Charm Decay @ BESIII

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(On behalf of the BESIII collaboration)

Outline

- Introduction
  - The BESIII experiment
  - Production new threshold and tag technique
- (Semi-)Leptonic Decays
  - Study of $D^+ \to \mu\nu$
  - Study of $D_s^+ \to \mu\nu$
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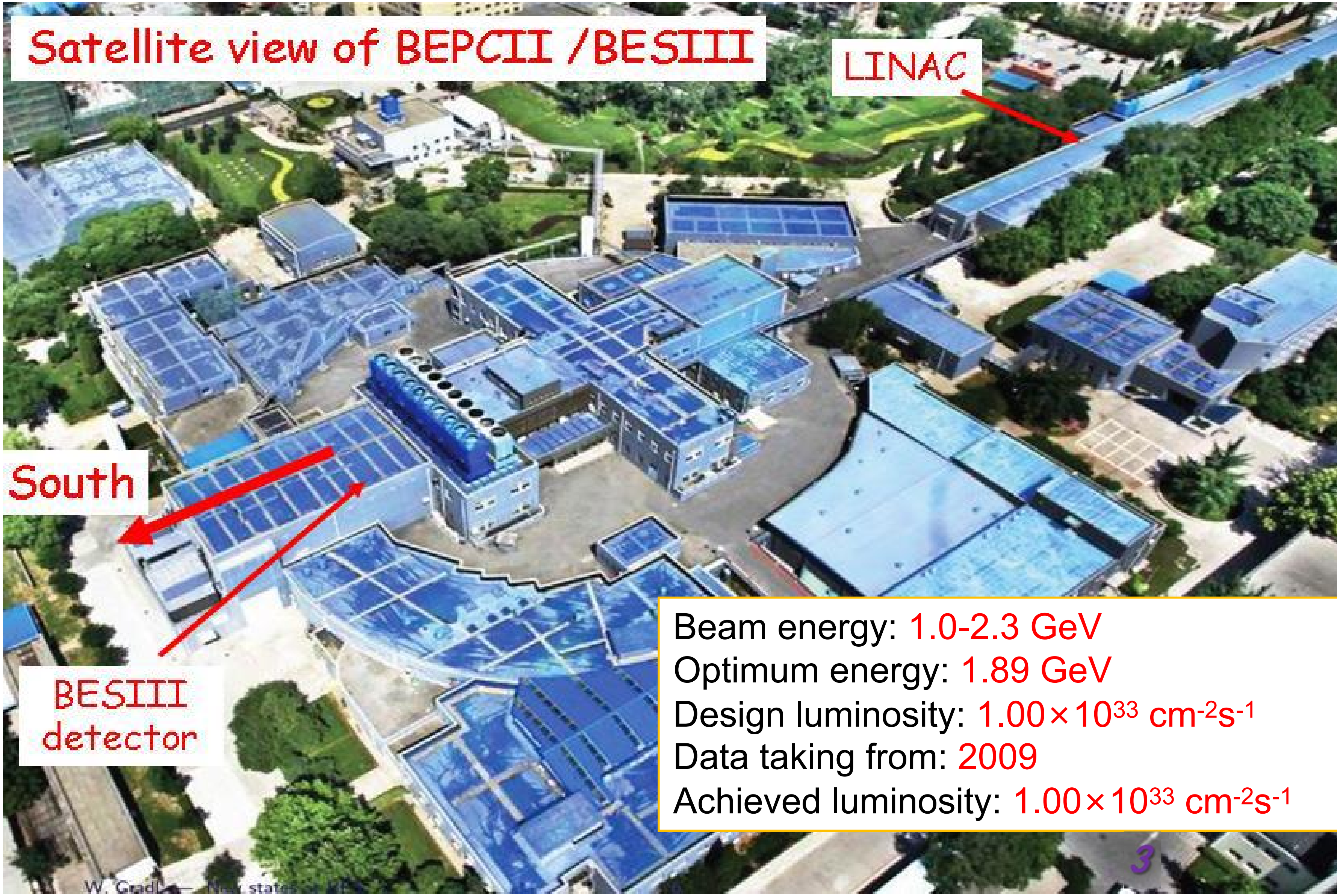
  - Study of $D^0 \to K^- \mu^+ \nu$
  - Study of $D_s^+ \to \eta e^+ \nu$
  - Study of $D_s^+ \to K^{(*)0} e^+ \nu_e$
- Hadronic Decay
  - Study of $D_s^+ \to p\bar{n}$,
  - Study of $D_s^+ \to \omega\pi^+$ and ωK^+
- Λ_c^+ Decays
  - Study of $\Lambda_c^+ \to \Lambda X$
  - Study of $\Lambda_c^+ \to e^+ \nu_e X$

The BESIII experiment

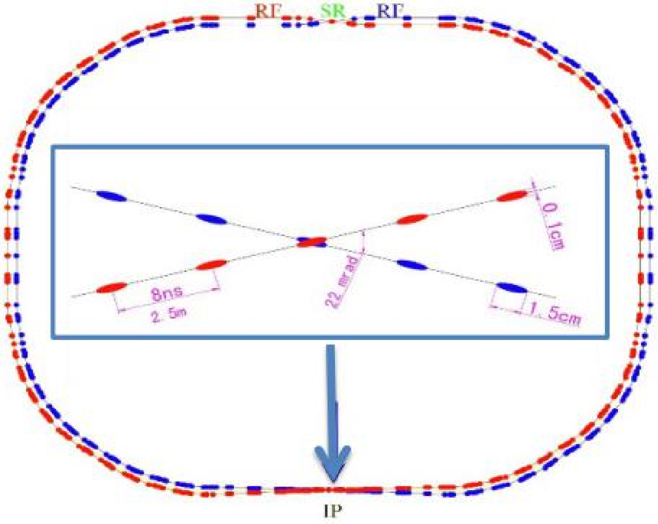


Beam energy: 1.0-2.3 GeV
Optimum energy: 1.89 GeV
Design luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$
Data taking from: 2009
Achieved luminosity: 1.00×10^{33} $cm^{-2}s^{-1}$

Beijing-Electron-Positron Collider II (BEPCII)

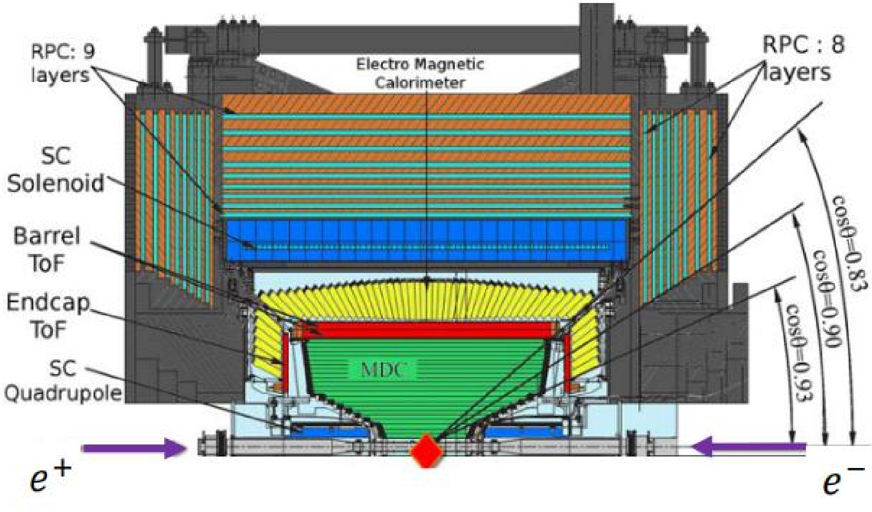
- e^+e^- collisions with $\sqrt{s} = 2.0 - 4.6 GeV$
- Direct production of charmonia
- Designed Luminosity

  $\mathcal{L} = 1 \times 10^{33} cm^{-2} s^{-1}$
  was achieved in April 2016.



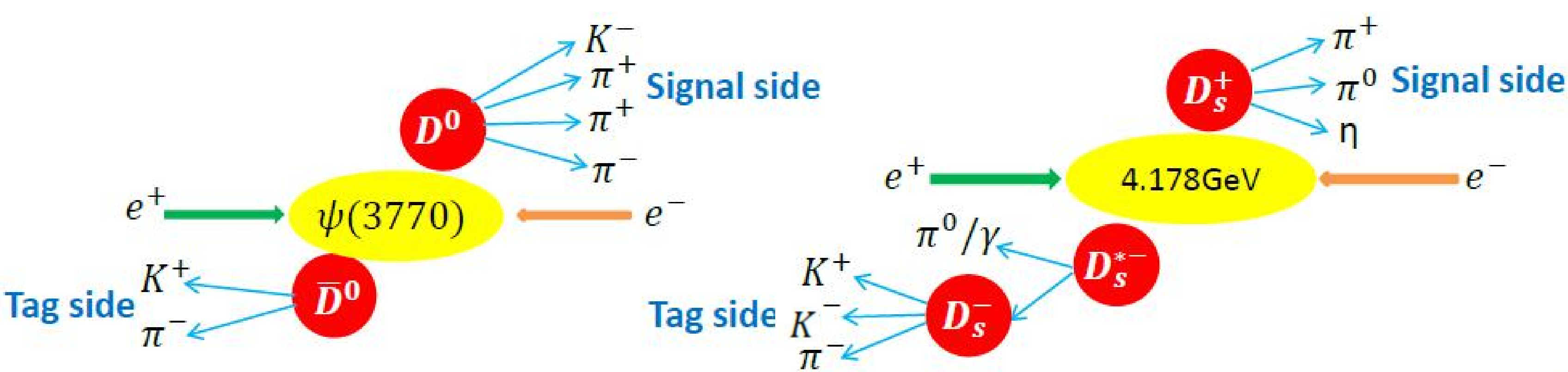
BESIII detector

- 93% coverage of the full solid angle
- Main drift chamber $\sigma_{\mathrm{p}}/\mathrm{p} = 0.5\%@1\mathrm{GeV}$
- Time-of-flight system $\sigma_{\mathrm{T}} = 100\mathrm{ps}$ in Barrel
- Elmg. Calorimeter $\Delta E/E = 2.5\%@1\mathrm{GeV}$
- Superconducting 1T magnet
- Muon system (RPC)

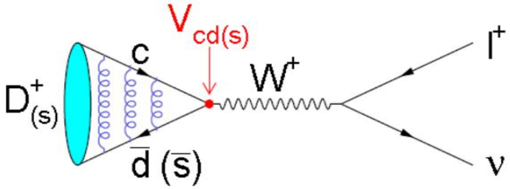


Production near threshold and tag technique

- Dataset used in this talk:
  - 2.93 fb^{-1} @E_{cm} = 3.773 GeV $e^+e^- \to \psi(3770) \to D\bar{D}$
  - 3.19 fb^{-1} @E_{cm} = 4.178 GeV $e^+e^- \to D_s^{\pm} D_s^{*\mp}, D_s^{*\mp} \to \pi^0/\gamma D_s^{\mp}$
  - 567 pb^{-1} @E_{cm} = 4.6GeV $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$
- Two ways to study $D_{(s)}$ decays:
  - Single Tag (ST): reonstruct only one of the $D\bar{D}(D_s^+D_s^-)$
  - Double Tag (DT): reconstruct both of $D\bar{D}(D_s^+D_s^-)$

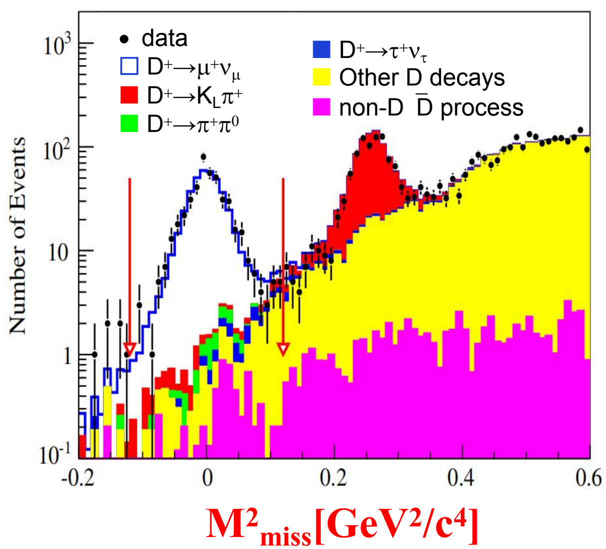


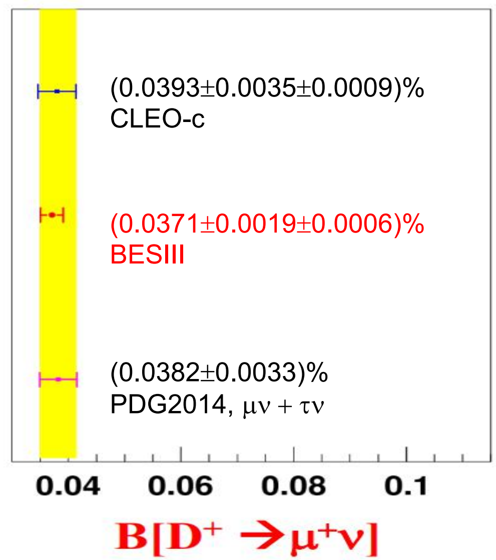
$D^+ \to \mu^+ \nu$ decay

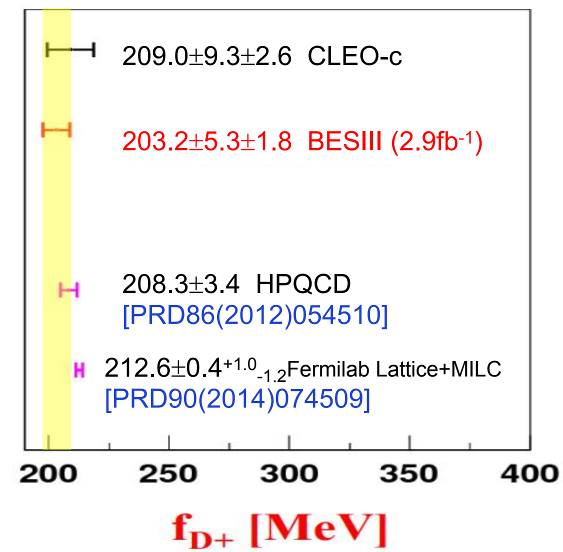


$$\Gamma(D^+_{(s)} \to \ell^+ \nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

PRD89(2014)051104R







- Decay constant f_{D+} with input $|V_{cd}|$
- CKM matric element $|V_{cd}|$ with input f^{LQCD}_{D+}

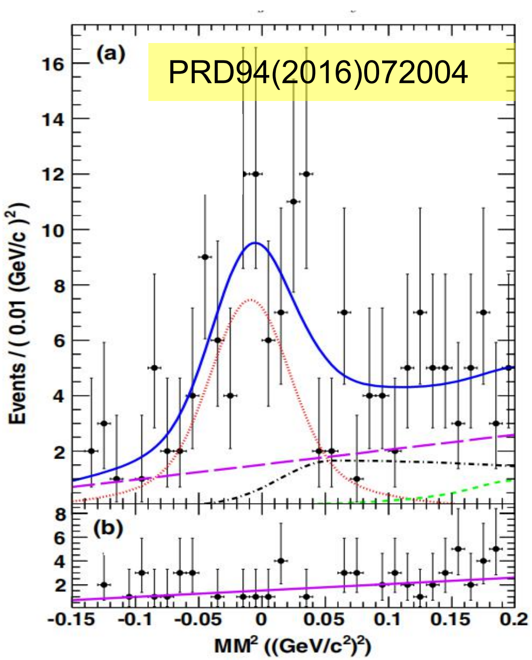
$B[D^+ \to \mu\nu] = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4}$

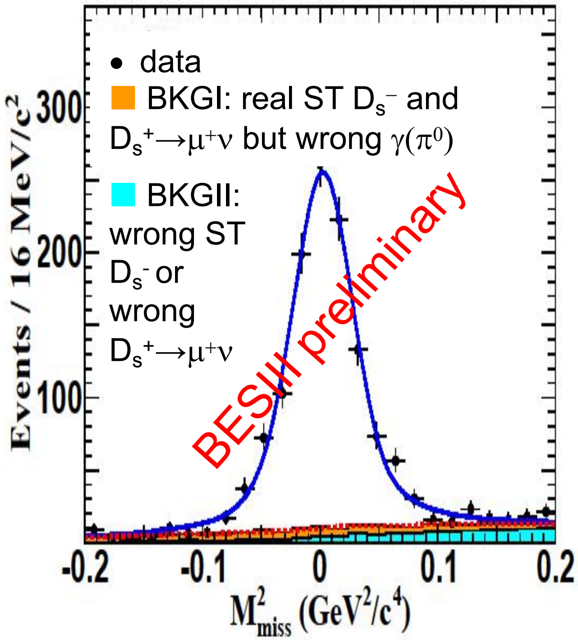
$f_{D+} = (203.2 \pm 5.3 \pm 1.8)$ MeV

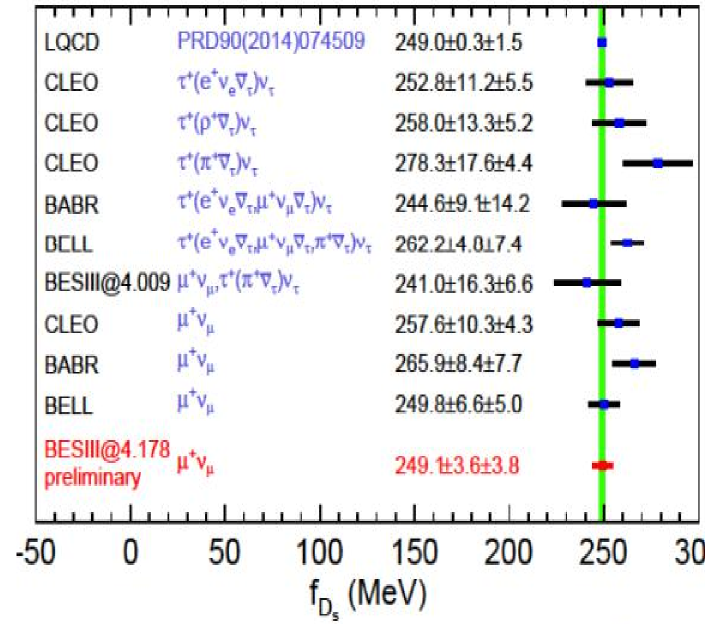
$|V_{cd}| = 0.2210 \pm 0.0058 \pm 0.0047$

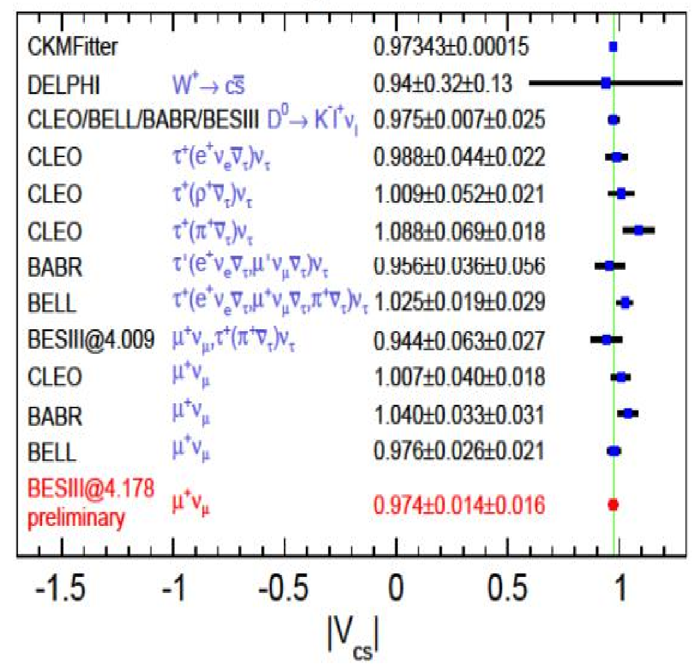
$D_s^+ \to \mu^+ \nu$

$0.48fb^{-1}$@4.01GeV ***$3.19fb^{-1}$ @4.178GeV***









$B[D_s^+\to\mu^+\nu] = (0.528\pm0.015\pm0.014)\%$

$f_{Ds}|V_{cs}| = (242.5\pm3.5\pm3.7)$ MeV

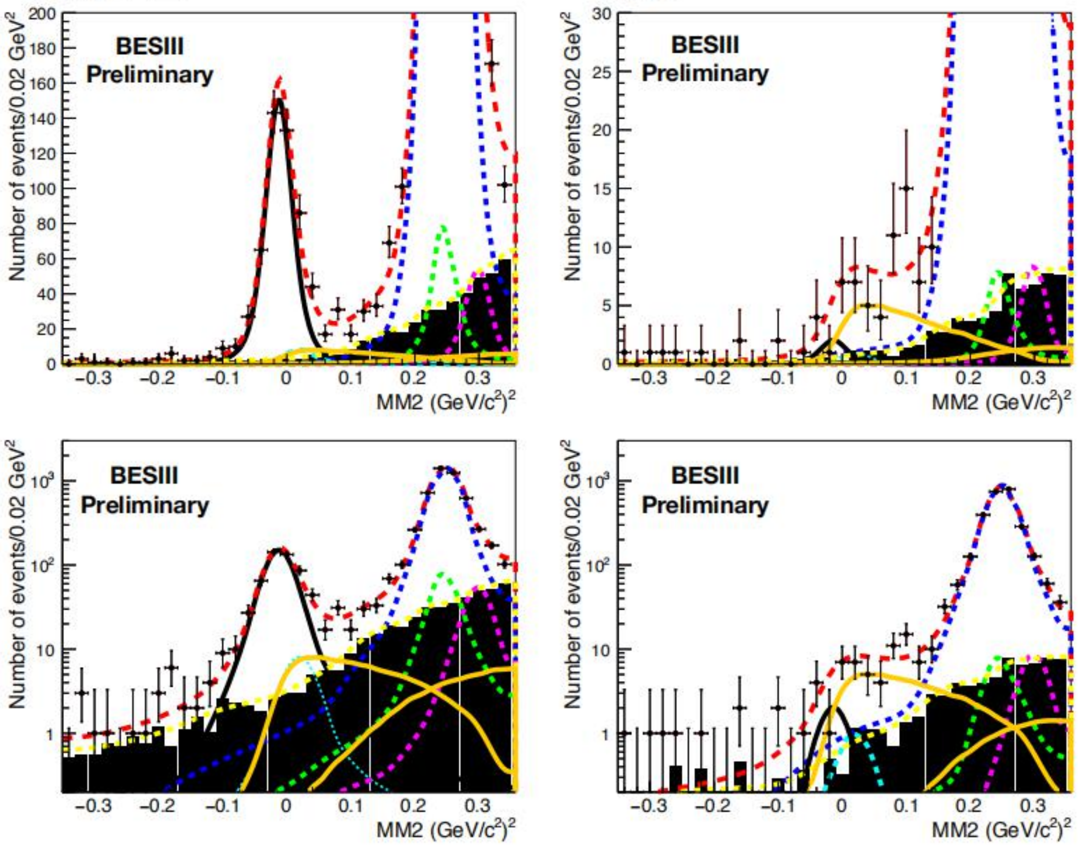
$$R \equiv \frac{\Gamma(D_s^+ \to \tau^+\nu)}{\Gamma(D_s^+ \to \mu^+\nu)} = \frac{m^2_{\tau^+}\left(1-\frac{m^2_{\tau^+}}{M^2_{D_s^+}}\right)^2}{m^2_{\mu^+}\left(1-\frac{m^2_{\mu^+}}{M^2_{D_s^+}}\right)^2}$$

SM: R = 9.74 ±0.01

BESIII: R = 10.2±0.5

$D^+ \to \tau^+ \nu$ decay

$E_{EMC} \leq 300\,\mathrm{MeV}$ $E_{EMC} > 300\,\mathrm{MeV}$



$D^+ \to \tau^+ \nu_\tau$

$D^+ \to \mu^+ \nu_\mu$

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

$D^+ \to \pi^+ K^0_L$

$D^+ \to \pi^+ \eta$

$D^+ \to \pi^+ K^0_S$

the rest

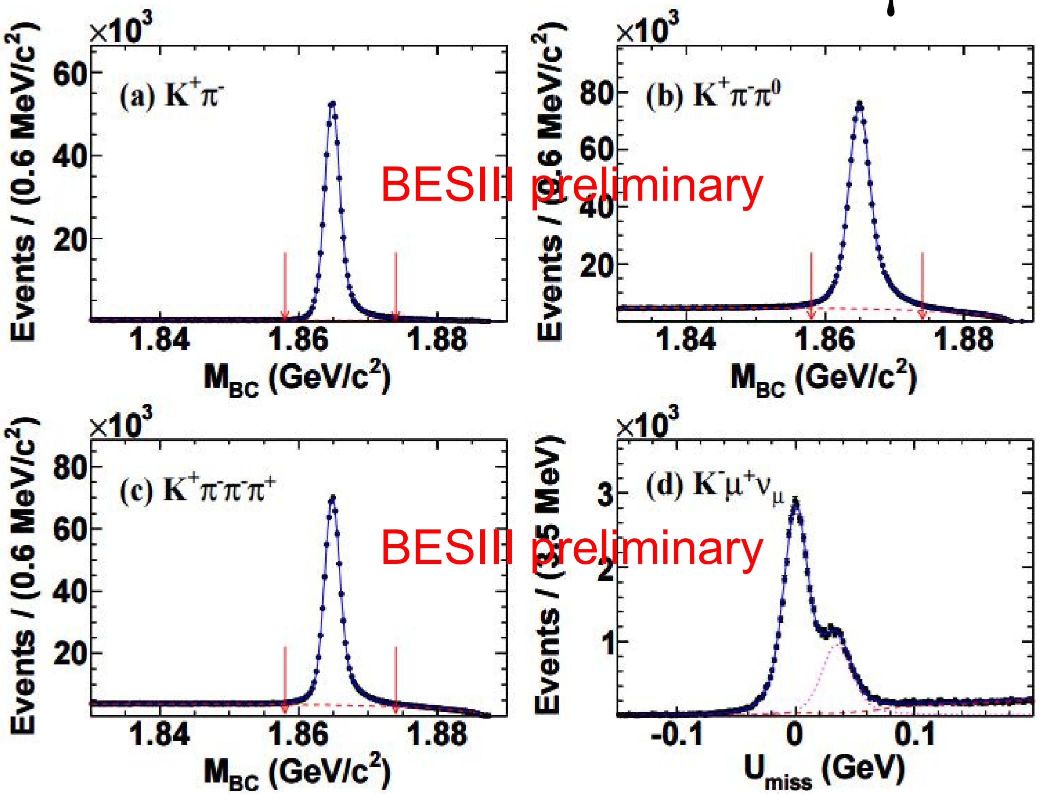
- $N_{sig} = 137 \pm 27$
- $\mathcal{B}_{D^+ \to \tau^+ \nu_\tau} = (1.20 \pm 0.24_{stat.}) \times 10^{-3}$
- significance $>4\sigma$

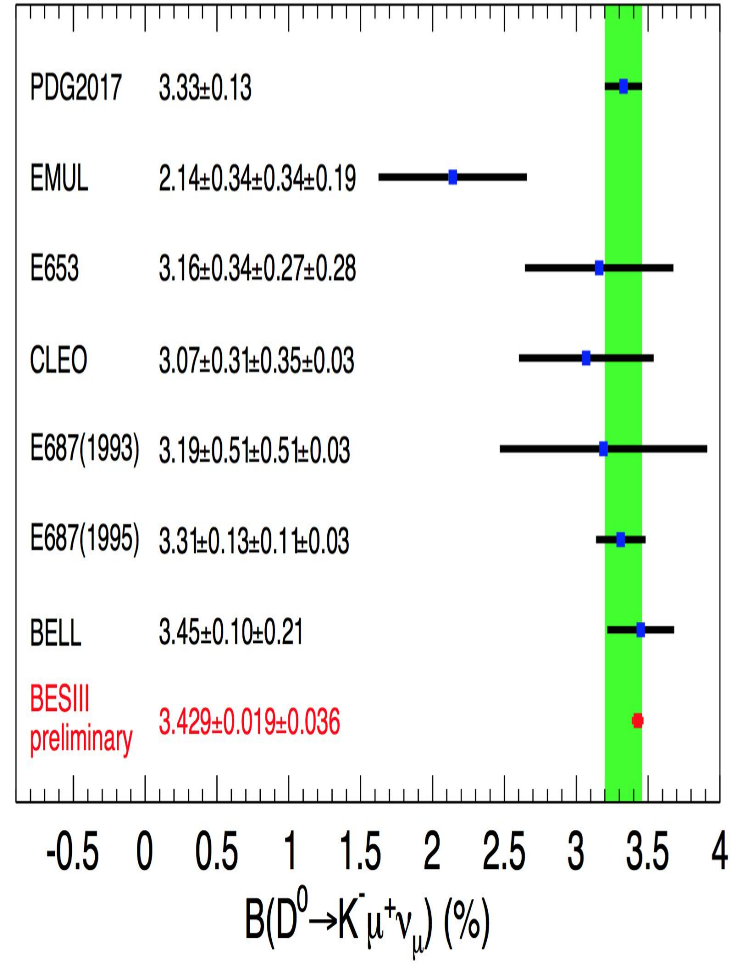
$$R \equiv \frac{\Gamma(D^+ \to \tau^+ \nu)}{\Gamma(D^+ \to \mu^+ \nu)} = \frac{m^2_{\tau^+}\left(1 - \frac{m^2_{\tau^+}}{M^2_{D^+}}\right)^2}{m^2_{\mu^+}\left(1 - \frac{m^2_{\mu^+}}{M^2_{D^+}}\right)^2}$$

SM: R=2.66

BESIII: R=3.21±0.64

Absolute Bf of $D^0 \to K^- \mu^+ \nu$

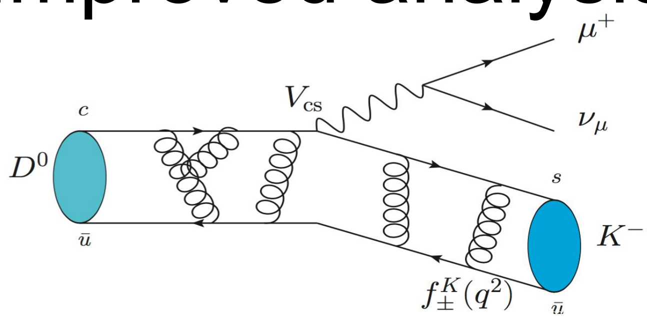




Total ST : $(234\pm2)\times10^4$

DT : 47100 ± 259

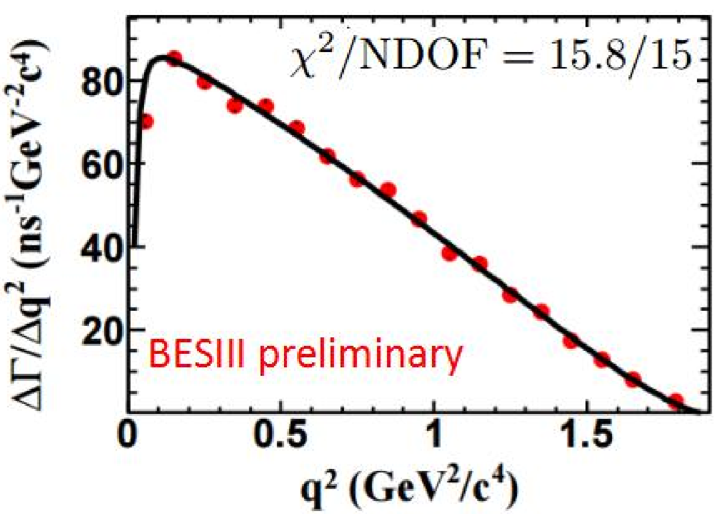
Improved analysis of $D^0 \to K^- \mu^+ \nu$ dynamics

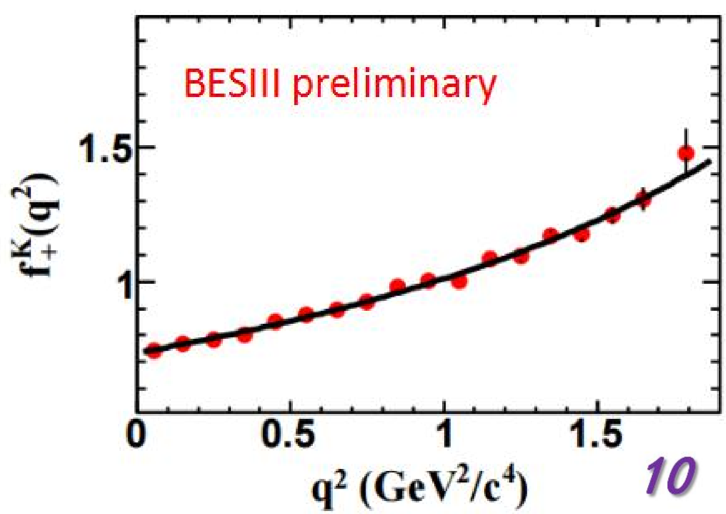


$$\frac{d\Gamma}{dq^2} = \frac{G_F^2|V_{cs}|^2}{8\pi^3 m_D}|\vec{p}_K||f_+^K(q^2)|^2\left(\frac{W_0 - E_K}{F_0}\right)^2$$
$$\times \left[\frac{1}{3}m_D|\vec{p}_K|^2 + \frac{m_\ell^2}{8m_D}(m_D^2 + m_K^2 + 2m_D E_K)\right.$$
$$+ \frac{1}{3}m_\ell^2\frac{|\vec{p}_K|^2}{F_0} + \frac{1}{4}m_\ell^2\frac{m_D^2 - m_K^2}{m_D}\mathrm{Re}\left(\frac{f_-^K(q^2)}{f_+^K(q^2)}\right)$$
$$\left. + \frac{1}{4}m_\ell^2 F_0\left|\frac{f_-^K(q^2)}{f_+^K(q^2)}\right|^2\right]$$

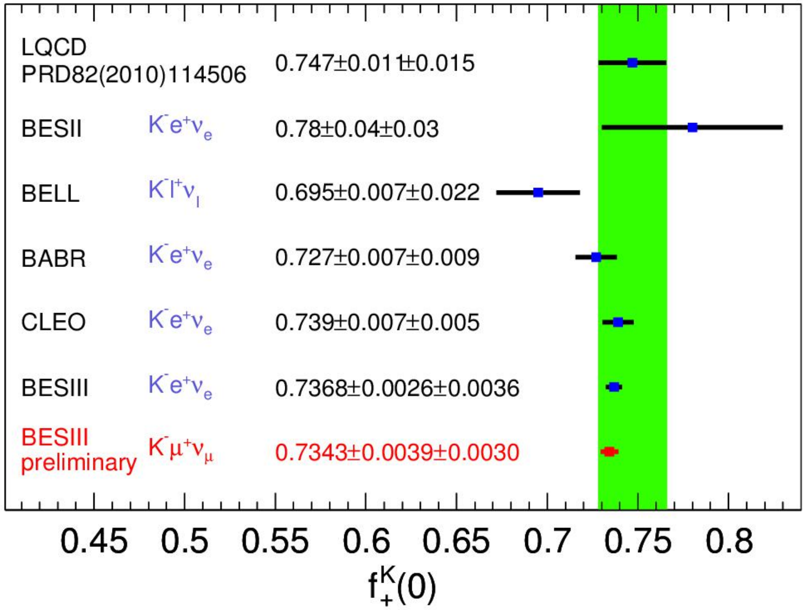
$$q = p_\mu + p_\nu$$
$$W_0 = (m_D^2 + m_K^2 - m_\ell^2)/2m_D$$
$$F_0 = W_0 - E_K + m_\ell^2/2m_D$$

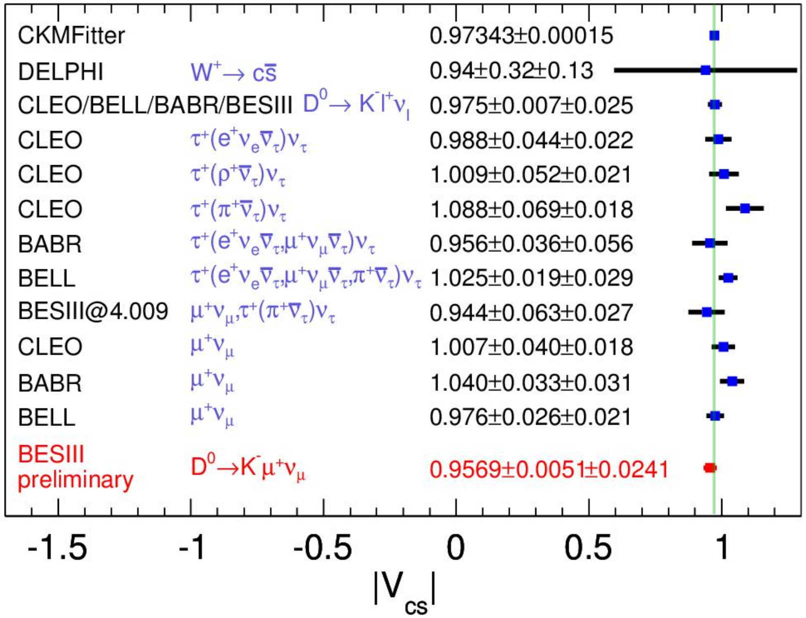
Assumed to be independent of q^2 following FOCUS's treatment (PLB607(2005)233)





Comparison of $f_+(0)$ and $|V_{cs}|$





Taking $|V_{cs}|_{[1]}$ as input

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

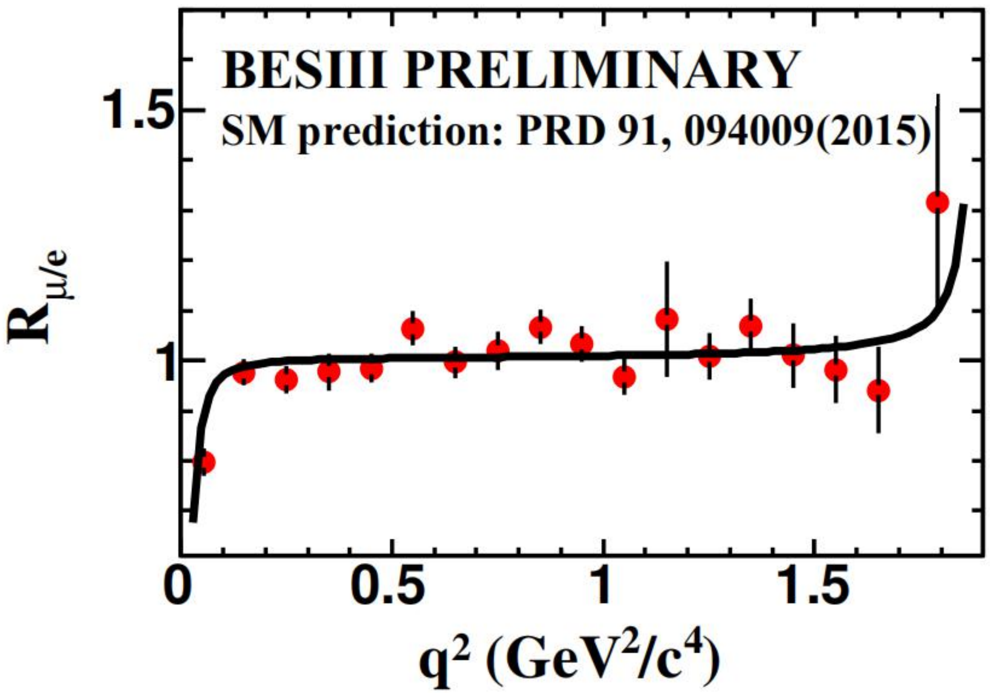
$$r_1 = -1.94 \pm 0.21_{\rm stat.} \pm 0.07_{\rm syst.}$$

$$f_-^K / f_+^K = -0.7 \pm 0.9_{\rm stat.} \pm 0.1_{\rm syst.}$$

Taking $f_+^K(0)_{[2]}$ as input

[1] CKMFitter
[2] PRD82(2010)114506

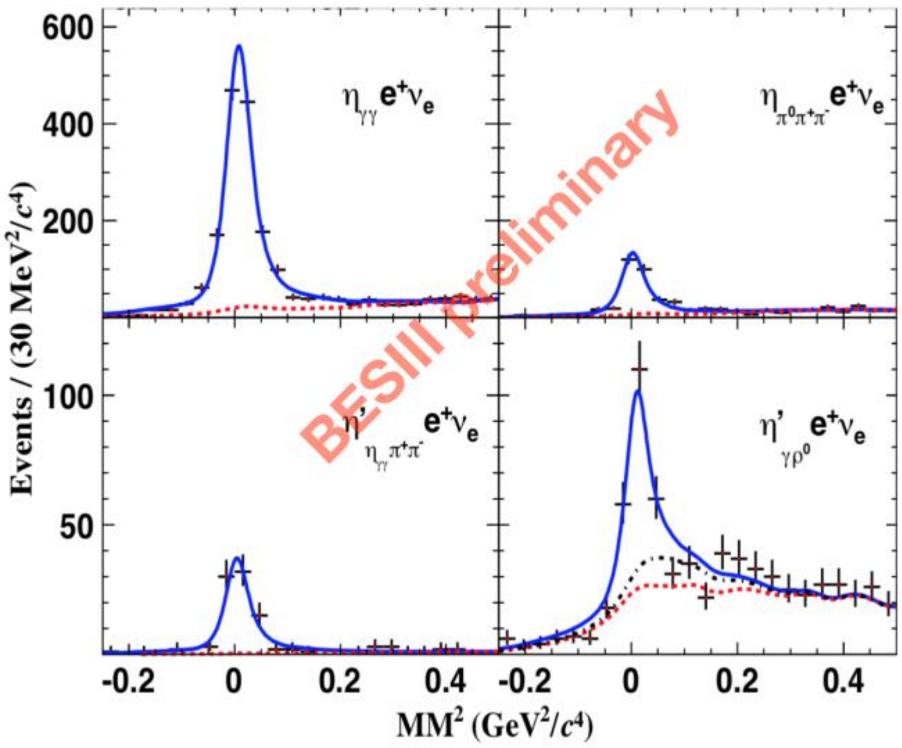
LFU test in $D^+ \to K^- \mu^+ \nu$ decay



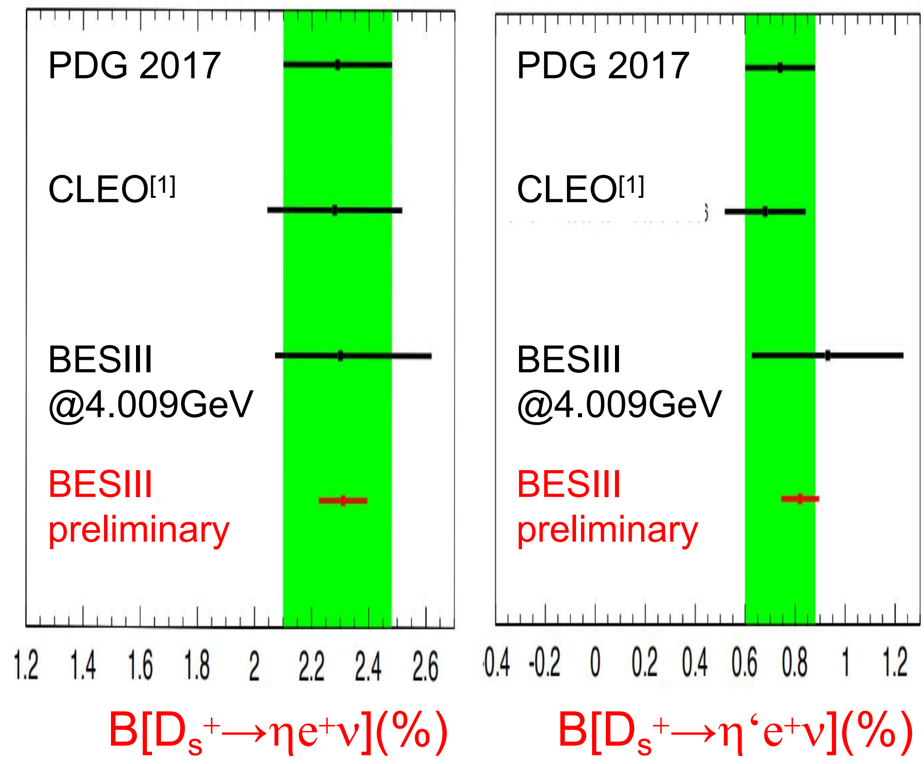
$$R_{\mu/e} = \frac{\Gamma(D^+ \to K^- \mu^+ \nu_\mu)}{\Gamma(D^+ \to K^- e^+ \nu_e)[PRD92,072012(2015)]} = 0.978 \pm 0.007 \pm 0.012$$

- No deviation larger than 2σ over the q^2 interval

Absolute Bf of $D_s \to \eta^{(\prime)} e^+ \nu$



Comparison of Bfs



Preliminary Result:

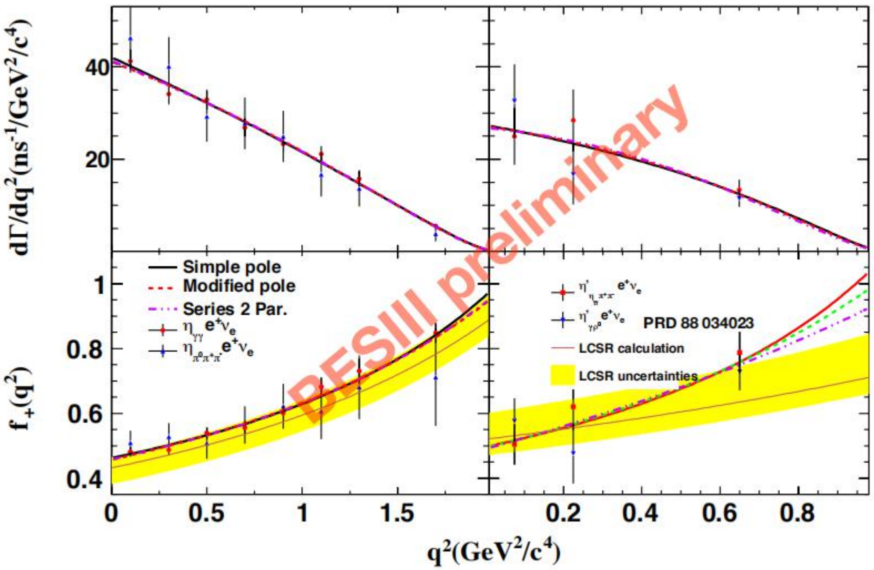
$B[D_s^+ \to \eta e^+ \nu] = 2.31 \pm 0.06 \pm 0.06\%$

$B[D_s^+ \to \eta' e^+ \nu] = 0.82 \pm 0.07 \pm 0.03\%$

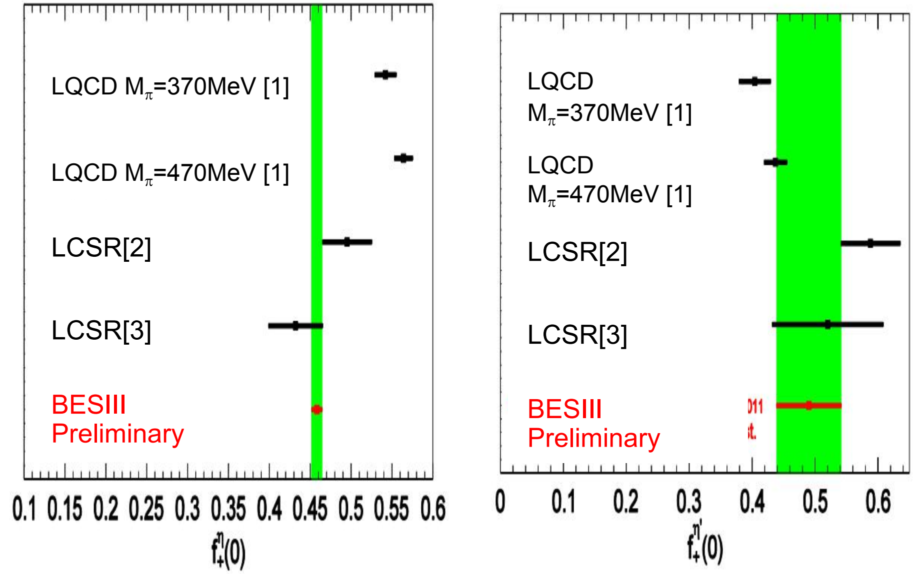
[1]PRD80 052007

Comparisons of $f_+^{\eta^{(\prime)}}(0)$s

Fit to partial decay rates



Comparisons of form factors

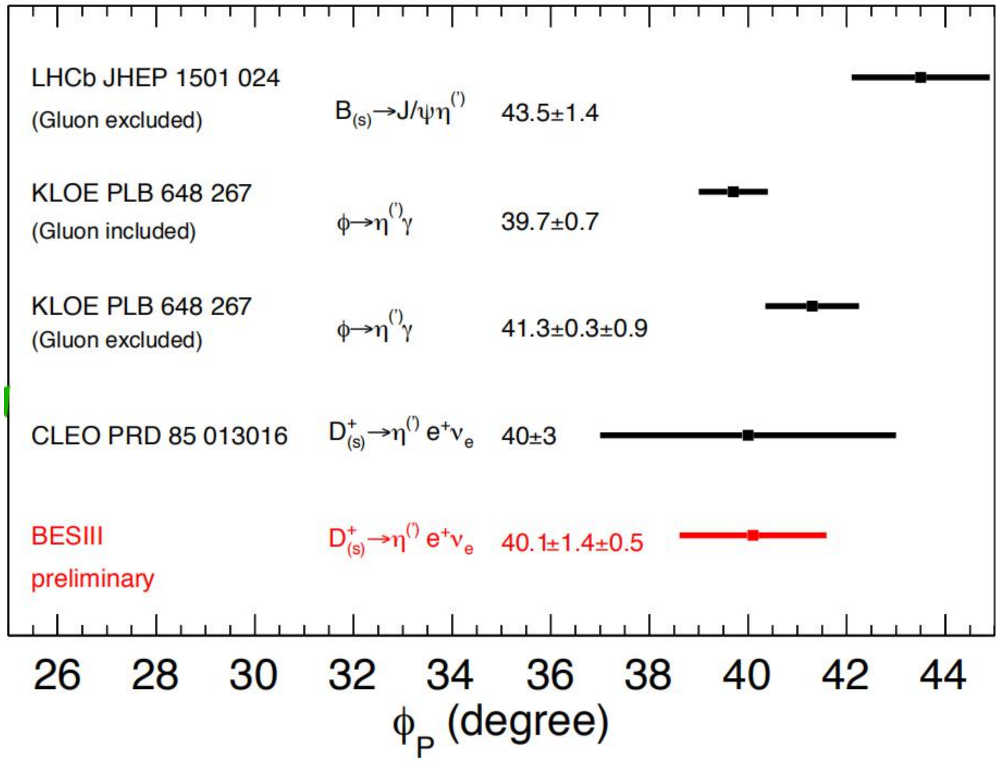


Case	Simple pole			Modified pole			Series 2 Par.		
	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	$M_{\rm pole}$	$\chi^2/{\rm NDOF}$	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	α	$\chi^2/{\rm NDOF}$	$f_+^{\eta^{(\prime)}}(0)\|V_{cs}\|$	r_1	$\chi^2/{\rm NDOF}$
$\eta e^+\nu_e$	0.450(5)(3)	3.77(8)(5)	12.2/14	0.445(5)(4)	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

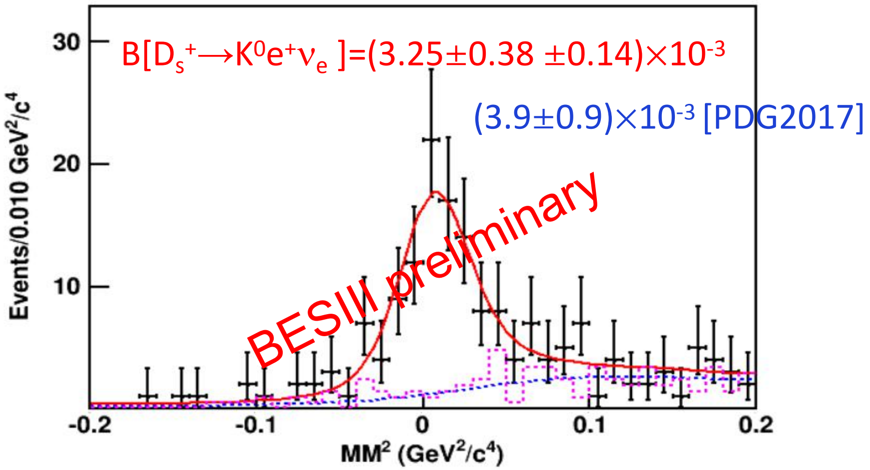
[1] PRD 91 014503
[2] JHEP 1511 138
[3] PRD 88 034023

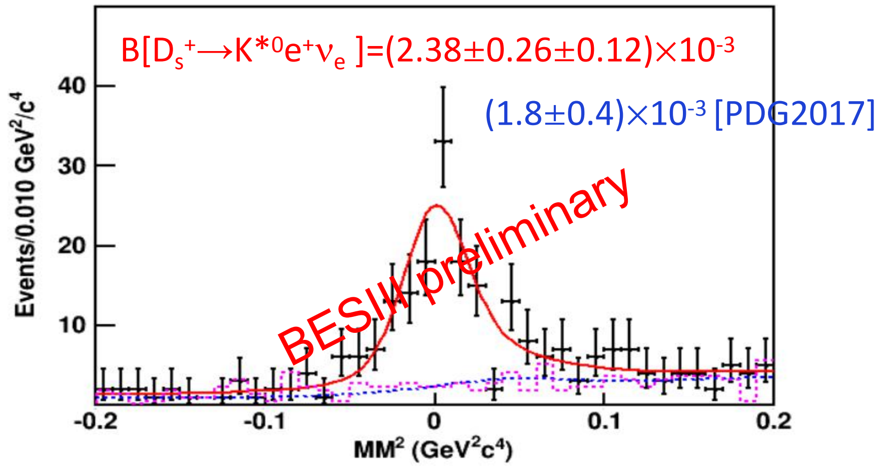
$\eta-\eta'$ mixing angle

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



Study of $D_s^+ \to K^{(*)0} e^+ \nu_e$





Fit to partial decay rates in $D_s^+ \rightarrow K^0 e^+ \nu_e$:

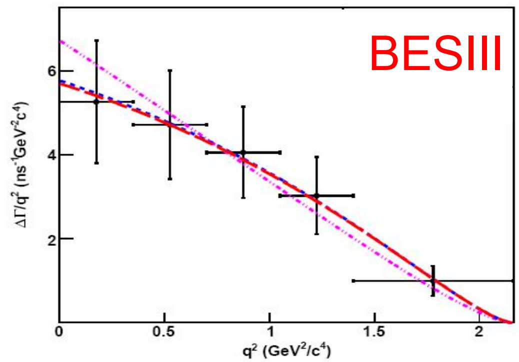
- data

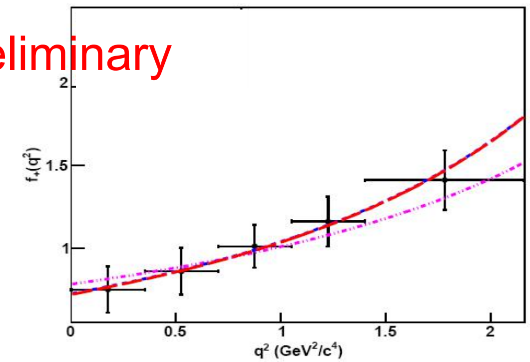
Simple pole model

Modified pole model

Series two parameter

BESIII preliminary





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	$-2.94 \pm 2.32 \pm 0.14$	

Observation of $D_s^+ \to p\bar{n}$

- Only kinematic allowed baryonic decay of charmed meson, and help for understanding the dynamical enhancement of W-annihilation
  - Short-distance expected: $Br \sim 10^{-6}$
  - Long-distance enhance to: $Br \sim 10^{-3}$

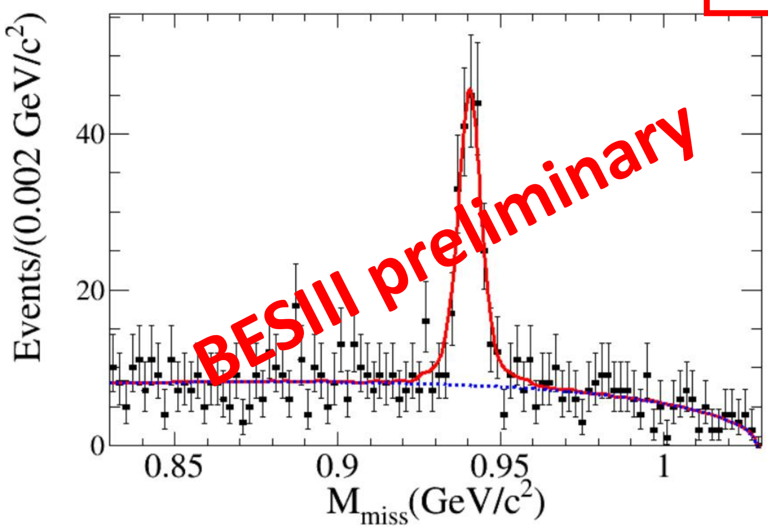
PLB663(2008)326

- First evidence was observed by CLEO-c: $(1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$

(PRL100, 181802(2008)).

preliminary result

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



- Confirm CLEO-c's measurement with greatly improved accuracy

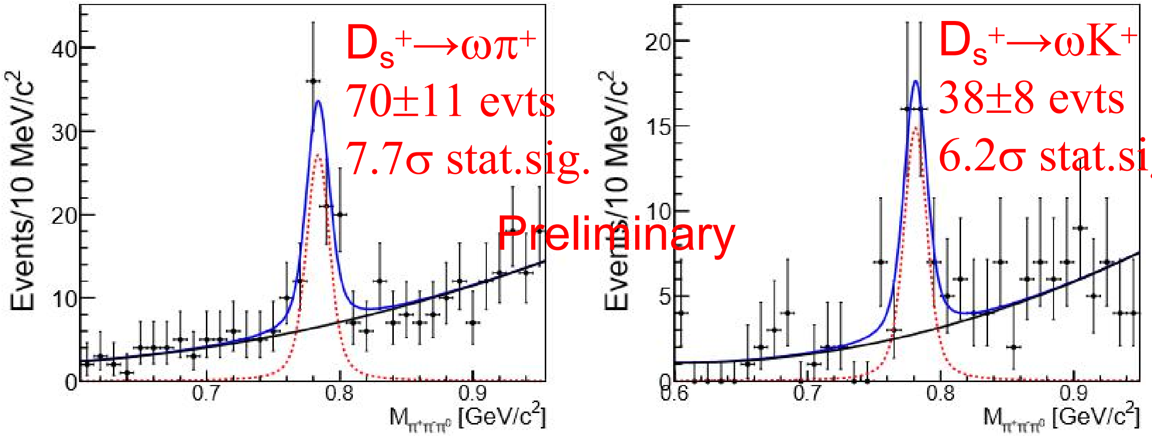
- Consistent with the prediction of the enhanced BR due to long-distance effect via hadronic loop

Observation of $D_s^+ \to \omega\pi^+$ and ωK^+

- To understand the W-annihilation amplitude
- With and without the $\rho-\pi$ mixing the Bf of $D_s^+ \to \omega K^+$, will be quite different
  - $B[D_s^+ \to \omega K^+] = 0.6\times10^{-3}$(without $\rho-\omega$ mixing)
  - $B[D_s^+ \to \omega K^+] = 0.07\times10^{-3}$(with $\rho-\omega$ mixing)

$D_s^+ \to \omega\pi^+$: Evidence by CLEO, BF = $(2.1\pm0.9\pm0.1)\times10^{-3}$ with a signal of 6.0±2.4 events.
$D_s^+ \to \omega K^+$: CLEO set an UL = 2.4×10^{-3} @90%C.L.

Fit to the invariant mass $M_{\pi+\pi-\pi0}$ to get the DT yield:



Preliminary results:

Consistent with CLEO's measurement, but more precise.

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

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

First observation !

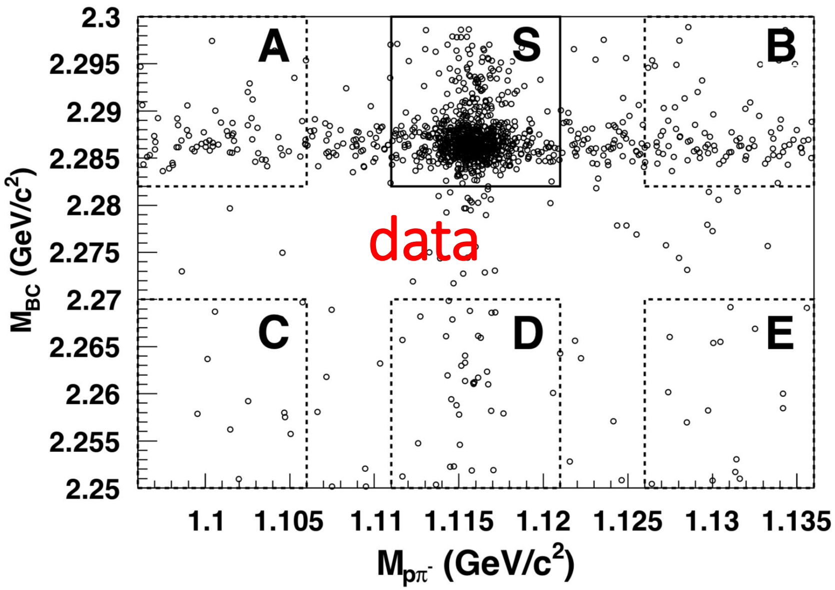
The measurement of $D_s^+ \to \omega K^+$ implies the $\rho-\omega$ mixing is negligible

Study of the inclusive decay $\Lambda_c^+ \to \Lambda X$

arXiv:1803.05706, accepted by PRL

- Mediated by c-s transition which help us understand dynamics of the lowest-lying charmed baryon [arXiv:1803.02267v3]
- Current PDG: B[$\Lambda_c^+ \to \Lambda + X$ = (35±11)%] with large uncertainty, and has not been updated since 1992.
- Search for the CPV by measuring the asymmetry

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



Extract yield from 2D distribution

$$N^{\rm sig} = N^{\rm S} - \frac{N^{\rm A} + N^{\rm B}}{2} - f \cdot (N^{\rm D} - \frac{N^{\rm C} + N^{\rm E}}{2})$$

- B[$\Lambda_c^+ \to \Lambda X$]=($38.2^{+2.8}_{-2.2}$±0.8)%
- All exclusive modes found in PDG is 24.5±2.1%. (~1/3 BFs are unknown)
- Acp = ($2.1^{+7.0}_{-6.6}$±1.4)%. (No CPV observed)

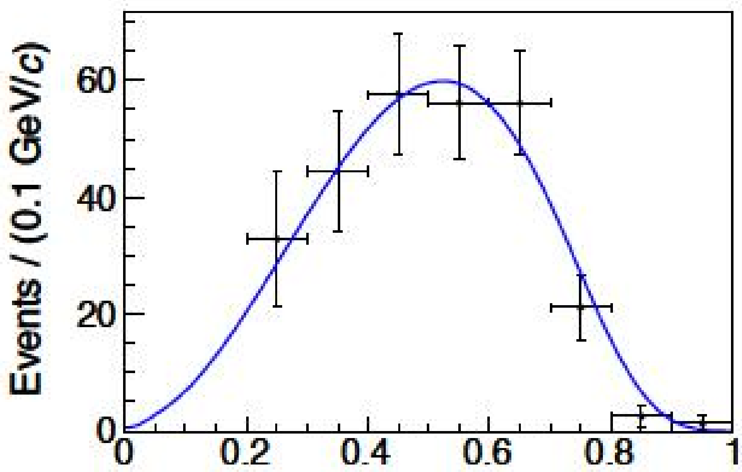
Study of the inclusive decay $\Lambda_c^+ \to e^+ X$

arXiv:1805.09060

- **Current PDG: BF($\Lambda_c^+ \to e$+X)=(4.5±1.7)%.**
- **Large rate, but also with large uncertainty**
- **Tagged with $\Lambda_c^+ \to pK^-\pi^+$ and pK_S^0**

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

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



e+ Momentum

- **The $\Lambda l^+\nu_l$ dominate the l^++X =>$\mathcal{B}$ ($pKl^+\nu_l$)~10^{-3}.**

Result	$\Lambda_c^+ \to Xe^+\nu_e$	$\frac{\Gamma(\Lambda_c^+ \to Xe^+\nu_e)}{\bar{\Gamma}(D \to Xe^+\nu_e)}$
BESIII	3.95 ± 0.35	1.26 ± 0.12
MARK II	4.5 ± 1.7	1.44 ± 0.54
Effective-quark Method		1.67
Heavy-quark Expansion		1.2

Summary

- Using e^+e^- collision data taken at 3.773, 4.178 GeV and 4.6 GeV with the BESIII detector, experimental studies of charm decays have been performed.
  - Measurements of decay constants $f_{D(s)+}$, form factors in semileptonic D decays $f_+^{K(p)}(0)$: improved calibrate LQCD/
  - Determinations of $|V_{cs(d)}|$: improved test on CKM matrix unitarity
  - $D_s^+ \to p\bar{n}$ show an enhanced branching fraction due to long-distance effect. $D_s^+ \to \omega\pi^+$ and ωK^+ confirm CLEO's measurements with greatly improved precision.
  - Inclusive decays are studied in Λc^+.

谢谢！！

- More result will be coming in the near future.