Charm Physics Results at BESIII

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Overview

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   - Charm Production and Charm Physics
   - Analysis Technique
2. Recent Charm Results
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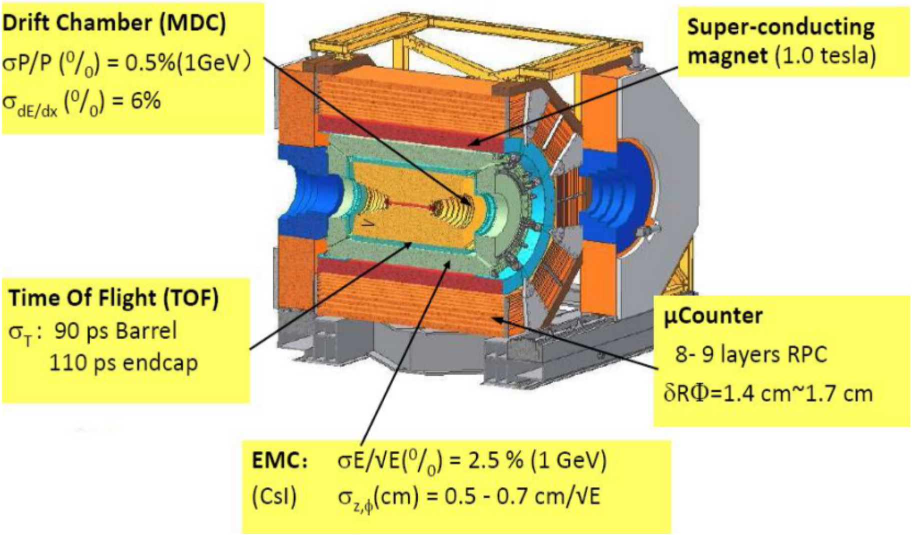
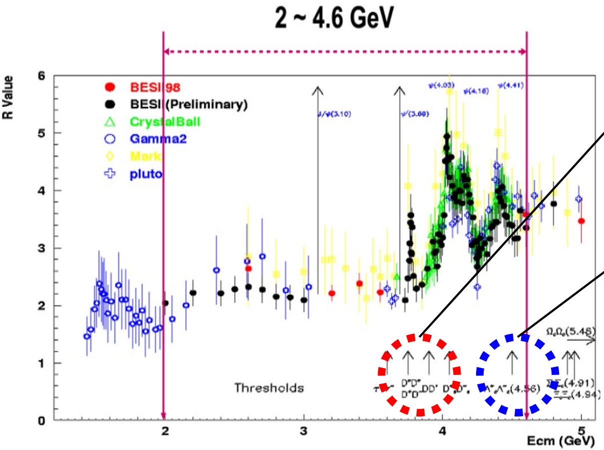
   - Measurement of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ Branching Fraction
   - Observation of $D^+ \to \omega\pi^+$ and Evidence for $D^0 \to \omega\pi^0$
   - Measurement of $D^+ \to \omega e^+ \nu_e$ and Search for $D^+ \to \phi e^+ \nu_e$
   - Analysis of $D^0 \to (K^-/\pi^-) e^+ \nu_e$
   - Decay Dynamics and CP Asymetry in $D^0 \to K_L^0 e^+ \nu_e$
   - Measurement of the branching fractions of $D_s^+ \to \eta' X$ and $D_s^+ \to \eta' \rho^+$ in $e^+e^- \to D_s^+ D_s^-$
3. Summary

Beijing Electron Positron Collider (BEPC-II)

BESIII


Drift Chamber (MDC)
σP/P (⁰/₀) = 0.5%(1GeV)
σ dE/dx (⁰/₀) = 6%
Super-conducting magnet (1.0 tesla)
Time Of Flight (TOF)
σT : 90 ps Barrel
110 ps endcap
μCounter
8- 9 layers RPC
δRΦ=1.4 cm~1.7 cm
EMC: σE/√E(⁰/₀) = 2.5 % (1 GeV)
(CsI) σz,φ(cm) = 0.5 - 0.7 cm/√E

Charm Production and Charm Physics



$2.93\mathrm{fb}^{-1}$ $D\bar{D}$ @3.773 GeV;

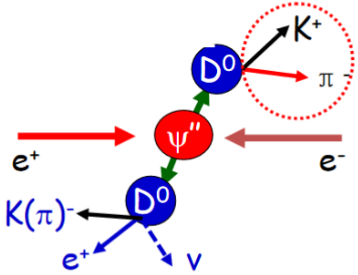
$0.482\mathrm{fb}^{-1}$ $D_s\bar{D}_s$ @4.009 GeV;

$0.567\mathrm{fb}^{-1}$ $\Lambda_c\bar{\Lambda}_c$ @4.599 GeV.

(Semi)leptonic and hadronic decays; Decay constant and formfactors; CKM matrix: V_{cd}, V_{cs}; Mixing and CP violation; Rare and forbidden decays

...

Analysis Technique



1. Single Tag(ST)
   $M_{BC} = \sqrt{E_{beam}^2/c^2 - |\mathbf{p}_D^2|}$
2. Double Tag(DT)
   for (semi)leptonic decays:
   $U_{miss} = E_{miss} - c|\mathbf{p}_{miss}|$
3. $\mathcal{B} = \frac{N_{sig}}{N_{tag} \times \epsilon_{sig}/\epsilon_{tag,sig}}$

Tag side:

Tag the charmed meson or baryon flavor via hadronic decays with large branching fractions, thus could suppress background effectively;

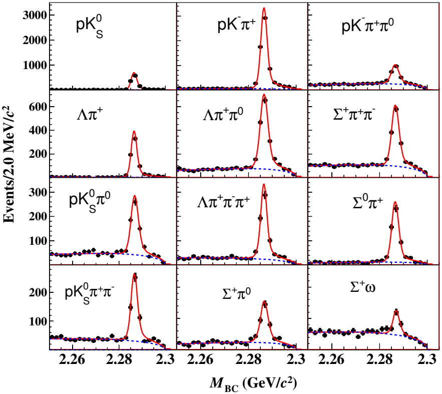
Signal side:

1. (Semi)leptonic charmed decays: reconstruct the "missing" neutrino;
2. Hadronic decays: fully reconstruct the final states.

Measurement of Hadronic Λ_c^+ Branching Fractions

Single Tag Λ_c^+ Events

[PhysRevLett.116.052001]



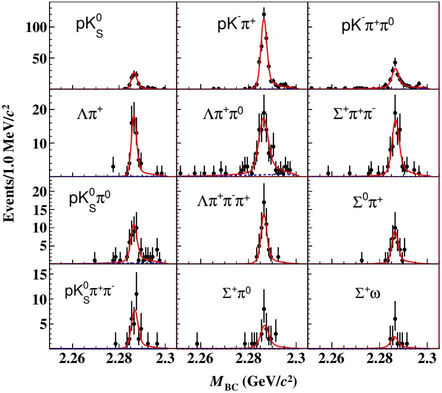
$\sim 1.5 \times 10^4$ single tag events

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

Dominated by $pK^-\pi^+$

Measurement of Hadronic Λ_c^+ Branching Fractions [PhysRevLett.116.052001]

Background free double tags



Mode	$N^{\rm DT}_{i-}$
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

A least square global fitter:

$$N^{DT}_{i^+j^-} = N_{\Lambda_c^+\Lambda_c^-}\mathcal{B}_i\mathcal{B}_j\epsilon^{DT}_{i^+j^-}$$

simultaneous fit to all the tag modes, while constraining the total $\Lambda_c\bar{\Lambda}_c$ pair number, taking into account the correlations.

Measurement of Hadronic Λ_c^+ Branching Fractions

Improved Branching Fractions [PhysRevLett.116.052001]

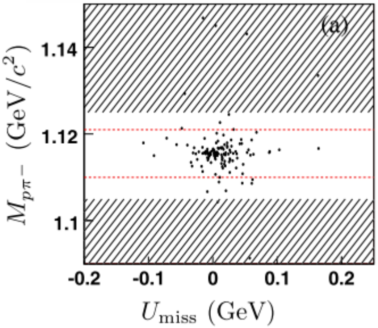
Mode	This work (%)	PDG (%)	BELLE (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	(PhysRevLett.113.042002)
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	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	

1. Branching fraction for $pK^-\pi^+$ is consistent with that of PDG value;
2. The BFs improve the precision of PDG value significantly.

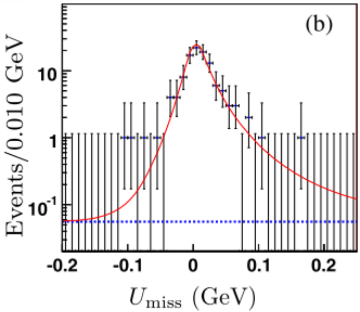
$\Lambda_c^+ \to \Lambda e^+ \nu_e$ Branching Fraction

[PhysRevLett.115.221805]

11 ST modes except $\Lambda_c^+ \to \Sigma^+ \omega$



$\mathcal{B} = (3.63 \pm 0.38 \pm 0.20)\%$

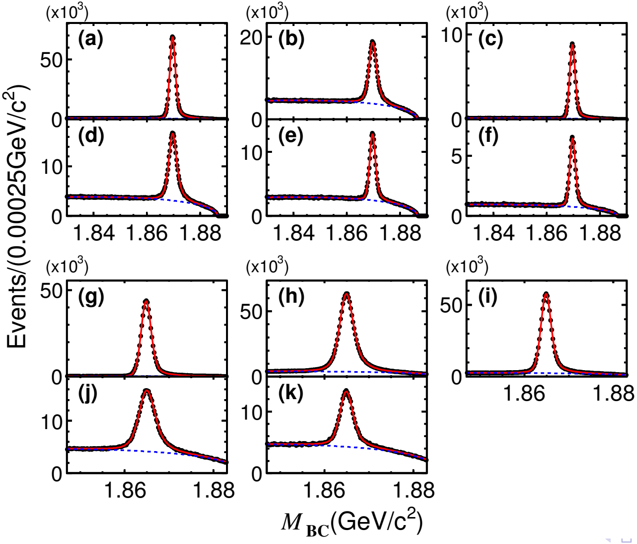


1. $\mathcal{B}_{PDG2015} = (2.9 \pm 0.5)\%$, using $\mathcal{B}_{BELLE}(pK^-\pi^+)$ as input;
2. The first absolute measurement;
3. A good test to non-perturbtive models and LQCD calculations.

Observation of $D^+ \to \omega\pi^+$ and Evidence for $D^0 \to \omega\pi^0$

Fit to ST M_{BC} in Data

[PhysRevLett.116.082001]



Charged D tag modes:

(a) $K^+\pi^-\pi^-$

(b) $K^+\pi^-\pi^-\pi^0$

(c) $K_S^0\pi^-$

(d) $K_S^0\pi^-\pi^0$

(e) $K_S^0\pi^+\pi^-\pi^-$

(f) $K^+K^-\pi^-$

Neutral D tag modes:

(g) $K^+\pi^-$

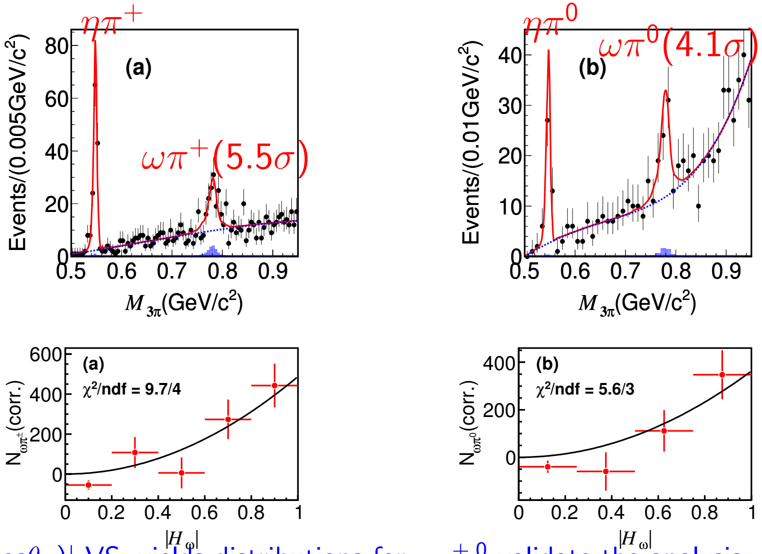
(h) $K^+\pi^-\pi^0$

(i) $K^+\pi^-\pi^+\pi^-$

(j) $K^+\pi^-\pi^0\pi^0$

(k) $K^+\pi^-\pi^+\pi^-\pi^0$

Observation of $D^+ \to \omega\pi^+$ and Evidence for $D^0 \to \omega\pi^0$ [PhysRevLett.116.082001]



$|H_\omega(\cos\theta_\omega)|$ VS. yields distributions for $\omega\pi^{+,0}$ validate the analysis

Observation of $D^+ \to \omega\pi^+$ and Evidence for $D^0 \to \omega\pi^0$ Result

[PhysRevLett.116.082001]

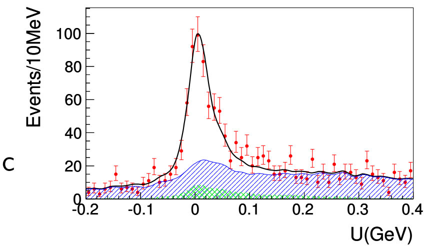
Table: Summary of branching fraction measurements, and comparison with the previous CLEO-c measurements.

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

1. Observation of $D^+ \to \omega\pi^+$ and a strong evidence for $D^0 \to \omega\pi^0$;
2. The $D^+ \to \eta\pi^+$ and $D^0 \to \eta\pi^0$ branching fractions are consistent with the PDG value;
3. Improved understanding of U-spin and $SU(3)$-flavor symmetry breaking effects in D decays.

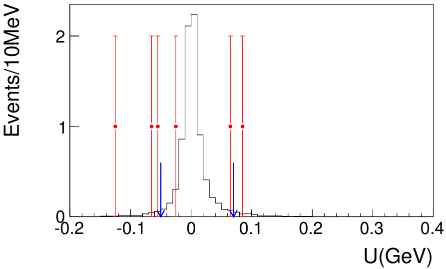
Analysis of $D^+ \to (\omega, \phi)e^+\nu$

[Phys.Rev. D92 (2015) 7, 071101



$D^+ \to \omega e^+\nu_e$

data; peaking background; total background and Fit

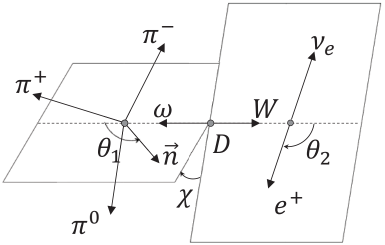


$D^+ \to \phi e^+\nu_e$

Dots:data; Arrow: signal region; Hist: signal MC.

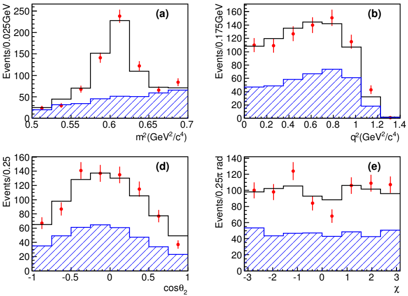
Mode	This work	CLEO-c
$\omega e^+\nu_e$	$(1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$	$(1.82 \pm 0.18 \pm 0.07) \times 10^{-3}$
$\phi e^+\nu_e$	$< 1.3 \times 10^{-5}$ (90%C.L.)	$< 9.0 \times 10^{-5}$ (90%C.L.)

Form Factor Measurement of $D^+ \to \omega e^+ \nu_e$ Phys.Rev. D92 (2015) 7, 071101



$$\frac{d\Gamma}{dq^2 d\cos\theta_1 d\cos\theta_2 d\chi dm_{\pi\pi\pi}} = \mathcal{F}(V(q^2),\ A_{1,2}(q^2)\ \cdots)$$

A five-dimensional maximum likelihood fit is performed in the space of m^2, q^2, $\cos\theta_1$, $\cos\theta_2$ and χ.



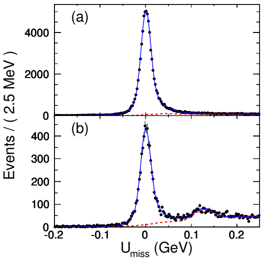
$$r_V = \frac{V(0)}{A_1(0)} = 1.24 \pm 0.09$$

$$r_2 = \frac{A_2(0)}{A_1(0)} = 1.06 \pm 0.15$$

Analysis of $D^0 \to (K^-/\pi^-)e^+\nu_e$

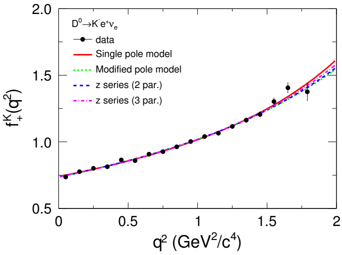
Branching Fraction and Form Factor Fit

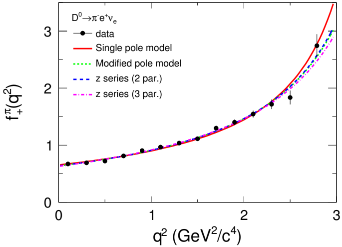
[Phys.Rev.D,92, 072012]



$\mathcal{B}(D^0 \to K^- e^+ \nu_e(a)) = (3.505 \pm 0.014 \pm 0.033)\%$

$\mathcal{B}(D^0 \to \pi^- e^+ \nu_e(b)) = (0.295 \pm 0.004 \pm 0.003)\%$





$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2|\vec{p}_{K^-(\pi^-)}|^3 |f_+^{K(\pi)}(q^2)|^2$$

$f_+(q^2)$

Simple pole model:

$$= \frac{f_+(0)}{1-\frac{q^2}{M^2_{\rm pole}}}$$

Modified pole model:

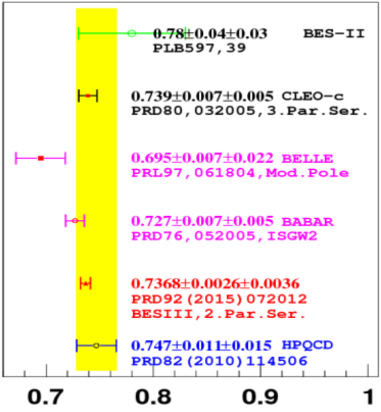
$$= \frac{f_+(0)}{(1-\frac{q^2}{M^2_{\rm pole}})(1-\alpha\frac{q^2}{M^2_{\rm pole}})}$$

Series expansion:

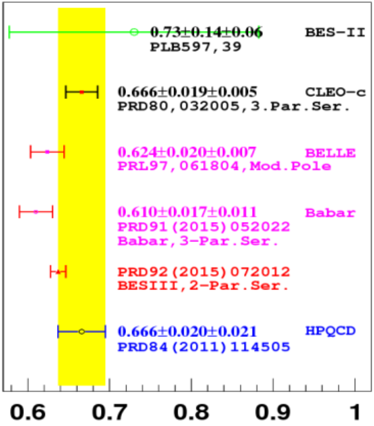
$$= \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0) \times (1 + r_1(t_0)[z(t,t_0)])$$

$$|V_{cs(d)}|f_+^{D^0\to(K^-/\pi^-)e^+\nu_e}(0) \to f_+^{D^0\to(K^-/\pi^-)e^+\nu_e}(0)$$

Input $V_{cs(d)}$ of CKM Fitter



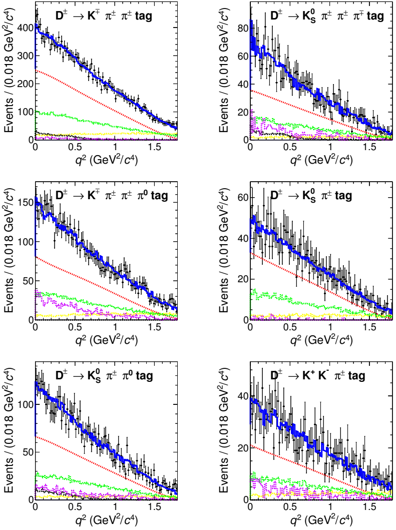
$f_+^K(0)$



$f_+^\pi(0)$

The most precise form factor measurement provides a good test to LQCD calculations.

The first measurement [Phys.Rev. D92 11, 112008]



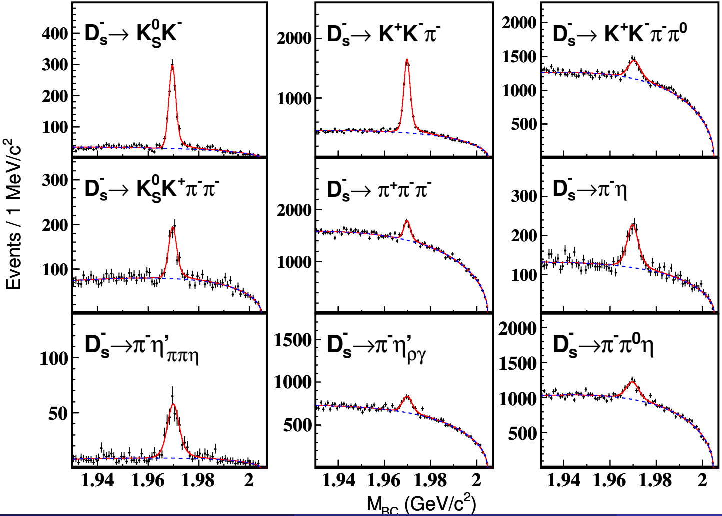
Red dashed: signal

1. $\mathcal{B}(D^+ \to K_L e^+ \nu_e) = (4.454 \pm 0.038 \pm 0.102)\%$
   $\mathcal{B}(D^- \to K_L e^- \bar{\nu}_e) = (4.507 \pm 0.038 \pm 0.104)\%$
2. $|V_{cs}| = 0.975 \pm 0.008 \pm 0.015 \pm 0.025$(with LQCD input $f_+^K(0)$), consistent with 0.986 ± 0.016 in PDG
3. $A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K_L e^+ \nu_e) - \mathcal{B}(D^- \to K_L e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K_L e^+ \nu_e) + \mathcal{B}(D^- \to K_L e^- \bar{\nu}_e)} = (-0.59 \pm 0.60 \pm 1.48)\%$

Branching Fractions of $D_s^+ \to \eta' X$ and $D_s^+ \to \eta' \rho^+$

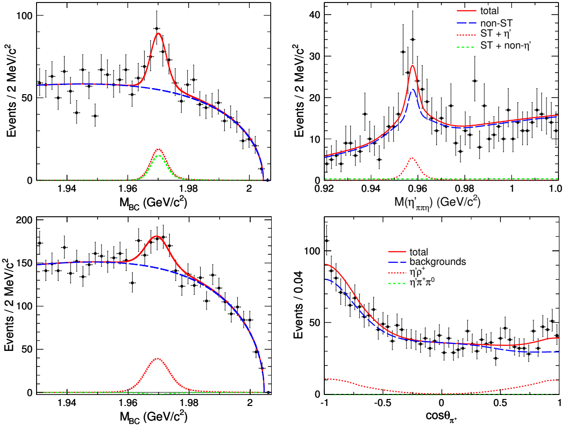
Fit to ST M_{BC} [Phys.Lett.B.750, 466]

9 single tag modes, and over 1.5×10^4 single tag events



Branching Fractions of $D_s^+ \to \eta' X$ and $D_s^+ \to \eta' \rho^+$

[Phys.Lett.B.750, 466]



(up) $N_{D_s^+ \to \eta' X} = 68 \pm 14$

$\mathcal{B}(\eta' X) = (8.8 \pm 1.8 \pm 0.5)\%$

(down) $N_{D_s^+ \to \eta' \rho^+} = 210 \pm 50$

$\mathcal{B}(\eta' \rho^+) = (5.8 \pm 1.4 \pm 0.4)\%$

$\mathcal{B}(\eta' X)$ is consistent with that of CLEO-c(PhysRevD.58.052002);
$\mathcal{B}(\eta' \rho^+)$ result resolves the disagreement between theoretical prediction(PRD.84.074019) and CLEO-c(PhysRevD.58.052002) measurement.

Large charm data sets

1. Form factor measurement in (semi)leptonic charm decays provide important test to LQCD calculations, CKM matrix unitary ;
2. Hadronic charmed meson and baryon decays improve understanding of non-perturbative QCD;
3. The first $\Lambda_c\bar{\Lambda}_c$ data set at threshold allows absolute branching fraction measurement;
4. *BESIII* will take more $D_s D_s^\star$ data at $4.180\mathrm{GeV}$; this would benefit the understanding of physics related to D_s further.
5. Other ongoing programs not covered in this talk:
   Searches for rare/forbidden decays, and quantum correlated analysis based on the world's largest $\psi(3770)$ data taken near it's nominal mass, find more on *BESIII* PUBLICATIONS

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