(Selected recent experimental results in) Hadronic charmed meson & baryon decays

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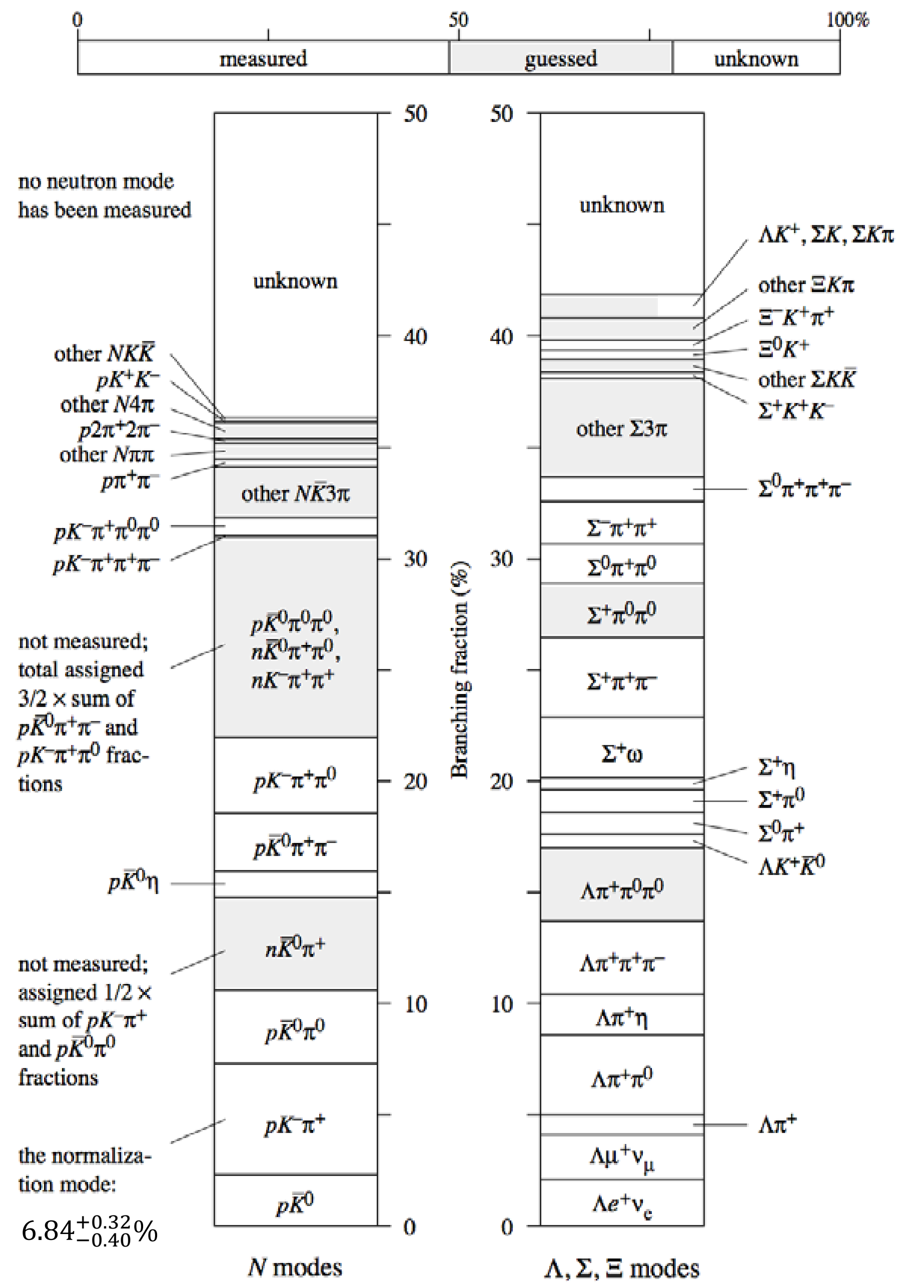
Outline

I apologize that I couldn't cover other recent results today

- Λ_c hadronic decays
  - BF($\Lambda_c^+ \to p\, K^- \pi^+$)
  - BF($\Lambda_c^+ \to n\, K_S^0 \pi^+$)
  - DCSD: BF($\Lambda_c^+ \to p\, K^+ \pi^-$)
  - BF($\Lambda_c^+ \to \Lambda\, \mu^+ \nu_\mu$)
- D hadronic decays
  - Line-shape of $\sigma(e^+e^- \to D\bar{D})$
  - Amplitude analysis : $D^0 \to K^- \pi^+ \pi^+ \pi^-$
  - BF($D \to \omega\pi$)
  - BF($D^0 \to K_S K^+ K^-$)
- Quantum-Correlated Charm analysis
  - $D^0 \to K_S \pi^+ \pi^-$ via GGSZ method

Λ_c

- **The lightest charmed baryons**
  → most of the charmed baryons will eventually decay into Λ_c. Important to know the decay properties of Λ_c.
- **Absolute BFs are not well determined, yet.**
  Often, used the golden mode, $\Lambda_c^+ \to p K^- \pi^+$ to normalize.
- **Total measured BF is ~ 50%.**
- **Also, no neutron mode has been measured.**

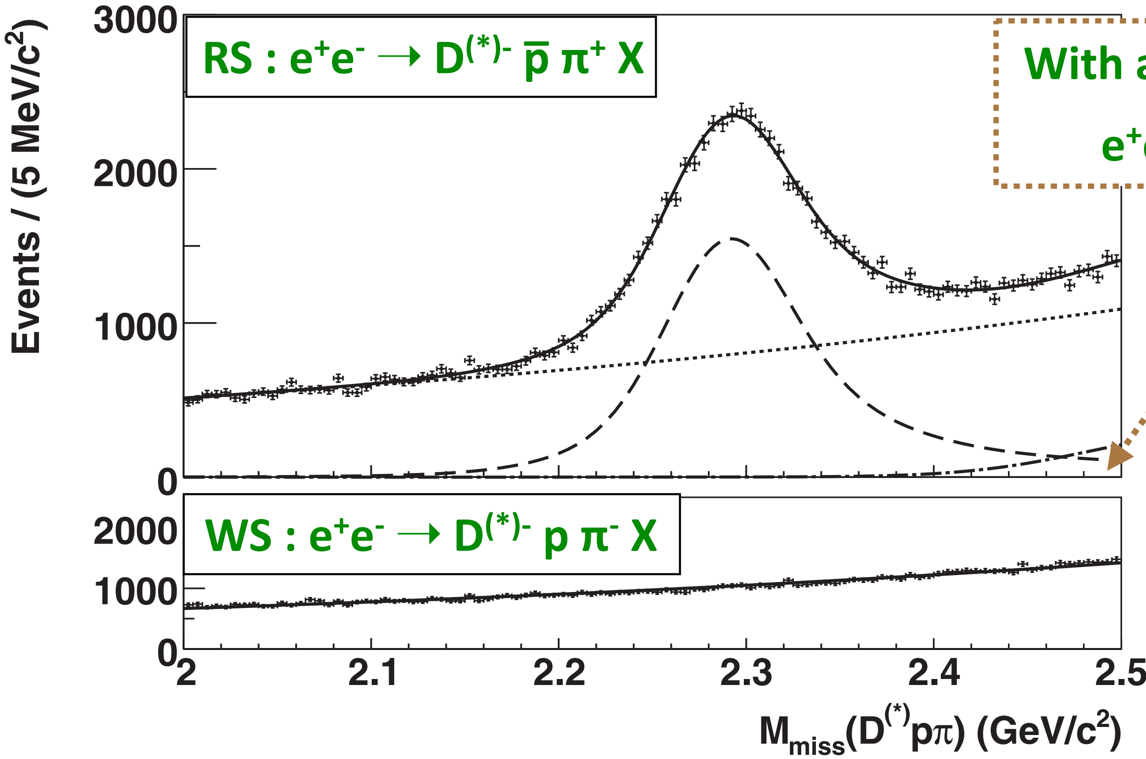


Belle:BF($\Lambda_c^+ \to p K^- \pi^+$)

PRL 113, 042002 (2014)

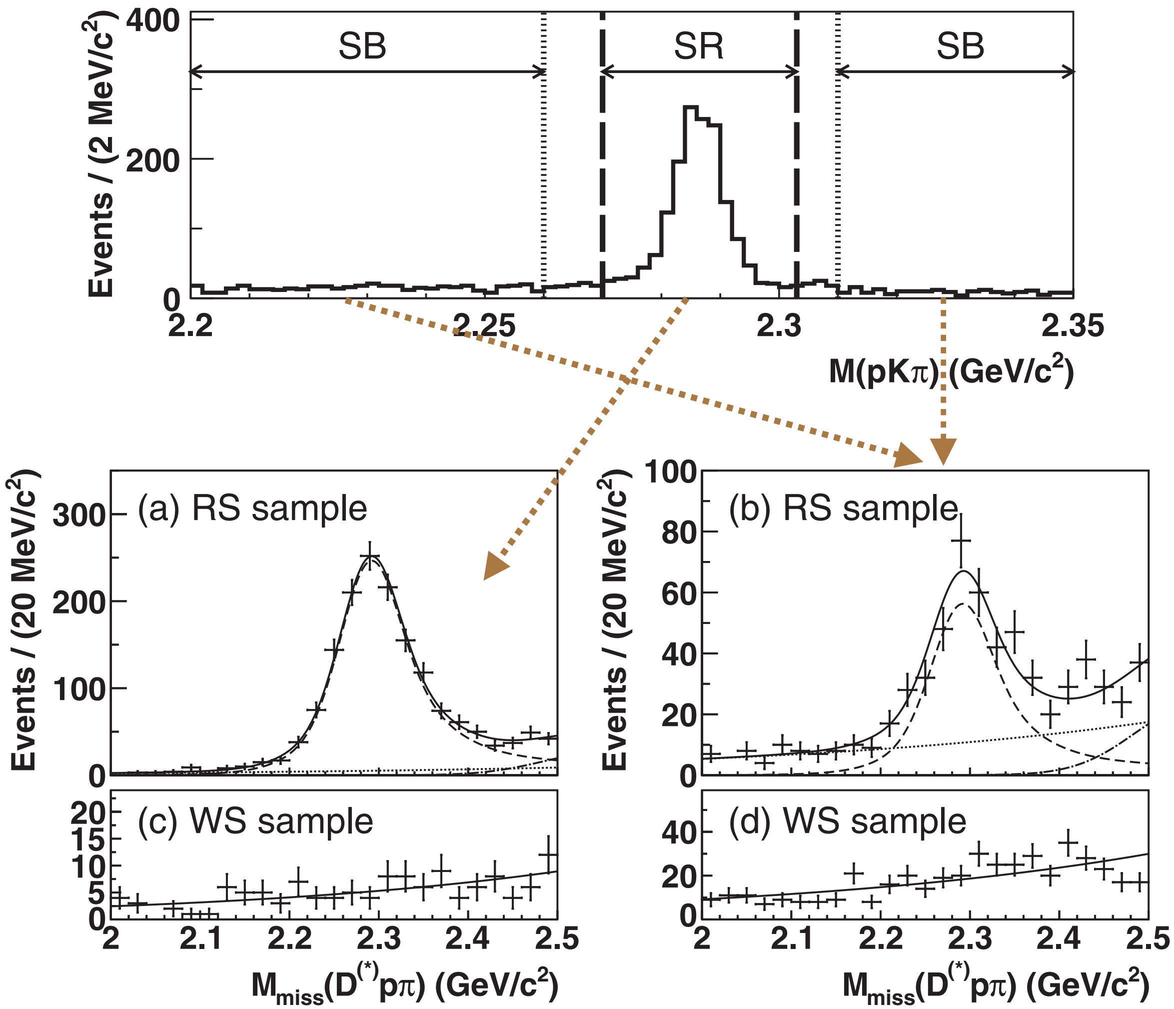
- First model independent measurement on the golden mode.
- Sample: 978 fb^{-1} near the Y(nS) resonances, with n = 1, 2, 3, 4, 5.
- Reconstruct $e^+e^- \to D^{(*)-} \bar{p} \pi^+ \Lambda_c^+$.

  # of inclusive Λ_c^+ is obtained from the recoil against $D^{(*)-} \bar{p} \pi^+$.



With additional particles X;

$e^+e^- \to D^{(*)-} \bar{p} \pi^+ \Lambda_c^+ X$



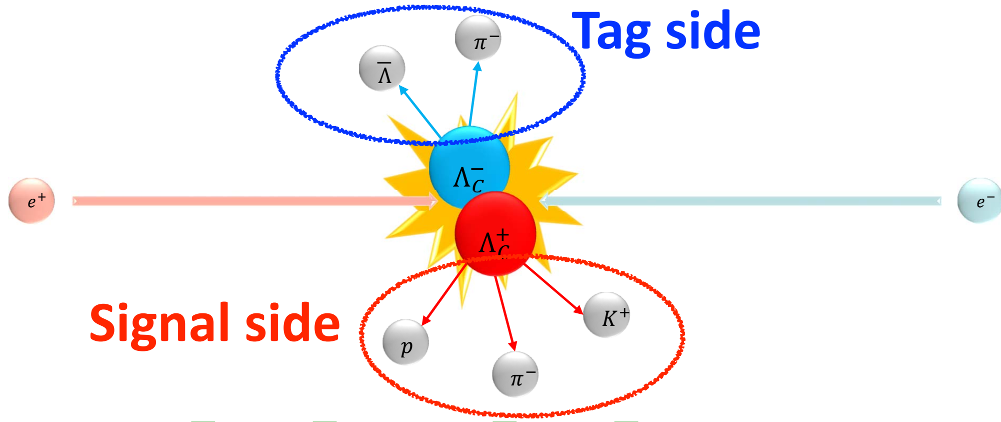
- Reconstruct $\Lambda_c^+ \to p K^- \pi^+$ based on the inclusive sample.
- BF = $(6.84 \pm 0.24^{+0.21}_{-0.27})\%$

  The most accurate measurement to date!

BESIII: BF($\Lambda_c^+ \to p K^- \pi^+$)

PRL 116, 052001 (2016)

- First absolute BF measurement.
- Sample: near $\Lambda_c^+\bar{\Lambda}_c^-$ mass threshold, E_{cm} = 4.6 GeV.
  567 pb^{-1}: Simple pair production: No additional particles produced.
  → Makes possible to employ the double-tag technique.
- For instance, for the case of $\Lambda_c^+ \to p K^- \pi^+$ and $\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-$:



Singe Tag: $N_{ST} = N_{\Lambda_c\bar{\Lambda}_c} \times BF(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-) \times \varepsilon(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-)$

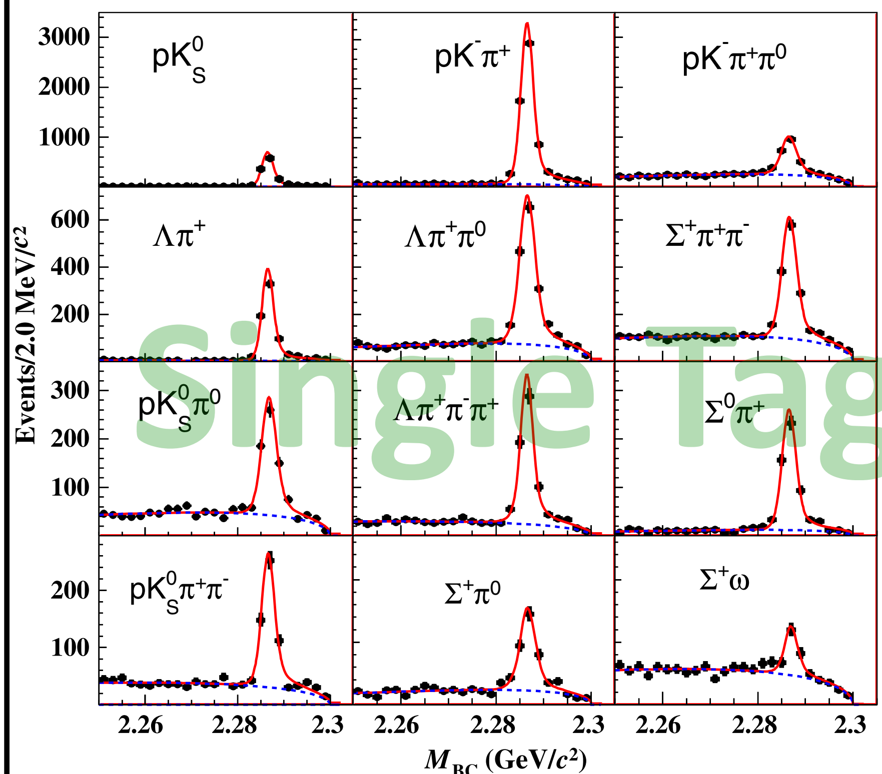
Double Tag: $N_{DT} = N_{\Lambda_c\bar{\Lambda}_c} \times BF(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-) \times BF(\Lambda_c^+ \to p K^- \pi^+) \times \varepsilon(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^- \text{ and } \Lambda_c^+ \to p K^- \pi^+)$

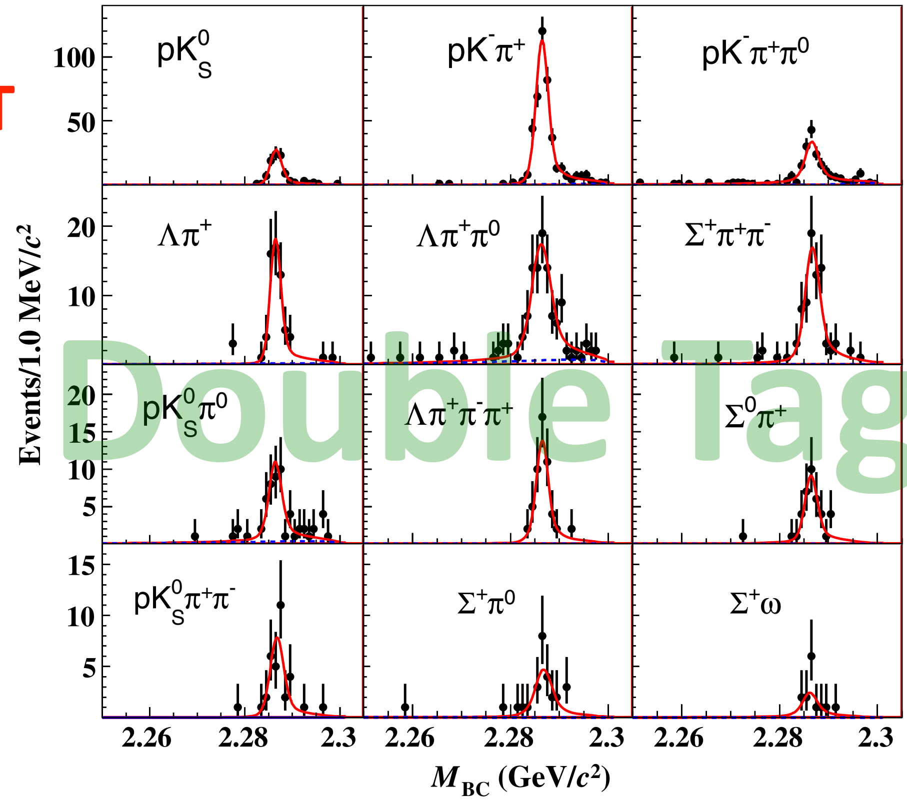
Then, $BF(\Lambda_c^+ \to p K^- \pi^+) = N_{DT}/N_{ST} \times \varepsilon(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-)/\varepsilon(\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^- \text{ and } \Lambda_c^+ \to p K^- \pi^+)$.

Notice that the systematic uncertainty associated with the reconstruction of $\bar{\Lambda}_c^- \to \bar{\Lambda} \pi^-$ tends to be canceled in the ratio of efficiencies.

Extracting N_{ST} and N_{DT}

- Look for 12 different tag modes.
- Fit to $M_{BC} = \sqrt{(E_{beam}^2 - |\vec{p}_\Lambda|)}$





- In the above DT case, summed over the 12 tag modes
- Simultaneously fit to the all $N_{DT} = N_{\Lambda_c\bar{\Lambda}_c} \times BF_{tag} \times BF_{sig} \times \varepsilon_{DT}$, while constraining $N_{\Lambda_c\bar{\Lambda}_c}$, taking into account correlations over modes.
  $N_{\Lambda_c\bar{\Lambda}_c}$ will be a byproduct.

Mode	This work (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$

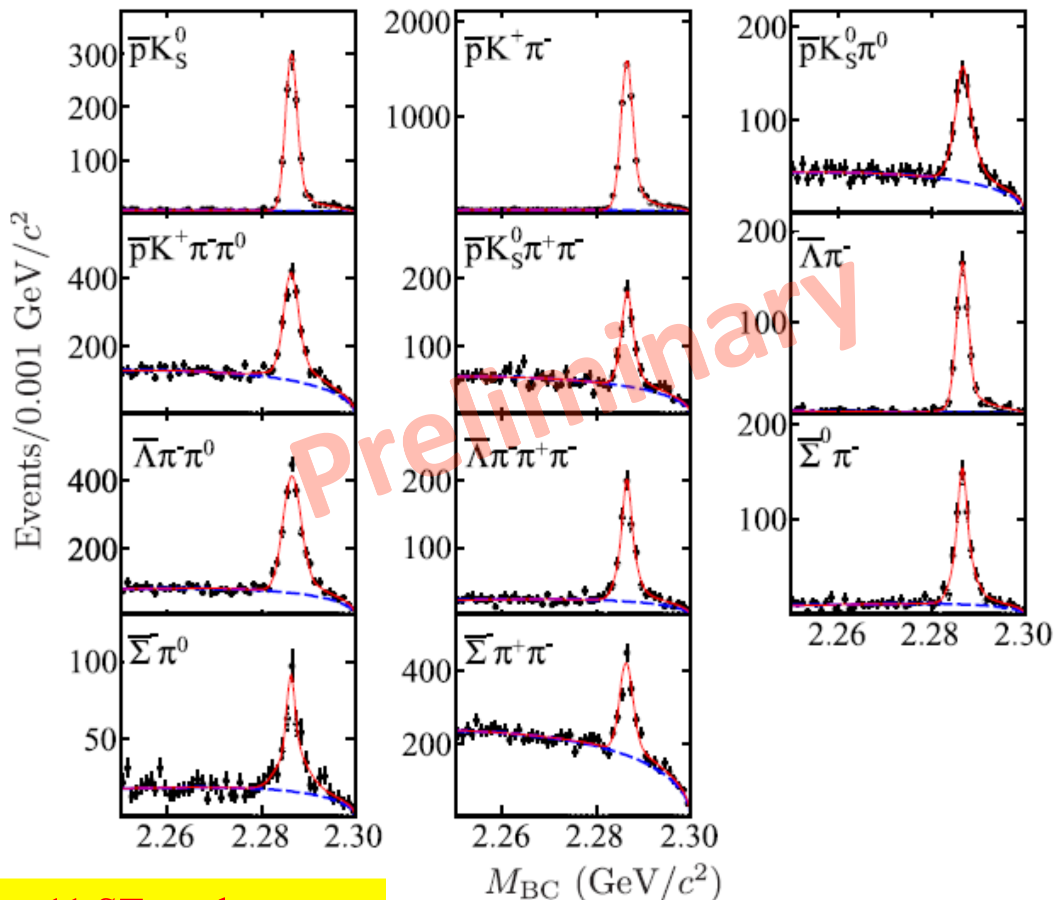
- **Also obtained $N_{\Lambda c\bar{\Lambda}c}$ = (105.9±4.8±0.5)×10^3.**
- **Other BF($\Lambda_c^+ \to$ hadrons) are measured with improved precisions.**

- **BESIII : BF($\Lambda_c^+ \to p\, K^- \pi^+$) = (5.84±0.27±0.23)%**
  Belle : BF($\Lambda_c^+ \to p\, K^- \pi^+$) = ($6.84 \pm 0.24^{+0.21}_{-0.27}$)%
- **Consistent? … within ~2σ …**
  Hopefully, the agreement would improve further in the near future. (more data? new technique?)

BESIII: BF($\Lambda_c^+ \to n K_S^0 \pi^+$)

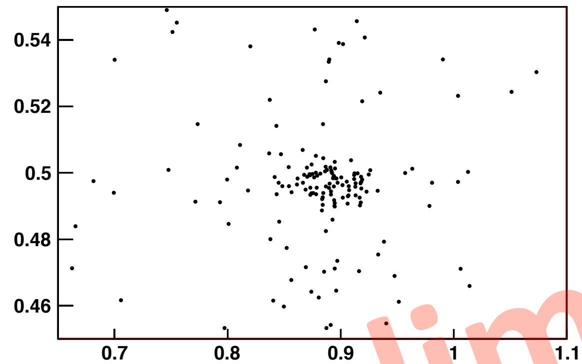
- BESIII preliminary result based on the same '4.6 GeV sample'.
- First direct measurement Λ_c decaying into the neutron.
- Employing the same double tag technique based on the 11 tag modes.

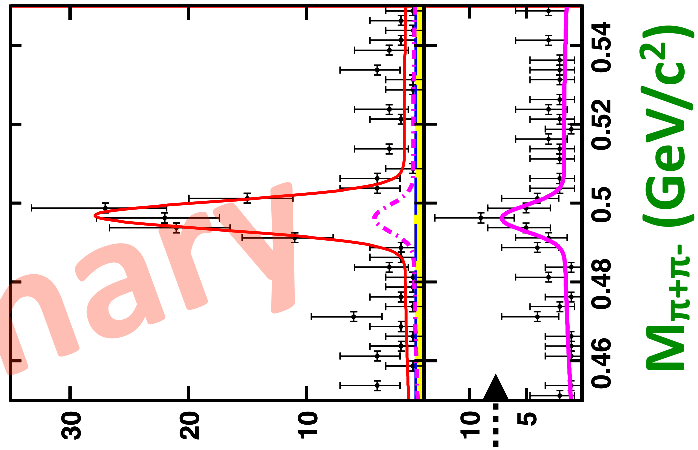
- $K_S^0 \to \pi^+\pi^-$,
- $\bar{\Lambda} \to \bar{p}\pi^+$,
- $\bar{\Sigma}^0 \to \gamma\bar{\Lambda}$ with $\bar{\Lambda} \to \bar{p}\pi^+$,
- $\bar{\Sigma}^- \to \bar{\Lambda}\pi^-$,
- $\pi^0 \to \gamma\gamma$.



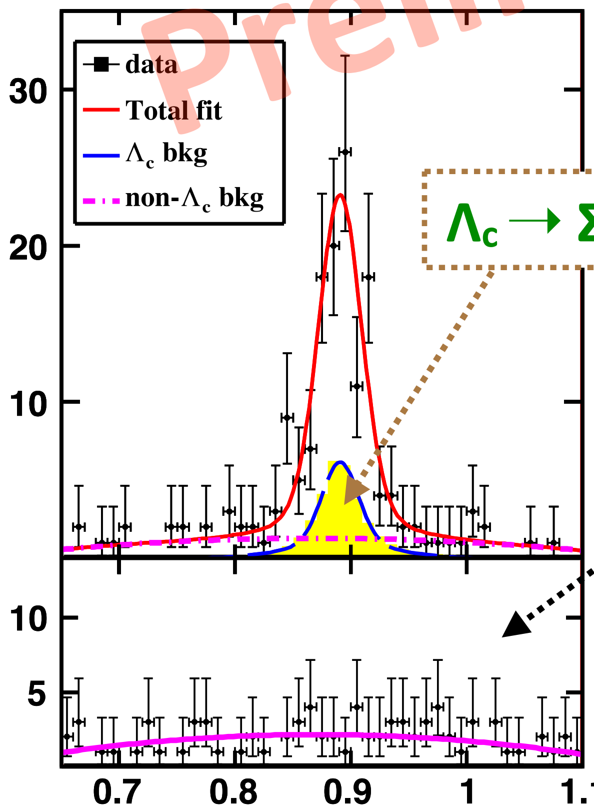
Totally, 11415±159 events are reconstructed by 11 ST modes.

83±11 signal events





non-Λ_c contribution:
Sideband from tag side M_{BC}



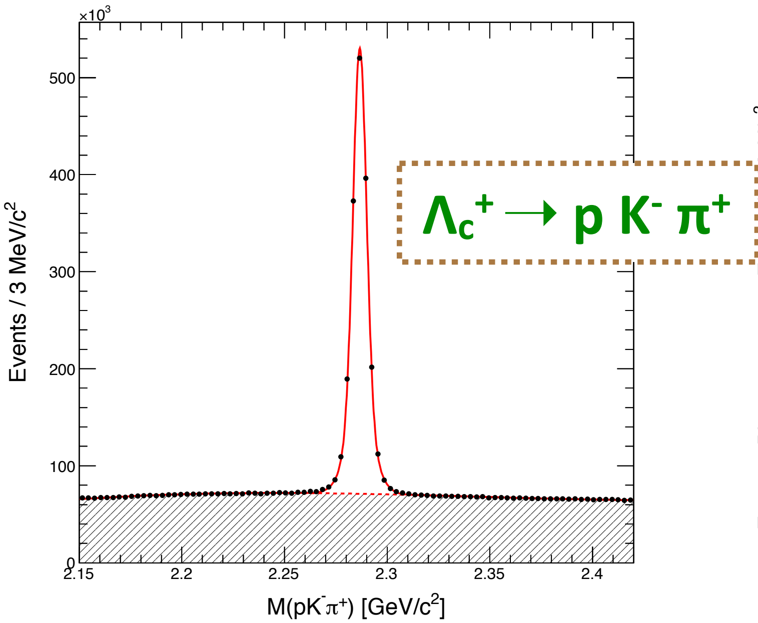
$\Lambda_c \to \Sigma^{\pm}(\to n\pi^{\pm})\pi^+\pi^{\mp}$

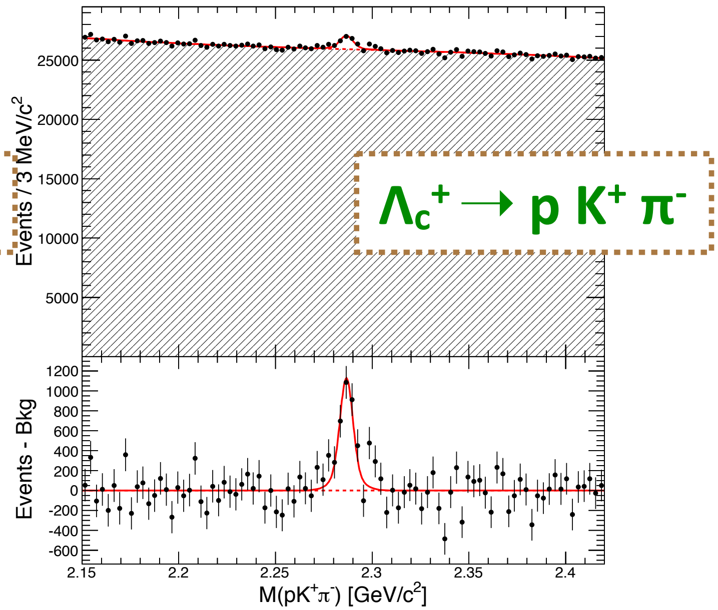
- **Preliminary result:**
  $BF(\Lambda_c^+ \to n K_S^0 \pi^+) = (1.82 \pm 0.23 \pm 0.11)\%$

Belle: BF($\Lambda_c^+ \rightarrow p K^+ \pi^-$)

arXiv:1512.07366

- First observation of Doubly Cabibbo-suppressed decay of Λ_c.
- 980 fb^{-1} near the Υ(nS) resonances, with n = 1, 2, 3, 4, 5.
- Stat. significance = 9.4σ.
  N_{SIG} = 3379±380(stat)±78 (SCS contamination: $\Lambda_c^+ \rightarrow \Lambda(\rightarrow p\pi^-)K^+$)





BF($\Lambda_c^+ \rightarrow p K^+ \pi^-$)/BF($\Lambda_c^+ \rightarrow p K^- \pi^+$) = (2.35±0.27±0.21)×10^{-3}

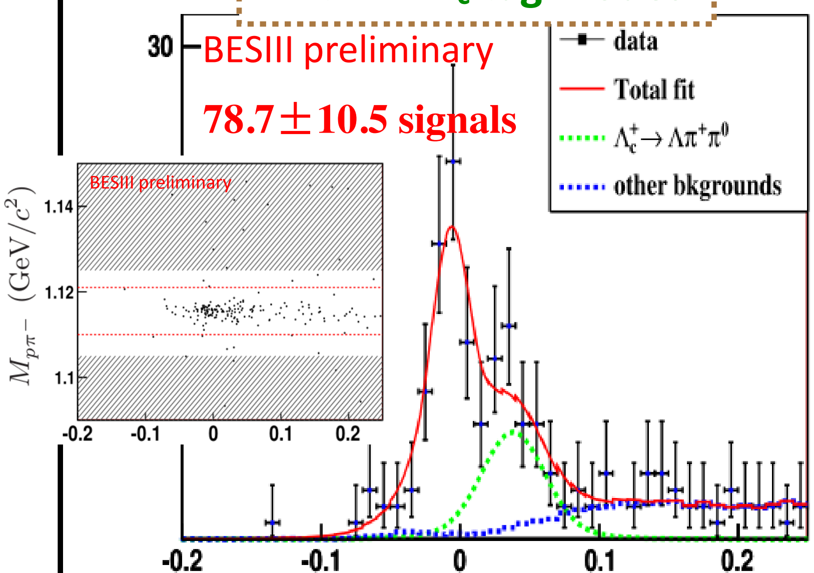
BESIII: BF($\Lambda_c^+ \to \Lambda\, l^+ \nu_l$)

$c \to s\, l^+ \nu_l$

- Not really a hadronic decay of Λ_c, but still interesting Λ_c decays.
  Last year, BESIII reported BF($\Lambda_c^+ \to \Lambda\, e^+ \nu_e$) = (3.63±0.38±0.20)%
  (PRL 115, 221805 (2015)).
  Based on the data taken near the threshold: 567 pb^{-1} at E_{cm} = 4.6 GeV.

- They now have a preliminary result on $\Lambda_c^+ \to \Lambda\, \mu^+ \nu_\mu$.

With 11 Λ_c tag modes



U_{miss} (GeV) (=E_{miss} - $|\vec{P}_{miss}|$)

Preliminary

- BF($\Lambda_c^+ \to \Lambda\, \mu^+ \nu_\mu$) = (3.49±0.46±0.26)%
  consistent with the measured electric mode.

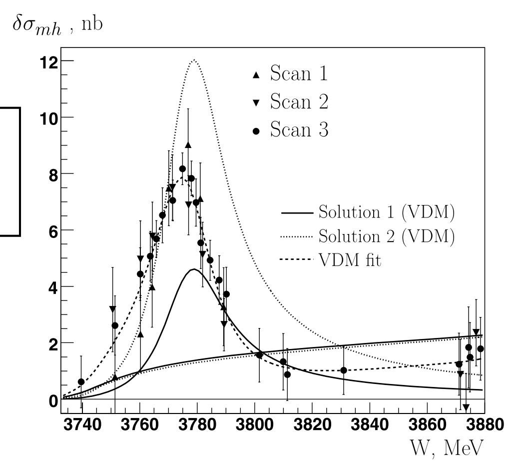
- Thus;

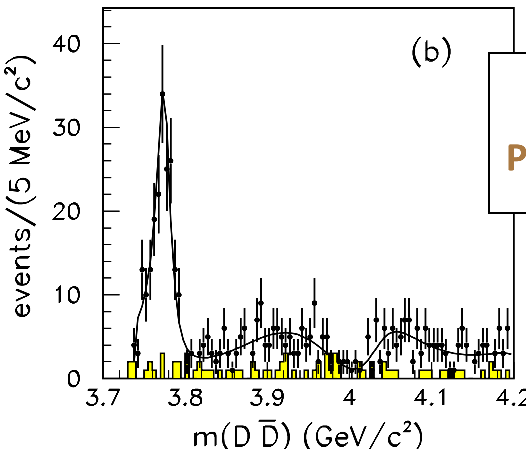
$$\Gamma(\Lambda_c^+ \to \Lambda\, \mu^+ \nu_\mu)/\Gamma(\Lambda_c^+ \to \Lambda\, e^+ \nu_e) = 0.96 \pm 0.16 \pm 0.04$$

BESIII: line shape of $D\bar{D}$ pair near the mass threshold

- Measurement of ψ(3770) parameters.
- It has been seen the distorted resonance shape in other experiments.

KEDR
PLB 711, 292 (2012)





BABAR
PRD 76, 111105 (R) (2007)

- Total ~ 70 pb^{-1} in $3643 < E_{cm} < 3890$ MeV.
- Single Tag method.
- Observed cross section = $N_D/(2\times\varepsilon_D\times\text{Luminosity})$ in each E_{cm} bin.

$$= \int z_{D\bar{D}}(W\sqrt{1-x})\,\sigma_{D\bar{D}}(W\sqrt{1-x})\,\mathcal{F}(x,W^2)\,dx$$

Coulomb, Born Level, ISR

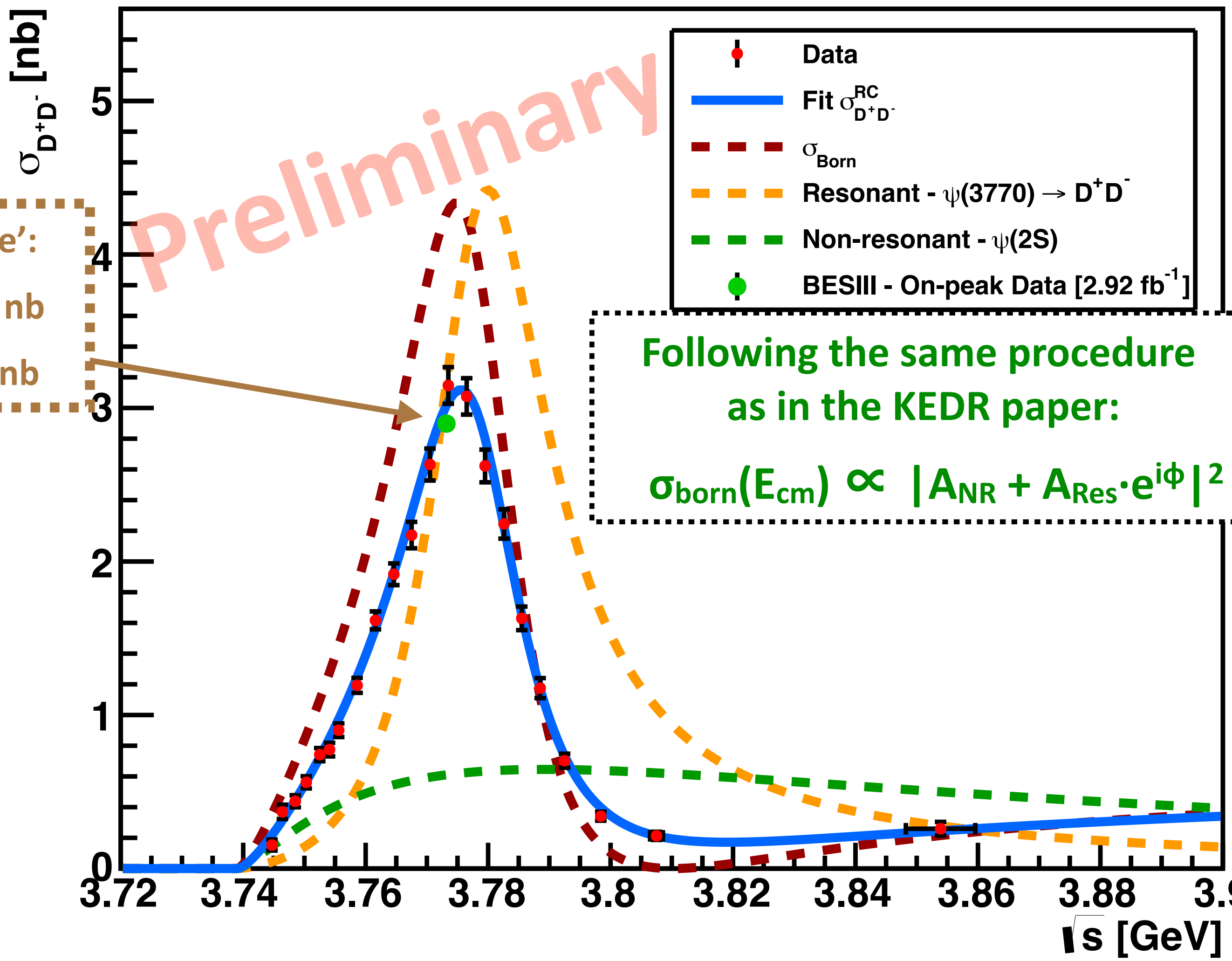
$\sigma_{obs}(e^+e^- \to D\bar{D})$ around E_{cm} = 3770 MeV

- Simultaneously fit to $\sigma_{obs}(W)$ of $D^0\bar{D}^0$ and D^+D^-.
- Only $\sigma_{obs}(e^+e^- \to D^+D^-)$ is shown here.

Based on the 'on-resonance sample':

-$\sigma(e^+e^- \to D^0\bar{D}^0)$ = 3.641±0.010 (stat.) nb

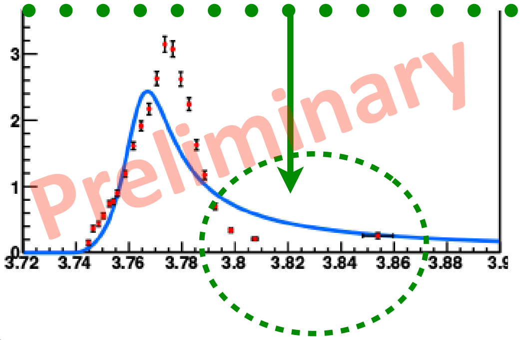
-$\sigma(e^+e^- \to D^+D^-)$ = 2.844±0.011 (stat.) nb



Following the same procedure as in the KEDR paper:

$\sigma_{born}(E_{cm}) \propto |A_{NR} + A_{Res} \cdot e^{i\phi}|^2$

Not easy to fit with a single BW?



Results

- Can only determine $\Gamma_{ee}^{\psi(3770)} \times BF(\psi(3770) \rightarrow D\bar{D})$ (this is essentially, our $D\bar{D}$ YIELDS).

Preliminary

Source	$M^{\psi(3770)}$ [MeV / c^2]	$\Gamma^{\psi(3770)}$ [MeV]	$\Gamma_{ee}^{\psi(3770)\to D\bar{D}}$ [eV]
Exponential	3783.0 ± 0.3	27.5 ± 0.9	270 ± 24
VDM	3781.5 ± 0.3	25.2 ± 0.7	230 ± 18
KEDR	$3779.3^{+1.8}_{-1.7}$	$25.3^{+4.4}_{-3.9}$	160^{+78}_{-58} , 420^{+72}_{-80}
PDG	3773.2 ± 0.3	27.2 ± 1.0	$[262 \pm 18] \times B_{D\bar{D}}$ †

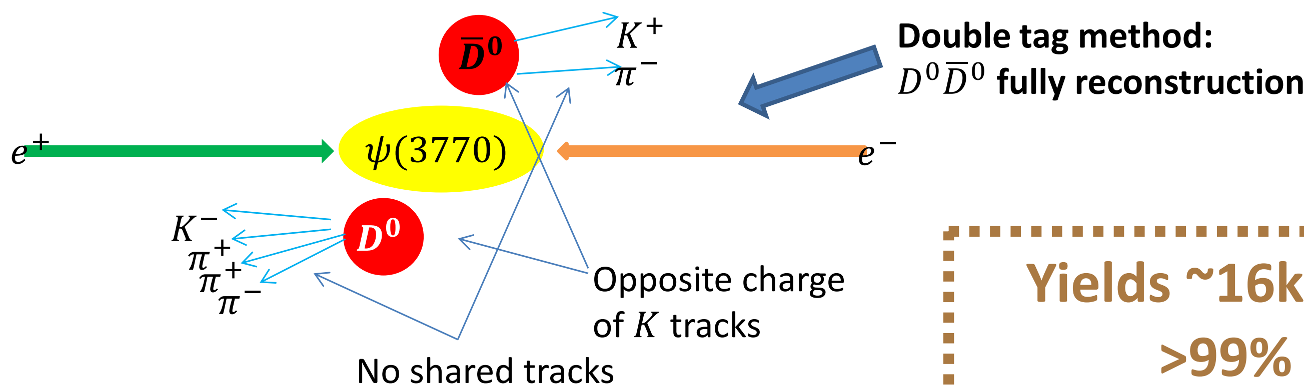
PRELIMINARY

† $B(\psi(3770) \rightarrow D\bar{D})$

- The shown errors are statistical errors only.
- Consistent with the KEDR's result (as they should).
  Higher mass than
  the results without any interference effect considered.

BESIII: $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$

- One of the 3 golden modes of neutral D decays.
- Based on the 2.93 fb^{-1} taken at E_{cm} = 3.773 GeV.
- The knowledge of various intermediate states improve measurements such as;
  - its branching fraction
  - strong phase difference between D^0 and $\bar{D}^0$ in this final state thus, eventually the CKM unitary triangle γ.
- Existing experimental results are old (from Mark III and E691).



Yields ~16k events with >99% purity!

Constructing amplitudes

- **Total decay amplitude = coherent sum of each amplitudes:**

$$M(p_j) = \sum_n \rho_n e^{i\phi_n} A_n(p_j)$$

ρ and ϕ are magnitude and phase of the n^{th} amplitude.
A_n describes the relative contributions of the n^{th} amplitude:

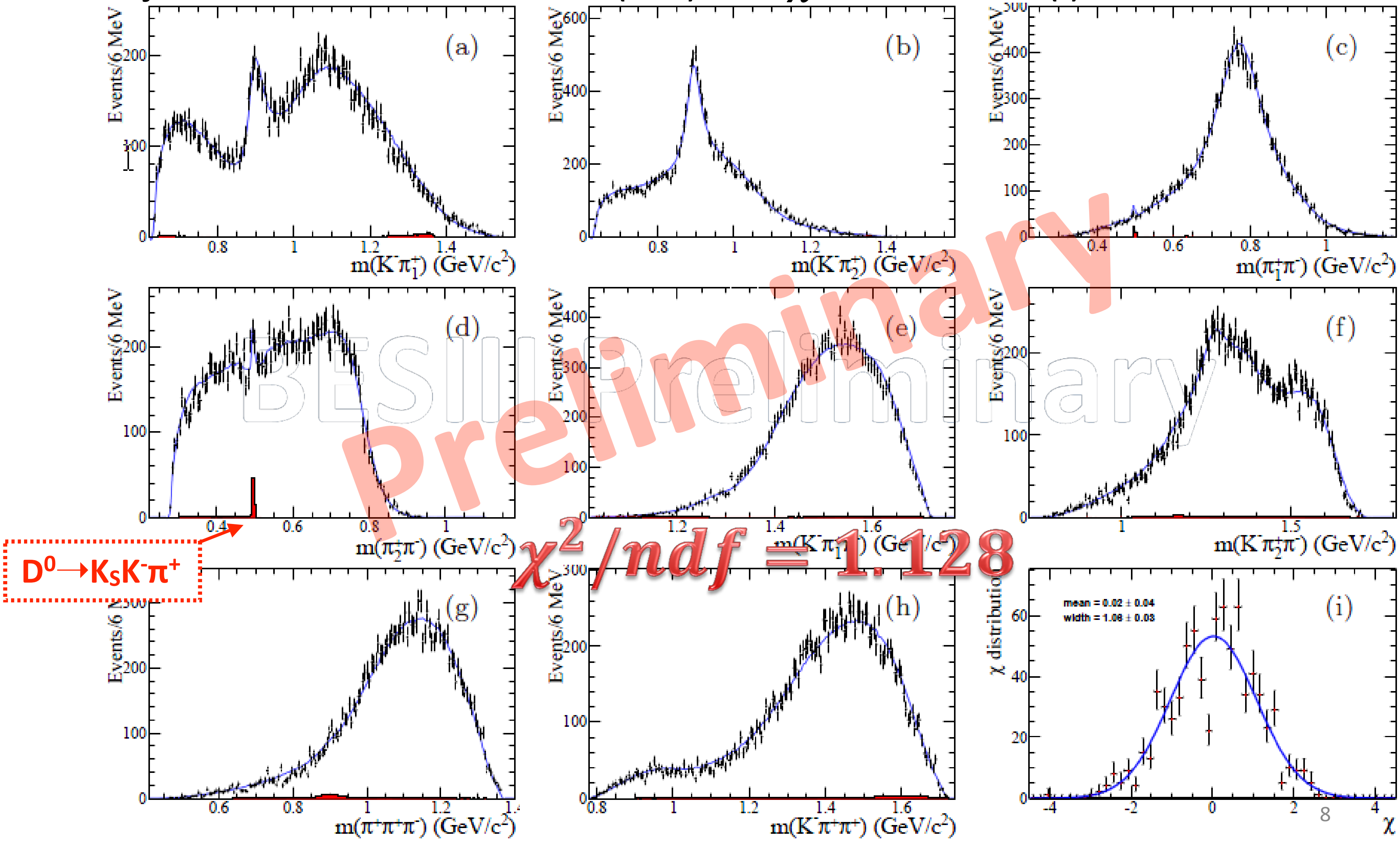
$$A_n(p_j) = P_n^1(m_1) P_n^2(m_2) S_n(p_j) F_n^1(p_j) F_n^2(p_j) F_D^2(p_j).$$

Propagators of intermediate resonances Spin factors Blatte-Weisskopf barriers

The spin factors are constructed with covariant tensor formalism.

Fitting to masses

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



Fitted phases and fit fractions (FF)

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

- $K^*(892)$ and $a_1(1260)$: RBW w/ energy dependent width
- $\rho(770)$: GS formula (PRL 21, 244 (1968))
- $K_1(1270)$: RBW
- $K\pi$ S-wave: the same parametrization used in the BABAR's Dalitz analysis of $D^0 \to K_S \pi^+\pi^-$ (PRD 78, 034023)

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

- According to the intermediate resonances, group the 23 amplitudes into 7 '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
$D^0 \to K_1^-(1270)(K^-\rho^0)\pi^+$	$0.27 \pm 0.02 \pm 0.02 \pm 0.01$	
$D^0 \to K^-\pi^+\rho^0$	$0.68 \pm 0.09 \pm 0.18 \pm 0.02$	0.51 ± 0.23
$D^0 \to \bar{K}^{*0}\pi^+\pi^-$	$0.57 \pm 0.03 \pm 0.03 \pm 0.02$	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

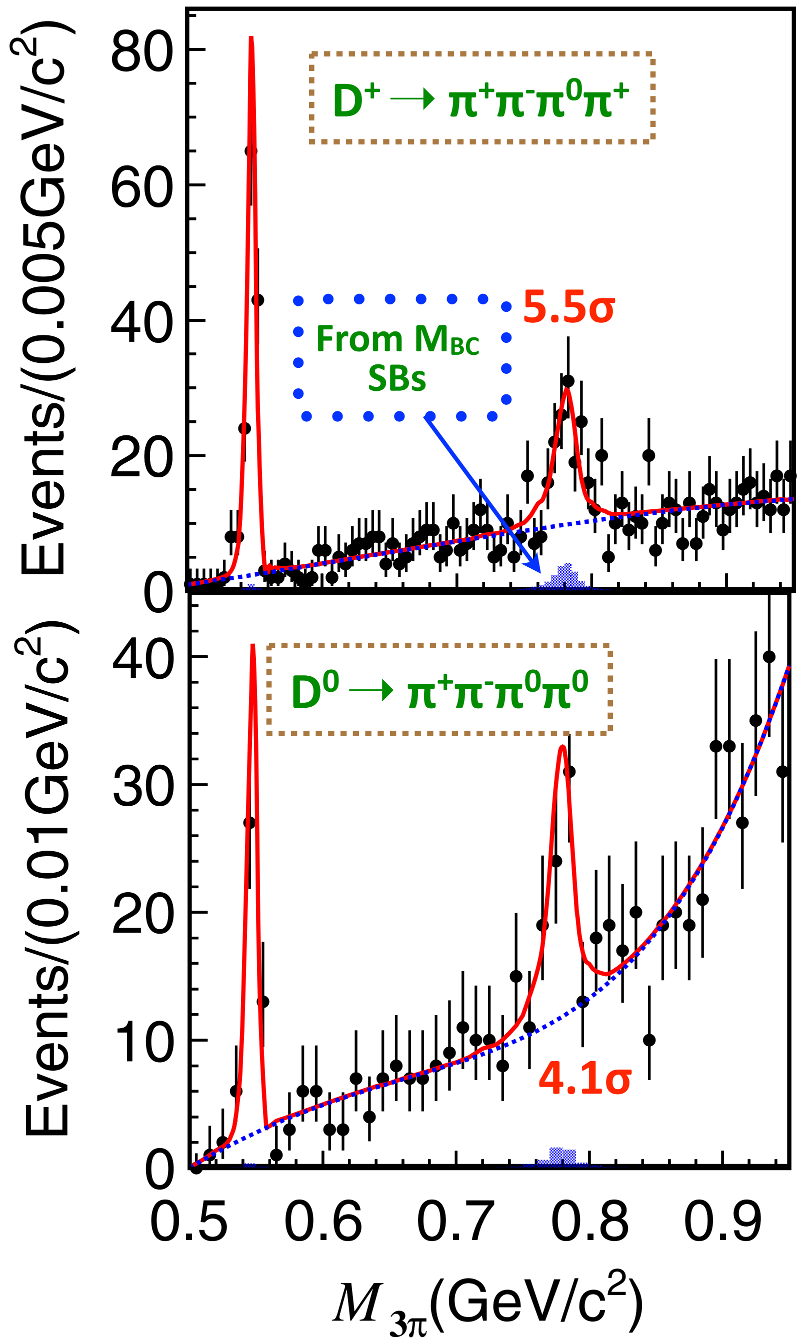
- BF = FF×$BF_{PDG}(D^0 \to K^- \pi^+ \pi^+ \pi^-)$.
- The first and second errors are statistical and systematic uncertainties.
- The third error is due to the PDG input.
- Improvements over the existing results!

BESIII: $D \to \omega\pi$

PRL 116, 082001 (2016)

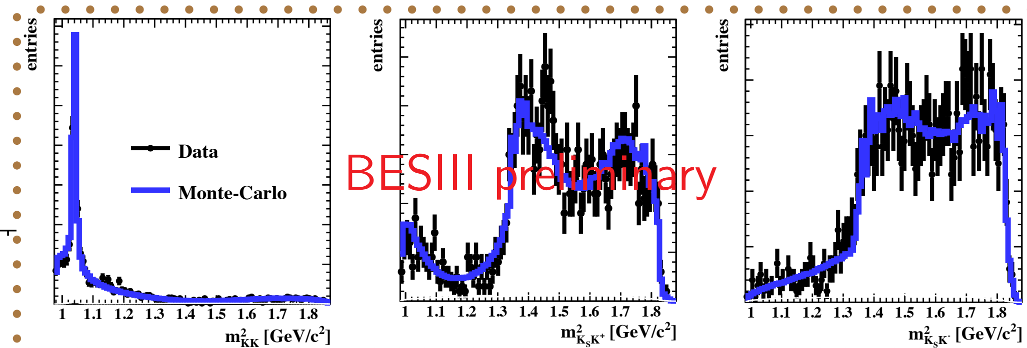
- The first observation of this singly Cabibbo-suppressed decay
- Sample: 2.93 fb^{-1} at E_{cm} = 3.773 GeV.
- Double tag technique to suppress contamination from continuum.
- Also measured $D \to \eta\pi$

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.
$D^+ \to \eta\pi^+$	$(3.07 \pm 0.22 \pm 0.13) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.65 \pm 0.09 \pm 0.04) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$

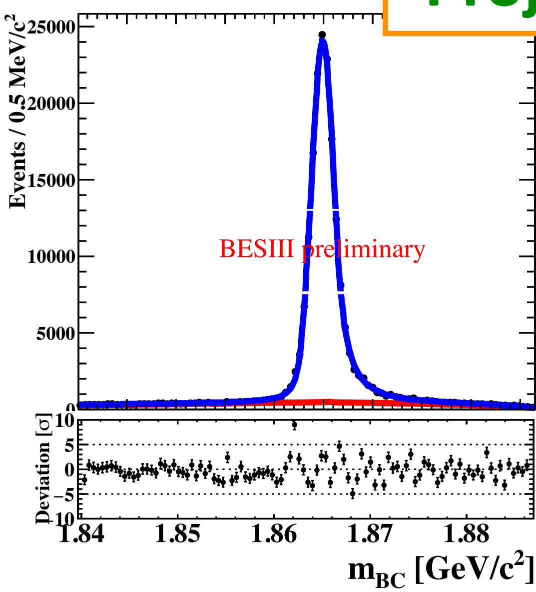


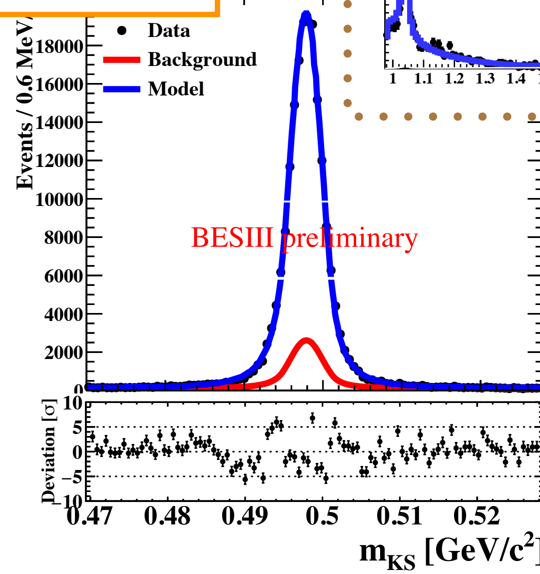
BESIII: $D^0 \rightarrow K_S^0 K^+ K^-$

- PDG: $BF(D^0 \rightarrow K_S^0 K^+ K^-) = (4.47 \pm 0.34) \times 10^{-3}$: 7.6% uncertainty
  And no absolute BF measurement.
- Has rich substructure: e.g., $a_0(980)$: Dalitz analysis is ongoing.
- Preliminary result on the BF measurement via Single Tag.
  Fit to "M_{BC} vs $M_{\pi\pi}$".



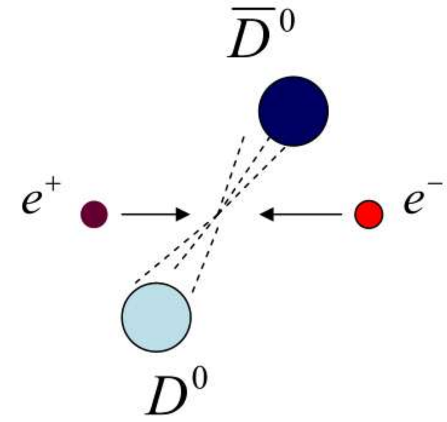
Projections





$BF(D^0 \rightarrow K_S^0 K^+ K^-)$
$= (4.62 \pm 0.05 \pm 0.18) \times 10^{-3}$
4.0% uncertainty now.

Quantum-Correlated Charm near mass threshold



At E_{cm}~ M(ψ(3770)), a pair of $D^0\overline{D}^0$ (and nothing else) is produced via

$e^+e^- \to \gamma^* (\to \psi(3770)) \to D^0\overline{D}^0$.

The produced $D^0\overline{D}^0$ is a C=-1 state.

Or

the two produced neutral mesons must have opposite CP

(i.e., see Goldhaber and Rosner, PRD15, 1254 (1977).

(one could also throw in an extra photon to have C=+1 state in $D^0\overline{D}^0\gamma$)

One application of this is to measure the strong phase difference between

D^0 and $\overline{D}^0 \to K^0 \pi^+ \pi^-$ over Dalitz bins.

Contributing to the measurement of γ/ϕ₃

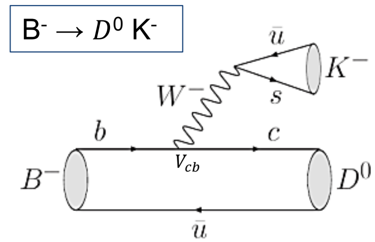
$$\phi_1/\beta = \left(21.85^{+0.68}_{-0.67}\right)^\circ$$

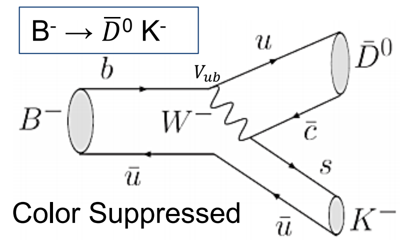
$$\phi_2/\alpha = \left(87.6^{+3.5}_{-3.3}\right)^\circ$$

$$\phi_3/\gamma = \left(73.2^{+6.3}_{-7.0}\right)^\circ$$

2015 CKMfitter (Direct Measurements)

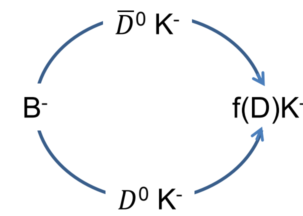
Least known!





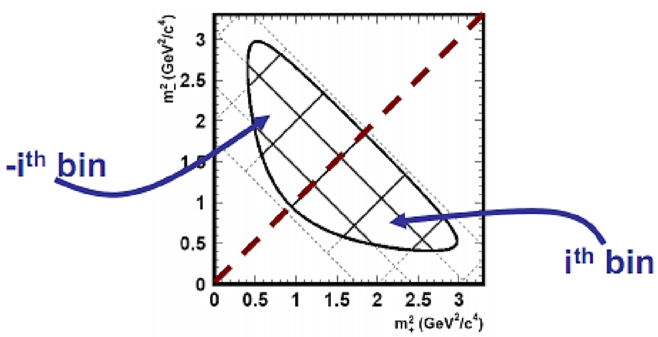
$$\frac{\langle B^- \to \overline{D^0} K^- \rangle}{\langle B^- \to D^0 K^- \rangle} = r_B e^{i(\delta_B - \phi_3)}$$

Determine ϕ_3 through the measurement of the interference between b →c and b →u transitions when D^0 and $\overline{D}^0$ both decay to the same final state f(D).



- **B-Factories measure γ/ϕ₃ through B → D K.**
- **For the case of $D^0 \to K_S \pi^+ \pi^-$, the binned decay rate over the Dalitz plot is given by;**

$$\Gamma(B^\pm \to D(K_s\pi^+\pi^-)K^\pm)_i = T_i + r_B^2 T_{-i} + 2r_B\sqrt{T_i T_{-i}}\cos(\delta_B \pm \phi_3 - \Delta\delta_D)$$
$$= T_i + r_B^2 T_{-i} + 2r_B\sqrt{T_i T_{-i}}\{c_i\cos(\delta_B \pm \phi_3) + s_i\sin(\delta_B \pm \phi_3)\}$$



Mirrored binning over x=y makes it so $c_i = c_{-i}$ and $s_i = -s_{-i}$

Distribution sensitive to variables:

- T_i : Bin yield measured in flavor decays
- r_B : color suppression factor ~ 0.1
- δ_B : strong phase of B decay
- c_i, s_i : weighted average of $\cos(\Delta\delta_D)$ and $\sin(\Delta\delta_D)$ respectively where $\Delta\delta_D$ is the difference between phase of D^0 and $\overline{D}^0$

Measured at B-Factories

Through QCA at Charm-Factories

Relations between c_i, s_i, and yields in Dalitz bins

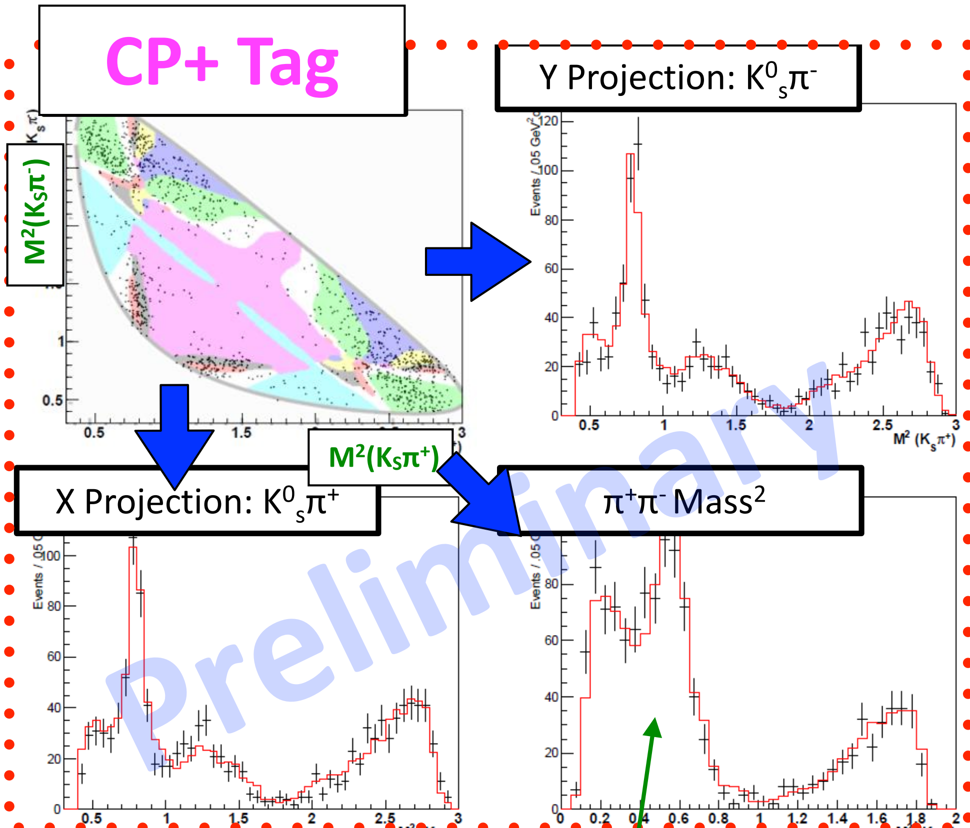
- Define 'CP tags' (CP definite final states):

CP Tag modes

Type	
CP+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$, $K_L\pi^0$
CP-	$K_S\pi^0$, $K_S\eta(\to\gamma\gamma)$, $K_S\eta(\to\pi^+\pi^-\pi^0)$, $K_S\omega$, $K_S\eta'$

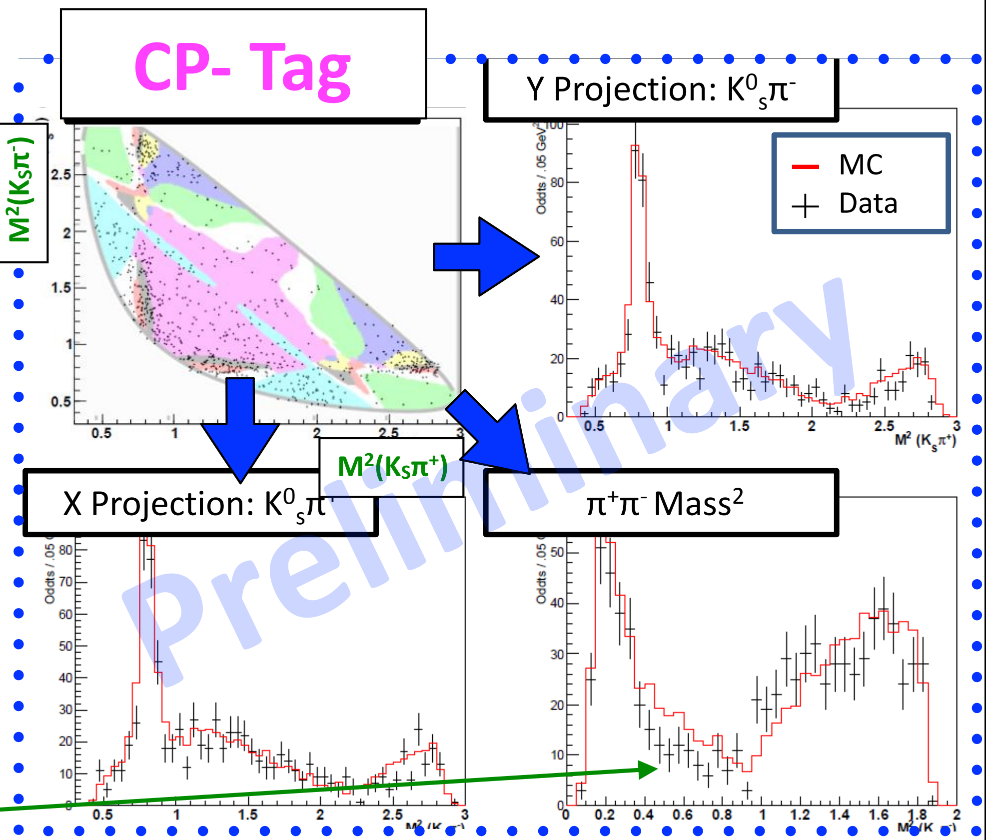
- Efficiency-corrected yields in the i[th] Dalitz bin are; (see PRD82, 112006 (2010) for more details)
  - $\propto$ $\pm c_i$ for DT: $D \to$ CP($\pm$) states vs $D \to K_S\pi^+\pi^-$
  - $\propto$ $c_ic_j + s_is_j$ for DT (two Dalitz): $D \to K_S\pi^+\pi^-$ vs $D \to K_S\pi^+\pi^-$
- Simultaneously fit to them to extract c_i and s_i.

For the case of "CP tag vs $K_S\pi^+\pi^-$"



CP Tag modes

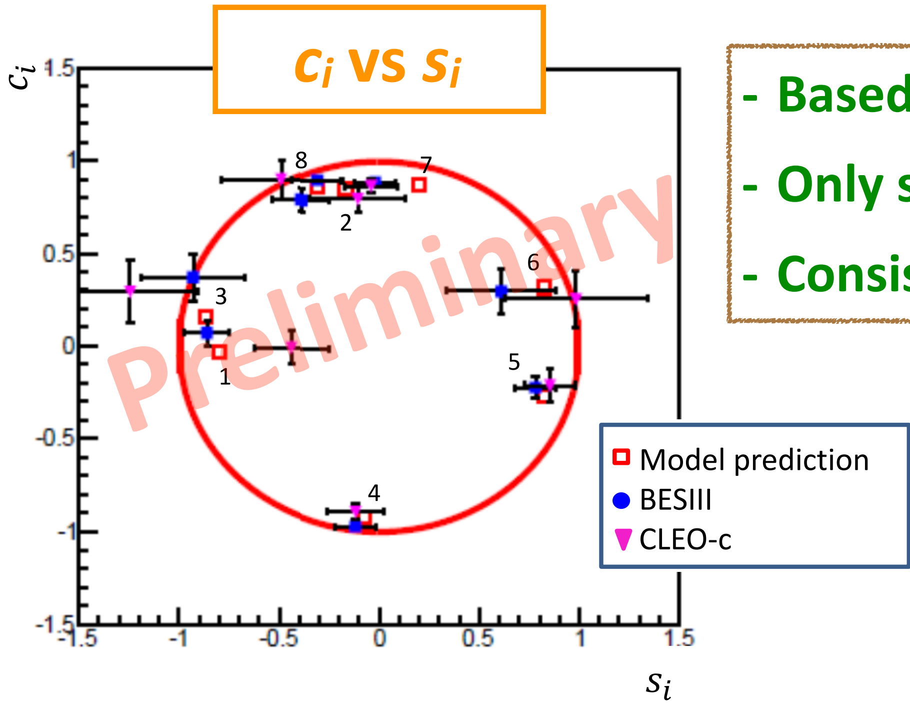
Type	
CP+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$, $K_L\pi^0$
CP-	$K_S\pi^0$, $K_S\eta(\to\gamma\gamma)$, $K_S\eta(\to\pi^+\pi^-\pi^0)$, $K_S\omega$, $K_S\eta'$



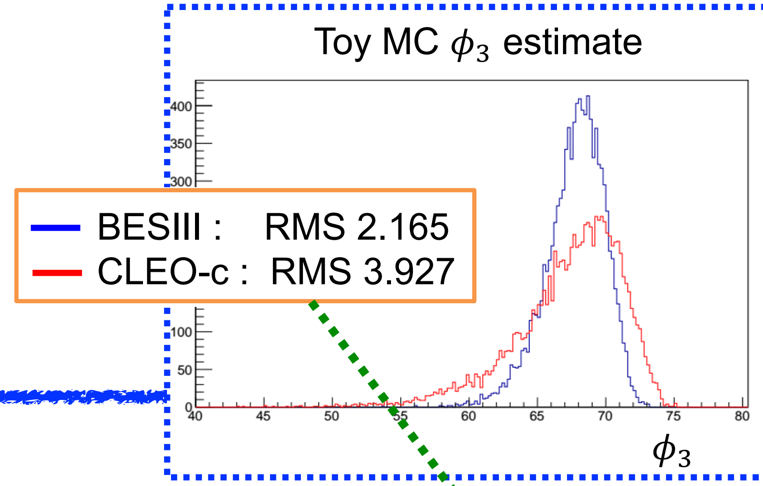
Example of quantum-correlated D decay, $D^0 \to K_S\rho$!!

Results presented here will be using Optimal Binning scheme

BESIII: Results on c_i and s_i



- Based on BESIII 2.93fb^{-1} at E_{cm} = 3.773 GeV.
- Only statistical errors are shown.
- Consistent with the previous CLEO measurement.



- What this result could do to the γ/ϕ3 is,
  if we take the Belle's Dalitz result (PRD85, 112014 (2012)),
  γ (in degrees) = $77.3^{+15.1}_{-14.9}$ (stat.) ± 4.2 (syst.) ± 4.3 (c_i/s_i) → ± 2.4 (c_i/s_i)
  We expect the uncertainly would be reduced by ~45%
- Very important inputs for the future analyses by LHCb and Belle II, where the statistical sensitivity starts to reach ~1~2 degrees.

Summary : Charmed baryon

- We are starting to;
  - see precision measurements in Λ_c decays
  - fill the unknown charts in the PDG
  - observe doubly Cabibbo-suppressed decays.
- B factories and BESIII will collect more data in the near future. Soon, we should be able to;
  - hopefully the agreement in BF($\Lambda_c^+ \rightarrow p K^+ \pi^-$) would be improved
  - push the precisions to the level as we have in D/D_S
  - and certainly start to improve the limit (or discovery) on the forbidden or rare decays.

Summary : Charmed mesons

- The large ψ(3770) sample of BESIII allows to make measurements with improved precisions, such as;
  - amplitude analysis of $D^0 \to K^- \pi^+ \pi^+ \pi^-$
  - the first observation of SCSD, $D \to \omega\pi$
  - improved BF($D^0 \to K_S^0 K^+ K^-$)
  - as well as resonance parameters of the ψ(3770) state.
- Quantum-correlated $D^0\bar{D}^0$ in e^+e^- annihilations near threshold provides unique inputs to the CKM angle measurements, such c_i and s_i.
  Could we see similar results based on '$D^0\bar{D}^0\gamma$' (C=+1 state) in the future?
- As BESIII is accumulating 'D_S' data around E_{cm} ~ 4180 MeV, (the goal is to collect 3 fb^{-1}), expect new results on D_S decays in the near future.