Semi-leptonic and leptonic $D^{0(+)}$ and $D_s$ decays at BESIII

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On behalf of BESIII Collaboration

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Outline

- Introduction
- BESIII @ BEPCII
  - Data samples
- D meson decays
- $D_s$ meson decays
(Semi-)leptonic decays

Heavy meson (semi-)leptonic decays provide an ideal window to study the interplay between strong and EW interactions.

From precise determination of the branching ratio it is possible to access to:
- $f_{D(s)}$ decay constant, $f_{+(q^2)}$ form factors,
- CKM matrix elements
- Lepton universality

Lattice QCD tuning
Unitarity test of CKM
New Physics?
BESIII Data samples

Center of mass energy can be **shifted** at **threshold openings**:

- Very low hadronic background
- Challenge for detector performance

**Dedicated data samples:**

**D_{0(+)**} data:
- $E_{cm} = 3773$ MeV
  - Integrated luminosity = 2.93 fb$^{-1}$

**$D_s^+$ data:**
- $E_{cm} = 4009$ MeV
  - Integrated luminosity = 0.482 fb$^{-1}$
- $E_{cm} = 4178$ MeV
  - Integrated luminosity = 3.19 fb$^{-1}$
Charmed meson decay at threshold at BESIII

Example of Double Tag technique with leptonic signal side

Variables of interest (calculated in e^+e^- reference frame)

- **Mass beam constrained**
  \[ M_{bc} = \sqrt{E_{beam}^2 - p_{candidate}^2} \]

- **Energy difference**
  \[ dE = E_{candidate} - E_{beam} \]

- **Missing mass**
  \[ U_{miss} = E_{miss} - |\vec{p}_{miss}| \]
D decays

Selected topics (*based on 21 M D⁰ and 16 M D⁺*):

- Semileptonic D⁺ → K⁰/π⁰ e⁺ νₑ (PRD 96, 012002 (2017))
- Semileptonic D⁰ → K⁻ μ⁺ ν_μ (preliminary)
- Semileptonic D⁺(0) → π⁰(-) μ⁺ ν_μ (arXiv: 1802.05492 – submitted to PRL)
- Leptonic D⁺ → τ⁺ ν_τ (preliminary)
**D^+ \rightarrow K^0/\pi^0 \ e^+ \ \nu_e**

Study to extract CKM parameters ($V_{cs}$ and $V_{cd}$) and form factors $f^K_+(0)$ $f^\pi_+(0)$ to tune the LQCD calculation

Differential decay rate

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

**World most precise** results – within $1\sigma$ agreement with PDG
\[ |f_+(0)V_{\text{cs}(d)}| \text{ from } D^+ \rightarrow K^0/\pi^0 \ e^+ \ \nu_e \]

It is also possible to extract the factors \( |f_+(0)V_{\text{cs}(d)}| \) by fitting to the differential decay rates with different form factor parametrizations and then extract the projections.

\[ q^2 = (E_{e^+} + E_{\nu_e})^2/c^4 - (\vec{p}_{e^+} + \vec{p}_{\nu_e})^2/c^2 \]

From 2 parameters z series expansion results:

\[ f_+(0)|V_{cs}| = 0.7053 \pm 0.0040 \pm 0.0112 \]
\[ f_+(0)|V_{cd}| = 0.1400 \pm 0.0026 \pm 0.0007 \]
$D^0 \rightarrow K^- \mu^+ \nu_\mu$ (preliminary)

$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{cs}|^2}{8\pi^3 m_D} |p_K|^2 \left| f_+^*(q^2) \right|^2 \frac{W_0 - E_K}{F_0} \times \left[ \frac{1}{3} m_D |p_K|^2 + \frac{m_\mu^2}{8m_D} (m_D^2 + m_K^2 + 2m_D E_K) + \frac{1}{3} m_\mu^2 \frac{|p_K|^2}{F_0} + \frac{1}{4} \frac{m_\mu^2 m_D - m_K^2}{m_D} R \frac{f_-(q^2)}{f_+(q^2)} + \frac{1}{4} \frac{m_\mu^2 F_0}{m_D} \left[ \frac{f_-(q^2)}{f_+(q^2)} \right] \right]$

W_0 = (m_D^2 + m_K^2 - m_\mu^2)/(2m_D)
F_0 = W_0 - E_K + m_\mu^2/(2m_D)

Tag side/Signal events

Assumed to be independent of $q^2$
following FOCUS (PLB607(2005)233)

No MUC, since $p_\mu$ too low
To reduce background, cut on $K\mu$ invariant mass

World most precise measurement
From ~4% to ~0.5% accuracy
\[ D^0 \rightarrow K^- \mu^+ \nu_\mu \] (preliminary)
Test of lepton flavor universality
Present data lower of about 15% with respect to SM prediction. 
Error dominated by the accurancy of $D^0 \rightarrow \pi^- \mu^+ \nu$ (10% level)

$D^{+(0)} \rightarrow \pi^0(-) \mu^+ \nu_{\mu}$

Improved precision on $D^0 \rightarrow \pi^- \mu^+ \nu$
$B^0_{\pi\mu\nu} = (0.267 \pm 0.007 \pm 0.007)\%$

First measurement of $D^+ \rightarrow \pi^0 \mu^+ \nu$
$B^+_{\pi\mu\nu} = (0.342 \pm 0.011 \pm 0.010)\%$

Combining with previous BESIII results
$R^0_{LU} = 0.905 \pm 0.027 \pm 0.023$  
$R^+_{LU} = 0.942 \pm 0.037 \pm 0.027$

Theoretically: $R^{0(+)} = 0.97$

Agreement at 1.9σ and 0.6σ level
Leptonic $D^+ \rightarrow \tau^+ \nu_\tau$ (preliminary)

Search for pure leptonic decay of D meson (never observed before) and possible test of lepton universality.

Signal: $D^+ \rightarrow \tau^+ \nu_\tau, \tau^+ \rightarrow \pi^+ \bar{\nu}_\tau$

Simultaneous Fit to the missing-mass-squared

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

Preliminary Results

$$BF(D^+ \rightarrow \tau^+\nu_\tau) = (1.20 \pm 0.24) \times 10^{-4}$$

$$R = 3.21 \pm 0.64,$$

consistent with SM prediction ($R = 2.66 \pm 0.01$) at 0.9σ level
D_{s} decays

Selected topics
• Leptonic D_{s}^{+} \rightarrow \mu^{+} \nu_{\mu} @ 4.178 \text{ GeV (Preliminary)}
• Semileptonic D_{s}^{+} \rightarrow \eta (^{(i)} \ e^{+} \nu_{e} @ 4.178 \text{ GeV (Preliminary)}}
**D_s data samples**

CLEO PRD80, 072001 (2009)

- **Clean sample, low production rate**
  - ~0.4 M D_s produced

- **Higher production rate, BF(D_s^* \rightarrow \gamma D_s)**
  - ~6 M D_s produced

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Clean sample, low production rate
~0.4 M D_s produced

Higher production rate, BF(D_s^* \rightarrow \gamma D_s)
~6 M D_s produced
Leptonic $D_s^+ \rightarrow l^+ \nu_l$

Leptonic $D_s$ decays are helicity suppressed.
The expected ratios of $D_s \rightarrow e \nu_e : \mu \nu_\mu : \tau \nu_\tau = 2 \times 10^{-5} : 1 : 10$

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

By studying the partial decay rate is possible to access
- form factor $f_{D_s}$
- CKM matrix element $V_{cs}$

There is a *discrepancy* in $f_{D_s}$ prediction from lattice ($f_{D_s} = 249.0 \pm 1.2$ MeV) and experiments ($f_{D_s} = 257.5 \pm 4.6$ MeV) that can be addressed by *New Physics* models (two Higgs-doublet, R-parity violation)
Leptonic $D_s^+ \to \mu^+ \nu_\mu$ @ 4.178 GeV (preliminary)

Fit to missing mass squared:
1) Signal/BKGI ratio constrained by signal MC
2) BKGII fixed via Inclusive MC

$\mathcal{B}(D_s^+ \to \mu^+ \nu_\mu) = (5.28 \pm 0.15 \pm 0.14) \cdot 10^{-3}$

Accuracy from 13% to 2.8%
Leptonic $D_s^+ \rightarrow \mu^+\nu_\mu$ @ 4.178 GeV (preliminary)

Closing the gap with the theoretical calculation!
\[ V_{cs} \text{ from } D_s^+ \rightarrow \mu^+ \nu_\mu \text{ and } D^0 \rightarrow K^- \mu^+ \nu_\mu \]

To extract \(|V_{cs}|\) for
\[ D^0 \rightarrow K^- \mu^+ \nu_\mu \]
Take \( f_K \) from
PRD82(2010)114506

**Comparable precision**
between
\[ D^0 \rightarrow K^- \mu^+ \nu_\mu \text{ and } D_s^+ \rightarrow \mu^+ \nu_\mu \]
Semileptonic $D_s^+ \rightarrow \eta^{(')} e^+ \nu_e @ 4178$ GeV (Preliminary)

At present time, no measurement of $f_{\eta^{(')}+}$ form factor. Moreover, complementary test of the $\eta$-$\eta'$ mixing

\[
\begin{pmatrix}
|\eta\rangle \\
|\eta'\rangle
\end{pmatrix} =
\begin{pmatrix}
\cos \phi_p & -\sin \phi_p \\
\sin \phi_p & \cos \phi_p
\end{pmatrix}
\begin{pmatrix}
|\eta_q\rangle \\
|\eta_s\rangle
\end{pmatrix}
\]

\[
\frac{\Gamma(D_s^+ \rightarrow \eta' e^+ \nu)}{\Gamma(D_s^+ \rightarrow \eta e^+ \nu)} \frac{\Gamma(D^+ \rightarrow \eta' e^+ \nu)}{\Gamma(D^+ \rightarrow \eta e^+ \nu)} \approx \cot^4 \phi_p
\]

Result of the simultaneous fit

<table>
<thead>
<tr>
<th>Decay</th>
<th>$\eta^{(')}$ decay</th>
<th>$\epsilon_{\gamma (\pi^0)_{SL}}$ (%)</th>
<th>$N_{DT}^{\text{tot}}$</th>
<th>$B_{SL}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta e^+ \nu_e$</td>
<td>$\gamma \gamma$</td>
<td>41.11±0.27</td>
<td>1834±47</td>
<td>2.32±0.06±0.06</td>
</tr>
<tr>
<td></td>
<td>$\pi^0 \pi^+ \pi^-$</td>
<td>16.06±0.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta' e^+ \nu_e$</td>
<td>$\eta \pi^+ \pi^-$</td>
<td>14.07±0.10</td>
<td>261±22</td>
<td>0.82±0.07±0.03</td>
</tr>
<tr>
<td></td>
<td>$\gamma \rho^0$</td>
<td>18.98±0.10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Semileptonic $D_s^+ \rightarrow \eta^{(')} e^+ \nu_e$ @ 4178 GeV (Preliminary)

World’s most precise results! Accuracy down to ~3%(~10%)
Semileptonic $D_s^+ \rightarrow \eta^{(')} e^+ \nu_e$ @ 4178 GeV (Preliminary)

World first measurement of form factor

<table>
<thead>
<tr>
<th>Case</th>
<th>Simple pole</th>
<th>Modified pole</th>
<th>Series 2 Par.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f^{\eta_{e+\nu_e}}_+(0)</td>
<td>M_{pole}</td>
<td>$\chi^2$/NDOF</td>
</tr>
<tr>
<td>$\eta^+\nu_e$</td>
<td>0.450(5)(3)</td>
<td>3.77(8)(5)</td>
<td>12.2/14</td>
</tr>
<tr>
<td>$\eta'^+\nu_e$</td>
<td>0.494(45)(10)</td>
<td>1.88(54)(5)</td>
<td>1.8/4</td>
</tr>
</tbody>
</table>

No systematic uncertainty is considered
Summary and outlook

- With the world largest sample at 3.773 GeV, BESIII has a leading role in D meson leptonic and semileptonic decays searches, with the ability to measure with high precision branching fraction, $f_D$, $f_\pi$ form factors and CKM matrix elements.
  - Thanks to the production at threshold, the environment is very clean and it is possible to start testing lepton universality in several D decays.

- The data at $D_s \bar{D}_s$ threshold can be used to search for studying complicated decay topologies, thanks to the almost background-free environment.

- The newest data sample at 4.178 GeV will be used to improve the statistical accuracy of the processes and in a near future other semileptonic decay measurements are expected.
  - First measurement of $f_{\eta}$ form factor to tune the LQCD calculation.
  - The CKM matrix elements and the form factor determination will follow.
THANKS

GRAZIE
Additional Material
List of D/D_s (semi-)leptonic publication

D Decay @ 3773 MeV
• $D^0 \to (K^-/\pi^-) e^+ \nu$ (PRD 92 (2015) 072012)
• $D^+ \to (\bar{K}^0/\pi^0) e^+ \nu$ (PRD 96 (2017) 012002)
• $D^+ \to K_L e^+ \nu$ (PRD 92 (2015) 112008)
• $D^+ \to \omega/\phi e^+ \nu$ (PRD 92 (2015) 071101)
• $D^+ \to K^- \pi^+ e^+ \nu$ (PRD 94 (2016) 032001)
• $D^+ \to \bar{K}^0 \mu^+ \nu$ (EPJC 76, (2016) 369)
• $D^+ \to \bar{K}^0 e^+ \nu, K_s \to \pi^0\pi^0$ (CPC 40 (2016) 113001)
• $D^+ \to \mu^+ \nu$ (PRD 89 (2014) 051104 (R))

D_s Decay @ 4008 MeV
• $D_{s}^+ \to \tau^+/\mu^+ \nu$ (PRD 94 (2016) 072004)
• $D_{s}^+ \to \eta^{(')} e^+ \nu$ (PRD 04 (2016) 112003)
• $D_{s}^+ \to \phi/\eta^{(')} e^+/\mu^+ \nu$ (PRD 97 (2018) 012006)
Tag side reconstruction

D decays

$K^{-}\pi^{+}\pi^{-}$

$K^{-}\pi^{+}\pi^{-}\pi^{0}$

$K_{S}\pi^{+}$

$K_{S}\pi^{+}\pi^{+}$$

$K_{S}\pi^{+}\pi^{0}$

$K^{-}\pi^{+}\pi^{-}$

$D_s$ decays

$D_s^+ \rightarrow K^+ K^+ \pi^-$

$D_s^- \rightarrow K^- K^+ \pi^-$

$D_s^- \rightarrow \pi^- K^+ \pi^-$

$M_{BC}$ (GeV/c$^2$)

Events / (0.03/MeV$^2$)
Form factor parametrizations

**Single pole**

\[
f_+(q^2) = \frac{f_+(0)}{1 - q^2/m_{\text{pole}}^2}
\]


**Modified pole**

\[
f_+(q^2) = \frac{f_+(0)}{(1 - q^2/m_{D^*(a)}^2)}(1 - \alpha q^2/m_{D^*(a)}^2)
\]


**ISGW2**

\[
f_+(q^2) = f_+(q_{\text{max}}^2) \left(1 + \frac{r^2}{12}(q_{\text{max}}^2 - q^2)\right)^{-2}
\]


**Series expansion**

\[
z(q^2, t_0) = \frac{\sqrt{t_+ - t_0} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}
\]

\[
f_+(q^2) = \frac{1}{P(q^2)\phi(q^2, t_0)} \sum_{k=0}^{\infty} a_k(t_0)[z(q^2, t_0)]^k
\]

BESIII @ BEPCII

Time Of Flight:
$\sigma_t$ (barrel) = 90 ps
$\sigma_t$ (endcap) = 110 ps

Main Drift Chamber:
$\sigma_x$ (1 GeV/c) ~ 130 $\mu$m
dp/p (1 GeV/c) = 0.5 %

1 Tesla Magnetic field

Muon counters:
$\delta_{r\phi} = 1.4$ cmv - 1.7 cm

Electromagnetic Calorimeter:
dE/$\sqrt{E}$ (1 GeV) = 2.5 %
BEPCII @ IHEP (Beijing)

e^+e^- central collider
CM energy: 2. - 4.6 GeV
L_{design}(@3770): 10^{33} \text{ cm}^{-2}\text{s}^{-1}
$D^+ \rightarrow K^0/\pi^0 \; e^+ \; \nu_e$

World **most precise** results – within $1\sigma$ agreement with PDG

Test of isospin symmetry using previous BESIII results (Phys. Rev. D92,072012 (2015)):

$$I_K \equiv \frac{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)}{\Gamma(D^+ \rightarrow K^0 e^+ \nu_e)} = 1.03 \pm 0.01 \pm 0.02$$

$$I_{\pi} \equiv \frac{\Gamma(D^0 \rightarrow \pi^- e^+ \nu_e)}{2 \Gamma(D^+ \rightarrow \pi^0 e^+ \nu_e)} = 1.03 \pm 0.03 \pm 0.02,$$

**Isospin prediction confirmed**
\[ |f_+(0)| \text{ and } |V_{cs(d)}| \text{ from } D^+ \rightarrow K^0/\pi^0 \ e^+ \ \nu_e \]

**Form factors**

Using the value of \( V_{cs} \) and \( V_{cd} \)

\[
|V_{cs}| = 0.97351 \pm 0.00013 \\
|V_{cd}| = 0.22492 \pm 0.00050
\]

from the Standard Model constraint fit

It is possible to extract

\[
f^K_+(0) = 0.725 \pm 0.004 \pm 0.012 \\
f^\pi_+(0) = 0.622 \pm 0.012 \pm 0.003
\]

**CKM matrix elements**

By using

\[
f^K_+(0) = 0.747 \pm 0.011 \pm 0.015 \\
f^\pi_+(0) = 0.666 \pm 0.020 \pm 0.021
\]

from LQCD calculation

It is possible to measure

\[
|V_{cs}| = 0.944 \pm 0.005 \pm 0.015 \pm 0.024 \\
|V_{cd}| = 0.210 \pm 0.004 \pm 0.001 \pm 0.009
\]
D^0 \rightarrow K^- \mu^+ \nu_\mu \text{ (preliminary)}

Combining with D^0 \rightarrow K^- e^+ \nu_e \text{ at BESIII (PRD 92 (2015) 072012)}

Integrating over all q^2 bins

\[ R_{\mu/e} = \frac{\Gamma(D^0 \rightarrow K^- \mu^+ \nu_\mu)}{\Gamma(D^0 \rightarrow K^- e^+ \nu_e)} = 0.978 \pm 0.007_{\text{stat.}} \pm 0.012_{\text{syst.}} \]

Lepton universality confirmed
Leptonic $D^+ \to \tau^+ \nu_\tau$ (preliminary)

Search for pure leptonic decay of $D$ meson and possible test of lepton universality.

**Previous measurements**

At present, only Upper limit ($BF < 1.2 \times 10^{-3}$ @ 90% C.L.) with an integrated luminosity of $L = 0.878$ fb$^{-1}$ (PRD 78, 052003 (2008))

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

**Expected sensitivity**

- Based on the theoretical ratio $R = 2.67 \pm 0.01$
- and previous measurement of $BF(D^+ \to \mu^+\nu) = (3.74 \pm 0.17) \times 10^{-4}$
- expected branching ratio is $BF(D^+ \to \tau^+\nu) = (9.99 \pm 0.45) \times 10^{-4}$

- BESIII has slightly more than three times the integrated luminosity of CLEO, so we expect to see some signals.

**BESIII Analysis strategy**

Signal: $D^+ \to \tau^+\nu_\tau, \tau^+ \to \pi^+\nu_\tau$

Main background: $D^+ \to \mu^+\nu_\mu$, but treated as part of the signal.

Other background: single charged tracks events

At present, only Upper limit ($BF < 1.2 \times 10^{-3}$ @ 90% C.L.) with an integrated luminosity of $L = 0.878$ fb$^{-1}$ (PRD 78, 052003 (2008))
Leptonic $D^+ \to \tau^+ \nu_\tau$ (preliminary)

Simultaneous Fit to the missing-mass-squared

$$M_{\text{miss}}^2 = (E_{\text{beam}} - E_{\mu^+})^2 - (\vec{p}_{D_{\text{tag}}} - \vec{p}_\mu)^2.$$ 

divided in two sample region, based on the energy deposited in the EMC

- $\mu$-like: $E_{\text{EMC}} < 300$ MeV (signal + $\mu$ contamination)
- $\pi$-like: $E_{\text{EMC}} > 300$ MeV (mostly signal)

Unbinned maximum likelihood fit components:

- Fixed $D^+ \to \mu^+\nu_\mu$ to PDG value
- Floating $D^+ \to \tau^+\nu_\tau$
- Floating $D^+ \to K_L\pi^+$
- Fixed $D^+ \to K_S\pi^+$ to PDG value
- Fixed $D^+ \to \pi^+\pi^0$ to PDG value
- Fixed $D^+ \to \eta\pi^0$ to PDG value

MC simulations

With expected (SM) signal size input:

118±25

$D^+ \to \tau^+(\to \pi^+\nu_\tau)\nu_\tau$ events

Black filled histograms are MC-based backgrounds
Leptonic D$^+ \rightarrow \tau^+ \nu_\tau$ (preliminary)

Simultaneous Fit to the missing-mass-squared $M^2_{\text{miss}} = (E_{\text{beam}} - E_{\mu^+})^2 - (\vec{p}_{D^+} - \vec{p}_{\mu})^2$ divided in two sample region, based on the energy deposited in the EMC

- $\mu$-like: $E_{\text{EMC}} < 300$ MeV (signal + $\mu$ contamination)
- $\pi$-like: $E_{\text{EMC}} > 300$ MeV (mostly signal)

Unbinned maximum likelihood fit components:

- Fixed $D^+ \rightarrow \mu^+\nu_\mu$ to PDG value
- Floating $D^+ \rightarrow \tau^+\nu_\tau$
- Floating $D^+ \rightarrow K_L\pi^+$
- Fixed $D^+ \rightarrow K_S\pi^+$ to PDG value
- Fixed $D^+ \rightarrow \pi^+\pi^0$ to PDG value
- Fixed $D^+ \rightarrow \eta\pi^0$ to PDG value
Leptonic $D^+ \to \tau^+ \nu_\tau$ (preliminary)

137 ± 27 events
Significance > 4σ
EVIDENCE

$BF(D^+ \to \tau^+ \nu_\tau) = (1.20 \pm 0.24) \times 10^{-4}$

$R = 3.21 \pm 0.64$, consistent with SM prediction ($R = 2.66 \pm 0.01$) at 0.9σ level
Leptonic $D_s^+ \rightarrow l^+ \nu_l$ @ 4.009 GeV

Measurements of $D_s^+ \rightarrow \tau^+\nu_\tau$ and $D_s^+ \rightarrow \mu^+\nu_\mu$

$\tau$ is reconstructed in $\pi^-\nu_\tau$ and fit to the missing mass squared distributions

Two branching ratios are extracted

1) Standard Model constrained

$$R \equiv \frac{\Gamma(D_s^+ \rightarrow \tau^+\nu_\tau)}{\Gamma(D_s^+ \rightarrow \mu^+\nu_\mu)} = \frac{m_{\tau^+}^2 (1 - \frac{m_{\nu_\tau}^2}{m_{D_s^+}^2})^2}{m_{\mu^+}^2 (1 - \frac{m_{\nu_\mu}^2}{m_{D_s^+}^2})^2} = 9.76$$

Results:

$\mathcal{B}(D_s^+ \rightarrow \tau^+\nu_\tau) = (4.83 \pm 0.65 \pm 0.26)\%$

$\mathcal{B}(D_s^+ \rightarrow \mu^+\nu_\mu) = (0.495 \pm 0.067 \pm 0.026)\%$
Leptonic $D_{s}^{+} \rightarrow l^{+} \nu_{l}$ @ 4.009 GeV

Measurements of $D_{s}^{+} \rightarrow \tau^{+}\nu_{\tau}$ and $D_{s}^{+} \rightarrow \mu^{+}\nu_{\mu}$

$\tau$ is reconstructed in $\pi_{\nu_{\tau}}$ and fit to the missing mass squared distributions

Two branching ratios are extracted

2) Non Standard Model constrained

Results:

$B(D_{s}^{+} \rightarrow \tau^{+}\nu_{\tau}) = (3.28 \pm 1.83 \pm 0.37)\%$

$B(D_{s}^{+} \rightarrow \mu^{+}\nu_{\mu}) = (0.517 \pm 0.075 \pm 0.021)\%$
Leptonic $D_s^+ \rightarrow l^+ \nu_l$ @ 4.009 GeV

Measurements of $D_s^+ \rightarrow \tau^+ \nu_{\tau}$ and $D_s^+ \rightarrow \mu^+ \nu_{\mu}$

\[ \tau \text{ is reconstructed in } \overline{\nu}_{\tau} \text{ and fit to the missing mass squared distributions} \]

Two branching ratios are extracted

\[ f_{D_s} \text{ decay constant} \]

\[ f_{D_s^+} = \frac{1}{G_F m_{\ell}(1 - \frac{m_{\ell}^2}{m_{D_s^+}^2}) |V_{cs}|} \sqrt{\frac{8\pi B(D_s^+ \rightarrow \ell^+ \nu_{\ell})}{m_{D_s^+} \tau_{D_s^+}}} \]

\[ D_s^+ \rightarrow \mu^+ \nu_{\mu} \text{ from SM constrained fit} \]

\[ |V_{cs}| = 0.97425 \]

Results:

\[ f_{D_s^+} = (241.0 \pm 16.3 \pm 6.6) \text{ MeV} \]
Data – MC simulation in very good agreement.

**World most precise measurement**
From ~4% to ~0.5% accuracy
Semileptonic $D_s^+ \rightarrow \eta^{} (\gamma) e^+\nu_e \ @ 4178$ GeV (Preliminary)

Combining this work results and the ones of ArXiv: 1803.0557
$D^+ \rightarrow \eta^{} (\gamma) e^+\nu_e$ in

$\Gamma(D_s^+ \rightarrow \eta^{} e^+\nu) / \Gamma(D_s^+ \rightarrow \eta e^+\nu) \approx \cot^4 \phi_P$