Recent results on charmed meson decays @ BESIII

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Outline

- **Introduction**
  - BESIII Experiment
  - Charmed Meson Data Set and Analysis Method
- **(Semi-)Leptonic Decays**
  - Leptonic Decays: $D^+ \to \tau^+\nu_\tau$, $D_s^+ \to \mu^+\nu_\mu$
  - Semi-leptonic Decays: $D^0 \to K^-\mu^+\nu_\mu$, $D^{0(+)} \to \pi^{-(0)}\mu^+\nu_\mu$, $D_s^+ \to K^{(*)0}e^+\nu_e$, $D_s^+ \to \eta^{(\prime)}e^+\nu_e$, $D \to a_0(980)e^+\nu_e$
- **Hadronic Decays**
  - Study of the Decay: $D_s^+ \to p\bar{n}$
  - Study of the Decays: $D_s^+ \to \omega\pi^+$, $D_s^+ \to \omega K^+$
  - Amplitude Analysis: $D_s^+ \to \pi^+\pi^-\eta$, $D^0 \to K^-\pi^+\pi^0\pi^0$
- **Rare decays**
  - Search for the FCNC Decays: $D \to h(h^{(\prime)})e^+e^-$
- **Summary**

Introduction: BESIII Experiment

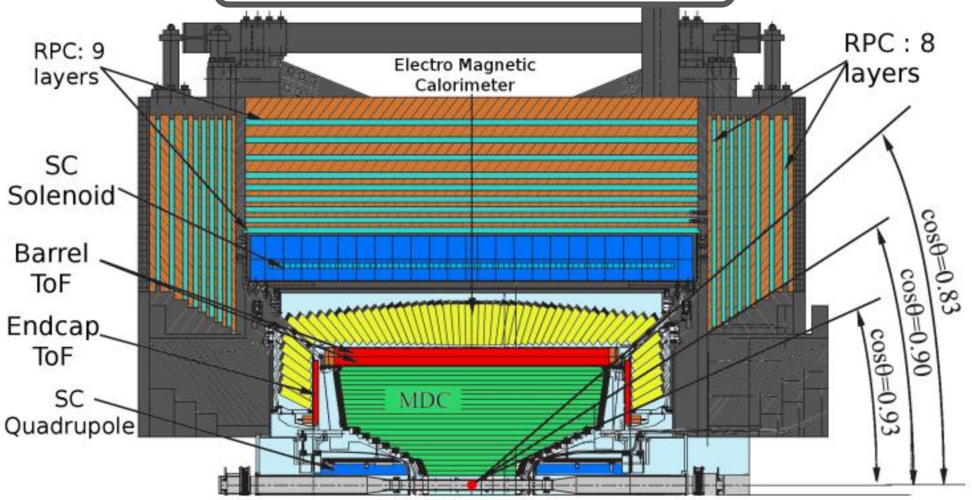
MDC: small cell & Gas: $He/C_3H_8(60/40)$, 43 layers
$\sigma_p/p = 0.5\%@1GeV$,
$\sigma_{dE/dx} = 6\%$

TOF: Barrel: $\sigma_T = 100ps$
endcap: $\sigma_T = 110ps$
(60ps for endcap after upgraded to MRPC in 2015)

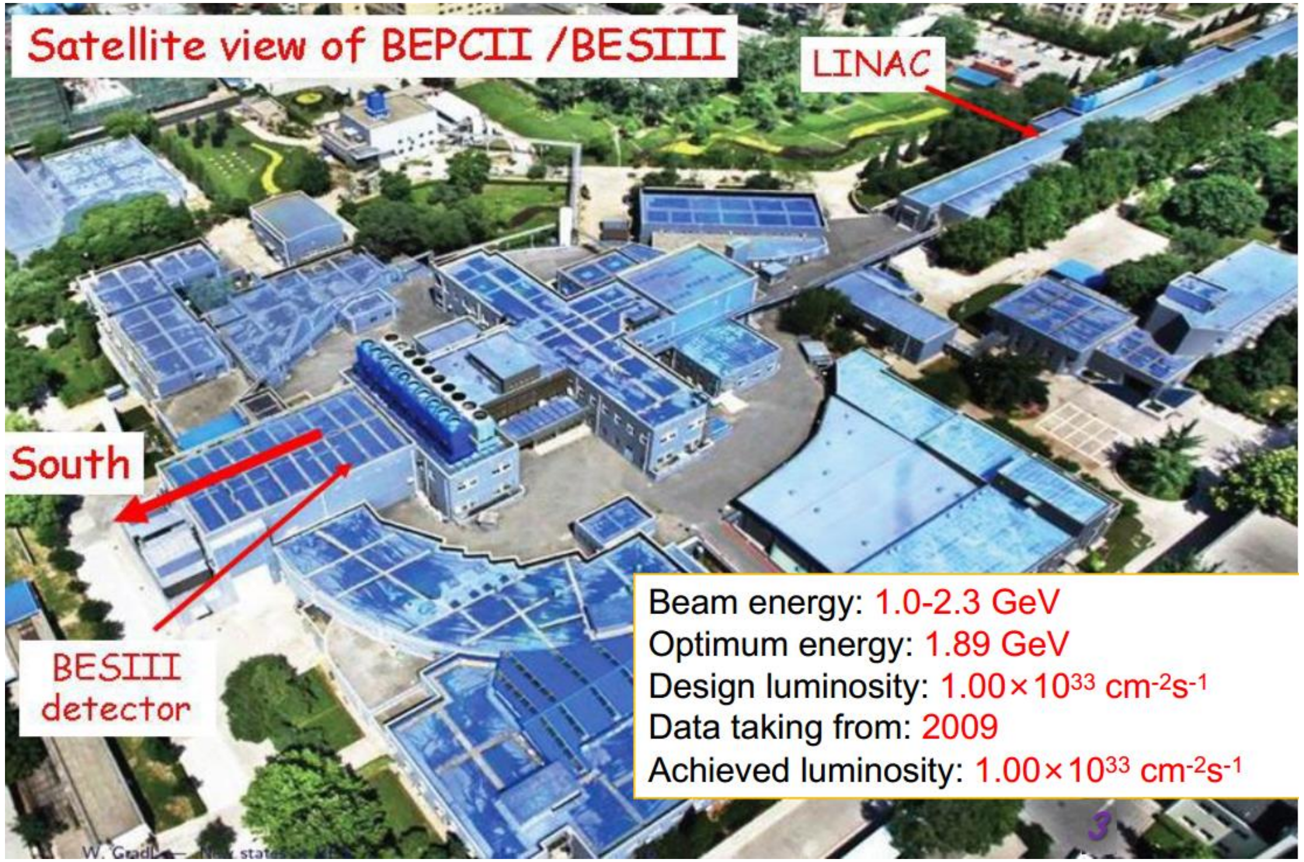
EMC: CsI crystal. 28cm
$\Delta E/E = 2.5\%@1GeV$,
$\sigma_z = 0.6cm/\sqrt{E}$

MUC: 9layers RPC
(8 layers in Endcap)
$\sigma_{R\phi} = 1.4\sim1.7cm$

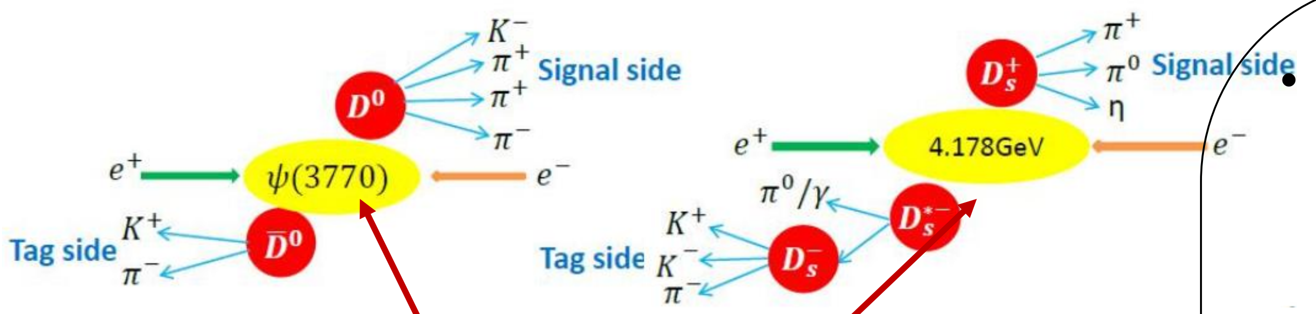
Magnet: 1T Super conducting

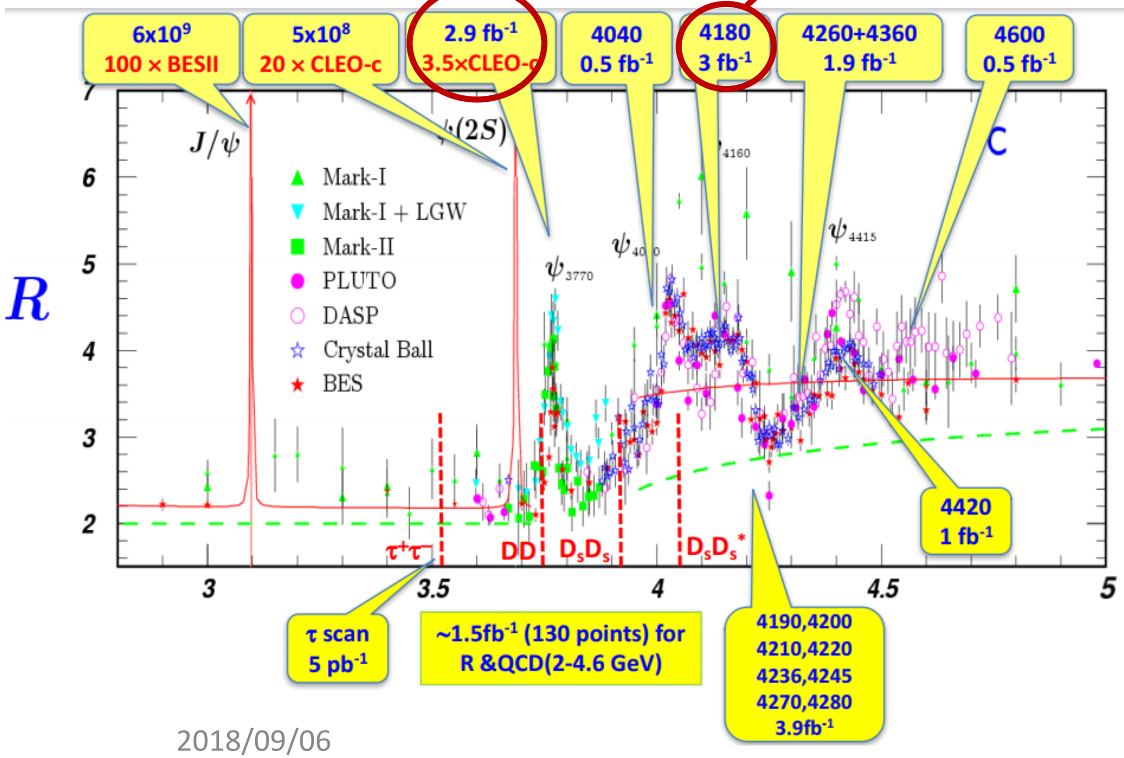


Nucl. Instr. Meth. A614, 345(2010)



Charmed Data Set and Analysis Method



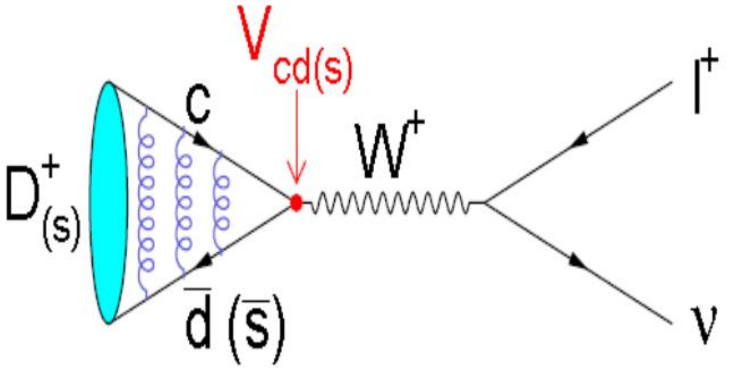


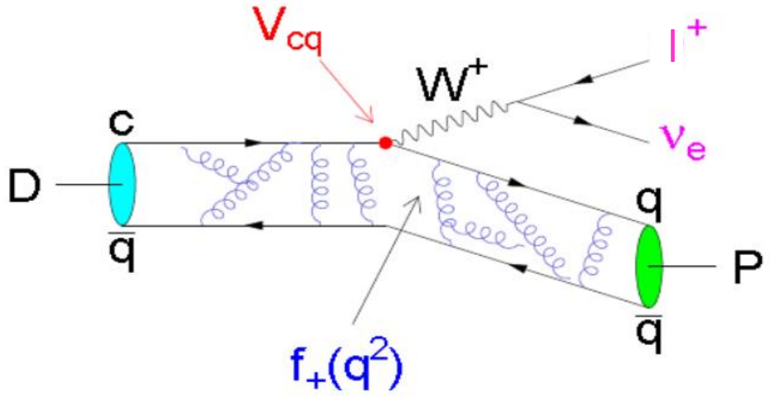
- **Data Set Used in this talk:**
  - $2.93\text{fb}^{-1}@E_{cm} = 3.773\text{GeV}$ (~3.5x CLEO-c)
    $e^+e^- \to \psi(3770) \to D\bar{D}$
  - $3.19\text{fb}^{-1}@E_{cm} = 4.178\text{GeV}$ (~5.3x CLEO-c)
    $e^+e^- \to D_s^{\pm}D_s^{*\mp} \to \gamma/\pi^0 D_s^+ D_s^-$

- **Analysis method (pair production):**
  - Single tag(ST): reconstruct only one of $D\bar{D}$
  - Double tag(DT): reconstruct both of $D\bar{D}$
  - Calculate absolute BFs: $B = \frac{N_{DT}}{N_{ST} \cdot \epsilon_{DT}/\epsilon_{ST}}$

- **Advantages:**
  - Absolute branching fraction measurement
  - Full kinematic constraint to reconstruct ν or neutral hadron(i.e. KL , n)
  - Low background

(Semi-)Leptonic Decay: Motivation





– **Single pole form**

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

– **ISGW2 model**

$$f_+(q^2) = f_+(q^2_{\max})\left(1 + \frac{r^2_{\text{ISGW2}}}{12}(q^2_{\max} - q^2)\right)^{-2}$$

– **Modified pole model**

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

– **Series expansion model**

$$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)\left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

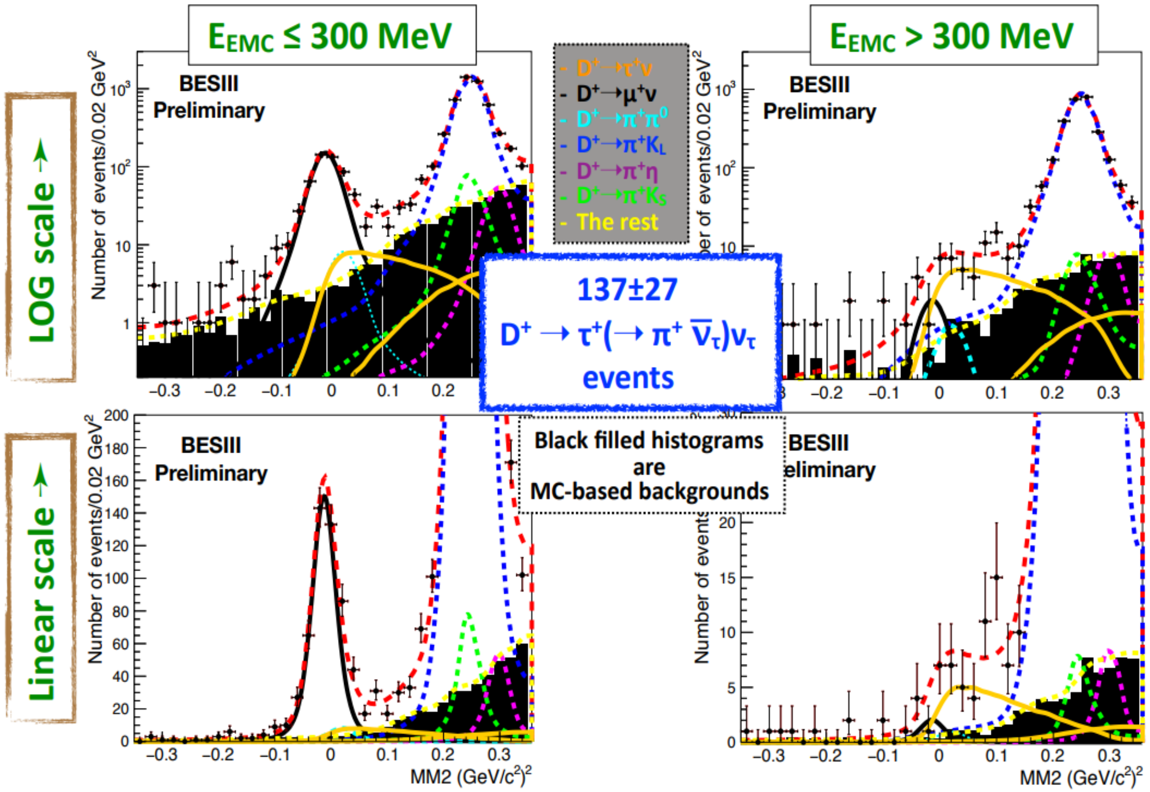
$$\Gamma(D^+ \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+}^2}{8\pi}|V_{cd}|^2 m_\ell^2 m_{D^+}\left(1 - \frac{m_\ell^2}{m_{D^+}^2}\right)^2$$

$$\frac{d\Gamma_{P\ell^+\nu_\ell}}{dq^2} = \frac{G_F^2|V_{cq}|^2}{8\pi^3 m_D}|\vec{p}_P||f_+^P(q^2)|^2\left(\frac{W_0 - E_P}{F_0}\right)^2 \times \left[\frac{1}{3}m_D|\vec{p}_P|^2 + \mathcal{O}(m_\ell^2)\right]$$

$$W_0 = (m_D^2 + m_P^2 - m_\ell^2)/2m_D,\ F_0 = W_0 - E_P + m_\ell^2/2m_D$$

- Measure $|V_{cd(s)}|$ to test the unitary of CKM matrix
- Measure the form factor $f_{D_{(s)}^+}$, $f_+^P(0)$ to calibrate the LQCD
- Test Lepton flavor universality in charmed meson decay

Leptonic Decay: $D^+ \to \tau^+(\to \pi^+\bar{\nu}_\tau)\nu_\tau$



$$M^2_{\rm miss} = (E_{\rm beam} - E_{\mu^+})^2 - (-\vec{p}_{D^-_{\rm tag}} - \vec{p}_\mu)^2$$

UL by CLEO: <1.2×10^{-3} @ 90% C.L.

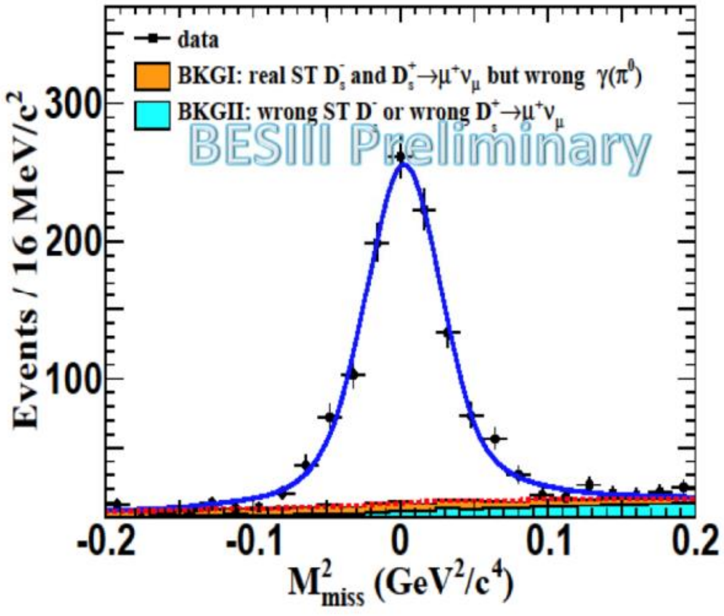
BESIII Preliminary:

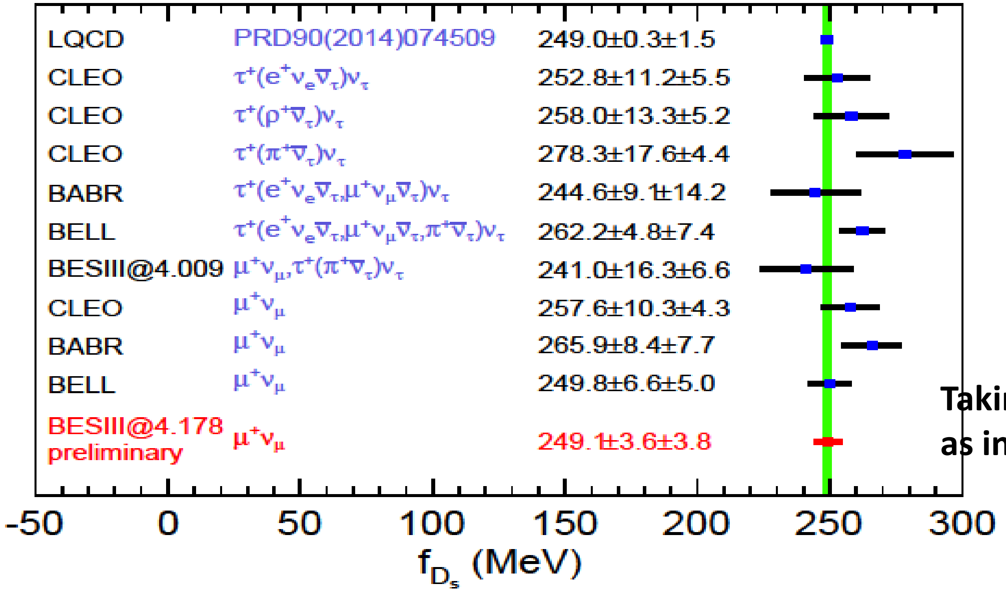
- $B(D^+ \to \tau^+\nu_\tau) = (1.20 \pm 0.24_{\rm stat.}) \times 10^{-3}$
- Significance > 4σ

Test lepton flavor universality:

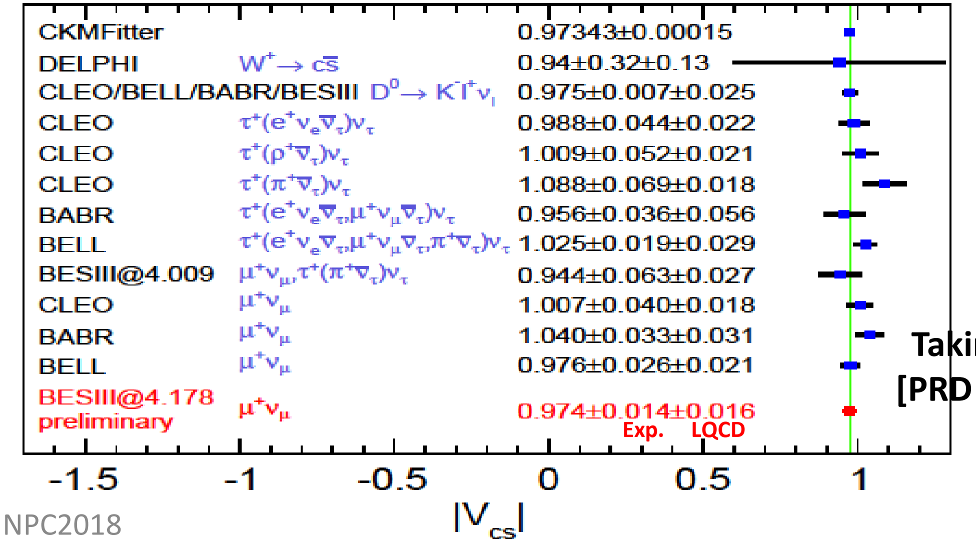
- $R = \frac{\Gamma(D^+\to\tau^+\nu_\tau)}{\Gamma(D^+\to\mu^+\nu_\mu)} = 2.66 \pm 0.01\ (\mathrm{SM})$
- $R = \frac{B(D^+\to\tau^+\nu_\tau)[\mathrm{BESIII\ Preliminary}]}{B(D^+\to\mu^+\nu_\mu)\ [\mathrm{PRD89,051104(R)(2014)}]}$
  $= 3.21 \pm 0.64$
- Consistent in 1σ

Leptonic Decay: $D_s^+ \to \mu^+\nu_\mu$





Taking $|V_{cs}|^{\text{CKMfitter}}$ as input



Taking $f_{D_s}^{\text{LQCD}}$ as input [PRD 90, 074509(2014)]

$$B(D_s^+ \to \mu^+\nu_\mu) = (5.28 \pm 0.15_{\text{stat}} \pm 0.14_{\text{syst}}) \times 10^{-3}$$

$$f_{D_s^+}|V_{cs}| = 242.5 \pm 3.5_{\text{stat.}} \pm 3.7_{\text{syst.}}\ \text{MeV}$$

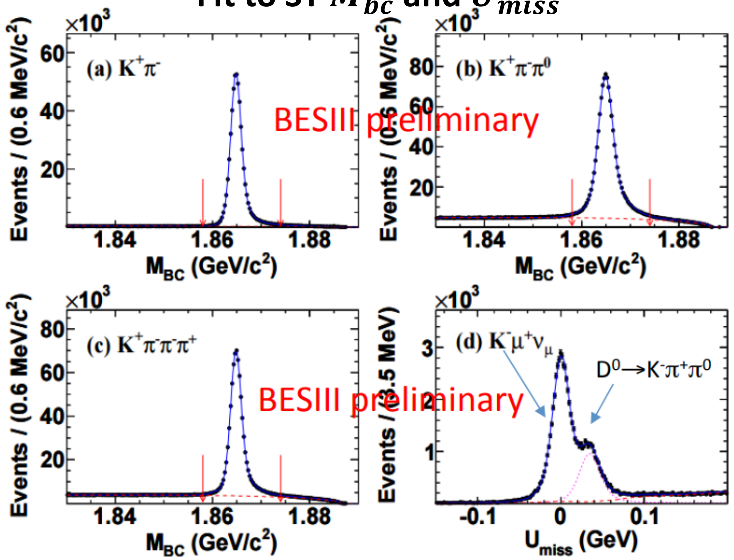
Test lepton flavor universality: $R = \dfrac{\Gamma(D_s^+\to\tau^+\nu_\tau)}{\Gamma(D_s^+\to\mu^+\nu_\mu)}$

SM : 9.74±0.01

BESIII: 10.2 ±0.5 ($B(D_s^+ \to \tau^+\nu_\tau)$ in PDG is used, we are working on this channel now)

Semi-Leptonic Decay: $D^0 \to K^- \mu^+ \nu_\mu$

Fit to ST M_{bc} and U_{miss}



$$M_{BC} \equiv \sqrt{E_{\mathrm{beam}}^2 - |\vec{p}_{\bar{D}^0}|^2} \qquad U_{\mathrm{miss}} \equiv E_{\mathrm{miss}} - |\vec{p}_{\mathrm{miss}}|c$$

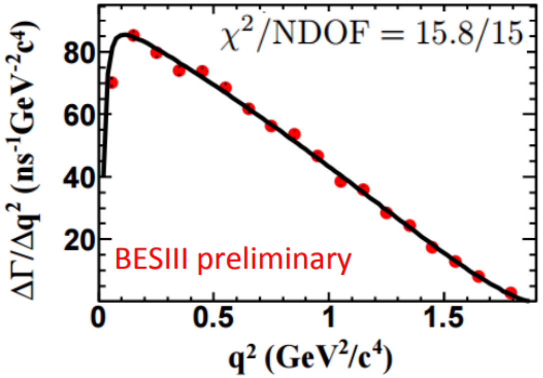
Series expansion parameterization for form factor (2nd order):

$$f_+^K(t) = \frac{1}{P(t)\Phi(t,t_0)} \frac{f_+^K(0)P(0)\Phi(0,t_0)}{1+r_1(t_0)z(0,t_0)} (1+r_1(t_0)[z(t,t_0)])$$

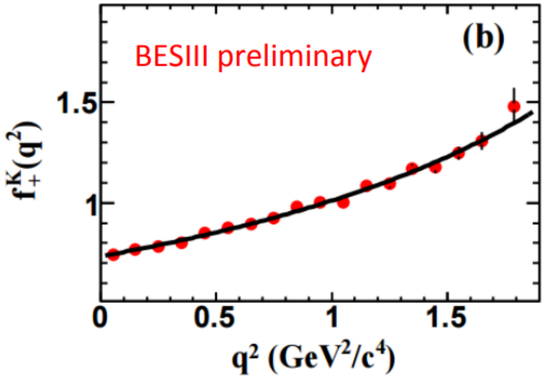
$$\Rightarrow \quad f_+^K(0)|V_{cs}| = 0.7148 \pm 0.0038_{\mathrm{stat.}} \pm 0.0029_{\mathrm{syst.}}$$

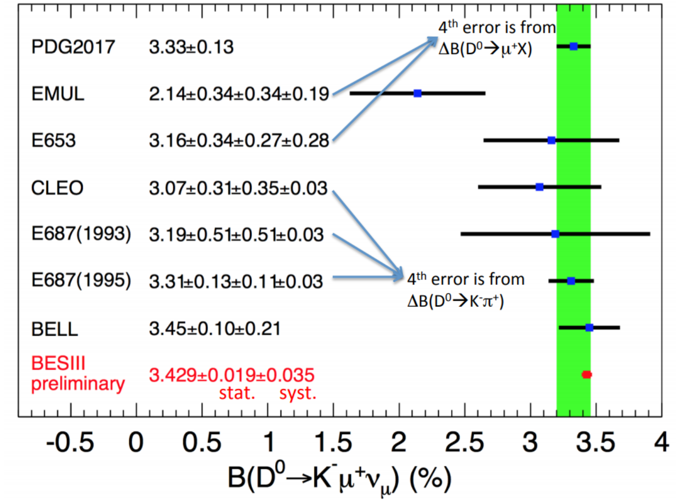
$$r_1 = -1.94 \pm 0.21_{\mathrm{stat.}} \pm 0.07_{\mathrm{syst.}}$$

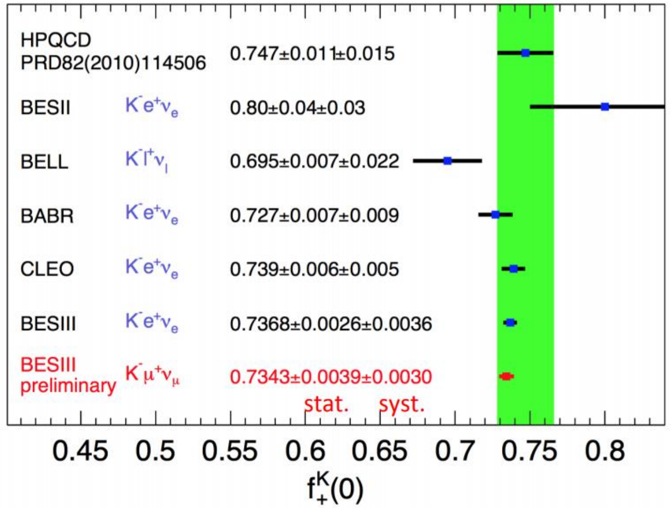
Fits to partial decay rates

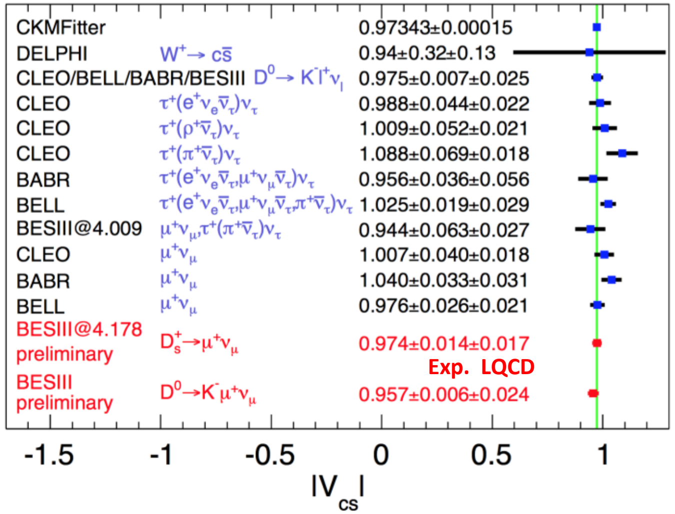


Projection on form factor





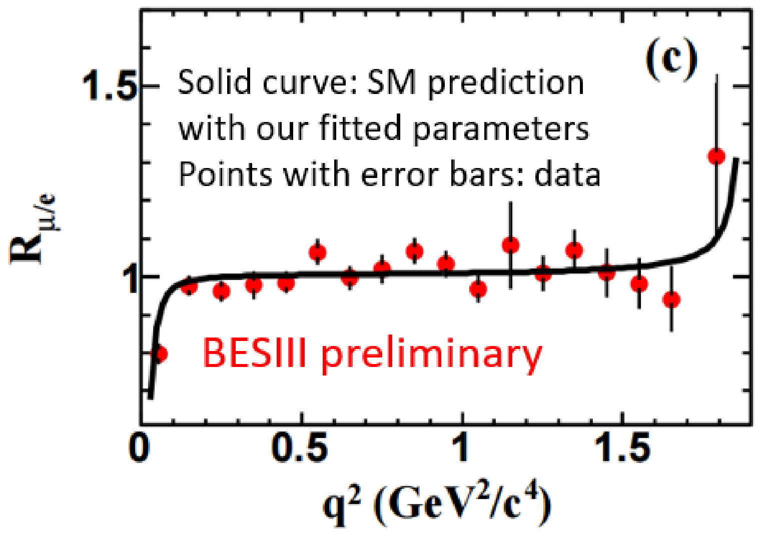


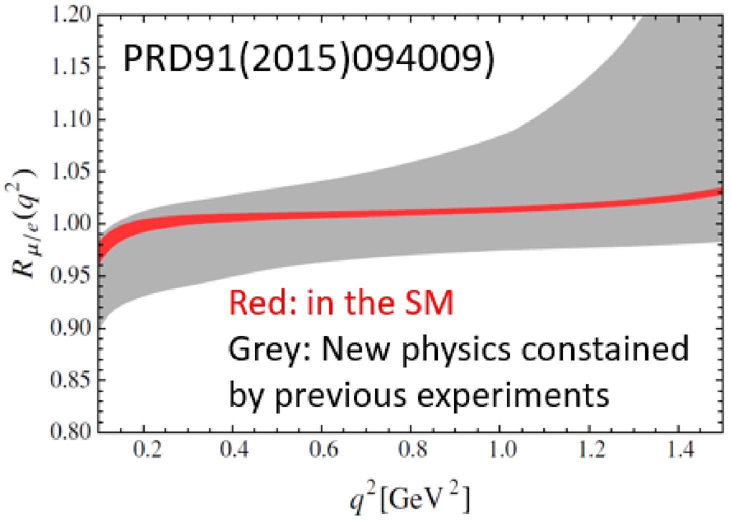


Semi-Leptonic Decay : $D^0 \to K^- \mu^+ \nu_\mu$

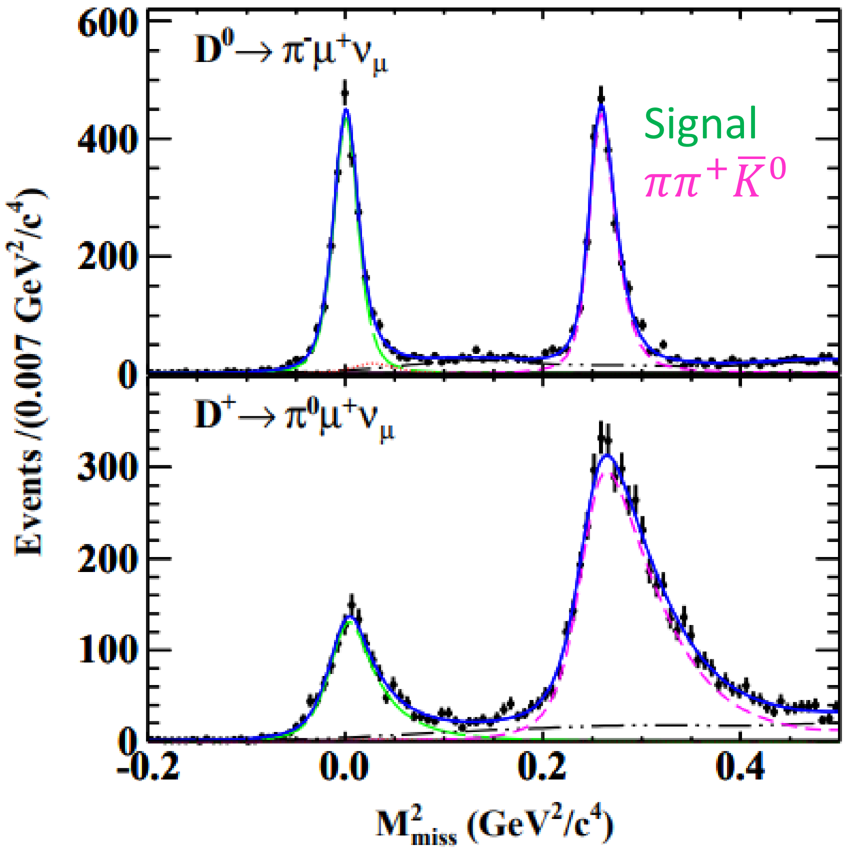
Test lepton flavor universality:

- In the full q^2 interval: $R_{\mu/e} = \frac{\Gamma(D^+ \to K^- \mu^+ \nu_\mu)}{\Gamma(D^+ \to K^- e^+ \nu_e)[PRD92,072012(2015)]} = 0.978 \pm 0.007 \pm 0.012$
- No deviation larger than 2σ over q^2 interval in this analysis





Semi-leptonic Decay: $D \to \pi\mu^+\nu_\mu$ [arXiv: 1802.05492]

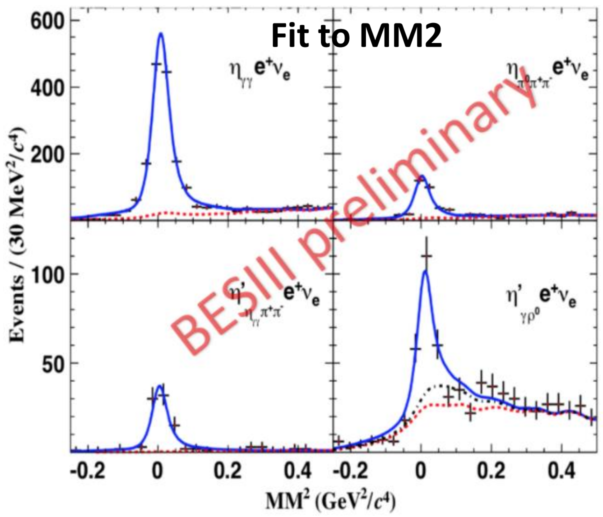


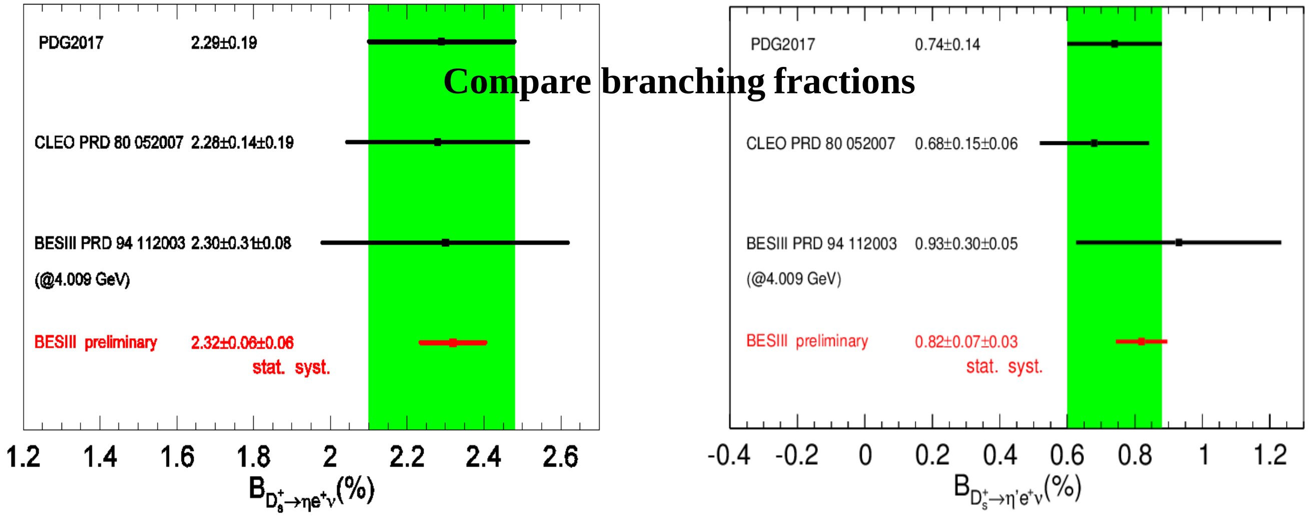
Measurement Results:

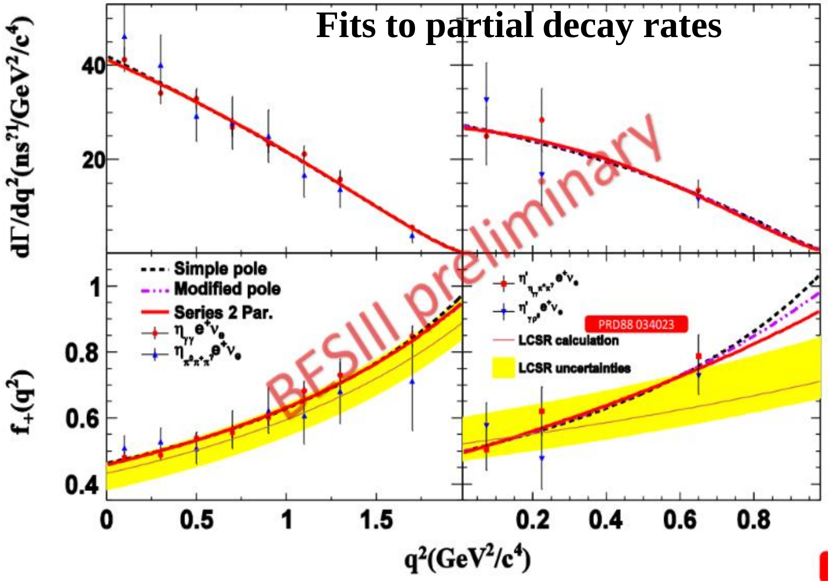
- $B(D^0 \to \pi^-\mu^+\nu_\mu) = (0.267 \pm 0.007 \pm 0.007)\%$
- $B(D^+ \to \pi^0\mu^+\nu_\mu) = (0.342 \pm 0.011 \pm 0.010)\%$ (first measurement)
- $R^{D^0}_{\mu/e} = \frac{B^{D^0}_{\mu}[arXiv{:}1802.05492]}{B^{D^0}_{e}[\text{PRD 92, 072012(2015)}]} = 0.905 \pm 0.027 \pm 0.023$
- $R^{D^+}_{\mu/e} = \frac{B^{D^+}_{\mu}[arXiv{:}1802.05492]}{B^{D^+}_{e}[\text{PRD 96, 012002(2017)}]} = 0.942 \pm 0.037 \pm 0.027$
- $R^{\mu}_{IS} = \frac{\Gamma(D^0 \to \pi^-\mu^+\nu_\mu)}{2\Gamma(D^+ \to \pi^0\mu^+\nu_\mu)} = \frac{\tau_{D^+} B(D^0 \to \pi^-\mu^+\nu_\mu)}{2\tau_{D^0} B(D^+ \to \pi^0\mu^+\nu_\mu)} = 0.990 \pm 0.041 \pm 0.035$

- $R^{D^{0(+)}}_{\mu/e}$ coincides with SM prediction 0.97 within 1.9(0.6)σ
- R^{μ}_{IS} is consistent with no isospin violation and the value of electronic decay R^{e}_{IS} [PRD 96, 012002(2017)]

Semi-leptonic Decay: $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$







- **Partial decay rates are fitted simultaneously by two η/η' subdecays**
- **Based on the result extracted with the series 2 Parameters, we determine $|V_{cs}|$ and $f_+^{\eta^{(\prime)}}(0)$**

BESIII Preliminary

Nominal result

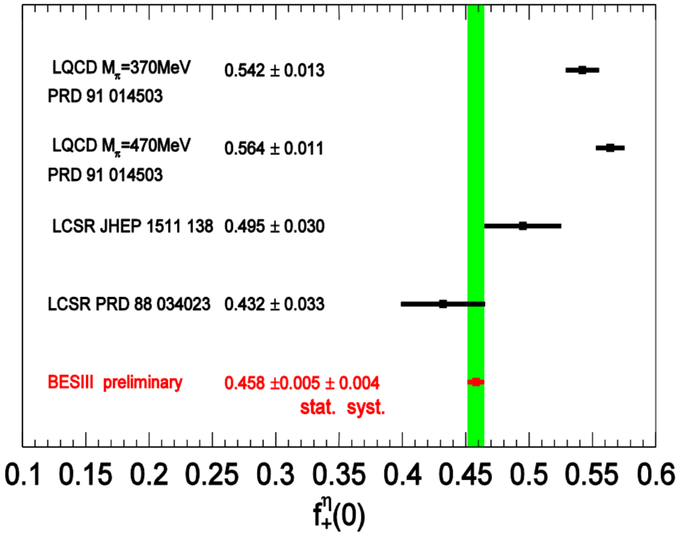
Case	Simple pole			Modified pole			Series 2 Par.		
	$f_+^{\eta^{(\prime)}}(0)\lvert V_{cs}\rvert$	$M_{\rm pole}$	χ^2/NDOF	$f_+^{\eta^{(\prime)}}(0)\lvert V_{cs}\rvert$	α	χ^2/NDOF	$f_+^{\eta^{(\prime)}}(0)\lvert V_{cs}\rvert$	r_1	χ^2/NDOF
$\eta e^+\nu_e$	0.450(5)(3)	3.77(8)(5)	12.2/14	0.445(5)(3)	0.30(4)(3)	11.4/14	0.446(5)(4)	−2.2(2)(1)	11.5/14
$\eta' e^+\nu_e$	0.494(45)(10)	1.88(54)(5)	1.8/4	0.481(44)(10)	1.62(91)(11)	1.8/4	0.477(49)(11)	−13.1(76)(11)	1.9/4

Semi-leptonic Decay: $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$

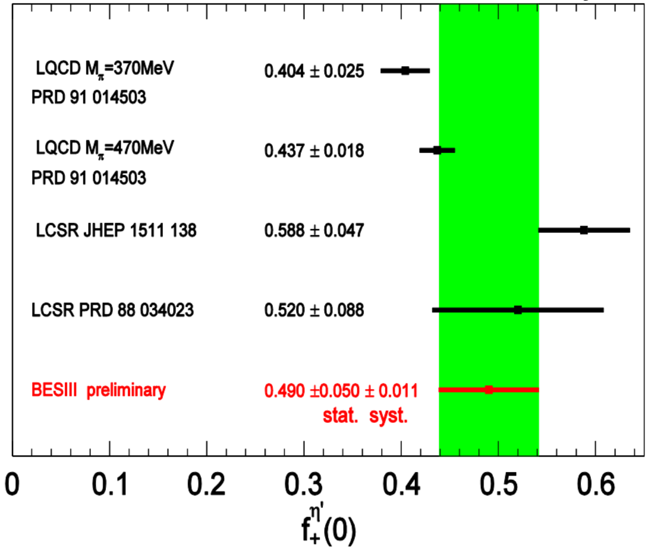
Taking $|V_{cs}|$ CKMfitter and $f_+^{\eta^{(\prime)}}(0)$ $|V_{cs}|$ extracted with the series 2 Parameters as input

obtain $f_+^{\eta}(0) = 0.458 \pm 0.005_{stat} \pm 0.004_{syst}$ $\quad f_+^{\eta'}(0) = 0.490 \pm 0.050_{stat} \pm 0.011_{syst}$

Compare $f_+^{\eta}(0)$



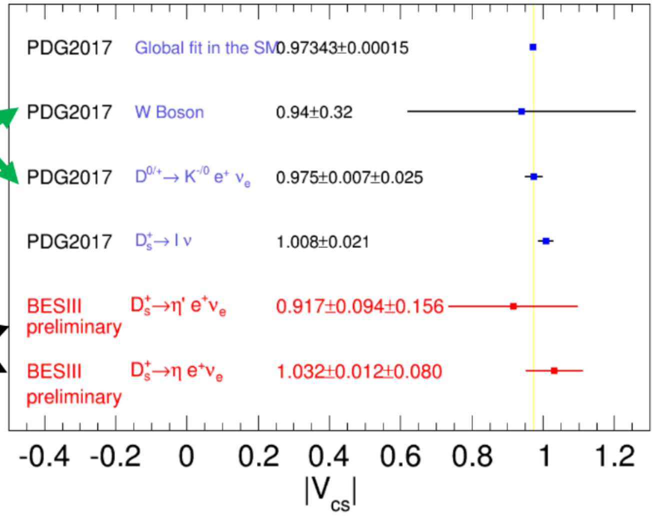
Compare $f_+^{\eta'}(0)$



Compare $|V_{cs}|$

Only reported one uncertainty, but include both statistical and systematic

Taking $f_+^{D_s \to \eta^{(\prime)}}(0)$ PRD88 034023 as input, we obtain

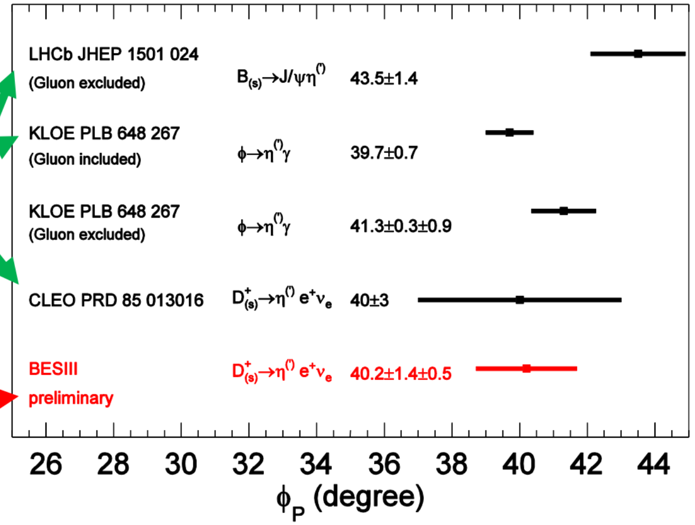


$\eta - \eta'$mxing

Paper only reported one uncertainty, but include both statistical and systematic

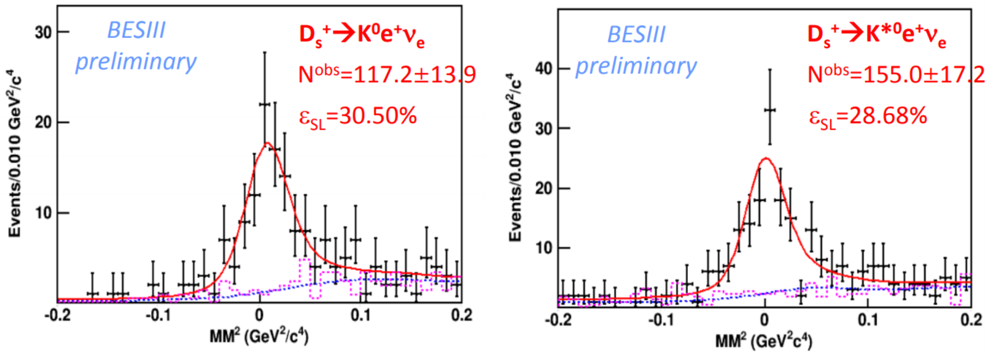
$$\frac{\Gamma(D_s^+ \to \eta' e^+ \nu)/\Gamma(D_s^+ \to \eta e^+ \nu)}{\Gamma(D^+ \to \eta' e^+ \nu)/\Gamma(D^+ \to \eta e^+ \nu)} \simeq \cot^4 \phi_P$$

$B(D^+ \to \eta^{(\prime)} e^+ \nu_e)$ in PRD.97.092009(2018) are used



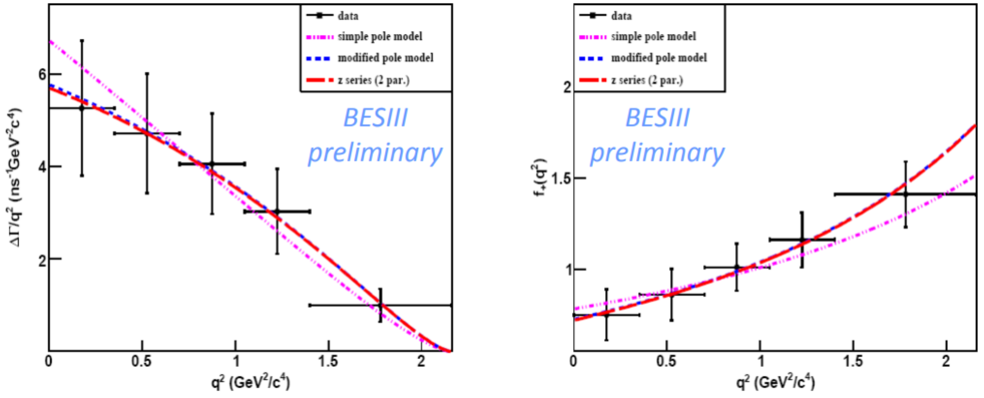
Semi-leptonic Decay: $D_s^+ \to K^{(*)0} e^+ \nu_e$

Fit to MM2



$Br[D_s^+ \to K^0 e^+ \nu_e] = (3.25 \pm 0.38_{stat} \pm 0.14_{syst}) \times 10^{-3}$ $(3.9 \pm 0.9) \times 10^{-3}$ [PDG2017]

$Br[D_s^+ \to K^{*0} e^+ \nu_e] = (2.38 \pm 0.26_{stat} \pm 0.12_{syst}) \times 10^{-3}$ $(1.8 \pm 0.4) \times 10^{-3}$ [PDG2017]

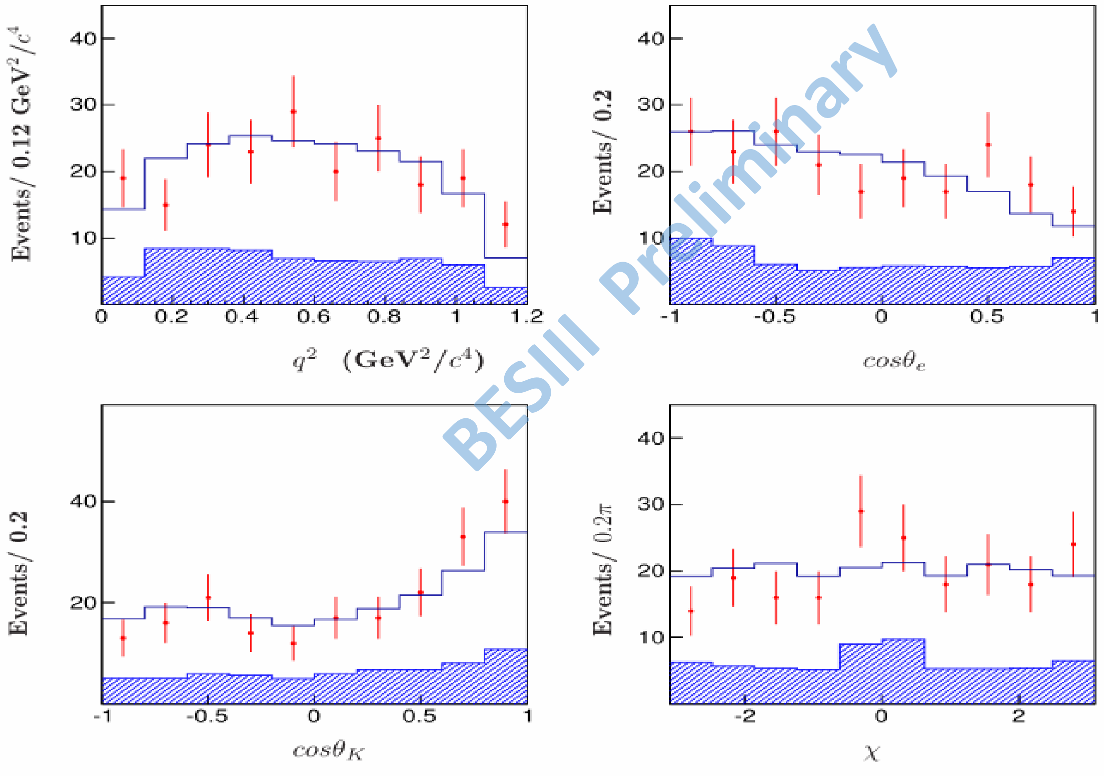


$D_s^+ \to K^0 e^+ \nu_e$ Fits to partial decay rates

Model	Parameter	Value	$f_+(0)$
Simple pole	$f_+(0)\|V_{cd}\|$	$0.175 \pm 0.010 \pm 0.001$	$0.778 \pm 0.044 \pm 0.004$
Modified pole model	$f_+(0)\|V_{cd}\|$	$0.163 \pm 0.017 \pm 0.003$	$0.725 \pm 0.076 \pm 0.013$
	α	$0.45 \pm 0.44 \pm 0.02$	
Series two parameters	$f_+(0)\|V_{cd}\|$	$0.162 \pm 0.019 \pm 0.003$	$0.720 \pm 0.084 \pm 0.013$
	r_1	$-2.94 \pm 2.32 \pm 0.14$	

BESIII Preliminary

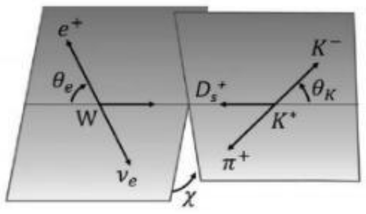
$D_s^+ \to K^{*0} e^+ \nu_e$ Four dimensional un-binned likelihood fit



$r_V = 1.67 \pm 0.34 \pm 0.16$

$r_2 = 0.77 \pm 0.28 \pm 0.07$

(Details of definition in back-up)



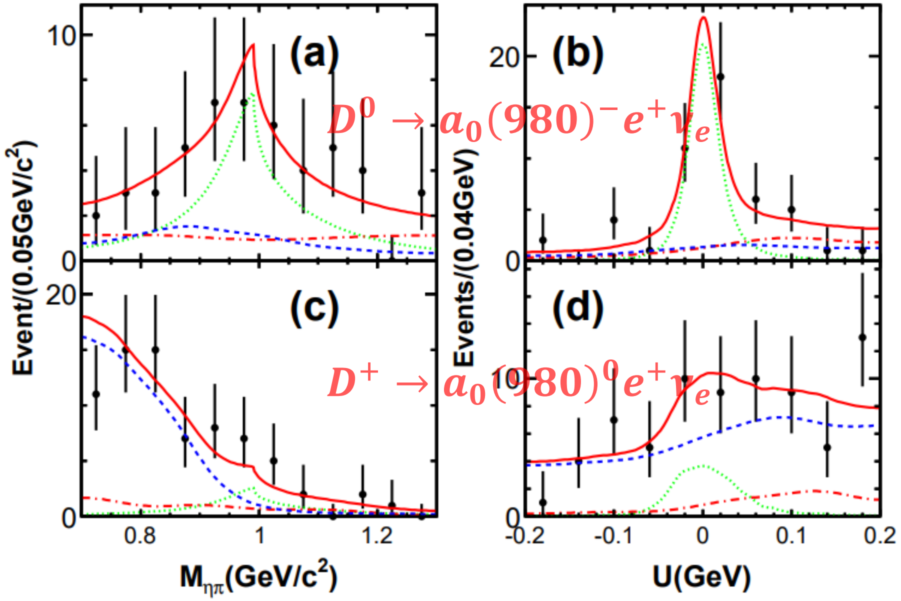
Semi-leptonic Decay: $D \rightarrow a_0(980)e^+\nu_e$ [PRL 121, 081802(2018)]

Explore the internal structure of light hadron mesons, traditional two quark states or tetra quark system:

- A prediction for the BF for $D^+ \rightarrow a_0(980)^0 e^+\nu_e$ is : $5\sim5.4(6\sim8)\times10^{-5}$ for two(tetra) quark description
- A model-independent way to distinguish two different descriptions: R=1(3) for two(tetra) quark

$$R = \frac{\mathcal{B}(D^+ \to f_0(980)l^+\nu) + \mathcal{B}(D^+ \to f_0(600)l^+\nu)}{\mathcal{B}(D^+ \to a_0^0(980)l^+\nu)}.$$

[PRD 82, 034016 (2010)]



$$\mathcal{B}(D^0 \to a_0(980)^- e^+\nu_e) \times \mathcal{B}(a_0(980)^- \to \eta\pi^-) = (1.33^{+0.33}_{-0.29} \pm 0.09) \times 10^{-4}$$

6.4σ first observation!

$$\mathcal{B}(D^+ \to a_0(980)^0 e^+\nu_e) \times \mathcal{B}(a_0(980)^0 \to \eta\pi^0) = (1.66^{+0.81}_{-0.66} \pm 0.11) \times 10^{-4}, \quad < 3.0 \times 10^{-4} \text{ at the } 90\% \text{ C.L.}$$

2.9σ

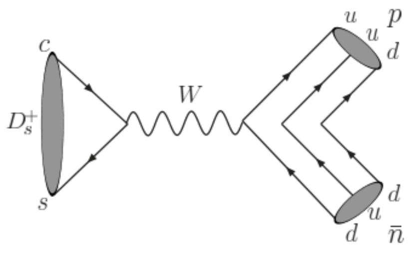
$$\frac{\Gamma(D^0 \to a_0(980)^- e^+\nu_e)}{\Gamma(D^+ \to a_0(980)^0 e^+\nu_e)} = 2.03 \pm 0.95 \pm 0.06,$$

The result for $D^+ \rightarrow f_0 e^+\nu_e$ is prepared by BESIII

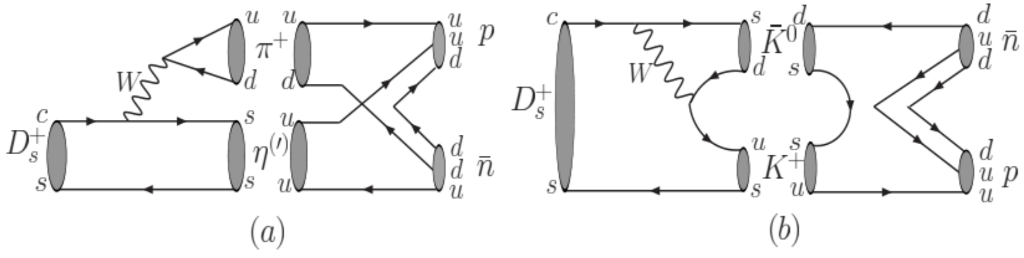
Hadronic Decay: $D_s^+ \to p\bar{n}$

- The only kinematic allowed baryonic D decay mode
- Help for understanding the dynamical enhancement of W-annihilation
  - Short-distance expected:Br~10^{-6}
  - Long-distance enhance to: Br~10^{-3}

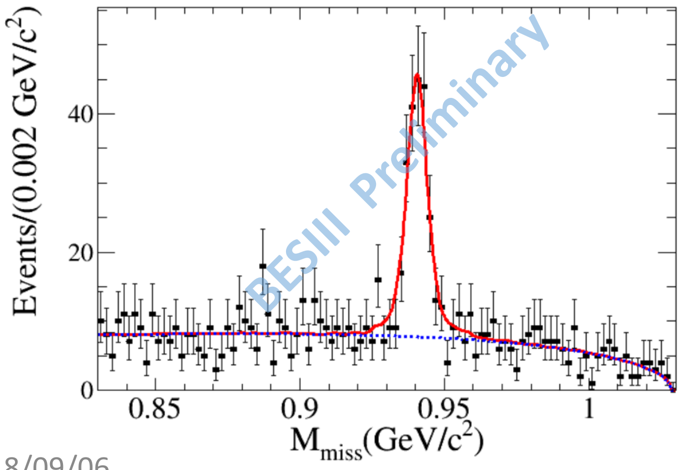
  [PLB 663, 326(2008)]
- First evidence by CLEO-c: $(1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$ **[PRL 100, 181802(2008)]**



(a) Short-distance effects



(b) Long-distance effects



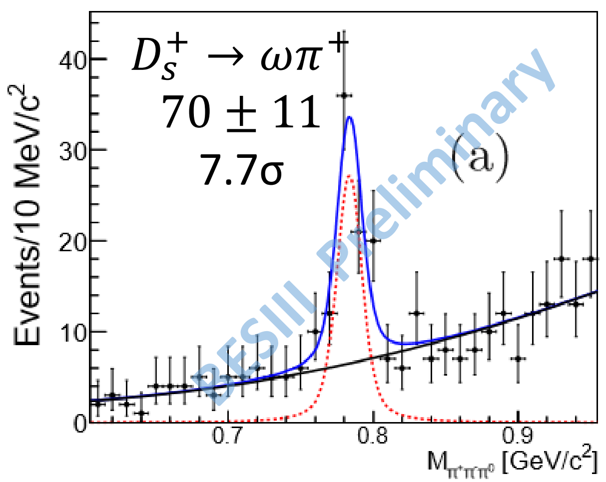
Preliminary result: $\boxed{\mathcal{B}_{D_s^+ \to p\bar{n}} = (1.22 \pm 0.10) \times 10^{-3}}$

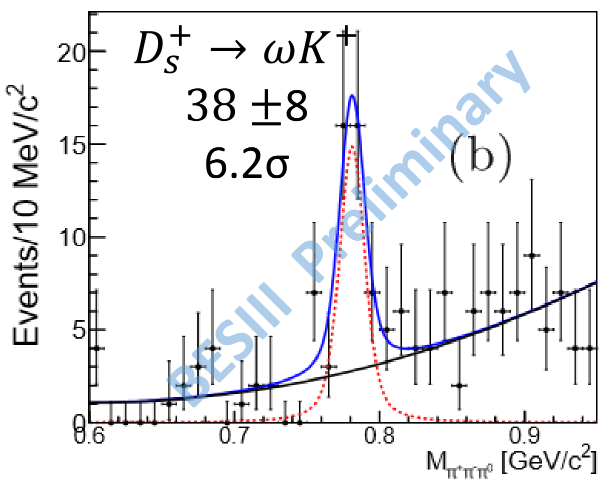
- Confirm CLEO-c's measurement with greatly improved accuracy
- Consistent with the prediction of the enhanced BR due to long-distance effect

Hadronic Decay: $D_s^+ \to \omega\pi^+$ and ωK^+

- $D_s^+ \to \omega\pi^+$ is a pure W-annihilation process,
- With the BF of $D_s^+ \to \omega\pi^+$ as as one of the inputs ,Q. Qin et al. **[PRD 89, 054006]** predicts:
  $\mathcal{B}(D_s^+ \to \omega K^+) = 0.6 \times 10^{-3}, A_{CP}(D_s^+ \to \omega K^+) = -0.6 \times 10^{-3}$ (without $\rho - \omega$ mixing)
  $\mathcal{B}(D_s^+ \to \omega K^+) = 0.7 \times 10^{-4}, A_{CP}(D_s^+ \to \omega K^+) = -2.3 \times 10^{-3}$ (with $\rho - \omega$ mixing)
- $D_s^+ \to \omega\pi^+$: evidence by CLEO $(2.1 \pm 0.9 \pm 0.1) \times 10^{-3}$ with a signal of 6.0 ± 2.4 events
- $D_s^+ \to \omega K^+$: CLEO set UL: $< 2.4 \times 10^{-3}$@90% C. L. **[PRD 80, 051102(R) (2009)]**

Fit to the invariant mass $M_{\pi^+\pi^-\pi^0}$ to get the DT yield





Consistent with CLEO's measurement, but more precise.

BESIII Preliminary results:

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

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

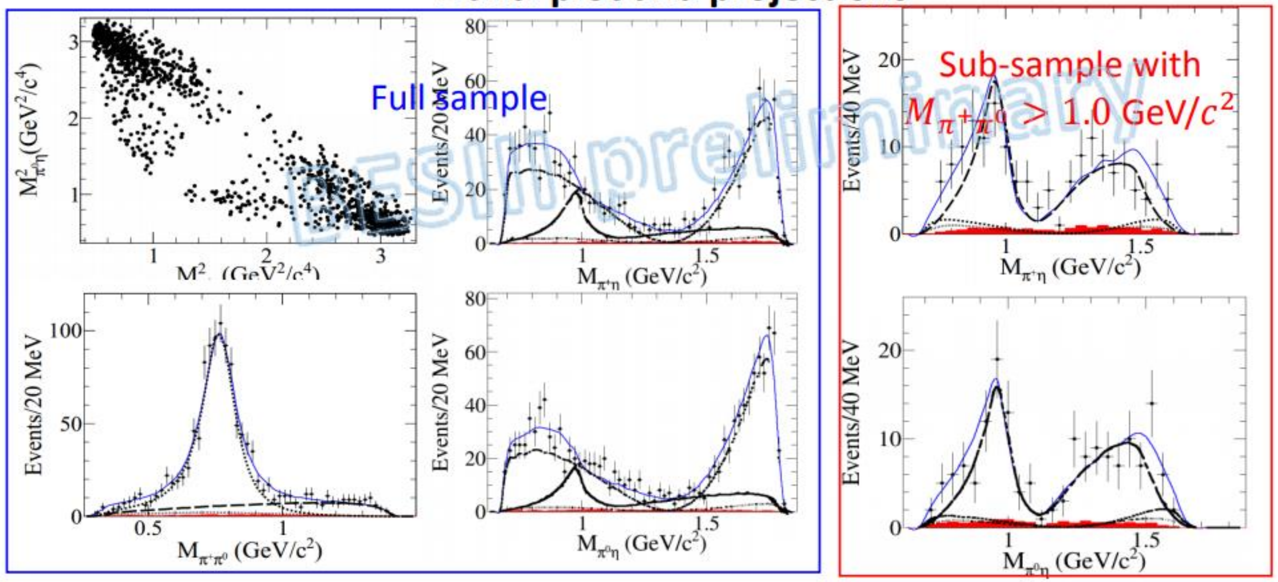
First observation ! implies a small $\rho - \omega$ mixing.

Amplitude Analysis : $D_s^+ \to \pi^+\pi^-\eta$

Motivation:
- Improve the precision of $\mathrm{Br}(D_s^+ \to \rho^0\eta)$
- Search for W-annihilation process $D_s^+ \to a_0(980)\pi$

Amplitude Analysis:
- Signal is selected by DT method with 7 tag modes
- Get 1239 events with purity ~98%
- Include 4 amplitudes in this fit

Dalitz plot and projections



Preliminary: significances, phases, and fit fractions (FFs) for intermediate processes:

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.

Amplitude Analysis : $D_s^+ \to \pi^+\pi^-\eta$

BESIII Preliminary: $B(D_s^+ \to \pi^+\pi^0\eta) = (9.50 \pm 0.28_{stat.} \pm 0.41_{sys.})\%$, **PDG**=$(9.2 \pm 1.2)\%$

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

Branching fraction	This measurement (%)	PDG value (%)
$BF(D_s^+ \to \rho^+\eta)$	$7.44 \pm 0.48_{stat.} \pm 0.44_{sys.}$	8.9 ± 0.9
$BF(D_s^+ \to a_0(980)\pi)$ *	$2.20 \pm 0.22_{stat.} \pm 0.34_{sys.}$	-
$BF(D_s^+ \to a_0(980)^+\pi^0)$ * $BF(D_s^+ \to a_0(980)^0\pi^+)$ *	$1.46 \pm 0.15_{stat.} \pm 0.22_{sys.}$	-

*here, $a_0(980) \to \pi\eta$

- Improved precision for $B(D_s^+ \to \pi^+\pi^0\eta)$ and $B(D_s^+ \to \rho^0\eta)$
- $D_s^+ \to a_0(980)\pi$ is the first observation !
- $D_s^+ \to a_0(980)\pi$ have larger BFs compared with $D_s^+ \to \omega\pi^+$ and $D_s^+ \to p\bar{n}$

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

Motivation:

- Provides a window to study the decays $D \to AP$ and $D \to VV$
- Result can be used in branching fraction measurement and strong phase measurement

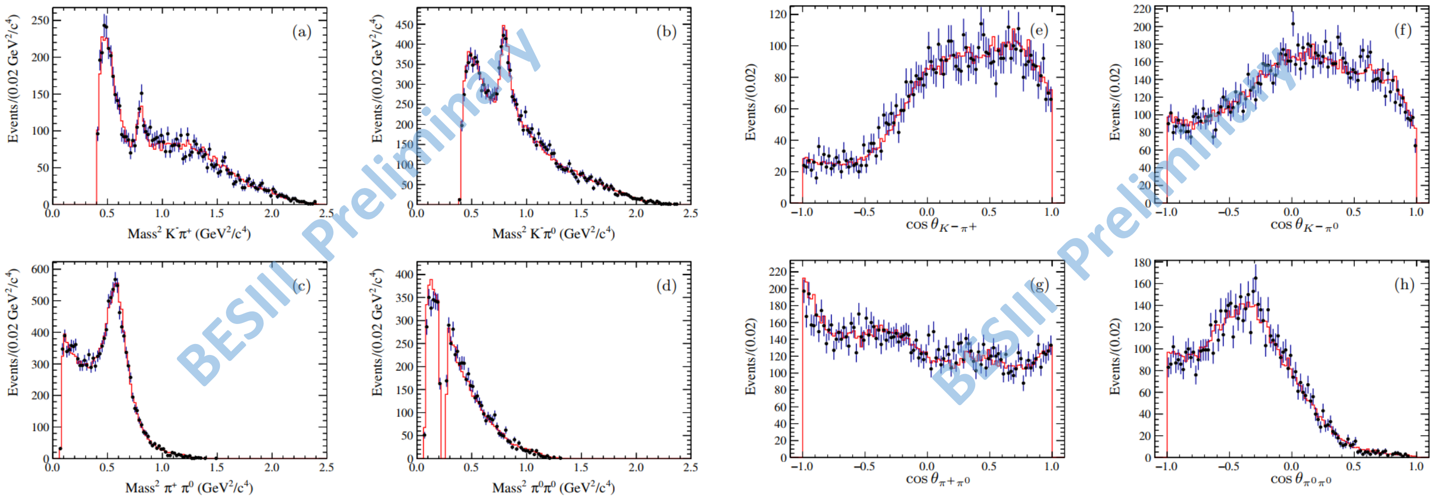
Amplitude Analysis:

- Signal is selected by DT method with 1 tag mode $D^0 \to K^-\pi^+$
- Get 5950 events with purity ~99%
- Include 26 amplitudes in this fit

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

BESIIIPreliminary

First measurement

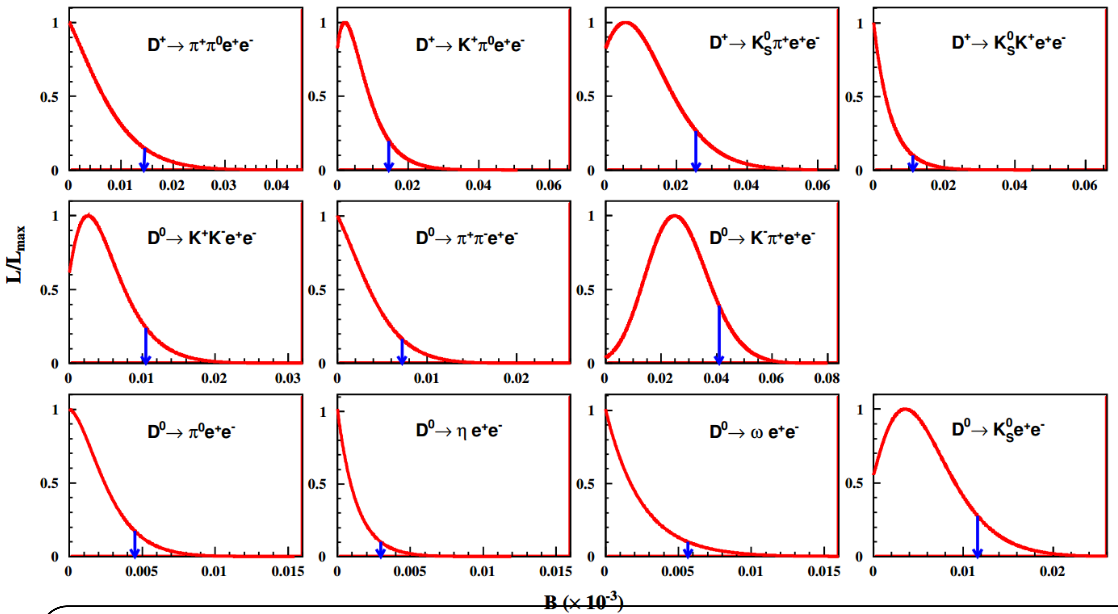


Amplitude mode	FF(%)	Phase (ϕ)	Significance(σ)
$D \to SS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$	> 10
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$	6.0
$D \to AP, A \to VP$			
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)	> 10
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$	6.1
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.15$	$1.84 \pm 0.34 \pm 0.43$	4.9
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$	4.8
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.11$	$-1.35 \pm 0.43 \pm 0.48$	4.0
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$	> 10
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$	7.8
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$	> 10
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$	5.9
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$	5.1
$D \to AP, A \to SP$			
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$	7.0
$D \to VS$			
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$	> 10
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$	4.1
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12^{+0.27}_{-0.12} \pm 0.12$	$1.45 \pm 0.48 \pm 0.51$	4.1
$D \to VP, V \to VP$			
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$	> 10
$D \to VV$			
$D[S] \to K^{*-}\rho^+$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$	> 10
$D[P] \to K^{*-}\rho^+$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$	> 10
$D[D] \to K^{*-}\rho^+$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$	> 10
$D[P] \to (K^-\pi^0)_V\rho^+$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$	5.7
$D[D] \to (K^-\pi^0)_V\rho^+$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$	> 10
$D[D] \to K^{*-}(\pi^+\pi^0)_V$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$	7.6
$D[S] \to (K^-\pi^0)_V(\pi^+\pi^0)_V$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$	7.6
$D \to TS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.30$	$-2.93 \pm 0.31 \pm 0.82$	5.8
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$	4.0

BESIII Preliminary

Search Rare Decay: $D \to h(h^{(\prime)})e^+e^-$ [PRD 97, 072015(2018)]

- $D \to X_u l^+ l^-$ are good channels to study FCNC transitions $c \to u l^+ l^-$
- BFs of $c \to u l^+ l^-$ in SM <10^{-9}, enhance by long distance effect through virtual vector $\sim 10^{-6}$
- Four-body D^0 decays with $[\mu^+\mu^-]_{\rho^0/\omega}$ pair have been observed at LHCb ($\sim 10^{-6} - 10^{-7}$) **[PRL 119, 181805(2017), PLB 757, 558(2016)]**
- The previous UL for four body D^0 decays with e^+e^- are $\sim 10^{-4} - 10^{-5}$



decay modes	$\mathcal{B}$ $(\times 10^{-5})$	PDG2015 $(\times 10^{-5})$
$D^+ \to \pi^+\pi^0 e^+e^-$	< 1.4	-
$D^+ \to K^+\pi^0 e^+e^-$	< 1.5	-
$D^+ \to \pi^+ K^0_S e^+e^-$	< 2.6	-
$D^+ \to K^+ K^0_S e^+e^-$	< 1.1	-
$D^0 \to K^- K^+ e^+e^-$	< 1.1	< 31.5
$D^0 \to \pi^+\pi^- e^+e^-$	< 0.7	< 37.3
$D^0 \to K^-\pi^+ e^+e^-$ †	$< 4.1(2.5\pm1.1,\ 2.6\sigma)$	< 38.5
$D^0 \to \pi^0 e^+e^-$	< 0.4	< 4.5
$D^0 \to \eta e^+e^-$	< 0.3	< 11
$D^0 \to \omega e^+e^-$	< 0.6	< 18
$D^0 \to K^0_S e^+e^-$	< 1.2	< 11
† in $M_{e^+e^-}$ regions:		
$[0.00,\ 0.20)$ GeV/c^2	$< 3.0\ (1.5^{+1.0}_{-0.9})$	-
$[0.20,\ 0.65)$ GeV/c^2	< 0.7	-
$[0.65,\ 0.90]$ GeV/c^2	$< 1.9\ (1.0^{+0.5}_{-0.4})$	-

- 4-body D^+decays have been searched for the first time.
- Precision of other decays have been improved with one order.

Summary

- Using $2.93fb^{-1}$ and $3.19fb^{-1}$ e^+e^- collision data taken @ 3.773 and 4.178 GeV with BESIII detector, experimental studies of charmed decays have been performed:
  - Measurements of FFs and $|V_{cd(s)}|$: better calibrate LQCD and test CKM unitarity
  - Test lepton flavor universality in (semi-)leptonic decay: consistent with SM
  - Measurements of W-annihilation process $D_s^+ \to p\bar{n}$, $D_s^+ \to \omega\pi^+$ and $D_s^+ \to a_0(980)\pi$
  - First observation of $D^0 \to a_0(980)^- e^+\nu_e$, $D_s^+ \to \omega K^+$
  - Amplitude analysis for $D_s^+ \to \pi^+\pi^-\eta$ and $D^0 \to K^-\pi^+\pi^0\pi^0$
  - Improved UL for FCNC process $D \to h(h^{(\prime)})e^+e^-$

Thank you!!

- More results will be coming in the near future.

BACK-UP

Semi-leptonic Decay: $D_s^+ \to K^{(*)0} e^+ \nu_e$

Study of the form factors in $D_s^+ \to K^{*0} e^+ \nu_e$ [preliminary]

The differential decay rate for $D_s^+ \to K^{*0} e^+ \nu_e$ can be expressed in terms of three helicity amplitudes ($H_+(q^2)$, $H_-(q^2)$ and $H_0(q^2)$) [PRL 110, 131802 (2013)]

$$\begin{aligned}
\frac{d^5\Gamma}{dm_{K\pi}\, dq^2\, dcos\theta_K\, dcos\theta_e\, d\chi} &= \frac{3}{8(4\pi)^4} G_F^2 |V_{cd}|^2 \frac{p_{K\pi} q^2}{M_{D_s}^2} \mathcal{B}(K^{*0} \to K^+\pi^-) |\mathcal{BW}(m_{K\pi})|^2 \\
&\times \quad [(1+cos\theta_e)^2 sin^2\theta_K |H_+(q^2, m_{K\pi})|^2 \\
&+ \quad (1-cos\theta_e)^2 sin^2\theta_K |H_-(q^2, m_{K\pi})|^2 \\
&+ \quad 4sin^2\theta_e cos^2\theta_K |H_0(q^2, m_{K\pi})|^2 \\
&+ \quad 4sin\theta_e(1+cos\theta_e) sin\theta_K cos\theta_K cos\chi H_+(q^2, m_{K\pi}) H_0(q^2, m_{K\pi}) \\
&- \quad 4sin\theta_e(1-cos\theta_e) sin\theta_K cos\theta_K cos\chi H_-(q^2, m_{K\pi}) H_0(q^2, m_{K\pi}) \\
&- \quad 2sin^2\theta_e sin^2\theta_K cos2\chi H_+(q^2, m_{K\pi}) H_-(q^2, m_{K\pi})].
\end{aligned}$$

The helicity amplitudes of $H_+(q^2)$, $H_-(q^2)$ and $H_0(q^2)$ take the form of
$H_\pm(q^2) = (M_{D_s} + m_{K\pi}) A_1(q^2) \mp \frac{2M_{D_s} P_{K\pi}}{M_{D_s} + M_{K\pi}} V(q^2)$ and

$H_0(q^2) = \frac{1}{2m_{K\pi} q} [(M_{D_s}^2 - m_{K\pi}^2 - q^2)(M_{D_s} + m_{K\pi}) A_1(q^2) - \frac{4M_{D_s}^2 p_{K\pi}^2}{M_{D_s} + M_{K\pi}} A_2(q^2)]$,
$A_i(q^2) = \frac{A_i(0)}{1 - q^2/M_A^2}$ and $V(q^2) = \frac{V(0)}{1 - q^2/M_V^2}$, $r_V = \frac{V(0)}{A_1(0)}$ and $r_2 = \frac{A_2(0)}{A_1(0)}$.
The Breit-Wigner function of K^{*0} line shape takes the form as
$\mathcal{BW}(M_{K\pi}) = \frac{\sqrt{m_0 \Gamma_0}(p/p_0)}{m_0^2 - m_{K\pi}^2 - i m_0 \Gamma(m_{K\pi})} \frac{B(p)}{B(p_0)}$
where $B(p) = \frac{1}{\sqrt{1 + R^2 p^2}}$ with $R = 3$ GeV^{-1} and $\Gamma(m_{K\pi}) = \Gamma_0 (\frac{p}{p_0})^3 \frac{m_0}{m_{K\pi}} (\frac{B(p)}{B(p_0)})^2$.

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Hadronic Decay: $D \to PP$ [PRD97,072004]

BFs of $D \to PP$ are obtained using ST method:

Mode	$\mathcal{B}$ $(\times 10^{-3})$	$\mathcal{B}_{\mathrm{PDG}}$ $(\times 10^{-3})$
$D^+ \to \pi^+\pi^0$	$1.259 \pm 0.033 \pm 0.023$	1.24 ± 0.06
$D^+ \to K^+\pi^0$	$0.232 \pm 0.021 \pm 0.006$	0.189 ± 0.025
$D^+ \to \pi^+\eta$	$3.790 \pm 0.070 \pm 0.068$	3.66 ± 0.22
$D^+ \to K^+\eta$	$0.151 \pm 0.025 \pm 0.014$	0.112 ± 0.018
$D^+ \to \pi^+\eta'$	$5.12 \pm 0.14 \pm 0.024$	4.84 ± 0.31
$D^+ \to K^+\eta'$	$0.164 \pm 0.051 \pm 0.024$	0.183 ± 0.023
$D^+ \to K_S^0\pi^+$	$15.91 \pm 0.06 \pm 0.30$	15.3 ± 0.6
$D^+ \to K_S^0 K^+$	$3.183 \pm 0.029 \pm 0.060$	2.95 ± 0.15
$D^0 \to \pi^+\pi^-$	$1.508 \pm 0.018 \pm 0.022$	1.421 ± 0.025
$D^0 \to K^+K^-$	$4.233 \pm 0.021 \pm 0.064$	4.01 ± 0.07
$D^0 \to K^\mp\pi^\pm$	$38.98 \pm 0.06 \pm 0.51$	39.4 ± 0.4
$D^0 \to K_S^0\pi^0$	$12.39 \pm 0.06 \pm 0.27$	12.0 ± 0.4
$D^0 \to K_S^0\eta$	$5.13 \pm 0.07 \pm 0.12$	4.85 ± 0.30
$D^0 \to K_S^0\eta'$	$9.49 \pm 0.20 \pm 0.36$	9.5 ± 0.5

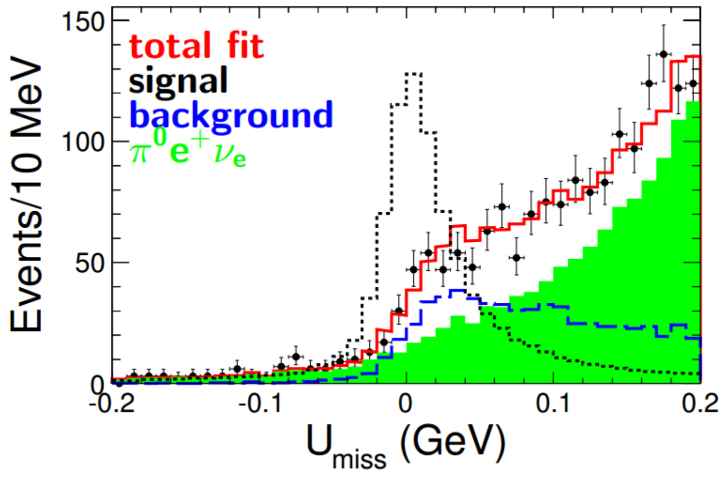
The results from BESIII are consistent with the world average values within uncertainties.
The BFs of $D^+ \to \pi^+\pi^0, K^+\pi^0, \pi^+\eta, \pi^+\eta', K_S^0\pi^+, K_S^0K^+$ and $D^0 \to K_S^0\pi^0, K_S^0\eta, K_S^0\eta'$ are determined with improved precision.

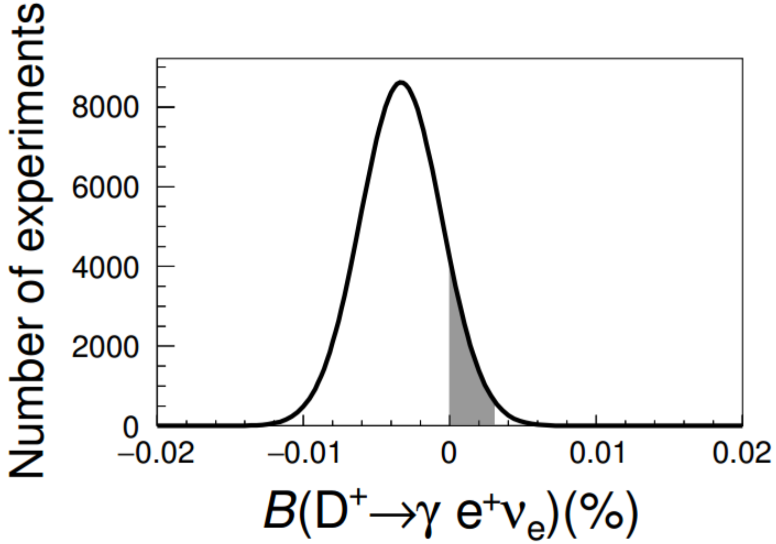
Search for $D^+ \to \gamma e^+ \nu_e$ [PRD 95, 071102(2017)]

- no helicity suppression in contrast to pure leptonic decay, and simpler non-perturbative QCD calculation without final-state hadron

models	pQCD[1]	light front quark[2] & NR constituent quark model[3]	VMD[4]	factorization[5]
$\mathcal{B}_{theo.}$	10^{-4}	10^{-6}	10^{-5}(enhanced by LD)	10^{-5}

[1][PRD 51, 111 (1995)] [2]MPLA 15, 2087 (2000); [3]PLB 562, 75 (2003); [4]MPLA 27, 1250120 (2012);[5]Nucl. Phys. B 889, 778 (2014); 914, 301 (2017)

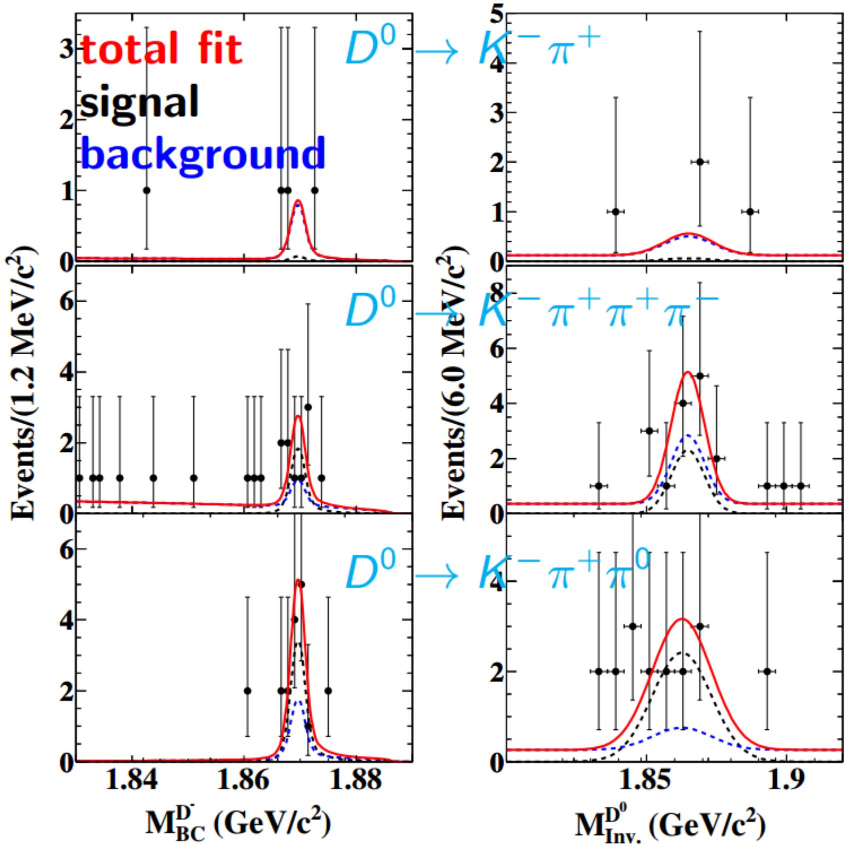


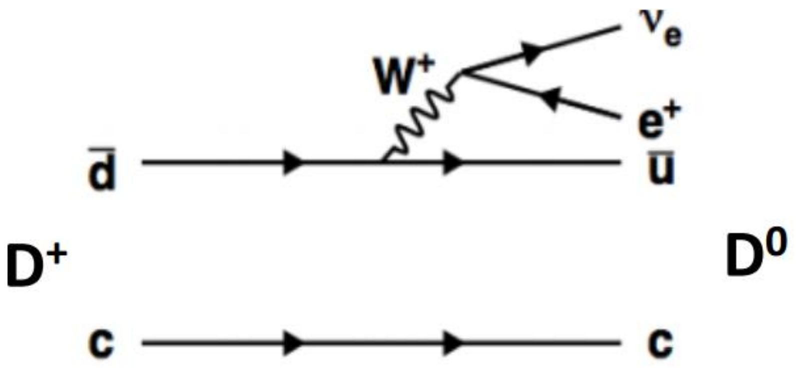


$$\mathbf{B(D^+ \to \gamma e^+ \nu_e) < 3.0 \times 10^{-5} @ 90\%\ C.L.}$$

Search for $D^+ \to D^0 e^+ \nu_e$ [PRD 96, 092002(2017)]

- The heavy *c* quark remains unchanged while the lighter *d* quark decays weakly
- $B_{theo} = 2.78 \times 10^{-13}$ by it's form factors in the SM [EPJC 59, 841 (2009)]





2D fit to each tag mode

$\mathbf{B(D^+ \to \gamma e^+ \nu_e) < 1.0 \times 10^{-4} @ 90\%\ C.L.}$