Charm Meson
Decay Constants

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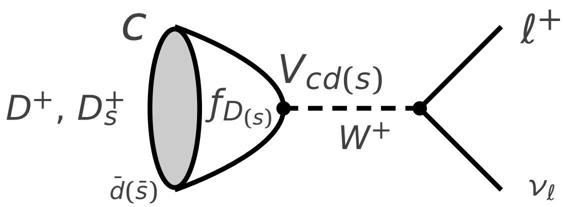
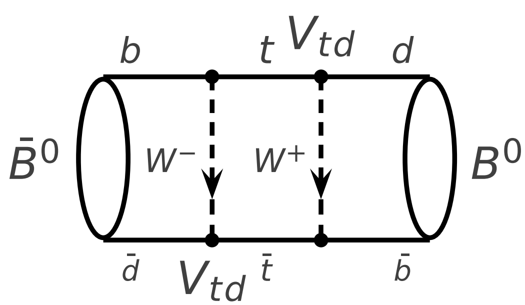
Introduction : Leptonic Decays





known to < 1% from the CKM unitarity

$\text{Rate} \propto f^2_{D(s)} \, |V_{cd(s)}|^2$

Experiment **LQCD**

$\text{Rate} \propto f^2_B \, |V_{td}|^2$

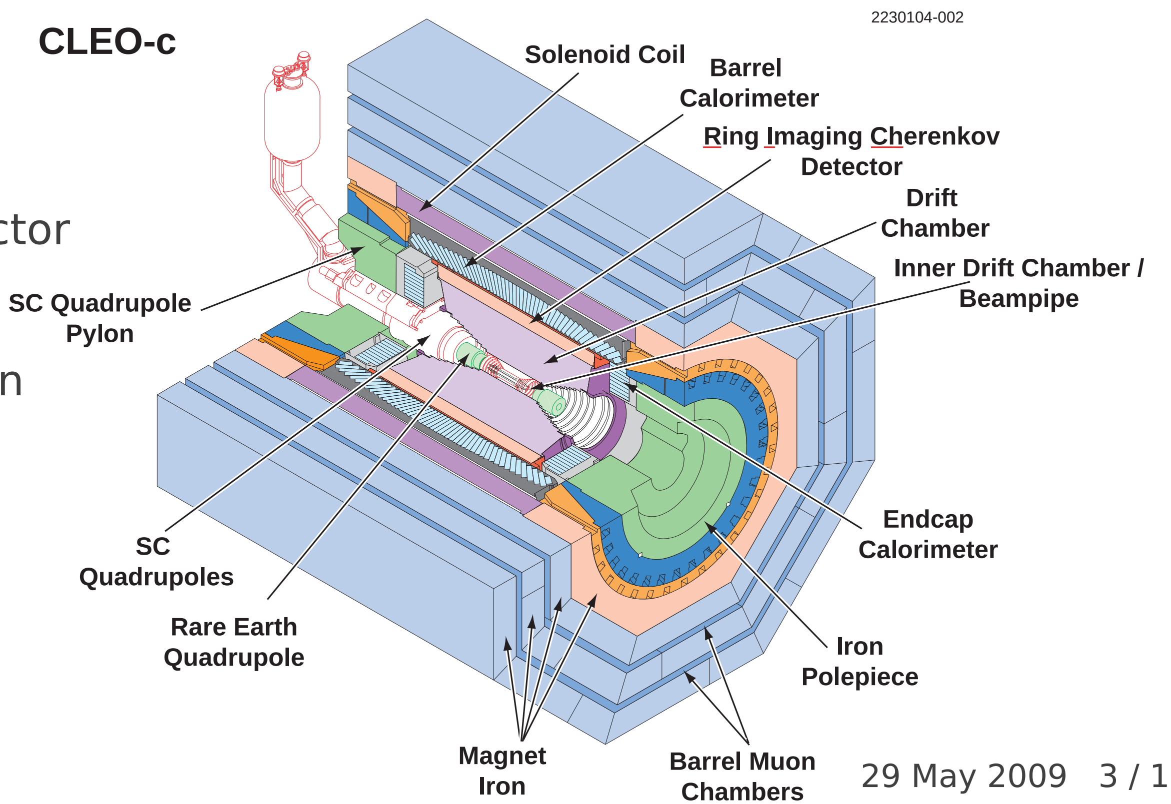
LQCD predicts f_B/f_D and f_B/f_{B_s} w/ small errors ⇒
precise f_D gives precise f_B and $|V_{td}|$
f_D/f_{D_s} checks f_B/f_{B_s}
and allows precise $|V_{td}|/|V_{ts}|$

- Leptonic decays provide a clean way to probe strong interactions. Measure **rates** to extract decay constant f_P.
- Calibrate lattice calculations of decay constants, so more reliable values of $|V_{td}|$ and $|V_{ts}|$ can be obtained from B factories:
  - f_D at CLEO-c and $(f_B/f_D)_{\text{LQCD}} \Rightarrow f_B$ for precise $|V_{td}|$.
  - f_D/f_{D_s} checks $(f_B/f_{B_s})_{\text{LQCD}}$ for $|V_{td}|/|V_{ts}|$.

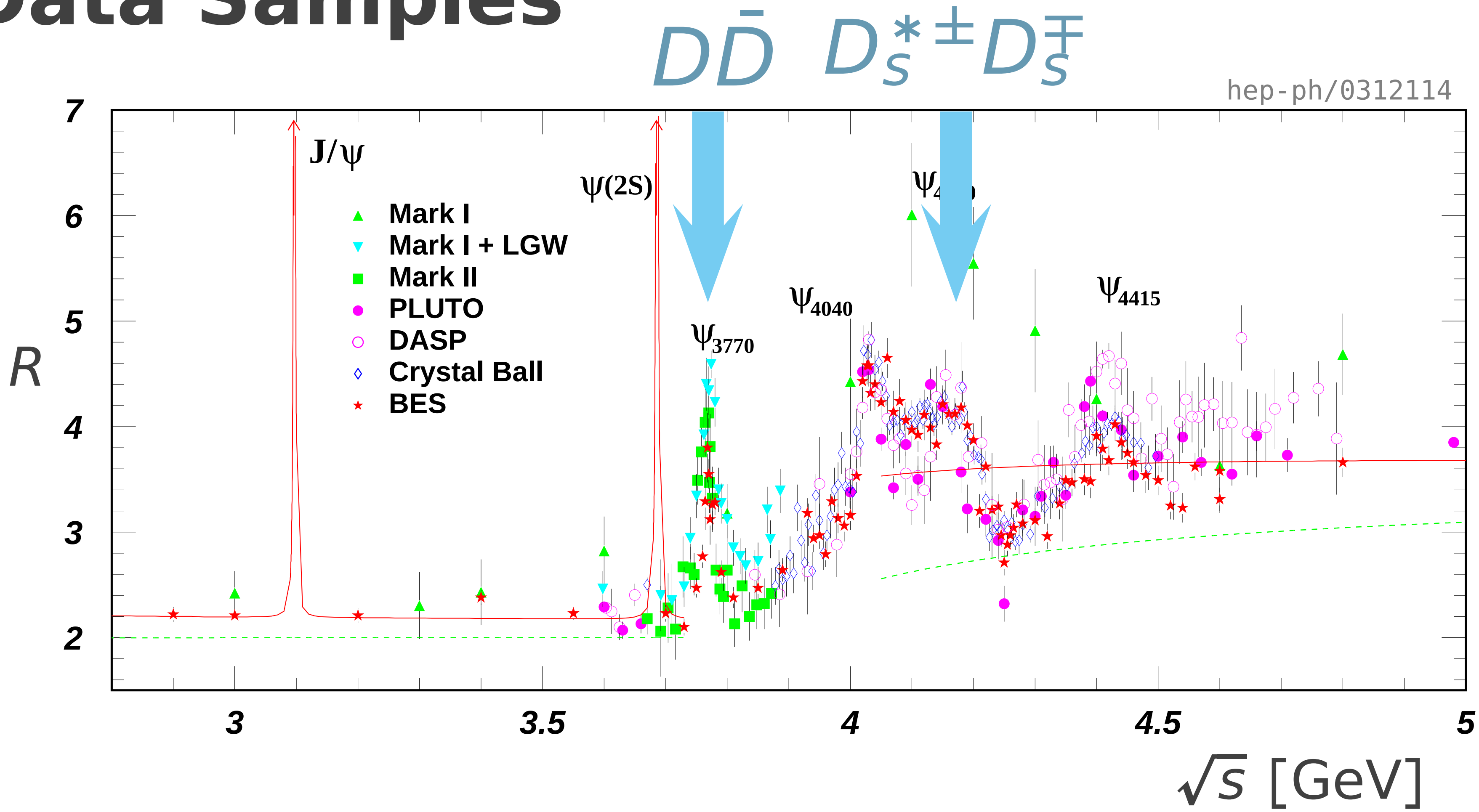
CLEO-c Open Charm Program

- Precision measurements of benchmark branching fractions of D^0, D^+, and D_s. , i.e. , those decay modes used by B factories and hadron colliders : $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s^+ \to K^+K^-\pi^+$, and others.
- Measurements to test, calibrate, validate Lattice QCD calculations, other calculations of strong interaction effects: D^+, $D_s^+ \to \ell^+\nu_\ell$, D exclusive semileptonic decays.

- General-purpose symmetric detector
- Particle ID (dE/dx, Ring Imaging Cherenkov) excellent in our momentum region
- Tracking: $\delta p/p = 0.6\%$ at 1 GeV
- CsI calorimeter: $\delta E/E \sim 5\%$ at 100 MeV



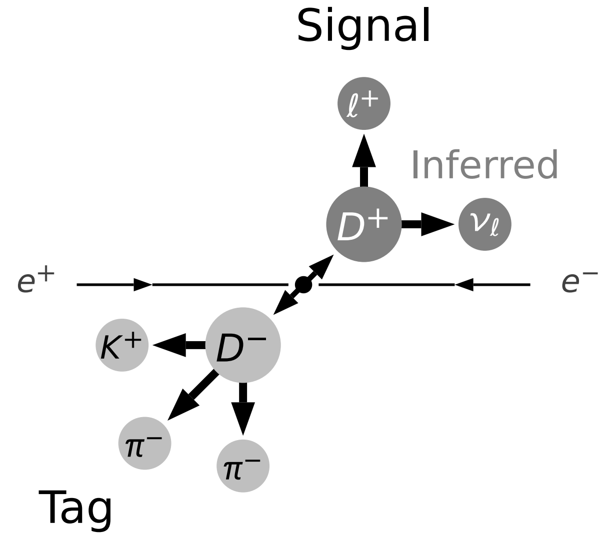
Data Samples

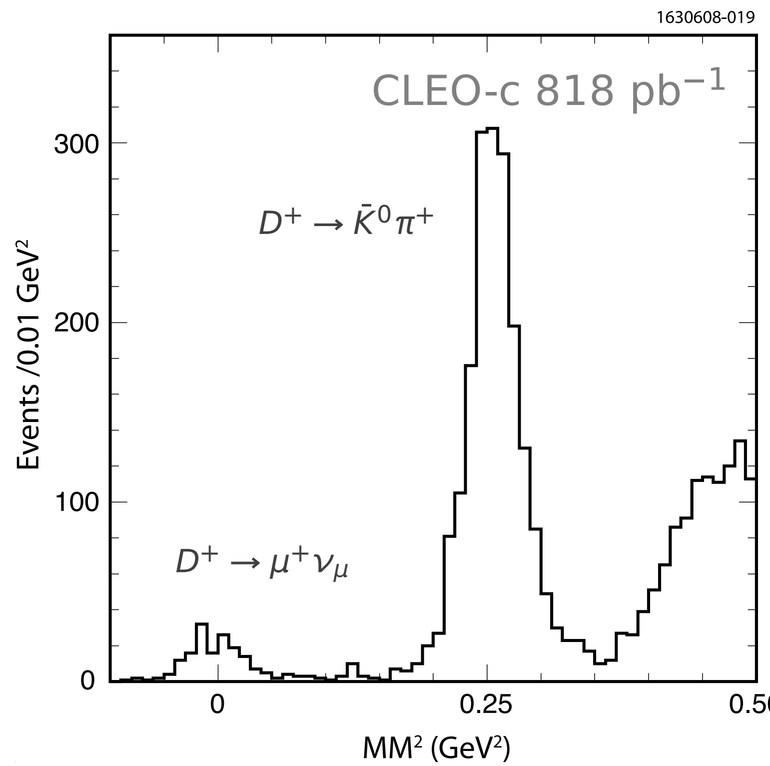


- CLEO-c : collected large data sets at charm threshold
  - E_{CM} near 3770MeV : 818 pb^{-1}, 3.0M $D^0\bar{D}^0$ and 2.4M D^+D^- events.
  - E_{CM} near 4170MeV : 600 pb^{-1}, 0.6M $D_s^{*\pm}D_s^{\mp}$ events.

Experimental Technique

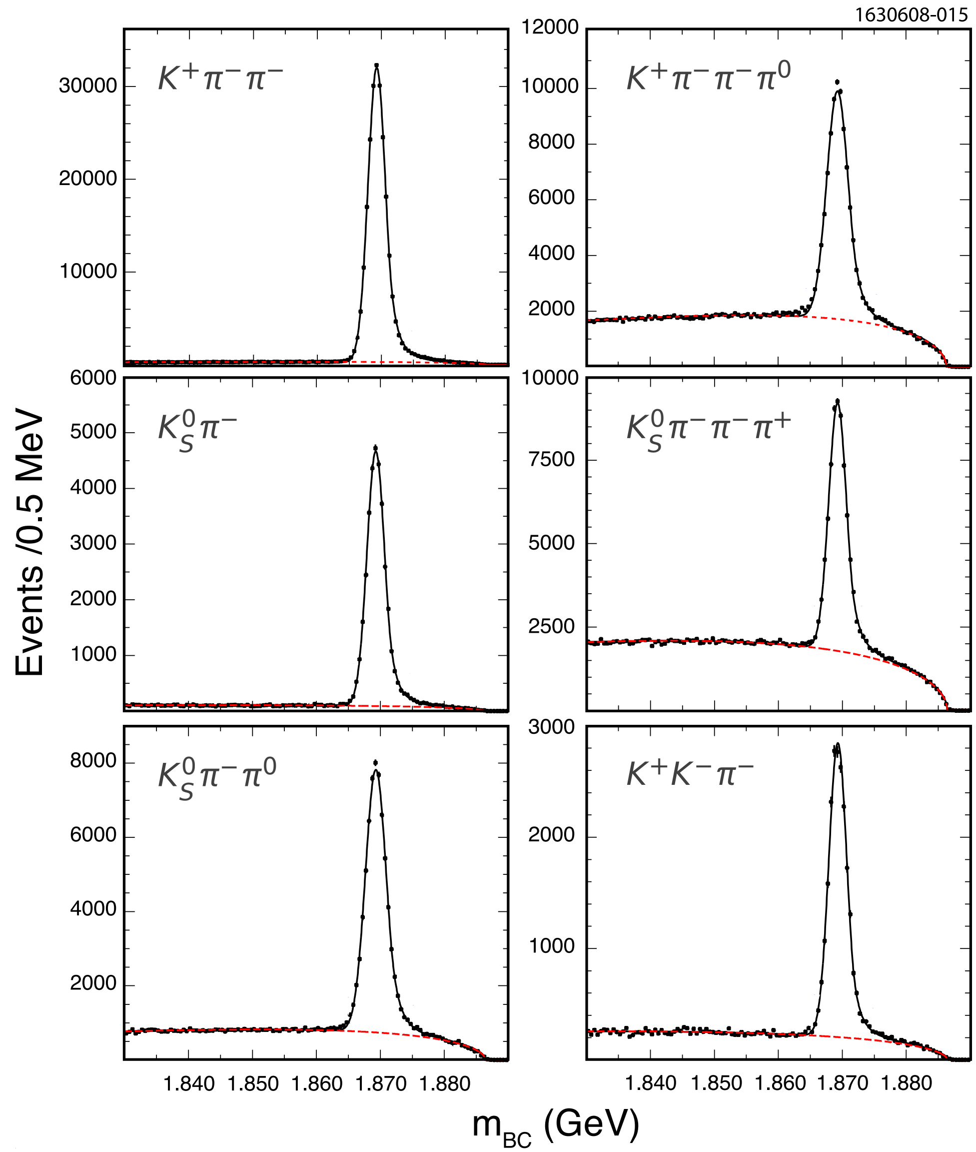
- $D\bar{D}$ threshold, no additional particles produced.
- Low multiplicity ($4 \sim 6$ tracks per event). Clean experimental environment.
- Event can be fully reconstructed, tagging D and recoiling signal, missing neutrino can be determined w/o kinematic ambiguity.
- $p_{\text{miss}} = p_{\text{CM}} - (p_{\text{tag}} + p_\ell)$
- Absolute branching fraction from $N_{\text{signal}}/N_{\text{tag}}$.





D Tagging – 3770 MeV

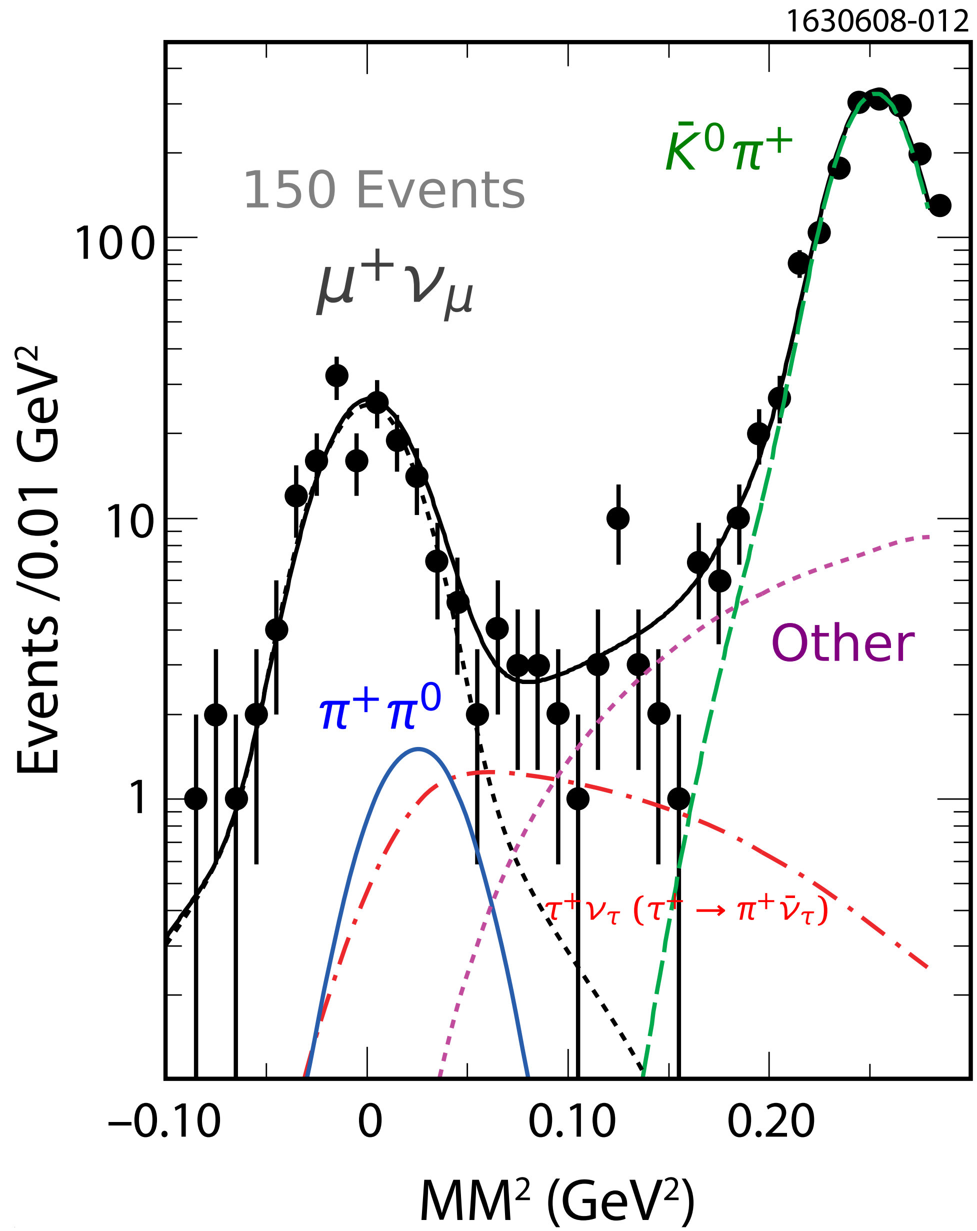
- $e^+e^- \to \psi(3770) \to D\bar{D}$ produced at threshold, no extra particles.
- $m_{BC} = [E^2_{\text{beam}} - \mathbf{p}^2_D]^{1/2}$
- 10% of D^- tagging, (15% of $\bar{D}^0$ tagging) in clean hadronic modes.
- 818pb^{-1}, 4.6×10^5 D^- tags in 6 modes.



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

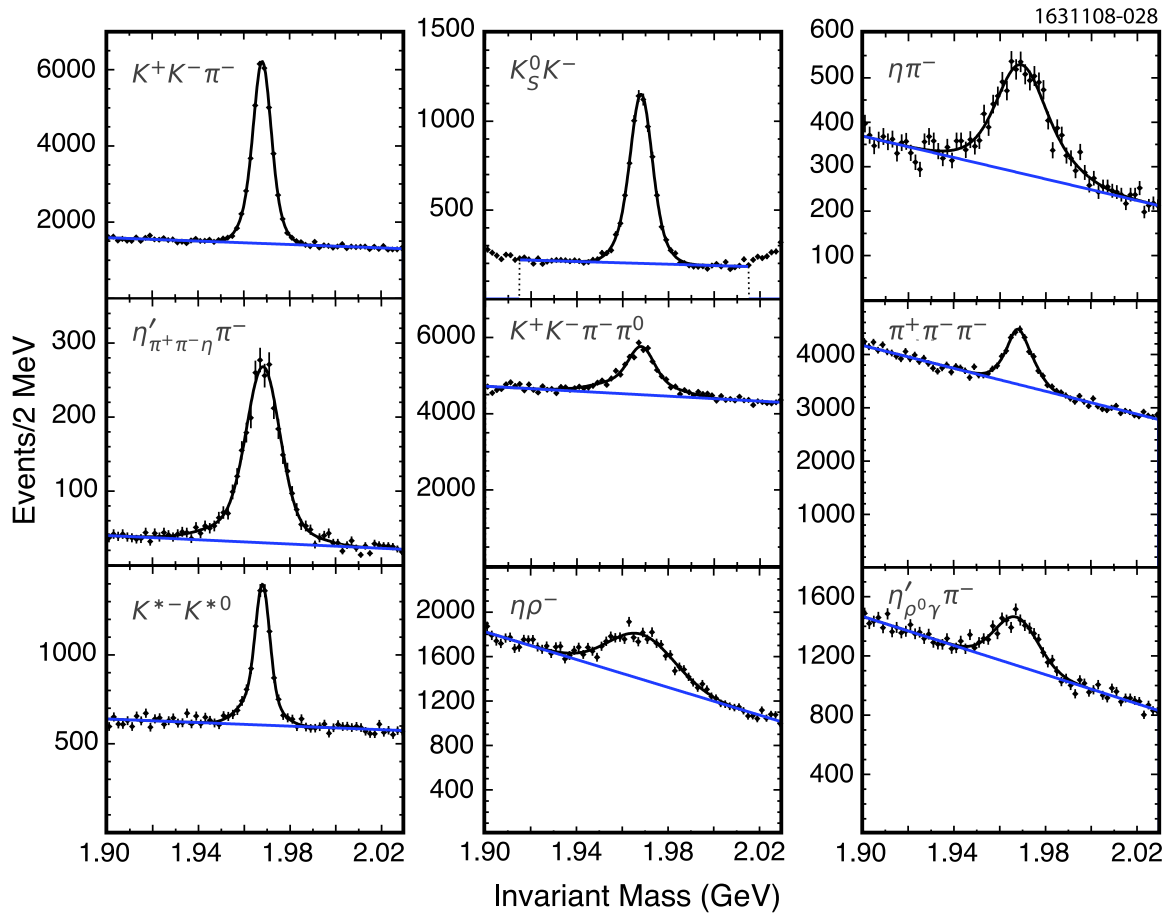
- Cabibbo- and helicity- suppressed.
- Combine D^- tag with μ^+ candidate, $E_{\text{cal}} < 300$ MeV, minimum ionizing.
- Reject events with extra tracks or large extra calorimeter energy.
- $MM^2 = (p_{\text{CM}} - p_D - p_\mu)^2$

- PRD **78**, 052003 (2008):
  - $B = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$
  - $f_D = (205.8 \pm 8.5 \pm 2.5)$ MeV
- Good agreement with LQCD, PRL **100**, 062002 (2008):
  - $f_D = (207 \pm 4)$ MeV



D_s Tagging – 4170 MeV

- $e^+e^- \to D_s^{*+}D_s^-$ produces extra γ (94.2%) or π^0 from D_s^{*+} decay.
- 6% of D_s^- tagging.
- 600pb^{-1}, 70.5k tags in 9 modes.

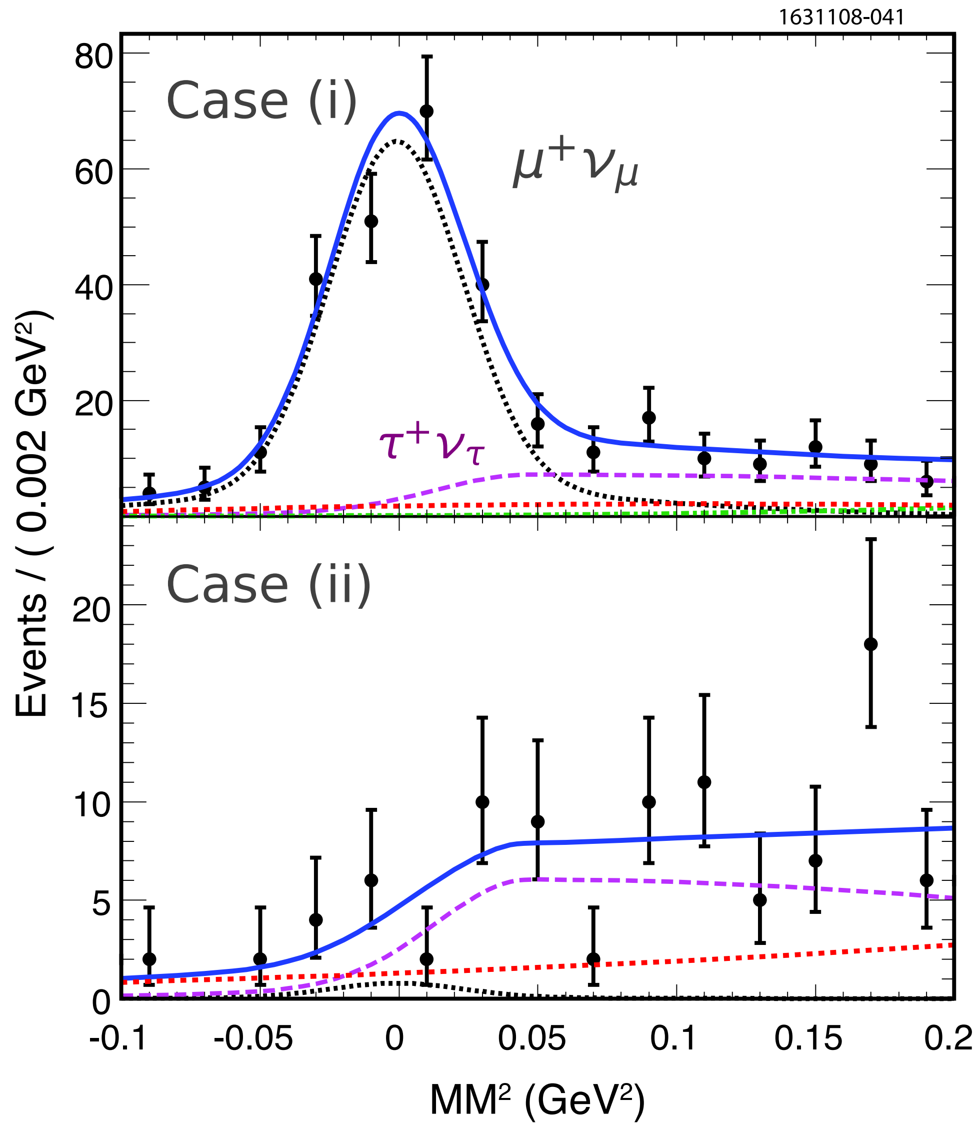


$D_s^+ \to \mu^+\nu_\mu$ & $D_s^+ \to \tau^+\nu_\tau$ $(\tau^+ \to \pi^+\bar{\nu}_\tau)$

- Cabibbo-favored, less helicity-suppressed (τ).
- Combine D_s^- tag, transition γ ($D_s^* \to D_s\gamma$), and additional track.
- Reject events with extra tracks or large extra calorimeter energy.
- $MM^2 = (p_{\rm CM} - p_{D_s} - p_\gamma - p_{\rm track})^2$
- Two cases:

  (i) $E_{\rm cal} < 300$ MeV, minimum ionizing
  (ii) $E_{\rm cal} \geq 300$ MeV, interacting pion

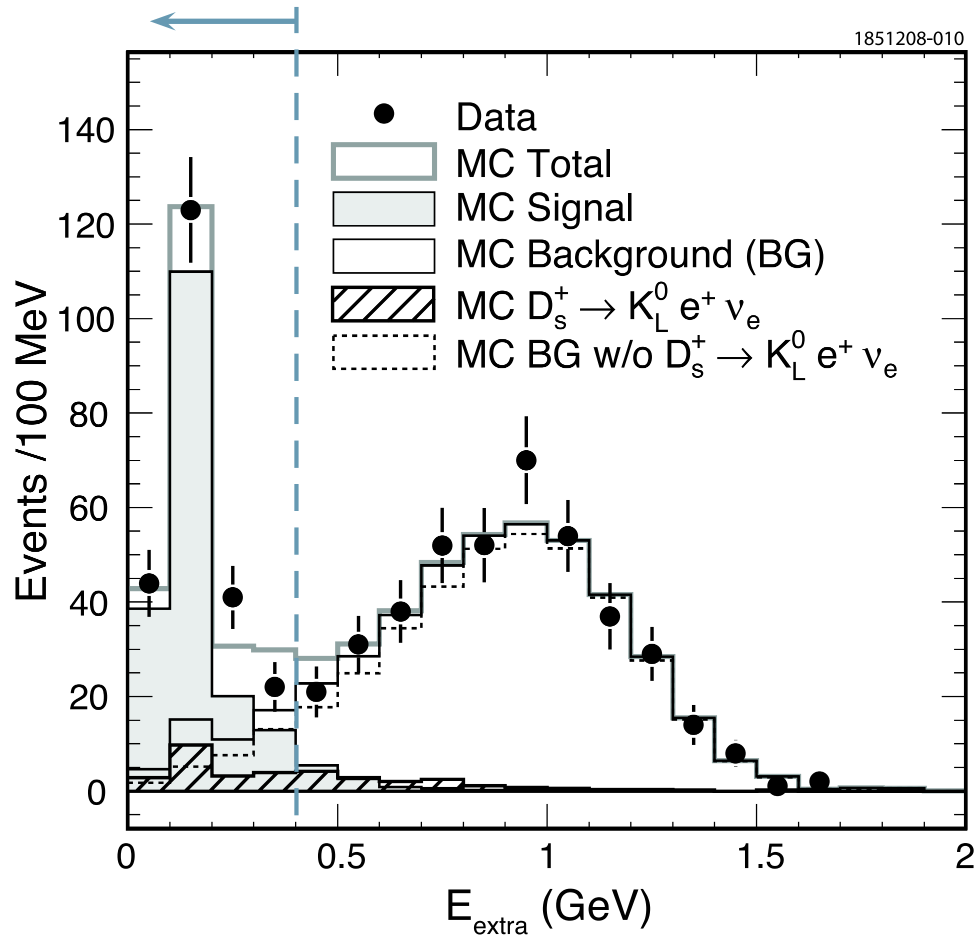
- PRD **79**, 052001 (2009):
  - $B(\mu\nu) = (5.65 \pm 0.45 \pm 0.17) \times 10^{-3}$
  - $B(\tau\nu) = (6.42 \pm 0.81 \pm 0.18)$ %



$D_s^+ \to \tau^+\nu_\tau$ $(\tau^+ \to e^+\nu_e\bar{\nu}_\tau)$

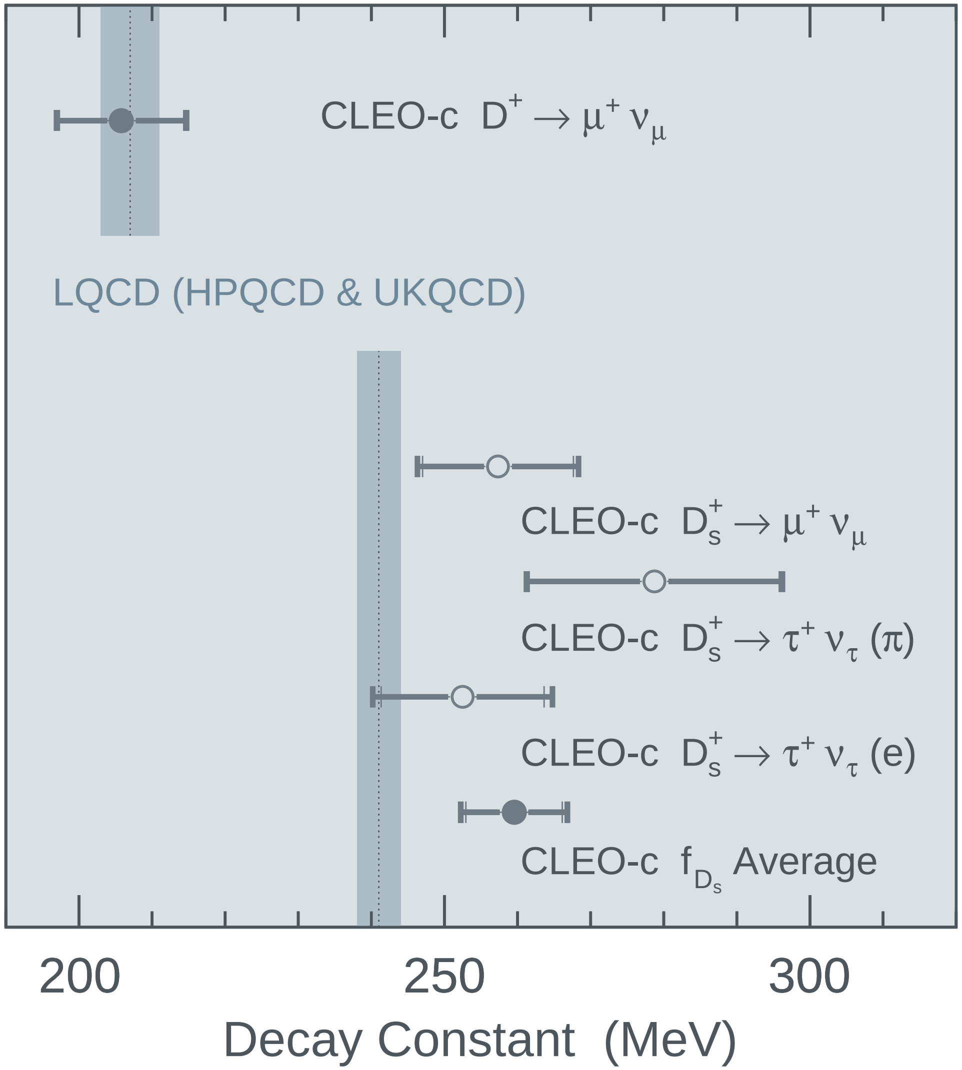
- Cabibbo-favored, less helicity-suppressed.
- Three cleanest tag modes are used ($D_s^- \to \phi\pi^-$, K^-K^{*0}, and $K_S^0K^-$), 22k tagged events.
- Combine D_s^- tag with e^+ candidate.
- Reject events with extra tracks.
- Three neutrinos in the final state, use extra calorimeter energy.
- $E_{\text{extra}} < 400$ MeV.
- $D_s^+ \to K_L^0 e^+\nu_e$ background from measured $B(D_s^+ \to K_S^0 e^+\nu_e)$, dominant systematic uncertainty.

- PRD **79**, 052002 (2009):
  - $B(D_s \to \tau\nu) = (5.30 \pm 0.47 \pm 0.22)\%$



CLEO-c and LQCD

- $\boldsymbol{f_D}$: in good agreement
  - CLEO-c $= (205.8 \pm 8.5 \pm 2.5)$ MeV
  - LQCD $= (207 \pm 4)$ MeV
- $\boldsymbol{f_{D_s}}$: 2.3σ apart
  - CLEO-c $= (259.5 \pm 6.6 \pm 3.1)$ MeV
  - LQCD $= (241 \pm 3)$ MeV
- $\boldsymbol{f_{D_s}/f_D}$:
  - CLEO-c $= 1.26 \pm 0.06 \pm 0.02$
  - LQCD $= 1.164 \pm 0.011$
- $R = \frac{\Gamma(D_S \to \tau\nu)}{\Gamma(D_S \to \mu\nu)} = 10.1 \pm 0.9 \pm 0.3$, consistent with lepton universality (SM $= 9.76$).



[1] CLEO-c: PRD **78**, 052003 (2008), PRD **79**, 052001 (2009), and PRD **79**, 052002 (2009).
[2] LQCD (HPQCD & UKQCD): PRL **100**, 062002 (2008).

Summary

- CLEO-c at charm threshold: leptonic decays of charm mesons is an excellent device to test, calibrate, and validate LQCD calculations of strong interaction effects.
- Theory and experiment are both making great strides in precision:
  - CLEO-c $\delta f_D/f_D \sim 4\%$ and $\delta f_{D_s}/f_{D_s} \sim 3\%$.
  - LQCD $\delta f_D/f_D \sim 2\%$ and $\delta f_{D_s}/f_{D_s} \sim 1\%$.
  - Allows for stringent test for LQCD.
- Prospects for charm meson decay constants at BES III : [arXiv:0809.1869], an order bigger sample on open charm
  - Independent cross check at charm threshold.
  - $\sim 1\%$ precision on f_D and f_{D_s}.