

New Belle result on f_{D_s} + experimental status of f_{D_s} and f_D

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Karlsruhe Institute of Technology



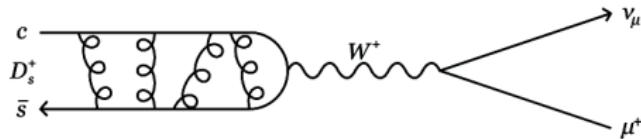
Outline

Experiment status of $D_{(s)} \rightarrow \ell\nu_\ell$ decays:

- Belle Preliminary
 - $D_s \rightarrow \mu\nu$
 - $D_s \rightarrow \tau\nu; \tau \rightarrow e\nu\nu, \mu\nu\nu, \pi\nu$
- Babar [PRD82,091103(2010)]
 - $D_s \rightarrow \mu\nu$
 - $D_s \rightarrow \tau\nu; \tau \rightarrow e\nu\nu, \mu\nu\nu$
- CLEO-c
 - $D_s \rightarrow \mu\nu$
 - $D_s \rightarrow \tau\nu; \tau \rightarrow \pi\nu$
 - $D_s \rightarrow \tau\nu; \tau \rightarrow e\nu\nu$
 - $D_s \rightarrow \tau\nu; \tau \rightarrow \rho\nu\nu$
 - $D \rightarrow \mu\nu$
- Prospects at BESIII

Motivation: $\mathcal{B}(D_s \rightarrow \ell\nu) \Rightarrow D_s$ decay constant f_{D_s}

In Standard Model:



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

- Extract D_s decay constant, f_{D_s} , by measuring $\mathcal{B}(D_s \rightarrow \ell\nu)$
 - to test lattice QCD calculations (needed in extraction of the SM parameters from measurements in $B_{(s)}$ meson system)
- Measurements of D^+ and D_s^+ decay constants provide the $SU(3)$ flavor breaking ratio f_{D_s}/f_D
 - To good approximation $f_{B_s}/f_B = f_{D_s}/f_D$ [see JHEP,1112,(2011)088 and references therein]
- sensitive to charged Higgs contribution, ...

Current experimental/theoretical status

Table taken from arXiv:1201.2401

Model	$f_{D_s^+}$ (MeV)	f_{D^+} (MeV)	$f_{D_s^+}/f_{D^+}$
Experiment (our averages)	260.0 ± 5.4	206.7 ± 8.9	1.26 ± 0.06
Lattice (HPQCD) [1]	248.0 ± 2.5	213 ± 4	1.164 ± 0.018
Lattice (FNAL+MILC) [2]	260.1 ± 10.8	218.9 ± 11.3	1.188 ± 0.025
PQL [3]	244 ± 8	197 ± 9	1.24 ± 0.03
QCD sum rules [4]	205 ± 22	177 ± 21	$1.16 \pm 0.01 \pm 0.03$
QCD sum rules [5]	$245.3 \pm 15.7 \pm 4.5$	$206.2 \pm 7.3 \pm 5.1$	$1.193 \pm 0.025 \pm 0.007$
Field correlators [6]	260 ± 10	210 ± 10	1.24 ± 0.03
Light front [7]	268.3 ± 19.1	206 (fixed)	1.30 ± 0.04

[1] PRD82,114504(2010); [2] arXiv:1112.3051; [3] JHEP0907,043(2009); [4] JHEP0511,014(2005); [5] PLB701,82(2011);
[6] PRD75,116001(2007); [7] PRD81,054022(2010)

Experiment and HPQCD lattice calculation consistent at 2σ level.
In past the discrepancy was around 4σ .

Previous Belle measurement (548 fb^{-1}) with $D_s \rightarrow \mu\nu$ decays only:
 $f_{D_s} = 275 \pm 20 \text{ MeV}$ [PRL100,241801(2008)]

Competitive measurement of f_{D_s} using final Belle data sample is possible.

Method overview

- Recoil method in charm events

$$e^+ e^- \rightarrow c\bar{c} \rightarrow \overline{D}_{\text{tag}} K X_{\text{frag}} D_s^{*+}$$

At B-factories $\sqrt{s} = 10.58$ GeV therefore all charmed hadron pairs are possible and additional light mesons (X_{frag}) can be produced in fragmentation process.

2 step reconstruction:

① Inclusive reconstruction of D_s mesons for normalization

- Reconstruct $\overline{D}_{\text{tag}} K X_{\text{frag}}$ and γ from $D_s^* \rightarrow D_s \gamma$ decay and identify D_s in missing mass spectrum (without any requirements upon D_s decay products)

$$M_{\text{miss}}(\overline{D}_{\text{tag}} K X_{\text{frag}} \gamma) = |p_{e^+ e^-} - p_{\overline{D}_{\text{tag}}} - p_K - p_{X_{\text{frag}}} - p_\gamma|^2$$

② Within the inclusive D_s sample search for $D_s \rightarrow f$ decays

- $D_s \rightarrow \mu\nu$: peak at $m_\nu^2 = 0$ in $M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma \mu)$
- $D_s \rightarrow \tau\nu$: peak towards 0 in extra energy in calorimeter

Method overview: inclusive D_s reconstruction

- $\overline{D}_{\text{tag}} = \overline{D^0}, D^-, \Lambda_c^-, D^{*-}, \overline{D}^{*0}$

D^0	$\mathcal{B} [\%]$
$K^- \pi^+$	3.9
$K^- \pi^+ \pi^0$	13.9
$K^- \pi^+ \pi^+ \pi^-$	8.1
$K^- \pi^+ \pi^+ \pi^- \pi^0$	4.2
$K_S^0 \pi^+ \pi^-$	2.9
$K_S^0 \pi^+ \pi^- \pi^0$	5.4
Sum	38.4

D^+	$\mathcal{B} [\%]$
$K^- \pi^+ \pi^+$	9.4
$K^- \pi^+ \pi^+ \pi^0$	6.1
$K_S^0 \pi^+$	1.5
$K_S^0 \pi^+ \pi^0$	6.9
$K_S^0 \pi^+ \pi^+ \pi^-$	3.1
$K^+ K^- \pi^+$	1.0
Sum	28.0

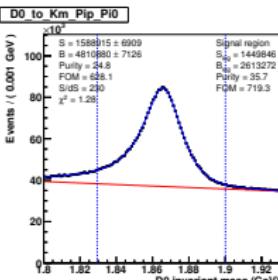
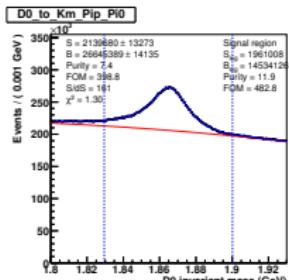
Λ_c^+	$\mathcal{B} [\%]$
$pK^- \pi^+$	5.0
$pK^- \pi^+ \pi^0$	3.4
pK_S^0	1.1
$\Lambda \pi^+$	1.1
$\Lambda \pi^+ \pi^0$	3.6
$\Lambda \pi^+ \pi^+ \pi^-$	2.6
Sum	16.8

$$D^{*+} \rightarrow D^0 \pi^+, D^+ \pi^0; D^{*0} \rightarrow D^0 \pi^-, D^0 \gamma;$$

- Multivariate tool NeuroBayes used in D_{tag} selection (trained on $\sim 1\%$ of real data) using sPlot technique to suppress wrong D_{tag} background

$$D^0 \rightarrow K^- \pi^+ \pi^0$$

Basic selection vs. Optimized selection



A. Zupanc (KIT)

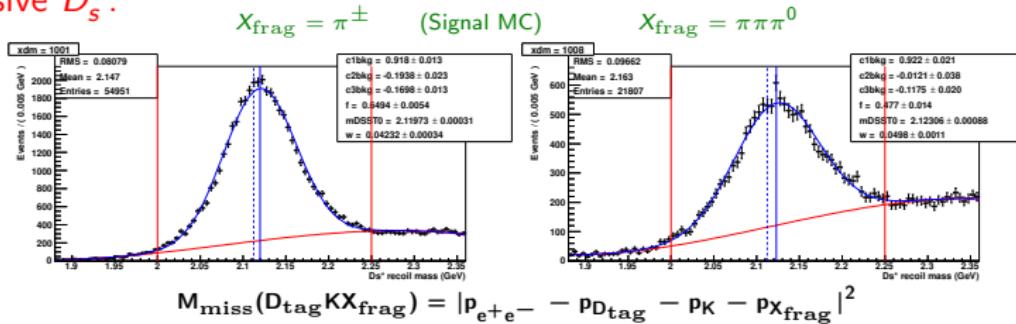
- Optimized selection rejects $\sim 75\%$ of wrong D_{tag} candidates while keeps $\sim 84\%$ of signal
- $\sim 100000 D_{\text{tag}}s$ per 1 fb^{-1}

$D_s \rightarrow \ell \nu$ and f_{D_s}

Method overview: obtaining inclusive D_s sample

$$e^+ e^- \rightarrow c\bar{c} \rightarrow \overline{D}_{\text{tag}} K X_{\text{frag}} D_s^{*+}$$

- Strangeness balancing kaon: $K = K^\pm, K_S^0$
- If $\overline{D}_{\text{tag}} = \Lambda_c^-$ additional p is required in the event
- Fragmentation system:
 $X_{\text{frag}} = \text{nothing}, \pi^\pm, \pi^0, \pi^\pm\pi^\pm, \pi^\pm\pi^0, \pi^\pm\pi^\pm\pi^\pm, \pi^\pm\pi^\pm\pi^0$
- Inclusive D_s^* :

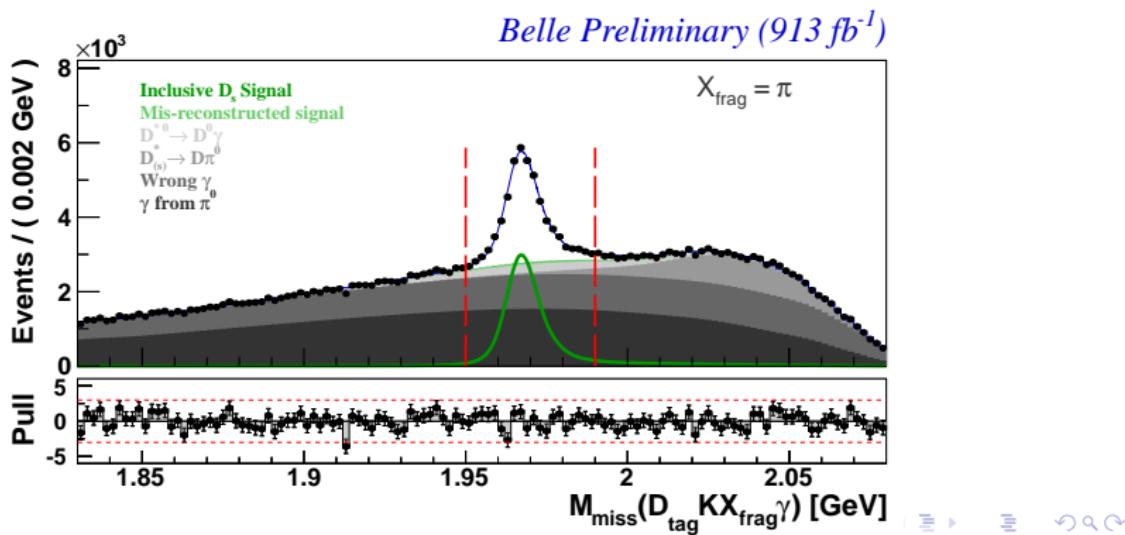


- Select one D_s^* candidate with $\min(|M_{\text{miss}} - m_{D_s^*}|)$ and $2.0 < M_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}}) < 2.25 \text{ GeV}$
- mass constrained vertex fit performed to improve the resolution in missing mass for inclusive D_s candidates

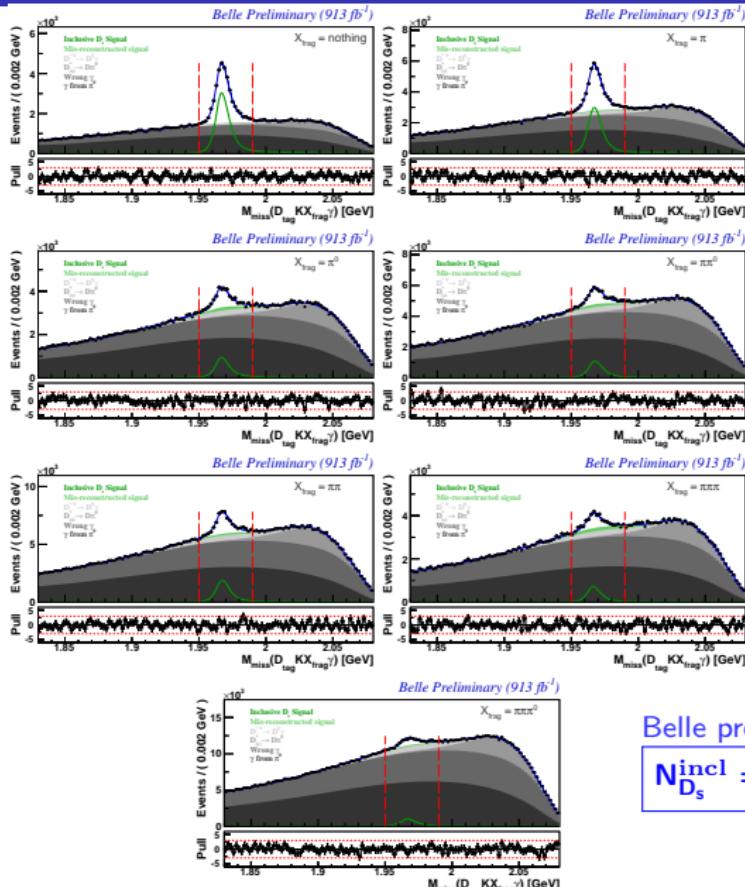
Method overview: obtaining inclusive D_s sample

$$e^+ e^- \rightarrow c\bar{c} \rightarrow \overline{D}_{\text{tag}} K X_{\text{frag}} D_s^{*+}$$

- γ from $D_s^* \rightarrow D_s \gamma$
 - $E_\gamma > 0.12$ GeV, in opposite hemisphere wrt. D_{tag}
- **Inclusive D_s**
 - $p_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma) > 2.8$ GeV
 - only one candidate per event is allowed (selection based on γ properties only)



Inclusive D_s yield extraction



Fit to $M_{\text{miss}}(D_{\text{tag}} KX_{\text{frag}}\gamma)$ for each X_{frag} :

- Histogram MC templates (6 categories)
- Peak resolution calibrated using real data
- Good description of the observed distributions achieved

Belle preliminary @ 913 fb^{-1}

$$N_{D_s}^{\text{incl}} = 94400 \pm 1300(\text{stat.}) \pm 1400(\text{syst.})$$

Reconstruction of $D_s \rightarrow f$ and $\mathcal{B}(D_s \rightarrow f)$

- Within inclusive D_s sample check if the remaining tracks or neutral pions are consistent with $D_s \rightarrow f$ decays:
 - $D_s^+ \rightarrow K^- K^+ \pi^+$ (cross-check of the method)
 - $D_s^+ \rightarrow \bar{K}^0 \pi^+, \eta \pi^+$ (cross-check of the method and calibration of M_{miss}^2)
 - $D_s^+ \rightarrow \mu^+ \nu_\mu$ and $D_s^+ \rightarrow \tau^+ \nu_\tau$

Absolute branching fraction given by:

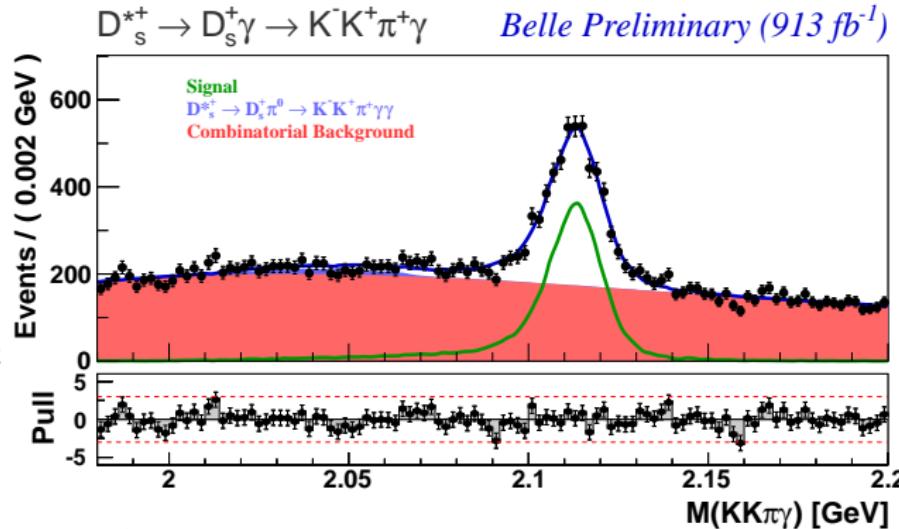
$$\mathcal{B}(D_s \rightarrow f) = \frac{N_{D_s \rightarrow f}^{\text{excl}}}{N_{D_s}^{\text{incl}} \cdot f_{\text{bias}} \cdot \varepsilon(f|\text{incl. } D_s \rightarrow f)}$$

$$f_{\text{bias}} = \frac{\frac{N_{D_s}^{\text{incl.}}}{N_{D_s \rightarrow f}^{\text{excl.}}} \cdot \varepsilon(D_s \rightarrow f)^{\text{incl.}}}{\sum_i \mathcal{B}(D_s \rightarrow i) \varepsilon(D_s \rightarrow f)^{\text{incl.}}}$$

$N_{D_s}^{\text{incl.}}$ # of incl.. recon. D_s mesons
 $N_{D_s \rightarrow f}^{\text{excl.}}$ # of excl. recon. $D_s \rightarrow f$ decays within inclusive D_s sample
 $\varepsilon(D_s \rightarrow f)^{\text{incl.}}$ ratio of efficiency to reconstruct D_s meson
inclusively if it decayed to f over average inclusive efficiency
 $\varepsilon(f|\text{incl. } D_s \rightarrow f)$ efficiency to excl. reconstruct f given correct inclusive D_s

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

Fit to the exclusive D_s^* inv. mass $M(KK\pi\gamma)$



$$N_{D_s \rightarrow KK\pi}^{\text{excl}} = 4094 \pm 123$$

Belle preliminary @ 913 fb⁻¹

$\mathcal{B}(D_s^+ \rightarrow K^+ K^- \pi^+) = (5.06 \pm 0.15(\text{stat.}) \pm 0.19(\text{syst.}))\%$

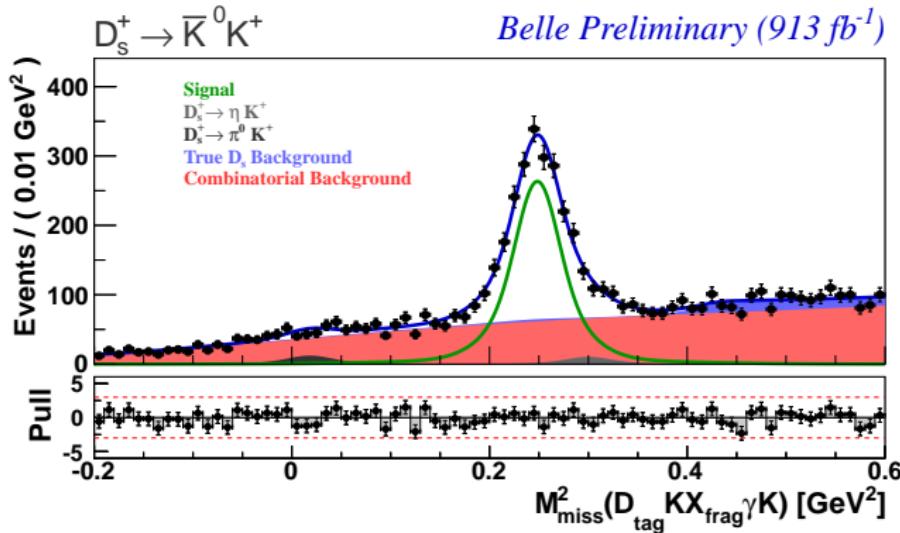
Consistent with $\mathcal{B}^{\text{PDG}}(D_s^+ \rightarrow K^+ K^- \pi^+) = (5.49 \pm 0.27)\%$.

$$D_s^+ \rightarrow \bar{K}^0 K^+$$

Fit to the missing mass squared – $M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma K^\pm)$

Selection:

- $M_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma)$ signal region
- 1 charged track pointing to the IP
- passing kaon PID requirements



$$N_{D_s \rightarrow K^0 K}^{\text{excl}} = 1943 \pm 82$$

Belle preliminary @ 913 fb⁻¹

$$\mathcal{B}(D_s^+ \rightarrow \bar{K}^0 K^+) = (2.84 \pm 0.12(\text{stat.}) \pm 0.08(\text{syst.}))\%$$

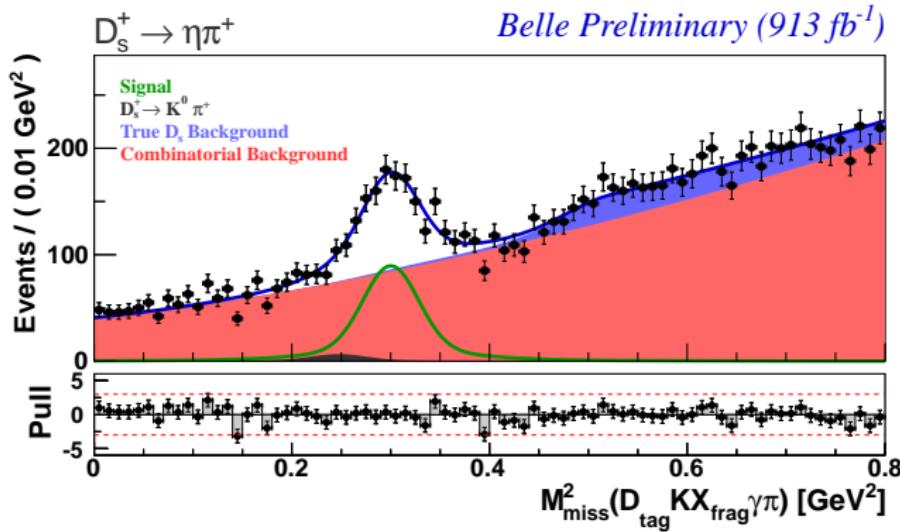
Consistent with $\mathcal{B}^{\text{PDG}}(D_s^+ \rightarrow \bar{K}^0 K^+) = 2 \times \mathcal{B}^{\text{PDG}}(D_s^+ \rightarrow K_S^0 K^+) = (2.96 \pm 0.16)\%$.

$$D_s^+ \rightarrow \eta\pi^+$$

Fit to the missing mass squared – $M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma \pi^\pm)$

Selection:

- $M_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma)$ signal region
- 1 charged track pointing to the IP
- passing pion PID requirements
- $E_{\text{ECL}} > 1 \text{ GeV}$ to remove $D_s \rightarrow \tau(\pi)\nu$ decays



$$N_{D_s \rightarrow \eta\pi}^{\text{excl}} = 773 \pm 58$$

Belle preliminary @ 913 fb⁻¹

$$\mathcal{B}(D_s^+ \rightarrow \eta\pi^+) = (1.79 \pm 0.14(\text{stat.}) \pm 0.05(\text{syst.}))\%$$

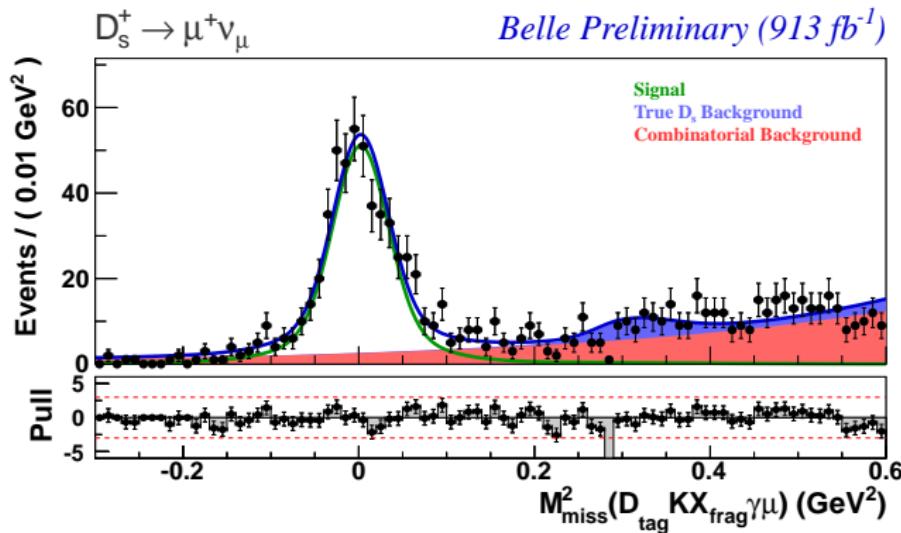
Consistent with $\mathcal{B}^{\text{PDG}}(D_s^+ \rightarrow \eta\pi^+) = (1.83 \pm 0.15)\%$.

$$D_s^+ \rightarrow \mu^+ \nu_\mu$$

Fit to the missing mass squared – $M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma \mu^\pm)$

Selection:

- $M_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma)$ signal region
- 1 charged track pointing to the IP
- passing muon PID requirements



$$N_{D_s \rightarrow \mu\nu}^{\text{excl}} = 489 \pm 26$$

Belle preliminary @ 913 fb⁻¹

$$\mathcal{B}(D_s^+ \rightarrow \mu^+ \nu_\mu) = (0.528 \pm 0.028(\text{stat.}) \pm 0.019(\text{syst.}))\%$$

Most precise measurement up to date.

$D_s \rightarrow \tau\nu$ Selection

τ reconstructed in three decay modes (covering 46% of all τ decays):

- $\tau \rightarrow \mu\nu\nu$
- $\tau \rightarrow e\nu\nu$
- $\tau \rightarrow \pi\nu$ (first time these decays are used at B-factories in $D_s \rightarrow \tau\nu$ studies)

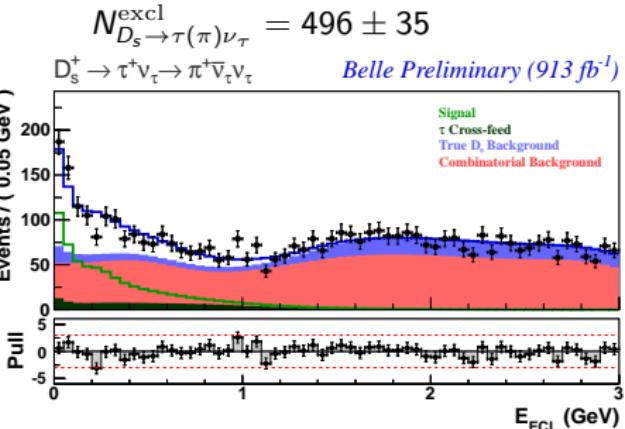
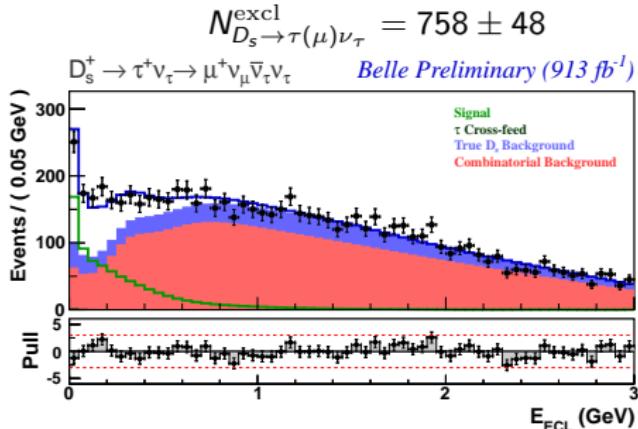
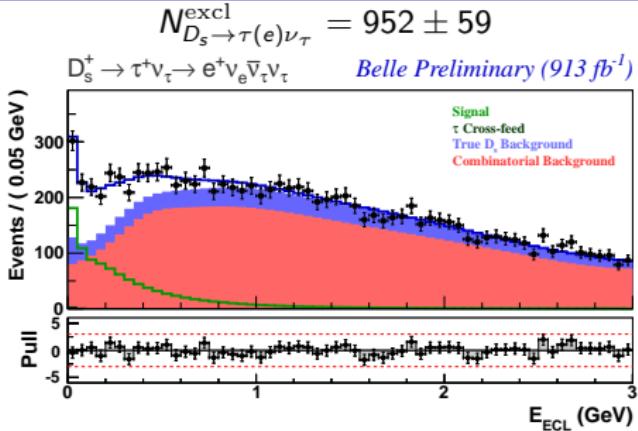
Selection:

- $M_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma)$ signal region
- Only 1 remaining track pointing to the IP
- charged tracks passing PID requirements
- $D_s \rightarrow \tau(\ell)\nu$ specific:
 - the $D_s \rightarrow \ell\nu$ decays are vetoed with $M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma \ell) > 0.3 \text{ GeV}^2$
- $D_s \rightarrow \tau(\pi)\nu$ specific:
 - Due to limited phase space $0.0 < M_{\text{miss}}^2(D_{\text{tag}} K X_{\text{frag}} \gamma \pi) < 0.6 \text{ GeV}^2$
 - $|p_{\text{miss}}(D_{\text{tag}} K X_{\text{frag}} \gamma \pi)| > 1.2 \text{ GeV}$ to reduce the background

$D_s \rightarrow \tau\nu$ Signal Yields

Fit to E_{ECL} :

- **Signal**
 $\hookrightarrow \tau$ cross-feed between modes, e.g.
 $\tau(\rho) \rightarrow \tau(\pi)$, is part of signal PDF
 and fixed
- **True D_s background is fixed**
 $\hookrightarrow \ell$ modes: dominantly $D_s \rightarrow X\ell\nu$
 $\hookrightarrow \pi$ mode: $D_s \rightarrow K^0K$, $\eta\pi$, ρK
- **Combinatorial background**



Absolute $\mathcal{B}(D_s \rightarrow \ell\nu)$

- $D_s \rightarrow \tau\nu$
 - \mathcal{B} consistent between different modes within statistical uncertainties

τ decay mode	$\mathcal{B}(D_s^+ \rightarrow \tau^+\nu_\tau)$ [$\times 10^{-2}$]
$e\nu\nu$	$5.37 \pm 0.33^{+0.35}_{-0.30}$
$\mu\nu\nu$	$5.88 \pm 0.37^{+0.34}_{-0.58}$
$\pi\nu$	$5.96 \pm 0.42^{+0.45}_{-0.39}$
Combination	$5.70 \pm 0.21^{+0.31}_{-0.30}$

Same precision as achieved by CLEO-c combining e , π and ρ modes

- $D_s \rightarrow \mu\nu$

$$\mathcal{B}(D_s^+ \rightarrow \mu^+\nu_\mu) = (0.528 \pm 0.028(\text{stat.}) \pm 0.019(\text{syst.}))\%.$$

Systematics Summary

Source	$\mu\nu$ [%]	$\tau(e)\nu$ [%]	$\tau(\mu)\nu$ [%]	$\tau(\pi)\nu$ [%]	$\tau\nu$ [%]
Statistical	± 5.32	± 6.18	± 6.33	± 7.04	± 3.75
Normalization	± 1.95	± 1.95	± 1.95	± 1.95	± 1.95
Tag bias	± 1.37	± 1.37	± 1.37	± 1.37	± 1.37
Tracking	± 0.35	± 0.35	± 0.35	± 0.35	± 0.35
Efficiency	± 1.78	± 1.28	± 1.51	± 1.88	± 0.84
PID	± 1.96	± 2.03	± 1.93	± 0.88	± 1.70
D_s background	± 0.82	± 3.88	± 3.56	± 3.15	± 2.84
Comb. bkg. PDF	± 0.02	$+0.11$	-8.31	$+0.92$	-2.54
Signal PDF	–	$+3.46$	$+1.96$	$+3.43$	$+2.95$
τ cross-feed	–	± 0.36	± 0.24	± 3.71	± 0.94
$\mathcal{B}(\tau \rightarrow X)$	–	± 0.22	± 0.23	± 0.64	± 0.19
PDF stat.	–	± 2.16	± 2.19	± 3.05	± 1.44
Total syst.	± 3.67	$+6.59$ -5.61	$+5.76$ -9.92	$+7.49$ -6.60	$+5.40$ -5.19
Stat. + Syst.	± 6.46	$+9.03$ -8.35	$+8.56$ -11.8	$+10.3$ -9.65	$+6.57$ -6.40

Most of the systematics scale with luminosity so there is still room for improvement at BelleII.

Extraction of f_{D_s}

$$f_{D_s} = \frac{1}{G_F m_\ell \left(1 - \frac{m_\ell^2}{M_{D_s}^2}\right) |V_{cs}|} \sqrt{\frac{8\pi \mathcal{B}(D_s \rightarrow \ell\nu_\ell)}{M_{D_s} \tau_{D_s}}}$$

External inputs:

Quantity	Value
M_{D_s}	1.96847(33) GeV
m_τ	1.77682(16) GeV
m_μ	0.105658367(9) GeV
τ_{D_s}	0.500(7) ps
G_F	$1.16637(1) \times 10^{-5}$ GeV $^{-2}$
$ V_{cs} $	0.97345(22)

Belle Preliminary (913 fb $^{-1}$)

$D_s \rightarrow \ell\nu$	f_{D_s} [MeV]
$\mu\nu$	$249.0 \pm 6.6(\text{stat.}) \pm 4.6(\text{syst.}) \pm 1.7(\tau_{D_s})$
$\tau\nu$	$261.9 \pm 4.9(\text{stat.}) \pm 7.0(\text{syst.}) \pm 1.8(\tau_{D_s})$
Combination	$255.0 \pm 4.2(\text{stat.}) \pm 4.7(\text{syst.}) \pm 1.8(\tau_{D_s})$

Compared to previous Belle measurement ($\mathcal{L} = 548$ fb $^{-1}$) total error reduced by factor of 3.

Most precise f_{D_s} measurement at single experiment.

Conclusions and Future Outlook

- Belle preliminary results presented:

$D_s^+ \rightarrow f$	$\mathcal{B} [\%]$	$D_s^+ \rightarrow f$	$\mathcal{B} [\%]$
$K^+ K^- \pi^+$	$5.06 \pm 0.15 \pm 0.19$	$\mu^+ \nu_\mu$	$0.528 \pm 0.028 \pm 0.019$
$K^0 K^+$	$2.84 \pm 0.12 \pm 0.08$	$\tau^+ \nu_\tau$	$5.70 \pm 0.21^{+0.31}_{-0.30}$
$\eta \pi^+$	$1.79 \pm 0.14 \pm 0.05$		

$$f_{D_s} = (255.0 \pm 4.2 \pm 5.0) \text{ MeV}$$

- Belle II

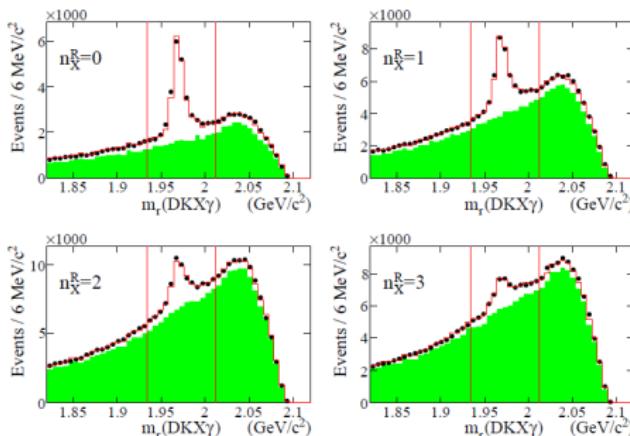
- Large inclusive samples of all charmed hadrons (D^0 , D^+ , D_s^+ , Λ_c) will enable
 - ↪ precise measurements of form factors with semileptonic decays
(e.g. $\sigma(f_+^\pi(0))/f_+^\pi(0) \sim 1\%$)
 - ↪ precise measurement of D and D_s decay constants and their ratio
 - ↪ searches of rare decays, e.g. $D \rightarrow h\nu\bar{\nu}$, $D^0 \rightarrow \nu\bar{\nu}$

BaBar: $D_s^+ \rightarrow \mu^+\nu$ & $D_s^+ \rightarrow \tau^+\nu$ (521 fb^{-1})

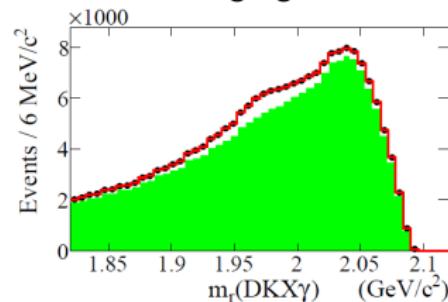
PRD 82, 091103 (2010)

- Similar method as Belle
- Inclusive D_s yield extraction different
 - allow multiple inclusive D_s candidates (assign $1/n$ weight to each candidate)
 - all candidates reconstructed in an event containing D_s meson are tagged as signal
 - background modeled using wrong sign candidates (charm or strangeness not consistent with charge of D_s)
 - requires yield extraction from 2D fit: missing mass vs. number of pions in X_{frag}

Right sign



Wrong sign



$$N_{D_s}^{\text{incl}} = 67200 \pm 1500 \quad \text{in missing mass signal region}$$

BaBar: $D_s^+ \rightarrow \mu^+\nu$ & $D_s^+ \rightarrow \tau^+\nu$ (521 fb^{-1})

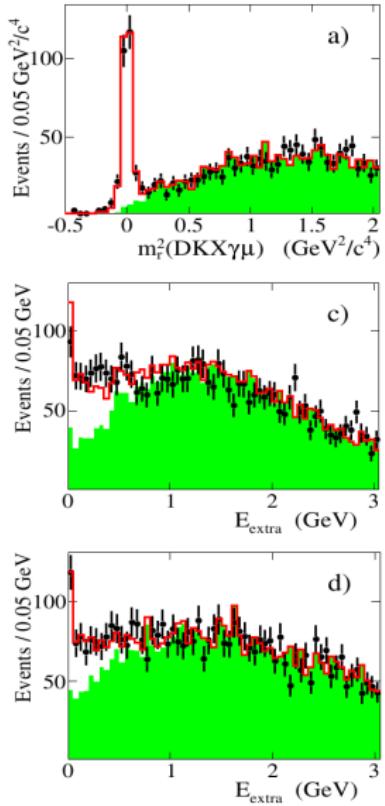
- Branching fractions:

$$\mathcal{B}(D_s^+ \rightarrow \mu^+\nu) = (0.602 \pm 0.038 \pm 0.034)\%$$

$$\mathcal{B}(D_s^+ \rightarrow \tau^+\nu) = (5.00 \pm 0.35 \pm 0.49)\%$$

- Decay constant

$$f_{D_s} = (258.6 \pm 6.4 \pm 7.5) \text{ MeV}$$

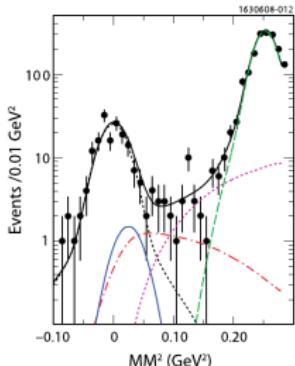
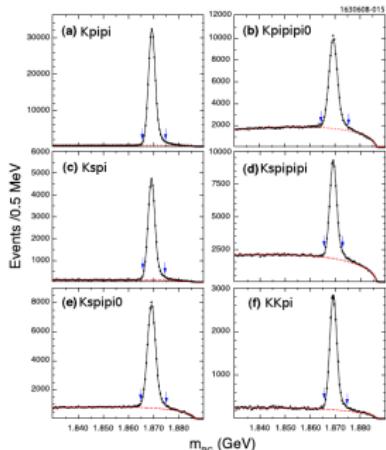


CLEO-c: $D^+ \rightarrow \mu^+ \nu$ (818 pb $^{-1}$)

PRD 78, 052003 (2008)

- Use $e^+ e^- \rightarrow D^+ D^-$ at $\psi(3770)$
↪ Pure DD , no additional particles
- Tag side:
 - reconstructed in six decay modes
 - tagging efficiency 22%
 - in total 460 000 signal tags
- Signal side:
 - single extra track of opposite charge to the tag and with $E_{\text{cal}} < 300$ MeV (minimum ionizing)
 - missing mass near zero (neutrino)
 - find 149.7 ± 12.0 $\mu\nu$ signal events (fixed τ/μ) or 153.9 ± 13.5 $\mu\nu$ and 13.5 ± 15.3 $\tau\nu$
 - backgrounds: $\tau^+ \nu$, $\pi^0 \pi^+$, $\bar{K}^0 \pi^+$, other

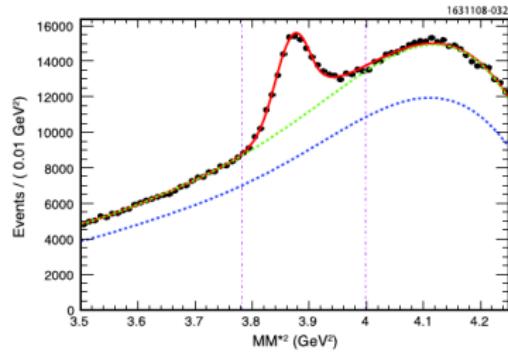
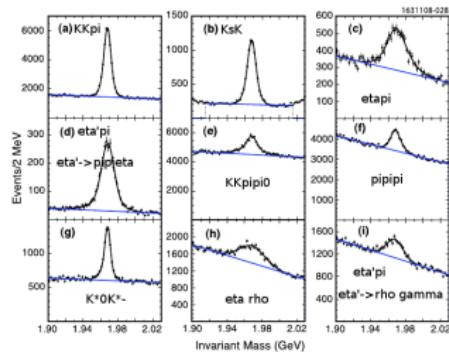
$$\mathcal{B}(D^+ \rightarrow \mu^+ \nu) = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$$



CLEO-c: $D_s \rightarrow \ell\nu_\ell$ (600 pb^{-1})

PRD 79, 052001 (2009); PRD 80, 112004 (2009); PRD 79, 052002 (2009)

- Use $e^+e^- \rightarrow D_s^+ D_s^{*-}, D_s^{*-} \rightarrow \gamma D_s^-$ at 4170 MeV
- Tag side:
 - Fully reconstruct $D_s\gamma$ to look for another D_s
 - D_s reconstructed in nine decay modes
 - tags selected in missing mass recoiling against $D_s\gamma$
→ for $D_s D_s^*$ events this always peaks at M_{D_s}
 - in total 44 000 signal tags found in missing mass spectrum



CLEO-c: $D_s \rightarrow \mu\nu$ & $D_s \rightarrow \tau(\pi, \rho)\nu$

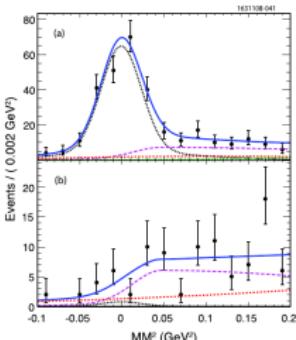
$D_s \rightarrow \mu\nu$ & $D_s \rightarrow \tau(\pi)\nu$

- single extra track with opposite charge to tag, not being identified as electron or kaon, with
 - $E_{\text{cal}} < 300$ MeV (99% μ , 55% π) or
 - $E_{\text{cal}} > 300$ MeV (1% μ , 45% π)
- 2D fit to D_s -tag mass and MM^2 to extract signal yields
- cases (a) and (b) fitted simultaneously
- find 235.5 ± 13.8 $\mu\nu$ events
and 125.6 ± 15.7 $\tau\nu(\tau \rightarrow \pi\nu)$ events
- backgrounds: about 10 events in total

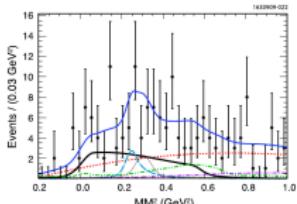
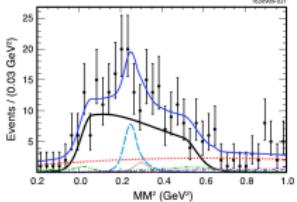
$D_s \rightarrow \tau(\rho)\nu$

- event with exactly one charged pion forming $\rho^+ \rightarrow \pi^+\pi^0$
- fit MM^2 distribution in the first two E_{extra} bins
- signal yields:
 155.2 ± 16.5 , $E_{\text{extra}} < 0.1$ GeV
 43.7 ± 11.3 , $0.1 < E_{\text{extra}} < 0.2$ GeV

$D_s \rightarrow \mu\nu, \tau(\pi)\nu$



$D_s \rightarrow \tau(\rho)\nu$



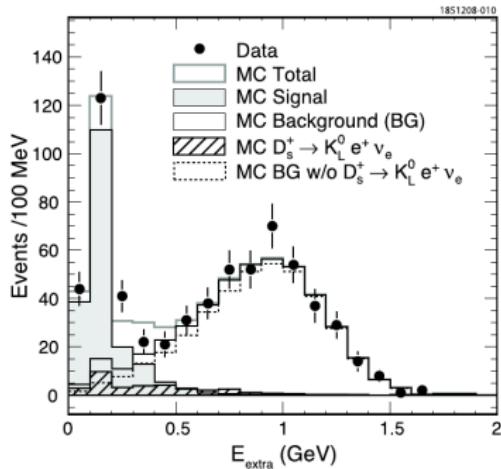
CLEO-c: $D_s \rightarrow \tau(e)\nu$ and Summary

- Tag side:

- similar to $D_s^+ \rightarrow \mu^+\nu$
- only cleanest modes used
 $(D_s^- \rightarrow \phi\pi^-, D_s^- \rightarrow K^-K^{*0}, D_s^- \rightarrow K^-K_s^0)$

- Signal side:

- event with exactly one electron
- estimate $D_s^+ \rightarrow K_L^0 e^+\nu$ peaking bkg. from MC
- signal yield: **180.6 ± 15.9**



CLEO-c averages:

$$\mathcal{B}(D_s^+ \rightarrow \mu^+\nu) = (0.565 \pm 0.045 \pm 0.017)\%$$

$$\mathcal{B}(D_s^+ \rightarrow \tau^+\nu) = (5.58 \pm 0.33 \pm 0.13)\%$$

$$f_{D_s} = (259.0 \pm 6.2 \pm 3.0) \text{ MeV}$$

BESIII prospects (with currently available data sets)

Based on Changzheng Yuan's talk at KEK Flavor Workshop (March 2012)

- $D^+ \rightarrow \mu^+ \nu_\mu$
 - 2.9 fb^{-1} at $\psi(3770)$ (0.818 fb^{-1} @ CLEO-c)
 - with 1.6×10^6 tagged D^+
 - expect 400 $D^+ \rightarrow \mu^+ \nu_\mu$ candidates $\sigma_{f_D}/f_D \sim 2.5\%(\text{stat.}) \pm 1\%(\text{syst.})$ (CLEO-c: 4.1%(stat.) \pm 1.2%(syst.))
- $D_s^+ \rightarrow \mu^+ \nu_\mu$
 - 0.5 fb^{-1} at 4.01 GeV (0.6 fb^{-1} at 4.17 GeV @ CLEO-c)
 - No need to detect low energy photon at 4.01 GeV, but
 - $\sigma(D_s D_s) = 0.27 \text{ nb}$ at 4.01 GeV
 - $\sigma(D_s D_s^*) = 0.92 \text{ nb}$ at 4.17 GeV
 - with 11×10^3 tagged D_s^+
 - Need larger data sample

Experimental averages

Experiment	Mode	\mathcal{B}	$f_{D_{(s)}^+}$ (MeV)
CLEO-c	$\mu^+\nu$	$(5.65 \pm 0.45 \pm 0.17) \times 10^{-3}$	$257.6 \pm 10.3 \pm 4.3$
BaBar	$\mu^+\nu$	$(6.02 \pm 0.38 \pm 0.34) \times 10^{-3}$	$265.9 \pm 8.4 \pm 7.7$
Belle	$\mu^+\nu$	$(5.28 \pm 0.28 \pm 0.19) \times 10^{-3}$	$249.0 \pm 6.6 \pm 4.9$
Average	$\mu^+\nu$	$(5.54 \pm 0.24) \times 10^{-3}$	255.1 ± 5.5
CLEO-c	$\tau^+\nu$	$(5.58 \pm 0.33 \pm 0.13) \times 10^{-2}$	$259.1 \pm 7.7 \pm 3.5$
BaBar	$\tau^+\nu$	$(5.00 \pm 0.35 \pm 0.49) \times 10^{-2}$	$245.3 \pm 8.6 \pm 12.2$
Belle	$\tau^+\nu$	$(5.70 \pm 0.21 \pm 0.31) \times 10^{-2}$	$261.9 \pm 4.9 \pm 7.2$
Average	$\tau^+\nu$	$(5.54 \pm 0.24) \times 10^{-2}$	258.2 ± 5.6
Experimental Average	$\mu^+\nu + \tau^+\nu$		257.2 ± 4.5
Lattice HPQCD			248.0 ± 2.5
CLEO-c	$D^+ \rightarrow \mu^+\nu$	$(3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$	$205.8 \pm 8.5 \pm 2.5$
Lattice HPQCD			213 ± 4

Test of lepton universality:

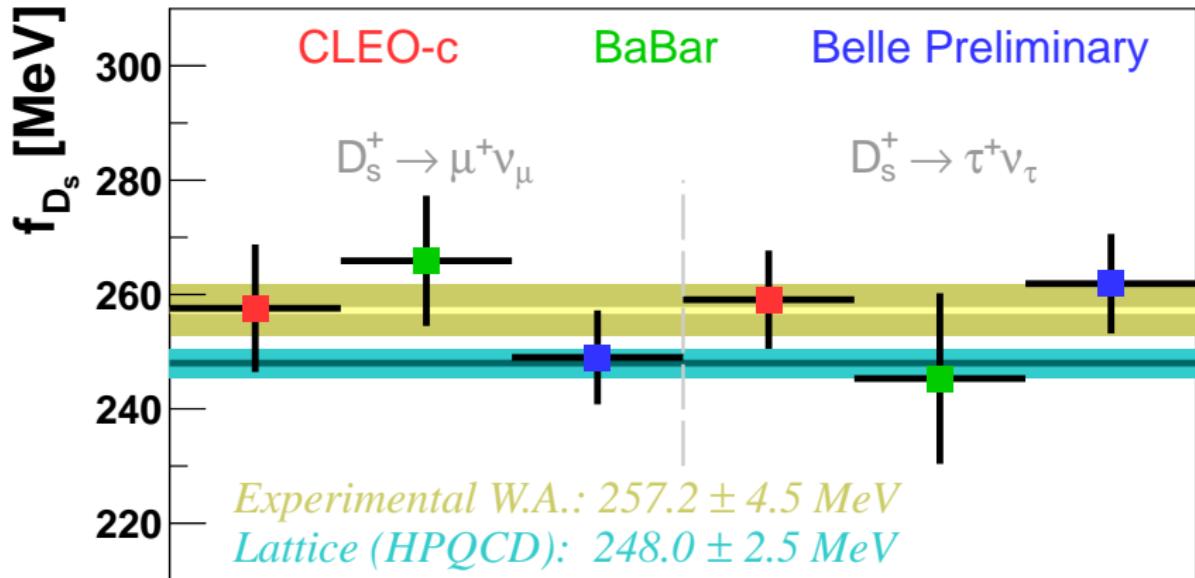
$$R_{\tau/\mu}^{\text{SM}} \equiv \frac{\mathcal{B}(D_s \rightarrow \tau\nu)}{\mathcal{B}(D_s \rightarrow \mu\nu)} = \frac{m_\tau^2 \left(1 - \frac{m_\tau^2}{M_{D_s}^2}\right)}{m_\mu^2 \left(1 - \frac{m_\mu^2}{M_{D_s}^2}\right)} = 9.76 \quad \text{vs.} \quad R_{\tau/\mu}^{\text{exp}} = 10.0 \pm 0.6$$

$D_{(s)}$ meson decay constants ratio:

$$f_{D_s}/f_D = 1.250 \pm 0.022(f_{D_s}) \pm 0.054(f_D)$$

f_{D_s} Comparison

Average of CLEO-c [PRD80,112004(2009)], BaBar [PRD82,091103(2010)] and Belle Preliminary.



Average of experimental determinations is consistent within 1.8σ with most precise lattice QCD calculation by HPQCD.

Need further lattice QCD results with comparable precision to confirm the calculation by HPQCD.

Conclusions

- Experimental value of f_{D_s} known with 1.75% relative precision
 - enables stringent tests of Lattice QCD calculations
 - agreement between experiment and most precise HPQCD calculation within 1.8σ
- In near future BESIII can provide significantly improved measurement of f_D
 - this will improve the precision of f_{D_s}/f_D ratio, which is precisely determined by many Lattice QCD calculations
- In not-so-near future Super B factories can provide even better measurements of f_D and f_{D_s}