Status and prospects of charm physics at BESIII

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For BESIII Collaboration

Current Trends in Flavor Physics, 29-31 March 2017, Institute Henri Poincare, Paris, France

Main goals of charm physics at BESIII

Leptonic and hadronic decays of charmed hadrons (D^0, D^+, D_s^+ and Λ_c^+) provide an ideal window to explore weak and strong effects

- **D leptonic decays**

  $f_{D(s)+}$, $f^{K(\pi)}_{+}(0)$: better calibrate LQCD

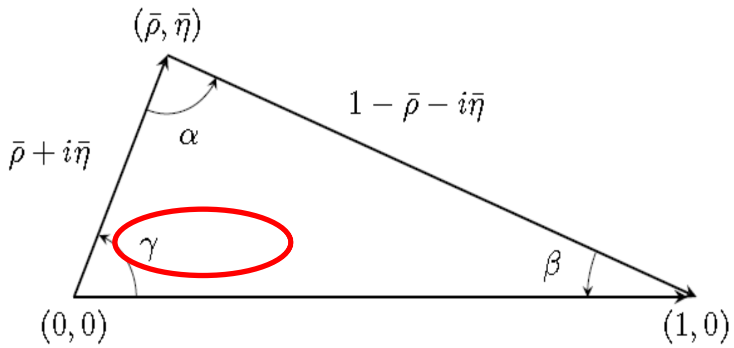
  $|V_{cs(d)}|$: better test on CKM unitarity

$$U = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & \boldsymbol{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- **D hadronic decays**

  $D^0\bar{D}^0$ mixing parameters and CP voilation

  Strong phase in D^0 decays: Constrain on the measurement of γ/ϕ_3 in B decay, which is the worst one of 3 CKM angles



- **Rare D decays → New physics**

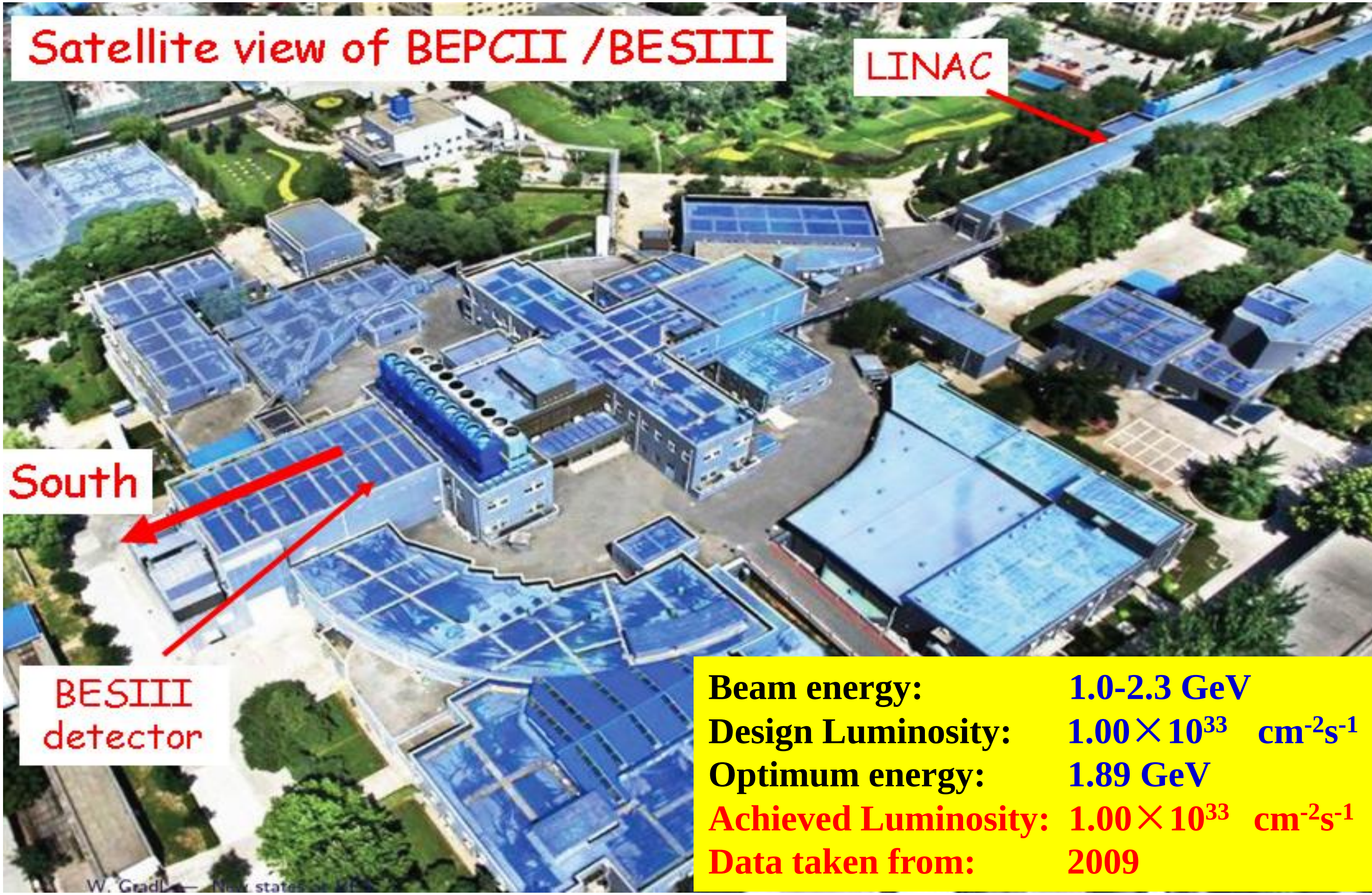
- **Absolute BFs of Λ_c^+**

  Before BESIII, no absolute BF measurements of Λ_c^+ using near $\Lambda_c^+\bar{\Lambda}_c^-$ production threshold data, in the past 38 years

Contents

- BESIII samples of $D_{(s)}^+$ and Λ_c^+
- $D_{(s)}^+ \rightarrow l^+ \nu$ ($l=\mu, \tau$)
- $D^{0(+)} \rightarrow K l^+ \nu$ and $\pi l^+ \nu$ ($l=e, \mu$)
- Search for $D^{0(+)} \rightarrow a_0(980)^{-(0)} e^+ \nu$, $D^+ \rightarrow hee$, $\gamma e^+ \nu$ and $D^0 e^+ \nu$
- $\Lambda_c^+ \rightarrow \Lambda l^+ \nu$
- Hadronic decays of Λ_c and D
- Summary

BEPCII: high luminosity double–ring collider



Beam energy:	1.0-2.3 GeV
Design Luminosity:	1.00×10^{33} $cm^{-2}s^{-1}$
Optimum energy:	1.89 GeV
Achieved Luminosity:	1.00×10^{33} $cm^{-2}s^{-1}$
Data taken from:	2009

BESIII detector

Nucl. Instr. Meth. A614, 345 (2010)

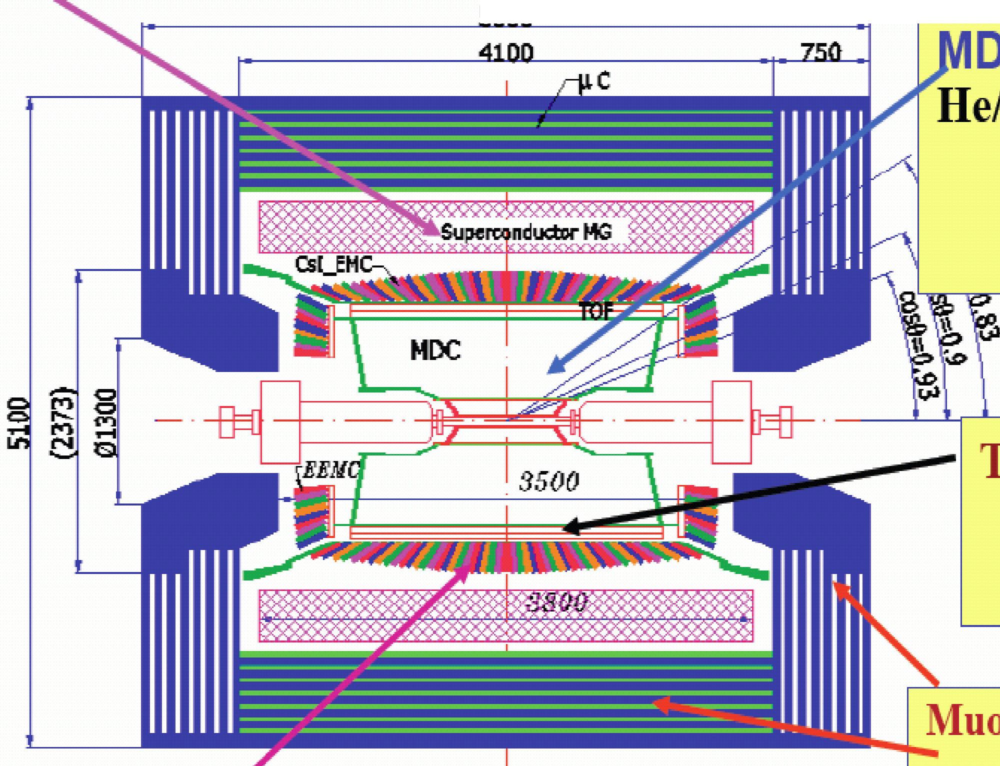
Magnet: 1 T Super conducting

MDC: small cell & Gas: He/C_3H_8 (60/40), 43 layers

σ_{xy}=130 μm

σ_p/p = 0.5% @1GeV

dE/dx=6%



TOF:

σ_T = 100 ps Barrel

110 ps Endcap

Muon ID: 9 layers RPC

8 layers for endcap

EMC: CsI crystal, 28 cm

ΔE/E = 2.5% @1 GeV

σz = 0.6 cm/√E

Data Acquisition:

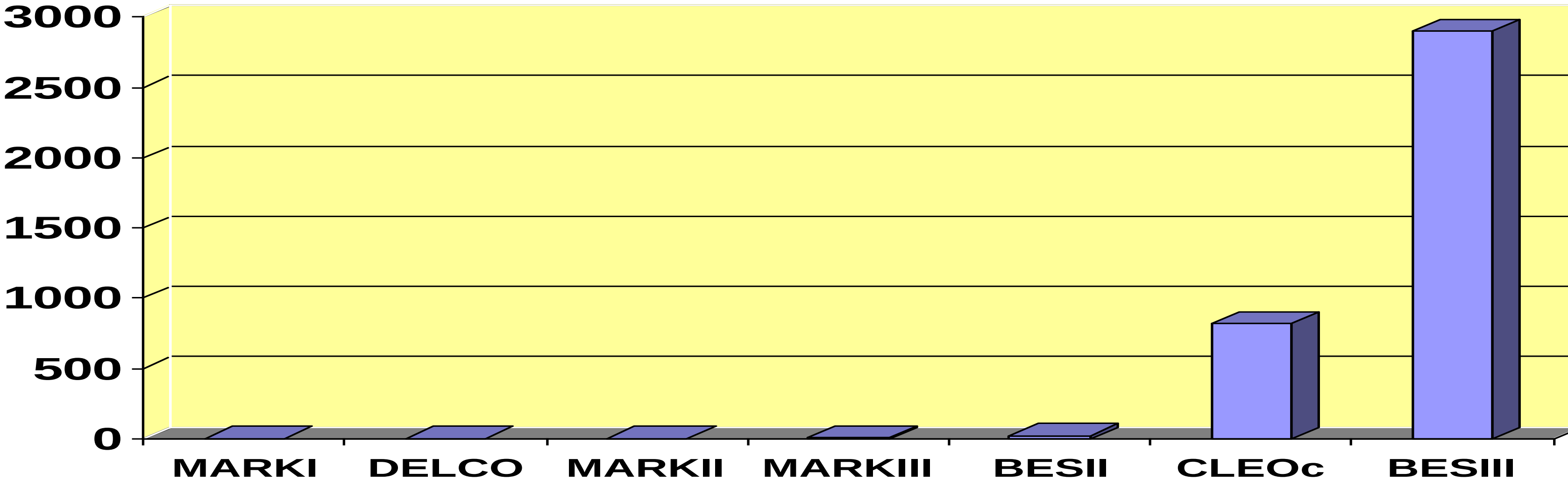
Event rate = 4 kHz

Total data volume ~ 50 MB/s

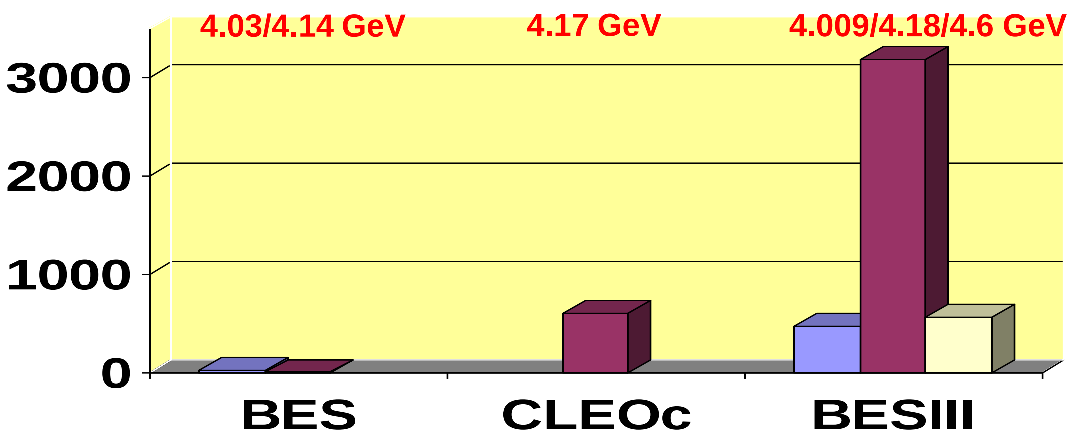
$D^{0(+)}$, D_s^+, Λ_c^+ samples at BESIII

- $D^{0(+)}$ samples at 3.773 GeV

$$\sigma_{D^0\bar{D}^0(D^+D^-)} \sim 3.6(2.9)\,\text{nb}$$



- $D_s^+/D_s^+/\Lambda_c^+$ samples at 4.009/4.18/4.6 GeV

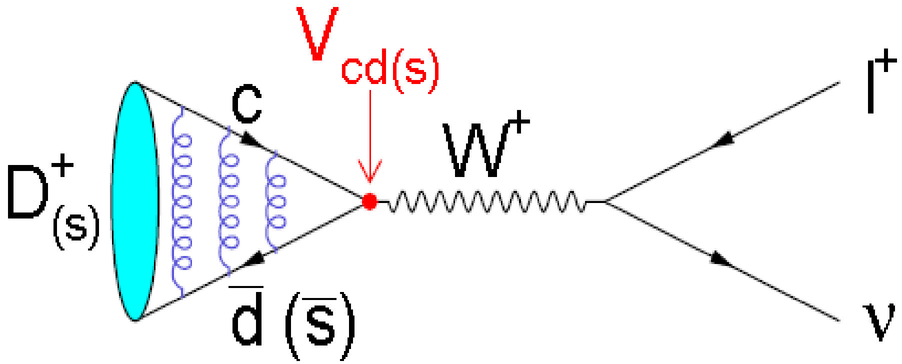


$$\sigma_{D_s^+D_s^-} \sim 0.3\,\text{nb@4.009 GeV}$$

$$\sigma_{D_s^+D_s^{*-}+c.c.} \sim 0.9\,\text{nb@4.18 GeV}$$

$$\sigma_{\Lambda^+\bar{\Lambda}^-} \sim 0.25\,\text{nb@4.6 GeV}$$

$D_{(s)}^+$ leptonic decays



In the SM:

$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

Bridge to precisely measure

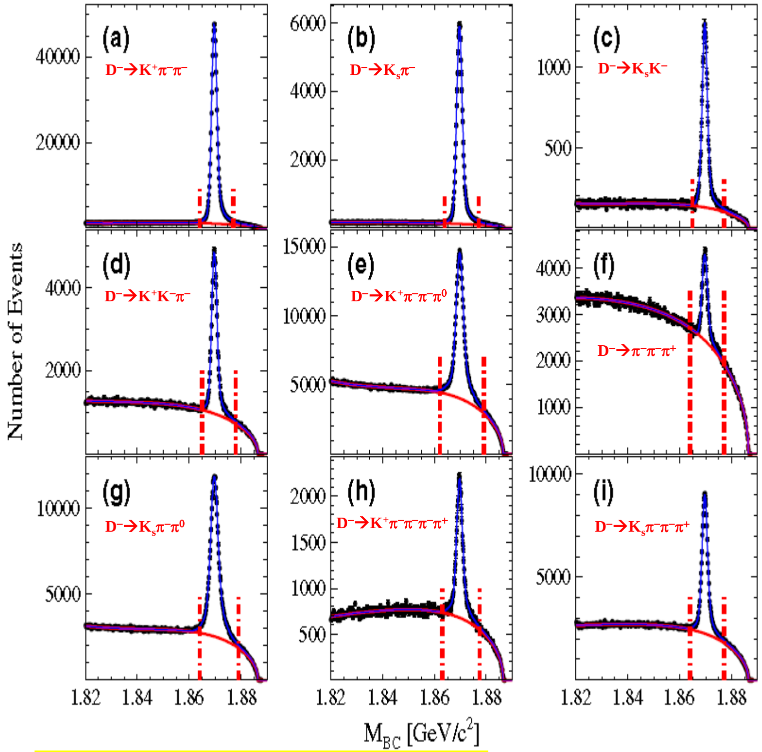
- **Decay constant $f_{D(s)+}$ with input $|V_{cd(s)}|^{CKMfitter}$**
- **CKM matrix element $|V_{cd(s)}|$ with input $f^{LQCD}_{D(s)+}$**

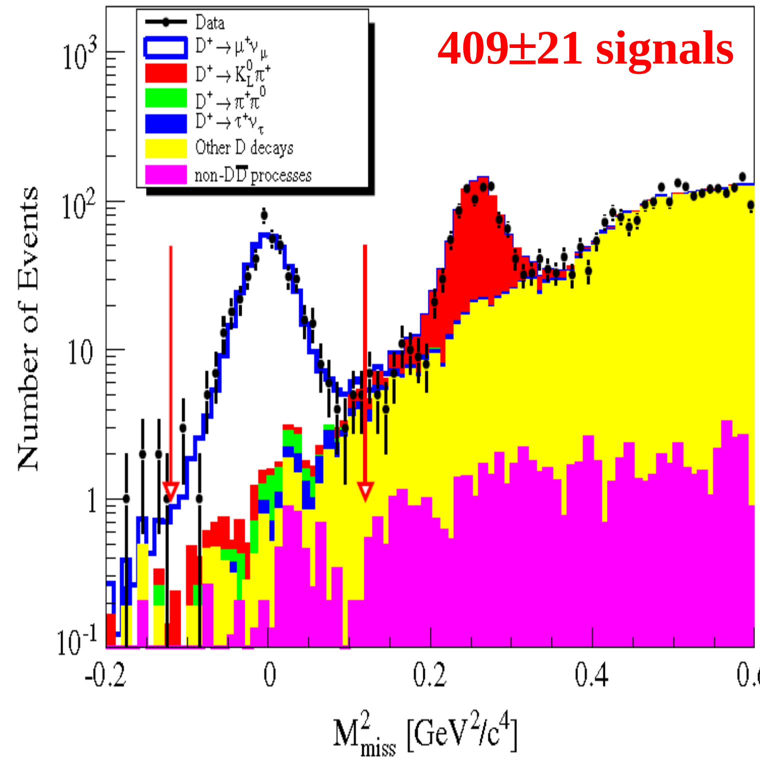
Improved $B[D^+ \to \mu^+ \nu]$, f_{D+} and $|V_{cd}|$

$e^+e^- \to \psi(3770) \to D^+D^-$

2.93 fb^{-1} data@ 3.773 GeV

PRD89(2014)051104R





$N_{D^-_{tag}} = (170.31 \pm 0.34) \times 10^4$

$B[D^+ \to \mu^+ \nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and $|V_{cd}|$ of CKM-Fitter

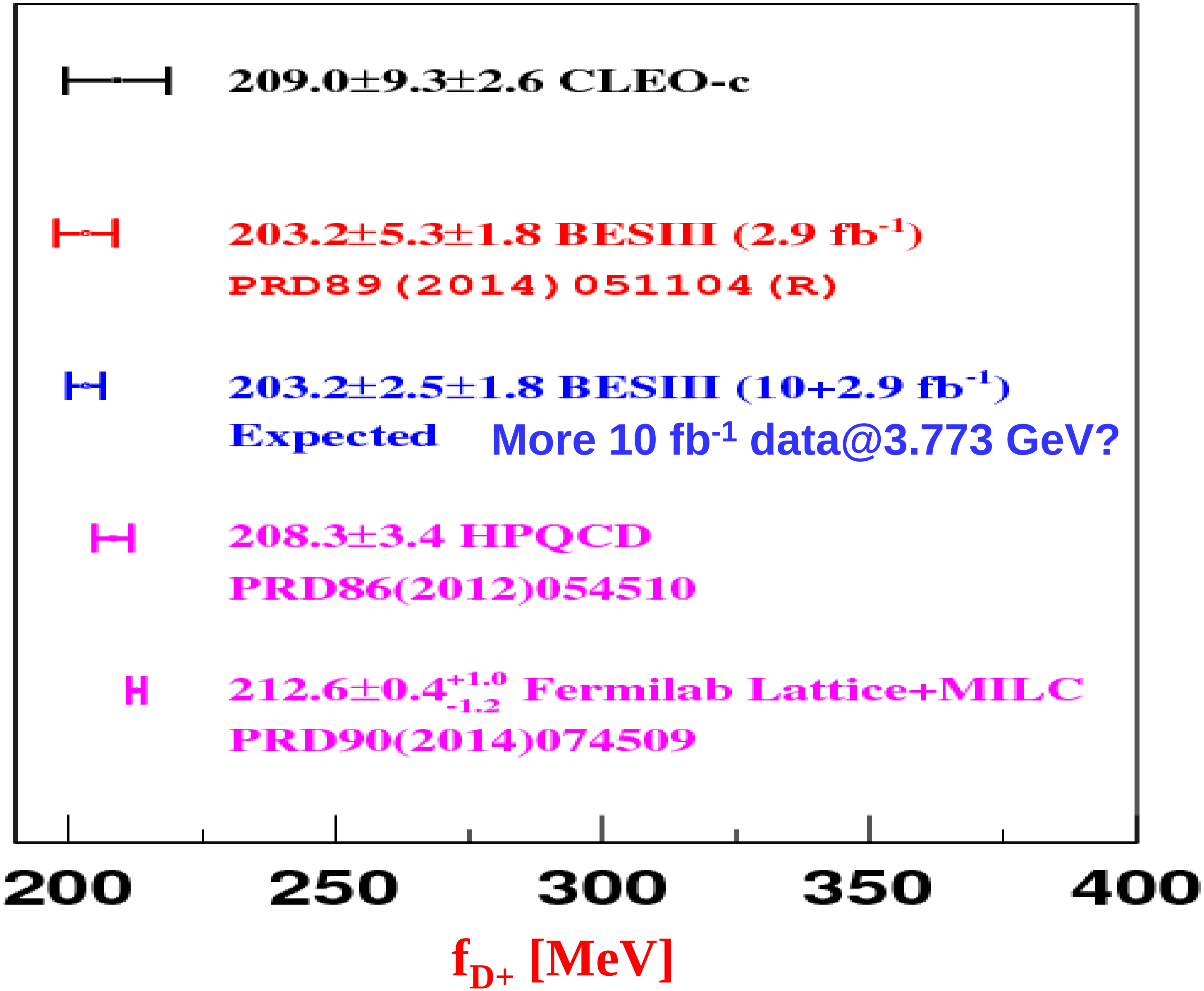
Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and LQCD calculated f_{D+}=207±4 MeV[PRL100(2008)062002]

BESIII

$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

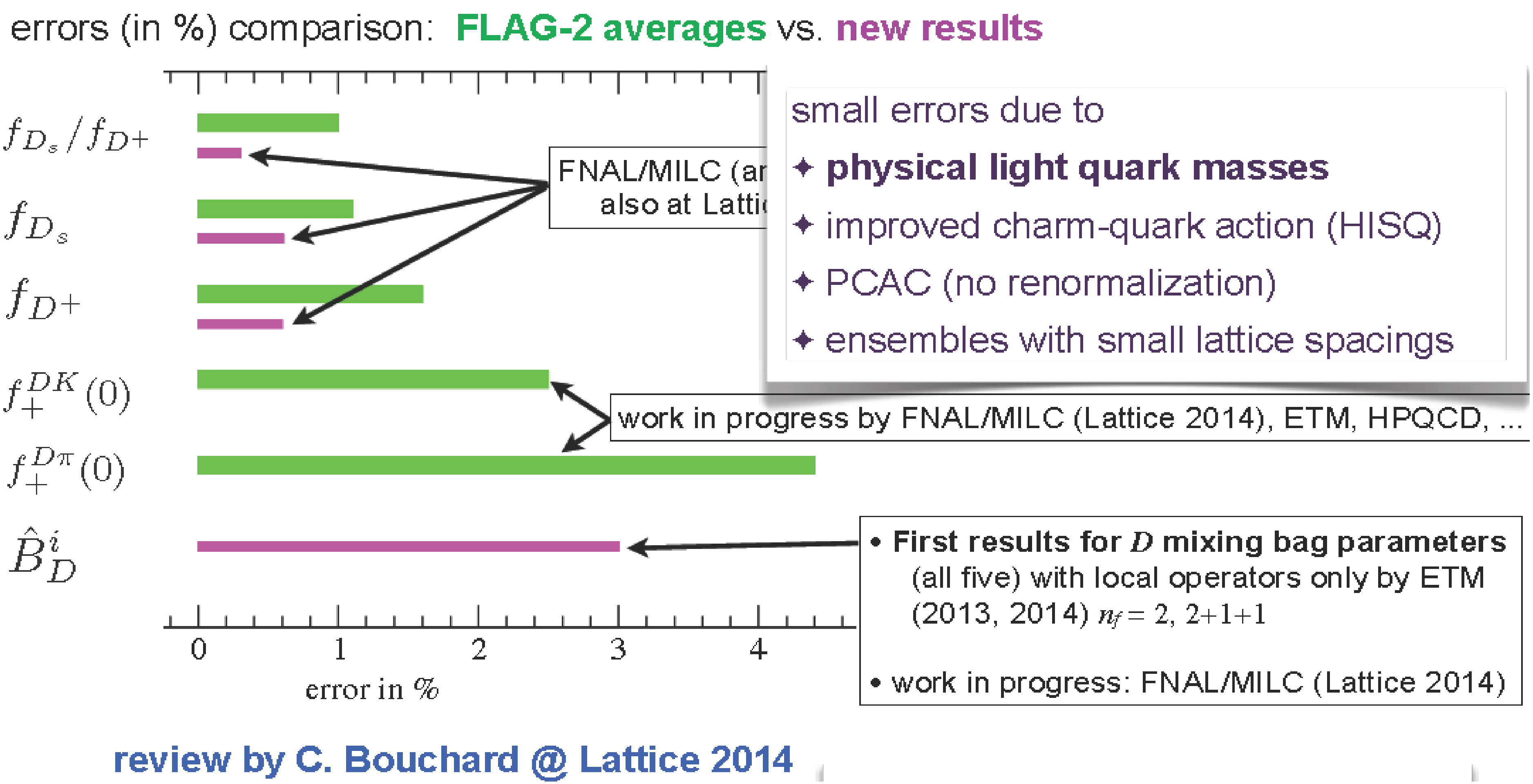
$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

Comparison of f_{D^+} and prospect at BESIII



Better input f_{D+} from LQCD

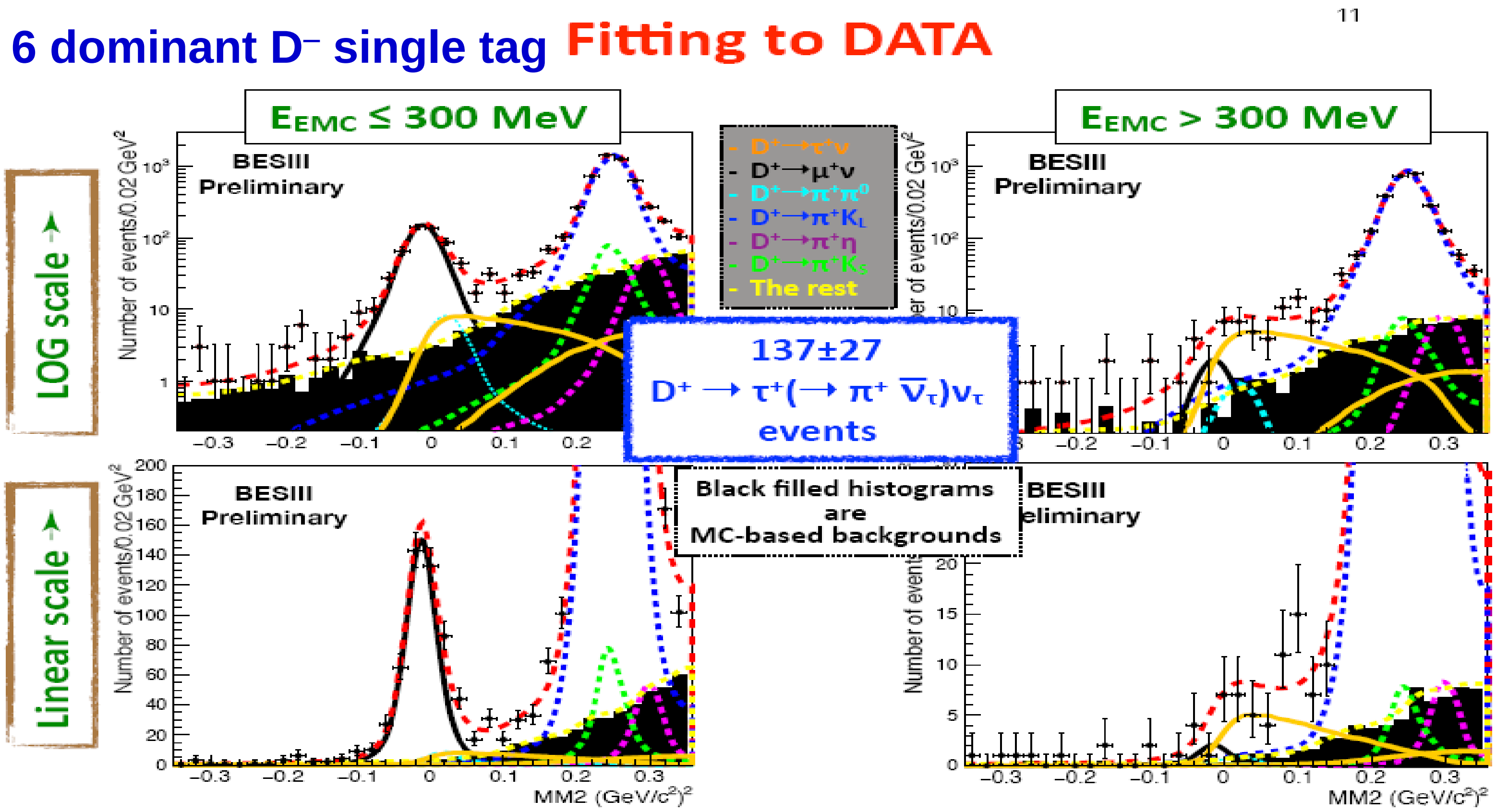
Taking from Aida X. El-Khadra's talk at Beauty2014



Better input benefit the systematic uncertainty

Evidence for $D^+ \to \tau^+(\pi^+\nu)\nu$ (4σ)

With 6 dominant D^- single tag Fitting to DATA



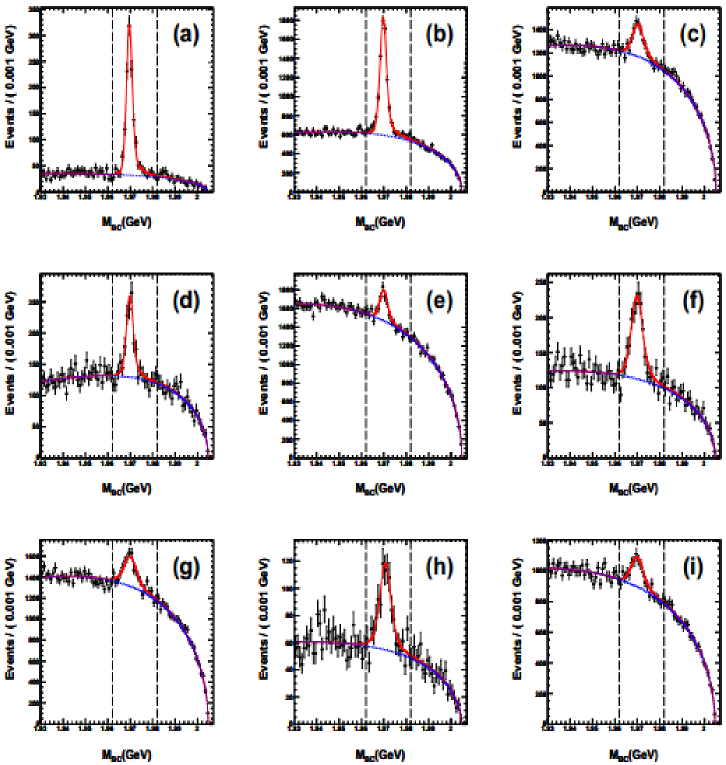
$B[D^+ \to \tau^+\nu] = (1.20 \pm 0.24_{stat.}) \times 10^{-3}$

$$R \equiv \frac{\Gamma(D^+ \to \tau^+\nu)}{\Gamma(D^+ \to \mu^+\nu)} = \frac{m_{\tau^+}^2\left(1 - \frac{m_{\tau^+}^2}{M_{D^+}^2}\right)^2}{m_{\mu^+}^2\left(1 - \frac{m_{\mu^+}^2}{M_{D^+}^2}\right)^2}$$

SM prediction: 2.66±0.01

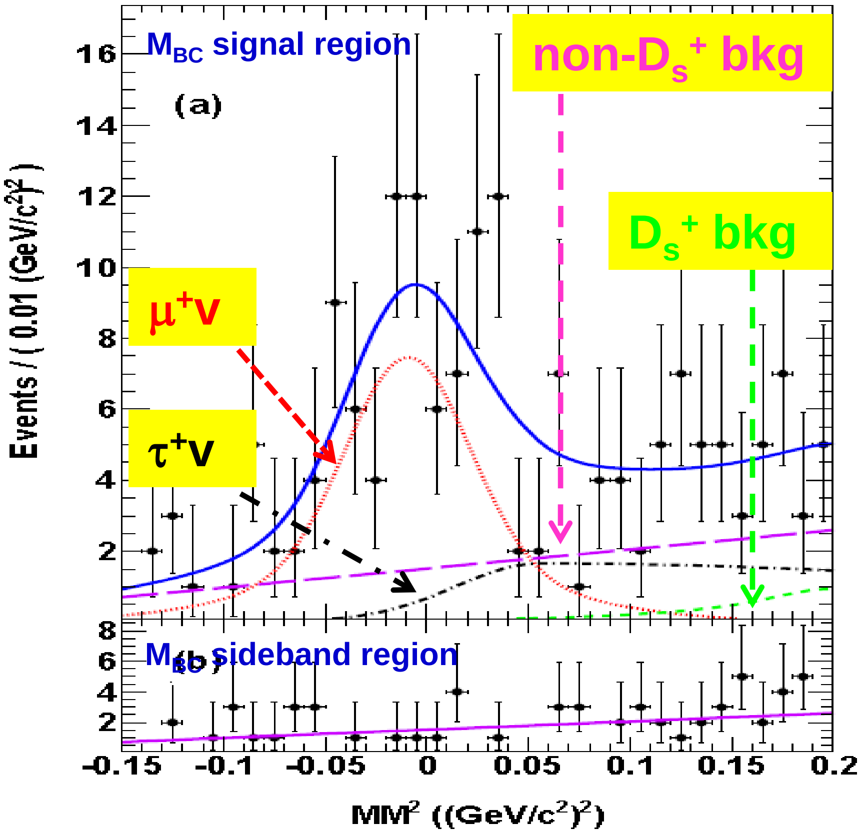
BESIII: 3.21±0.64

$f_{D_{s^+}}$ at 4.009 GeV



$N_{D_s^- tag} = 15127 \pm 312$

PRD94(2016)072004



$B[D_s^+ \to \mu^+\nu] = (0.495 \pm 0.067 \pm 0.026)\%$

$B[D_s^+ \to \tau^+\nu] = (4.83 \pm 0.65 \pm 0.26)\%$

$f_{D_{s^+}} = (241.0 \pm 16.3 \pm 6.6)$ MeV

Comparison of $f_{D_s^+}$ and prospect at BESIII

$$|V_{cs}^{D_s^+ \to l^+ \nu_l}| = 1.012 \pm 0.015 \pm 0.009$$

$$|V_{cs}^{D_s^+ \to K l^+ \nu_l}| = 0.962 \pm 0.005 \pm 0.014$$

$$|V_{cs}^{CKM\ fitter}| = 0.97343 \pm 0.00015$$

EPJC75(2015)10

~2σ difference can be better understood by ~3 fb^{-1} data@4.18 GeV

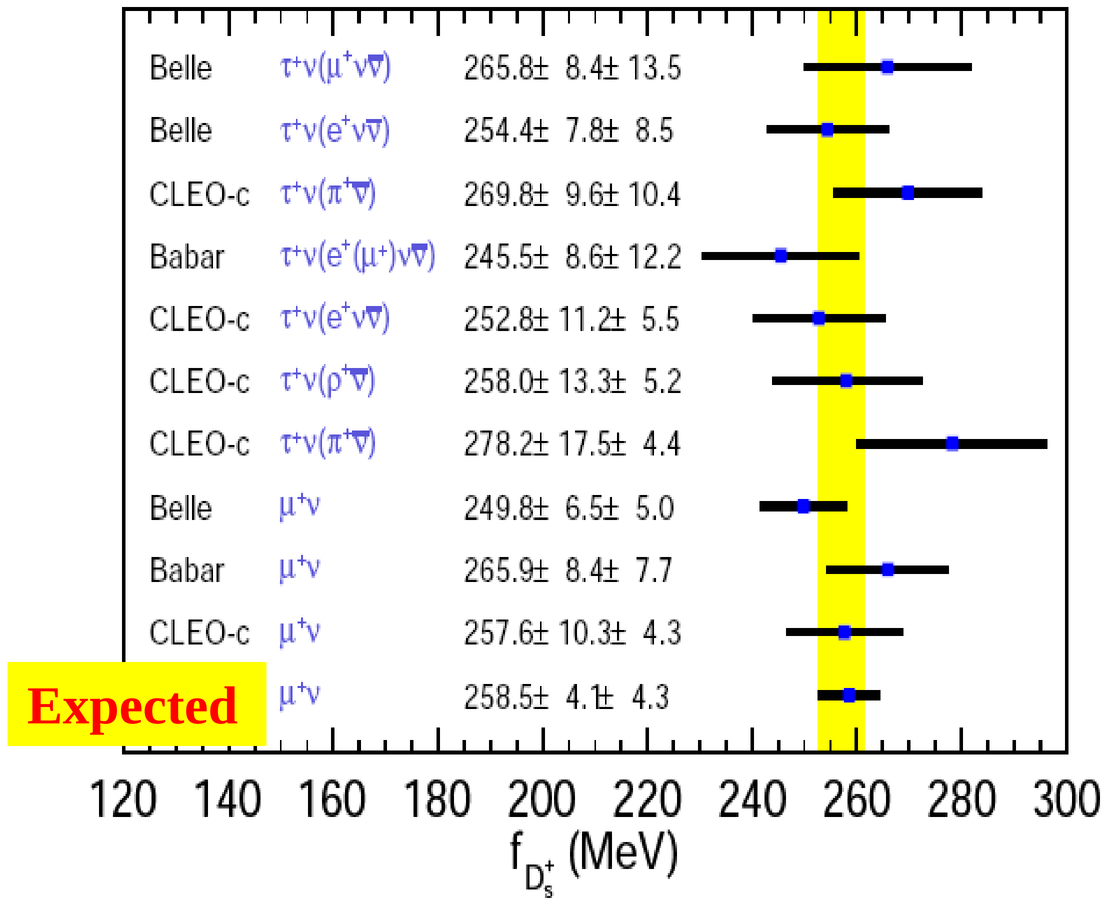
μ counter of BESIII may help to suppress background in $D_s^+ \to \mu^+ \nu$

Roughly estimated with CLEO-c results

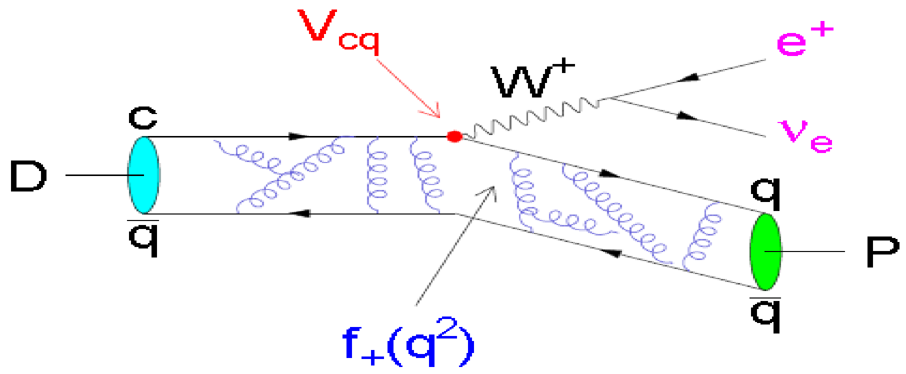
If systematic is the same as CLEO-c measurement

Result at 4.009 GeV is not included due to large error

$D_s^+ \to \tau^+ \nu$ will further improve measurements



Semi-leptonic decay $D \to K(\pi) l^+ \nu$



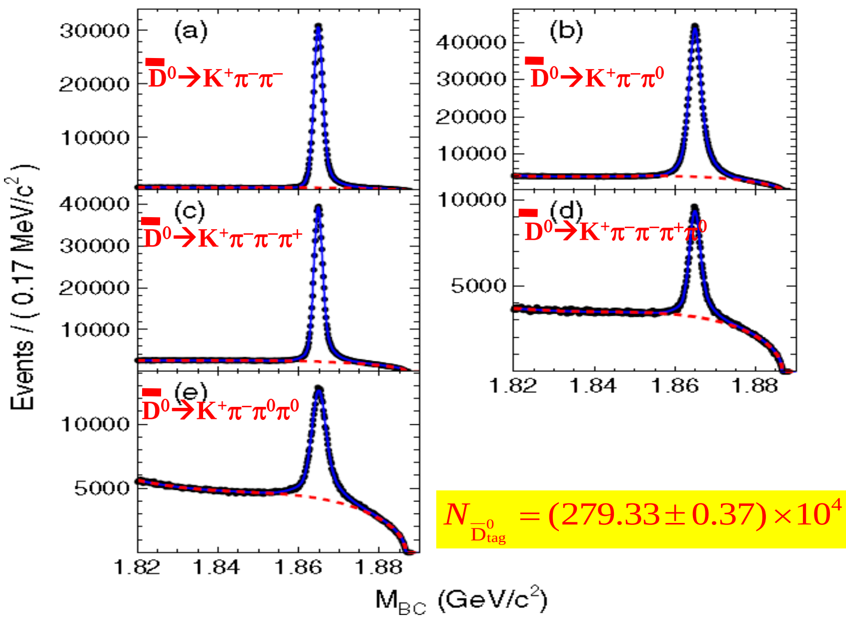
Differential rates:

$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

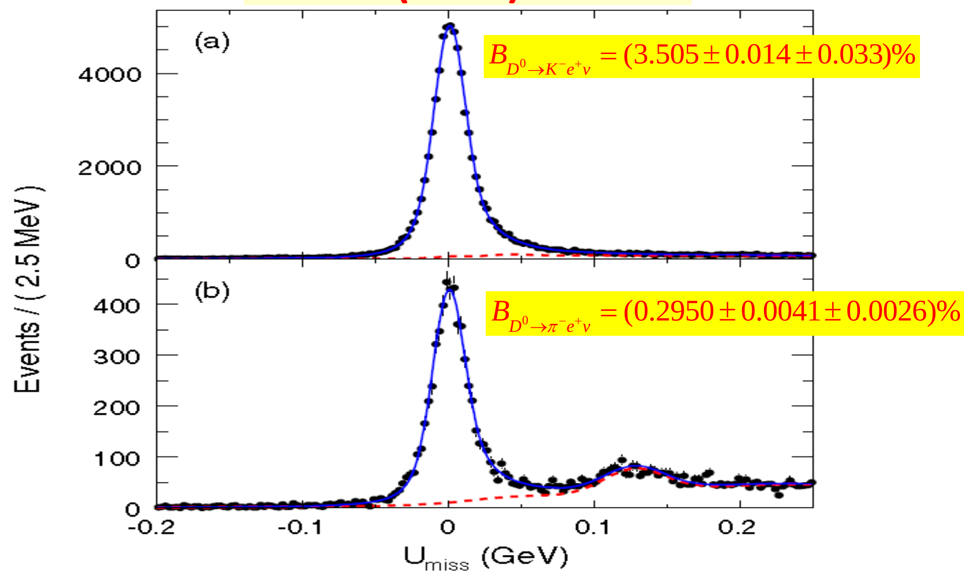
Bridge to precisely measure:

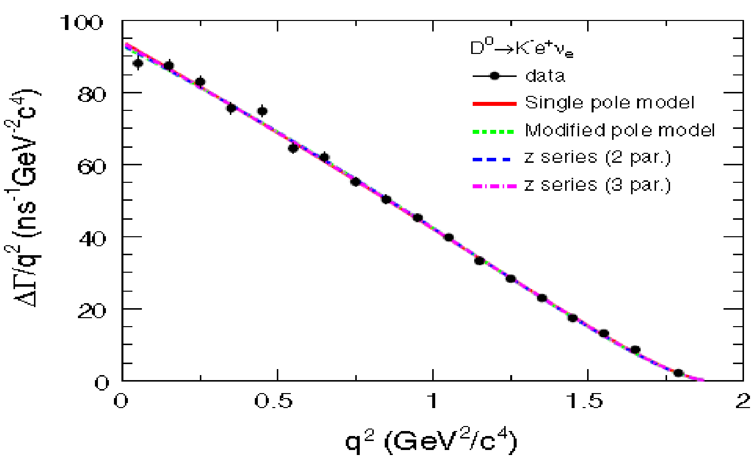
- **Form factors $f_+^{D \to K(\pi)}(0)$ with input $|V_{cd(s)}|^{CKMfitter}$**
  - **Single pole form**
    $$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M^2_{\mathrm{pole}}}}$$
  - **Modified pole model**
    $$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M^2_{\mathrm{pole}}})(1 - \alpha \frac{q^2}{M^2_{\mathrm{pole}}})}$$
  - **ISGW2 model**
    $$f_+(q^2) = f_+(q^2_{\mathrm{max}}) \left(1 + \frac{r^2_{\mathrm{ISGW2}}}{12}(q^2_{\mathrm{max}} - q^2)\right)^{-2}$$
  - **Series expansion model**
    $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$
- **CKM matrix element $|V_{cs(d)}|$ with input $f_+^{LQCD, D \to K(\pi)}(0)$**

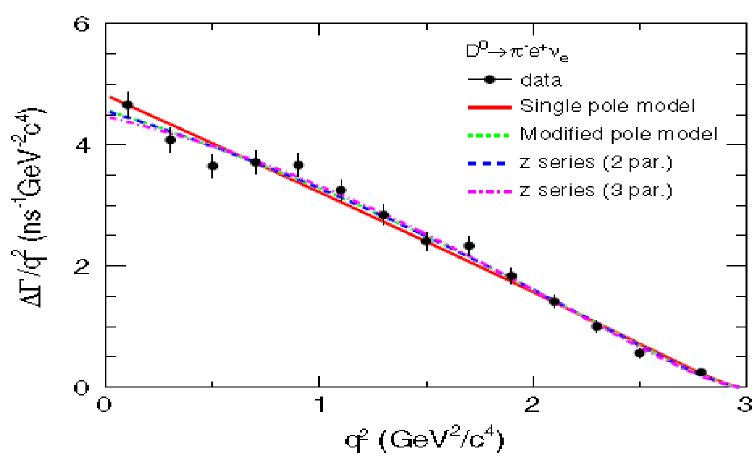
$D^0 \rightarrow K(\pi)^- e^+ \nu \rightarrow f_+^{D \rightarrow K(\pi)}(q^2)|V_{cs(d)}|$



PRD92(2015)072012

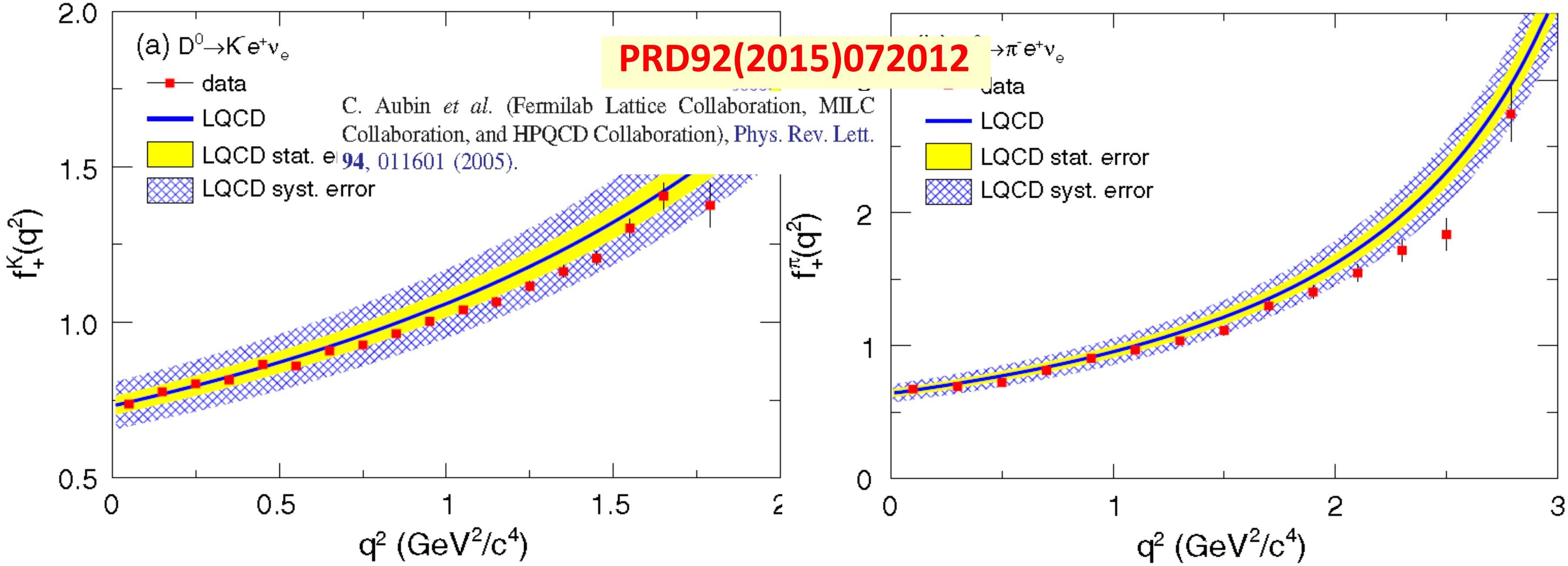






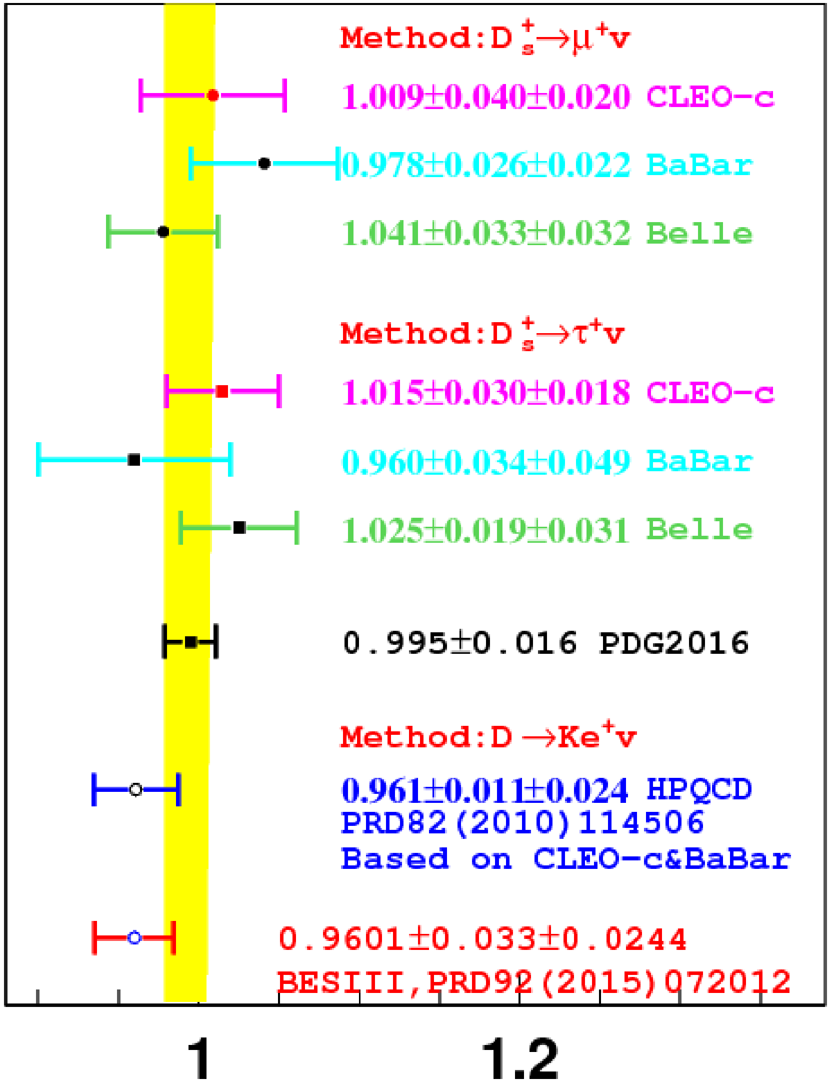
$B[D^0 \rightarrow K^- e^+ \nu]$ **$B[D^0 \rightarrow \pi^- e^+ \nu]$**

Calibration of LQCD

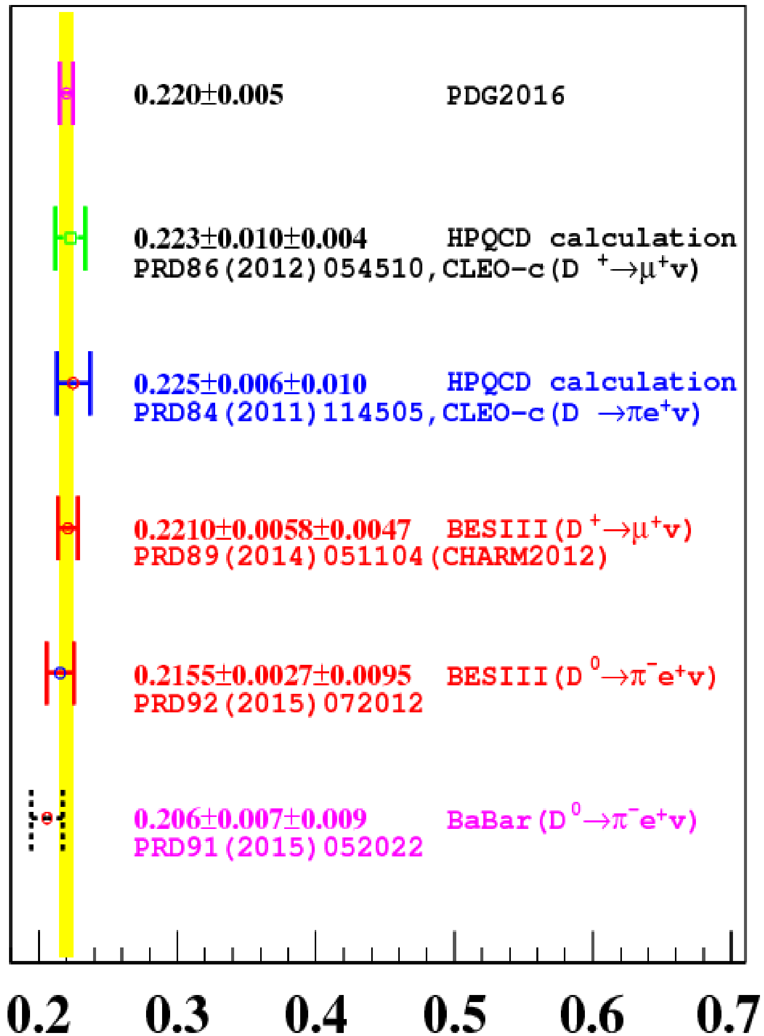


		$D^0 \to K^- e^+ v$		$D^0 \to \pi^- e^+ v$
Simple Pole	$f_K^+(0)\|V_{cs}\|$	0.7209±0.0022±0.0033	$f_\pi^+(0)\|V_{cd}\|$	0.1475±0.0014±0.0005
	M_{pole}	1.9207±0.0103±0.0069	M_{pole}	1.9114±0.0118±0.0038
Mod. Pole	$f_K^+(0)\|V_{cs}\|$	0.7163±0.0024±0.0034	$f_\pi^+(0)\|V_{cd}\|$	0.1437±0.0017±0.0008
	α	0.3088±0.0195±0.0129	α	0.2794±0.0345±0.0113
Series.2.Par	$f_K^+(0)\|V_{cs}\|$	0.7172±0.0025±0.0035	$f_\pi^+(0)\|V_{cd}\|$	0.1435±0.0018±0.0009
	r_1	-2.2278±0.0864±0.0575	r_1	-2.0365±0.0807±0.0260
Series.3.Par	$f_K^+(0)\|V_{cs}\|$	0.7196±0.0035±0.0041	$f_\pi^+(0)\|V_{cd}\|$	0.1420±0.0024±0.0010
	r_1	-2.3331±0.1587±0.0804	r_1	-1.8434±0.2212±0.0690
	r_2	3.4223±3.9090±2.4092	r_2	-1.3871±1.4615±0.4677

Comparison of $|V_{cs}|$



$|V_{cs}|$



$|V_{cd}|$

Semileptonic method is limited by large LQCD uncertainty

Analysis of $D^+ \to K_L e^+ v$

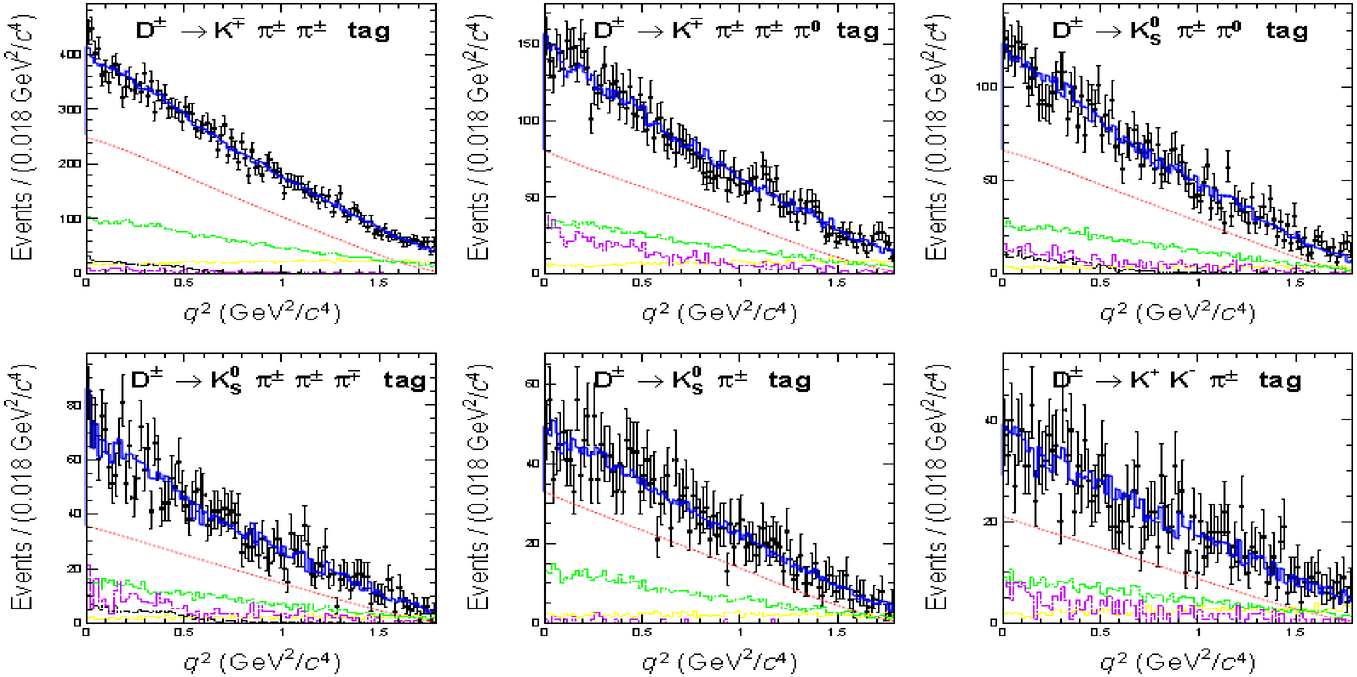
- Regardless of long flight distance, K_L interact with EMC and deposit part of energy, thus giving position information
- After reconstructing all other particles, K_L can be inferred with position information and constraint $U_{miss} \to 0$

$\bar{B}(D^+ \to K_L e^+ v) = (4.482 \pm 0.027 \pm 0.103)\%$

$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) - \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}{\mathcal{B}(D^+ \to K_L^0 e^+ \nu_e) + \mathcal{B}(D^- \to K_L^0 e^- \bar{\nu}_e)}$$

$A_{CP}^{D+ \to KLe+v} = (-0.59 \pm 0.60 \pm 1.50)\%$

Simultaneous fit to event density $I(q^2)$ with 2-par. series Form Factor



$D^+ \to K_L e+v$ is measured for the first time

PRD92(2015)112008

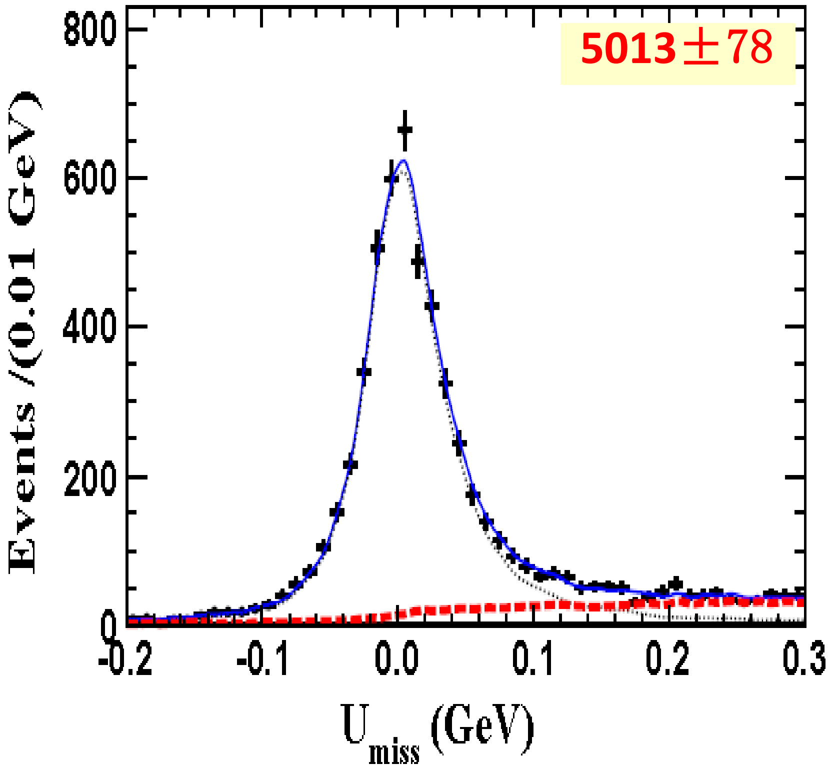
With 6 dominant D^- single tag

$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$

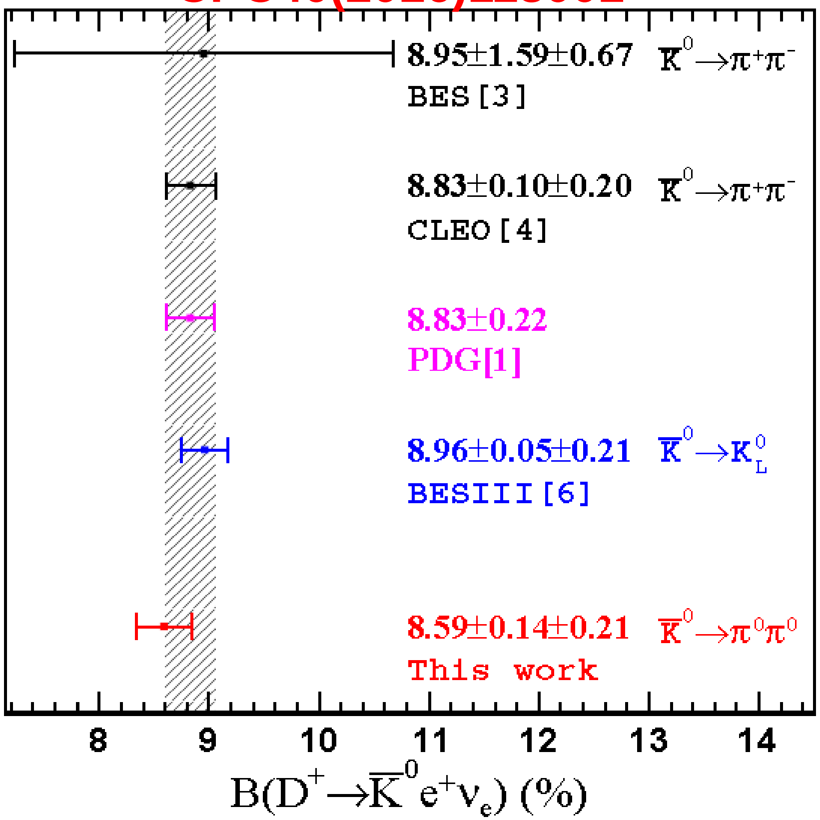
$r_1 = a_1/a_0 = -1.91 \pm 0.33 \pm 0.24$

Absolute BF for $D^+ \to \bar{K}^0 e^+ \nu$ via $\bar{K}^0 \to \pi^0\pi^0$

With 6 dominant D^- single tag



CPC40(2016)113001

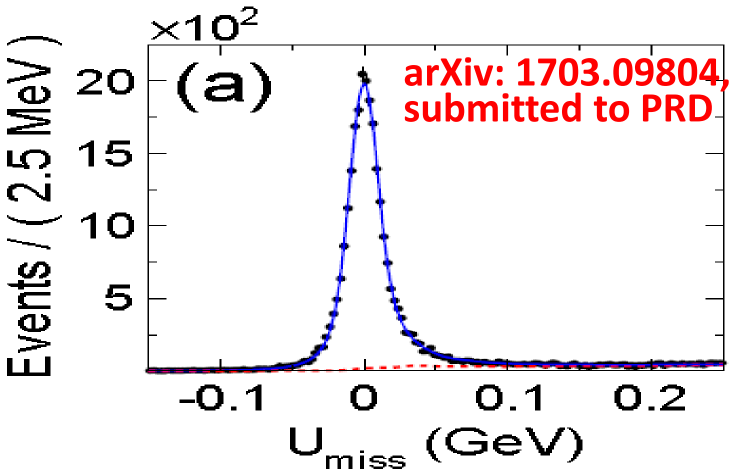


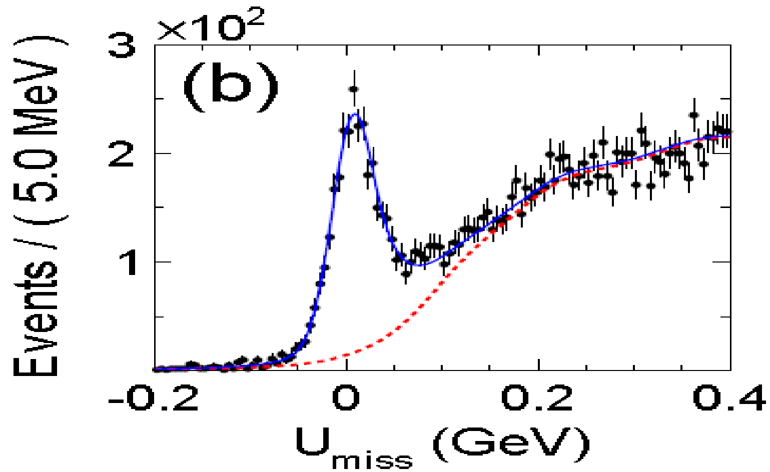
Taking τ_{D+}, τ_{D0}, $B[D^0 \to K^- e^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

$$\frac{\Gamma[D^0 \to K^- e^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.969 \pm 0.025$$

Agrees with isospin conservation within 1.2σ

Analysis of $D^+ \rightarrow \bar{K}^0(\pi^0)\, e^+\nu$



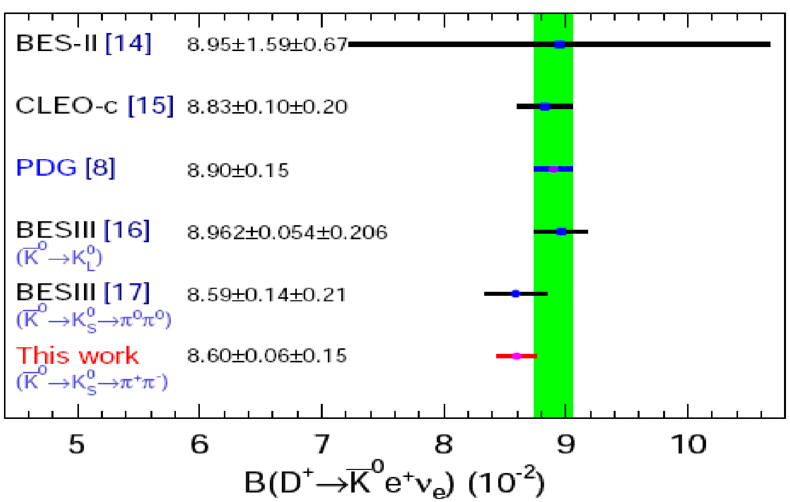


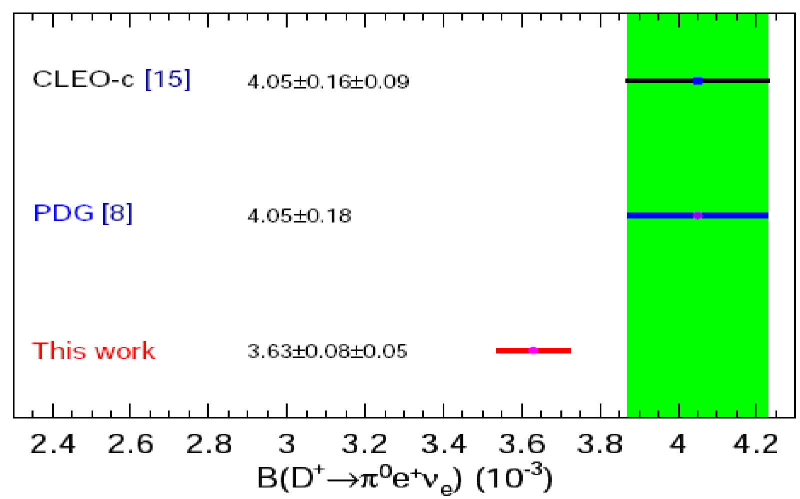
$$B[D^+ \rightarrow \overline{K}^0 e^+ v] = (8.604 \pm 0.056 \pm 0.151)\%$$

$$B[D^+ \rightarrow \pi^0 e^+ v] = (3.631 \pm 0.075 \pm 0.051) \times 10^{-3}$$

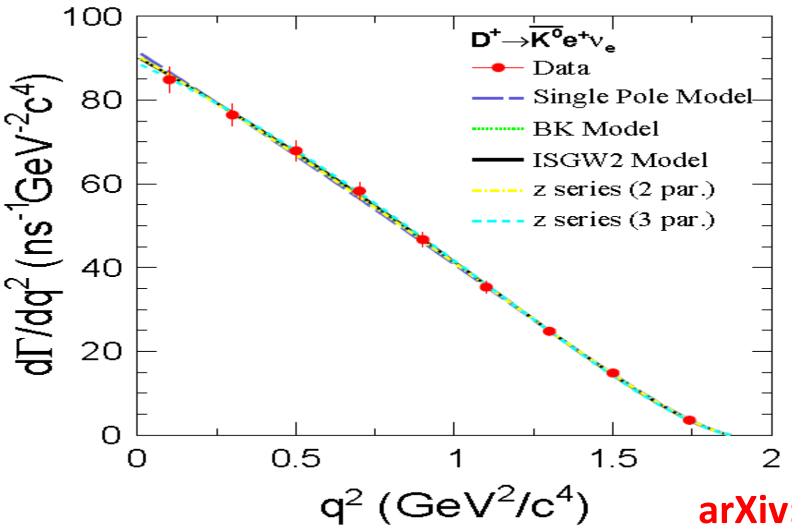
$$\frac{\Gamma[D^0 \rightarrow K^- e^+ v]}{\Gamma[D^+ \rightarrow \overline{K}^0 e^+ v]} = 1.03 \pm 0.01 \pm 0.02$$

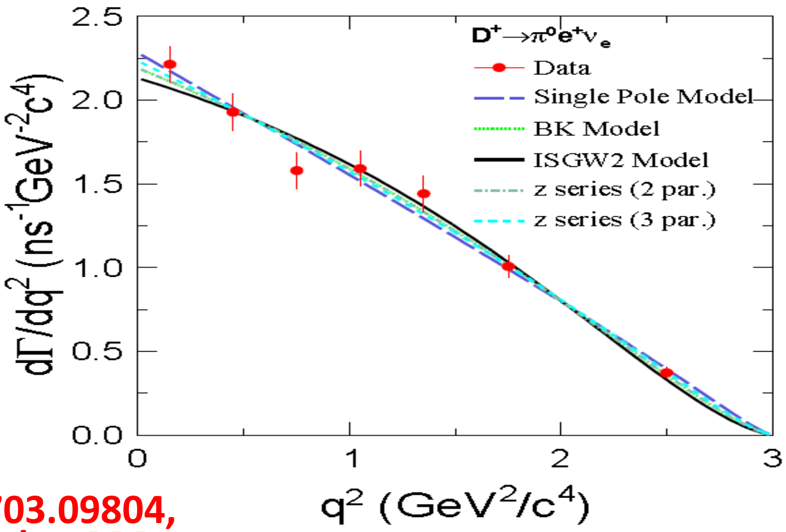
$$\frac{\Gamma[D^0 \rightarrow \pi^- e^+ v]}{2\Gamma[D^+ \rightarrow \pi^0 e^+ v]} = 1.03 \pm 0.03 \pm 0.02$$



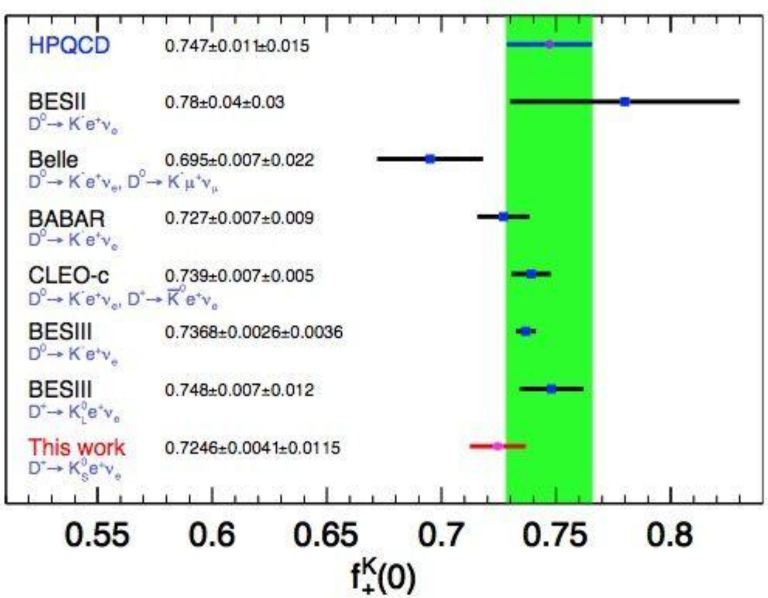


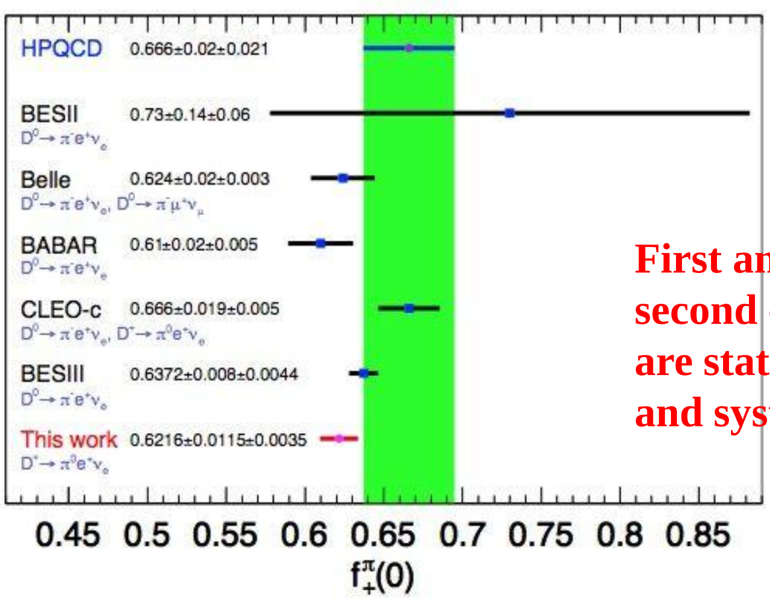
Comparisons of FFs by $D^+ \to \bar{K}^0(\pi^0)e^+\nu$





arXiv: 1703.09804, submitted to PRD



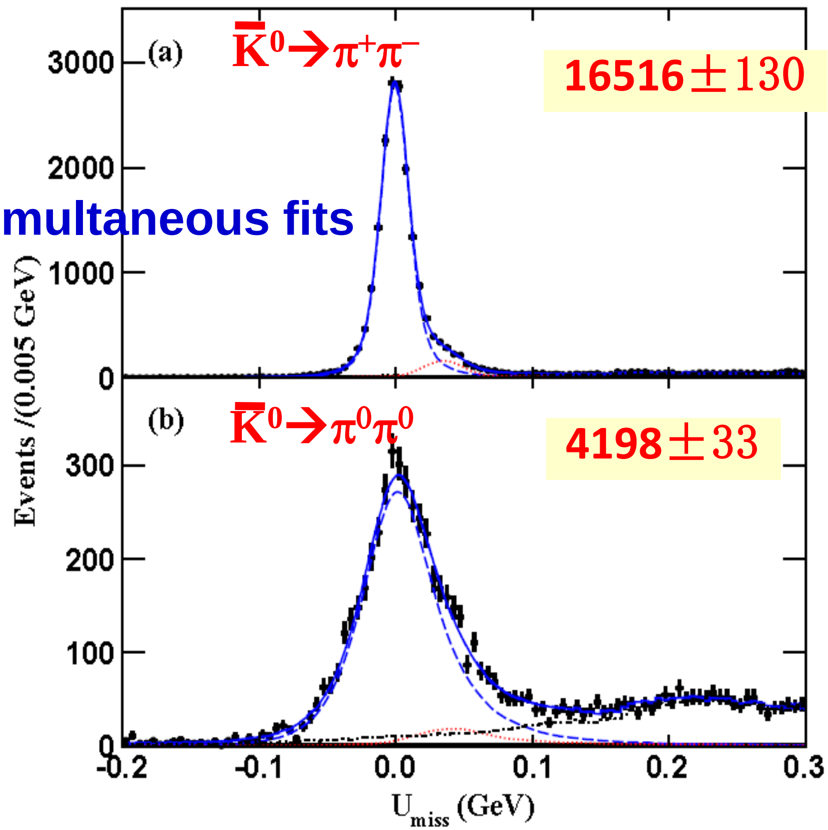


First and second errors are statistical and systematic

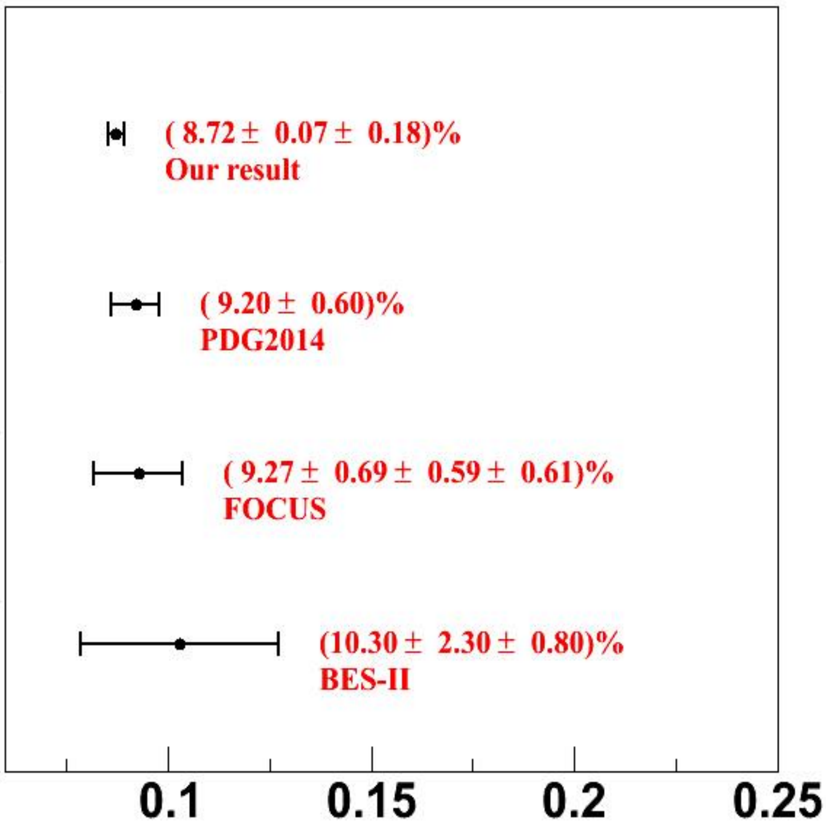
Improved BF for $D^+ \to \bar{K}^0 \mu^+ \nu$

With 6 dominant D^- single tag

Simultaneous fits



EPJC76(2016)369



Taking $B[D^0 \to K^- \mu^+ \nu]$ and $B[D^+ \to \bar{K}^0 e^+ \nu]$ from the PDG as input

$$\frac{\Gamma[D^0 \to K^- \mu^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 \mu^+ \nu]} = 0.963 \pm 0.044$$

$$\frac{\Gamma[D^+ \to \bar{K}^0 \mu^+ \nu]}{\Gamma[D^+ \to \bar{K}^0 e^+ \nu]} = 0.988 \pm 0.033$$

Support isospin conservation in these two decays within errors

Consistent with theory prediction 0.97 within error

Lepton universality in $D^{0(+)} \to \pi^{-(0)} l^+ \nu$

- **Lepton universality (LU)**

$$R_{\rm LU}^{0(+)} = \frac{B(D^{0(+)} \to \pi^{-(0)} \mu^+ \nu)}{B(D^{0(+)} \to \pi^{-(0)} e^+ \nu)} \sim 0.97$$

Expectations based on ZPC46 (1990)93, PRD69 (2004)074025, PLB633(2006)61 and PDG16

BFs on PDG16:

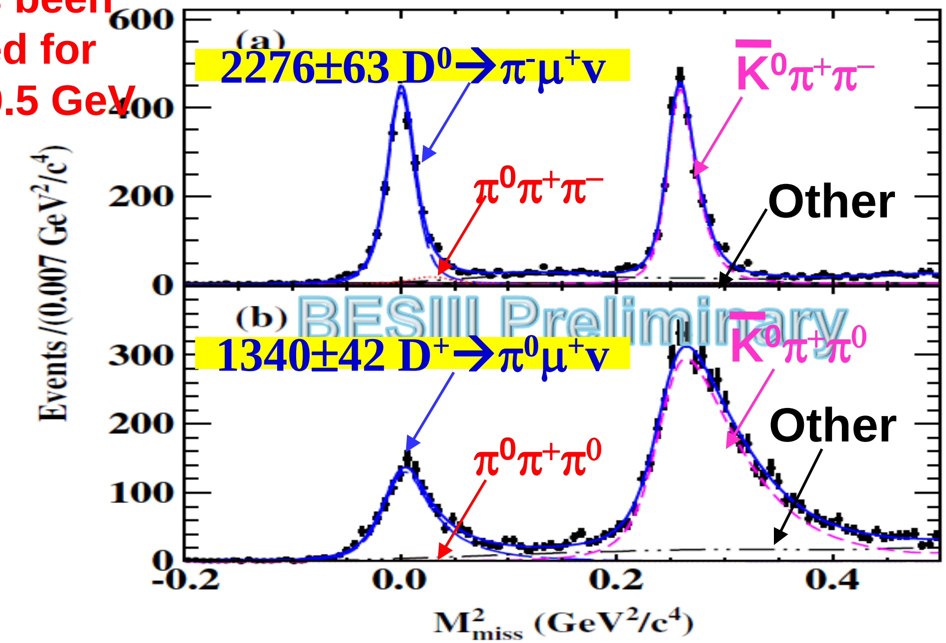
$$R_{\rm LU}^{0} = 0.82 \pm 0.08 \quad (\sim 2.0\sigma)$$

$B(D^0 \to \pi^- \mu^+ \nu) = (0.237 \pm 0.024)\%$

Large error in $B[D^0 \to \pi^- \mu^+ \nu]$ and no $B[D^+ \to \pi^0 \mu^+ \nu]$ measurement. Improved measurements are desired

μ counter has been used for p>0.5 GeV

With 3(6) dominant $D^{0(-)}$ single tag



BFs: $B(D^0 \to \pi^- \mu^+ \nu) = (0.267 \pm 0.007 \pm 0.007)\%$

agrees with PDG and with better precision

$B(D^+ \to \pi^0 \mu^+ \nu) = (0.342 \pm 0.011 \pm 0.010)\%$

measured for the first time

LU: $R_{\rm LU}^{0} = 0.918 \pm 0.036$ $\quad R_{\rm LU}^{+} = 0.921 \pm 0.045$

agree with expectation in 1.5(1.1) σ

- **Isospin symmetry (IS)**

$$R_{\rm IS}^{\ell} = \frac{\Gamma(D^0 \to \pi^- \ell^+ \nu)}{2\Gamma(D^+ \to \pi^0 \ell^+ \nu)} \sim 1$$

PDG16: $R_{\rm IS}^{e} = 0.911 \pm 0.043 \quad (2.1\sigma)$

BESIII: $R_{\rm IS}^{e} = 1.03 \pm 0.03 \pm 0.02$

IS: $R_{\rm IS}^{\mu} = 0.990 \pm 0.054$

agrees with IS prediction within uncertainty

Search for $D^{0(+)} \rightarrow a_0(980)^{-(0)} e^+ \nu$

- Explore the nontrivial internal structure of light hadron mesons, traditional $q\bar{q}$ states, tetra quark system.

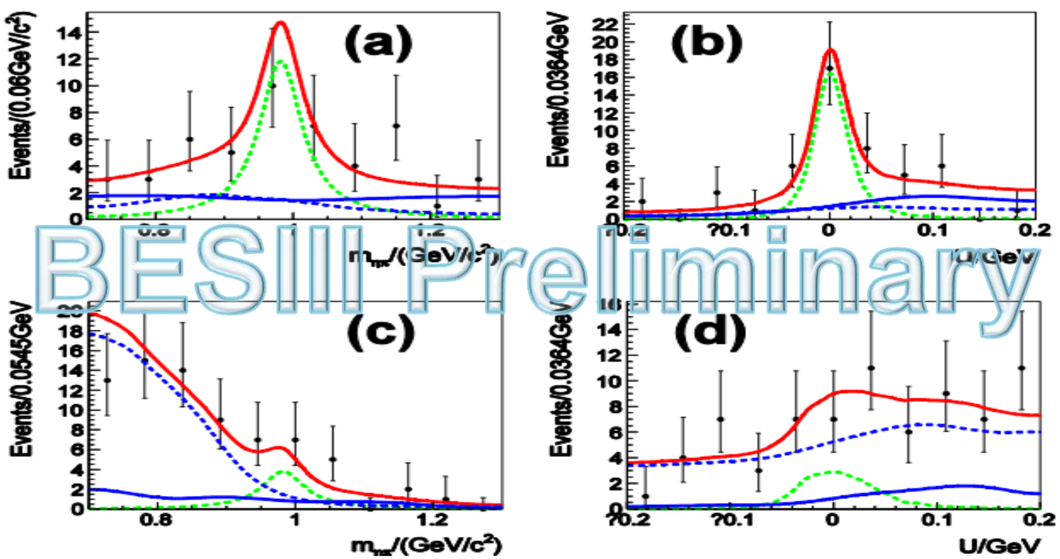
- With chiral unitarity approach in the coupled channels, BF is predicted to be order of $5(6)\times10^{-5}$ for $D^{0(+)}$ decays

- Improve understanding of classification of light scalar mesons

$$R \equiv \frac{B(D^+\to f_0 l^+ \nu)+B(D^+\to \sigma l^+\nu)}{B(D^+\to a_0 l^+ \nu)}$$

R=1(3) if traditional $q\bar{q}$ (tetra quark) system

With 3(6) dominant $D^{0(-)}$ single tag



⊙ $B(D^0 \to a_0(980)^- e^+ \nu_e) \times B(a_0(980)^- \to \eta\pi^-)$
$= (1.12^{+0.31}_{-0.28}(stat) \pm 0.10(syst)) \times 10^{-4}$ 5.9σ

⊙ $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$
$= (1.47^{+0.73}_{-0.59}(stat) \pm 0.14(syst)) \times 10^{-4}$ 3.0σ

⊙ $B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$
$< 2.7 \times 10^{-4}$ @ 90% C.L.

Search for $D^+ \to hee$

In SM, $D^0\bar{D}^0$ mixing, CP violation and rare decay of charm are small

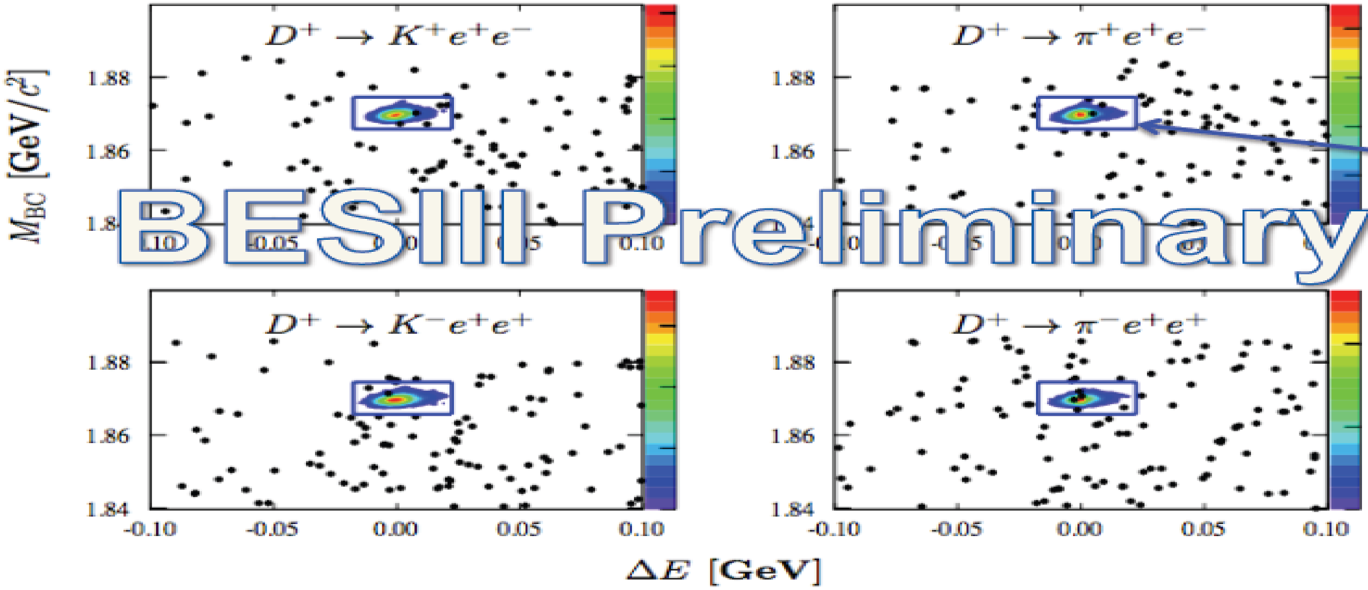
$D^0\bar{D}^0$ mixing $\quad x \approx y \approx 10^{-3} \Rightarrow r_D = [x^2 + y^2]/2 \approx 10^{-6}$

CP violation asymmetries $\sim 10^{-3}$

Rare decays $\leq 10^{-6}$

With single tag method

M.G. Zhao (BESIII) arXiv: 1605.08952, prepared proceeding of Charm2015



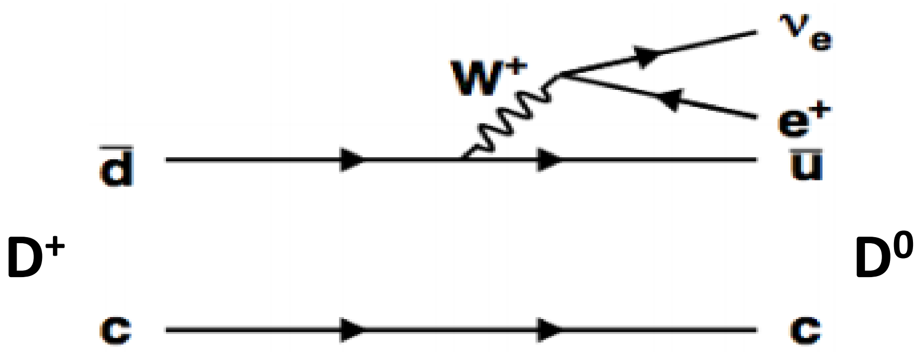
FCNC decay

Blinding signal region, optimize cuts and study backgrounds based on MC and sideband data.

LNV decay

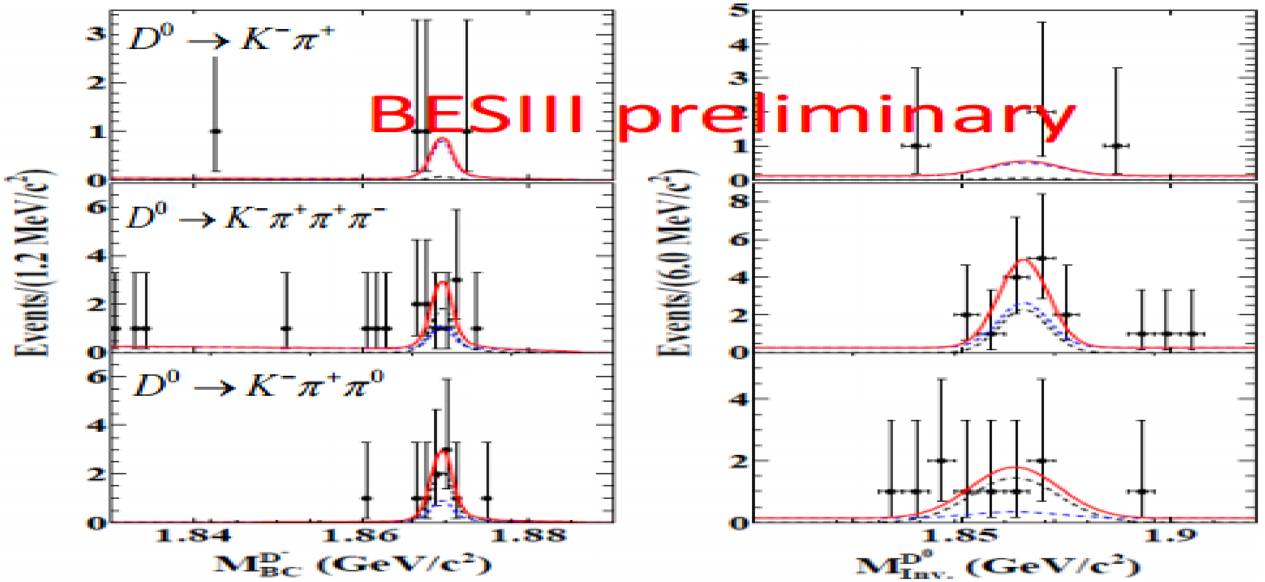
$B(D^+ \to) \setminus [\times 10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
CLEO	3.0	3.5	5.9	1.1
Babar	1.0	0.9	1.1	1.9
PDG	1.0	0.9	1.1	1.1
This work	1.2	0.6	0.3	1.2

Search for $D^+ \rightarrow D^0 e^+ \nu$



Applying the SU(3) symmetry for the light quarks, this rare decay branching fraction can be predicted by theoretical calculation and its theoretical value is 2.78×10^{-13} [EPJC, 59:841-845(2009)].

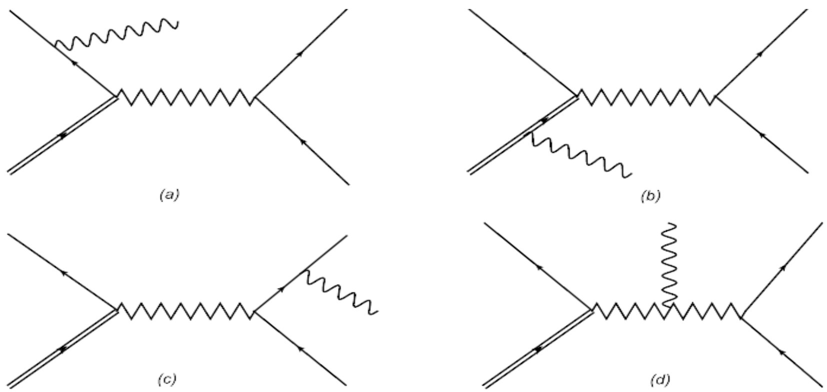
With 6 dominant D^- single tag



$B[D^+ \rightarrow D^0 e^+ \nu] < 8.7 \times 10^{-5}$ @90%C.L.

Search for $D^+ \rightarrow \gamma e^+ \nu$

J.C. Yang and M.Z. Yang, NPB889,778(2014)



Various theory models predict BFs in 10^{-6}–10^{-4}

Figure 1: Feynman diagrams of short-distance contribution at tree level (taken from Ref. [1]). The double line represents the heavy quark propagator. Fig.(a) and (b) are structure-dependent radiative decays, Fig.(c) is the Bremsstrahlung radiative decay. Fig.(d) is suppresssed by a factor of $1/m_W^2$.

Tree level amplitudes

arXiv: 1702.05837[hep-ex], accepted by PRD(RC)

With 6 dominant D^- single tag

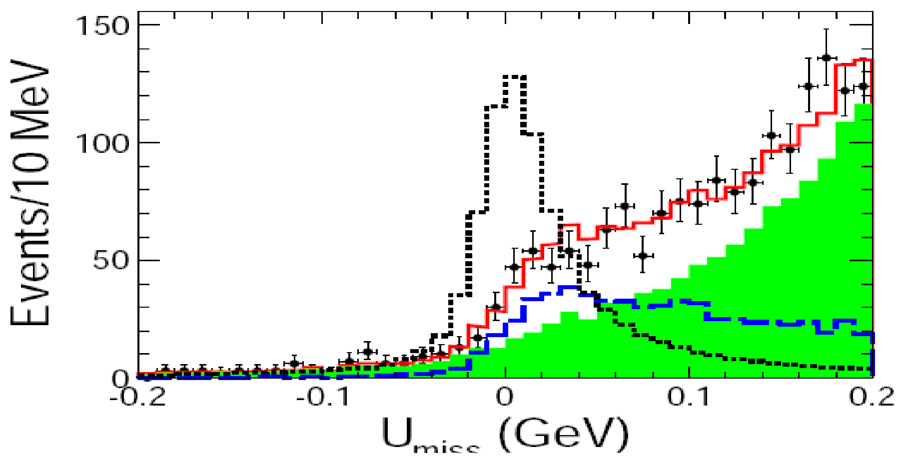
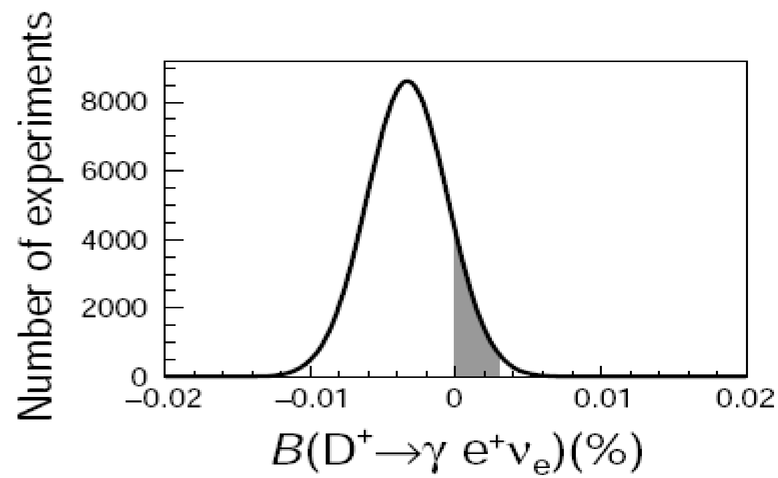


FIG. 2. (color online) The $U_{\rm miss}$ distribution. Dots with error bars are data, the red solid-line histogram shows the overall fit curve, the blue dash-line histogram shows the background $D^+ \to \pi^0 e^+ \nu_e$, and the green shaded histogram includes all other background. The black dotted line shows the signal MC simulation normalized to the branching fraction $\mathcal{B}(D^+ \to \gamma e^+ \nu_e) = 100 \times 10^{-5}$.



$B[D^+ \rightarrow \gamma e^+ \nu]|_{E\gamma>10\ \mathrm{MeV}} < 3.0 \times 10^{-4}$ @90%C.L.

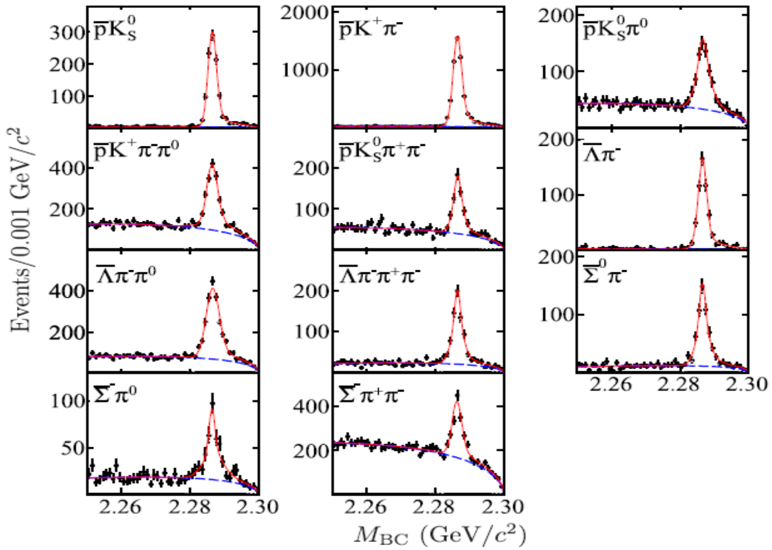
Λ_c^+ decays

- Λ_c^+ was observed in 1979
- **Before 2014, all decays of Λ_c^+ are measured relative to $\Lambda_c^+ \to pK^-\pi^+$, which suffer large error of 25%, with high energy data. No absolute measurement using data produced at Λ_c^+ pair threshold**
- **Sum of BFs of known decays Λ_c^+ is only about 60%**
- **In 2014, Belle reported improved measurement of $B[\Lambda_c^+ \to pK^-\pi^+]$, with a precision of ~5%**

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S=-1$ final states				
$p\overline{K}^0$		(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a]	(5.0 ± 1.3) %		823
$p\overline{K}^*(892)^0$	[b]	(1.6 ± 0.5) %		685
$\Delta(1232)^{++}K^-$		$(8.6 \pm 3.0) \times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b]	(1.8 ± 0.6) %		627
$pK^-\pi^+$ nonresonant		(2.8 ± 0.8) %		823
$p\overline{K}^0\pi^0$		(3.3 ± 1.0) %		823
$p\overline{K}^0\eta$		(1.2 ± 0.4) %		568
Hadronic modes with a hyperon: $S=-1$ final states				
$\Lambda\pi^+$		(1.07 ± 0.28) %		864
$\Lambda\pi^+\pi^0$		(3.6 ± 1.3) %		844
$\Lambda\rho^+$		< 5 %	CL=95%	636
$\Lambda\pi^+\pi^+\pi^-$		(2.6 ± 0.7) %		807
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} \to \Lambda\pi^+$		$(7 \pm 4) \times 10^{-3}$		688
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-} \to \Lambda\pi^-$		$(5.5 \pm 1.7) \times 10^{-3}$		688
$\Lambda\pi^+\rho^0$		(1.1 ± 0.5) %		524
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+} \to \Lambda\pi^+$		$(3.7 \pm 3.1) \times 10^{-3}$		363
$\Lambda\pi^+\pi^+\pi^-$ nonresonant		$< 8 \times 10^{-3}$	CL=90%	807
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(1.8 ± 0.8) %		757
$\Lambda\pi^+\eta$	[b]	(1.8 ± 0.6) %		691
$\Sigma(1385)^+\eta$	[b]	$(8.5 \pm 3.3) \times 10^{-3}$		570
$\Lambda\pi^+\omega$	[b]	(1.2 ± 0.5) %		517
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		$< 7 \times 10^{-3}$	CL=90%	757
$\Lambda K^+\overline{K}^0$		$(4.7 \pm 1.5) \times 10^{-3}$	S=1.2	443
$\Xi(1690)^0K^+$, $\Xi^{*0} \to \Lambda\overline{K}^0$		$(1.3 \pm 0.5) \times 10^{-3}$		286
$\Sigma^0\pi^+$		(1.05 ± 0.28) %		825
$\Sigma^+\pi^0$		(1.00 ± 0.34) %		827
$\Sigma^+\eta$		$(5.5 \pm 2.3) \times 10^{-3}$		713
$\Sigma^+\pi^+\pi^-$		(3.6 ± 1.0) %		804
$\Sigma^+\rho^0$		< 1.4 %	CL=95%	575
$\Sigma^-\pi^+\pi^+$		(1.7 ± 0.5) %		799
$\Sigma^0\pi^+\pi^0$		(1.8 ± 0.8) %		803
$\Sigma^0\pi^+\pi^+\pi^-$		$(8.3 \pm 3.1) \times 10^{-3}$		763
$\Sigma^+\pi^+\pi^-\pi^0$		—		767
$\Sigma^+\omega$	[b]	(2.7 ± 1.0) %		569
Semileptonic modes				
$\Lambda\ell^+\nu_\ell$	[c]	(2.0 ± 0.6) %		871
$\Lambda e^+\nu_e$		(2.1 ± 0.6) %		871
$\Lambda\mu^+\nu_\mu$		(2.0 ± 0.7) %		867
Inclusive modes				
e^+ anything		(4.5 ± 1.7) %		—
pe^+ anything		(1.8 ± 0.9) %		—
p anything		(50 ± 16) %		—

Systematic studies of Λ_c^+, search for new decays, absolute BF measurements are important to fully explore the Λ_c^+ decay mechanisms

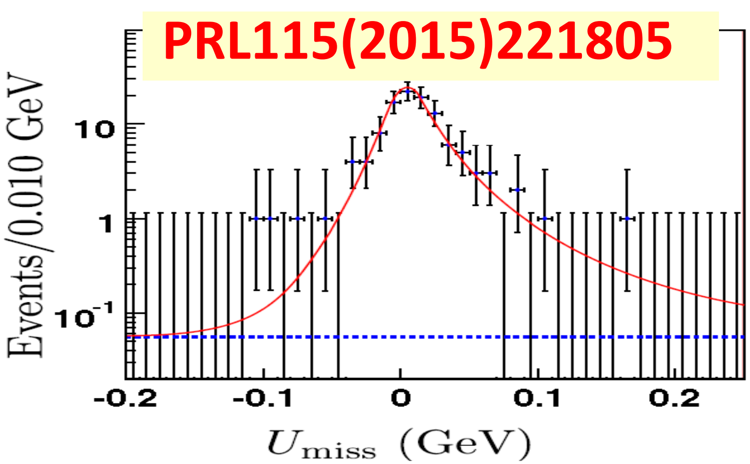
First absolute BFs of $\Lambda_c^+ \rightarrow \Lambda l^+ \nu$

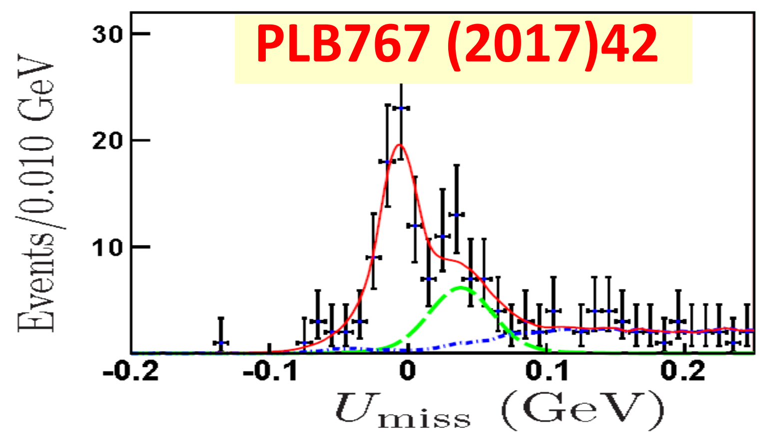


Theory: (1.4-9.2)%

Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$

3 fb^{-1} help to explore FF studies





$B[\Lambda_c^+ \rightarrow \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$

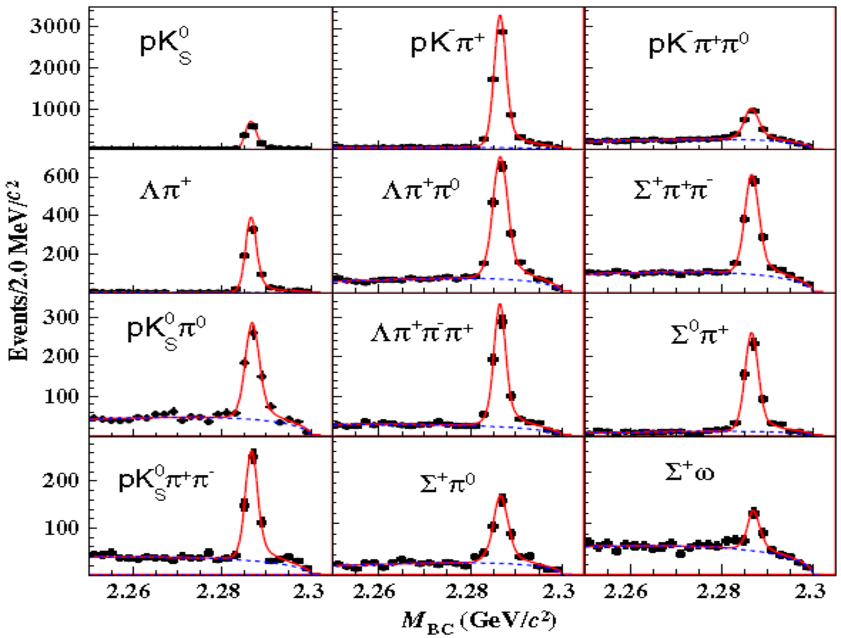
$B[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

$\Gamma[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] / \Gamma[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

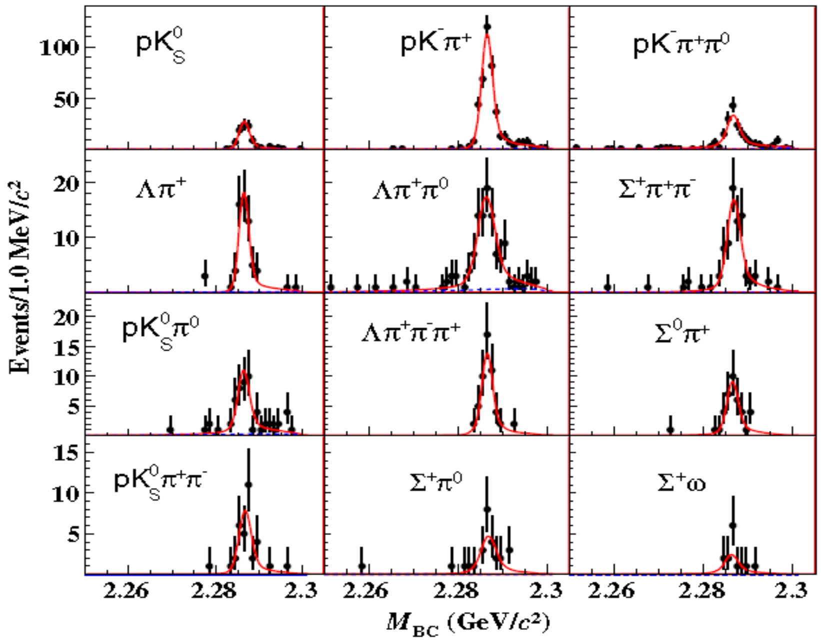
Significantly improved BFs of $\Lambda_c^+ \rightarrow$ decays

PRL116(2016)052001

ST: ~15000



DT: ~1000



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

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

$$\mathcal{B}_i = \frac{N_{ij}^{\rm DT}}{N_j^{\rm ST}}\frac{\varepsilon_j}{\varepsilon_{ij}}$$

$$N_{i-}^{\rm DT} = N_{\Lambda_c^+\bar{\Lambda}_c^-}\sum_j \mathcal{B}_i\mathcal{B}_j\varepsilon_{i-}^{\rm DT}$$

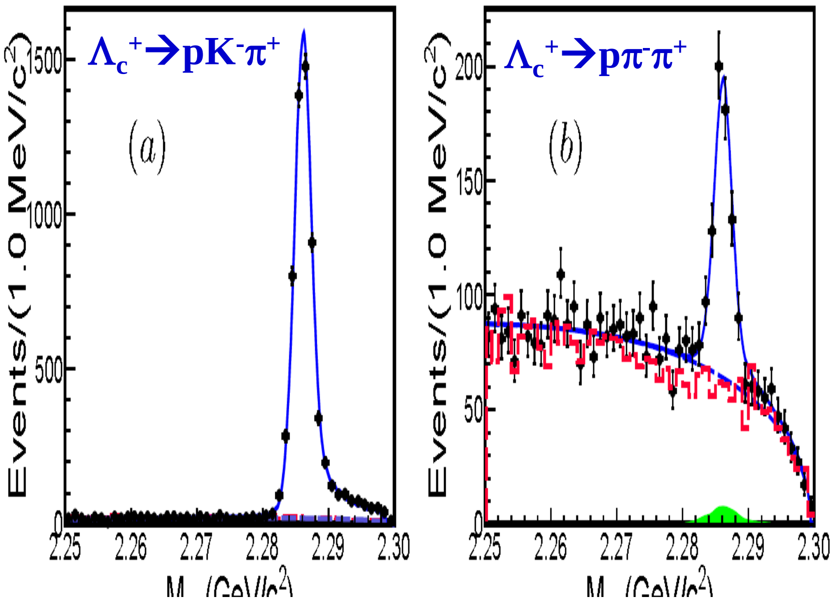
$$\varepsilon_{i-}^{\rm DT} \equiv [\sum_j(\mathcal{B}_j\varepsilon_{ij})/\sum_j\mathcal{B}_j]$$

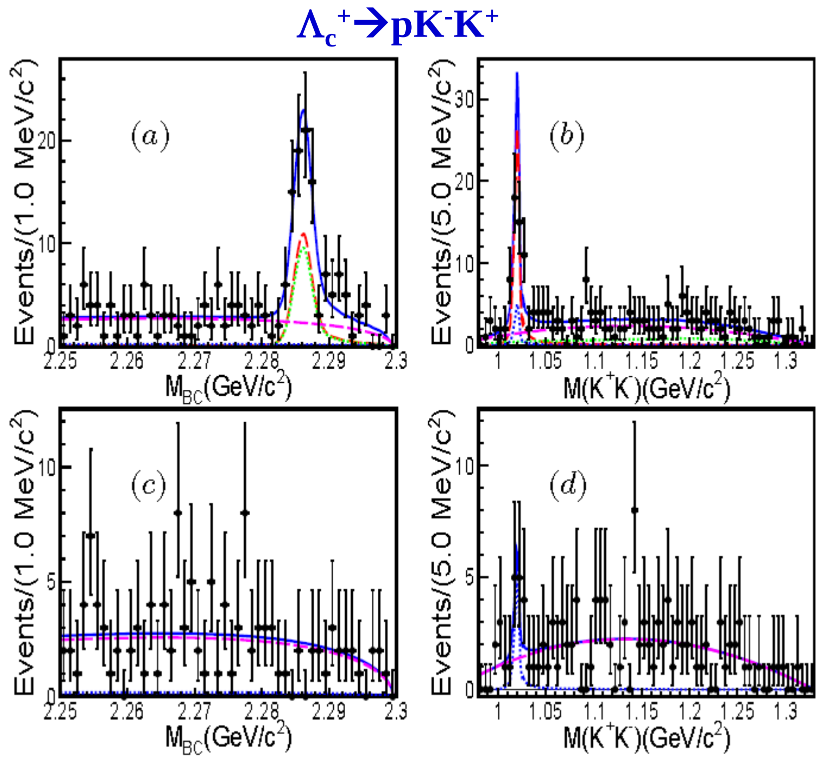
Mode	This work (%)	PDG (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	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

Much better precision

SCS decays $\Lambda_c^+ \rightarrow pK^+K^-$ and $p\pi^+\pi^-$

PRL117(2016)232002



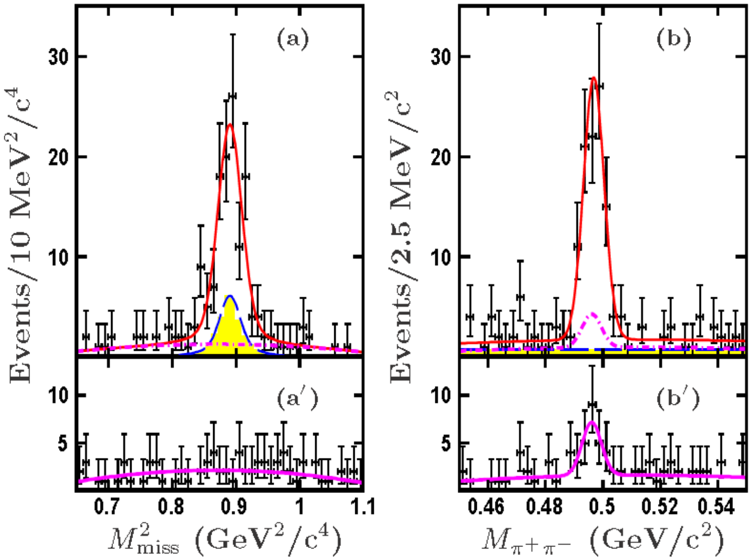


These help to distinguish predictions from different theoretical models and understand contributions from factorizable effects

Decay modes	$\mathcal{B}_{\mathrm{mode}}/\mathcal{B}_{\mathrm{ref.}}$	$\mathcal{B}_{\mathrm{mode}}$	$\mathcal{B}$(PDG)
$\Lambda_c^+ \rightarrow p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \rightarrow p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \rightarrow pK^+K^-$ (non-ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

Observation of $\Lambda_c^+ \rightarrow nK_S\pi^+$

PRL118(2017)112001



$B[\Lambda_c^+ \rightarrow nK_S\pi^+]=(1.82\pm0.23\pm0.11)\%$

$\Gamma[\Lambda_c^+ \rightarrow n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \rightarrow pK^-\pi^+]=0.62\pm0.09$

$\Gamma[\Lambda_c^+ \rightarrow n\bar{K}^0\pi^+]/\Gamma[\Lambda_c^+ \rightarrow p\bar{K}^0\pi^+]=0.97\pm0.16$

First measurement of BF of Λ_c^+ decay containing neutron

$$\cos\delta = -0.24 \pm 0.08$$

$$|I^{(1)}|/|I^{(0)}| \quad 1.14 \pm 0.11$$

Help to understand SU(3) and isospin symmetry and determine strong phase

Cai-Dian Lv et al, PRD93(2016)056008

$$\cos\delta = \frac{\mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(pK^-\pi^+)}{2\sqrt{\mathcal{B}(p\bar{K}^0\pi^0)(\mathcal{B}(pK^-\pi^+) + \mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(p\bar{K}^0\pi^0))}}$$

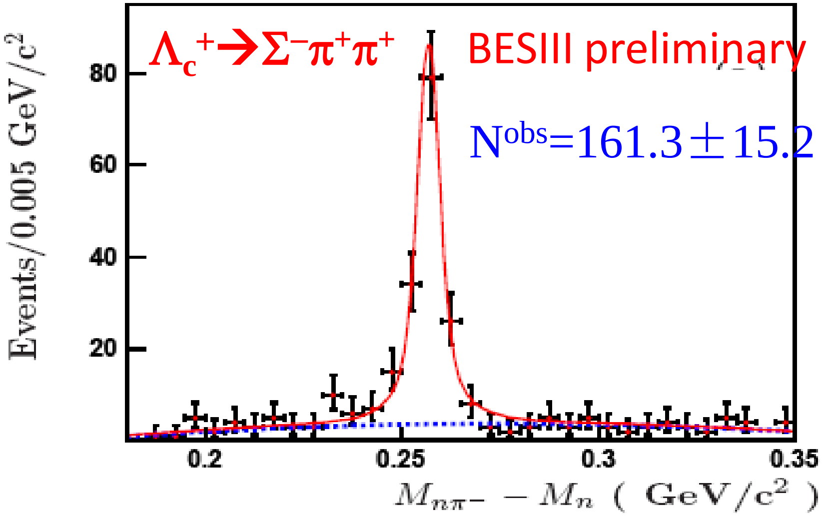
$$R_p = \frac{\mathcal{B}(\Lambda_c \to p\bar{K}^0\pi^0)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}, \qquad R_n = \frac{\mathcal{B}(\Lambda_c \to n\bar{K}^0\pi^+)}{\mathcal{B}(\Lambda_c \to pK^-\pi^+)}$$

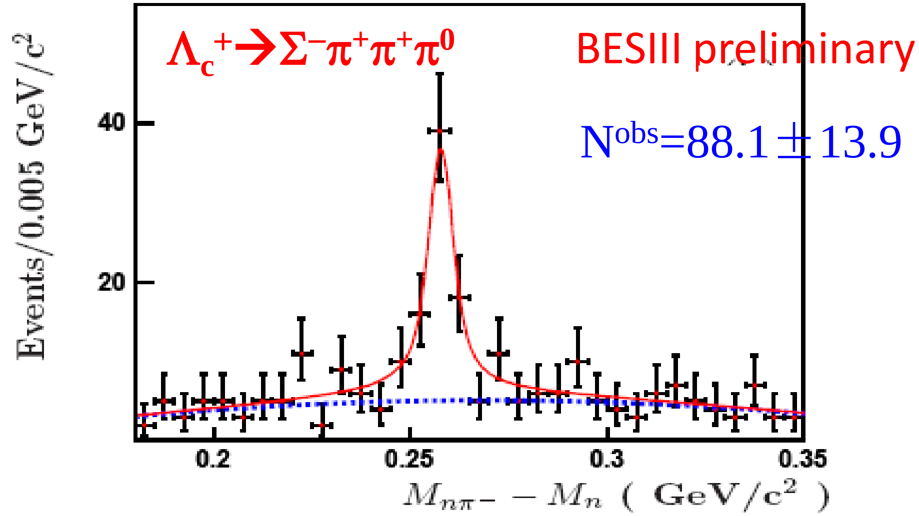
involving a neutron. Under the isospin symmetry, its amplitude is related to those of the most favored proton modes $\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to p\bar{K}^0\pi^0$ as $\mathcal{A}(n\bar{K}^0\pi^+) + \mathcal{A}(pK^-\pi^+) + \sqrt{2}\mathcal{A}(p\bar{K}^0\pi^0) = 0$. Hence, precise measure-

[2,3]. In the three-body Λ_c^+ decay to $N\bar{K}\pi$, the total decay amplitudes can be decomposed into two isospin amplitudes of the $N\bar{K}$ system as isosinglet ($I^{(0)}$) and isospin-one ($I^{(1)}$). In the factorization limit, the color-allowed tree diagram, in which the π^+ is emitted and the $N\bar{K}$ is an isosinglet, dominates $I^{(0)}$, and $I^{(1)}$ is expected to be small compared to $I^{(0)}$ as it can only proceed through the color-suppressed tree diagrams. Though the factorization scheme is spoiled in

Observation of $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$

More studies of decays containing neutron





Preliminary results :

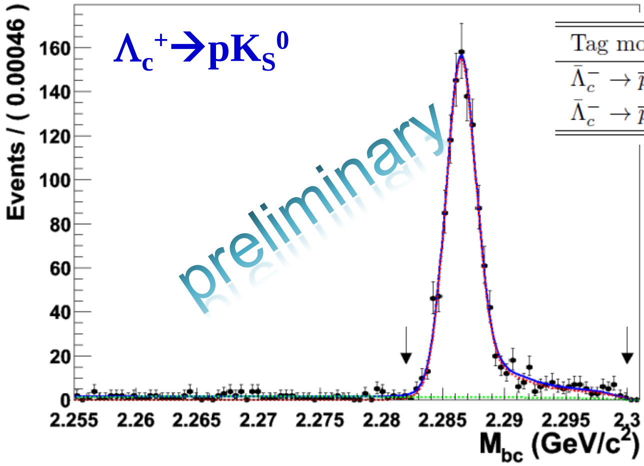
$B[\Lambda_c^+ \to \Sigma^-\pi^+\pi^+] = (1.81 \pm 0.17)\%$

$B[\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0] = (2.11 \pm 0.33)\%$ **[First observation]**

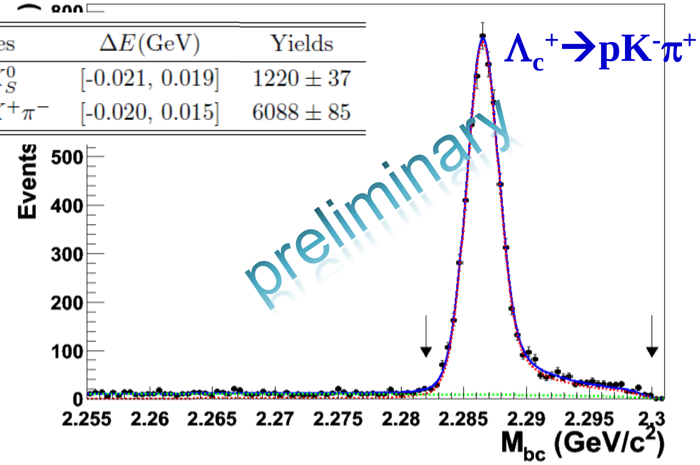
where the errors are statistical only. The sources of the systematic errors arise mainly from the systematic uncertainties in PID, tracking, π^0 efficiency, fitting, MC statistics and number of $\bar{\Lambda}_c^-$ tags. The total systematic errors are estimated to be about 5%.

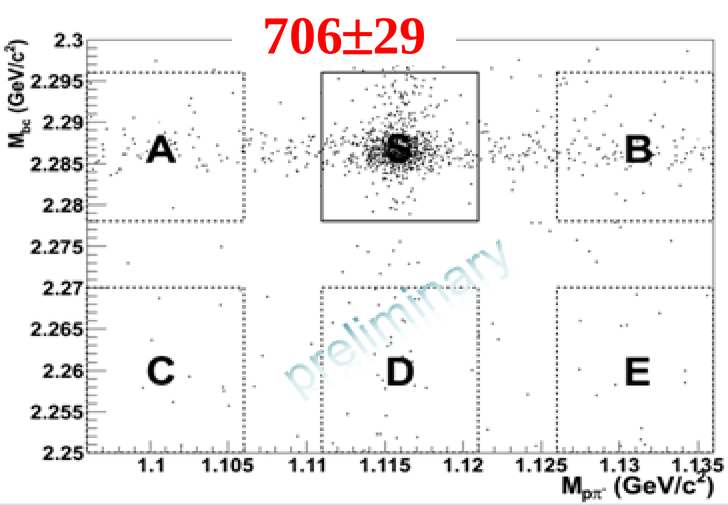
The measured branching fraction for $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ is consistent with and more precise than $B[\Lambda_c^+ \to \Sigma^-\pi^+\pi^+] = (2.3 \pm 0.4)\%$ in PDG2015.

Inclusive decay $\Lambda_c^+ \to \Lambda X$



Tag modes	ΔE(GeV)	Yields
$\bar{\Lambda}_c^- \to \bar{p}K_S^0$	[-0.021, 0.019]	1220 ± 37
$\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$	[-0.020, 0.015]	6088 ± 85





$$\mathcal{A}_{CP} = \frac{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}.$$

Help to explore the source of missing decays and search for new decay. Better input for charm baryon and B physics

$$N_{sig} = N_S - (N_A + N_B)/2 - r \cdot N_D + r \cdot (N_C + N_E)/2$$

$\mathcal{B}(\Lambda_c^+ \to \Lambda + X) = (36.98 \pm 2.18)\%$ **stat. only**

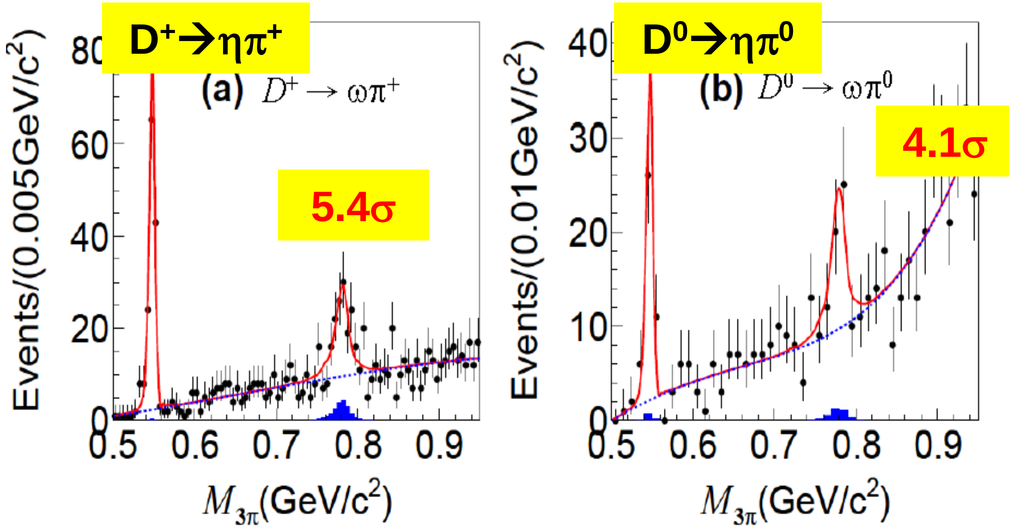
Agrees with PDG2015 value (35±11)%,

Decay mode	Branching fraction(%)	$\mathcal{A}_{CP}$
$\Lambda_c^+ \to \Lambda + X$	38.02 ± 3.24	0.02 ± 0.06
$\bar{\Lambda}_c^- \to \bar{\Lambda} + X$	36.70 ± 3.04	

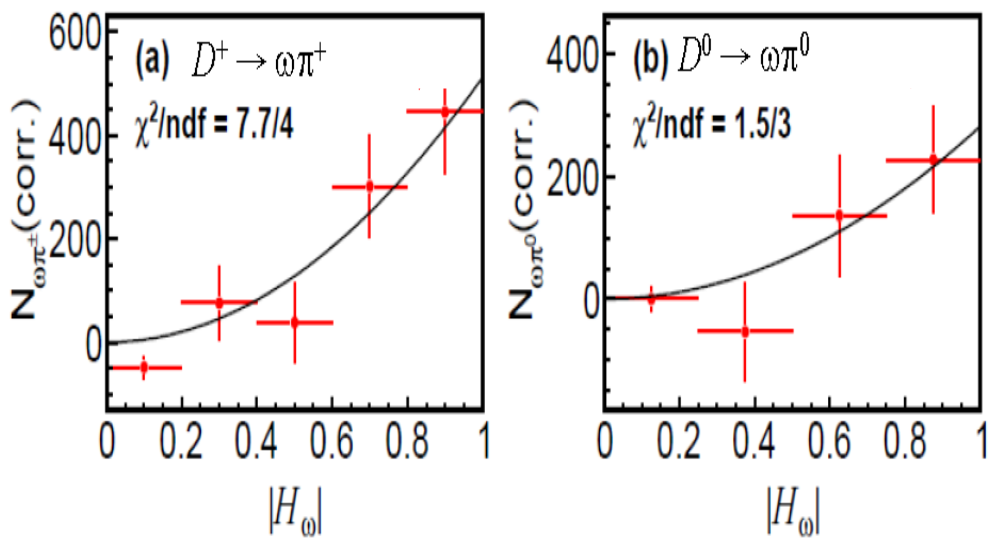
Observation/Evidence of D→ωπ

Double tag method

PRL116(2016)082001



Decay mode	This work	Previous meausurements
$D^+ \to \omega\pi^+$	$(2.74 \pm 0.58 \pm 0.17) \times 10^{-4}$	$< 3.4 \times 10^{-4}$ at 90% C.L.
$D^0 \to \omega\pi^0$	$(1.05 \pm 0.41 \pm 0.09) \times 10^{-4}$	$< 2.6 \times 10^{-4}$ at 90% C.L.
$D^+ \to \eta\pi^+$	$(3.13 \pm 0.22 \pm 0.19) \times 10^{-3}$	$(3.53 \pm 0.21) \times 10^{-3}$
$D^0 \to \eta\pi^0$	$(0.67 \pm 0.10 \pm 0.05) \times 10^{-3}$	$(0.68 \pm 0.07) \times 10^{-3}$



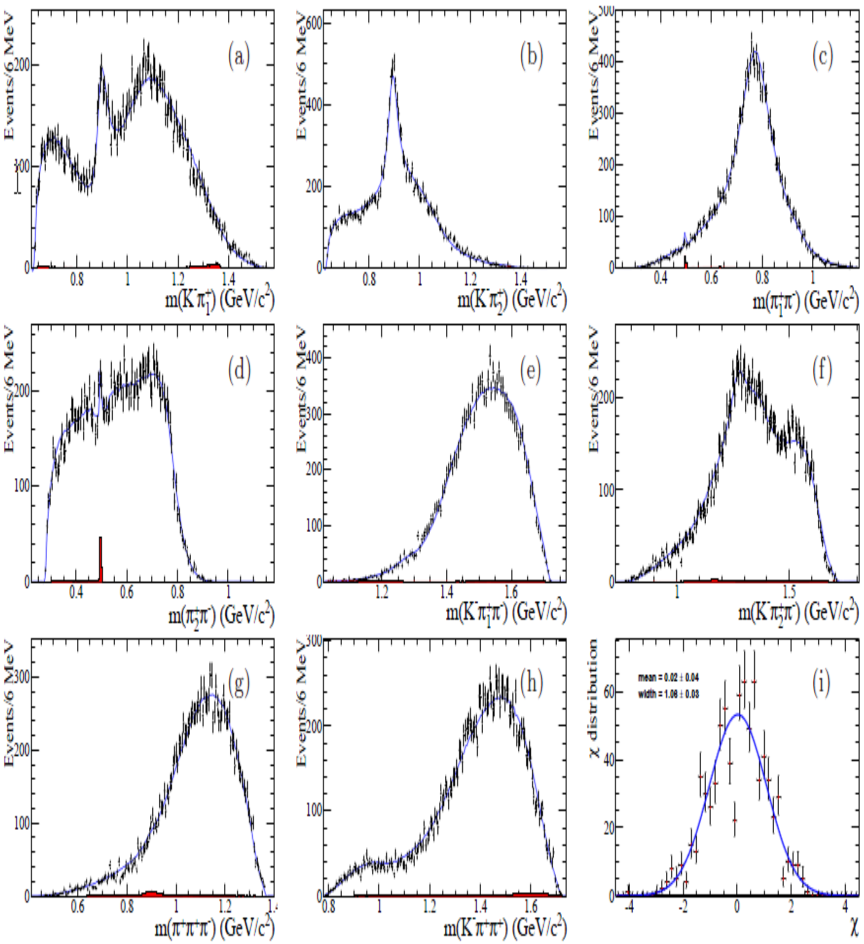
Studies of Singly Cabibbo-suppressed decays is limited by data set and background

Benefit the understanding of SU(3) symmetry breaking and CP violation, improve theory calculation

Amplitude analysis of $D^0 \rightarrow K^-\pi^+\pi^+\pi^-$

Help to determine the absolute BF, strong phase, benefit γ/ϕ_3

Previous analyses only from MarkIII and E691

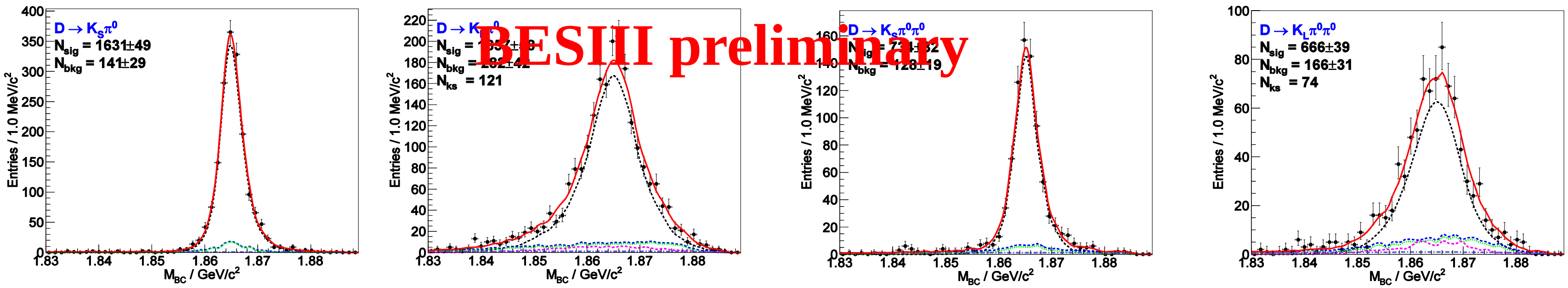


Amplitude	ϕ_i	Fit fraction (%)
$D^0[S] \to \bar{K}^*\rho^0$	$2.35 \pm 0.06 \pm 0.18$	$6.5 \pm 0.5 \pm 0.8$
$D^0[P] \to \bar{K}^*\rho^0$	$-2.25 \pm 0.08 \pm 0.15$	$2.3 \pm 0.2 \pm 0.1$
$D^0[D] \to \bar{K}^*\rho^0$	$2.49 \pm 0.06 \pm 0.11$	$7.9 \pm 0.4 \pm 0.7$
$D^0 \to K^- a_1^+(1260),\ a_1^+(1260)[S]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

arXiv: 1701.08591,
submitted to PRD

Absolute BFs and y_{CP} of $D^0 \rightarrow K_{S/L}\pi^0(\pi^0)$

- Two dimensional fits to M_{BC}(tag) versus M_{BC}(signal)
- Projections of DT evens on the M_{BC}(sig) vs. $K\pi$ (for example)



Branching fractions and asymmetries

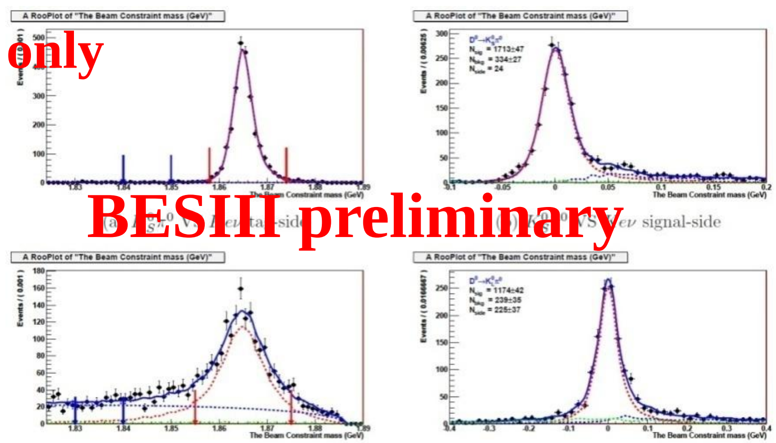
Statistical only

$$R(D \rightarrow K_{S,L} + \pi's) = \frac{Br(D \rightarrow K_S\pi's) - Br(D \rightarrow K_L\pi's)}{Br(D \rightarrow K_S\pi's) + Br(D \rightarrow K_L\pi's)}$$

Table 10: Decay rates and the asymmetries of $D \rightarrow K^0_{S,L}\pi^0$ and $D \rightarrow K^0_{S,L}\pi^0\pi^0$.

$D \rightarrow K^0_{S,L}\pi^0$			
	$Br_{K_S\pi^0}(\%)$	$Br_{K_L\pi^0}(\%)$	$R(D \rightarrow K_{S,L}\pi^0)$
$K\pi$	1.208±0.041	1.061±0.038	0.0646±0.0245
$K3\pi$	1.212±0.037	0.985±0.036	0.1035±0.0237
$K\pi\pi^0$	1.251±0.028	0.953±0.029	0.1351±0.0186
All	1.230±0.020	0.991±0.019	0.1077±0.0125

$D \rightarrow K^0_{S,L}\pi^0\pi^0$			
	$Br_{K_S 2\pi^0}(\%)$	$Br_{K_L 2\pi^0}(\%)$	$R(D \rightarrow K_{S,L}2\pi^0)$
$K\pi$	1.024±0.049	1.299±0.080	-0.1183±0.0385
$K3\pi$	0.887±0.043	1.097±0.073	-0.1060±0.0409
$K\pi\pi^0$	1.010±0.036	1.158±0.060	-0.0681±0.0313
All	0.975±0.024	1.175±0.040	-0.0929±0.0209

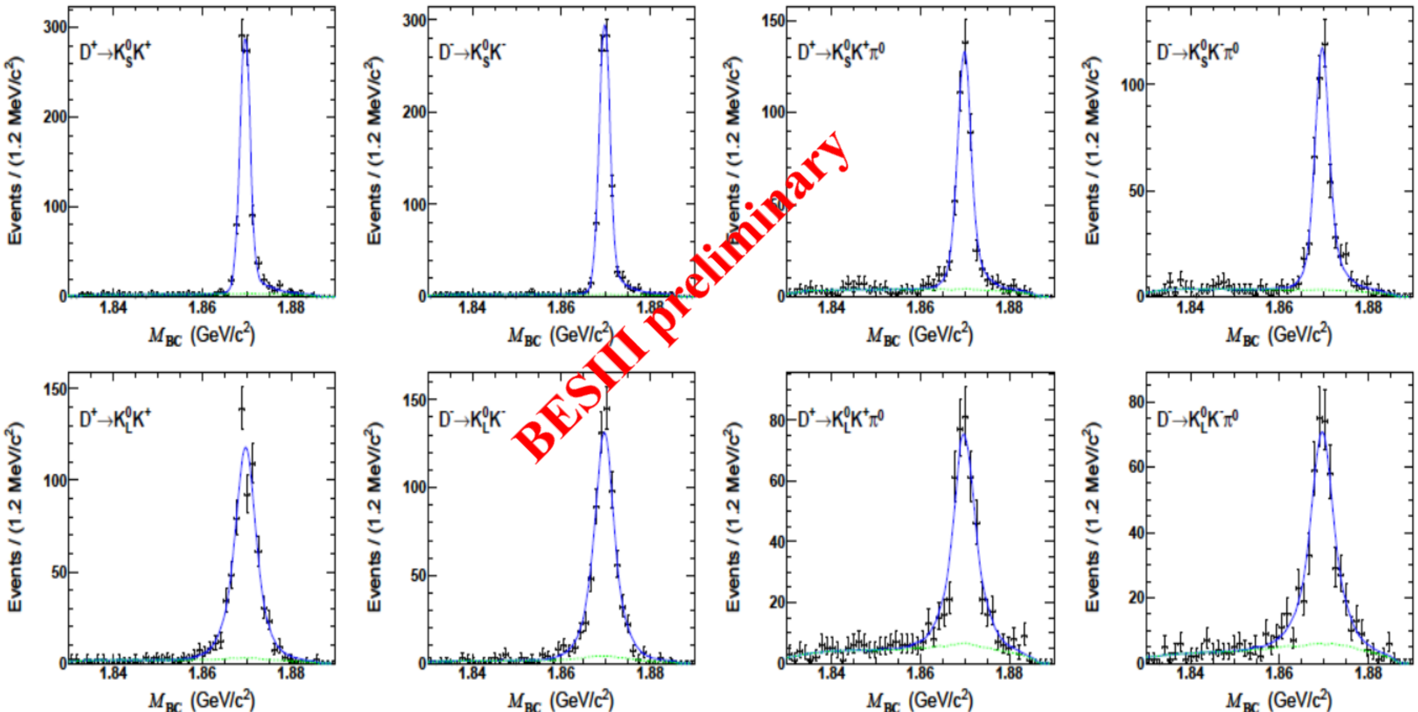


(c) $K^0_L\pi^0$ VS $Ke\nu$ tag-side

(d) $K^0_L\pi^0$ VS $Ke\nu$ signal-side

- y_{CP} (($K_S\pi^0$, $K_L\pi^0$) vs. $Ke\nu$) = (0.98±2.43)%

Absolute BFs and A_{CP} of $D^+ \to K_{S/L}K^+(\pi^0)$



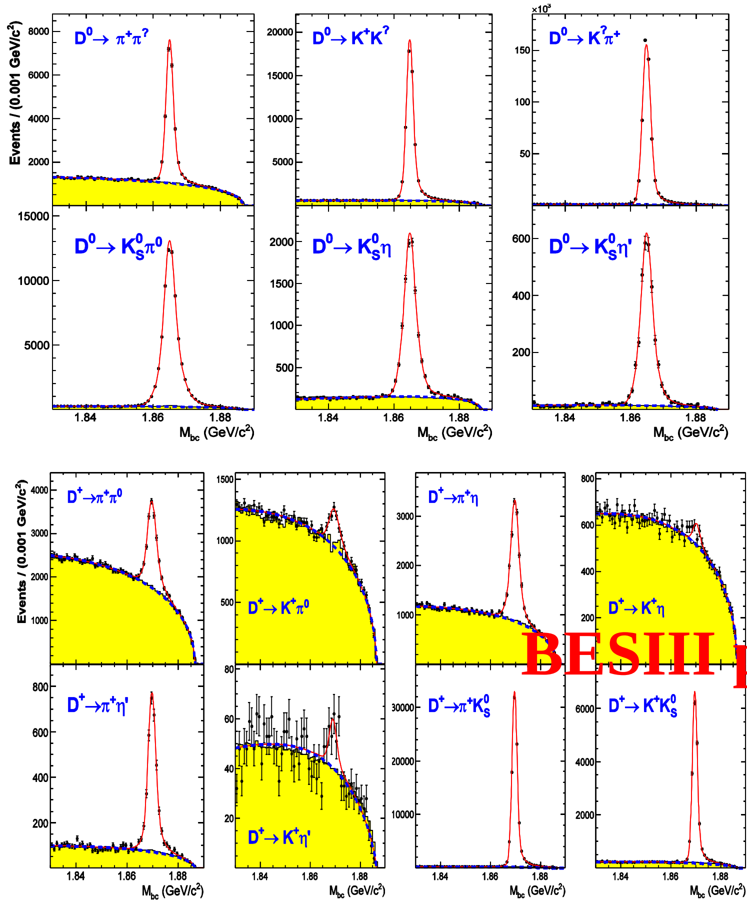
$$\mathcal{A}_{CP} = \frac{\mathcal{B}(D^+) - \mathcal{B}(D^-)}{\mathcal{B}(D^+) + \mathcal{B}(D^-)}$$

The first and second uncertainties are statistical and systematic

Mode	$\mathcal{B}(D^+)$ $(\times 10^{-3})$	$\mathcal{B}(D^-)$ $(\times 10^{-3})$	$\overline{\mathcal{B}}$ $(\times 10^{-3})$	$\mathcal{A}_{CP}$ (%)
$K^0_S K^\pm$	$3.01 \pm 0.12 \pm 0.10$	$3.10 \pm 0.12 \pm 0.10$	$3.06 \pm 0.09 \pm 0.10$	$-1.5 \pm 2.8 \pm 1.6$
$K^0_S K^\pm \pi^0$	$5.23 \pm 0.28 \pm 0.24$	$5.09 \pm 0.29 \pm 0.22$	$5.16 \pm 0.21 \pm 0.23$	$1.4 \pm 4.0 \pm 2.4$
$K^0_L K^\pm$	$3.13 \pm 0.14 \pm 0.13$	$3.32 \pm 0.15 \pm 0.13$	$3.23 \pm 0.11 \pm 0.13$	$-3.0 \pm 3.2 \pm 1.2$
$K^0_L K^\pm \pi^0$	$5.17 \pm 0.30 \pm 0.21$	$5.26 \pm 0.30 \pm 0.20$	$5.22 \pm 0.22 \pm 0.21$	$-0.9 \pm 4.1 \pm 1.6$

BESIII preliminary

BF measurements of some $D^{0(+)} \to PP$



- The study of the hadronic decays of charmed D mesons is of great significance in the study of the strong and weak interactions in D decays.
- The analysis on $D \to PP$ modes will provide materials for the study of SU(3) breaking effect[1] . And the observation of CP violation in D decay is commonly believed to be indications of new physics.
- $D^0 \to K^-\pi^+$ is an important normalization mode.
- Most of the D decays have been studied by CLEO in 2010[2] , other measurements come from Belle[3] , BaBar[4] and CDF[5] , etc.
- Some of the branching fractions (BFs) are not well established. With the 2.93 fb^{-1} data taken at 3.773 GeV within BESIII , the results will help to improve these measurements.

BESIII preliminary

Mode	$N^{\rm net}_{\rm signal}$	ε (%)	$\mathcal{B}\pm$(stat)$\pm$(sys)	$\mathcal{B}_{\rm PDG}$
$\pi^+\pi^-$	21105 ± 249	66.03 ± 0.25	$(1.505 \pm 0.018 \pm 0.031) \times 10^{-3}$	$(1.421 \pm 0.025) \times 10^{-3}$
K^+K^-	5543[illegible] $\pm$ 273	62.82 ± 0.32	$(4.229 \pm 0.020 \pm 0.087) \times 10^{-3}$	$(4.01 \pm 0.07) \times 10^{-3}$
$K^-\pi^+$	537745 ± 767	64.98 ± 0.09	$(3.896 \pm 0.006 \pm 0.073)$ %	(3.93 ± 0.04) %
$K^0_S\pi^0$	66539 ± 302	38.06 ± 0.17	$(1.236 \pm 0.006 \pm 0.032)$ %	(1.20 ± 0.04) %
$K^0_S\eta$	9532 ± 126	31.96 ± 0.14	$(5.149 \pm 0.068 \pm 0.134) \times 10^{-3}$	$(4.85 \pm 0.30) \times 10^{-3}$
$K^0_S\eta'$	3007 ± 61	12.66 ± 0.08	$(9.562 \pm 0.197 \pm 0.379) \times 10^{-3}$	$(9.5 \pm 0.5) \times 10^{-3}$
$\pi^0\pi^+$	10108 ± 267	48.98 ± 0.34	$(1.259 \pm 0.033 \pm 0.025) \times 10^{-3}$	$(1.24 \pm 0.06) \times 10^{-3}$
π^0K^+	1834 ± 168	51.52 ± 0.42	$(2.171 \pm 0.198 \pm 0.060) \times 10^{-4}$	$(1.89 \pm 0.25) \times 10^{-4}$
$\eta\pi^+$	11636 ± 215	46.96 ± 0.25	$(3.790 \pm 0.070 \pm 0.075) \times 10^{-3}$	$(3.66 \pm 0.22) \times 10^{-3}$
ηK^+	439 ± 72	48.21 ± 0.31	$(1.393 \pm 0.228 \pm 0.124) \times 10^{-4}$	$(1.12 \pm 0.18) \times 10^{-4}$
$\eta'\pi^+$	3088 ± 83	21.49 ± 0.18	$(5.122 \pm 0.140 \pm 0.210) \times 10^{-3}$	$(4.84 \pm 0.31) \times 10^{-3}$
$\eta'K^+$	87 ± 25	22.39 ± 0.22	$(1.377 \pm 0.428 \pm 0.202) \times 10^{-4}$	$(1.83 \pm 0.23) \times 10^{-4}$
$K^0_S\pi^+$	93884 ± 352	51.38 ± 0.18	$(1.591 \pm 0.006 \pm 0.033) \times 10^{-2}$	$(1.53 \pm 0.06) \times 10^{-2}$
$K^0_SK^+$	17704 ± 151	48.45 ± 0.14	$(3.183 \pm 0.028 \pm 0.065) \times 10^{-3}$	$(2.95 \pm 0.15) \times 10^{-3}$

$$\mathcal{B} = \frac{N^{signal}_{net}}{2 \cdot N_{D^0\bar{D}^0(D^+D^-)} \cdot \varepsilon}, N_{D^0\bar{D}^0} = (10{,}621 \pm 29_{(stat)}) \times 10^3, N_{D^+D^-} = (8{,}296 \pm 31_{(stat)}) \times 10^3$$

quoted from Derrick's talk given at APS2014

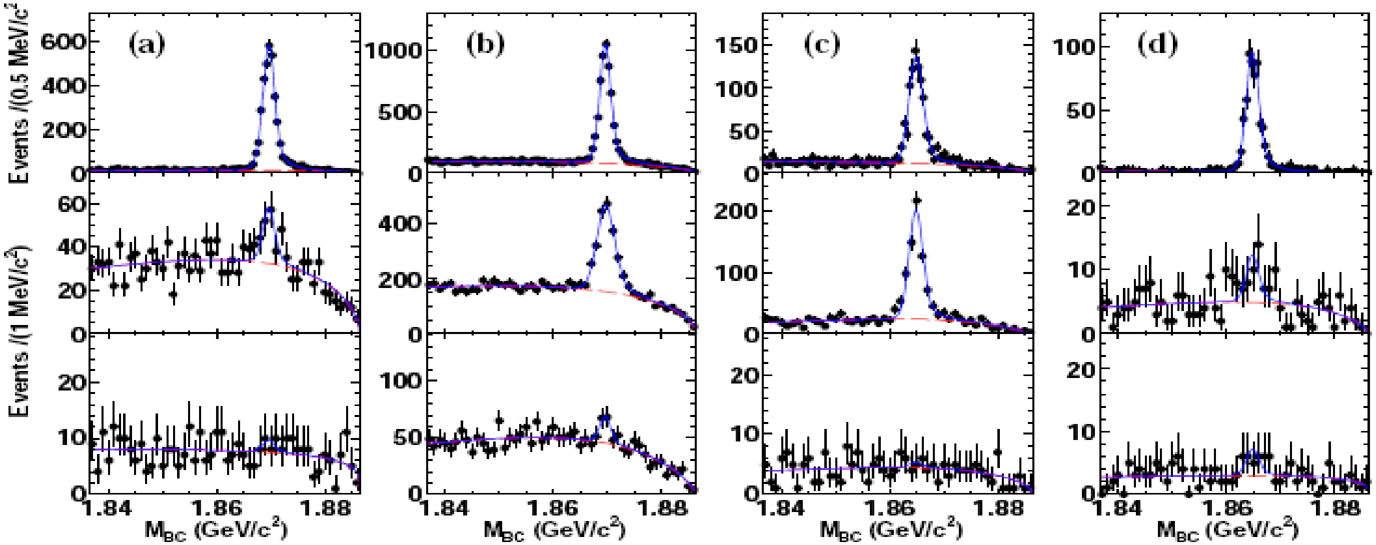
The $\mathcal{B}(D^0 \to K^-\pi^+)$ has been corrected by the PDG value of $\mathcal{B}(D^0 \to K^+\pi^-)$.

For $D^0 \to K^0_S\eta$, $D^+ \to \pi^0\pi^+$, $D^+ \to \eta\pi^+$, $D^+ \to \eta'\pi^+$, $D^+ \to K^0_S\pi^+$ and $D^+ \to K^0_SK^+$, it shows better precision than the present values.

BFs of $D^+ \rightarrow 2K_S K(\pi)^+$ and $D^0 \rightarrow 2(3)K_S$

Comprehensive or improved measurements of 3-body decays benefit the understanding of the interplay between weak and strong interactions in multibody decays, where theory is poor than 2-body decays

BF of $D^0 \rightarrow K_S K_S$ will be helpful to explore the SU(3) symmetry breaking in D decays



Comparisons of the branching fractions (in 10^{-4}) measured in this work with the PDG values

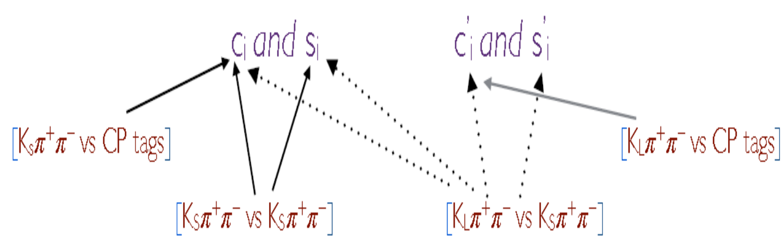
Decay modes	This work	PDG
$D^+ \rightarrow K_S^0 K_S^0 K^+$	$25.4 \pm 0.5 \pm 1.2$	45 ± 20
$D^+ \rightarrow K_S^0 K_S^0 \pi^+$	$27.0 \pm 0.5 \pm 1.2$	–
$D^0 \rightarrow K_S^0 K_S^0$	$1.67 \pm 0.11 \pm 0.11$	1.7 ± 0.4
$D^0 \rightarrow K_S^0 K_S^0 K_S^0$	$7.21 \pm 0.33 \pm 0.44$	9.1 ± 1.3

PLB765(2017)231

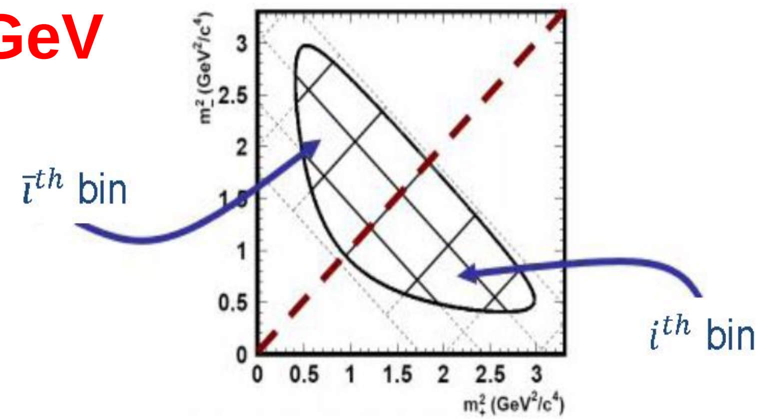
$D^0 \to \bar{K}^0\pi^+\pi^-$ DPA $\to$ (ci,si)

c_i,s_i can be measured using the Double Tags:
$D^0 \to K_S\pi^+\pi^-$ vs ($K_{S/L}\,\pi^+\pi^-$ or CP tags)

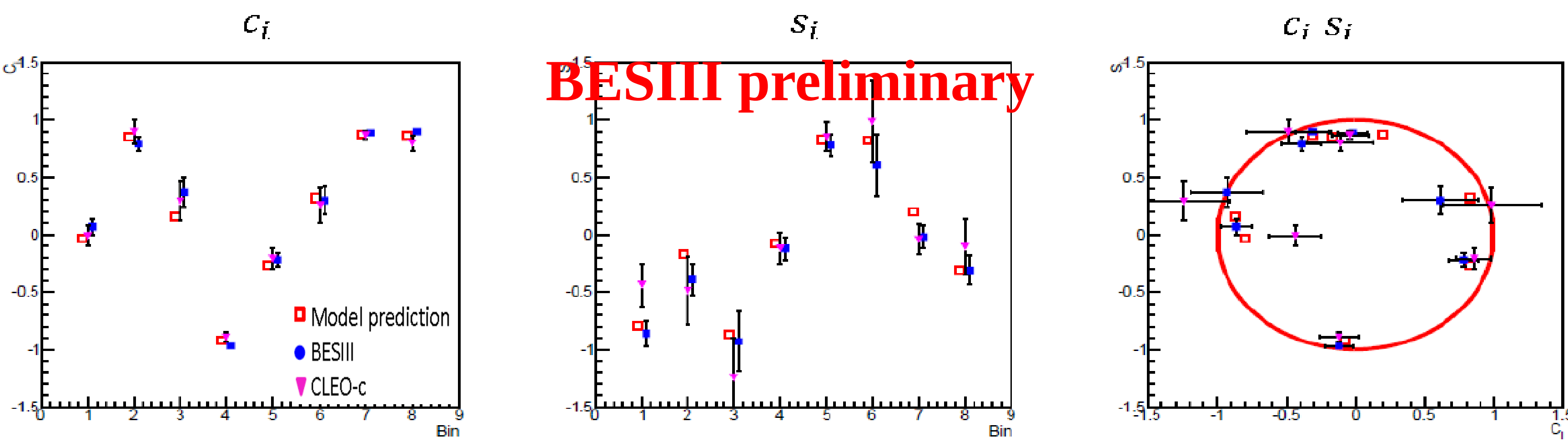
at 3.773 GeV



Use both (c_i,s_i) and (c_i',s_i') to further constrain the results (c_i,s_i)



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



Better input to constrain γ/ϕ_3

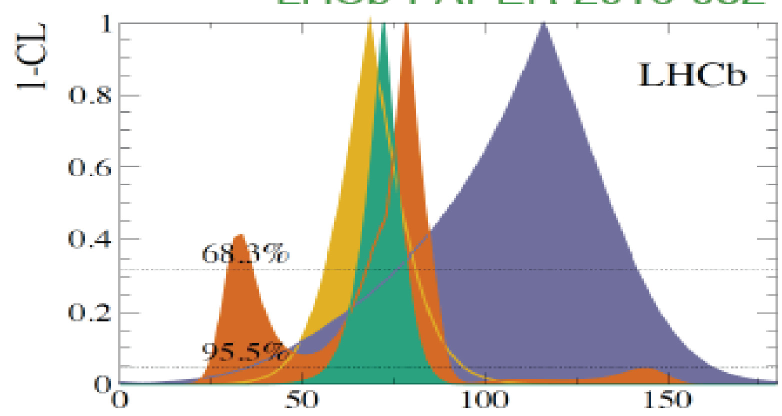
Constrain on γ/ϕ_3 measurement

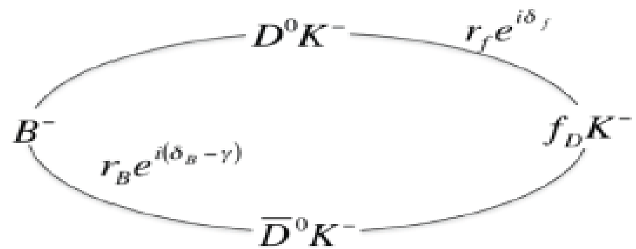
Blow slide is taken from Liming Zhang's talk at FPCPV2016

γ combination at LHCb

Determine γ from CPV measurements

LHCb-PAPER-2016-032





$\gamma = (72.2^{+6.8}_{-7.3})^\circ$ syst. included

BaBar: $\gamma = (70\pm18)^\circ$

Belle: $\gamma = (73^{+13}_{-15})^\circ$

Used D decay modes

GLW: $D \to K^+K^-$, $\pi^+\pi^-$, $K_S\pi^0$

ADS: $D \to \pi^-K^+$

quasi-ADS $D \to \pi^-K^+\pi^+\pi^-$, $\pi^-K^+\pi^0$

quasi-GLW $D \to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^0$, $\pi^+\pi^-\pi^0$

GGSZ $D \to K_S\pi^+\pi^-$, $K_SK^+K^-$

GLS $D \to K_SK^-\pi^+$, $K_S\pi^-K^+$

Prospects

Sample	$\sigma_{stat}(\gamma)^\circ$
Run 1	8
Run 2	4
Upgrade	~ 1
Future upgrade	<0.5

- **Current one syst. ~2° from CLEO strong phase measurements**
- **15-20 fb^{-1} $\psi(3370)$ data from BESIII are desired to avoid syst. limitation for upgrade scenario**

More $\psi(3770)$ data at BESIII will better constrain on γ/ϕ_3

Prospects on $f_{D(s)+}$, $f^{K(\pi)}_{+}(0)$, $|V_{cs(d)}|$ and Λ_c^+

- Precision of the LQCD calculations of f_{D+}, f_{Ds+}, $f_{D+}:f_{Ds}$ is 0.5%, 0.5% and 0.3%. Measurements of $f_{D(s)+}$ and $|V_{cs(d)}|$ by $D_{(s)}^+ \to l^+ v$ are still statistics limited. More 10 fb^{-1} data near 3.773/4.18 GeV will help to improve precision to 1% level

- Measurements of $|V_{cs(d)}|$ by $D \to K(\pi)e^+v$ is restricted by precision of LQCD calcualtion 2.4(4.4)%. Improved theoretical calculation will be very helpful

- Measurement of $f^{\pi}_{+}(0)$ by $D \to \pi e^+ v$ decay is still statistics limited. More 10 fb^{-1} data at 3.773 GeV can improve precision to 1% level

- In addition, with more 3 fb^{-1} data in 4.6-4.65 GeV will help to improve $B[\Lambda_c^+ \to pK^- \pi^+]$ to about 2% level and further explore FF in $\Lambda_c^+ \to \Lambda l^+ v$ decays

Summary

- With 2.93, 0.482, 0.567 fb^{-1} data taken at 3.773, 4.009 and 4.6 GeV, BESIII have studied $D_{(s)}^+ \to l^+ v$ and $D^0 \to K(\pi)^- l^+ v$, searched for $D^{+(0)} \to a_0(980)^{0(-)} e^+ v$, hee, $\gamma e^+ v$ and $D^0 e^+ v$, measurements of D haronic decays, absolute Λ_c^+ BFs using near threshold data

- Improved measurements of decay constant f_{D+} and form factor $f_+^{D\to K(\pi)}(q^2)$ are important to calibrate LQCD calculations

- Improved measurements of CKM matrix element $|V_{cs(d)}|$ are important to test the CKM matrix unitarity

- ~80/80/60% of exclusive $D^0/D^+/\Lambda_c^+$ decays are known, more studies and BFs of $D^{0(+)}$ and Λ_c^+ are expected in the near future

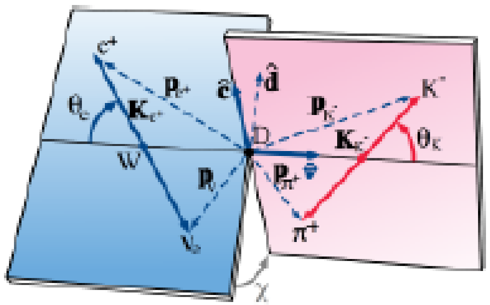
- ~3 fb^{-1} data@4.18 GeV was accumulated in 2016, measurement of f_{Ds+} and $|V_{cs}|$ by $D_s^+ \to l^+ v$, first FF studies of $D_s^+ \to \eta^{(')} e^+ v$, improved BFs of D_s^+ decays…are expected in the near future

- More results with better precision are expected with more data

Thank you!

45

Study of D→Ve⁺ν



- $m^2 = (p_{\pi^+} + p_{K^-})^2$
- $\cos(\theta_K) = \frac{\hat{\nu}\cdot \boldsymbol{K}_{K^-}}{|\boldsymbol{K}_{K^-}|}$
- $\cos(\chi) = \hat{\boldsymbol{c}} \cdot \hat{\boldsymbol{d}}$
- $q^2 = (p_{e^+} + p_{\nu_e})^2$
- $\cos(\theta_e) = -\frac{\hat{\nu}\cdot \boldsymbol{K}_{e^+}}{|\boldsymbol{K}_{e^+}|}$
- $\sin(\chi) = (\hat{\boldsymbol{c}} \times \hat{\boldsymbol{\nu}}) \cdot \hat{\boldsymbol{d}}$

Decay rate depend on 5 variables and 3 form factors

$$d^5\Gamma = \frac{G_F^2|V_{cs}|^2}{(4\pi)^6 m_D^2} X\beta\mathcal{I}(m^2, q^2, \theta_K, \theta_e, \chi)\, dm^2\, dq^2\, d\cos(\theta_K)\, d\cos(\theta_e)\, d\chi$$

- $X = p_{K\pi} m_D$, $p_{K\pi}$ is the momentum of the $K\pi$ system in the D rest frame
- $\beta = 2p^*/m$, p^* is the breakup momentum of the $K\pi$ system in its rest frame
- $\mathcal{I}$ can be expressed in terms of helicity amplitudes $H_{0,\pm}$:
  $H_0(q^2) = \frac{1}{2m_q}\left[(m_D^2 - m^2 - q^2)(m_D + m)A_1(q^2) - 4\frac{m_D^2 p_{K\pi}^2}{m_D + m}A_2(q^2)\right]$
  $H_\pm(q^2) = (m_D + m)A_1(q^2) \mp \frac{2m_D p_{K\pi}}{m_D + m}V(q^2)$
- Vector form factor: $V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}$; or: FF ratio $r_V = V(0)/A_1(0)$
- Axial-vector form factor: $A_1(q^2) = \frac{A_1(0)}{1 - q^2/m_A^2}$, $A_2(q^2) = \frac{A_2(0)}{1 - q^2/m_A^2}$; or: FF ratio $r_2 = A_2(0)/A_1(0)$

PWA analysis of $D^+ \to K^- \pi^+ e^+ \nu$

PRD94(2016)032001

- **Fractions with >5σ significance**

$$f(D^+ \to (K^-\pi^+)_{K^{*0}(892)}\, e^+\nu_e) = (93.93 \pm 0.22 \pm 0.18)\%$$

$$f(D^+ \to (K^-\pi^+)_{S-wave}\, e^+\nu_e) = (6.05 \pm 0.22 \pm 0.18)\%$$

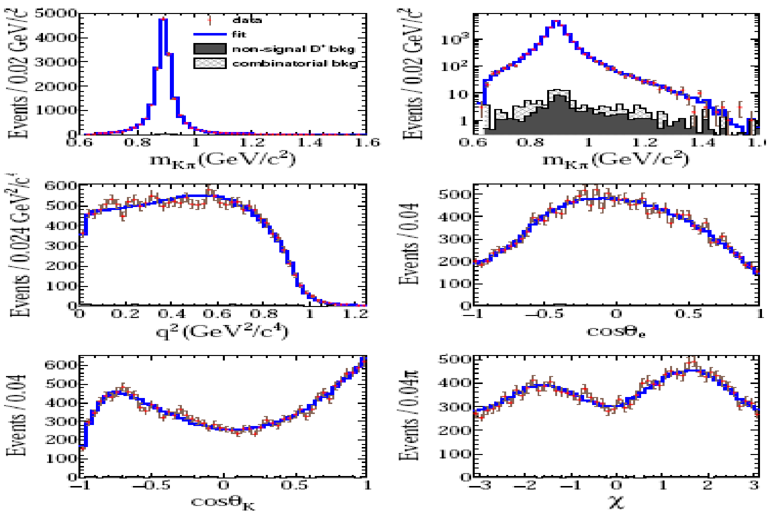
- **Properties of different Kπ (non-) resonant amplitudes**

$$m_{K^{*0}(892)} = (894.60 \pm 0.25 \pm 0.08)\ \mathrm{MeV}/c^2$$

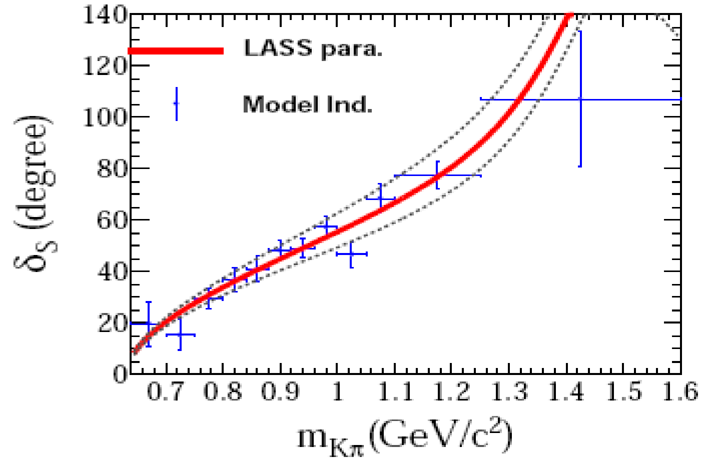
$$\Gamma_{K^{*0}(892)} = (46.42 \pm 0.56 \pm 0.15)\ \mathrm{MeV}/c^2$$

$$r_{BW} = (3.07 \pm 0.26 \pm 0.11)\ (\mathrm{GeV}/c)^{-1}$$

- **q^2 dependent form factors in $D^+ \to \overline{K}^{*0}(892) e^+ \nu$**



Model independent S-wave phase measurement



$$V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}, \quad A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1 - q^2/m_A^2}$$

$M_{V/A}$ is expected to $M_{D^*(1^{-}/^{+})}$

$$m_V = (1.81^{+0.25}_{-0.17} \pm 0.02)\ \mathrm{GeV}/c^2$$

$$m_A = (2.61^{+0.22}_{-0.17} \pm 0.03)\ \mathrm{GeV}/c^2$$

$$A_1(0) = 0.573 \pm 0.011 \pm 0.020$$

$$r_V = V(0)/A_1(0) = 1.411 \pm 0.058 \pm 0.007$$

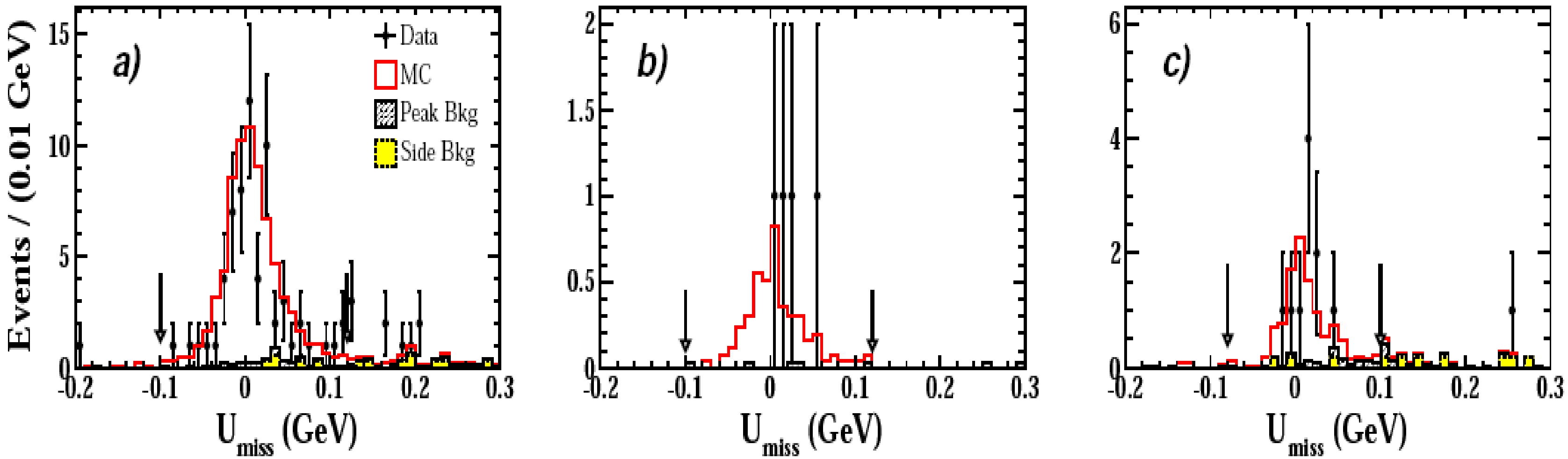
$$r_2 = A_2(0)/A_1(0) = 0.788 \pm 0.042 \pm 0.008$$

Model independent form factors

Measurements of BFs of $D_s^+ \to \eta^{(')} e^+ \nu$

- **Benefit the understanding of the source of difference of inclusive decay rates of $D^{0(+)}$ and D_s^+**
- **Complementary information to understand η–η' mixing**

PRD94(2016)112003



	BESIII	CLEOII 95	CLEOc09	CLEOc15	PDG [4]
$B(D_s^+ \to \eta e^+ \nu_e)[\%]$	$2.30 \pm 0.31 \pm 0.08$	—	$2.48 \pm 0.29 \pm 0.13$	$2.28 \pm 0.14 \pm 0.20$	2.67 ± 0.29
$B(D_s^+ \to \eta' e^+ \nu_e)[\%]$	$0.93 \pm 0.30 \pm 0.05$	—	$0.91 \pm 0.33 \pm 0.05$	$0.68 \pm 0.15 \pm 0.06$	0.99 ± 0.23
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	—	—	—