in our understanding of charm quarks.

Beam constrained Mass (M_{bc})

$$M_{bc} \equiv \sqrt{E_{beam}^2 - \left(\sum_i \vec{p_i}\right)^2} = \sqrt{E_{beam}^2 - p_D^2}$$

$$\delta M_{bc} \equiv \frac{E_{beam}}{M_{bc}} \delta E_{beam} \oplus \frac{p_D}{M_{bc}} \delta p_D$$

$\vec{p_i}$: measured momentum of daughter particle

p_D: measured momentum of D meson

M_{bc} peaks at D meson mass: momentum conservation

Note: $\frac{p_D}{M_{bc}} = \frac{1}{7} \frac{E_{beam}}{M_{bc}}$

Most uncertainty comes from beam energy smearing.

Energy difference (ΔE)

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

$$\delta \Delta E = \delta E_D \oplus \delta E_{beam}$$

E_D: measured energy of D meson

ΔE peaks at zero:
energy conservation

BESIII Data Taken near the Pair Threshold

- BEPCII collider: $e^+e^- \to \psi(3770) \to DD^{bar}$
- 2.9 fb^{-1} dataset at $\psi(3770)$ resonance

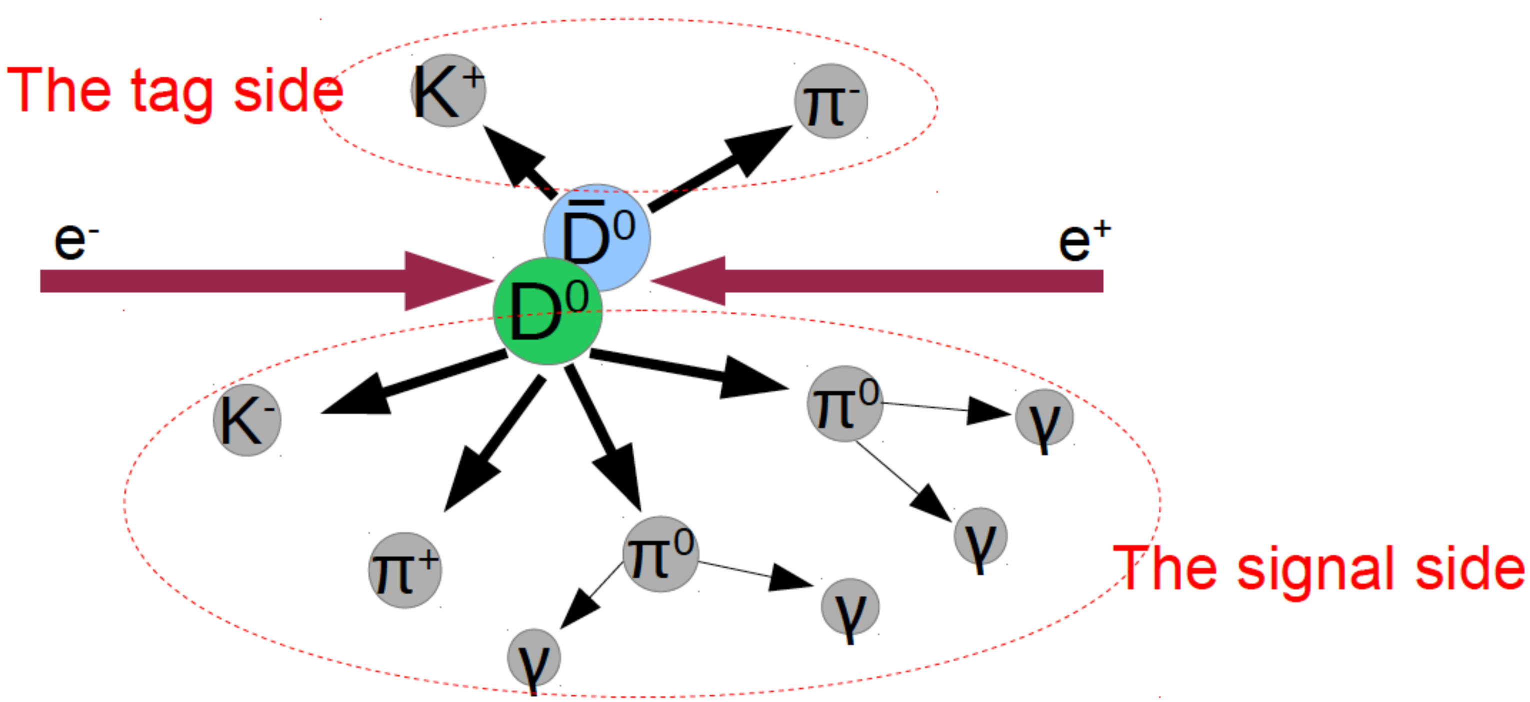
  M_{D0}= 1864.84 MeV M_{D+}= 1869.62 MeV

  $2M_{D0}$= 3729.68 MeV $2M_{D+}$= 3739.24 MeV

- New 3.19 fb^{-1} dataset at E_{cm} = 4.178GeV
  - D_s are produced mostly via $e^+e^- \to D_sD_s^*$
- 567 pb^{-1} dataset at E_{cm} = 4.599GeV
  - 26 MeV above the Λ_c^+ Λ_c^- pair mass
- Advantages of particle pair production near threshold
  - The events are clean; not enough energy for even one additional pion
  - Tagging reduces background from light-quark “continuum” and other charm final states
  - Double tag technique can provide access to absolute BFs
  - Many systematic uncertainties cancel with tag technique

DTag Technique

- There are two types of samples used in the Dtag technique: single tag (ST) and double tag (DT).
- Single tag: only one D meson is reconstructed through a chosen hadronic decay.
- Double tag: both D and $\bar{D}$ are reconstructed,
  - the D reconstructed through the studied hadronic decay is called "the signal side"
  - the $\bar{D}$ reconstructed through well-known and clean hadronic decay modes is called "the tag side".
- (Charge-conjugate states are implied throughout this talk.)



Branching Fraction and Tagging

- Single tag (ST)

$$N^{\mathrm{ST}}_{\mathrm{tag}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\mathrm{tag}}\varepsilon_{\mathrm{tag}}$$

- Double tag (DT)

$$N^{\mathrm{DT}}_{\mathrm{tag,sig}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\mathrm{tag}}\mathcal{B}_{\mathrm{sig}}\varepsilon_{\mathrm{tag,sig}}$$

$\varepsilon_{\mathrm{tag,sig}} \approx \varepsilon_{\mathrm{tag}}\varepsilon_{\mathrm{sig}}$ (factorization)

where $N_{D^0\bar{D}^0}$ is the total number of produced $D^0\bar{D}^0$ pairs, $\mathcal{B}_{\mathrm{tag(sig)}}$ is the branching fraction of the tag (signal) side, and the ε are the corresponding efficiencies.

$$\mathcal{B}_{\mathrm{sig}} = \frac{N^{\mathrm{DT}}_{\mathrm{tag,sig}}}{N^{\mathrm{ST}}_{\mathrm{tag}}}\frac{\varepsilon_{\mathrm{tag}}}{\varepsilon_{\mathrm{tag,sig}}}$$

$N_{D^0\bar{D}^0}$, $\mathcal{B}_{\mathrm{tag}}$ are canceled.
$\varepsilon_{\mathrm{tag}}$ is approximately canceled due to factorization

This is the basic idea for branching fraction.
Equations used in analysis vary case by case.

Observation of the Singly Cabibbo-Suppressed Decay $D^+ \to \omega\pi^+$ and Evidence for $D^0 \to \omega\pi^0$

Chose six (five) decay modes for $D^{+(0)}$.

In order to have a better solution for $D^{+(0)} \to \pi^+\pi^-\pi^0\pi^{+(0)}$ background, DT samples $D^{+(0)} \to \pi^+\pi^-\pi^0\pi^{+(0)}$ vs. tag modes are reconstructed first. Then fits to $\pi^+\pi^-\pi^0$ mass are performed.

Note that we are searching for $\omega \to \pi^+\pi^-\pi^0$.

$$\mathcal{B}_{\rm sig} = \frac{\sum_\alpha N^{\rm obs,\alpha}_{\rm sig}}{\sum_\alpha N^{\rm obs,\alpha}_{\rm tag}\epsilon^\alpha_{\rm tag,sig}/\epsilon^\alpha_{\rm tag}}$$

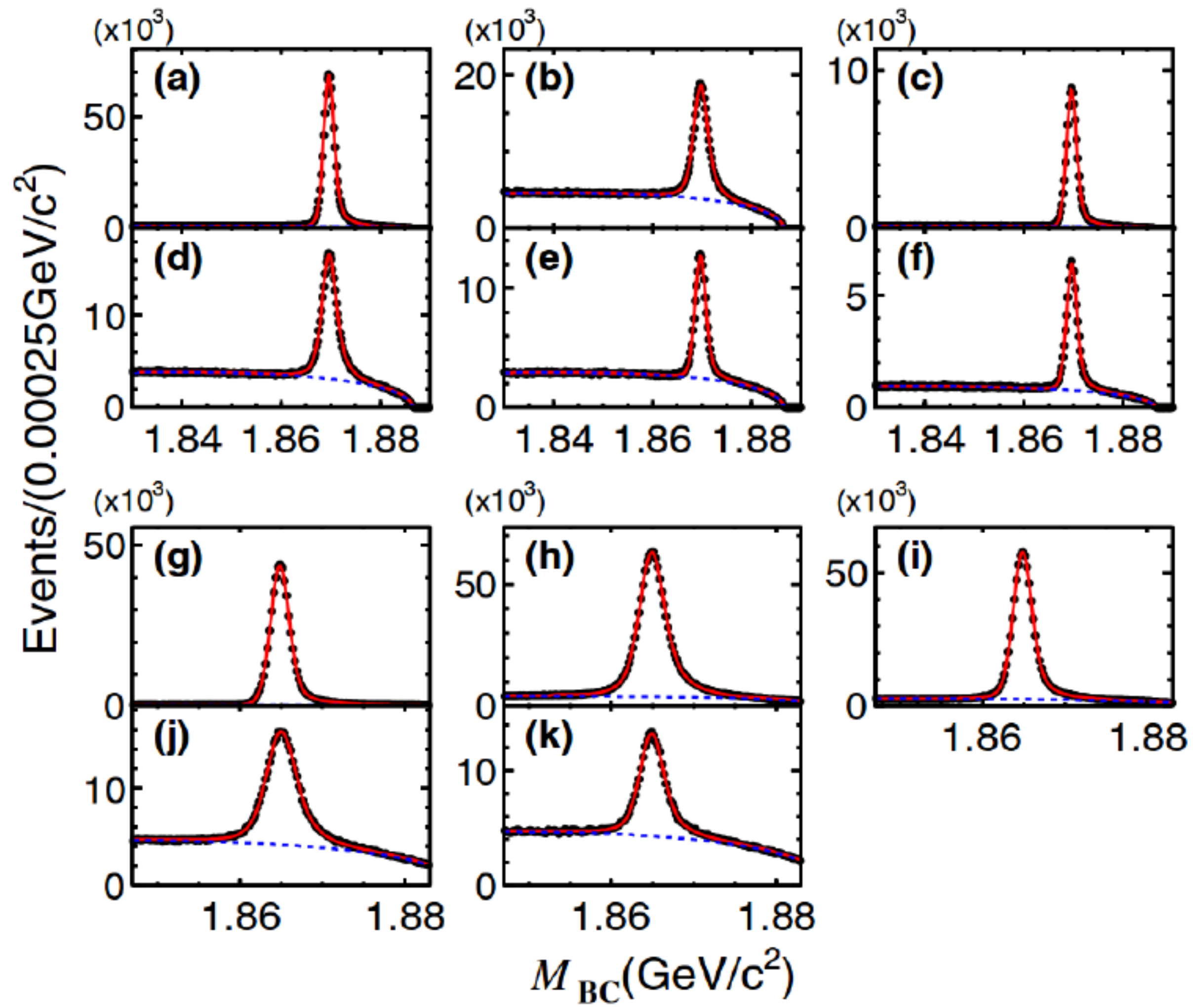


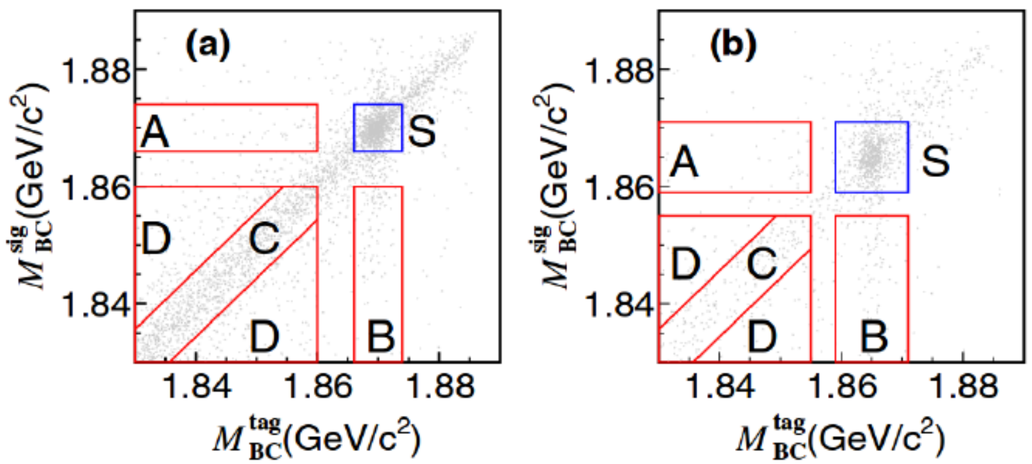
FIG. 1. $M_{\rm BC}$ distributions of ST samples for different tag modes. The first two rows show charged D decays: (a) $K^+\pi^-\pi^-$, (b) $K^+\pi^-\pi^-\pi^0$, (c) $K^0_S\pi^-$, (d) $K^0_S\pi^-\pi^0$, (e) $K^0_S\pi^+\pi^-\pi^-$, (f) $K^+K^-\pi^-$, the latter two rows show neutral D decays: (g) $K^+\pi^-$, (h) $K^+\pi^-\pi^0$, (i) $K^+\pi^-\pi^+\pi^-$, (j) $K^+\pi^-\pi^0\pi^0$, (k) $K^+\pi^-\pi^+\pi^-\pi^0$. Data are shown as points, the (red) solid lines are the total fits and the (blue) dashed lines are the background shapes. D and $\bar{D}$ candidates are combined.

DT $D^{+(0)} \to \pi^+\pi^-\pi^0\pi^{+(0)}$ vs. tag modes

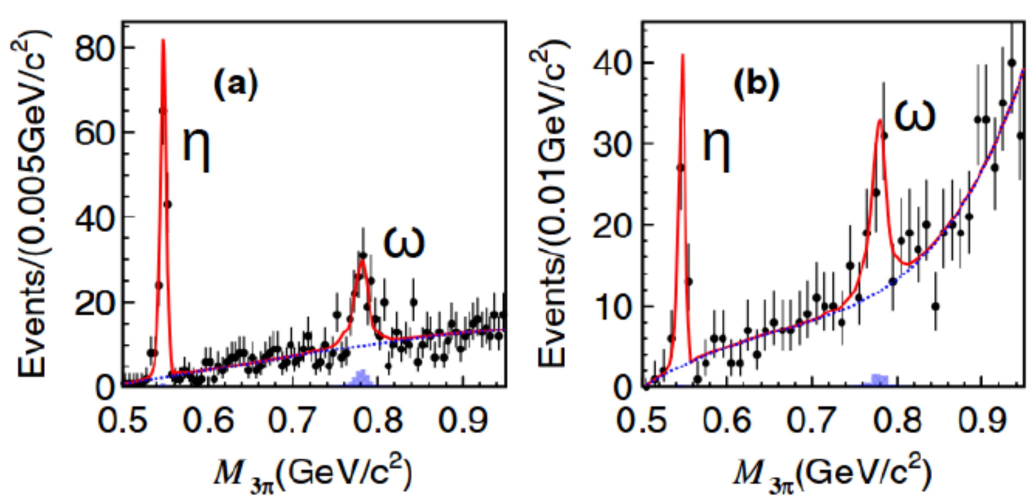
Fits to M3π distributions of signal and sideband regions to obtain the signal and peaking background yields, respectively.

Events counts in sidebands are projected into the signal region with scale factors.

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



ModeH	$N_{\omega(\eta)}$	$N_{\omega(\eta)}^{bkg}$	N_{sig}^{obs}
$D^+ \to \omega\pi^+$	100 ± 16	21 ± 4	79 ± 16
$D^0 \to \omega\pi^0$	50 ± 12	5 ± 5	45 ± 13
$D^+ \to \eta\pi^+$	264 ± 17	6 ± 2	258 ± 18
$D^0 \to \eta\pi^0$	78 ± 10	3 ± 2	75 ± 10



Mode	This work	Previous measurements
$D^+ \to \omega\pi^+$	$(2.79 \pm 0.57 \pm 0.16) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.
$D^0 \to \omega\pi^0$	$(1.17 \pm 0.34 \pm 0.07) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.
$D^+ \to \eta\pi^+$	$(3.07 \pm 0.22 \pm 0.13) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.65 \pm 0.09 \pm 0.04) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

Red line: total fit

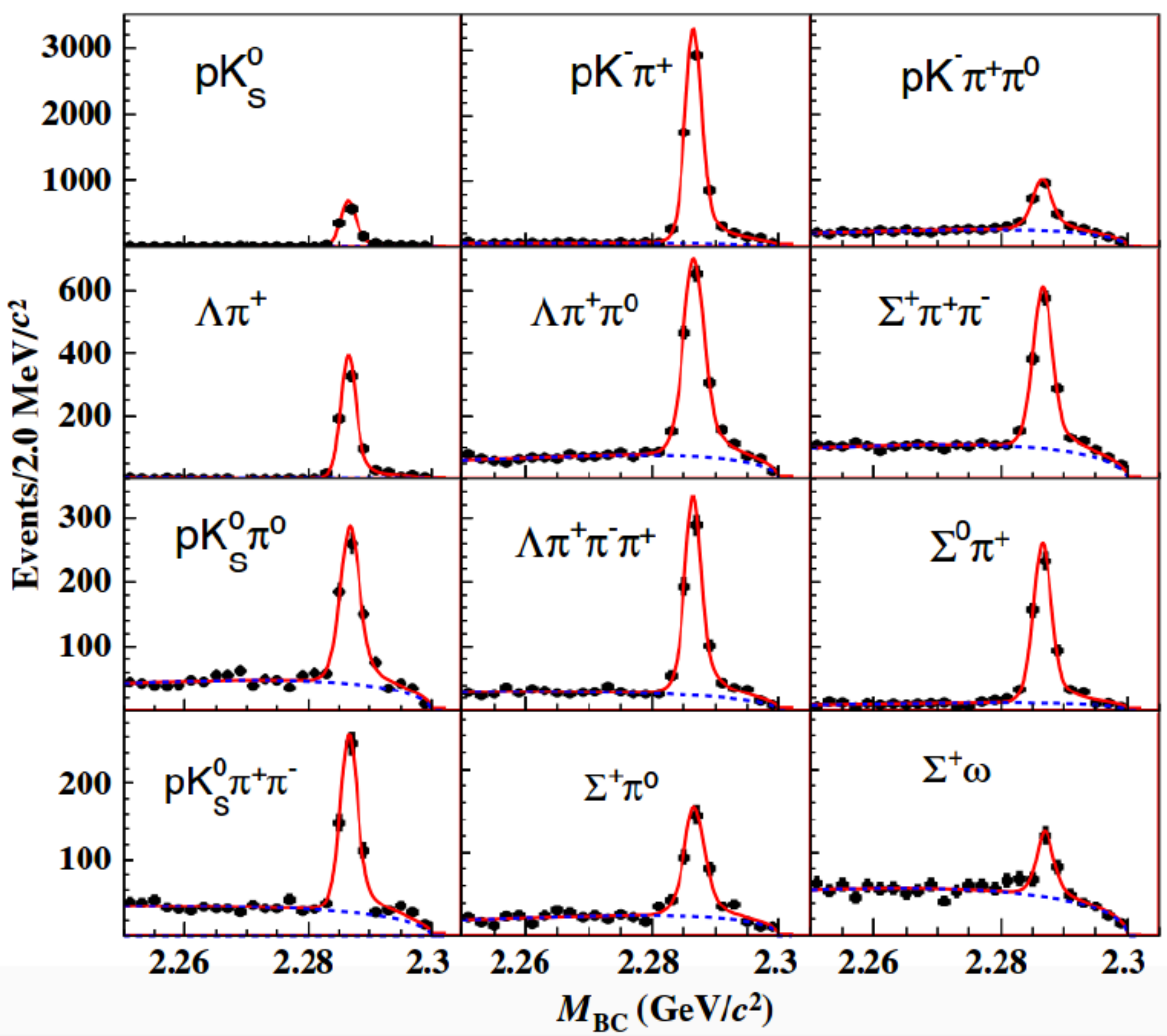
Blue line: background

Hatched histogram:
peaking background
From sidebands

PRL **116,** 082001 (2016)

Absolute Hadronic BFs of Λ_c^+ Baryon

- Fit to the ST M_{BC} distributions in data for the twelve decay modes
- Use signal MC shape with Gaussian convolution, plus Argus background

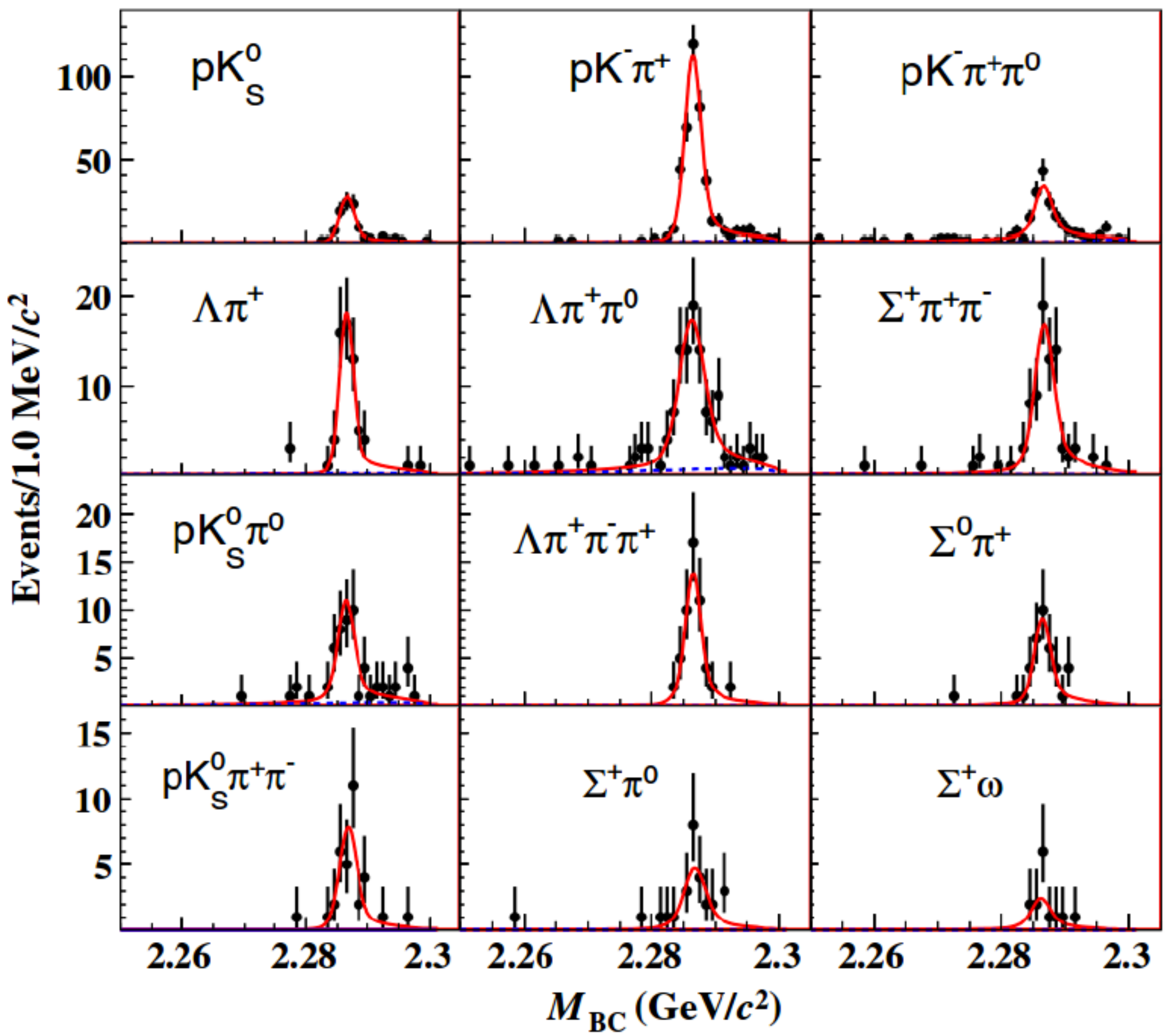


Mode	N^{ST}
pK_S^0	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK_S^0\pi^0$	558 ± 33
$pK_S^0\pi^+\pi^-$	485 ± 29
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	522 ± 27
$\Sigma^+\pi^0$	309 ± 24
$\Sigma^+\pi^+\pi^-$	1156 ± 49
$\Sigma^+\omega$	157 ± 22

$$N_j^{\mathrm{ST}} = N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_j\varepsilon_j$$

Absolute Hadronic BFs of Λ_c^+ Baryon

- Fit to the DT M_{BC} distributions in data



Mode	N^{DT}_{i-}
pK^0_S	97 ± 10
$pK^-\pi^+$	420 ± 22
$pK^0_S\pi^0$	47 ± 8
$pK^0_S\pi^+\pi^-$	34 ± 6
$pK^-\pi^+\pi^0$	176 ± 14
$\Lambda\pi^+$	60 ± 8
$\Lambda\pi^+\pi^0$	101 ± 13
$\Lambda\pi^+\pi^-\pi^+$	53 ± 7
$\Sigma^0\pi^+$	38 ± 6
$\Sigma^+\pi^0$	25 ± 5
$\Sigma^+\pi^+\pi^-$	80 ± 9
$\Sigma^+\omega$	13 ± 3

$$N^{DT}_{ij} = N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_i\mathcal{B}_j\varepsilon_{ij}$$

- BFs obtained from a simultaneous fit to ST, DT rates:
- Results in higher precision since “tag” mode in a given DT combination are also used as “signal”

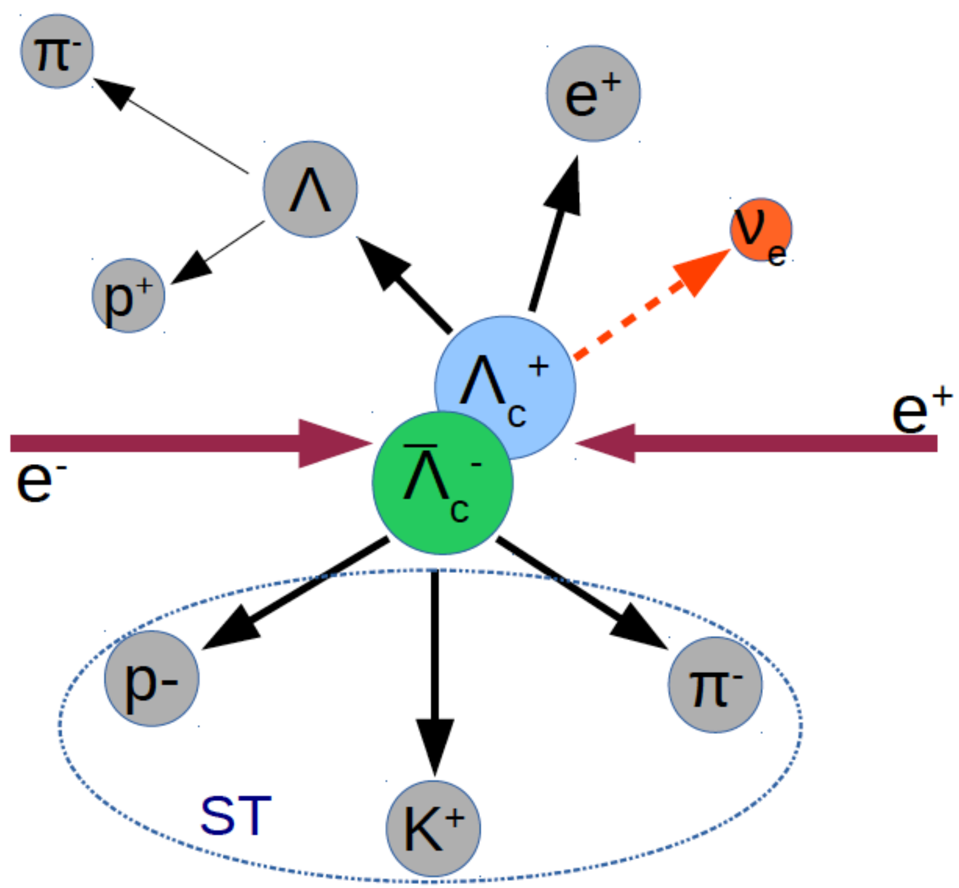
Absolute Hadronic BFs of Λ_c^+ Baryon

Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

- We report the first absolute measurement of the Λ_c^+ decay branching fractions at the $\Lambda_c^+\bar{\Lambda}_c^-$ production threshold
- The precision is improved significantly, compared to PDG values

Phys. Rev. Lett. 116 (2016) 052001

Measurement of the Absolute BF for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$



- 11 ST modes are used

  (Had. BF analysis STs, w/o $\Sigma^+ \omega$)

- Identify p, π^- (from Λ) and e^+ among the remaining tracks

- The neutrino is not detected

  A variable, U_{miss} , which peaks at 0 if only a neutrino is missing, is used to obtain the yield

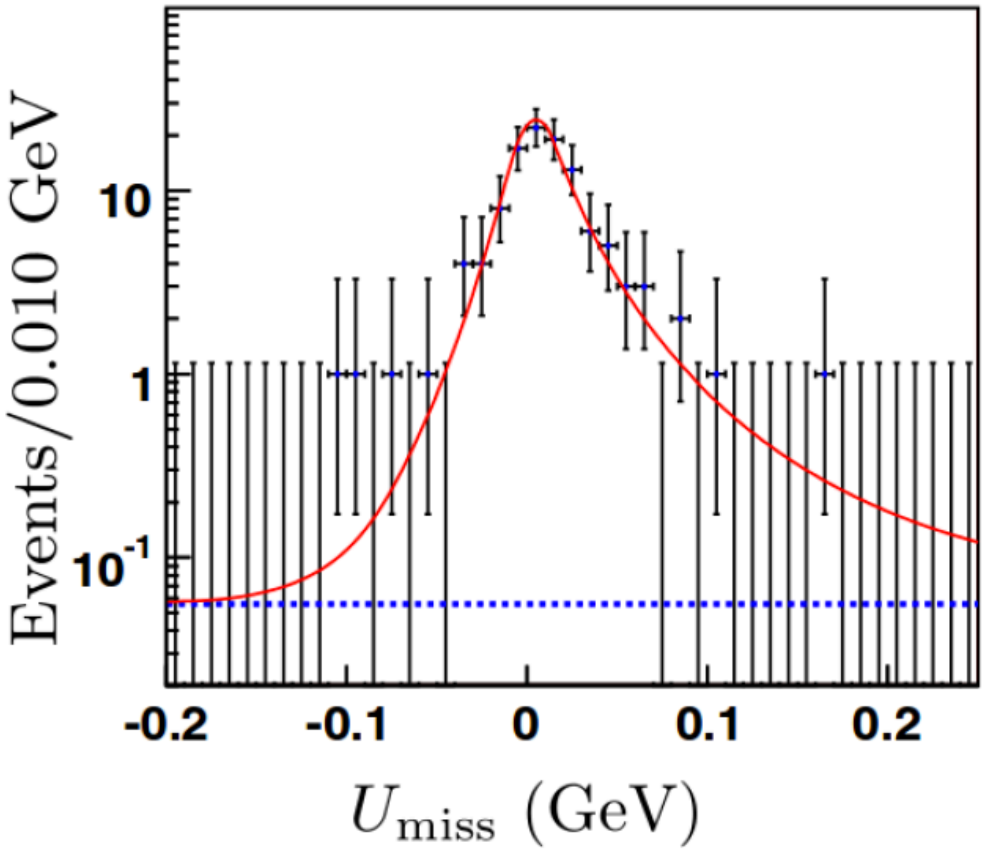
- U_{miss} is similar to missing mass squared

$$U_{\rm miss} = E_{\rm miss} - |\vec{p}_{\rm miss}|$$
$$M^2_{\rm miss} = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$$

Measurement of the Absolute BF for $\Lambda_c^+ \to \Lambda e^+ \nu_e$

Fit to the U_{miss} distribution to obtain the yield

$$U_{\rm miss} = E_{\rm miss} - |\vec{p}_{\rm miss}|$$
$$E_{\rm miss} = E_{\rm beam} - E_{\Lambda} - E_{e^+}$$
$$\vec{p}_{\rm miss} = \vec{p}_{\Lambda_c^+} - \vec{p}_{\Lambda} - \vec{p}_{e^+}$$
$$\vec{p}_{\Lambda_c^+} = -\hat{p}_{\rm tag}\sqrt{E_{\rm beam}^2 - m_{\bar{\Lambda}_c^-}^2}$$



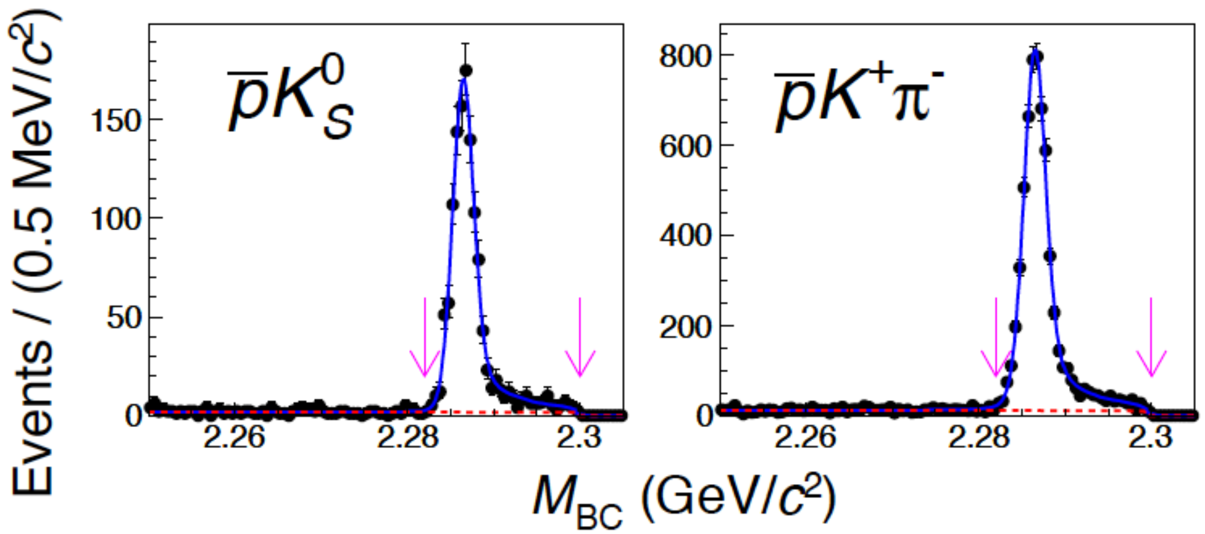
$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38(\text{stat}) \pm 0.20(\text{syst}))\%$

The first absolute measurement, and improved precision!

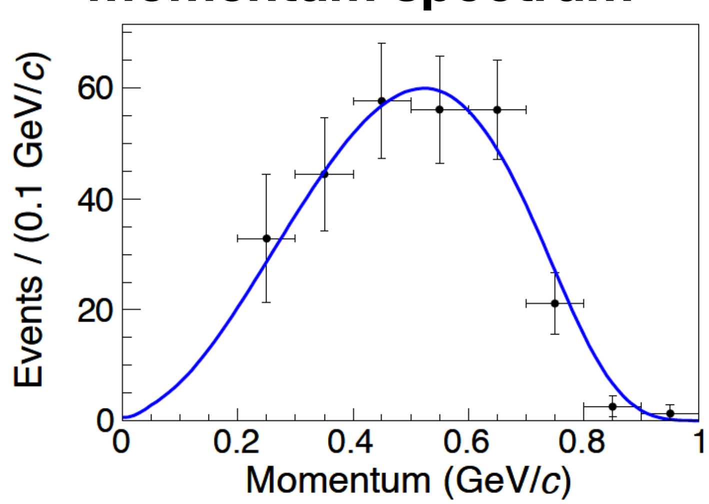
Phys. Rev. Lett. 115 (2015) 221805

Measurement of the absolute branching fraction of the inclusive semileptonic Λ_c^+ decay

Single tag



Extrapolation of the positron momentum spectrum



$$\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e) = \frac{N^{\rm pro}(p_e > 200\ {\rm MeV}/c)}{N_{\rm tag}[1 - f(p_e < 200\ {\rm MeV}/c)]}$$

- **Detailed study of the PID efficiency to evaluate sizable back-grounds from misidentified hadrons**
- **The wrong-sign samples, where the charge of the track is required to be equal to that of the ST candidate, are studied to remove secondary positrons arising from γ conversions and π^0 decays.**

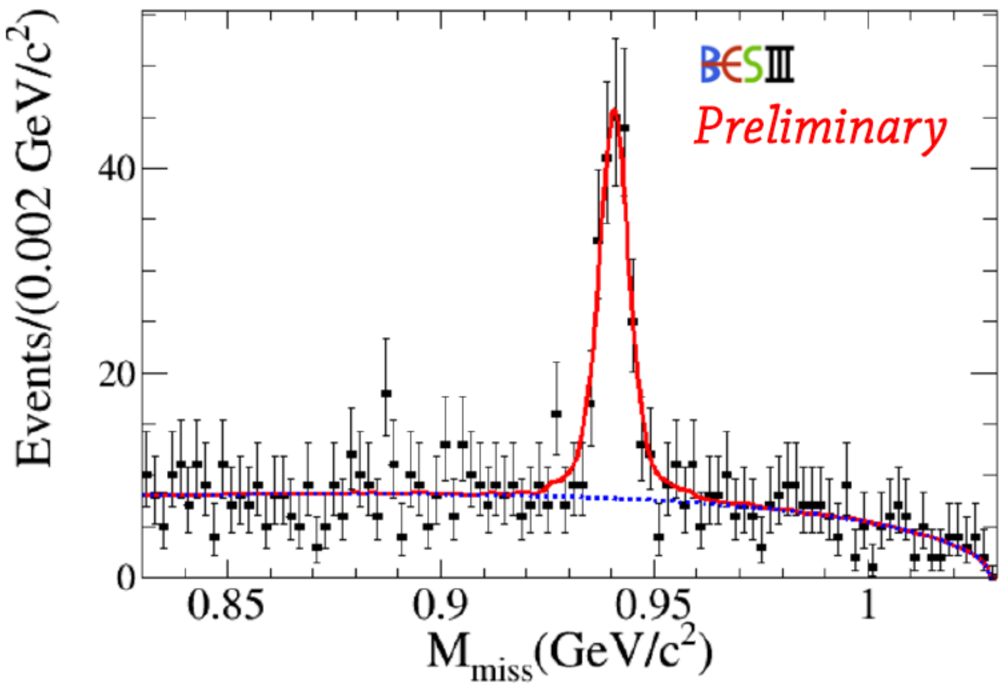
$$\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e) = (3.95 \pm 0.34 \pm 0.09)\%$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e)}{\mathcal{B}(\Lambda_c^+ \to X e^+\nu_e)} = (91.9 \pm 12.5 \pm 5.4)\%$$

$$\frac{\Gamma(\Lambda_c^+ \to X e^+\nu_e)}{\Gamma(D \to X e^+\nu_e)} = 1.26 \pm 0.12$$

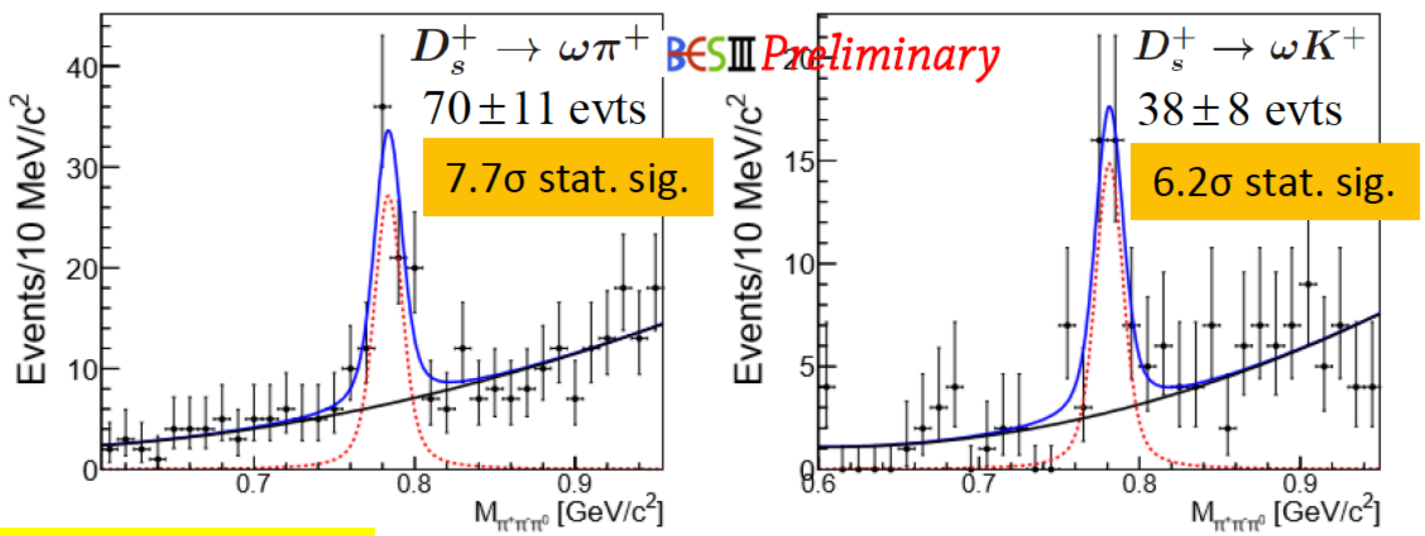
Phys.Rev.Lett. 121 (2018) 251801

Measurements of pure W-annihilation decays in D_s^+



Preliminary result:

$$\mathcal{B}_{D_s^+\to p\bar{n}} = (1.22 \pm 0.10) \times 10^{-3}$$



Preliminary results:

Consistent with CLEO's measurement, but more precise.

$$\mathcal{B}(D_s^+ \to \omega\pi^+) = (1.85 \pm 0.30_{stat.} \pm 0.19_{sys.}) \times 10^{-3}$$

$$\mathcal{B}(D_s^+ \to \omega K^+) = (1.13 \pm 0.24_{stat.} \pm 0.14_{sys.}) \times 10^{-3}$$

First observation !

This measurement of implies the ρ–ω mixing is negligible.

Amplitude Analysis of $K\pi\pi\pi$

- There are seven $D \to K\pi\pi\pi$ modes:

  $D^0 \to K^-\pi^+\pi^+\pi^-$ (published on PRD) PhysRevD.95.072010

  $D^0 \to K^-\pi^+\pi^0\pi^0$ (expected to publish on PRD soon)

  $D^0 \to K_S\pi^0\pi^0\pi^0$

  $D^0 \to K_S\pi^+\pi^-\pi^0$ (on-going)

  $D^+ \to K^-\pi^+\pi^+\pi^0$ (on-going)

  $D^+ \to K_S\pi^+\pi^0\pi^0$ (on-going)

  $D^+ \to K_S\pi^+\pi^+\pi^-$ (expected to publish on PRD soon)

- Four-body decays are in five-dimensions
- We have
  - Partial Wave Analysis Tools based on CPU and GPU kernel
  - Great Electro-Magnetic Calorimeter (EMC) with CsI

    → superior resolution and efficiency of π^0
  - Largest dataset at ψ(3770) resonance

    → small statistical errors and clean background

Amplitude Analysis of $K\pi\pi\pi$

- The measurement of the sub-modes in $D \to K\pi\pi\pi$ provides a window to study the decays $D \to AP$ and $D \to VV$ (*A*=axial-vector, *V*=vector),

  both of them are important in learning the CPV in charm decays but less effective experimental measurements.

- The knowledge of sub-modes can be widely used in many measurements:
  - Branching fraction measurement
  - Strong phase measurement
  - CKM unitary triangle measurement

Partial Wave Analysis

The Signal PDF

I am going to fit

$$A(a_i, p_j) = \sum_i a_i A_i(p_j)$$

$$S(a_i, p_j) = \frac{\epsilon(p_j)|A(a_i, p_j)|^2 R_4(p_j)}{\int \epsilon(p_j)|A(a_i, p_j)|^2 R_4(p_j) dp_j}$$

where p_j is the daughter particles' four momenta and a_i is the complex coefficient for amplitude modes. $\epsilon(p_j)$ is the efficiency parameterized in terms of the daughter particles' four momenta. R_4 is the 4-body phase space

$$A_i(p_j) = P_i^1(p_j) P_i^2(p_j) S_i(p_j) F_i^1(p_j) F_i^2(p_j) F_i^D(p_j)$$

where $F_i^D(p_j)$ is the Blatt-Weisskopf Barrier factor for D meson. $P_i^{1,2}(p_j)$ and $F_i^{1,2}(p_j)$ is the propagator and the Blatt-Weisskopf Barrier factor, respectively, of the two resonance states for the quasi-two-body type or of the first and the second resonance states for the cascade type. $S_i(p_j)$ is the spin factor. Finally, the likelihood can be defined as

For n events $\prod_{j=1}^{n} S(a_i, p_j)$

Define the likelihood $L = \prod_{j=1}^{n} S(a_i, p_j)$

Partial Wave Analysis

Independent of a_i

$$\ln L = \sum_{j}^{N_{selected}} \ln\left(\frac{|A(a_i,p_j)|^2 R_4(p_j)}{\int \epsilon(p_j)|A(a_i,p_j)|^2 R_4(p_j)dp_j}\right) + \sum_{j}^{N_{selected}} \ln \epsilon(p_j)$$

$$\int \epsilon(p_j)|A(a_i,p_j)|^2 R_4(p_j)dp_j \approx \frac{1}{N_{generated}} \sum_{j}^{N_{selected}} |A(a_i,p_j)|^2$$

Phase space MC sample can be used to deal with the MC integration.
We replace phase space MC sample by signal MC sample
for better precision.

$$\int \epsilon(p_j)|A(a_i,p_j)|^2 R_4(p_j)dp_j \approx \frac{1}{N_{MC}} \sum_{j}^{N_{MC}} \frac{|A(a_i,p_j)|^2}{|A(a_i^{gen},p_j)|^2}$$

We further consider the effects of detector efficiency difference
between data and MC simulation for pi0 reconstruction, PID, and tracking

$$\int \epsilon(p_j)|A(a_i,p_j)|^2 R_4(p_j)dp_j \approx \frac{1}{N_{MC}} \sum_{j}^{N_{MC}} \frac{|A(a_i,p_j)|^2 \gamma_\epsilon(p_j)}{|A(a_i^{gen},p_j)|^2}$$

where $\gamma_\epsilon(p_j) = \prod_j \frac{\epsilon_{j,\mathrm{data}}(p_j)}{\epsilon_{j,\mathrm{MC}}(p_j)}$

Amplitude Analysis Results of $D^0 \to K^-\pi^+\pi^+\pi^-$

Double tag $D^0 \to K^-\pi^+\pi^+\pi^-$ vs. $\bar{D}^0 \to K^+\pi^-$

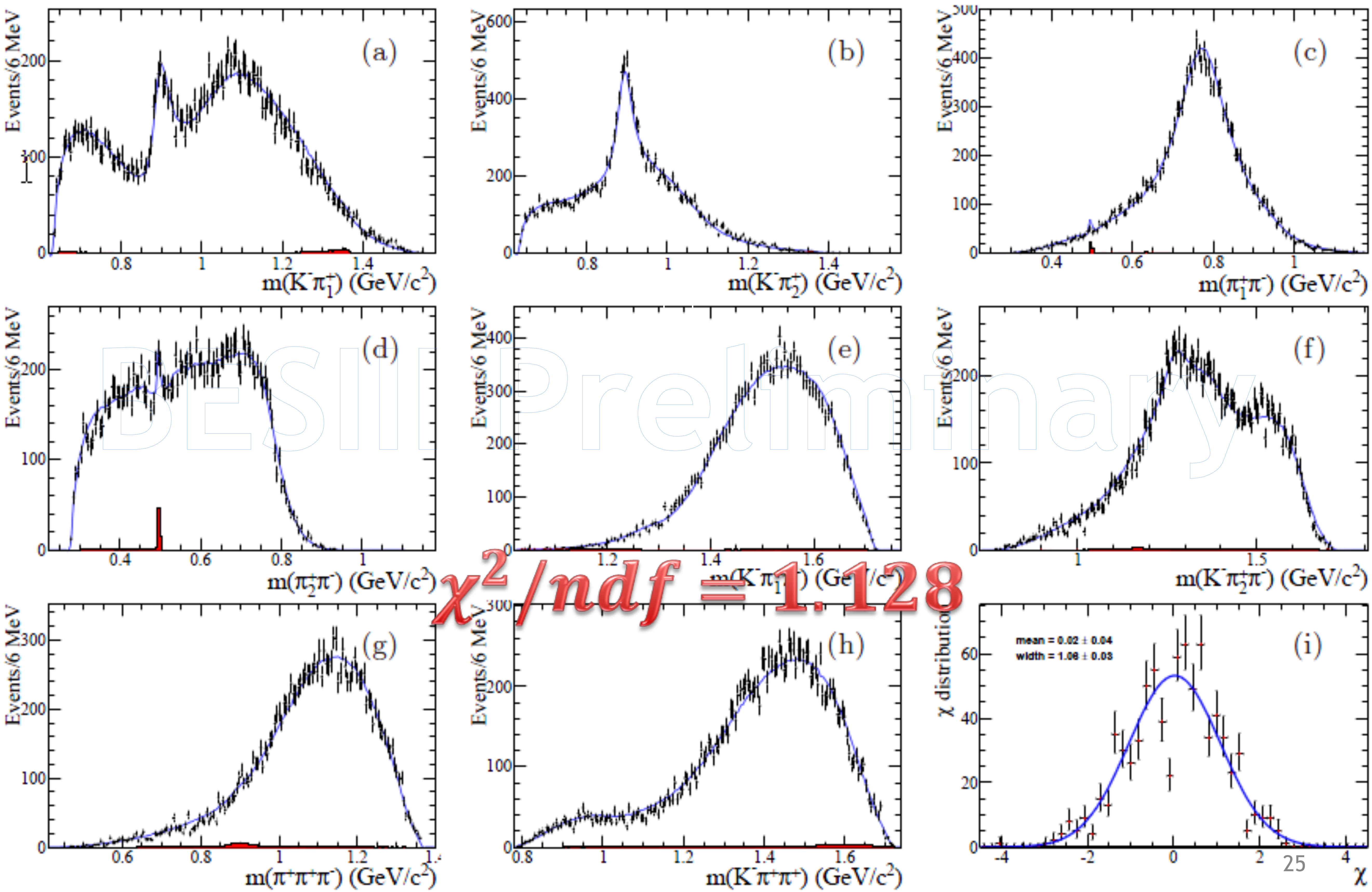
The number of event selected is 15912 with a purity of 99.4%

The data can be described with 23 amplitudes:

Amplitude	ϕ_i	Fit fraction (%)
$D^0[S] \to \bar{K}^*\rho^0$	$2.35 \pm 0.06 \pm 0.18$	$6.5 \pm 0.5 \pm 0.8$
$D^0[P] \to \bar{K}^*\rho^0$	$-2.25 \pm 0.08 \pm 0.15$	$2.3 \pm 0.2 \pm 0.1$
$D^0[D] \to \bar{K}^*\rho^0$	$2.49 \pm 0.06 \pm 0.11$	$7.9 \pm 0.4 \pm 0.7$
$D^0 \to K^-a_1^+(1260),\ a_1^+(1260)[S] \to \rho^0\pi^+$	0(fixed)	$53.2 \pm 2.8 \pm 4.0$
$D^0 \to K^-a_1^+(1260),\ a_1^+(1260)[D] \to \rho^0\pi^+$	$-2.11 \pm 0.15 \pm 0.21$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[S] \to \bar{K}^{*0}\pi^-$	$1.48 \pm 0.21 \pm 0.24$	$0.1 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[D] \to \bar{K}^{*0}\pi^-$	$3.00 \pm 0.09 \pm 0.15$	$0.7 \pm 0.2 \pm 0.2$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270) \to K^-\rho^0$	$-2.46 \pm 0.06 \pm 0.21$	$3.4 \pm 0.3 \pm 0.5$
$D^0 \to (\rho^0K^-)_A\pi^+,\ (\rho^0K^-)_A[D] \to K^-\rho^0$	$-0.43 \pm 0.09 \pm 0.12$	$1.1 \pm 0.2 \pm 0.3$
$D^0 \to (K^-\rho^0)_P\pi^+$	$-0.14 \pm 0.11 \pm 0.10$	$7.4 \pm 1.6 \pm 5.7$
$D^0 \to (K^-\pi^+)_S\rho^0$	$-2.45 \pm 0.19 \pm 0.47$	$2.0 \pm 0.7 \pm 1.9$
$D^0 \to (K^-\rho^0)_V\pi^+$	$-1.34 \pm 0.12 \pm 0.09$	$0.4 \pm 0.1 \pm 0.1$
$D^0 \to (\bar{K}^{*0}\pi^-)_P\pi^+$	$-2.09 \pm 0.12 \pm 0.22$	$2.4 \pm 0.5 \pm 0.5$
$D^0 \to \bar{K}^{*0}(\pi^+\pi^-)_S$	$-0.17 \pm 0.11 \pm 0.12$	$2.6 \pm 0.6 \pm 0.6$
$D^0 \to (\bar{K}^{*0}\pi^-)_V\pi^+$	$-2.13 \pm 0.10 \pm 0.11$	$0.8 \pm 0.1 \pm 0.1$
$D^0 \to ((K^-\pi^+)_S\pi^-)_A\pi^+$	$-1.36 \pm 0.08 \pm 0.37$	$5.6 \pm 0.9 \pm 2.7$
$D^0 \to K^-((\pi^+\pi^-)_S\pi^+)_A$	$-2.23 \pm 0.08 \pm 0.22$	$13.1 \pm 1.9 \pm 2.2$
$D^0 \to (K^-\pi^+)_S(\pi^+\pi^-)_S$	$-1.40 \pm 0.04 \pm 0.22$	$16.3 \pm 0.5 \pm 0.6$
$D^0[S] \to (K^-\pi^+)_V(\pi^+\pi^-)_V$	$1.59 \pm 0.13 \pm 0.41$	$5.4 \pm 1.2 \pm 1.9$
$D^0 \to (K^-\pi^+)_S(\pi^+\pi^-)_V$	$-0.16 \pm 0.17 \pm 0.43$	$1.9 \pm 0.6 \pm 1.2$
$D^0 \to (K^-\pi^+)_V(\pi^+\pi^-)_S$	$2.58 \pm 0.08 \pm 0.25$	$2.9 \pm 0.5 \pm 1.7$
$D^0 \to (K^-\pi^+)_T(\pi^+\pi^-)_S$	$-2.92 \pm 0.14 \pm 0.12$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to (K^-\pi^+)_S(\pi^+\pi^-)_T$	$2.45 \pm 0.12 \pm 0.37$	$0.5 \pm 0.1 \pm 0.1$

Amplitude Analysis Results of $D^0 \to K^-\pi^+\pi^+\pi^-$

Projections of invariant mass (a-h) and χ distribution (i)



Amplitude Analysis Results of $D^0 \to K^-\pi^+\pi^+\pi^-$

Results of branching fractions for different components:

Component	Branching fraction (%)	PDG value (%)
$D^0 \to \bar{K}^{*0}\rho^0$	$0.99 \pm 0.04 \pm 0.04 \pm 0.03$	1.05 ± 0.23
$D^0 \to K^- a_1^+(1260)(\rho^0\pi^+)$	$4.41 \pm 0.22 \pm 0.30 \pm 0.13$	3.6 ± 0.6
$D^0 \to K_1^-(1270)(\bar{K}^{*0}\pi^-)\pi^+$	$0.07 \pm 0.01 \pm 0.02 \pm 0.00$	0.29 ± 0.03
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.04 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.20 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.04 \pm 0.02$	0.99 ± 0.23
$D^0 \to K^-\pi^+\pi^+\pi^-$	$1.77 \pm 0.05 \pm 0.04 \pm 0.05$	1.88 ± 0.26

stat. uncertainty from FF

sys. uncertainty from FF

uncertainties related to BF($D^0 \to K^-\pi^+\pi^+\pi^-$) in PDG

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Amplitude Analysis Results of $D^0 \to K^-\pi^+\pi^0\pi^0$

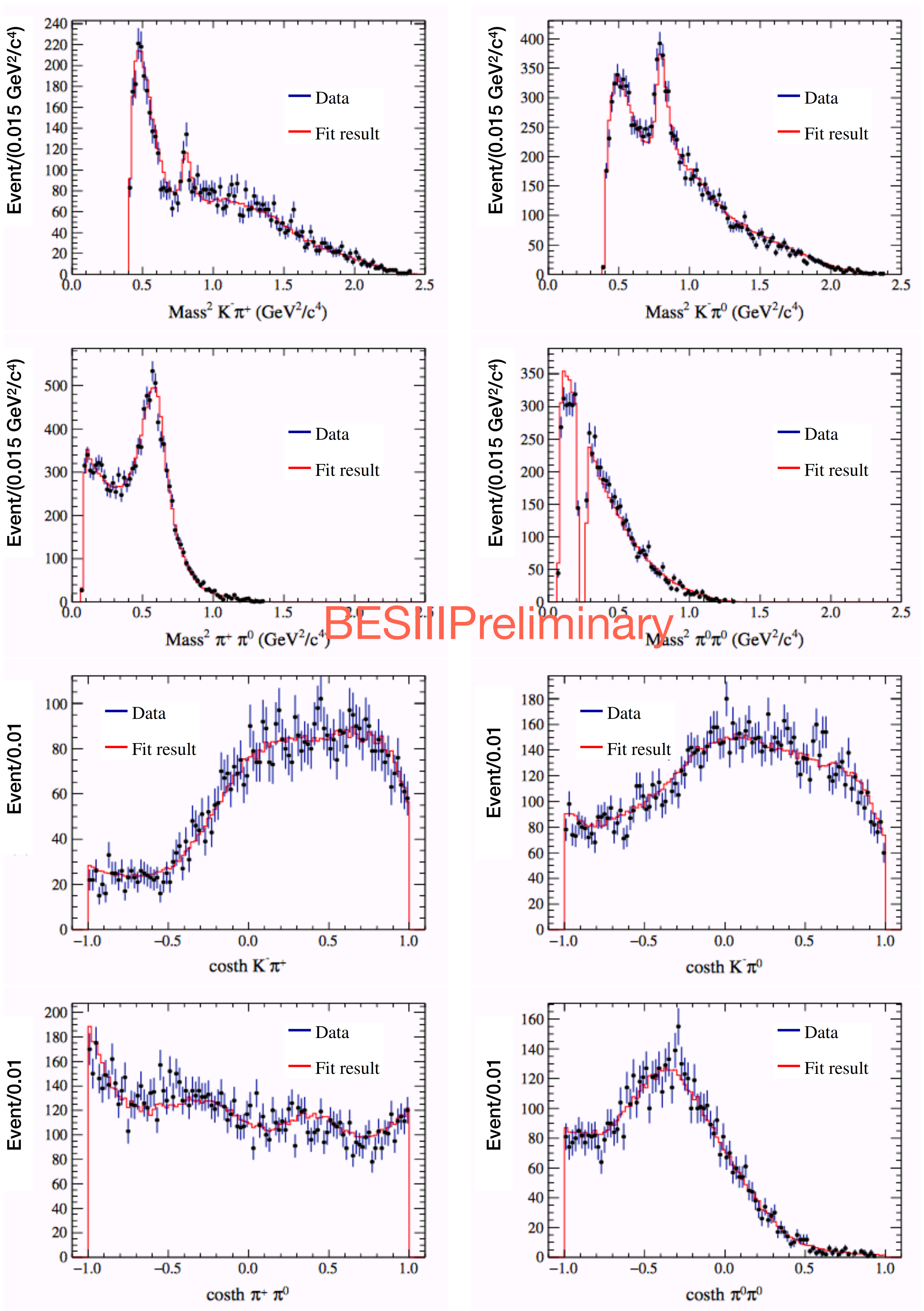
Double tag: $D^0 \to K^-\pi^+\pi^0\pi^0$ (signal) vs. $\bar{D}^0 \to K^+\pi^-$ (tag)

The number of event selected is 5950 with a purity of ~99%

The data can be described with 26 amplitudes:

Amplitude mode	**FF(%)**	**Phase (ϕ)**
$D \to SS$		
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$
$D \to AP, A \to VP$		
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.18$	$1.84 \pm 0.34 \pm 0.43$
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.13$	$-1.35 \pm 0.43 \pm 0.48$
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$
$D \to AP, A \to SP$	BESIIIPreliminary	
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$
$D \to VS$		
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12 \pm 0.27 \pm 0.27$	$1.45 \pm 0.48 \pm 0.51$
$D \to VP, V \to VP$		
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$
$D \to VV$		
$D[S] \to K^{*-}\rho^+$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$
$D[P] \to K^{*-}\rho^+$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$
$D[D] \to K^{*-}\rho^+$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$
$D[P] \to (K^-\pi^0)_V\rho^+$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$
$D[D] \to (K^-\pi^0)_V\rho^+$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$
$D[D] \to K^{*-}(\pi^+\pi^0)_V$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$
$D[S] \to (K^-\pi^0)_V(\pi^+\pi^0)_V$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$
$D \to TS$		
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.32$	$-2.93 \pm 0.31 \pm 0.82$
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$

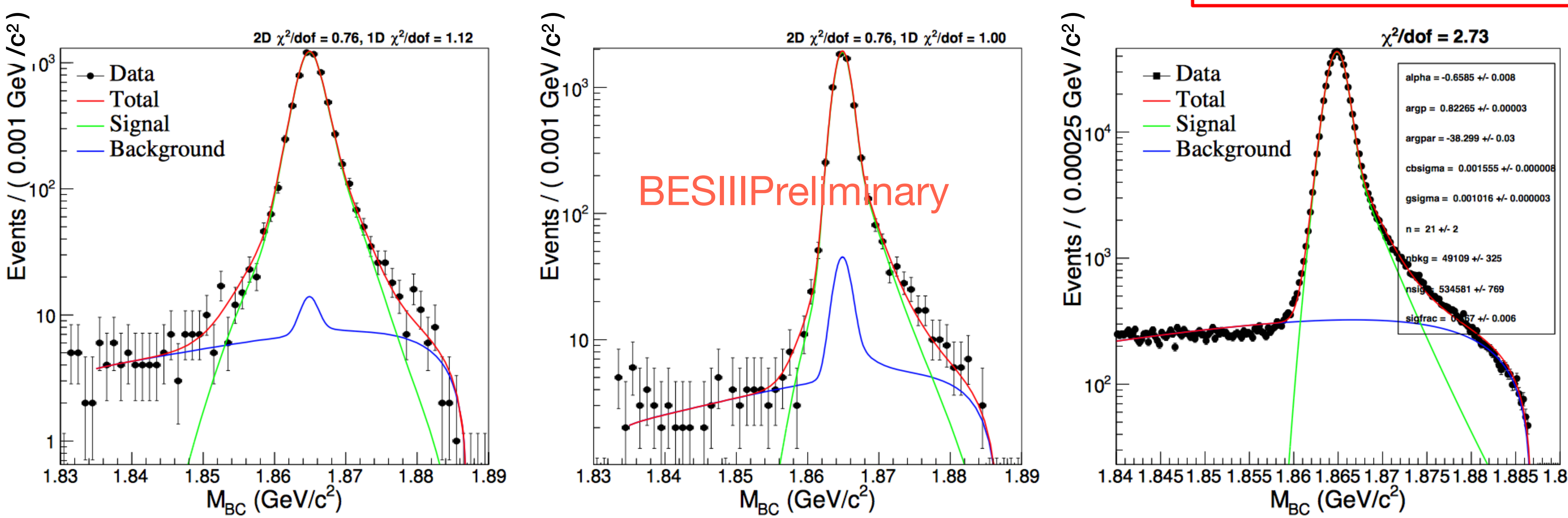
Amplitude Analysis Results of $D^0 \to K^-\pi^+\pi^0\pi^0$



Branching Fraction Results of $D^0 \to K^-\pi^+\pi^0\pi^0$

Double tag(DT) $D^0 \to K^-\pi^+\pi^0\pi^0$ vs. $\bar{D}^0 \to K^+\pi^-$
Single tag(ST) $\bar{D}^0 \to K^+\pi^-$

$$\mathcal{B}_{\rm sig} = \frac{N^{\rm DT}_{\rm tag,sig}}{N^{\rm ST}_{\rm tag}} \frac{\varepsilon_{\rm tag}}{\varepsilon_{\rm tag,sig}}$$



(a)DT $(K^-\pi^+\pi^0\pi^0)$ (b)DT $(K^+\pi^-)$ (c)ST

The amplitude analysis result is used to determine the detection efficiency, where the DT efficiency is 8.39%

The branching fraction is determined to be

$$\mathcal{B}(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.98 \pm 0.13(\text{stat}) \pm 0.40(\text{syst}))\%$$

BESIIIPreliminary

Amplitude Analysis of $D^+ \to K_S\pi^+\pi^+\pi^-$

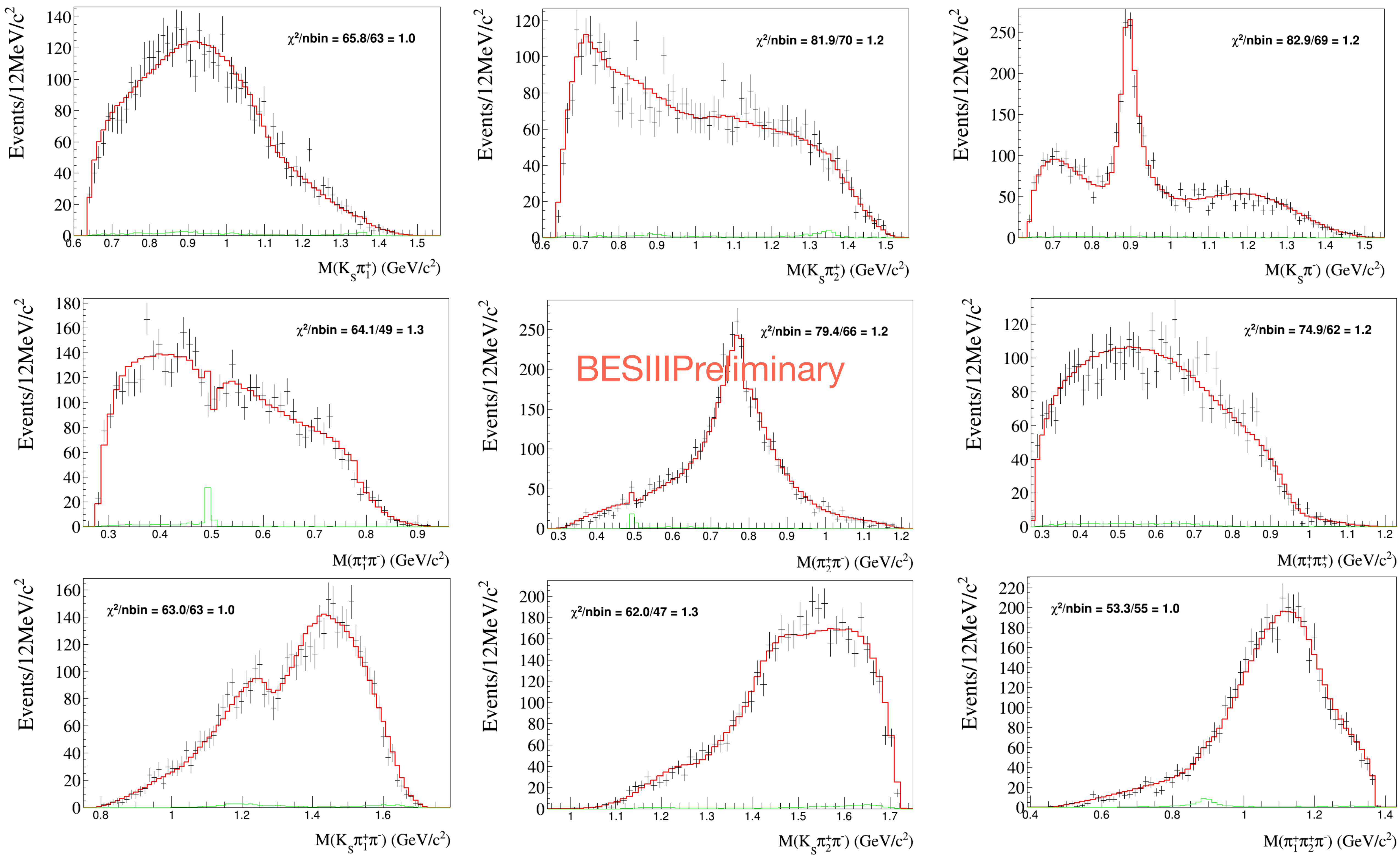
Double tag $D^+ \to K_S\pi^+\pi^+\pi^-$ vs. $D^- \to K^+\pi^-\pi^-$

The number of event selected is 4559 with a purity of ~99%

The data can be described with 12 amplitudes:

Amplitude	ϕ	fit fraction
$D^+ \to K^0_S a_1(1260)^+, a_1(1260)^+ \to \rho^0\pi^+[S]$	0.000(fixed)	$0.567 \pm 0.020 \pm 0.044$
$D^+ \to K^0_S a_1(1260)^+, a_1(1260)^+ \to f_0(500)\pi^+$	$-2.023 \pm 0.068 \pm 0.113$	$0.050 \pm 0.006 \pm 0.007$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[S]$	$-2.714 \pm 0.038 \pm 0.051$	$0.380 \pm 0.013 \pm 0.014$
$D^+ \to \bar{K}_1(1400)^0\pi^+, \bar{K}_1(1400)^0 \to K^{*-}\pi^+[D]$	$3.431 \pm 0.137 \pm 0.117$	$0.015 \pm 0.004 \pm 0.005$
$D^+ \to \bar{K}_1(1270)^0\pi^+, \bar{K}_1(1270)^0 \to K^0_S\rho^0[S]$	$-0.418 \pm 0.070 \pm 0.087$	$0.036 \pm 0.004 \pm 0.002$
$D^+ \to \bar{K}(1460)^0\pi^+, \bar{K}(1460)^0 \to K^0_S\rho^0$	$-1.850 \pm 0.120 \pm 0.223$	$0.014 \pm 0.004 \pm 0.003$
$D^+ \to (K^0_S\rho^0)_A[D]\pi^+$	$2.328 \pm 0.097 \pm 0.068$	$0.011 \pm 0.003 \pm 0.002$
$D^+ \to K^0_S(\rho^0\pi^+)_P$	$1.656 \pm 0.083 \pm 0.056$	$0.031 \pm 0.004 \pm 0.010$
$D^+ \to (K^{*-}\pi^+)_A[S]\pi^+$	$-4.321 \pm 0.047 \pm 0.073$	$0.132 \pm 0.011 \pm 0.011$
$D^+ \to (K^{*-}\pi^+)_A[D]\pi^+$	$0.989 \pm 0.158 \pm 0.229$	$0.013 \pm 0.004 \pm 0.004$
$D^+ \to (K^0_S(\pi^+\pi^-)_S)_A\pi^+$	$-2.935 \pm 0.060 \pm 0.125$	$0.051 \pm 0.004 \pm 0.003$
$D^+ \to ((K^0_S\pi^-)_S\pi^+)_P\pi^+$	$1.864 \pm 0.069 \pm 0.288$	$0.022 \pm 0.003 \pm 0.003$

Amplitude Analysis of $D^+ \rightarrow K_S\pi^+\pi^+\pi^-$



Amplitude Analysis of $D^+ \to K_S\pi^+\pi^+\pi^-$

The preliminary results of branching fractions for different components：

BESIII *Preliminary*

Component	Branching fraction (%)
$D^+ \to K_S^0 a_1(1260)^+(\rho^0\pi^+)$	$1.684 \pm 0.059 \pm 0.131 \pm 0.062$
$D^+ \to K_S^0 a_1(1260)^+(f_0(500)\pi^+)$	$0.149 \pm 0.018 \pm 0.021 \pm 0.006$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+)\pi^+$	$1.105 \pm 0.045 \pm 0.048 \pm 0.041$
$D^+ \to \bar{K}_1(1270)^0(K_S^0\rho^0)\pi^+$	$0.107 \pm 0.012 \pm 0.006 \pm 0.004$
$D^+ \to \bar{K}(1460)^0(K_S^0\rho^0)\pi^+$	$0.042 \pm 0.012 \pm 0.009 \pm 0.002$
$D^+ \to K_S^0\pi^+\rho^0$	$0.131 \pm 0.015 \pm 0.015 \pm 0.005$
$D^+ \to K^{*-}\pi^+\pi^+$	$0.413 \pm 0.036 \pm 0.059 \pm 0.015$
$D^+ \to K_S^0\pi^+\pi^+\pi^-$	$0.220 \pm 0.015 \pm 0.024 \pm 0.008$

stat. uncertainty from FF

sys. uncertainty from FF

uncertainties related to BF($D^+ \to K_S^0\pi^+\pi^+\pi^-$) in PDG

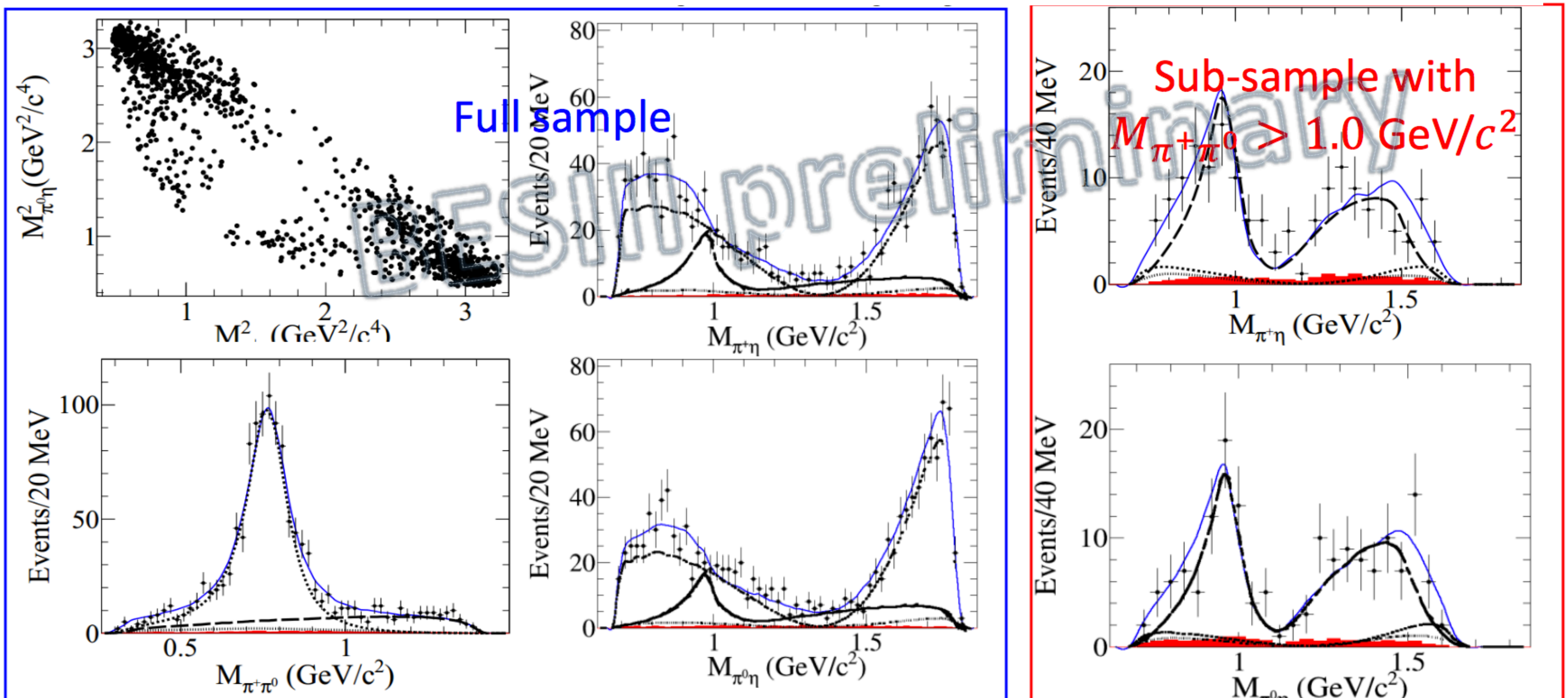
The measurements of the decays with $K1(1270)$and $K1(1400)$involved provide some experimental information in understanding the mixture of the two excited Kaons.

Amplitude Analysis of $D_s^+ \to \pi^+\pi^0\eta$

Observation of $D_s^+ \to a^0(980)^+\pi^0$

Amplitude	Significance (σ)	Phase	FF
$D_s^+ \to \rho^+\eta$	> 20	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \to (\pi^+\pi^0)_V\eta$	5.7	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.026$
$D_s^+ \to a_0(980)\pi$	16.2	$2.794 \pm 0.087 \pm 0.041$	$0.232 \pm 0.023 \pm 0.034$

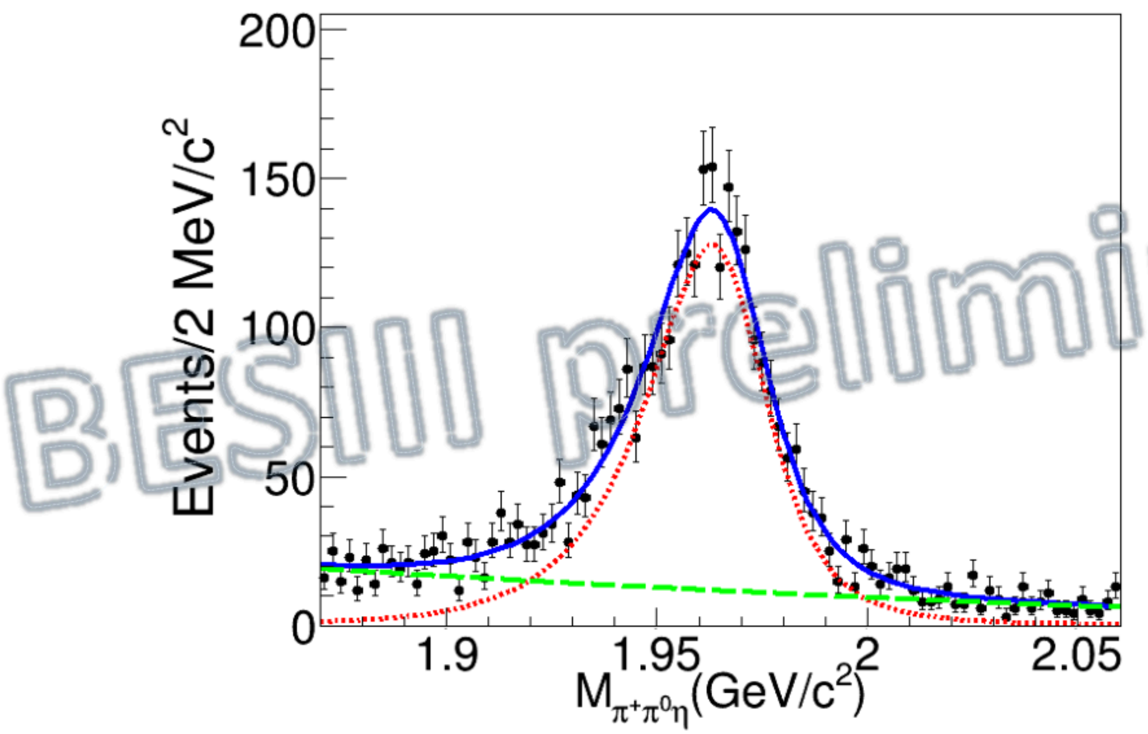
The amplitudes agree with: $A(D_s^+ \to a_0(980)^+\pi^0) = -A(D_s^+ \to a_0(980)^0\pi^+)$ within stat. uncertainty, thus we set the magnitudes to be the same with the phase difference fixed to π.



Dots with error bar: data; solid: total fit; dashed: $D_s^+ \to \rho^+\eta$; dotted: $D_s^+ \to (\pi^+\pi^0)_V\eta$; long dashed: $D_s^+ \to a_0(980)\pi$ (**with a Stat. significance of 16. 2σ**).

Amplitude Analysis of $D_s^+ \to \pi^+\pi^0\eta$

Fit to signal mode



Total Tag yield: 255895 ± 1358 .

DT yield: 2626 ± 77.

Efficiency is determined with the amplitude analysis result.

- Dots with error bars: data.
- Total fit.
- Signal: MC shape convoluted with a Gaussian.
- Background: second-order Chebychev.

$BF(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28_{stat.} \pm 0.41_{sys.})\%$

Branching fraction (%) BESIII *Preliminary*
$\mathcal{B}(D_s^+ \to \rho^+\eta) = 7.44 \pm 0.48_{stat.} \pm 0.44_{sys.}$
$\mathcal{B}(D_s^+ \to a_0(980)\pi)^* = 2.20 \pm 0.22_{stat.} \pm 0.34_{sys.}$
$\mathcal{B}(D_s^+ \to a_0(980)^+\pi^0)^* = 1.46 \pm 0.15_{stat.} \pm 0.22_{sys.}$
$\mathcal{B}(D_s^+ \to a_0(980)^0\pi^+)^* = 1.46 \pm 0.15_{stat.} \pm 0.22_{sys.}$

BF(sub-mode n) = $\mathcal{B}(D_s^+ \to \pi^+\pi^0\eta)FF(n)$

First observation

- The measured $\mathcal{B}(D_s^+ \to a^0(980)^+\pi^0)$ is larger than other measured pure *W*-annihilation decays ($D_s^+ \to pn$, $D_s^+ \to w\pi^+$) by one order. This provides theoretical challenge in understanding such a large *W*-annihilation contribution in D→SP.

Summary

- Tag technique and pair threshold data allows us to perform inclusive and exclusive branching fraction measurement
- Double tag provides clean samples for amplitude analysis
- Many charm physics studies have been published, more related measurements are on-going
- More D_s studies are on going based on our new 3.19 fb^{-1} data at E_{cm} = 4.178 GeV
  - $K_S K$-$K_L K$ asymmetry, amplitude analyses of $KK\pi$, $\pi\pi$eta, $\pi\pi\pi$, and four-body decays, such as $KK\pi\pi$ and $\pi\pi\pi$eta