Pure and semi-leptonic decays of $D_{(s)}$ at BESIII

Huijing LI

(On behalf of BESIII Collaboration)
(Institute of High Energy Physics, Beijing, China)

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MEETING OF THE AMERICAN PHYSICAL SOCIETY DIVISION OF PARTICLES AND FIELDS

Outline

- **Introduction**

- **$D_{(s)}$ pure leptonic decay**
  - $D^+ \to l^+ \nu, (l = \mu,\tau)$
  - $D_s^+ \to l^+ \nu, (l = \mu,\tau)$

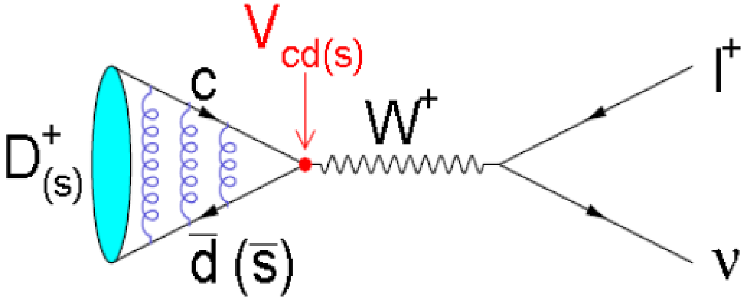
- **$D_{(s)}$ semi-leptonic decay**
  - $D^{0(+)} \to P\, l^+ \nu\ (P= K, \pi;\ l = e, \mu)$
  - $D^{0(+)} \to a0(980)^{-(0)} e^+ \nu_e$
  - $D_s^+ \to K^{(*)0} e^+ \nu_e$

- **D rare decay**
  - $D^+ \to \gamma\, e^+ \nu_e$
  - $D^+ \to D^0 e^+ \nu_e$

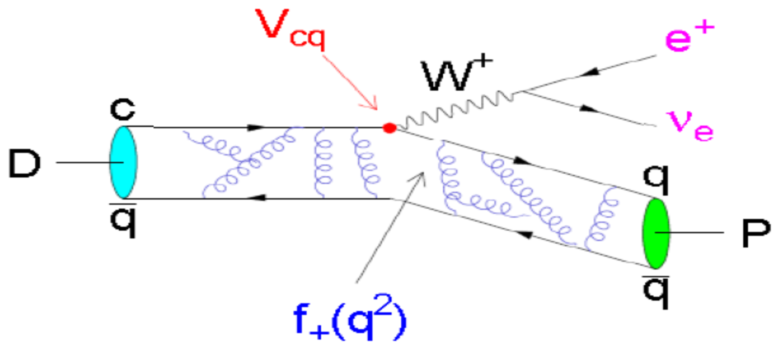
- **Summary**

Main goals

$D_{(s)}$ pure leptonic decay



$D_{(s)}$ semi-leptonic decay



$$\Gamma(D^+_{(s)} \rightarrow l^+ \nu_l) \propto |f_{D(s)+}|^2 \cdot |V_{cd(s)}|^2$$

$$\Gamma(D^+_{(s)} \rightarrow P\, l^+ \nu_l) \propto |f_+^{K(\pi)}(q^2)|^2 \cdot |V_{cd(s)}|^2$$

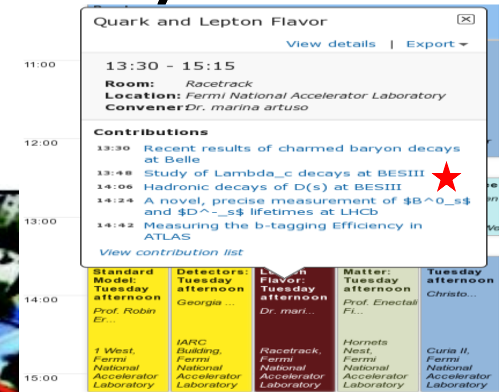
- **Decay constant $f_{D(s)+}$, form factor $f_+^{K(\pi)}(0)$: better calibrate Lattice QCD**
- **CKM matrix element $|V_{cs(d)}|$: better test the unitarity of the CKM matrix.**

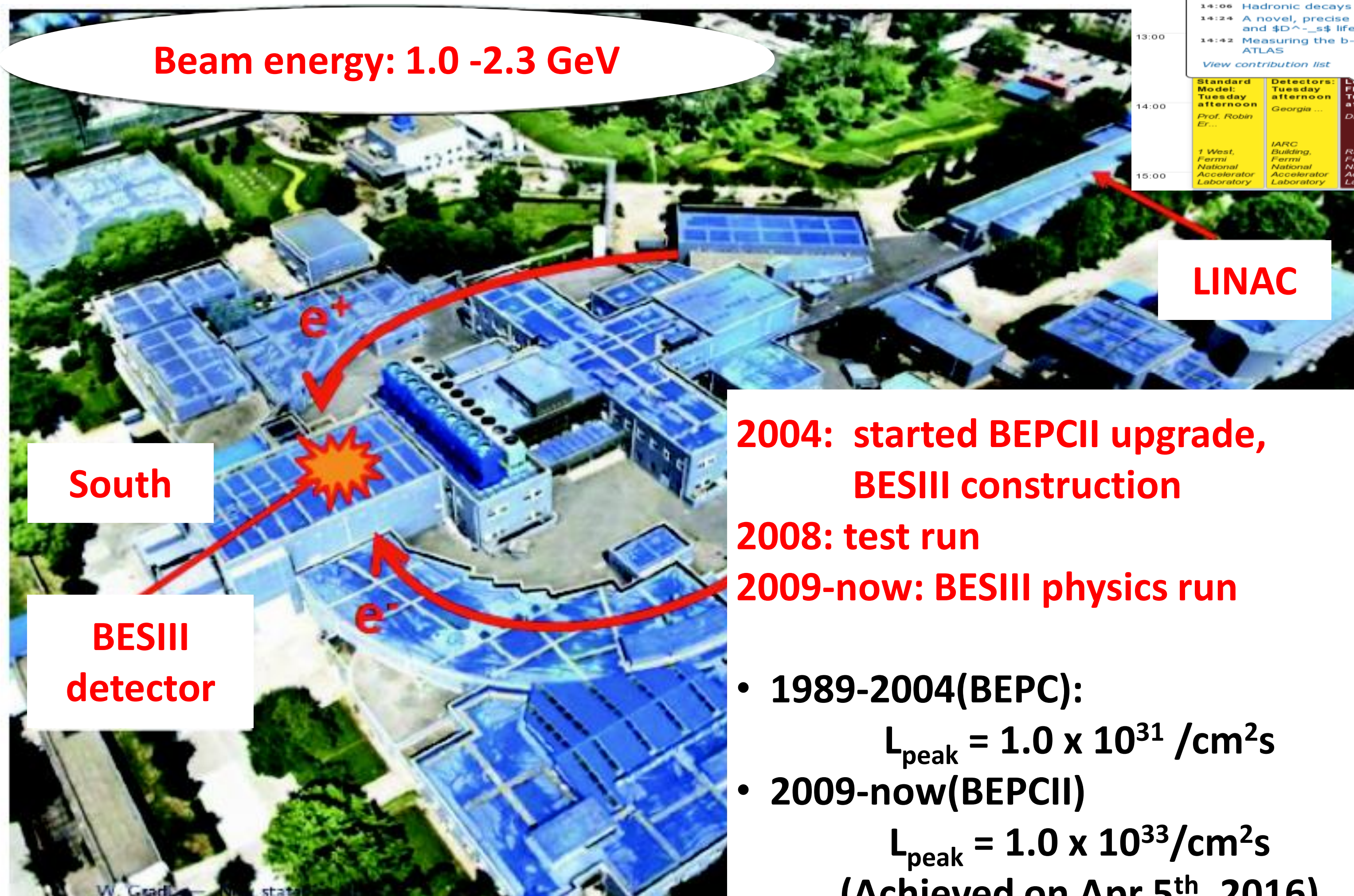
$$U = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

Beijing Electron Positron Collider (BEPCII) in China

A double-ring collider with high luminosity

See Hajime and Bai-Cian's talks at BESIII in the afternoon on August 1st.





2004: started BEPCII upgrade, BESIII construction

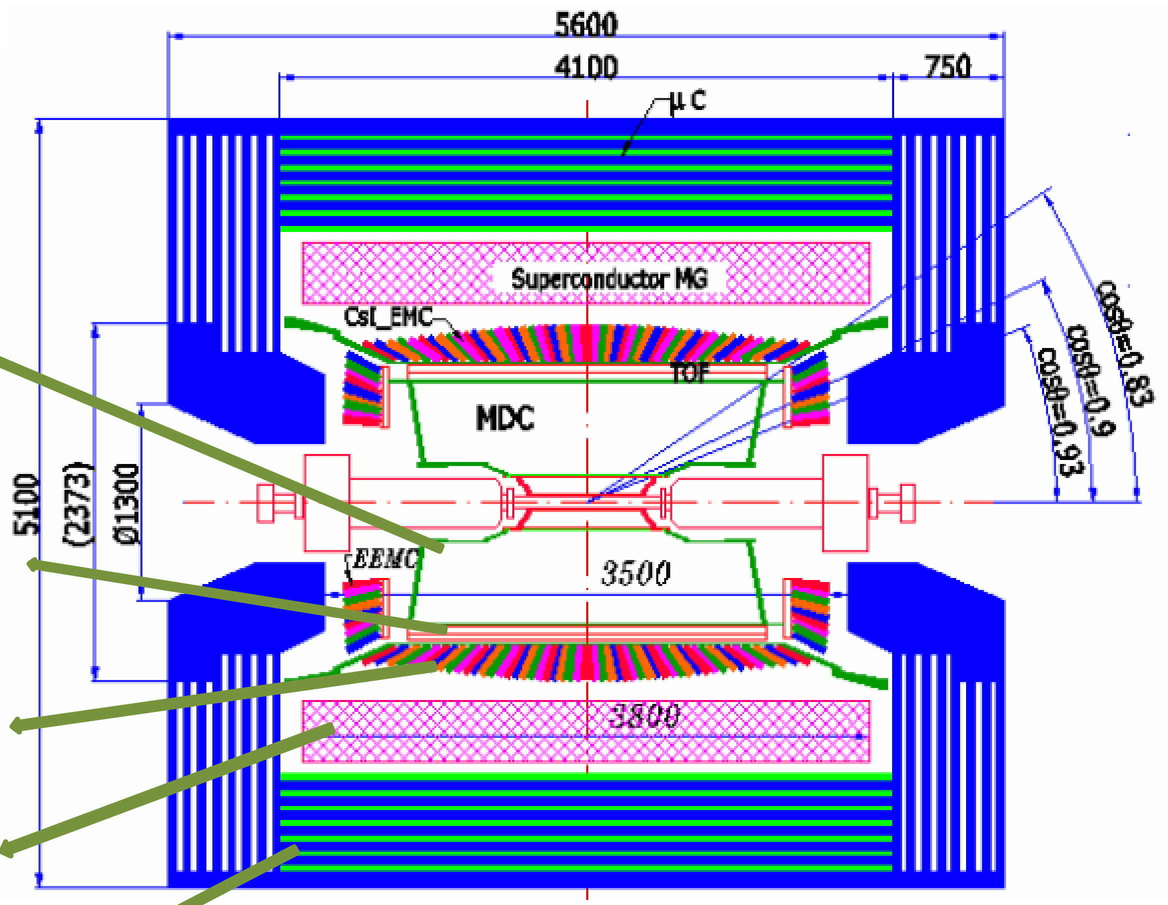
2008: test run

2009-now: BESIII physics run

- 1989-2004(BEPC):
  $L_{peak} = 1.0 \times 10^{31}\ /cm^2s$
- 2009-now(BEPCII)
  $L_{peak} = 1.0 \times 10^{33}/cm^2s$
  (Achieved on Apr 5th, 2016)

BESIII detector

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



From inner to outside:

MDC: small cell & Gas:He/C_3H_8(60/40), 43 layers; σ_{xy} = 130 μm ; σ_p/p = 0.5% @1 GeV; dE/dx = 6%

TOF: σ_T = 100 ps Barrel, 110 ps Endcap

EMC: CsI crystal, 28 cm; ΔE/E = 2.5% @1 GeV ; σ_z = 0.6 cm/√E

Magnet: 1T Super conducting

MUC: 9 layers RPC, 8 layers for endcaps

Data Acquisition:
Event rate = 4k Hz
Total data volume ~ 50 MB/s

$D^{0(+)}$ and D_s^+ data set at BESIII

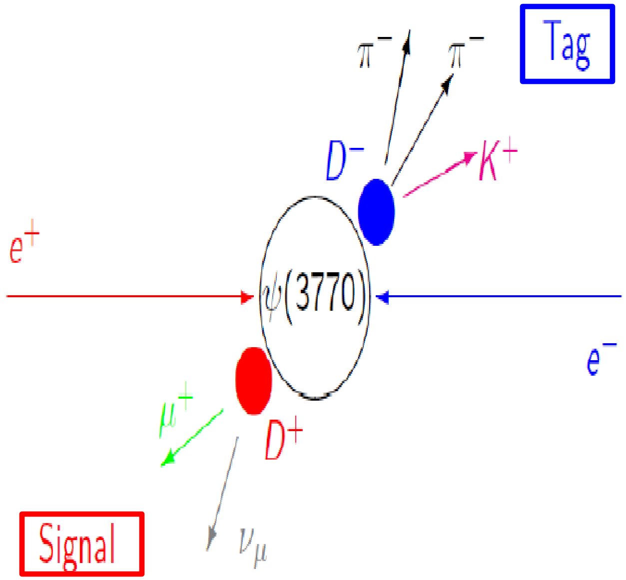
- $D^{0(+)}$ data:
  - Taken @ E_{cm} = 3.773 GeV.
  - Integrated luminosity = 2.93 fb^{-1}
    (The world's largest e^+e^- annihilation sample taken at the mass-threshold).
  - cross section: $\sigma(e^+e^- \to D^0\bar{D}^0)$ ~ 3.6 nb $\Rightarrow$ 21 M D^0 produced!
  - cross section: $\sigma(e^+e^- \to D^+D^-)$ ~ 2.9 nb $\Rightarrow$ 16 M D^+ produced!

- D_s^+ data:
  - @E_{cm} = 4.009 GeV.
    - Integrated luminosity = 0.482 fb^{-1}
    - $\sigma(e^+e^- \to D_s^+D_s^-)$ ~ 0.3 nb $\Rightarrow$ 0.3 M D_s produced.
    - D_s is produced in pair with equal mass.
  - @E_{cm} = 4.178 GeV.
    - Based on the data accumulated in 2016!
    - Integrated luminosity = 3.19 fb^{-1}
    - $\sigma(e^+e^- \to D_s^*D_s)$ ~ 1 nb $\Rightarrow$ ~ 6 M D_s produced!!

Tagging method

$e^+ e^- \to \psi(3770) \to D^+ D^-$
2.93 fb^{-1} @3.773 GeV

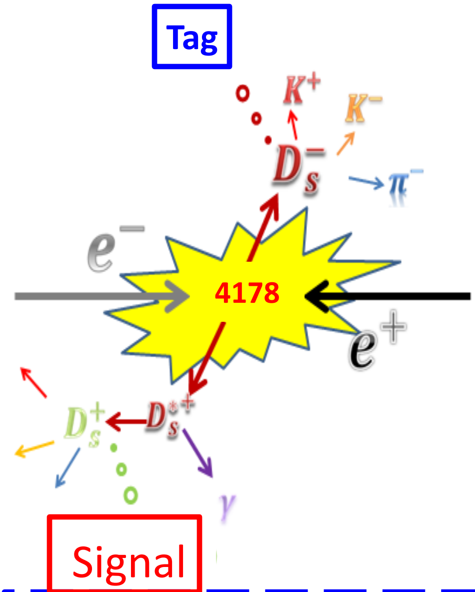
$e^+ e^- \to D_s^{*+} D_s^-$
3.19 fb^{-1} @4.178 GeV



Charge conjugated processes are implied

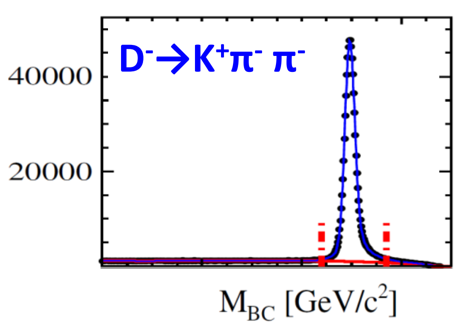
The signal branching fraction:

$$\mathcal{B}_{\rm sig} = \frac{N_{\rm sig}}{N_{D_{(s)}}^{\rm tag} \times \epsilon}$$



For Tag side(reconstructed from $K^+\pi^-\pi^-$):

$$\Delta E = E_{D^-} - E_{\rm beam}$$
$$M_{\rm BC} = \sqrt{E^2_{\rm beam} - |\vec{p}_{D^-}|^2}$$

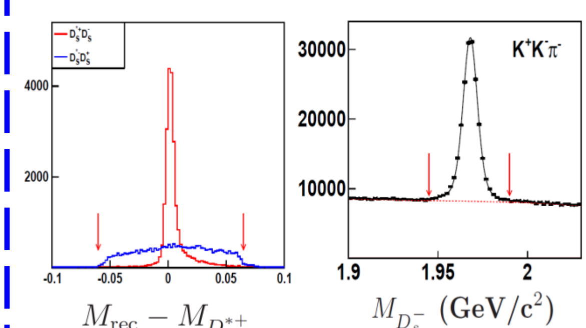


For Signal side(reconstruct μ^+):

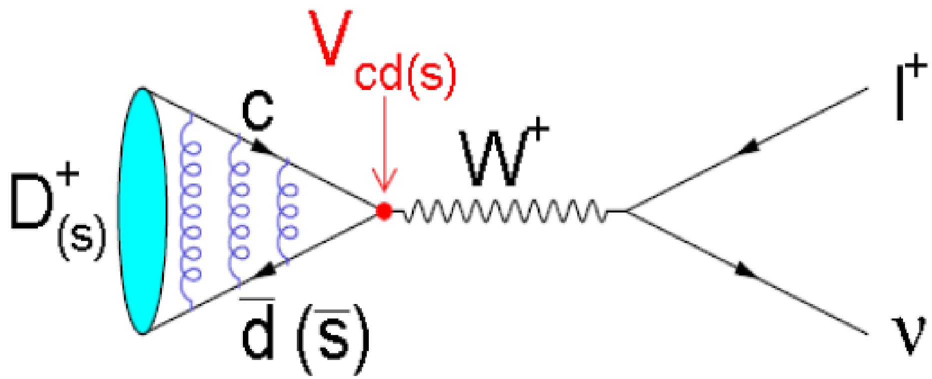
$$E_{\rm miss} = E_{\rm beam} - E_{\mu^+}$$
$$\vec{p}_{\rm miss} = -\vec{p}_{D^-} - \vec{p}_{\mu^+}$$
$$M^2_{\rm miss} = E^2_{\rm miss} - |\vec{p}_{\rm miss}|^2$$
$$U_{\rm miss} = E_{\rm miss} - |\vec{p}_{\rm miss}|$$

For Tag side(reconstructed from $K^+K^-\pi^-$):

$$M_{\rm rec} = \sqrt{(E_{\rm cm} - \sqrt{|\vec{p}_{D_s^-}|^2 + m^2_{D_s^-}})^2 - |-\vec{p}_{D_s^-}|^2}$$



$D_{(s)}^+$ pure leptonic decay



In the SM: $$\Gamma(D_{(s)}^{+} \to l^{+}\nu) = \frac{G_F^2 f_{D_{(s)}^{+}}^2}{8\pi} |V_{cd(s)}|^2 m_l^2 m_{D_{(s)}^{+}} (1 - \frac{m_l^2}{m_{D_{(s)}^{+}}^2})^2$$

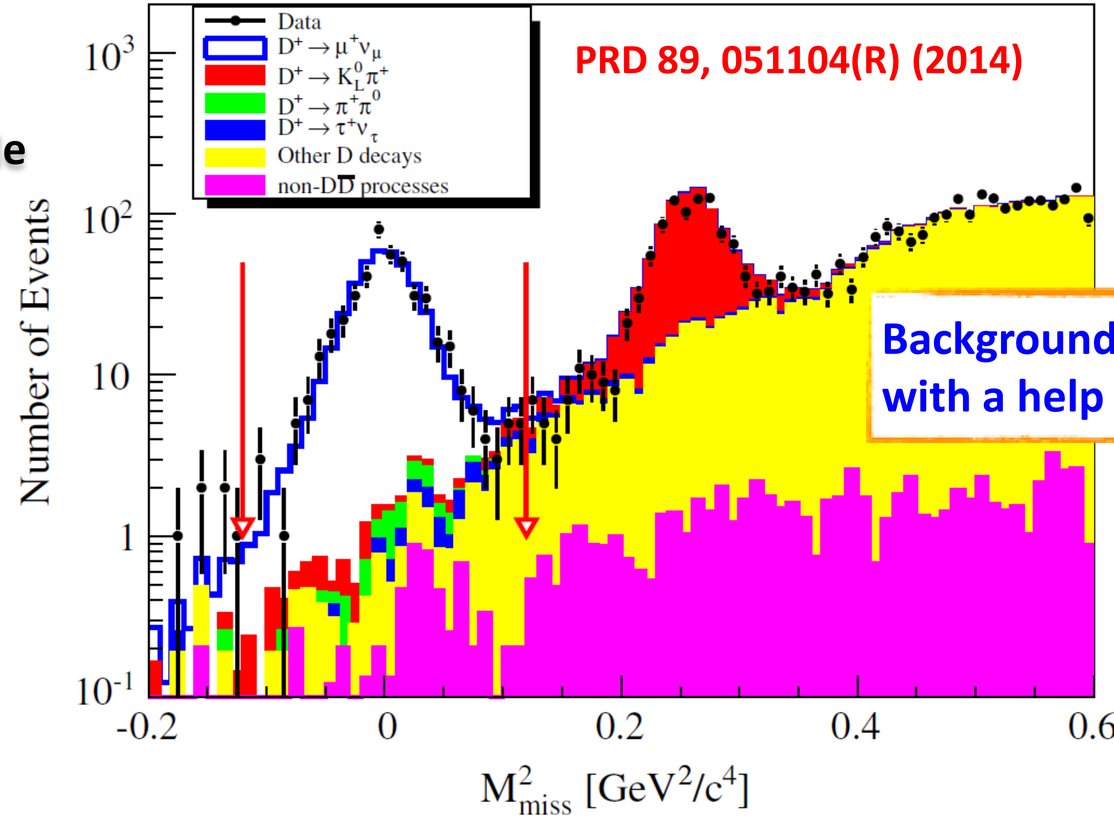
Measure the product of $f_{D(s)+}$ and $|V_{cd(s)}|$ directly

Bridge to precisely measure

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

Precision measurements of B($D^+ \rightarrow \mu^+ \nu$), f_{D+} and $|V_{cd}|$

Log scale



$D^+ \rightarrow \mu^+ \nu$

409±21 signals

Backgrounds are greatly suppressed with a help of our Muon-Counter!

B($D^+ \rightarrow \mu^+ \nu$) = (3.71 ± 0.19 ± 0.06) x 10^{-4}

Input
$|V_{cd}|$ = 0.22520 ± 0.0065
from SM global fit

Input
f_{D+} = (207 ± 4) MeV
from LQCD [PRL 100, 062002(2008)]

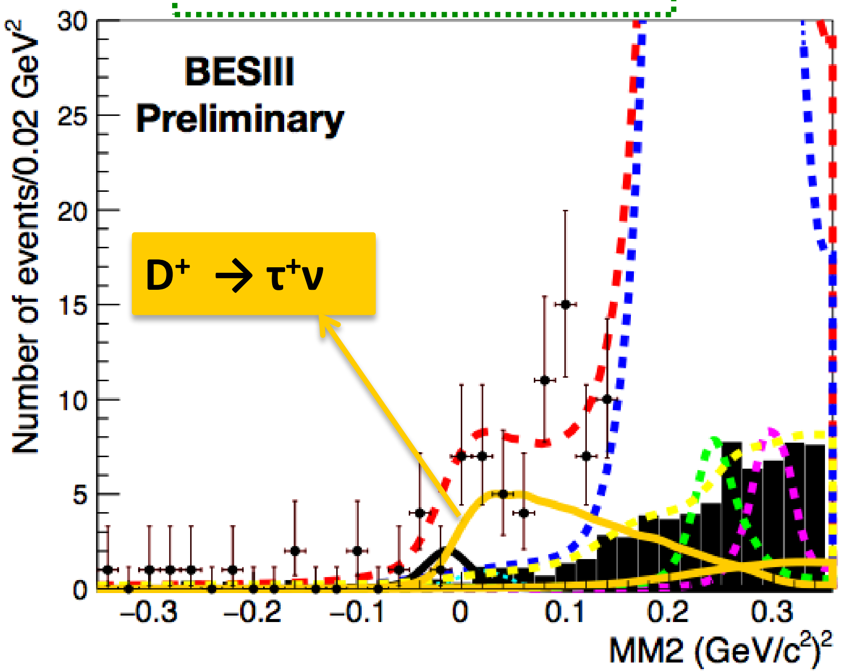
f_{D+} = (203.2 ± 5.3 ± 1.8) MeV

$|V_{cd}|$ = 0.2210 ± 0.0058 ± 0.0047

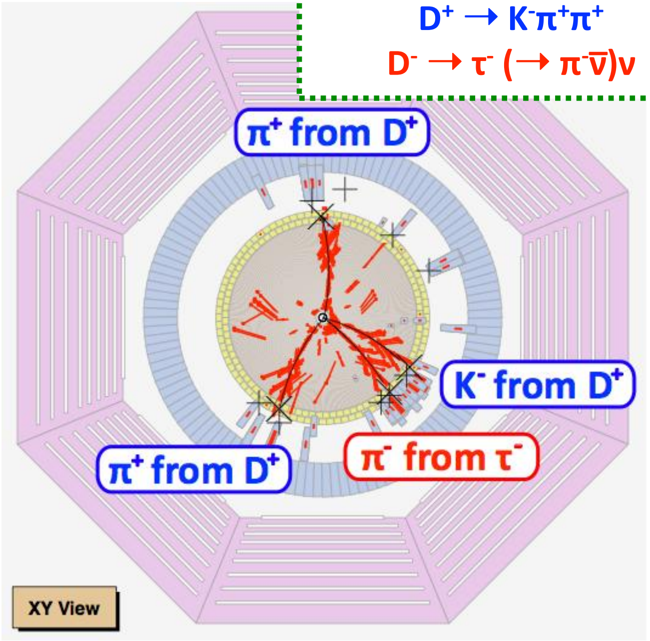
First evidence for $D^+ \to \tau^+\nu$ via $\tau^+ \to \pi^+\nu$ (> 4σ)

- Split sample into TWO (μ dominant & π dominant)
- Simultaneous un-binned maximum likelihood fit

The π dominant sample



A single candidate event:
$D^+ \to K^-\pi^+\pi^+$
$D^- \to \tau^-(\to \pi^-\bar{\nu})\nu$



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

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

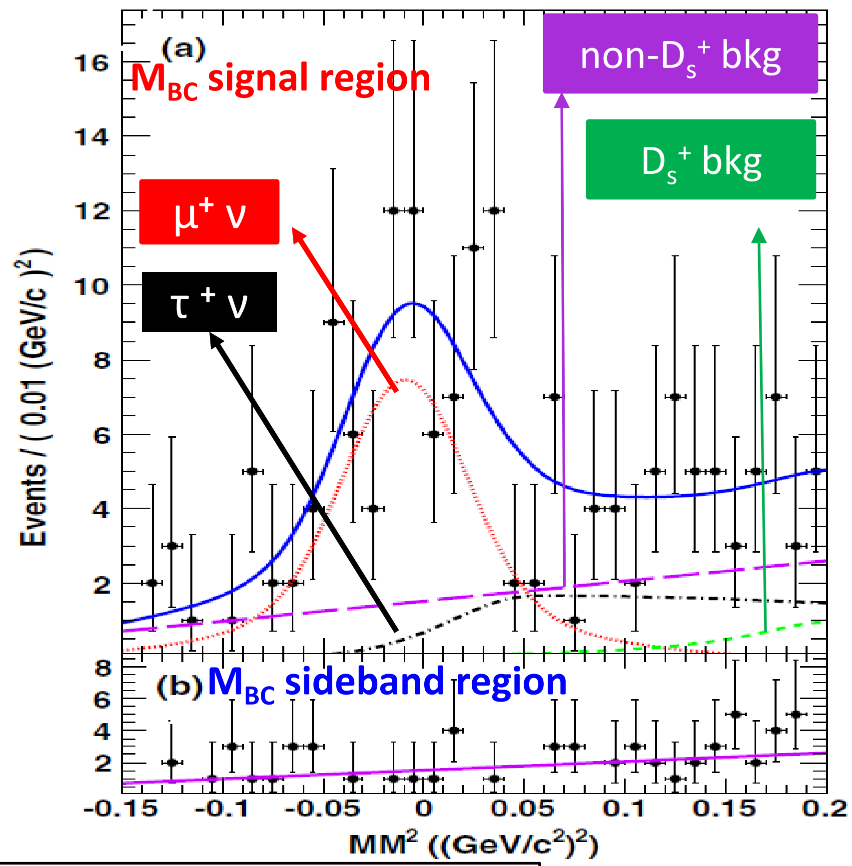
= 3.21 ± 0.64 (BESIII)

= 2.66 ± 0.01 (SM prediction)

$D_s^+ \to l^+ \nu$ ($l = \mu, \tau$) decays

$e^+ e^- \to D_s^+ D_s^-$ 482 pb^{-1} @4.009 GeV

Simultaneous fit **PRD 94, 072004(2016)**



Fixing ratio of the two;

(fix $R \equiv \Gamma(D_s^+ \to \tau^+\nu_\tau)/\Gamma(D_s^+ \to \mu^+\nu_\mu) = 9.76$)

	N_{sig}	$\mathcal{B}$ (%)
$D_s^+ \to \mu^+ \nu$	69.3 ± 9.3	0.495 ± 0.067 ± 0.026
$D_s^+ \to \tau^+(\pi^+\nu)\nu$	32.5 ± 4.3	4.83 ± 0.65 ± 0.26

From the measured BF($D_s^+ \to \mu^+\nu$)

Input

$|V_{cs}| = |V_{ud}| = 0.97425(22)$

in PDG

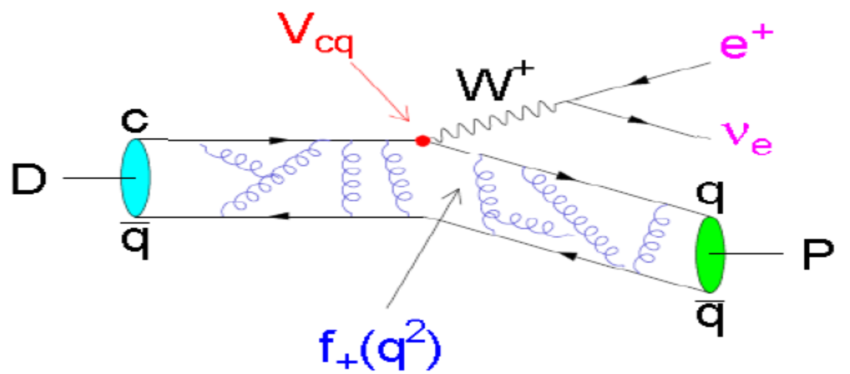
f_{Ds+} = (241.0 ± 16.3 ± 6.6) MeV

If we don't fix the ratio

	N_{sig}	$\mathcal{B}$ (%)
$D_s^+ \to \mu^+ \nu$	72.4 ± 10.4	0.517 ± 0.075 ± 0.021
$D_s^+ \to \tau^+(\pi^+\nu)\nu$	22.1 ± 12.3	3.28 ± 1.83 ± 0.37

$D_{(s)}$ semi-leptonic decay

$D \to P e^+ \nu$ (P= K, π)



Differential rates: $\frac{d\Gamma}{dq^2} = X \frac{G_F^2 p^3}{24\pi^3} |f_+(q^2)|^2 |V_{cd(s)}|^2$ $(X = 1 \text{ for } K^-, \pi^-, \bar{K}^0;\ X = 1/2 \text{ for } \pi^0)$

Bridge to precisely measure

- **Form factors $f_+^{D\to K(\pi)}(0)$ with input $|V_{cd(s)}|^{\text{CKM fitter}}$**
  - -- Single pole form

    $$f_+(q^2) = \frac{f_+(0)}{1 - q^2/M_{\text{pole}}^2}$$
  - -- Modified pole model

    $$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{M_{\text{pole}}^2}\right)\left(1 - \alpha \frac{q^2}{M_{\text{pole}}^2}\right)}$$
  - -- ISGW2 model

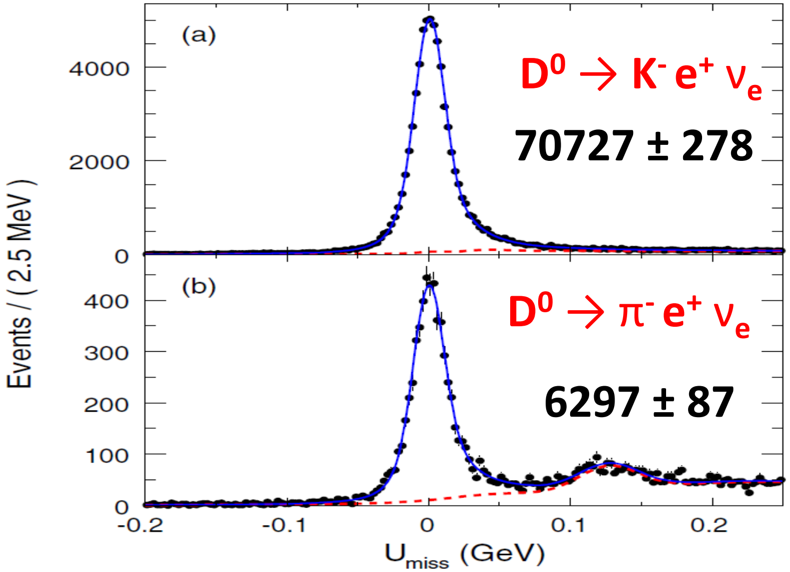
    $$f_+(q^2) = f_+(q_{\text{max}}^2)(1 + \frac{r^2}{12}(q_{\text{max}}^2 - q^2))^{-2}$$
  - -- Series expansion

    $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0)\left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$
- **CKM matrix element $|V_{cd(s)}|$ with input $f_+^{LQCD, D\to K(\pi)}(0)$**

$D \to K(\pi) e^+ \nu_e$

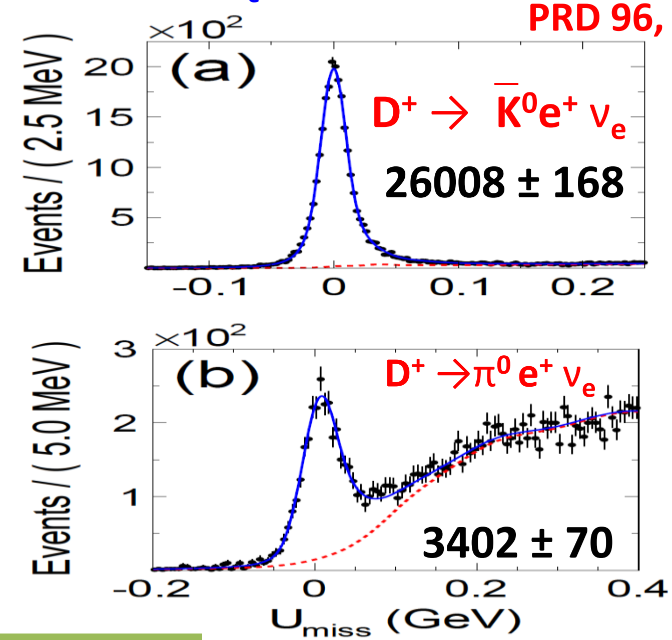
$B(D^0 \to K^- e^+ \nu_e) = (3.505 \pm 0.014 \pm 0.033)\%$
$B(D^0 \to \pi^- e^+ \nu_e) = (0.295 \pm 0.004 \pm 0.003)\%$

PRD 92, 072012 (2015)

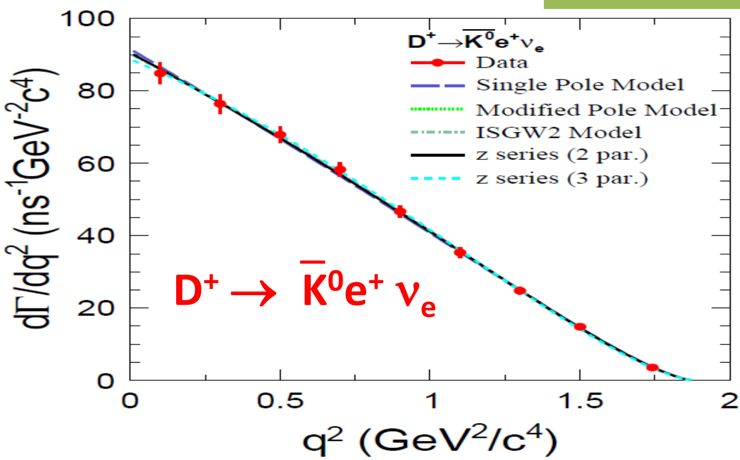


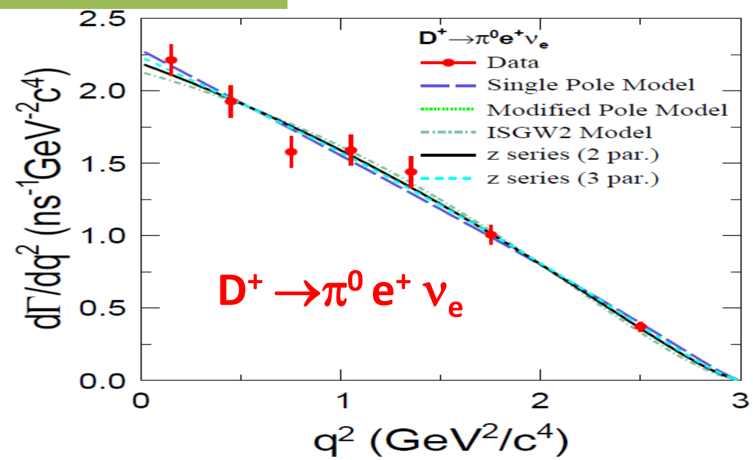
$B(D^+ \to \bar{K}^0 e^+ \nu_e) = (8.60 \pm 0.06 \pm 0.15)\%$
$B(D^+ \to \pi^0 e^+ \nu_e) = (0.363 \pm 0.008 \pm 0.005)\%$

PRD 96, 012002 (2017)



Differential decay rates





Other D → K(π) $l^+ \nu_l$ at BESIII

- $B(D^+ \to K_L^0 e^+ \nu_e)$ = (4.481 ± 0.027 ±0.103) % [PRD 92, 112008 (2015)]
- $B(D^+ \to K_S^0 (\to \pi^0\pi^0) e^+ \nu_e)$ = (8.59 ± 0.14 ±0.21) % [CPC 40, 113001 (2016)]
- $B(D^+ \to K_S^0 (\to \pi^+\pi^-/\pi^0\pi^0) \mu^+ \nu_\mu)$ = (8.72 ± 0.07 ±0.08) % [EPJC 76, 369 (2016)]
- $B(D^+ \to \pi^0 \mu^+ \nu_\mu)$ = (0.342 ± 0.011 ±0.010) % Preliminary
- $B(D^0 \to \pi^- \mu^+ \nu_\mu)$ = (0.267 ± 0.007 ±0.007) % Preliminary

❑ **Isospin conservation: consistent**

$$\frac{\Gamma(D^0\to\pi^-\mu^+\nu)}{2\Gamma(D^+\to\pi^0\mu^+\nu)} = 0.990 \pm 0.054$$ within uncertainty $$\frac{\Gamma(D^0\to\pi^-e^+\nu)}{2\Gamma(D^+\to\pi^0e^+\nu)} = 1.03 \pm 0.03 \pm 0.02$$

$$\frac{\Gamma(D^0\to K^-\mu^+\nu)}{\Gamma(D^+\to \bar{K}^0\mu^+\nu)} = 0.963 \pm 0.044$$ within errors $$\frac{\Gamma(D^0\to K^-e^+\nu)}{\Gamma(D^+\to \bar{K}^0e^+\nu)} = 1.03 \pm 0.01 \pm 0.02$$

❑ **Leptonic universality: consistent with the predicted value 0.97**

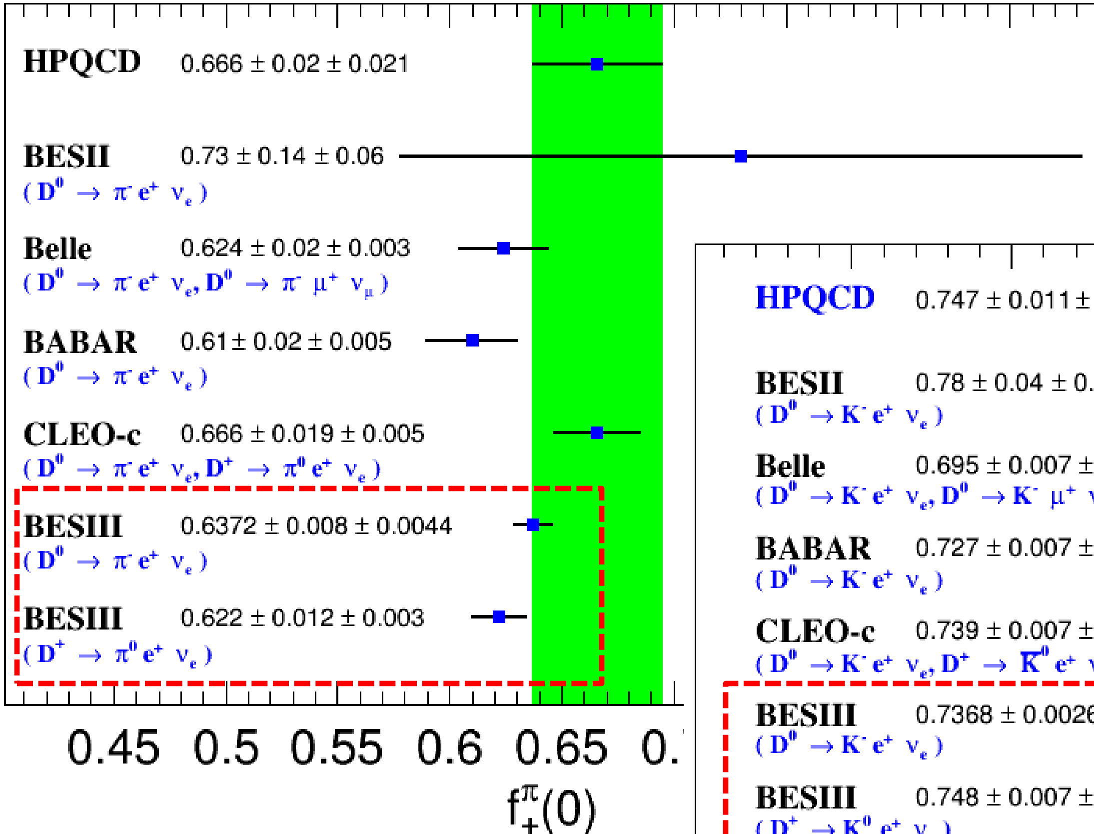
[ZPC 46, 93 (1990); PRD 69, 074025 (2004); PLB 633, 61 (2006)]

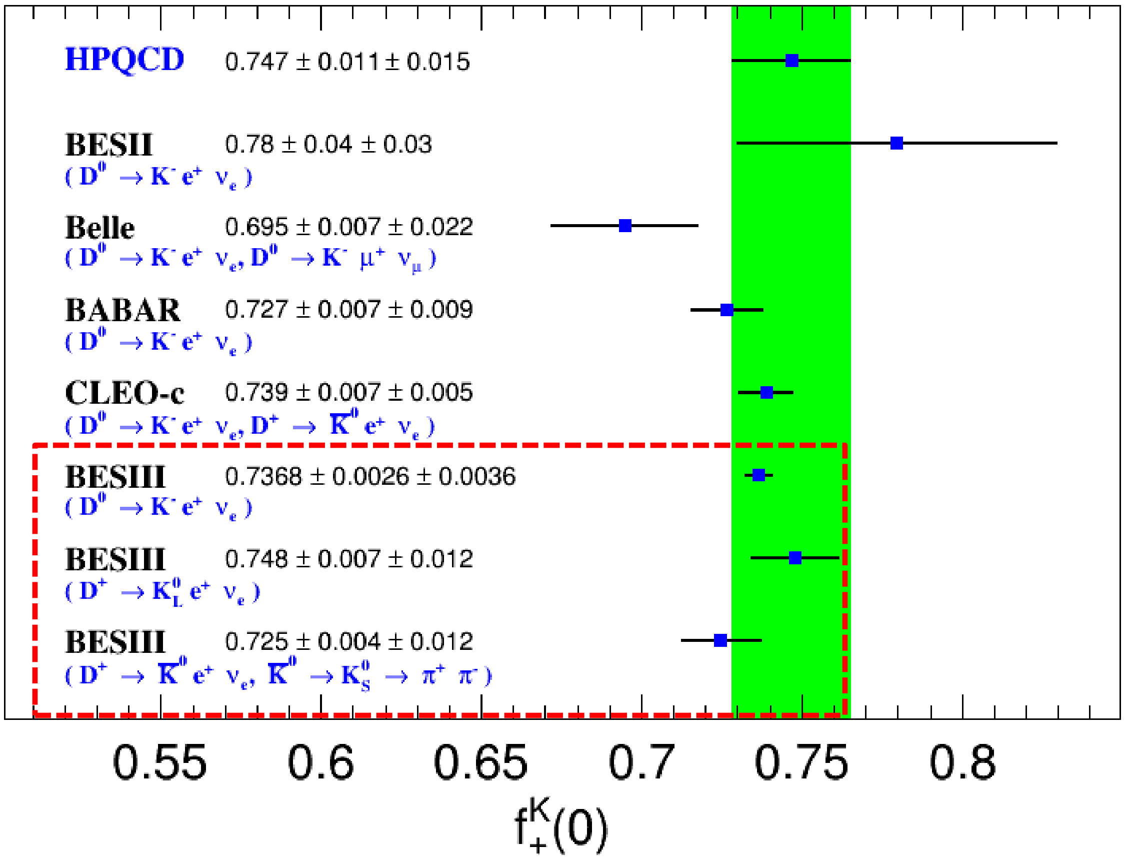
$$\frac{B(D^+\to\pi^0\mu^+\nu)}{B(D^+\to\pi^0e^+\nu)} = 0.921 \pm 0.045$$ within 1.1σ Preliminary

$$\frac{B(D^0\to\pi^-\mu^+\nu)}{B(D^0\to\pi^-e^+\nu)} = 0.918 \pm 0.036$$ within 1.5σ Preliminary

$$\frac{\Gamma(D^+\to\bar{K}^0\mu^+\nu)}{\Gamma(D^+\to\bar{K}^0e^+\nu)} = 0.988 \pm 0.033$$ within error

Comparisons of FFs by D → K(π) $e^+ \nu_e$





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

- Nontrivial internal structure of light hadron mesons.
- With chiral unitarity approach in the coupled channels, BF is predicted to be ~5×10^{-5}.

2-dimentional fit

BESIII preliminary

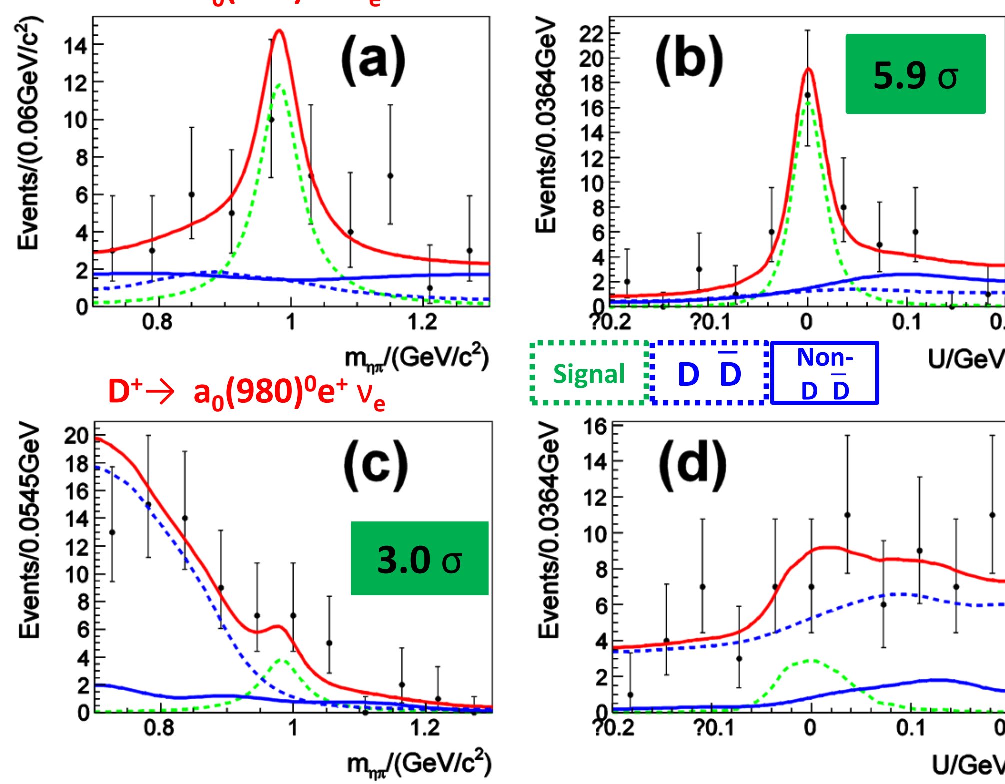
- Improve understanding of classification of light scalar mesons

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

R= 1(3) if traditional qqbar (tetra quark) system

(W. Wang and C-D. Lu, PRD 82 034016 (2010)

$D^0 \to a_0(980)^- e^+ \nu_e$



$B(D^0 \to a_0(980)^- e^+ \nu_e) \times B(a_0(980)^- \to \eta\pi^-)$

$$= (1.12 \pm 0.29(\text{stat}) \pm 0.10(\text{syst})) \times 10^{-4}$$

$B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0) =$

$$= (1.47 \pm 0.66(\text{stat}) \pm 0.14(\text{syst})) \times 10^{-4}$$

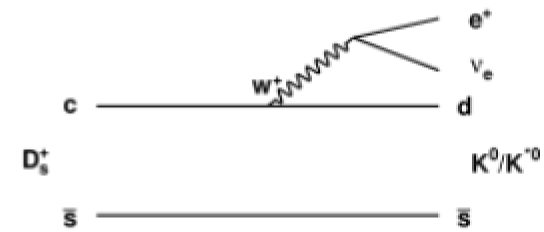
$B(D^+ \to a_0(980)^0 e^+ \nu_e) \times B(a_0(980)^0 \to \eta\pi^0)$
$< (2.7 \times 10^{-4})$ at 90% C.L.

NEW result based on the 4178 MeV data!

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

- Based on the data accumulated last year!
- Taken @ E_{cm} = 4178 MeV
- Integrated luminosity = 3.19 fb^{-1}
- $\sigma(e^+e^- \to D_s^* D_s)$ ~ 1 nb ⇒ ~ 6 M D_s produced!!

Cabibbo-suppressed



Currently measurements are only from one single experiment

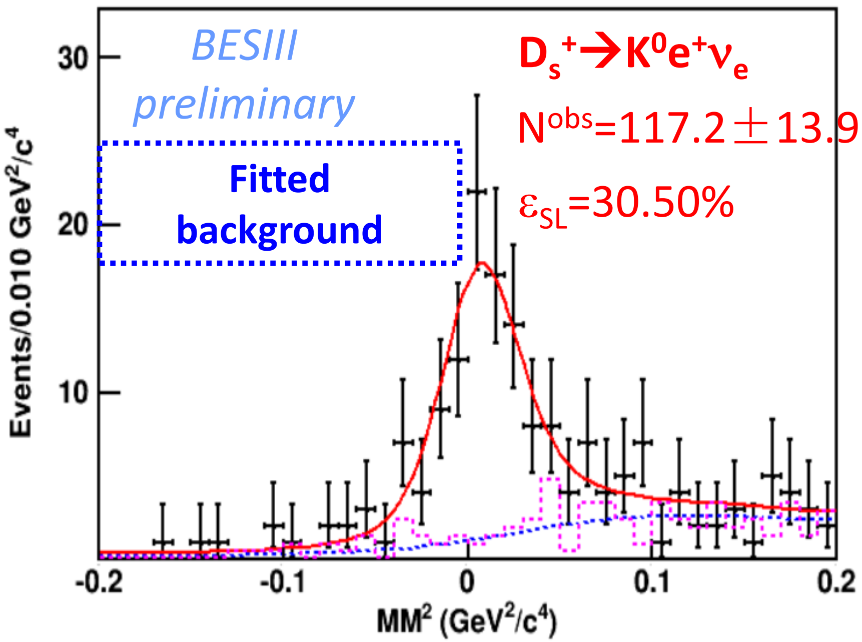
$\Gamma(D_s^+ \to K^*(892)^0 e^+ \nu_e)/\Gamma_{total}$ Γ_{29}/Γ

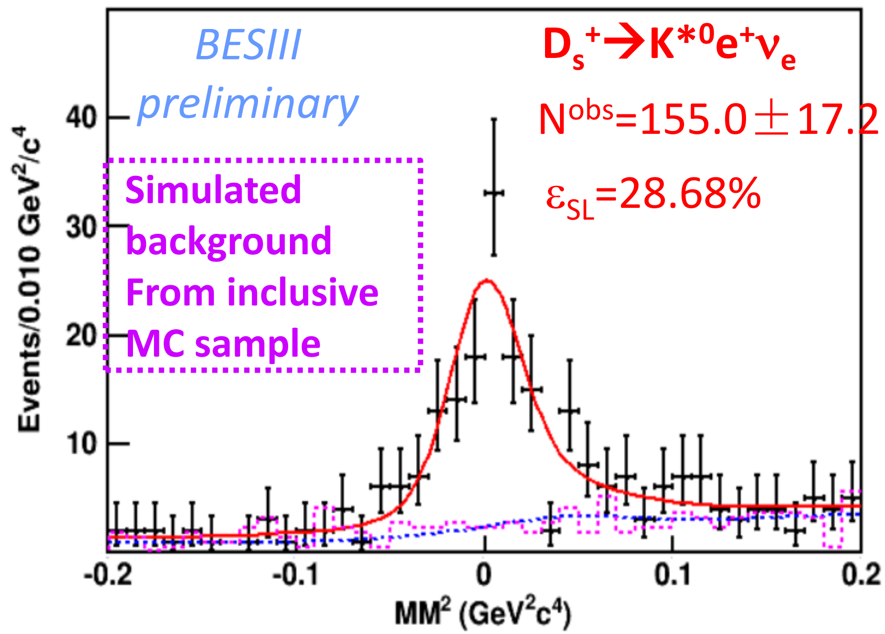
VALUE (10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
0.18 ±0.04 ±0.01	32	HIETALA	2015		Uses CLEO data
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.18 ±0.07 ±0.01	7.5	YELTON	2009	CLEO	See HIETALA 2015

$\Gamma(D_s^+ \to K^0 e^+ \nu_e)/\Gamma_{total}$ Γ_{28}/Γ

VALUE (10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
0.39 ±0.08 ±0.03	42	HIETALA	2015		Uses CLEO data
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.37 ±0.10 ±0.02	14	YELTON	2009	CLEO	See HIETALA 2015

Branching fraction of $D_s^+ \rightarrow K^{(*)0} e^+ \nu_e$

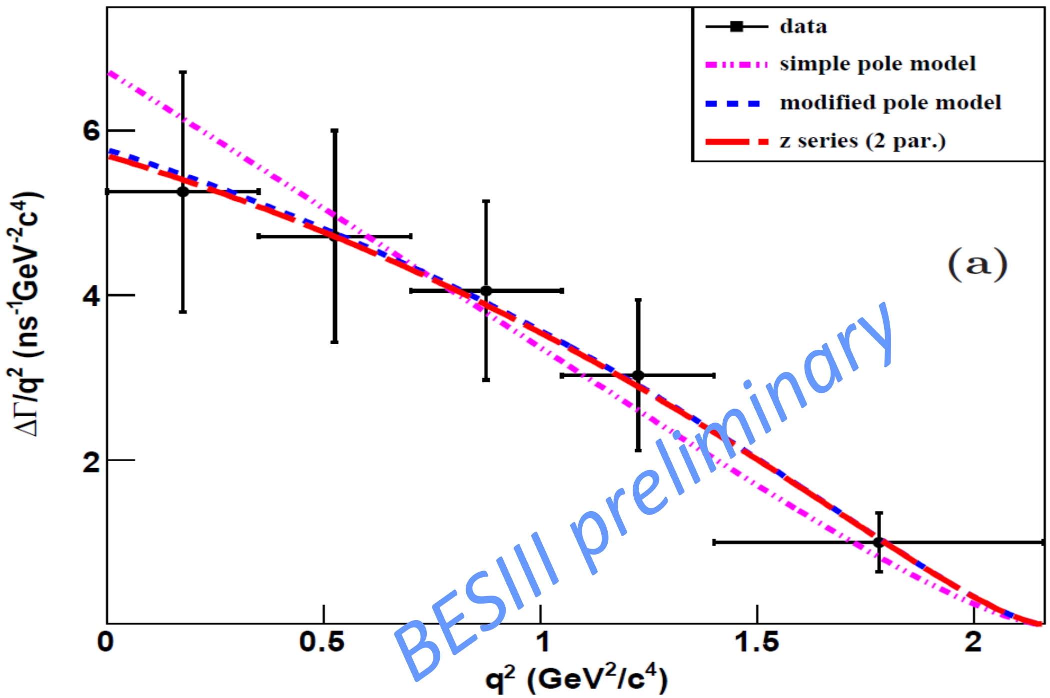




Channel	Measured BFs [$\times 10^{-3}$]	Predicated BFs [$\times 10^{-3}$]
$D_s^+ \rightarrow K^0 e^+ \nu_e$	3.9 ± 0.9 [PDG2017] $3.25 \pm 0.38 \pm 0.14$ [BESIII preliminary]	2.0 [1] 3.2 [2] $3.90^{+0.74}_{-0.57}$ [3] 2.9 [4]
$D_s^+ \rightarrow K^{*0} e^+ \nu_e$	1.8 ± 0.4 [PDG2017] $2.38 \pm 0.26 \pm 0.12$ [BESIII preliminary]	2.2 [5] 1.9 [2] $2.33^{+0.29}_{-0.30}$ [3] 1.7 [4]

- **Consistent with the PDG.**
- **Still, statistically limited.**
- **Fitting error dominates systematics.**

Form factor measurement from $D_s^+ \to K^0 e^+ \nu_e$



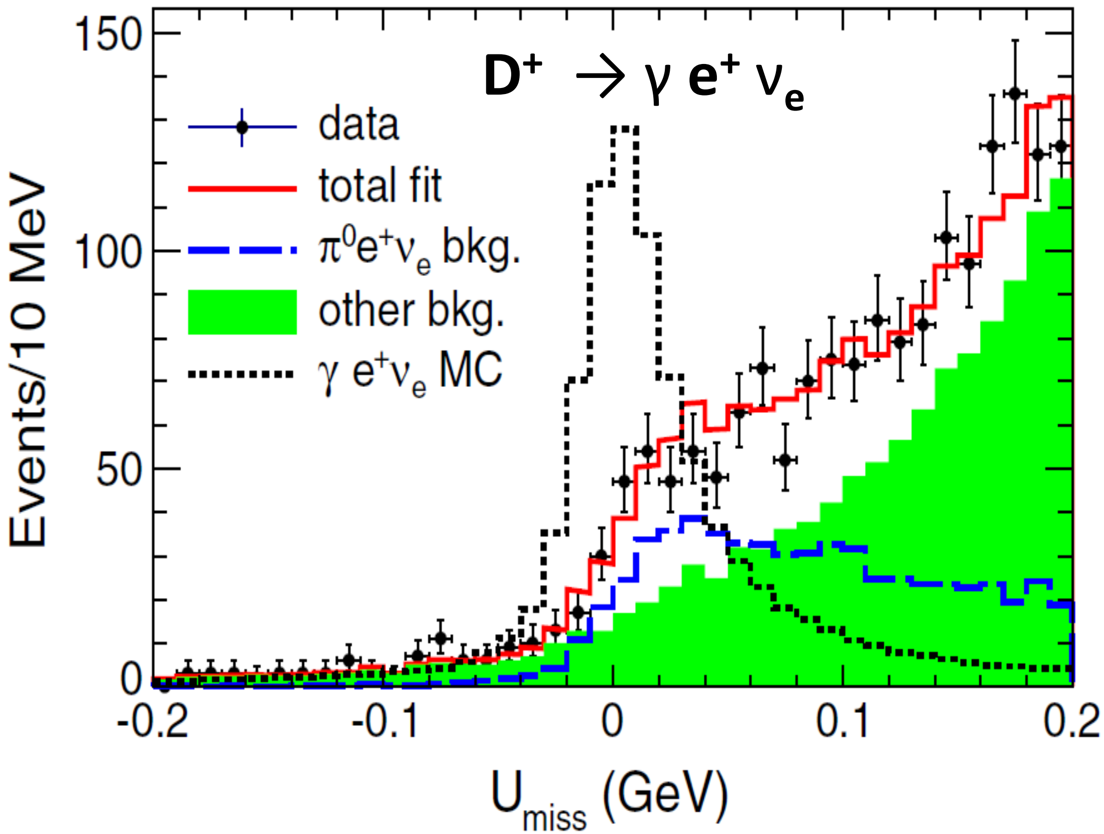
- The preliminary results for form factors:

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

Inserting $|V_{cd}| = 0.22492 \pm 0.00050$ obtained by CKMfitter, the $f_+(0)$ can be obtained.

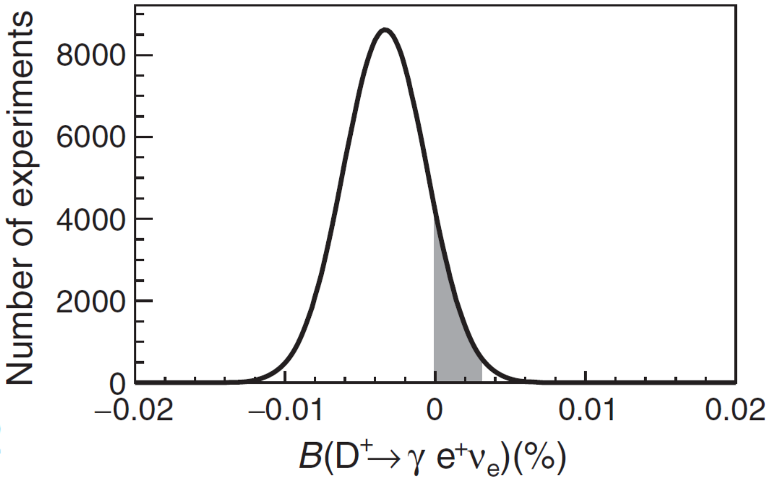
Search for the radiative leptonic decay $D^+ \to \gamma e^+ \nu_e$

- Not subject to the helicity suppression rule due to the presence of a radiative photon.
- Predicted rates are reachable range :
  e.g., J.-C. Yang and M.-Z. Yang predict $B(D^+ \to \gamma e^+ \nu_e) \sim 2\times10^{-5}$ via Factorization.



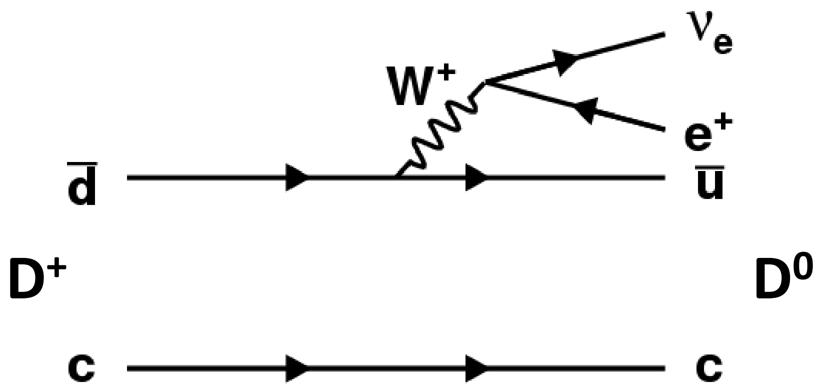
PRD 95, 071102(R) (2017)

- Only $E_\gamma > 10$ MeV considered.
- (-21 ± 23) signal events.

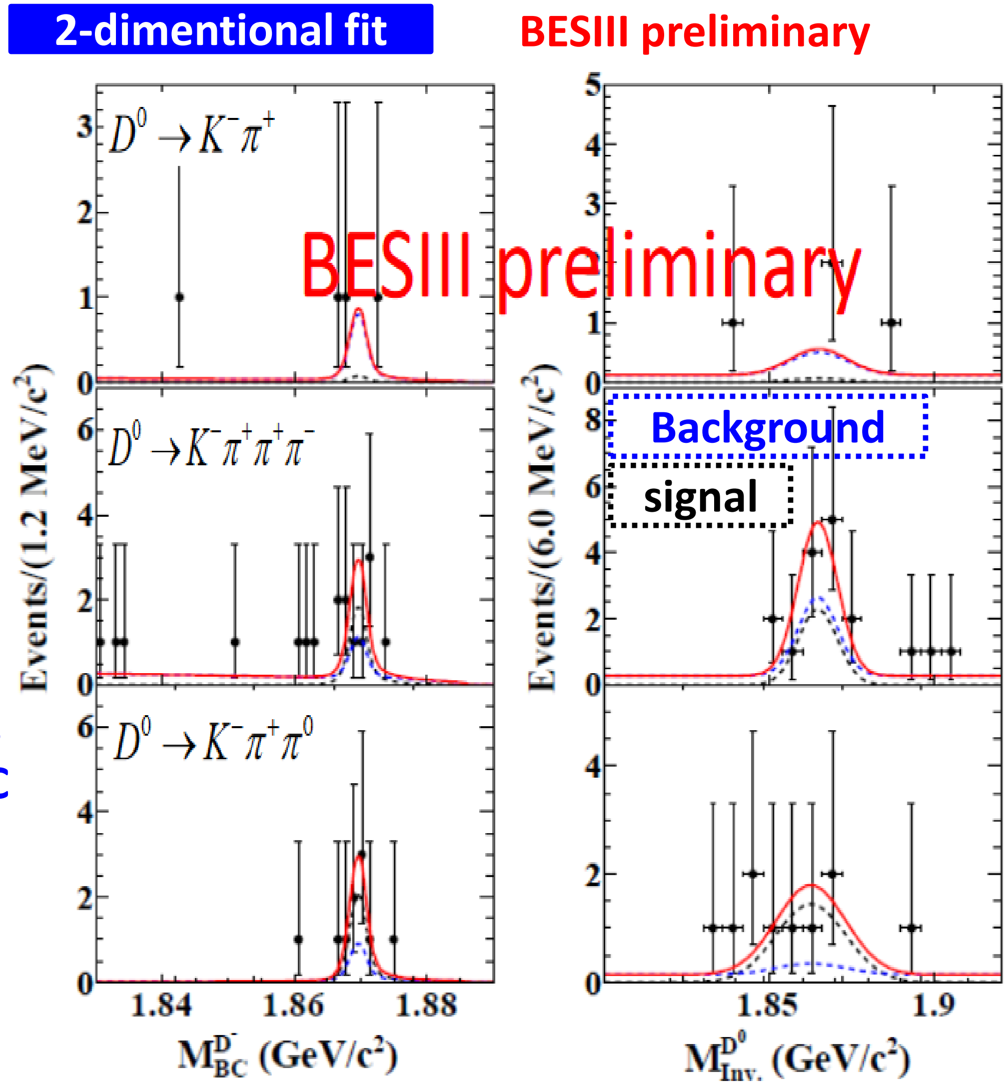


$B(D^+ \to \gamma e^+ \nu_e) < 3.0 \times 10^{-5}$ at 90% C.L.

Search for the rare decay $D^+ \to D^0 e^+ \nu_e$



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 (2009)]



$B(D^+ \to D^0 e^+ \nu_e) < 8.7 \times 10^{-5}$ at 90% C.L..

Summary

- With 2.93, 0.482, 3.19 fb^{-1} data taken at 3.773, 4.009, 4.18 GeV, BESIII have studied $D_{(s)}^+ \to l^+ \nu$, $D^{0(+)} \to K(\pi) l^+ \nu$ and $D_s^+ \to K^{(*)0} e^+ \nu_e$, and searched for $D^{0(+)} \to a_0(980)^{-(0)} e^+ \nu_e$, $\gamma e^+ \nu_e$ and $D^0 e^+ \nu_e$.

- There are some uncovered analyses at BESIII (see backup parts): $D^+ \to K^- \pi^+ e^+ \nu_e$, $D_s^+ \to \eta e^+ \nu_e$.
- Some other analyses are on going at BESIII @ 3.773 GeV: $D^+ \to \eta^{(\prime)} e^+ \nu_e$, $D^+ \to X e^+ \nu_e$....

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

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

- Based on 3.19 fb^{-1} data at 4.178 GeV accumulated in 2016, the measurements of f_{Ds+} and $|V_{cs}|$ by $D_s^+ \to l^+ \nu$, the form factor studies of $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$ ... can be expected in the near future.

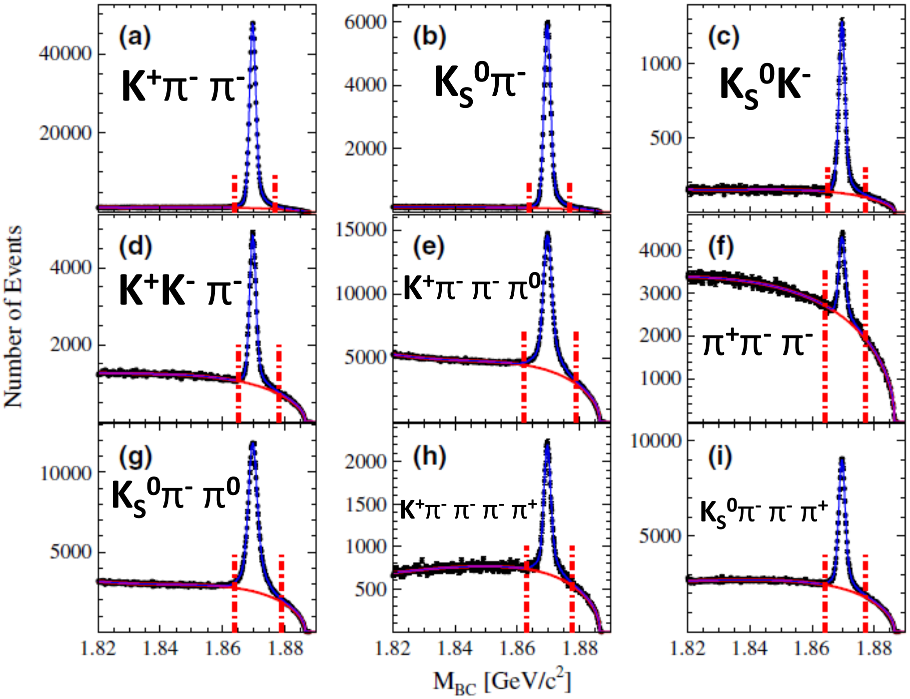
Thanks for your attention!

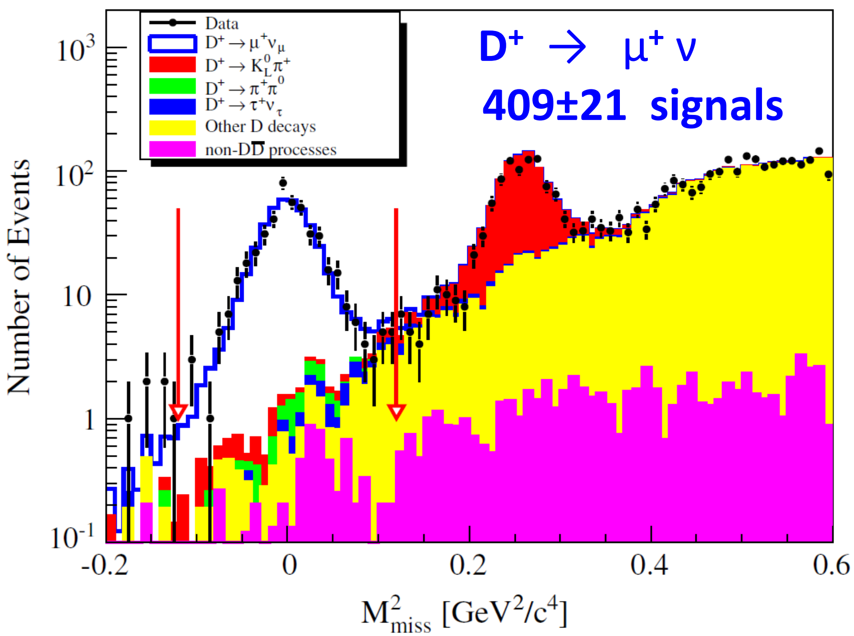
Back up

Precision measurements of $B(D^+ \to \mu^+ \nu)$, f_{D+} and $|V_{cd}|$

$e^+ e^- \to \psi(3770) \to D^+ D^-$ 2.93 fb^{-1} @3.773 GeV

PRD 89, 051104(R) (2014)

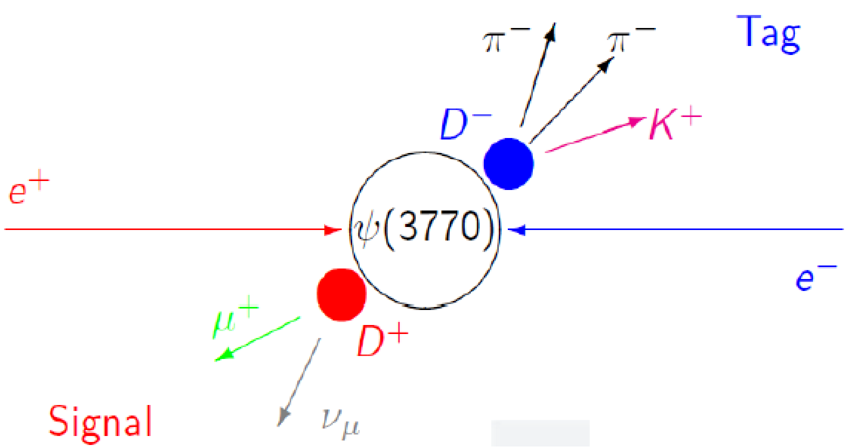




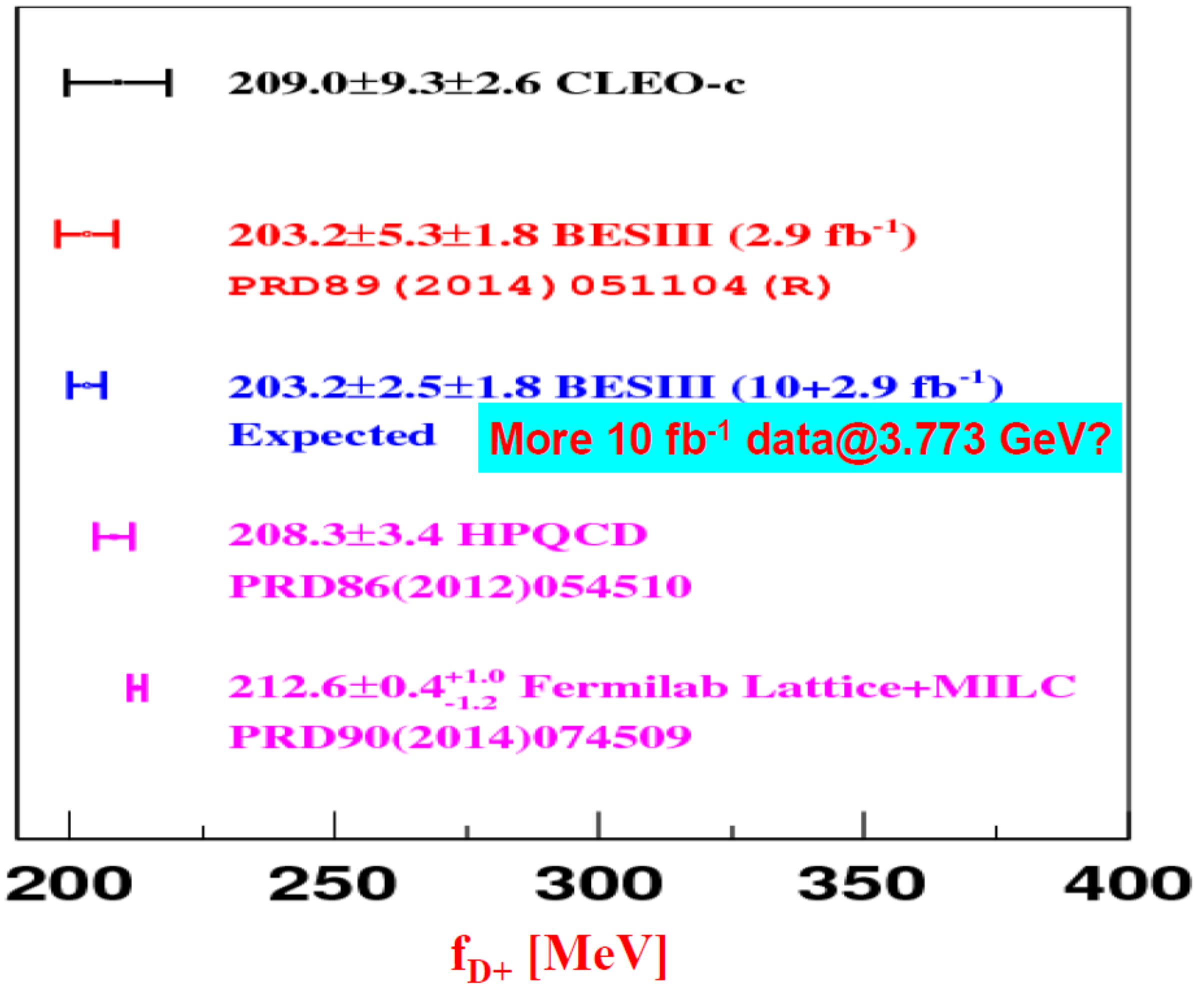
$$N_{D^-_{tag}} = (170.31 \pm 0.34) \times 10^4$$

$$M_{BC} = \sqrt{E^2_{beam} - p^2_{\bar{D}_{tag}}}$$

$$M^2_{missing} = E^2_{miss} - p^2_{miss} \sim 0$$



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

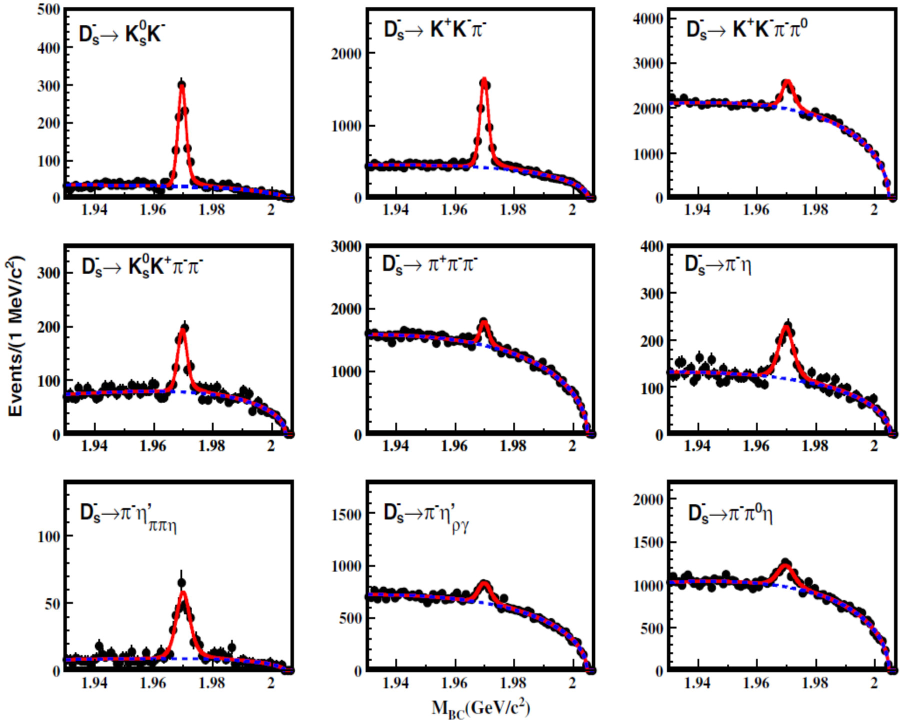


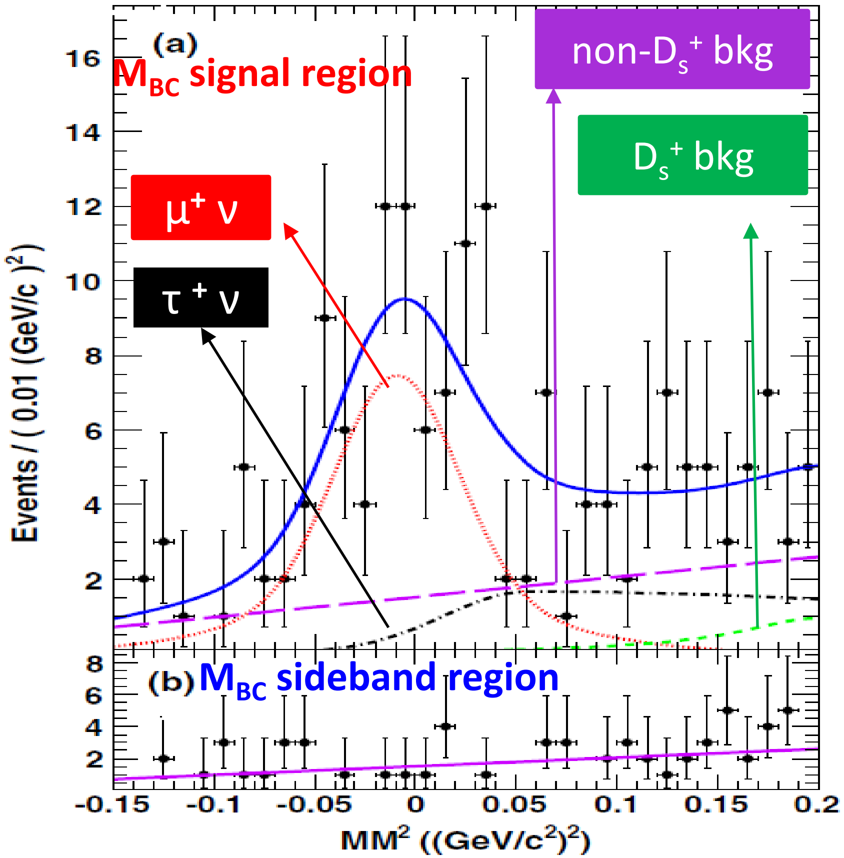
$D_s^+ \to l^+ \nu$ ($l = \mu, \tau$) decays

$e^+ e^- \to D_s^+ D_s^-$ 482 pb^{-1} @4.009 GeV

Simultaneous fit

PRD 94, 072004(2016)





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

➢Comparison of $f_{D_{s+}}$ and prospect at BESIII

~3fb^{-1} data @4.18 GeV in hand

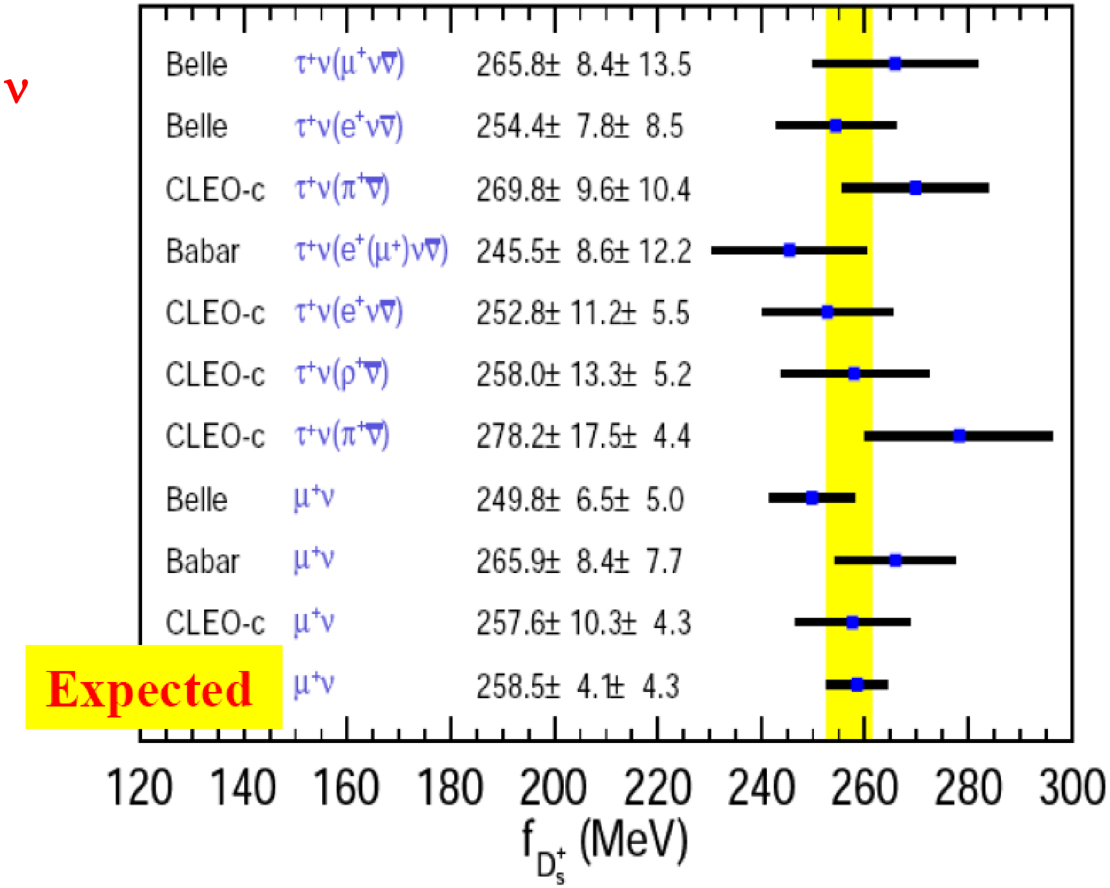
μ counter of BESIII may help to suppress background in $D_s^+ \to \mu^+ \nu$

Roughly estimated with CLEO-c results

If systematic is the same as CLEO-c measurement

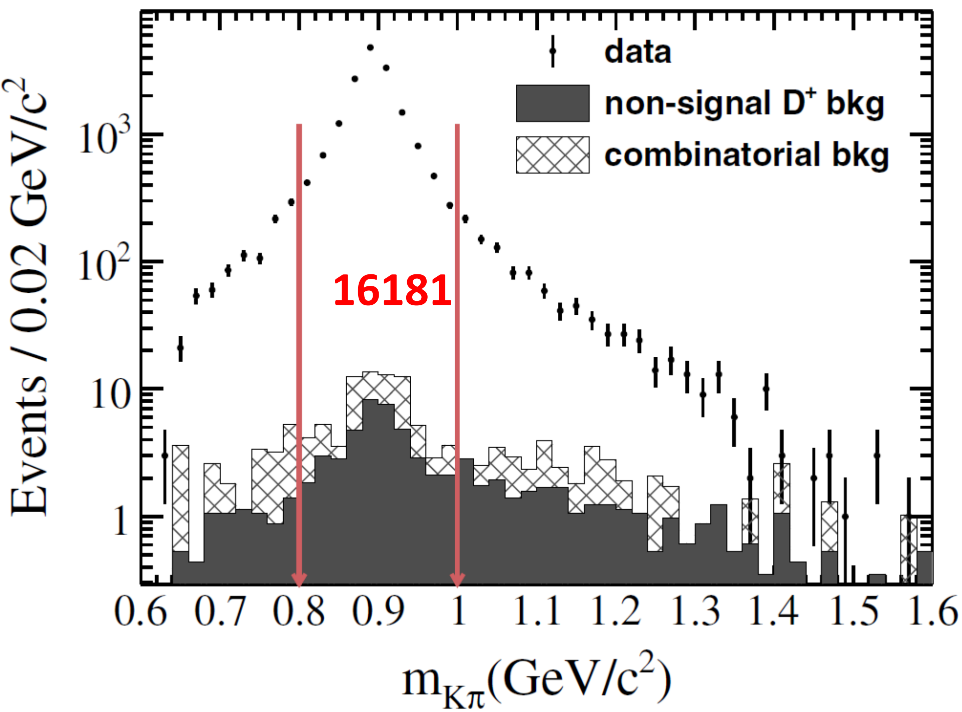
Result at 4.009 GeV is not included due to large error

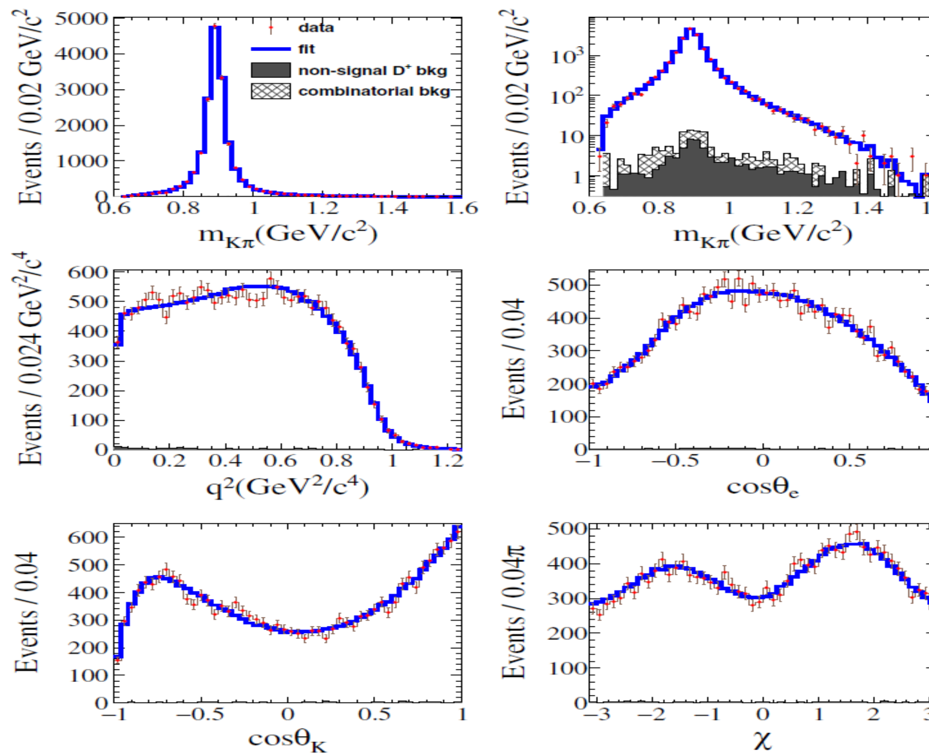
$D_s^+ \to \tau^+ \nu$ will further improve measurement



Study of $D^+ \to K^- \pi^+ e^+ \nu_e$

PRD 94, 032001 (2016)





For M(Kπ) : [0.6, 1.6] GeV/c^2 (full range):
$B(D^+ \to K^- \pi^+ e^+ \nu_e) = (3.77 \pm 0.03 \pm 0.08)\%$

For M(Kπ) : [0.8, 1.0] ($\bar{K}^*(892)^0$-dominated):
$B(D^+ \to K^- \pi^+ e^+ \nu_e) = (3.39 \pm 0.03 \pm 0.08)\%$

A partial wave analysis shows that the dominant $\bar{K}^*(892)^0$ component is accompanied by an S-wave contribution accounting for (6.05 ± 0.22 ± 0.18)% of the total rate and that other components are negligible.

Measurements of BFs of $D_s^+ \to \eta^{(\prime)} e^+ \nu_e$

$e^+ e^- \to D_s^+ D_s^-$ 482 pb^{-1} @4.009 GeV

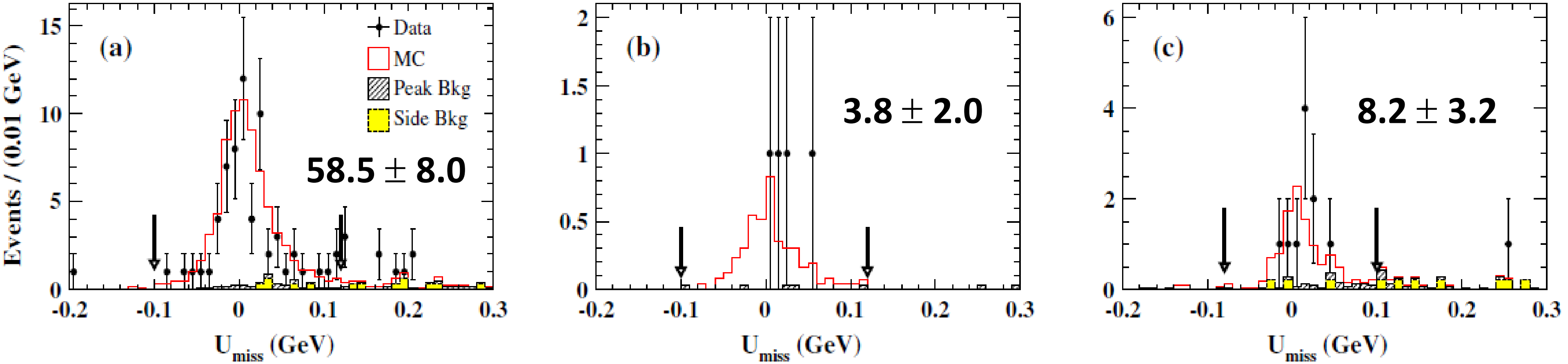
PRD 94, 112003 (2016)

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

$$U_{\rm miss} \equiv E_{\rm miss} - |\vec{p}_{\rm miss}| \sim 0$$

With 10 D_s^- tag modes

$D_s^+ \to \eta e^+ \nu_e$ $D_s^+ \to \eta' e^+ \nu_e$, $\eta' \to \eta\pi^+\pi^-$ $D_s^+ \to \eta' e^+ \nu_e$, $\eta' \to \gamma\rho^0$



	BESIII	CLEOII 95	CLEOc 09	CLEOc 15	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
$\frac{B(D_s^+ \to \eta' e^+ \nu_e)}{B(D_s^+ \to \eta e^+ \nu_e)}$	$0.40 \pm 0.14 \pm 0.02$	$0.35 \pm 0.09 \pm 0.07$	...	...	...

$D_s^+ \rightarrow K^0 e^+ \nu_e$

The correlation matrix including both statistical and systematic Uncertainties. [preliminary]

	$0.00 < q^2 <= 0.35$	$0.35 < q^2 <= 0.70$	$0.70 < q^2 <= 1.05$	$1.05 < q^2 <= 1.40$	$1.40 < q^2 <= q^2_{\max}$
$\rho_i^{\text{stat+syst}}$	1.000	-0.154	0.016	-0.000	0.001
	-0.154	1.000	-0.117	0.011	-0.001
	0.016	-0.117	1.000	-0.102	0.008
	-0.000	0.011	-0.102	1.000	-0.075
	0.001	-0.001	0.008	-0.075	1.000

In the calculation of the systematic covariance matrix, we have considered the systematic uncertainties arising from the uncertainties in the number of D_s^- tags, D_s^+ lifetime, MC statistics, $E_{\gamma max}$ cut, M_{Ks0e+} cut, fits to MM^2 distribution, tracking and PID efficiencies.

$D_s^+ \to K^{*0} e^+ \nu_e$

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 $H_0(q^2)$)

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

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

$\mathcal{BW}(M_{K\pi}) = \frac{\sqrt{m_0\Gamma_0(p/p_0)}}{m_0^2 - m_{K\pi}^2 - im_0\Gamma(m_{K\pi})} \frac{B(p)}{B(p_0)}$

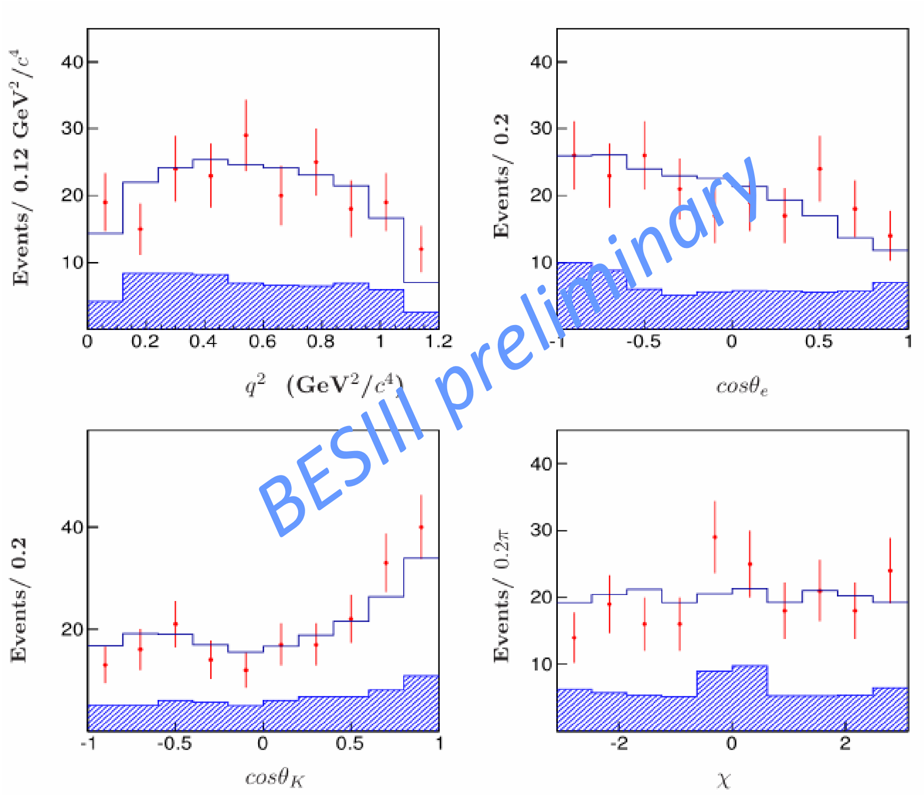
where $B(p) = \frac{1}{\sqrt{1+R^2p^2}}$ with $R = 3$ GeV^{-1} and $\Gamma(m_{K\pi}) = \Gamma_0(\frac{p}{p_0})^3 \frac{m_0}{m_{K\pi}} (\frac{B(p)}{B(p_0)})^2$.

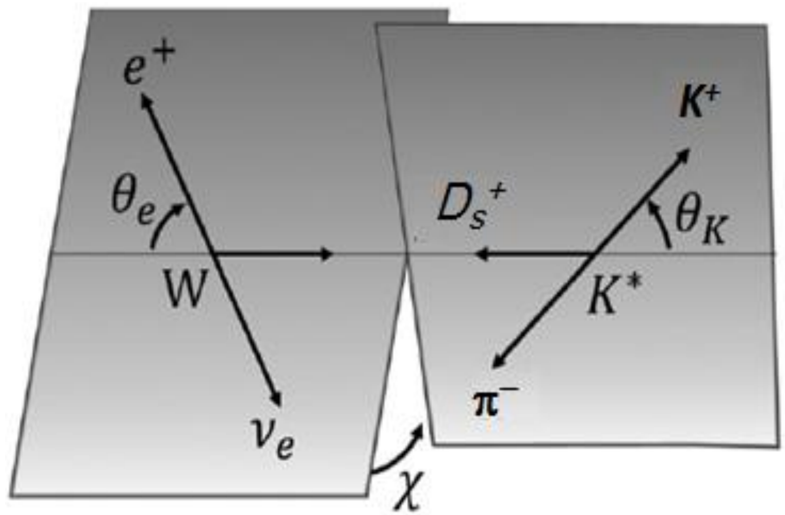
$D_s^+ \to K^{*0} e^+ \nu_e$

Following the same parametrization used in;

[1] BESIII Collaboration, M. Ablikim, *et al.*, Phys. Rev. D 94, 032001 (2016).

[1] CLEO Collaboration, S. Dobbs, *et al.*, Phys. Rev. Lett. 110, 131802 (2013).





- The preliminary results for form factors:

r_V=1.67±0.34 ±0.16 and r_2=0.77 ± 0.28±0.07

The first errors are statistical and the second are systematic.