Review of Results on Leptonic Decays of D^+ and Ds^+

G. Rong

(Institute of High Energy Physics, Beijing)

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OUTLINE

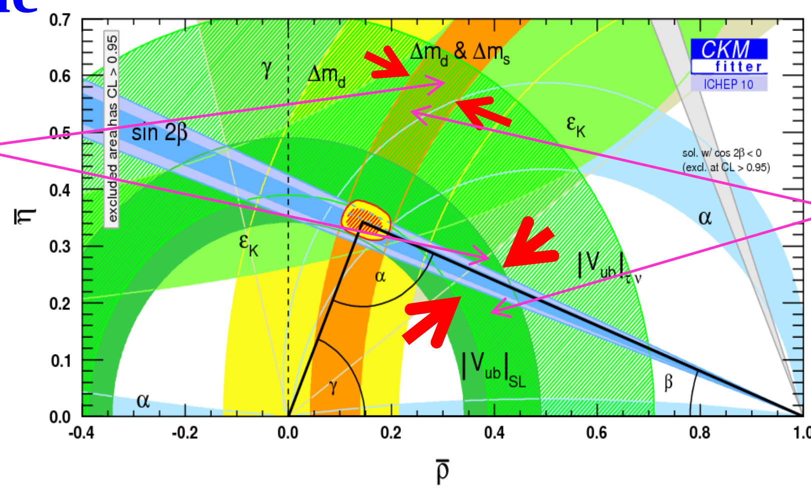
- **Charm role in test of SM**
- **D^+ leptonic decays**
- **Ds^+ leptonic decays**
- **Determination of $|V_{cd}|$ & $|V_{cs}|$**
- **Summary**

Charm role

- **D^+ and D_S^+ leptonic decays play an important role in understanding of the SM of particle physics**

- **Unitary triangle**

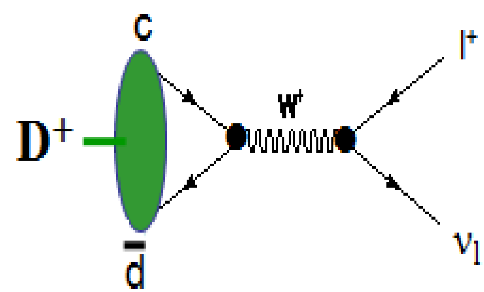
Widths of bands are dominated by errors of f_B and f_{Bs} from LQCD.



The widths of bands will be reduced if the LQCD pass the test with measured f_D, f_{Ds}.

- **$f_{D(Ds)}$ test LQCD calculations of $f_{B(Bs)}$**

$$\Gamma_{\mathrm{SM}}(D^+_{(s)} \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1-\frac{m_l^2}{m^2_{D_{(s)}}}\right)^2 |V_{cd(s)}|^2 \; f_{D^+_{(s)}}$$



- **Reduced width of band in triangle would lead to precisely test the SM, and search for new physics beyond the SM.**

Charm role

- **Two charm decay constants ($f_{D(Ds)} \rightarrow f_{B(Bs)}$) affect**
  - $|V_{ub}|$ extracted from $B^+ \rightarrow l^+ v$
  - $|V_{td}|$ extracted from Δm_d in $B^0 B^0$ mixing
  - $|V_{ts}|$ extracted from Δm_s in $B_s^0 B_s^0$ mixing

  These are used to constraint the unitary triangle

- **Two decay branching fractions determine**
  - $|V_{cd}|$ extracted from $D^+ \rightarrow l^+ v$
  - $|V_{cs}|$ extracted from $D_s^+ \rightarrow l^+ v$

- **Precise measurements of f_{Ds} and f_D probe New Physics**

  Accumulating Evidence for Nonstandard Leptonic Deacsy of Ds Mesons

  B.A. Dobressu and A.S. Kronfeld, PRL100, 241802 (2008)

  R-parity violating supersymmetry, B_s mixing, and $Ds \rightarrow l\nu$.

  A. Kundu and S. Nandi, PRD78, 015009 (2008)

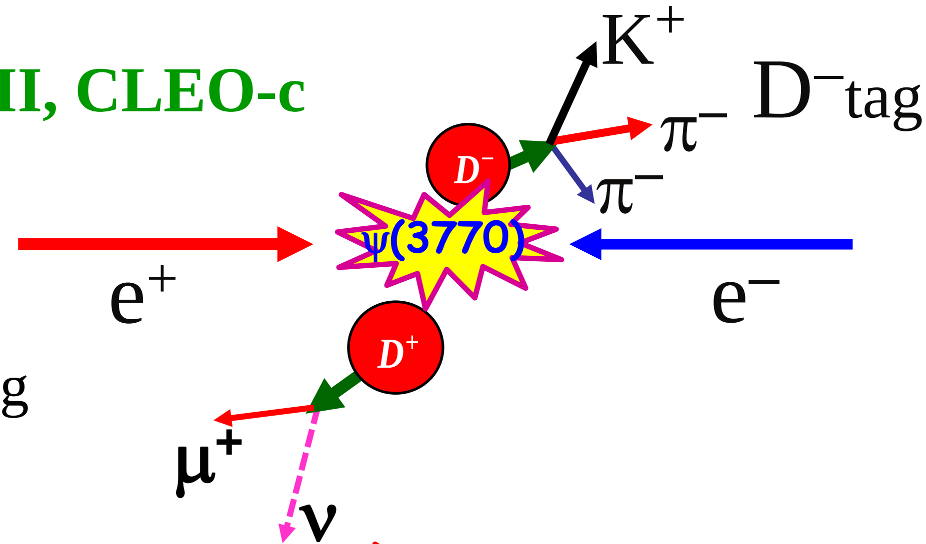
  ....

Experiments near threshold

- $\psi(3770) \rightarrow D\bar{D}$ events

MARK-III, BES-I, BES-II, CLEO-c and BES-III

Single tag events



- D^+D^- production in pair
- Measure absolute branching fraction for $D^+ \rightarrow \mu^+\nu$

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

energy of μ^+

momentum of D_{tag}

momentum of μ^+

The neutrino is reconstructed with the missing energy and missing momentum of the D^+ meson.

$$B(D^+ \rightarrow \mu^+\nu) = \frac{N_{D^+\rightarrow\mu^+\nu}}{N_{D^-_{\rm tag}}\,\varepsilon_{D^+\rightarrow\mu^+\nu}}$$

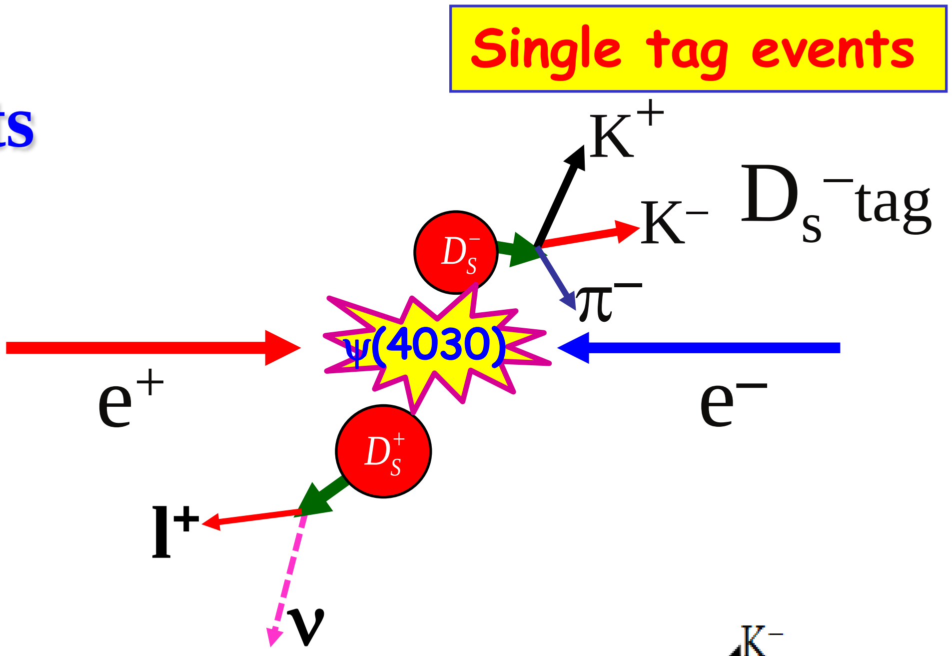
Experiments near threshold

- $\psi(4030) \rightarrow D_s^+ D_s^-$ events

  ~4.03 GeV

  BES-I, and BES-III

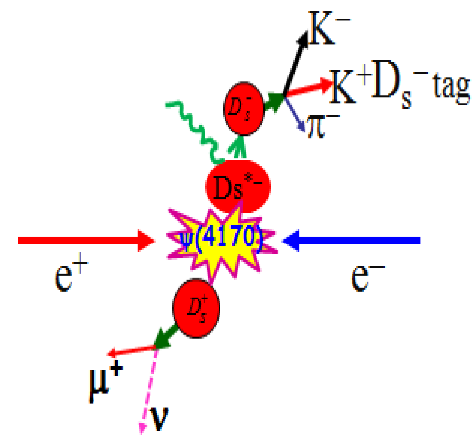
$$B(D_s^+ \to l^+\nu) = \frac{N_{D_s^+ \to l^+\nu}}{N_{Ds^-_{tag}}\, \varepsilon_{Ds^+ \to l^+\nu}}$$



- $\psi(4170) \rightarrow D_s^+ D_s^{*-}$ events

  ~4.017 GeV

  MARK-III and CLEO-c



Double tag can also be used to reconstruct the pure leptonic decays of $Ds^+ \rightarrow l^+\nu$

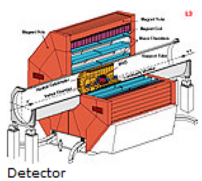
Experiments at higher energies

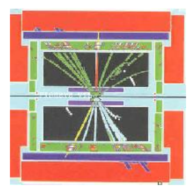
- **Fixed target experiments**

  WA75, E653

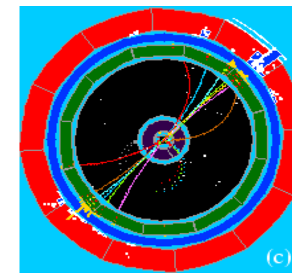
- **$e^+e^- \rightarrow Z$ @ ~91 GeV events**

  L3, OPAL, ALEPH





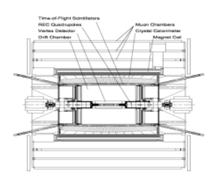
$$e^+e^- \to Z \to c\bar{c} \to D_s^{*-} X$$
$$\hookrightarrow \gamma D_s^-$$
$$\hookrightarrow \tau \bar{\nu}_\tau$$
$$\hookrightarrow \ell^- \bar{\nu}_\ell \nu_\tau \ (\ell = e, \mu)$$



- **$e^+e^- \rightarrow c\bar{c}$ @ 10.6 GeV**

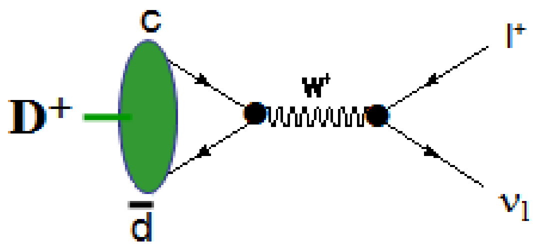
  CLEO II, BaBar, Belle

  $e^+e^- \rightarrow$ cc-bar events

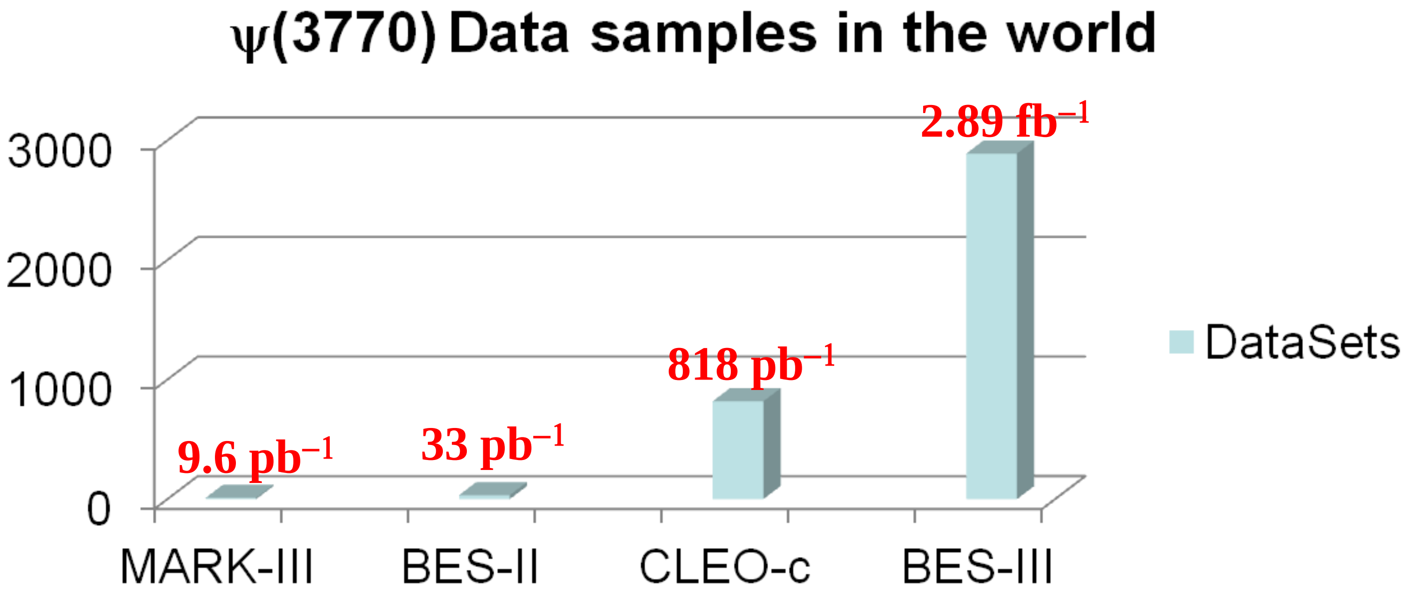


$$e^+e^- \to D_S^* D^{\pm,0} K^{\pm,0} X,\ D_S^* \to \gamma D_S\ , X = n\pi(\gamma)$$

D^+ leptonic decays

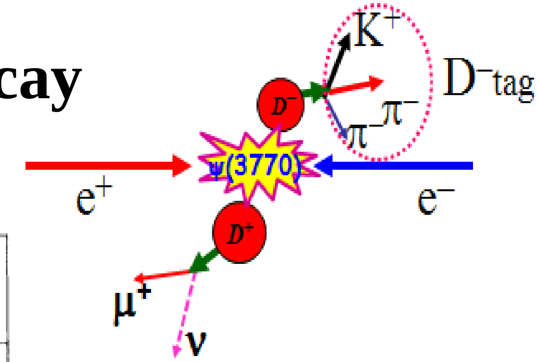


Due to that this is a Cabbibo suppressed decay, measurements of this process were made at energies near threshold.



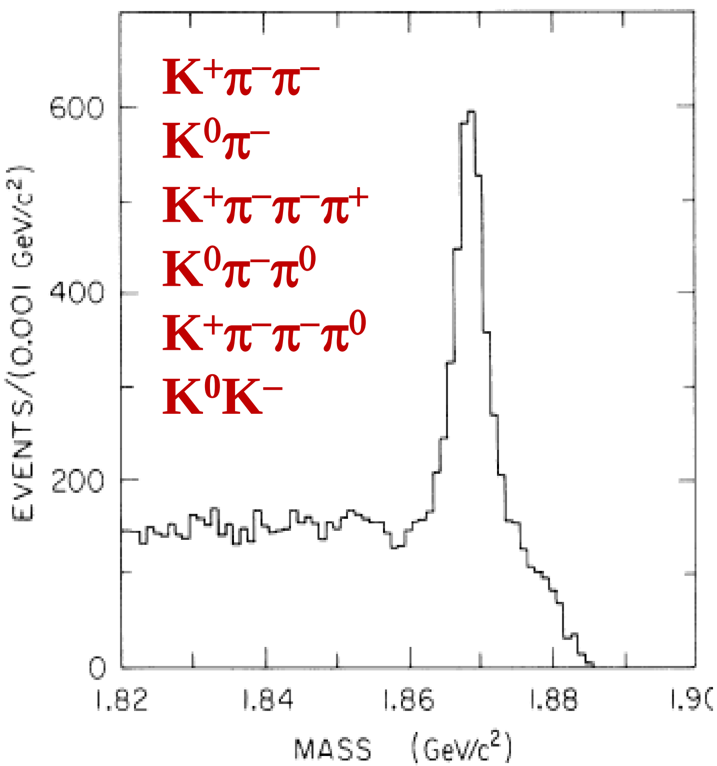
D^+ leptonic decays at MARK-III

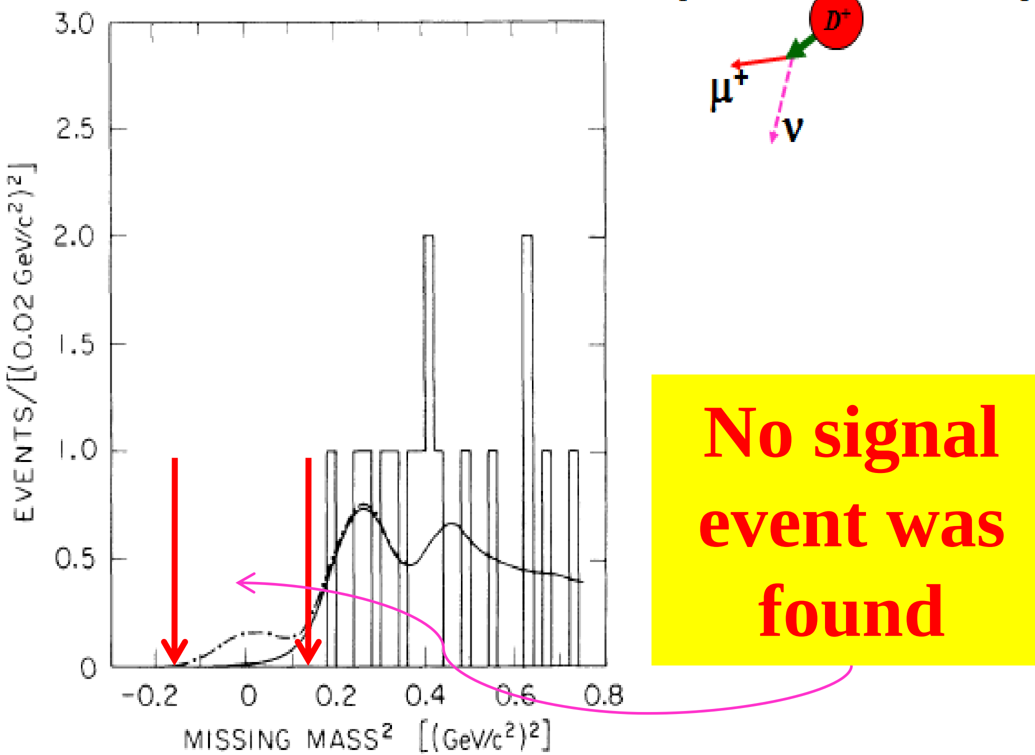
In 1988, MARK-III first searched for the decay



PRL60, 1375(1988)

9.6 pb^{-1} @ 3.773 GeV

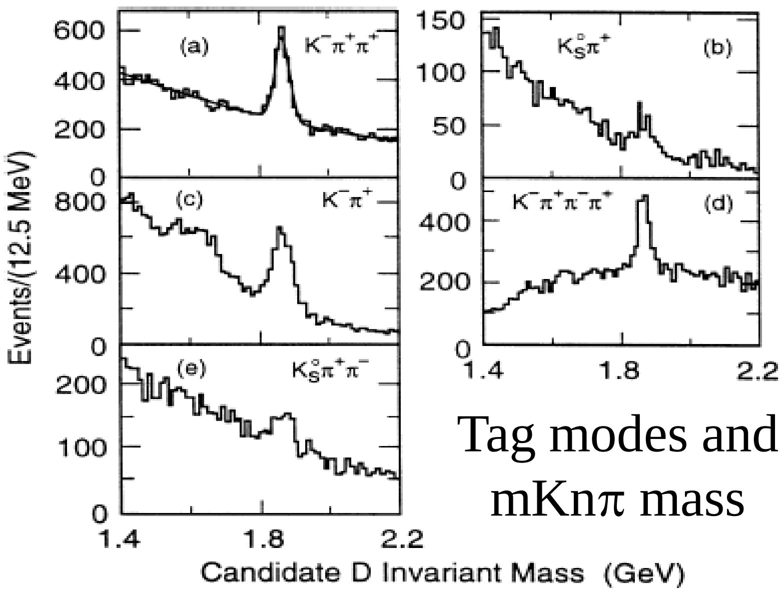




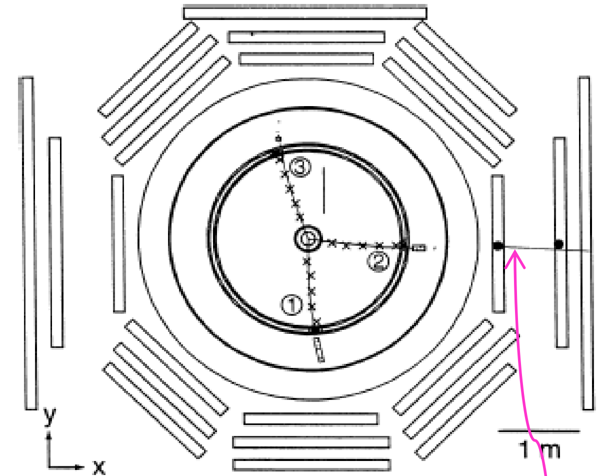
MARK-III did not observe signal for this decay, they set an upper limit on decay constant f_D<290 MeV

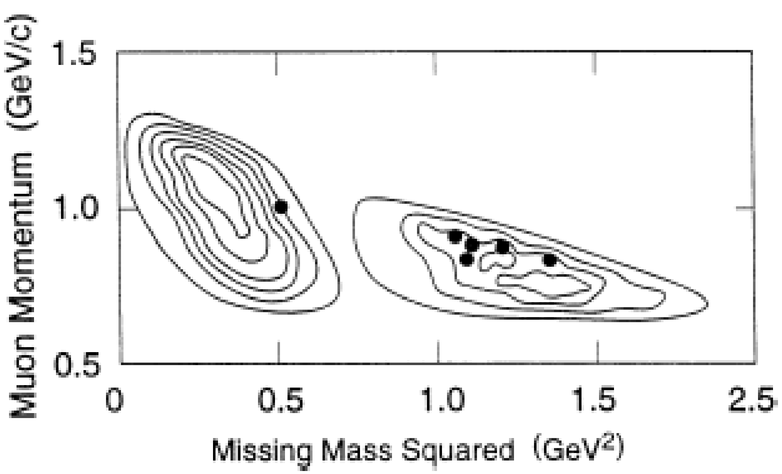
D^+ leptonic decays at BES-I

22.3 pb^{-1} @ 4.03 GeV PLB429, 188 (1998)



Tag modes and mKnπ mass





5 single tag modes

$$N_{D^+}^{PRD} = 10082$$

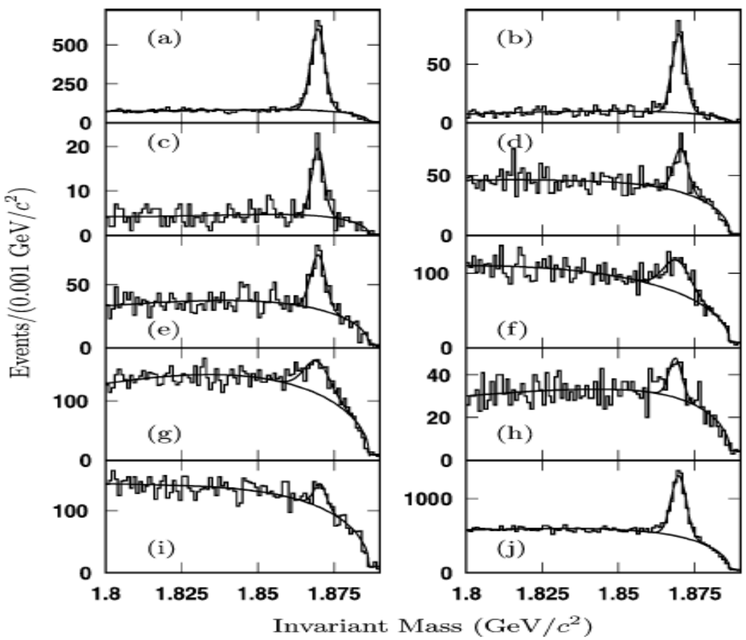
$$N_{D^+ \to \mu^+\nu} = 1$$

One signal events observed

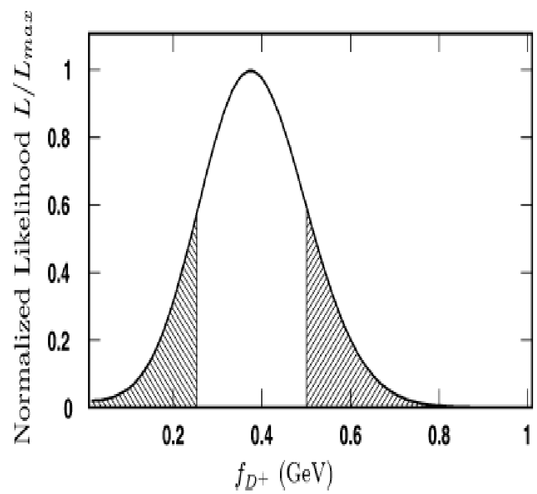
$$B(D^+ \to \mu^+\nu) = (0.08^{+0.16+0.05}_{-0.05-0.02})\%$$

$$f_{D^+} = (300^{+180+80}_{-150-40})\ \text{MeV}$$

D^+ leptonic decays at BES-II

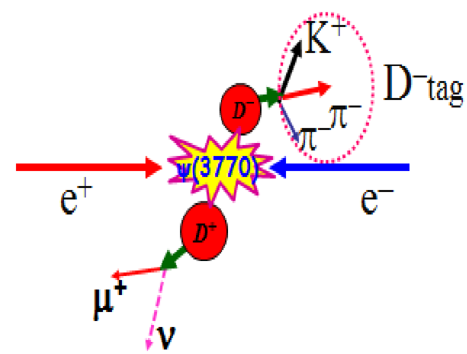


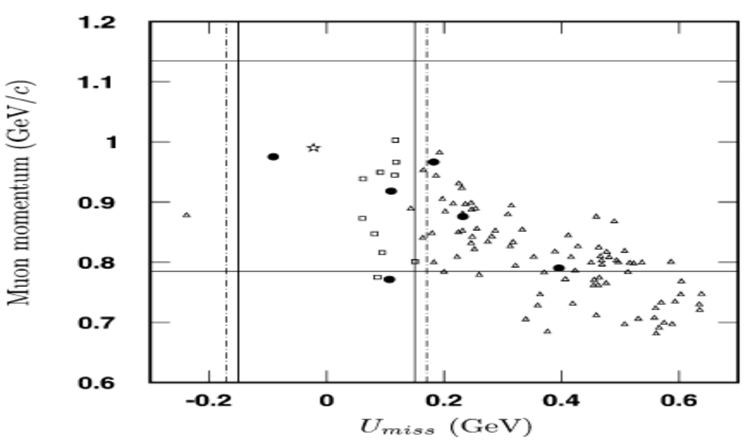
33 pb^{-1} @ 3.773 GeV



'04 Electroweak Interactions & Unified Theories

PLB610, 183 (2005)





9 single tag modes

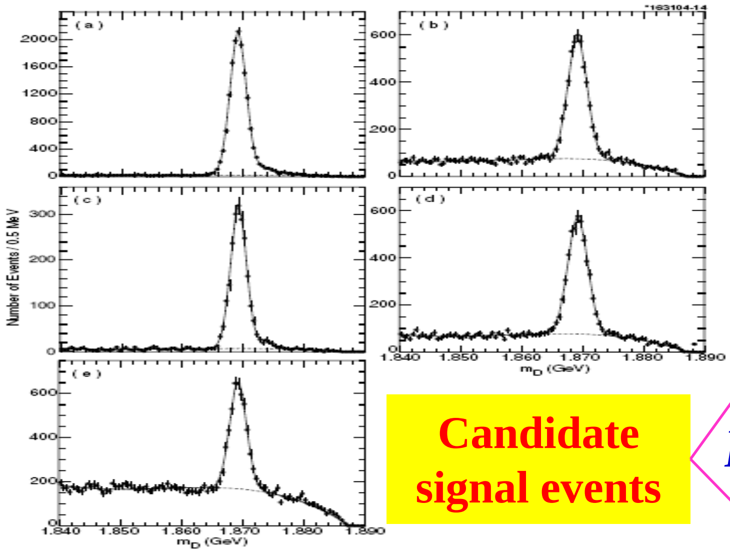
$$N_{D^-_{tag}} = 5321 \pm 149 \pm 160$$

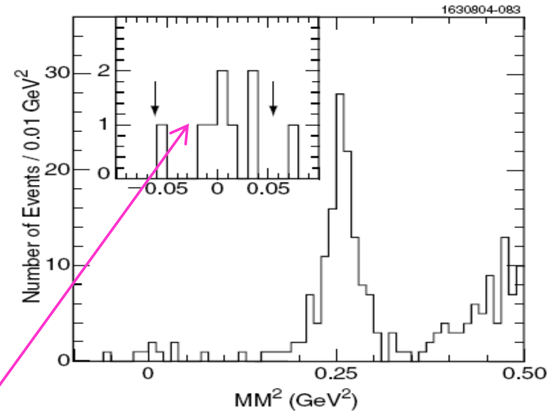
$$N_{D^+ \to \mu^+ \nu} = 2.7 \pm 1.7$$

$$B(D^+ \to \mu^+ \nu) = (0.122^{+0.111}_{-0.053} \pm 0.010)\%$$

$$f_{D^+} = (371^{+129}_{-119} \pm 25)\ \text{MeV}$$

D^+ leptonic decays at CLEO-c





60 pb^{-1}

PRD70, 112004 (2004)

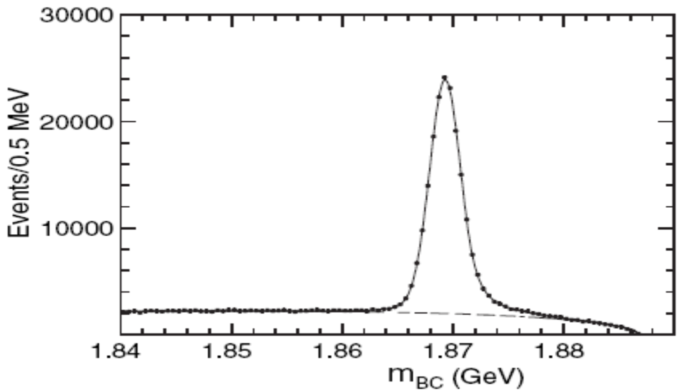
$$N_{D^-_{tag}} = 28651$$

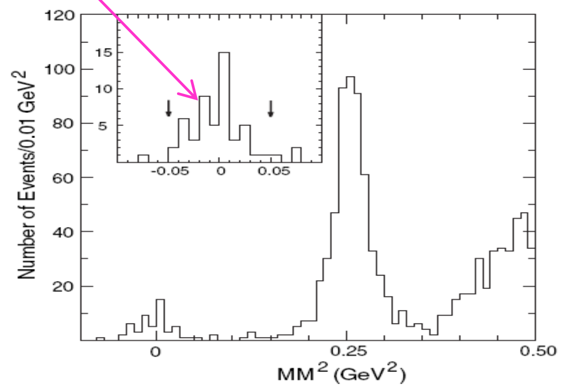
$$N_{D^+\to\mu^+\nu} = 7 \pm 2.8$$

Candidate signal events

$$B(D^+ \to \mu^+\nu) = (3.5 \pm 1.4 \pm 0.6) \times 10^{-4}$$

$$f_{D^+} = (202 \pm 41 \pm 17)\ \text{MeV}$$





281 pb^{-1}

PRL95 251801 (2005)

$$N_{D^-_{tag}} = 158354 \pm 496$$

$$N_{D^+\to\mu^+\nu} = 47.2 \pm 7.1$$

$$B(D^+ \to \mu^+\nu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4} \quad f_{D^+} = (222.6 \pm 16.7^{+2.8}_{-3.4})\ \text{MeV}$$

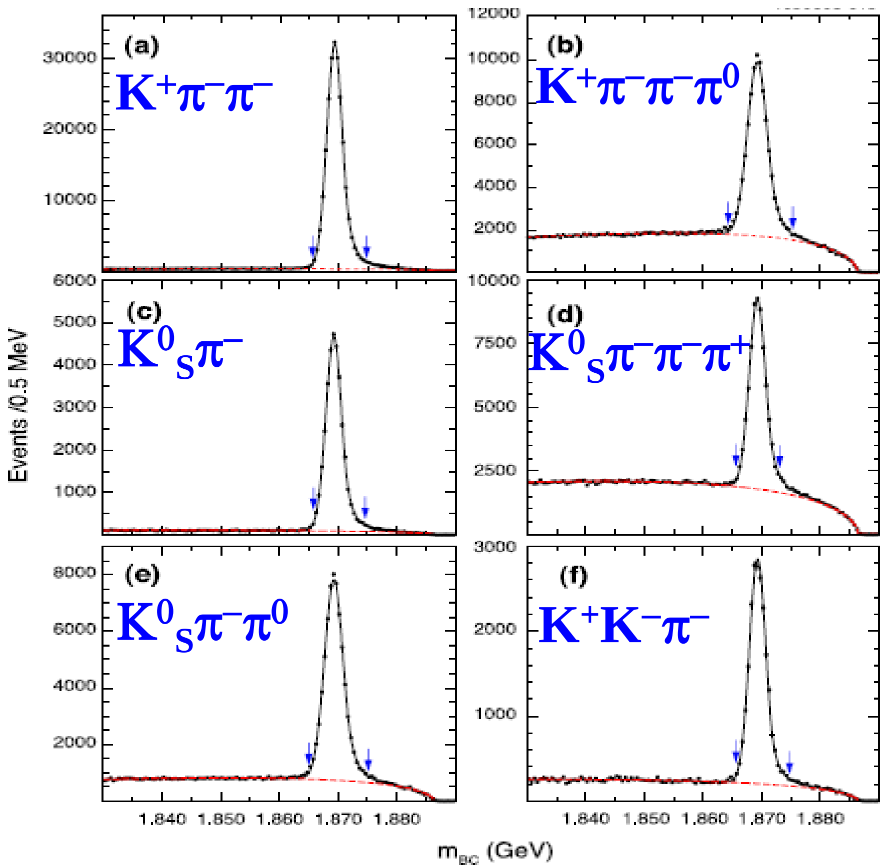
D^+ leptonic decays at CLEO-c

PHYSICAL REVIEW D 78, 052003 (2008)

818 pb^{-1}

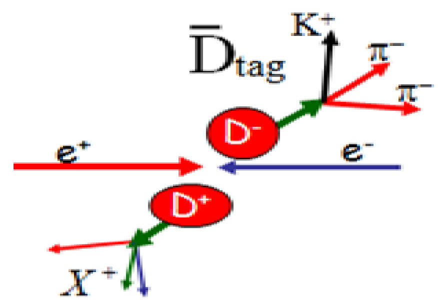
Precision measurement of $\mathcal{B}(D^+ \to \mu^+\nu)$ and the pseudoscalar decay constant f_{D^+}

B. I. Eisenstein,[1] I. Karliner,[1] S. Mehrabyan,[1] N. Lowrey,[1] M. Selen,[1] E. J. White,[1] J. Wiss,[1] R. E. Mitchell,[2] M. R. Shepherd,[2] D. Besson,[3] T. K. Pedlar,[4] D. Cronin-Hennessy,[5] K. Y. Gao,[5] J. Hietala,[5] Y. Kubota,[5] T. Klein,[5]



Mode	Signal	Background
$K^+\pi^-\pi^-$	$24\,778 \pm 497$	5957
$K^+\pi^-\pi^-\pi^0$	$71\,605 \pm 359$	37 119
$K_S\pi^-$	$32\,696 \pm 189$	1576
$K_S\pi^-\pi^-\pi^+$	$52\,554 \pm 315$	26 352
$K_S\pi^-\pi^0$	$59\,298 \pm 289$	14 837
$K^+K^-\pi^-$	$19\,124 \pm 159$	3631
Sum	$460\,055 \pm 787$	89 472

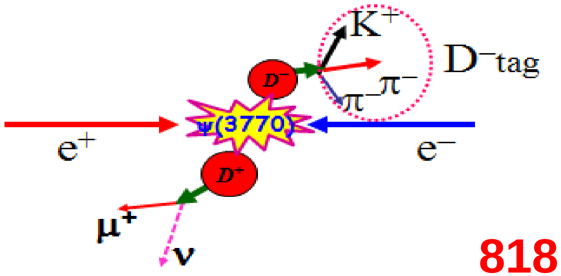
$$N_{D^-_{\text{tag}}} = 0.46 \times 10^6$$



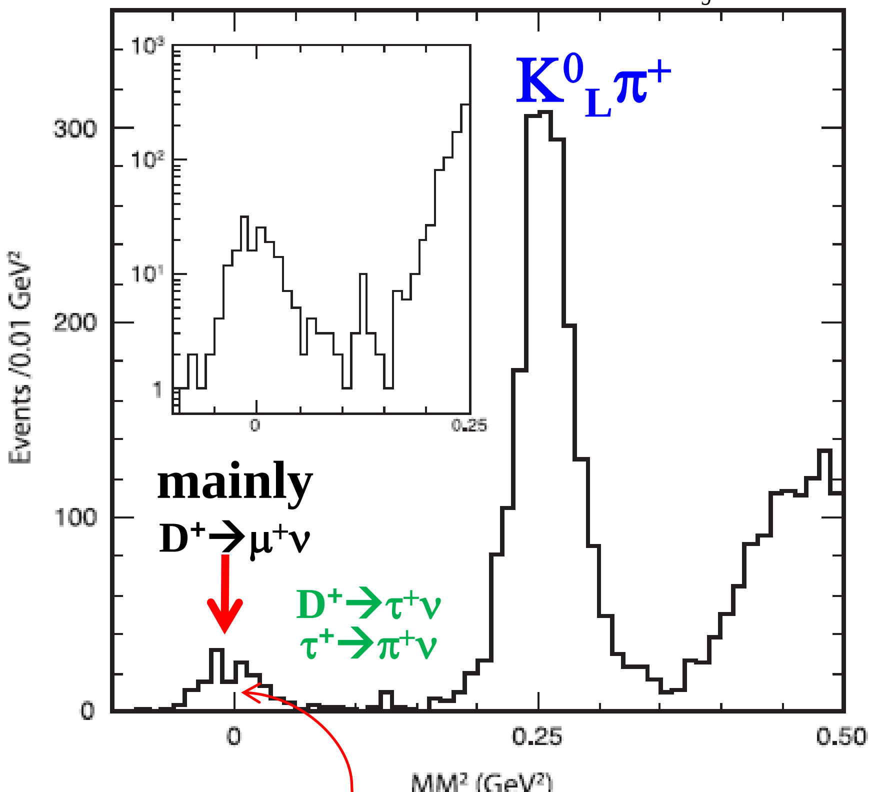
CLEO-c
D^- tags

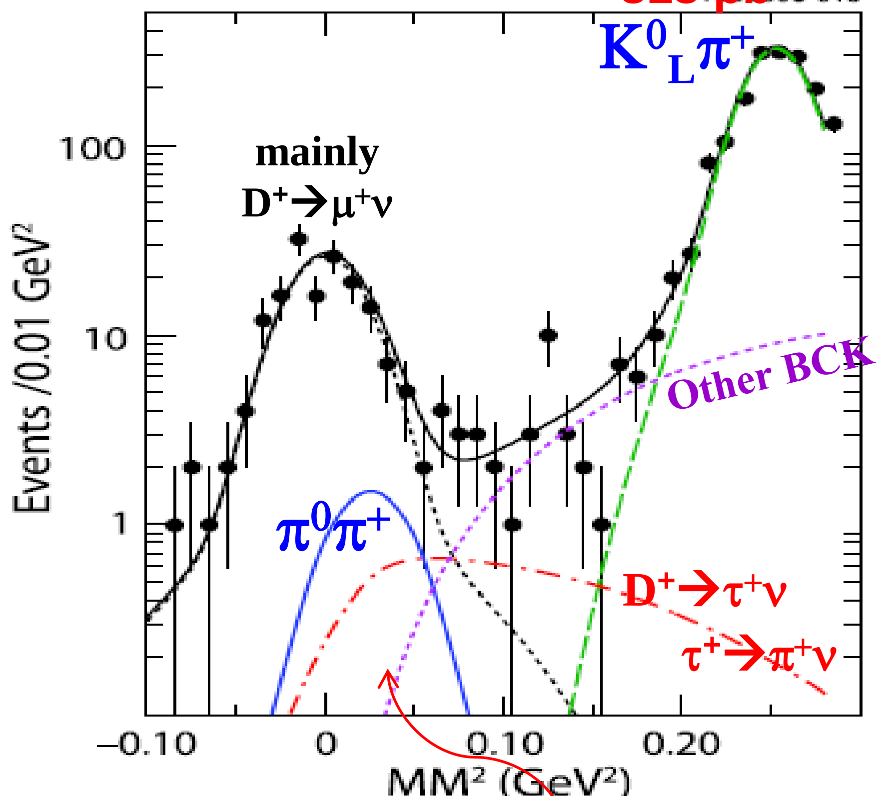
D^+ leptonic decays at CLEO-c

Recoil side is one track plus one missing neutrino



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





There are also some background events

D^+ leptonic decays at CLEO-c

Results:

$N(D^+ \rightarrow \mu^+\nu) = 149.7 \pm 12.0$

The statistical error is a little bit smaller than square root of 149.7

$N(D^+ \rightarrow \tau^+\nu) = 25.8$ (fixed in fit)

$N(D^+ \rightarrow \pi^0 \pi^+) = 9.2$ (fixed in fit)

Other background events : 2.4 ± 1.0

37.4 BCK Events

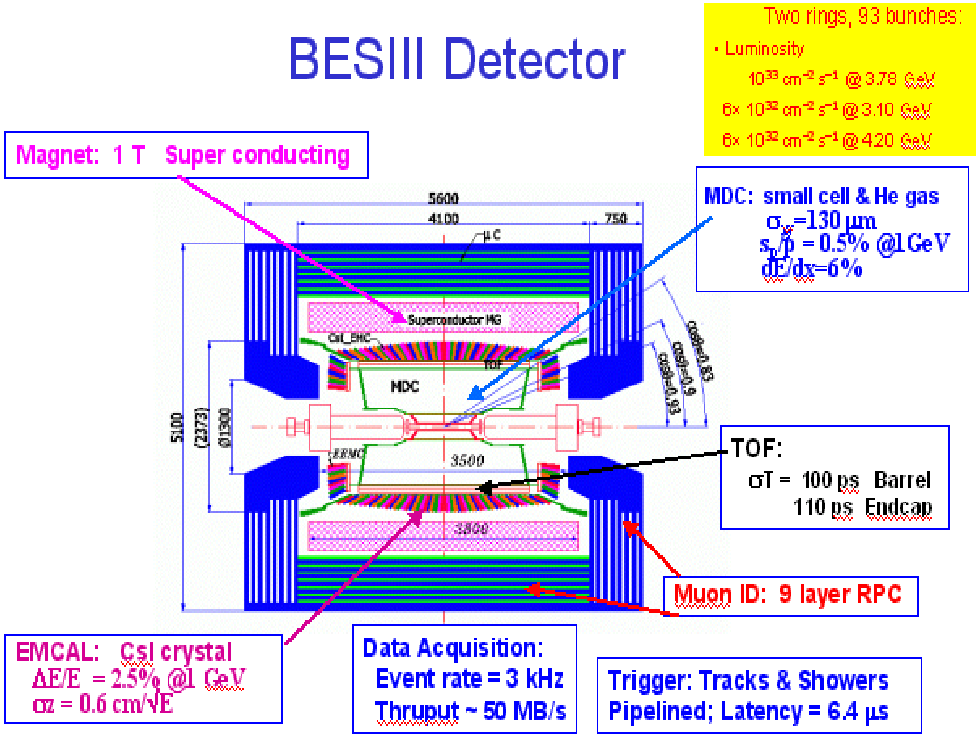
Mode	# of Events
Continuum	0.8 ± 0.4
$\bar{K}^0\pi^+$	1.3 ± 0.9
D^0 modes	0.3 ± 0.3
Sum	2.4 ± 1.0

	Systematic errors (%)
Track finding	0.7
PID cut	1.0
MM^2 width	0.2
Minimum ionization cut	1.0
Number of tags	0.6
Extra showers cut	0.4
Radiative corrections	1.0
Background	0.7
Total	2.2

$$Br(D^+ \rightarrow \mu^+\nu) = (0.0382 \pm 0.0032 \pm 0.0009)\%$$

$$f_{D^+} = (205.8 \pm 8.5 \pm 2.5)\ \text{MeV}$$

D^+ leptonic decays at BES-III



The detector is hermetic for neutral and charged particle with excellent resolution ,PID, and large coverage.

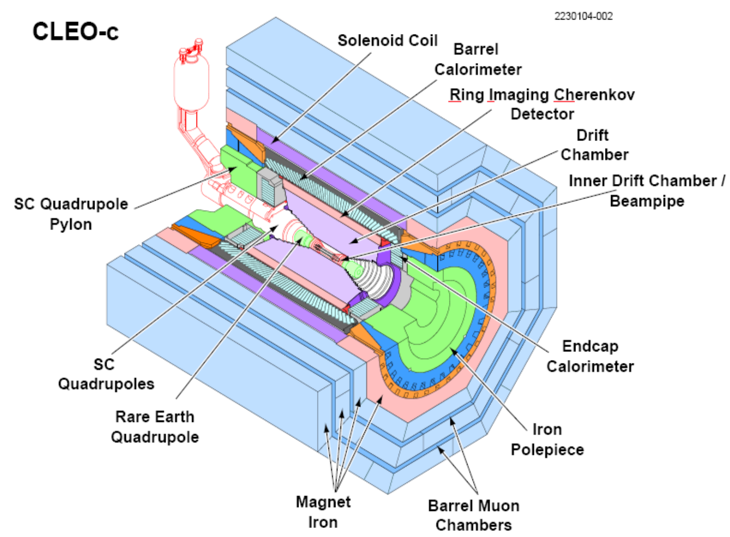


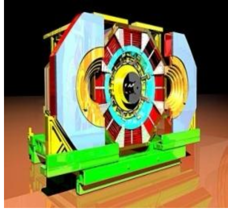
Figure 2.4: The CLEO-c detector.

Background level for D^+ leptonic decays at the BES-III is lower than that at the CELO-c

$L=2.89\ fb^{-1}$ @ 3.773 GeV

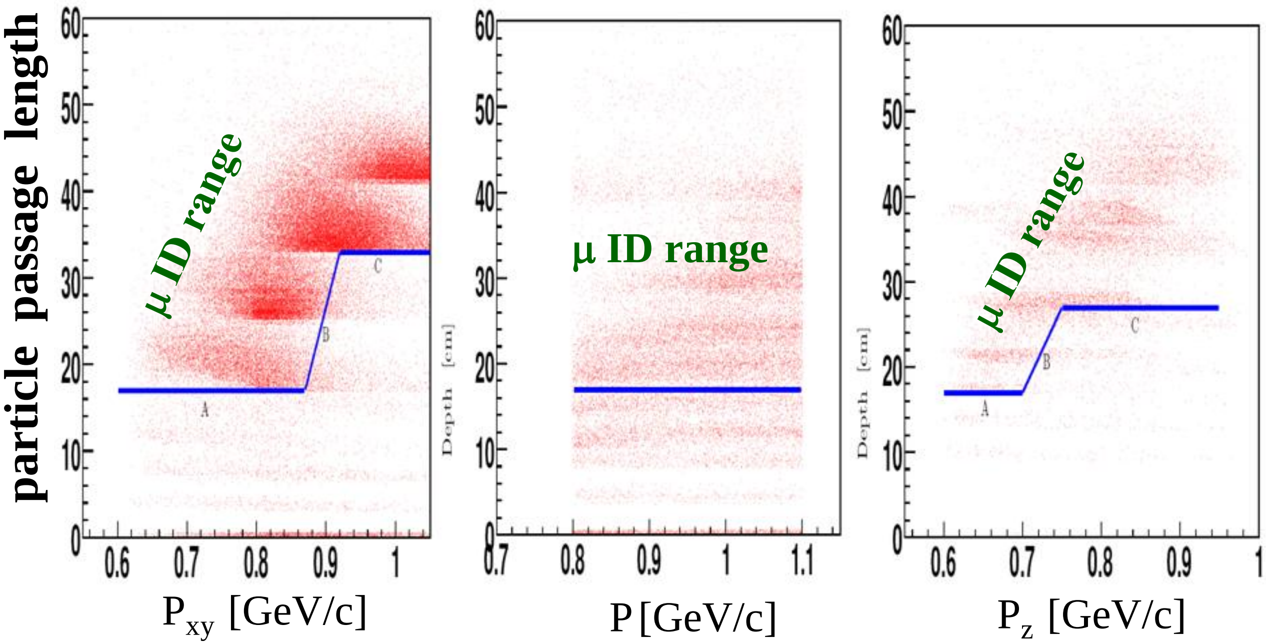
Advantage of the BES-III detector over CLEO-c is the MUC chamber with which BES-III can identify muon

$L=818\ pb^{-1}$ @ 3.773 GeV

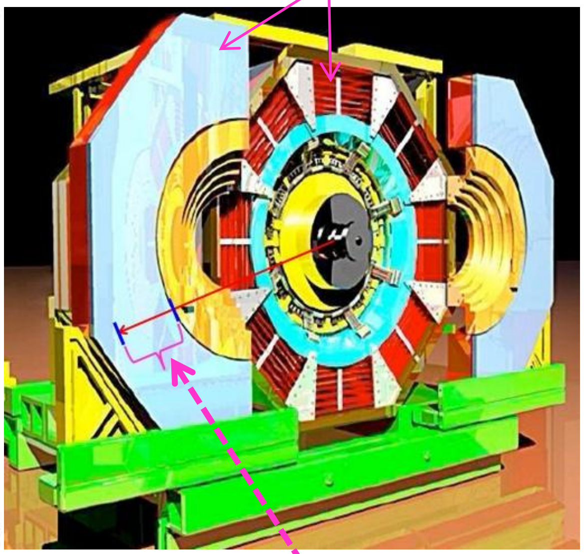


μ ID for $D^+ \rightarrow \mu^+\nu_\mu$ at BES-III

Particle passage length in MUC VS momentum



μ chamber

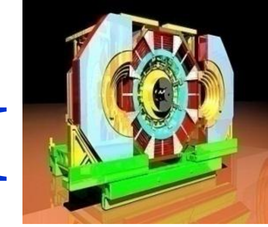


BES-III Detector

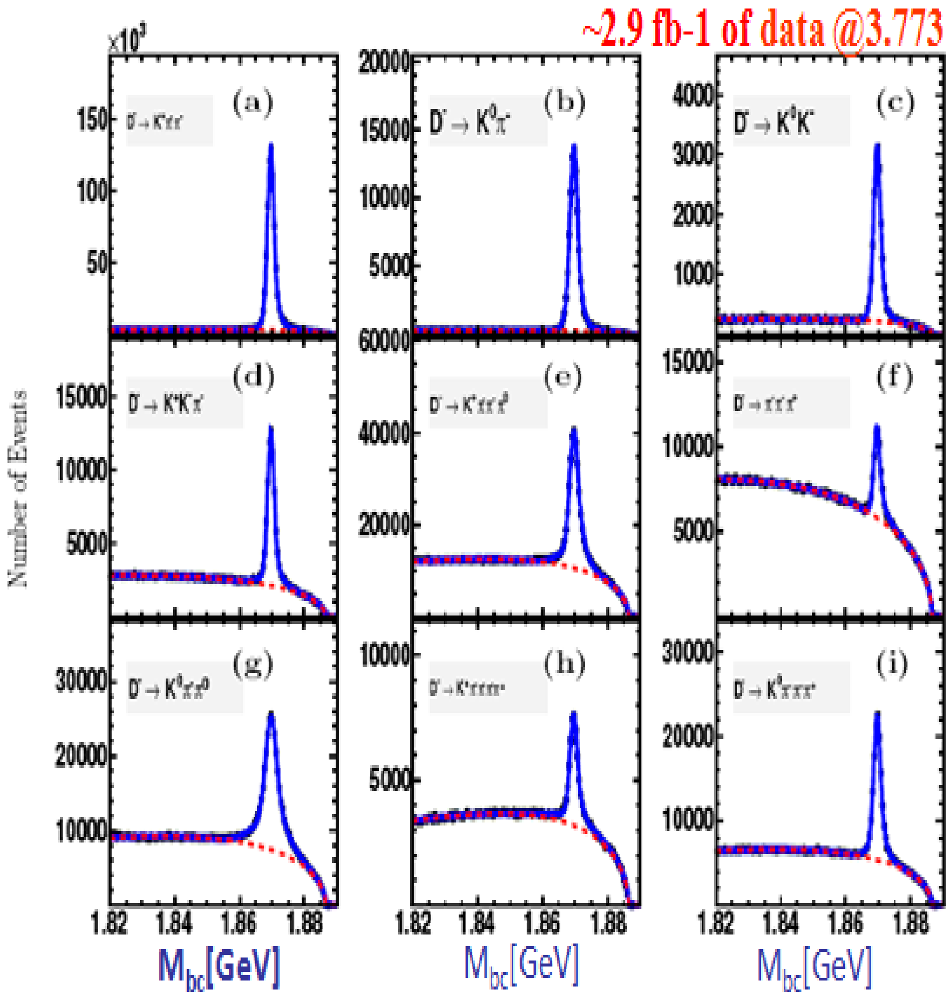
passage length of particle going through MUC

- ➢Muon can be well identified with the passage length of a particle going through the MUC.
- ➢If the passage length is greater than the one marked by the blue lines, the particle is assigned to be μ.

D^+ leptonic decays at BES-III



BES-III D^- tags



Single tag channels

$D^- \to K^+\pi^-\pi^-$

$D^- \to K^0\pi^-$

$D^- \to K^0K^-$

$D^- \to K^+K^-\pi^-$

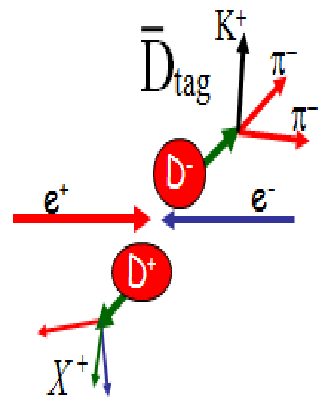
$D^- \to K^-\pi^+\pi^+\pi^0$

$D^- \to \pi^-\pi^-\pi^+$

$D^- \to K^0\pi^-\pi^0$

$D^- \to K^+\pi^-\pi^-\pi^-\pi^+$

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

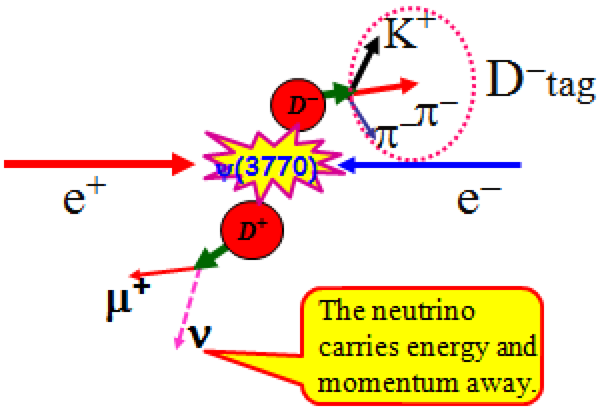


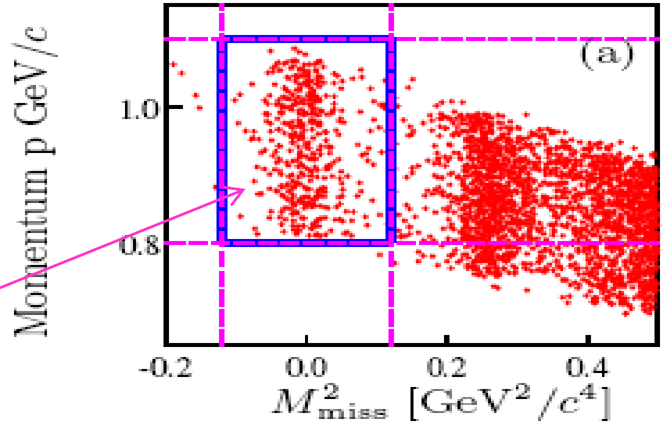
Using 9 singly tagged D^- modes to accumulate the D^+D^- events.

$$N_{D^-_{tag}} = (1.57 \pm 0.2) \times 10^6$$

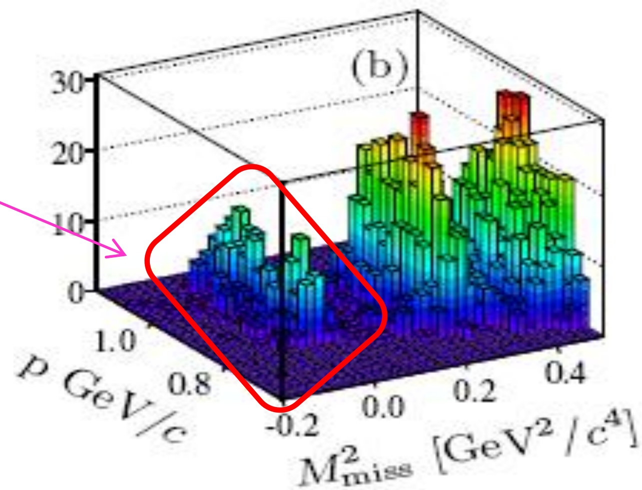
$D^+ \rightarrow \mu^+\nu$ at BES-III

In the system recoiling against the singly tagged D^-, BES-III selected the purely leptonic decay events for $D^+ \rightarrow \mu^+\nu$



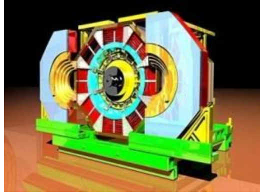


425 candidates for $D^+ \rightarrow \mu^+\nu$

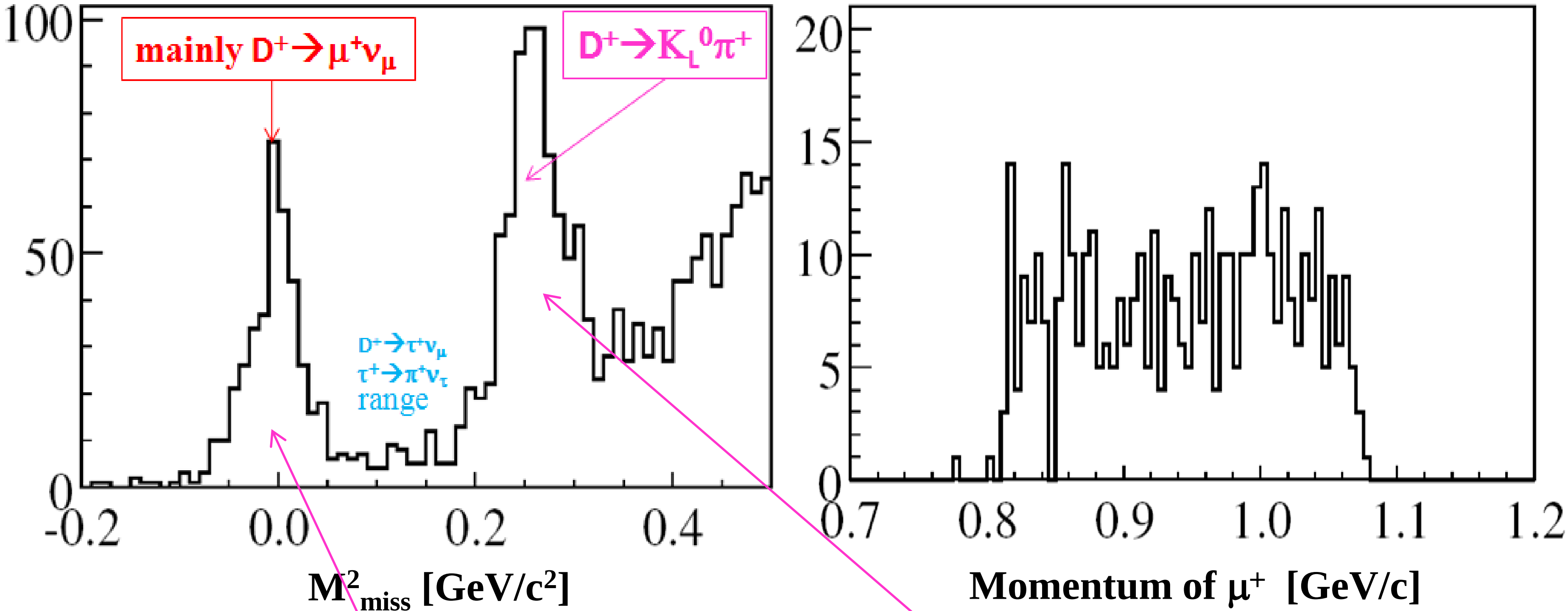


they require:

- **One charged track only**
- **Positively identified μ**
- **No isolate photon**

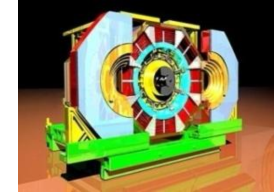


$D^+ \rightarrow \mu^+\nu$ at BES-III

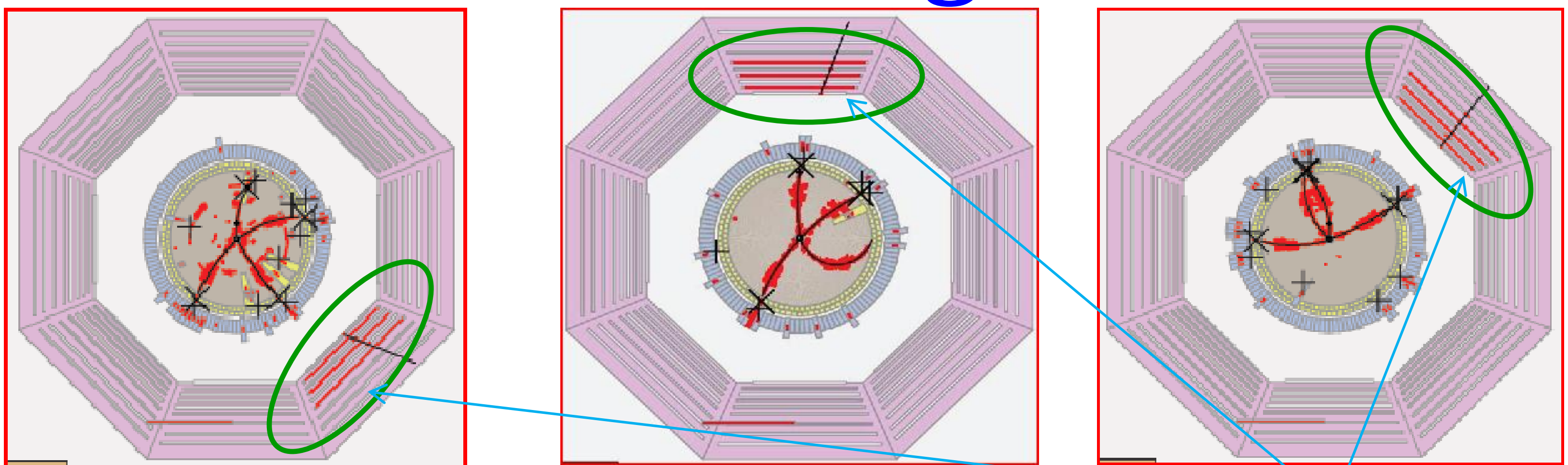


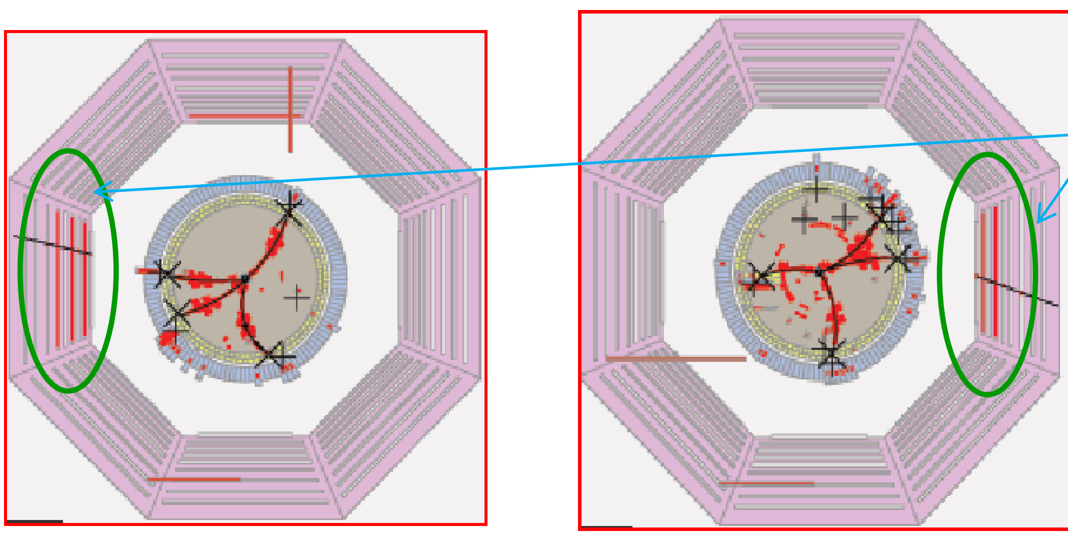
The K^0_L escape from the detector.

There are still some backgrounds



Event display for $D^+ \to \mu^+\nu$ VS D^- tags

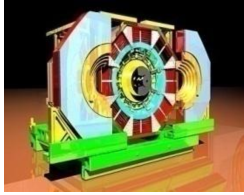


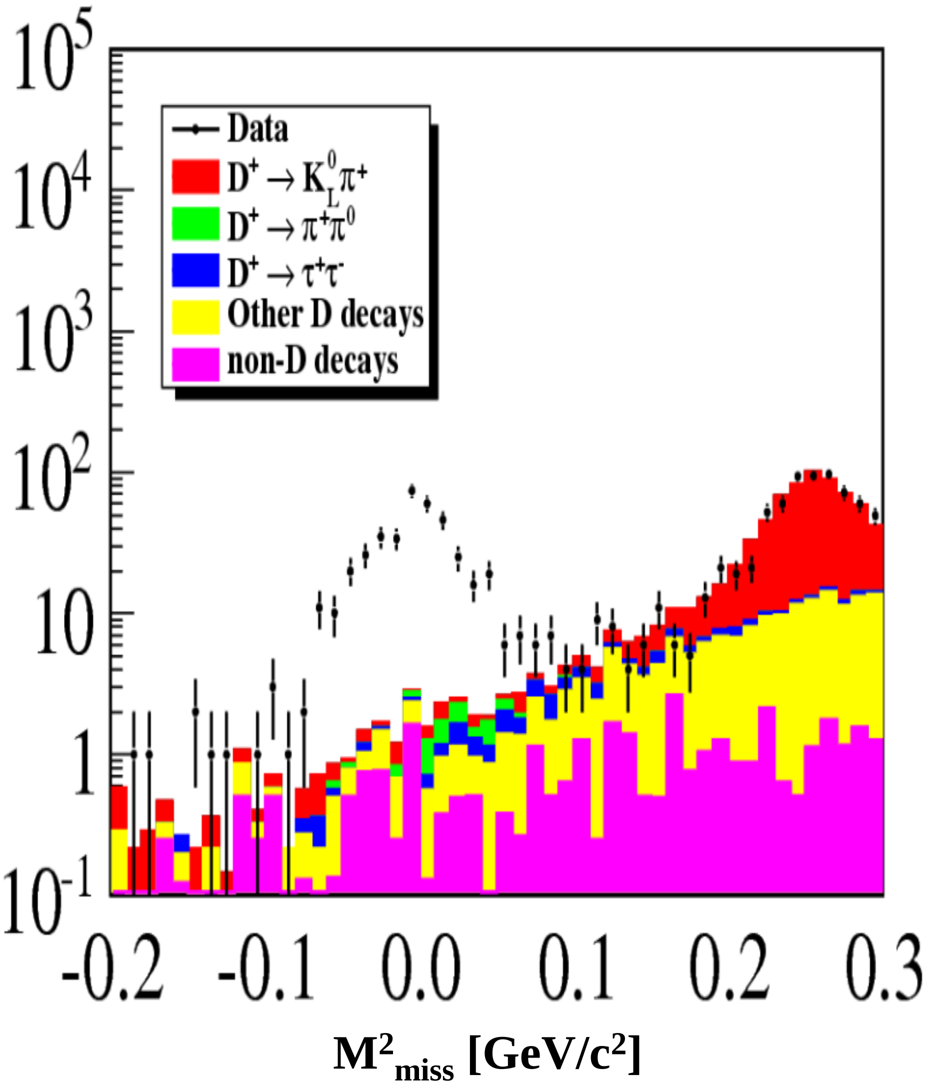


The muon can well be identified by MUC chamber

Each of the events is with a good μ hit in the μ chamber

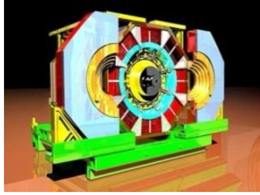
Backgrounds for $D^+ \rightarrow \mu^+ \nu_\mu$



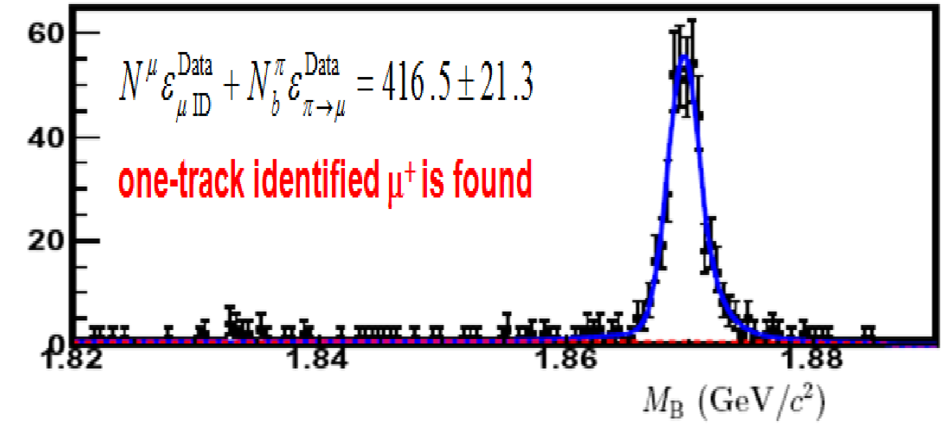


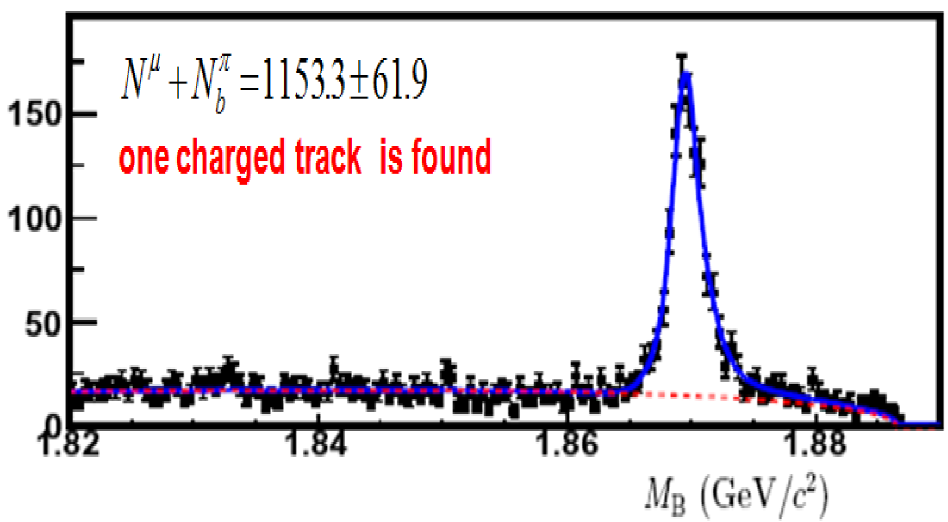
Estimated with Monte Carlo events

Source mode	Number of events
$D^+ \to K_L^0 \pi^+$	7.9 ± 0.8
$D^+ \to \pi^+ \pi^0$	3.8 ± 0.5
$D^+ \to \tau^+ \nu_\tau$	6.9 ± 0.7
Other decays of D mesons	17.9 ± 1.1
$e^+e^- \to \gamma\psi(3686)$	0.2 ± 0.2
$e^+e^- \to \gamma J/\psi$	0.0 ± 0.0
$e^+e^- \to$ *light hadron* (continuum)	8.2 ± 1.4
$e^+e^- \to \tau^+\tau^-$	1.9 ± 0.5
$\psi(3770) \to non - D\bar{D}$	0.9 ± 0.4
Total	47.7 ± 2.3



Backgrounds for $D^+ \rightarrow \mu^+ \nu_\mu$





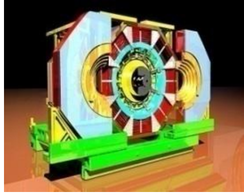
The number of backgrounds is also estimated with data.

By examining number of events with only one charged track in recoil side of the D^- tags, one can estimate number of background events as well.

$$N_b^{D\,\text{Decays}} = 29.0 \pm 3.4$$

$$N_b^{\text{cmb}} = 19.9 \pm 3.4$$

$$N_b^{\text{tot}} = 48.9 \pm 4.8$$



Br. & f_{D+} at BES-III

Results:

N($D^+ \rightarrow \mu^+ \nu$) = 377.3±20.6

$$BF(D^+ \rightarrow \mu^+ \nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$$

f_{D+} = (203.91±5.72±1.97) MeV

These are Preliminary !

Source	Systematic uncertainty [%]
Number of D^- tags ($N_{D^-_{tag}}$)	0.6
Muon tracking	0.5
μ selection	0.3
$E_{\gamma_{max}}$ cut	0.7
Muon momentum cut	0.1
M^2_{miss} cut	0.5
Background estimation	0.7
Monte Carlo statistics	0.2
Radiative correction	1.0
Total	1.7

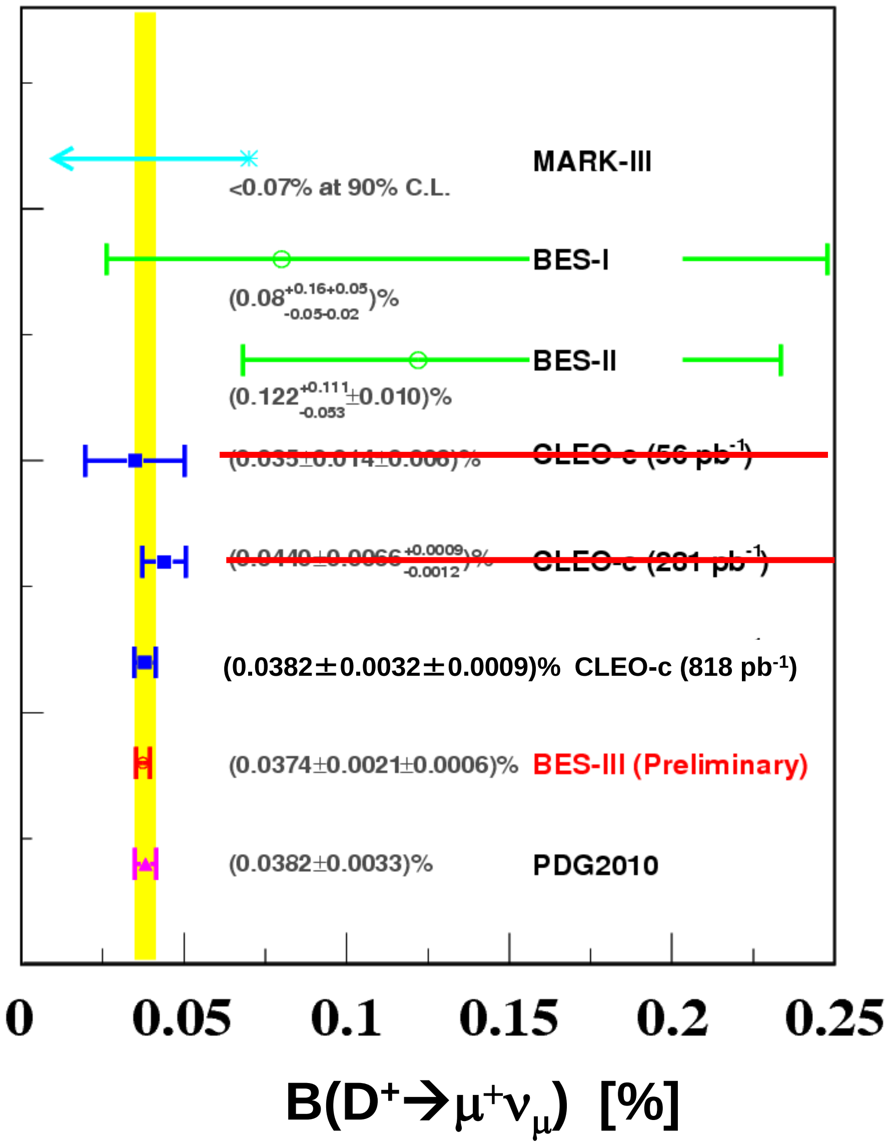
Average of Br. & f_D

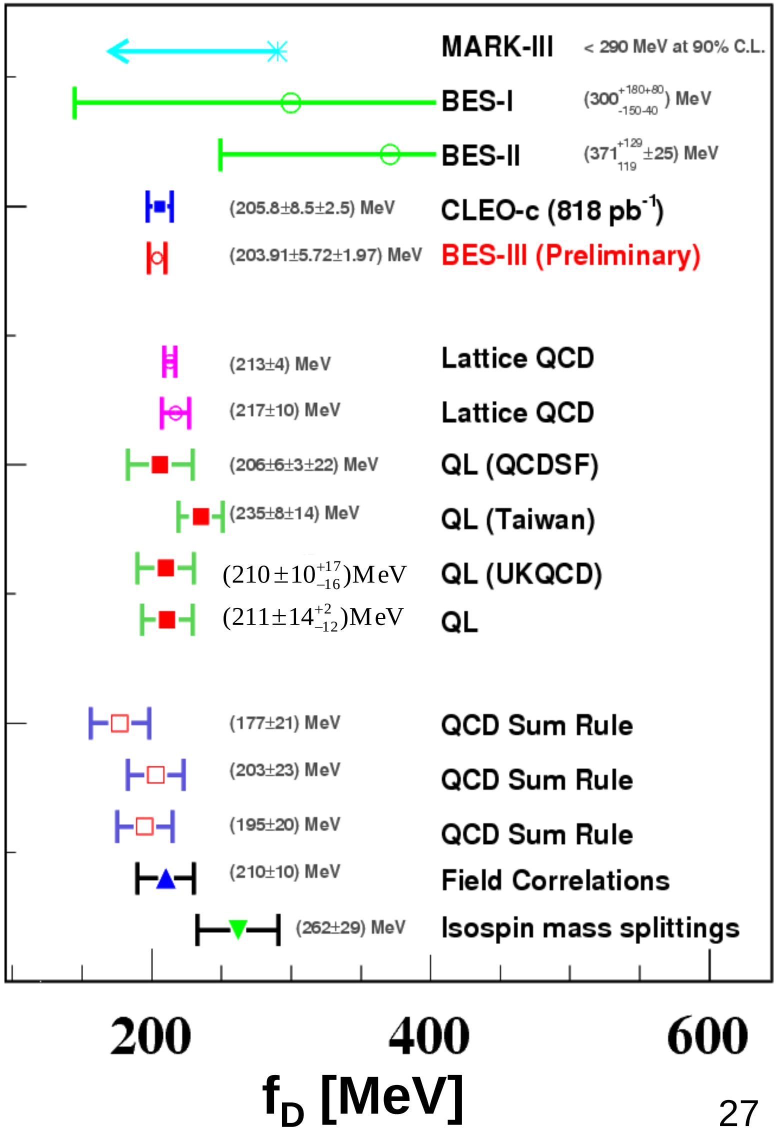
Experiment	$B(D^+ \to \mu^+ \nu_\mu)$ ($\times 10^{-4}$)	Average
CLEO-c	$(3.82 \pm 0.32 \pm 0.09)$	(3.76 ± 0.18)
BES-III(PRLMNRY)	$(3.74 \pm 0.21 \pm 0.06)$	

Experiment	f_D (MeV)	Average
CLEO-c	$(205.8 \pm 8.5 \pm 2.5)$	(204.5 ± 5.0)
BES-III(PRLMNRY)	$(203.91 \pm 5.72 \pm 1.97)$	

At present, the error is still dominated by statistics, needing more data to be taken at 3.773 GeV to reduce the error.

Comparison of $B(D^+ \to \mu^+\nu)$ & f_D



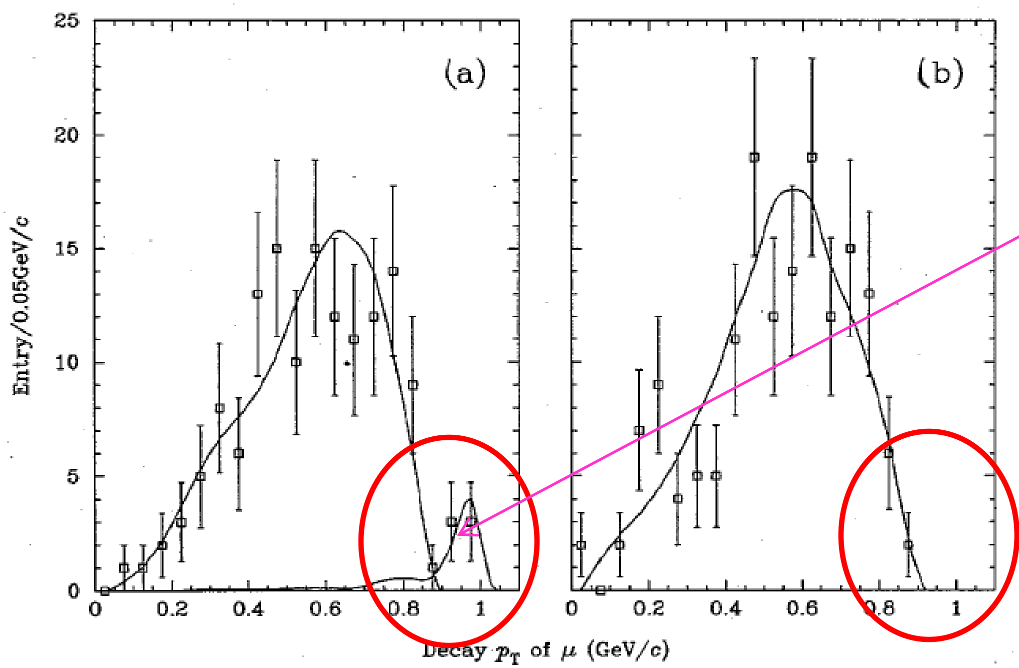


D_S^+ leptonic decays

$D_s^+ \to l^+\nu$ at WA75 Experiment

Fixed target experiment **PTP,89, 131(1993)**

A π^- beam is incident on an emulsion target and muon is required in the online trigger.



Charged D decays Neutral D decays

They found 9.1±3.8 $D_s^+ \to \mu^+\nu$ decays

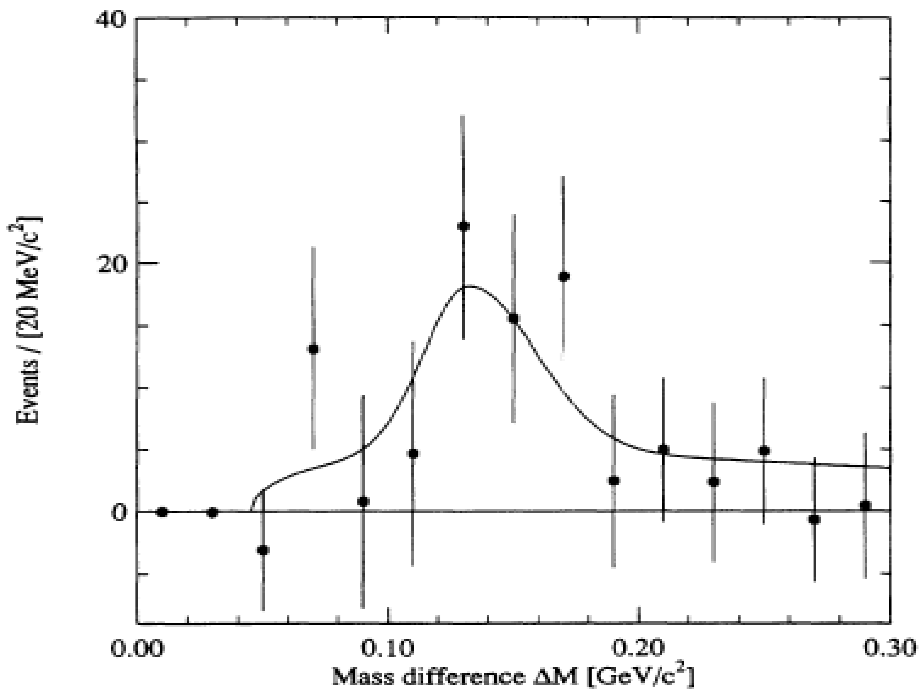
$$B(D_S^+ \to \mu^+\nu) = (0.40^{+0.18+0.08}_{-0.14-0.06} \pm 0.18)\%$$

$$f_{D_S^+} = 232 \pm 45 \pm 20 \pm 48 \ \text{MeV}$$

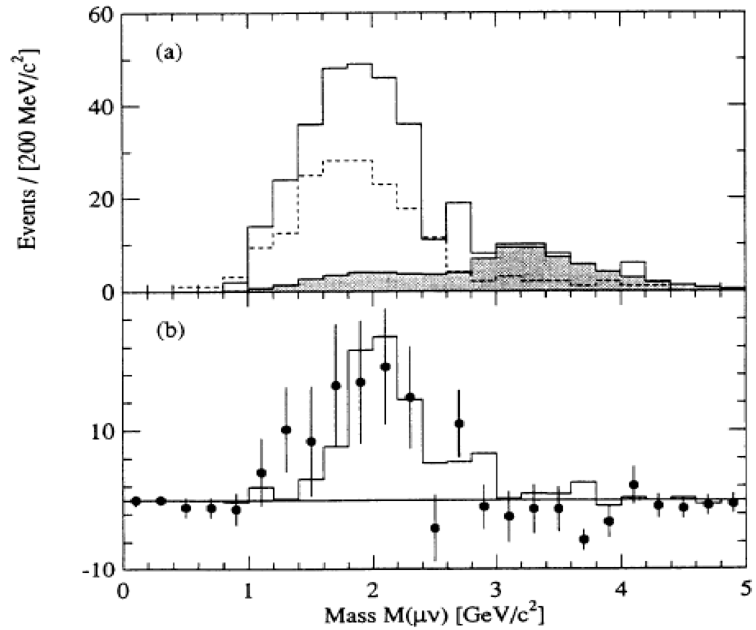
This is the first measurement of f_{Ds}. But, it is not an absolute measurement.

$D_s^+ \rightarrow l^+\nu$ at CLEO II

In 1994, the CLEO II observed 38±10 events for $Ds^{*+} \rightarrow \gamma Ds^+$ followed by $Ds^+ \rightarrow \mu^+\nu$ by analyzing 2.13 fb^{-1} data taken at 10.6 GeV.



PRD49, 5690 (1994)



$$f_{D_S^+} = 344 \pm 37 \pm 52 \pm 42 \text{ MeV}$$

It is not an absolute measurement.

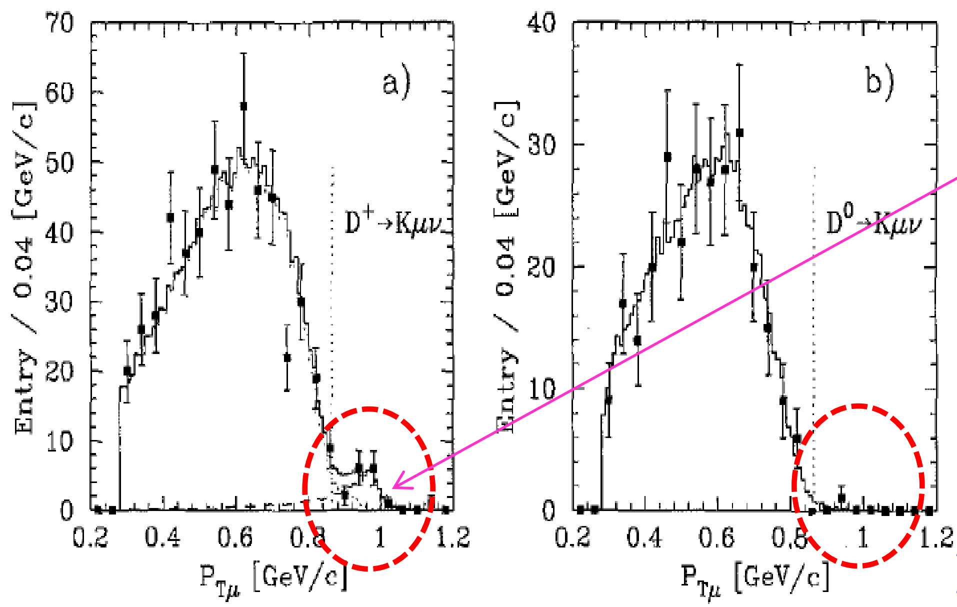
$D_s^+ \to l^+\nu$ at E653 Experiment

Fermilab fixed target experiment

PLB,382, 299(1996)

A π^- beam is incident on an emulsion target and muon is required in the online trigger.

They found 23 $D_s^+ \to \mu^+\nu$



Charged D decays

Neutral D decays

$$B(D_S^+ \to \mu^+\nu) = (0.30 \pm 0.12 \pm 0.06 \pm 0.05)\%$$

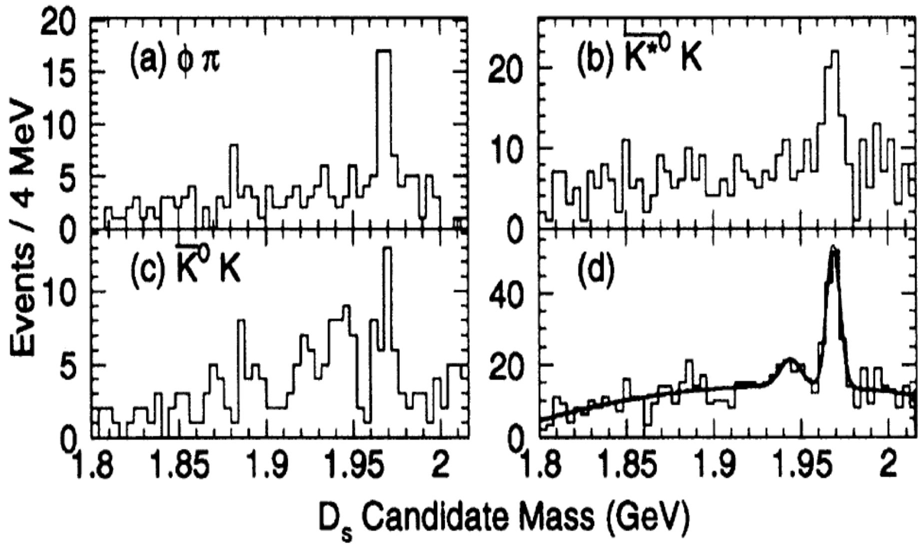
$$f_{D_S^+} = 194 \pm 35 \pm 20 \pm 14 \ \text{MeV}$$

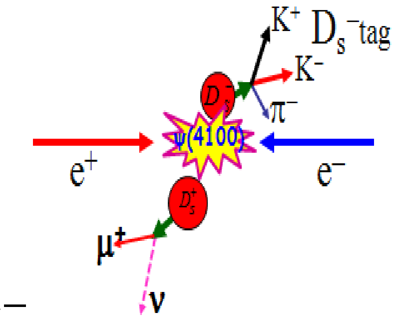
It is not an absolute measurement, it needs branching fraction for $Ds^+ \to \phi\pi^+$ to make normalization

$D_s^+ \rightarrow l^+\nu$ at BES-I

PRL74, 4599 (1995)

22.3 pb^{-1} @4.03 GeV

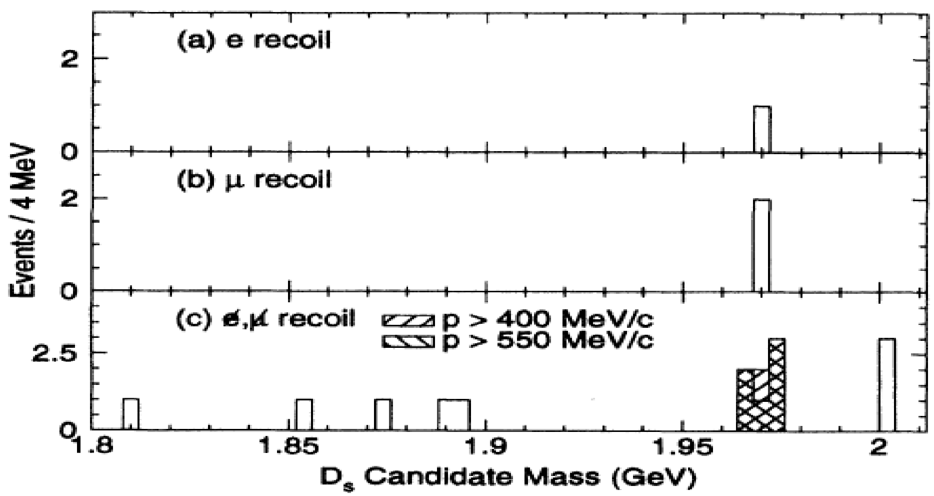




$e^+e^- \rightarrow Ds^+Ds^-$

3 singly tagged D_s^- modes

94 singly tagged D_s^-



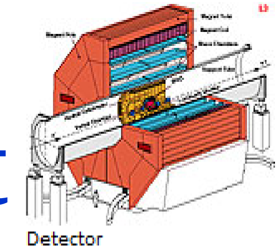
3 events for $Ds^+ \rightarrow l^+\nu$

$$B(D_S^+ \rightarrow \mu^+\nu) = (1.5^{+1.3+0.3}_{-0.6-0.2})\%$$

$$f_{D_S^+} = 430^{+150+40}_{-130-40} \text{ MeV}$$

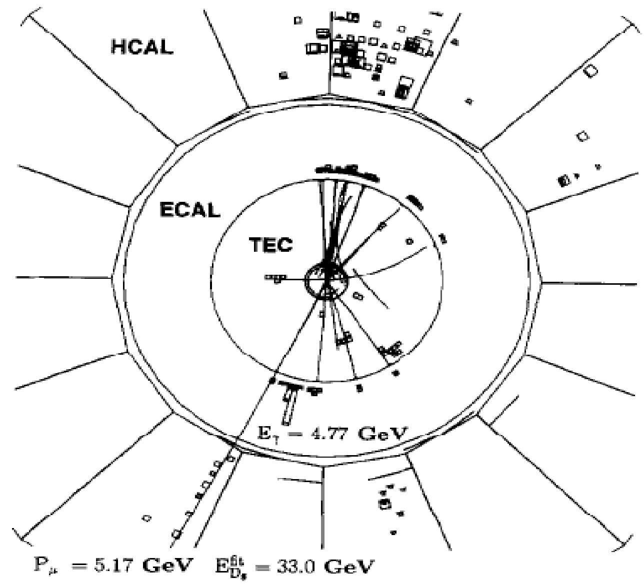
It is the first absolute measurement.

$D_s^+ \rightarrow \tau^+\nu$ at L3 Experiment



LB396P, 327 (1997)

$Ds^+ \rightarrow \tau^+\nu$ selected from analysis of fragmentation and decay chain $Z \rightarrow$ cc-bar, c-bar$\rightarrow Ds^{*-}$ followed by $Ds^{*-} \rightarrow \gamma Ds^-$, $Ds^- \rightarrow \tau^-\nu$, $\tau^- \rightarrow l^-\nu\nu$

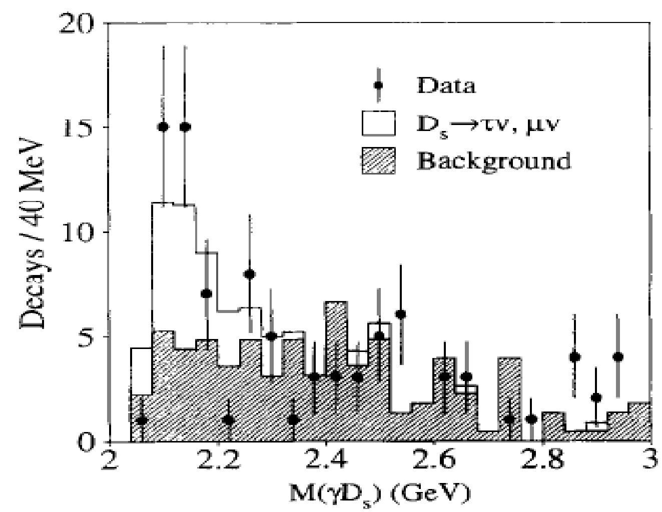


1.5×10^6 $Z \rightarrow$ qq-bar(γ) events

15.6±6.0 $Ds^+ \rightarrow \tau^+\nu$ events

$$B(D_S^+ \rightarrow \tau^+\nu) = (7.4 \pm 2.8 \pm 1.6 \pm 1.8)\%$$

$$f_{D_S^+} = 309 \pm 58 \pm 33 \pm 38 \text{ MeV}$$



$D_s^+ \rightarrow \tau^+\nu$ at OPAL

PLB516 236 (2001)

The measurements were made based on reconstruction of decay sequence

$$e^+e^- \rightarrow Z \rightarrow c\bar{c} \rightarrow D_s^{\star -} X$$
$$\hookrightarrow \gamma D_s^-$$
$$\hookrightarrow \tau \bar{\nu}_\tau$$
$$\hookrightarrow \ell^- \bar{\nu}_\ell \nu_\tau \ (\ell = e, \mu)$$

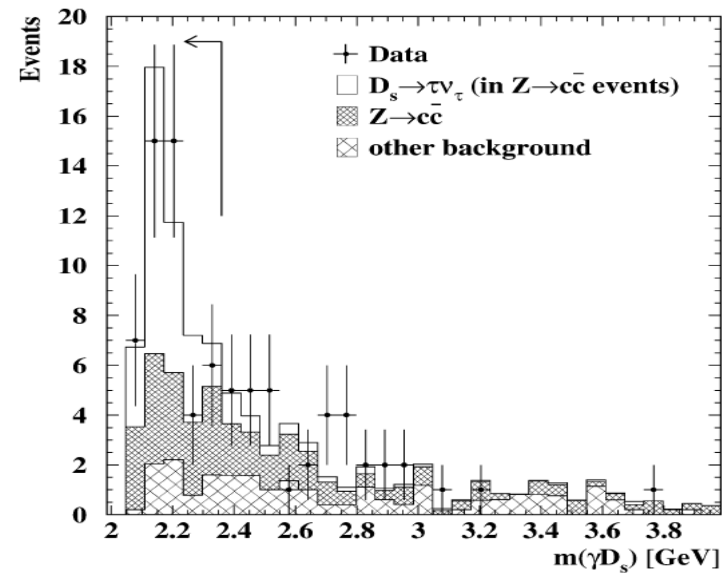
$$\vec{P}_{D_s} = - \sum_{i \neq \text{lepton}} \vec{p}_i ,$$

$$E_{D_s} = \sqrt{s} - \sum_{i \neq \text{lepton}} E_i ,$$

$$\sqrt{E_{D_s}^2 - P_{D_s}^2} = M_{D_s} .$$

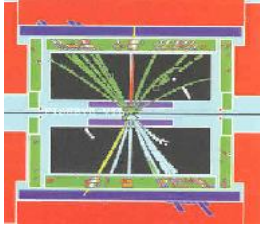
$3.9\text{x}10^6$ $Z \rightarrow q\bar{q}(\gamma)$ events

22.5 ± 6.9 $D_s^+ \rightarrow \tau^+\nu$ events



$$B(D_S^+ \rightarrow \tau^+\nu) = (7.0 \pm 2.1 \pm 2.0)\%$$

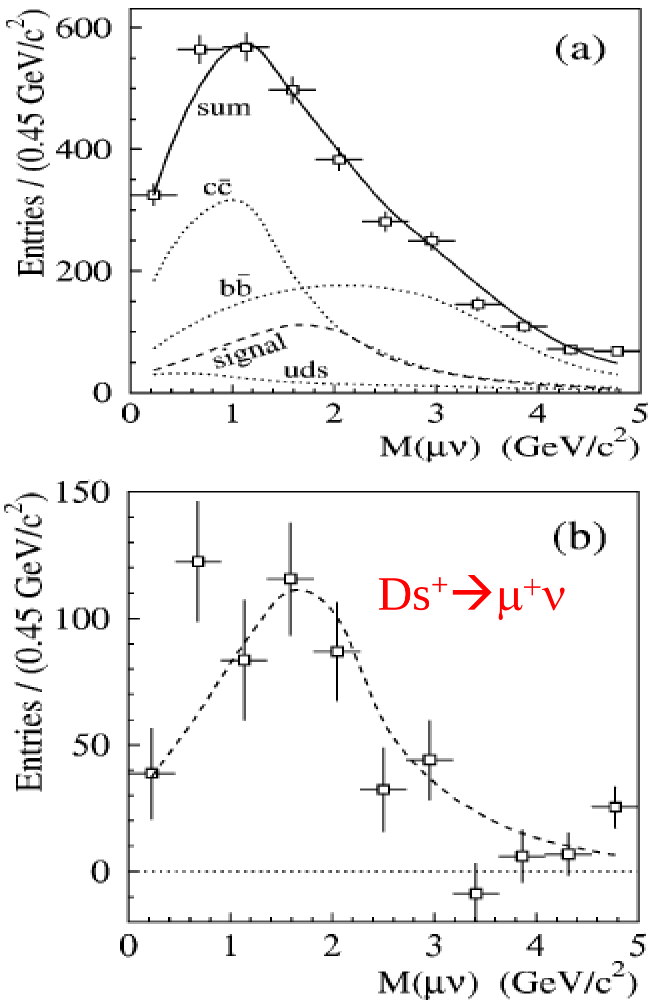
$$f_{D_S^+} = 286 \pm 44 \pm 41 \ \text{MeV}$$



$D_s^+ \rightarrow \tau^+\nu$ at ALEPH

PLB528, 1 (2002)

The measurements were made based on almost the same technique as used by L3 and OPAL. But the ALEPH reconstructed the $Ds^+ \rightarrow \mu^+\nu$ decay in their invariant mass.



3.97×10^6 hadronic Z decays

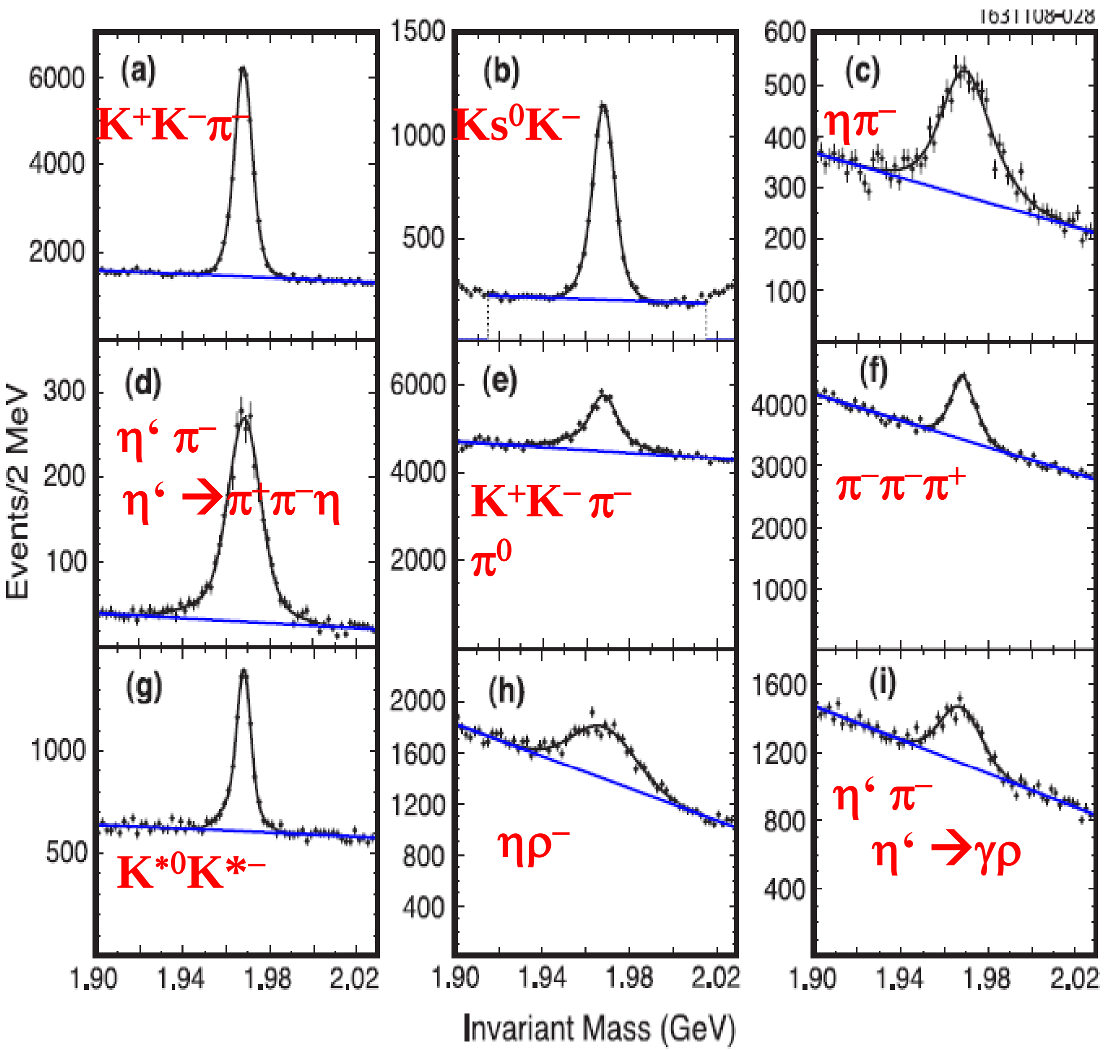
$$B(D_S^+ \rightarrow \tau^+\nu) = (5.79 \pm 0.77 \pm 1.84)\%$$

$$B(D_S^+ \rightarrow \mu^+\nu) = (0.68 \pm 0.11 \pm 0.18)\%$$

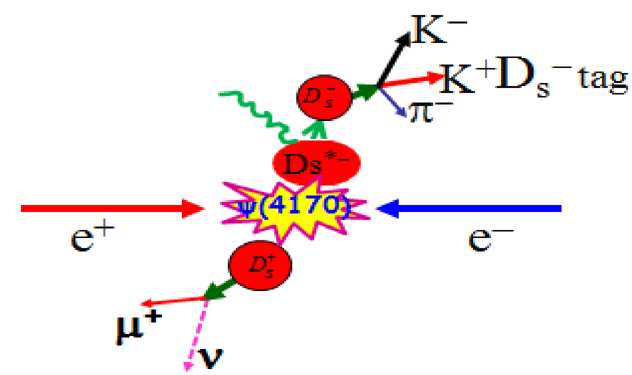
$$f_{D_S^+} = 285 \pm 19 \pm 40 \ \text{MeV}$$

D_s^- tags at CLEO-c

PRD79, 052001 (2009)



600 pb^{-1} @ 4.170 GeV



$e^+e^-\to Ds^+Ds^{*-}$

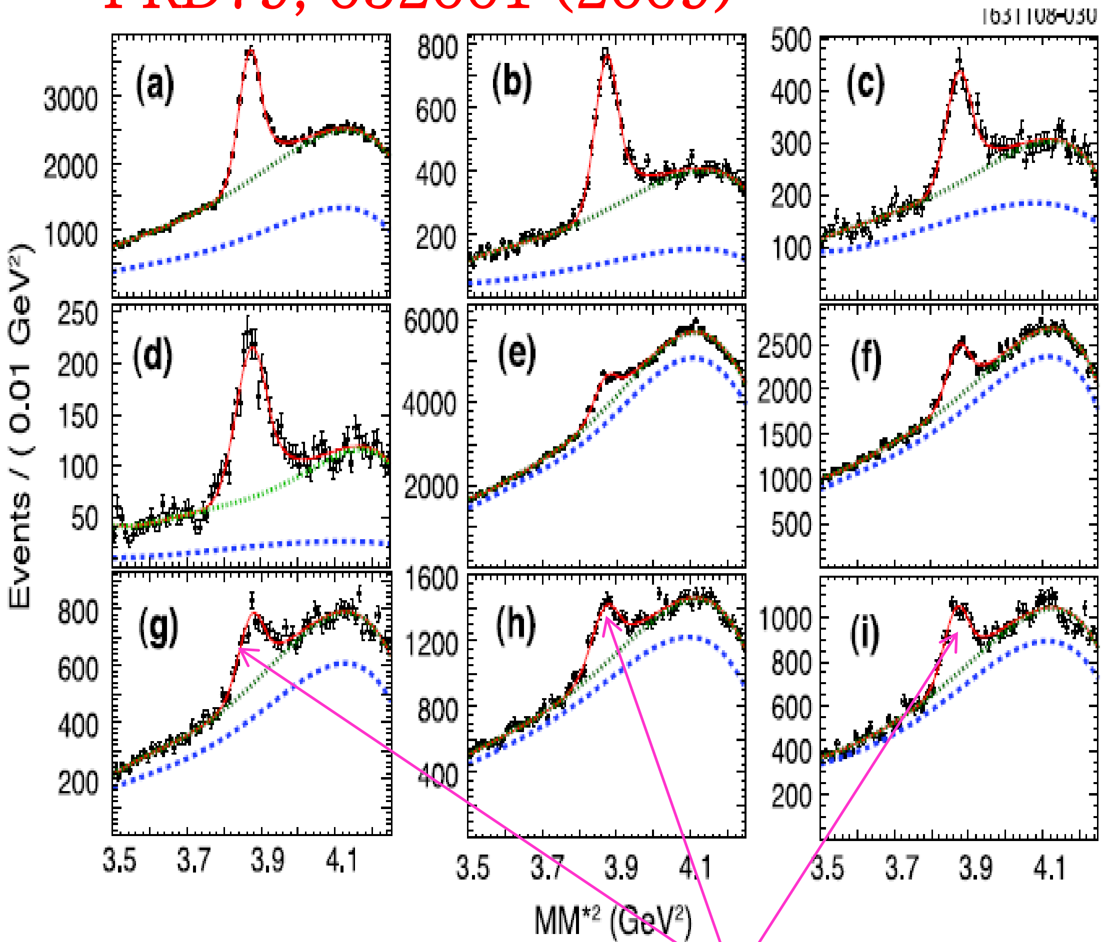
$Ds^{*-}\to\gamma Ds^-$

9 singly tagged Ds^- modes

Absolute measurement.

D_s^{*-} tags at CLEO-c

PRD79, 052001 (2009)



Needing reconstruction of Ds^{*-}

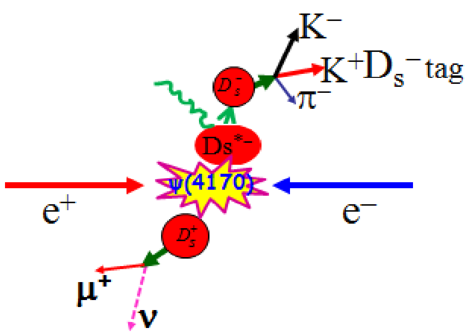
$e^+e^- \rightarrow Ds^+ Ds^{*-}$

$Ds^{*-} \rightarrow \gamma Ds^-$

$$MM^2 = (E_{CM} - E_{D_s^-} - E_\gamma)^2 - (-\vec{p}_{CM} - \vec{p}_{D_s^-} - \vec{p}_\gamma)^2$$

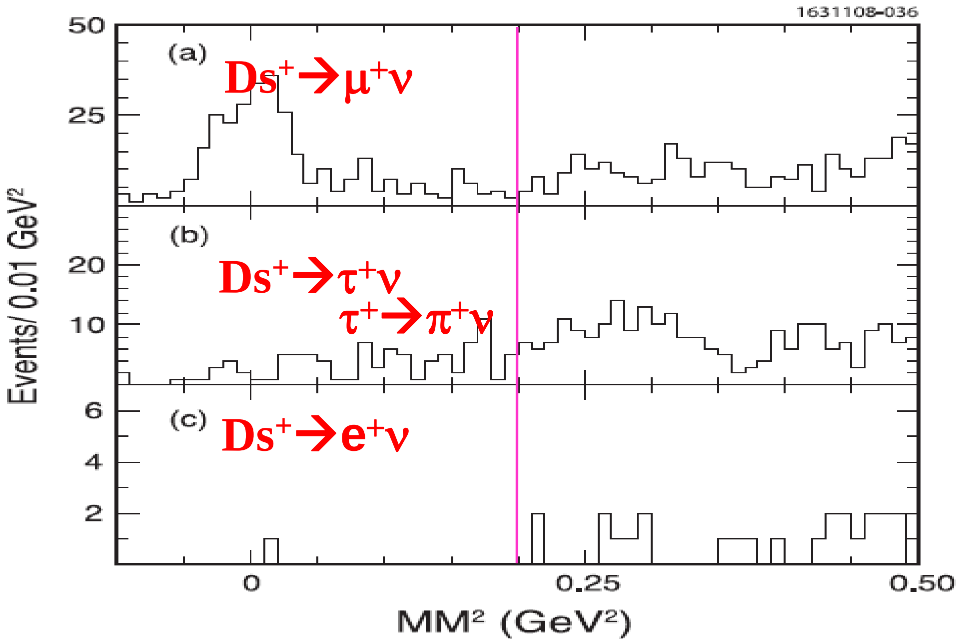
MM^{*2} is the missing mass square of the system recoiling against the γD_s^-

These peaks indicate that the D_s^{*-} are well reconstructed

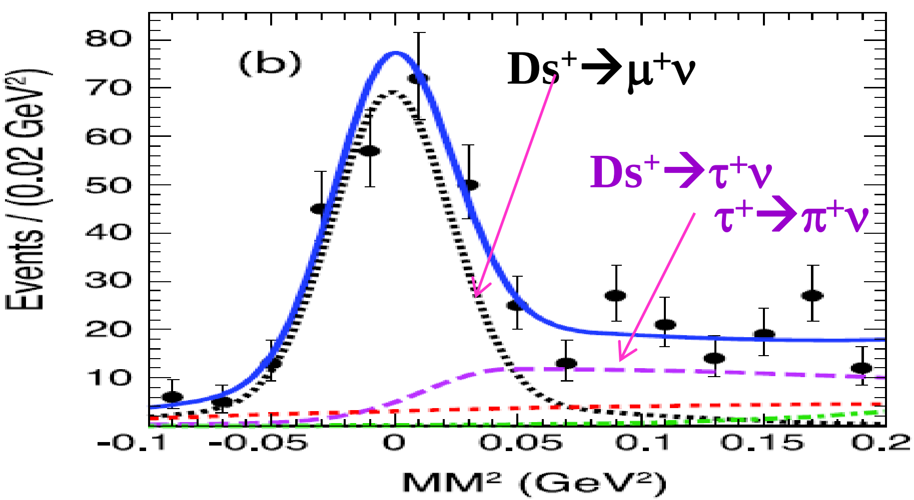


$D_s^+ \rightarrow l^+\nu$ at CLEO-c

PRD79, 052001 (2009)



$$MM^2 = (E_{CM} - E_{D_S^-} - E_\gamma - E_\mu)^2$$
$$-(-\vec{p}_{CM} - \vec{p}_{D_S^-} - \vec{p}_\gamma - \vec{p}_\mu)^2$$



$$B(D_S^+ \rightarrow \mu^+\nu) = (0.591 \pm 0.037 \pm 0.018)\%$$

$$B(D_S^+ \rightarrow \tau^+\nu) = (6.42 \pm 0.81 \pm 0.18)\%$$

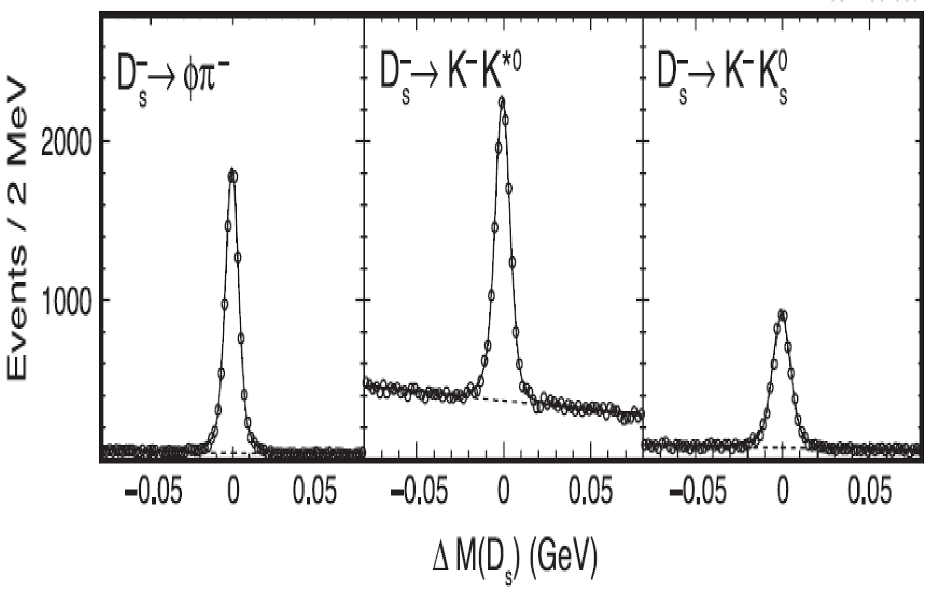
$$f_{D_S^+} = 263.3 \pm 8.2 \pm 3.9 \text{ MeV}$$

Absolute measurement.

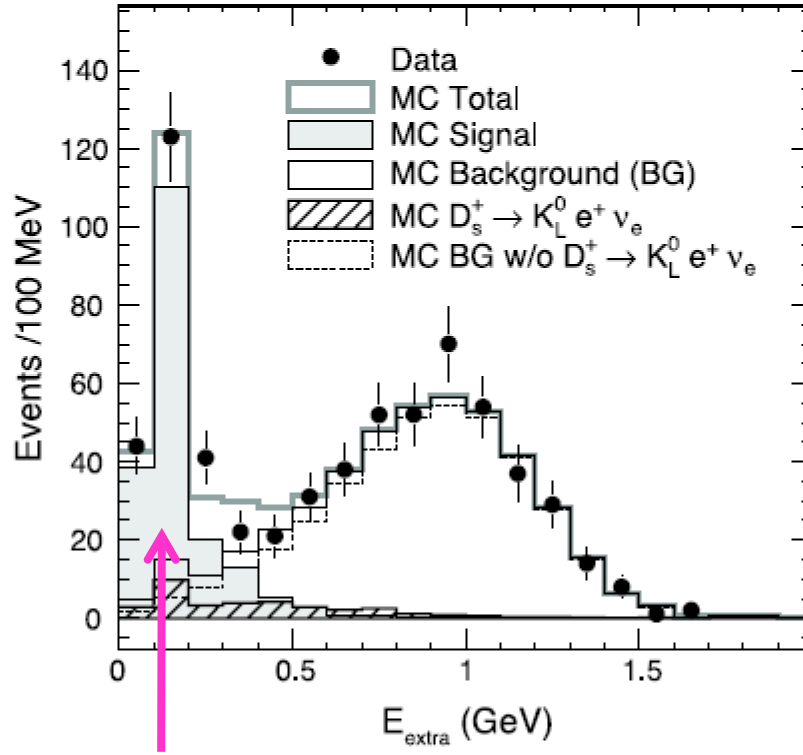
$D_s^+ \rightarrow \tau^+\nu$ at CLEO-c

600 pb^{-1} PRD79, 052002 (2009)

$Ds^+ \rightarrow \tau^+\nu,\ \tau^+ \rightarrow e^+\nu\nu$



Three cleanest single tag Ds mode were used



Signal for $Ds^+ \rightarrow \tau^+\nu$

$$f_{D_S^+} = 252.5 \pm 11.1 \pm 5.2\ \text{MeV}$$

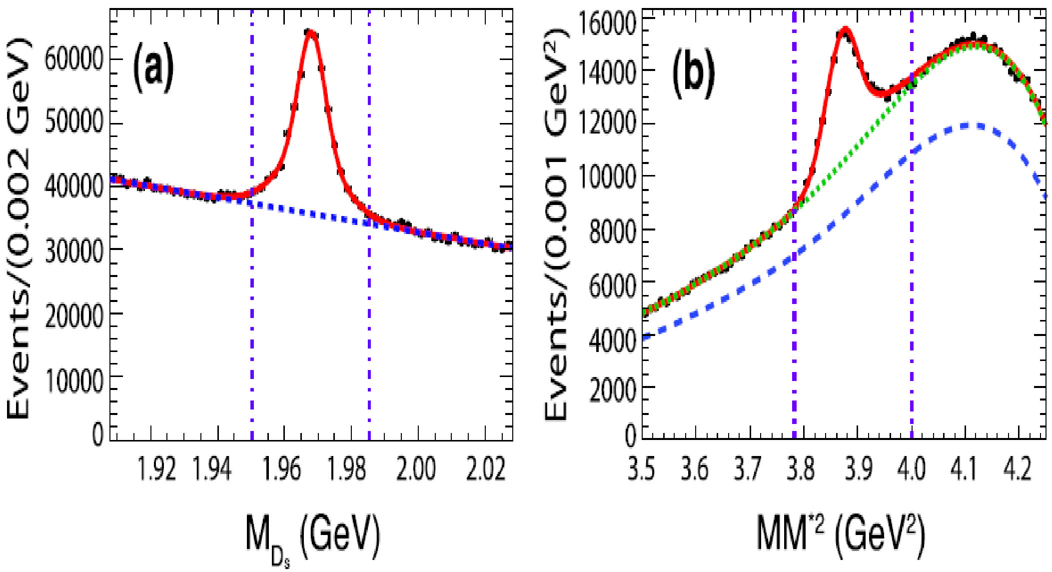
E_{extra} is the total energy of rest of the event measured in the electromagnetic calorimeter

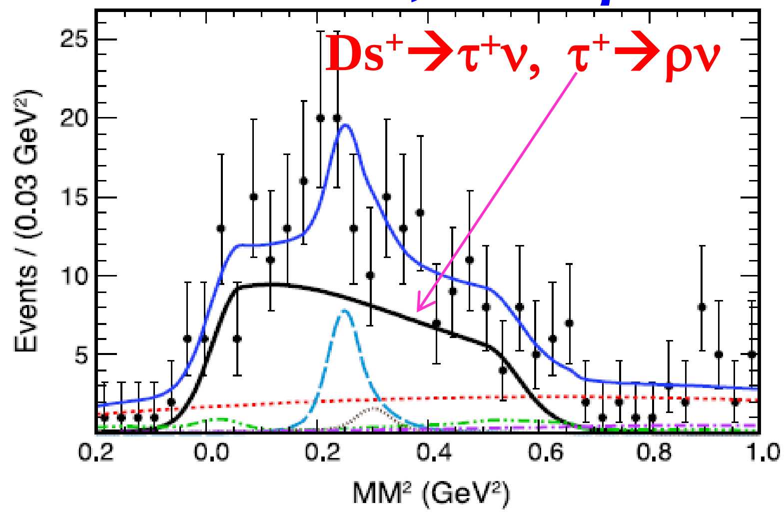
Absolute measurement.

$D_s^+ \rightarrow \tau^+\nu$ at CLEO-c

PRD80, 112004 (2009)

D_s^- tags **600 pb^{-1}** **$D_s^+ \rightarrow \tau^+\nu,\ \tau^+ \rightarrow \rho\nu$**





$$B(D_S^+ \rightarrow \tau^+\nu)$$
$$= (5.52 \pm 0.57 \pm 0.21)\%$$
$$f_{D_S^+} = 257.8 \pm 13.3 \pm 5.2\ \text{MeV}$$

Absolute measurement.

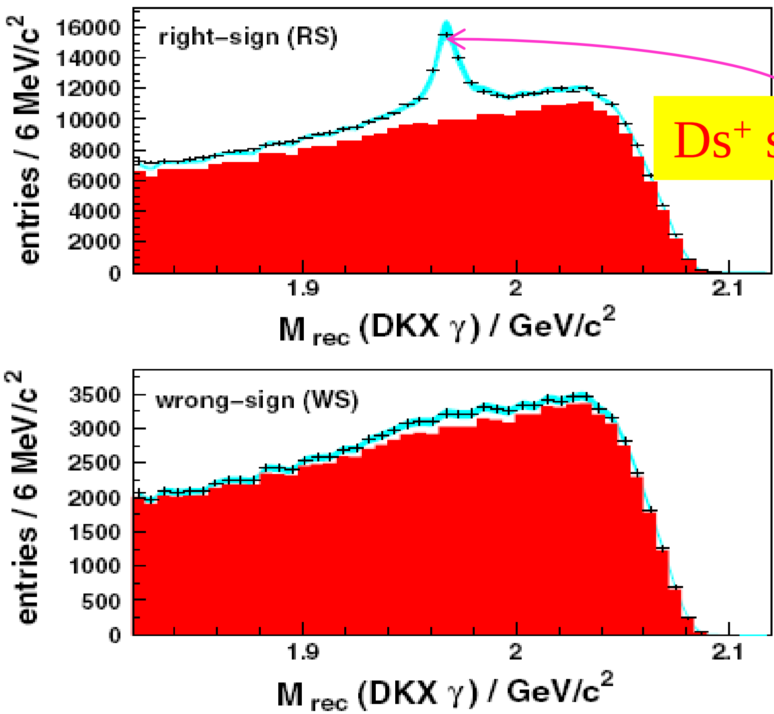
$D_s^+ \rightarrow l^+\nu$ at Belle

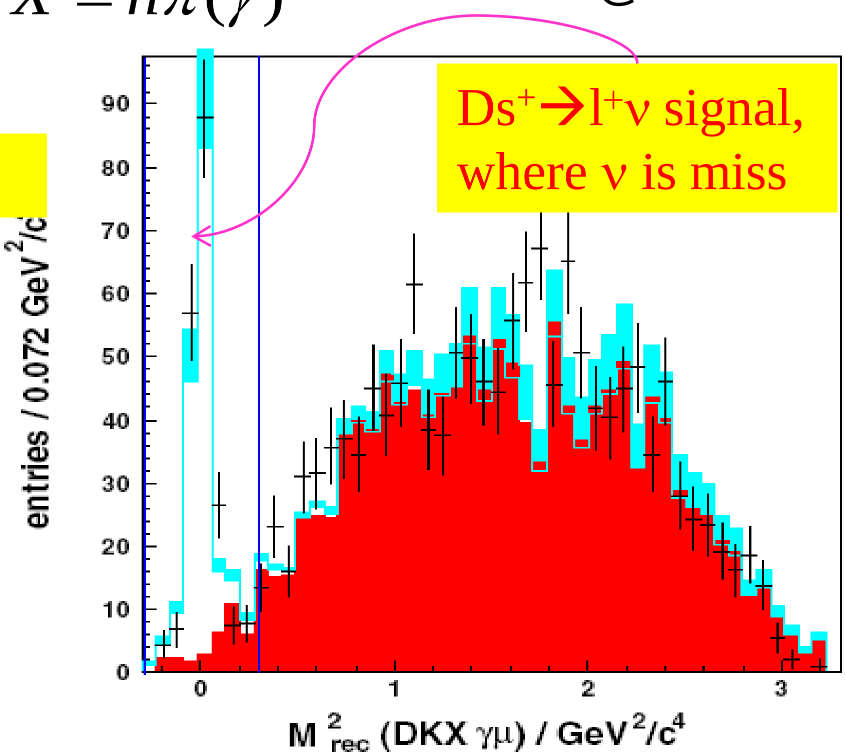
$e^+e^- \rightarrow$ cc-bar events

PRL100, 241801(2008)

$$e^+e^- \rightarrow D_S^* D^{\pm,0} K^{\pm,0} X,\ D_S^* \rightarrow \gamma D_S\ , X = n\pi(\gamma)$$

548 fb-1 @ 10.6 GeV





$$N_{D_S}^{\mathrm{REC}} = 32100 \pm 870(\mathrm{stat}) \pm 1210(\mathrm{syst})$$

$$B(D_S^+ \rightarrow \mu^+\nu) = [0.644 \pm 0.076 \pm 0.057]\%$$

$$N_{\mu\nu}^{\mathrm{REC}} = 169 \pm 16(\mathrm{stat}) \pm 8(\mathrm{syst})$$

$$f_{D_S^+} = [275 \pm 16 \pm 12]\ \mathrm{MeV}$$

Absolute measurement.

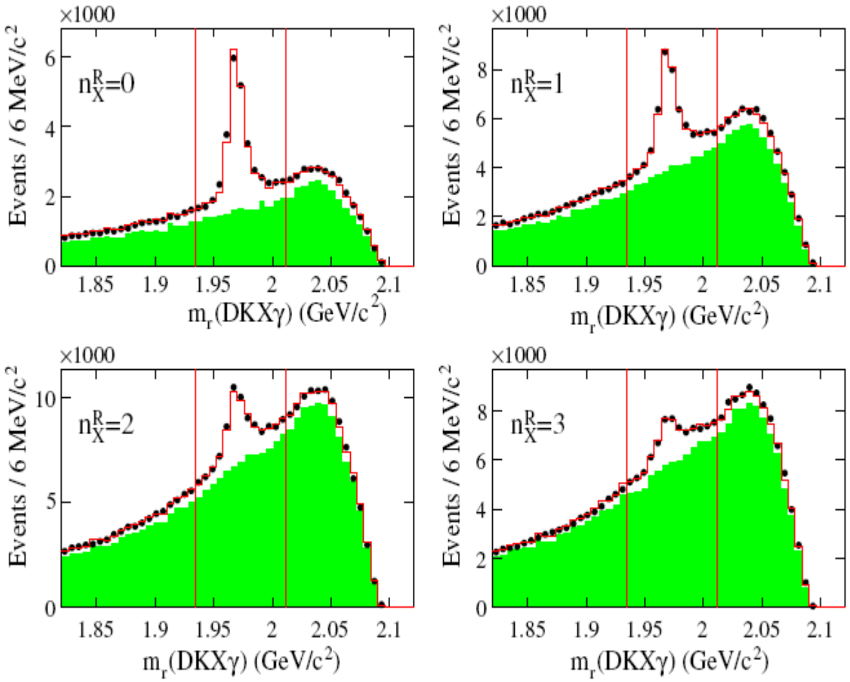
$D_s^+ \to l^+\nu$ at BaBar

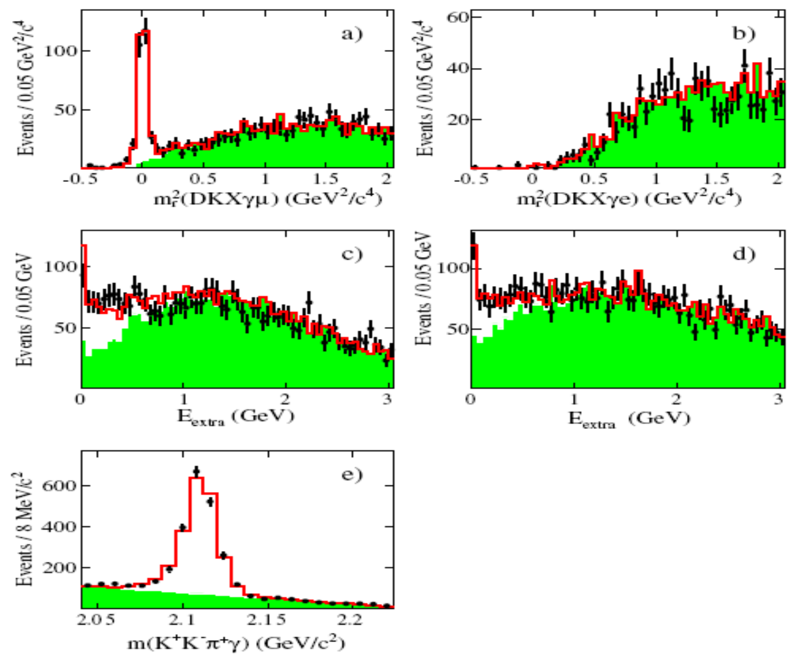
$e^+e^- \to$ cc-bar events

PRD82, 091103(R) (2010)

$$e^+e^- \to D_S^* D^{\pm,0} K^{\pm,0} X,\ D_S^* \to \gamma D_S\ , X = n\pi(\gamma)$$

521fb^{-1} @ 10.6 GeV





$$B(D_S^+ \to \mu^+\nu) = [0.602 \pm 0.038 \pm 0.034]\%$$

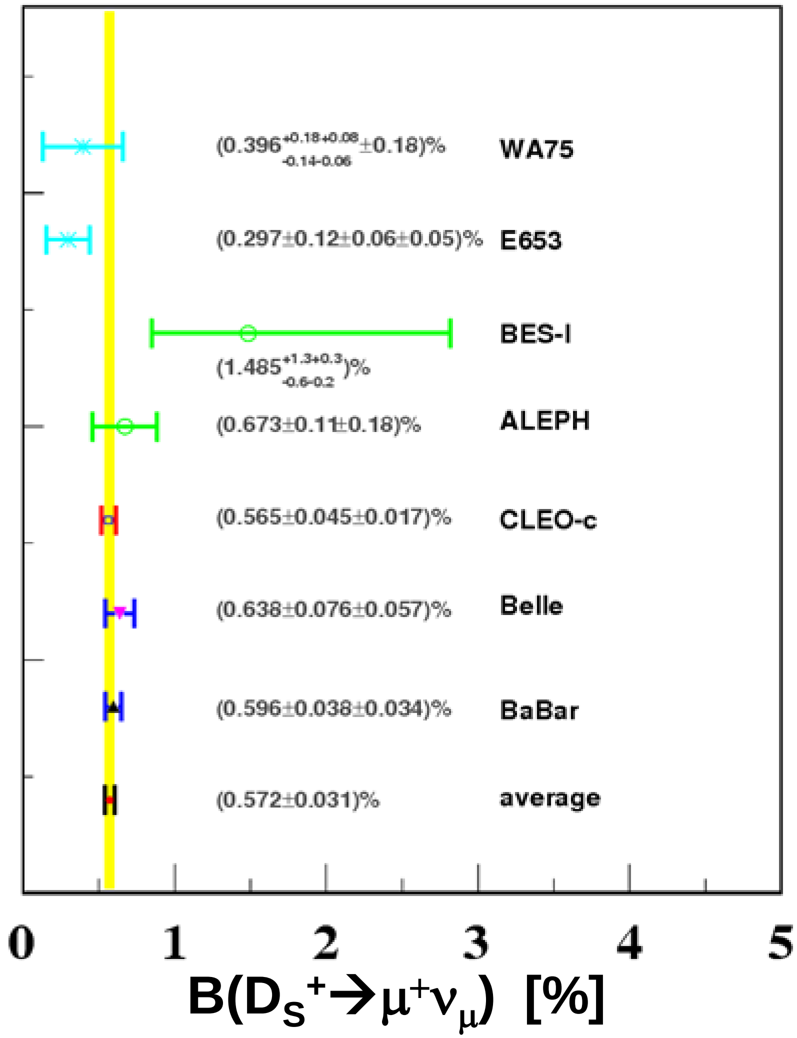
$$B(D_S^+ \to \tau^+\nu) = [5.07 \pm 0.52 \pm 0.68]\%\ (\tau^+ \to e\nu\nu)$$

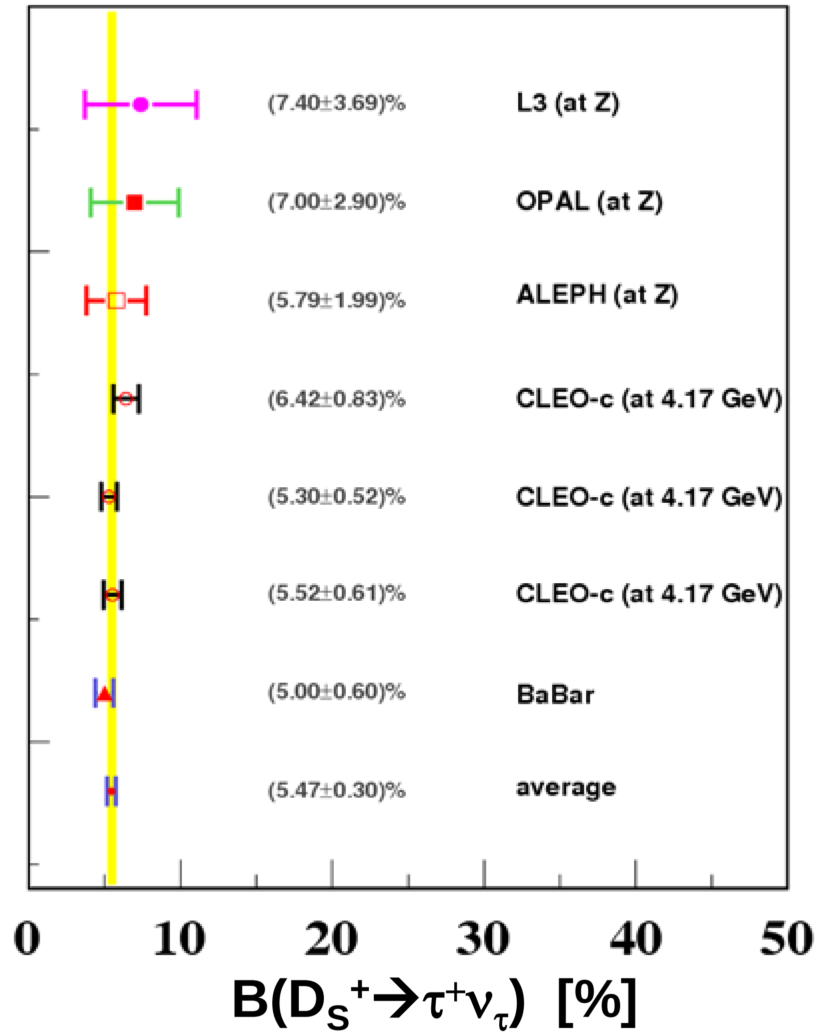
$$B(D_S^+ \to \tau^+\nu) = [4.91 \pm 0.47 \pm 0.54]\%\ (\tau^+ \to \mu\nu\nu)$$

$$f_{D_S^+} = (258.6 \pm 6.4 \pm 7.5)\ \text{MeV}$$

Absolute measurement.

Comparison of the measured Br.



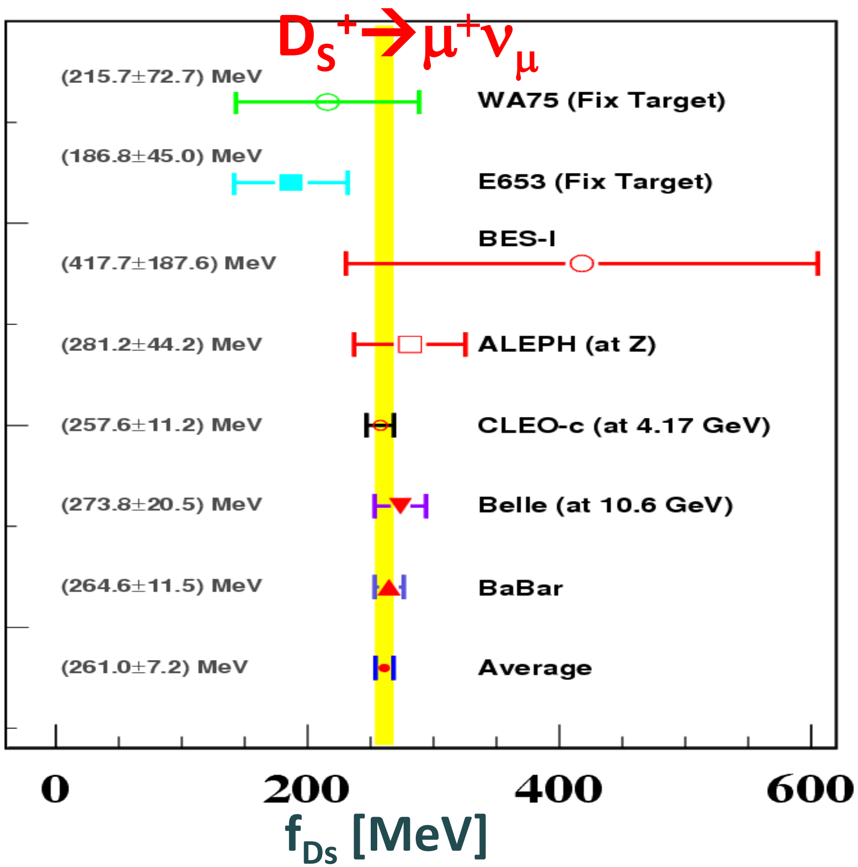


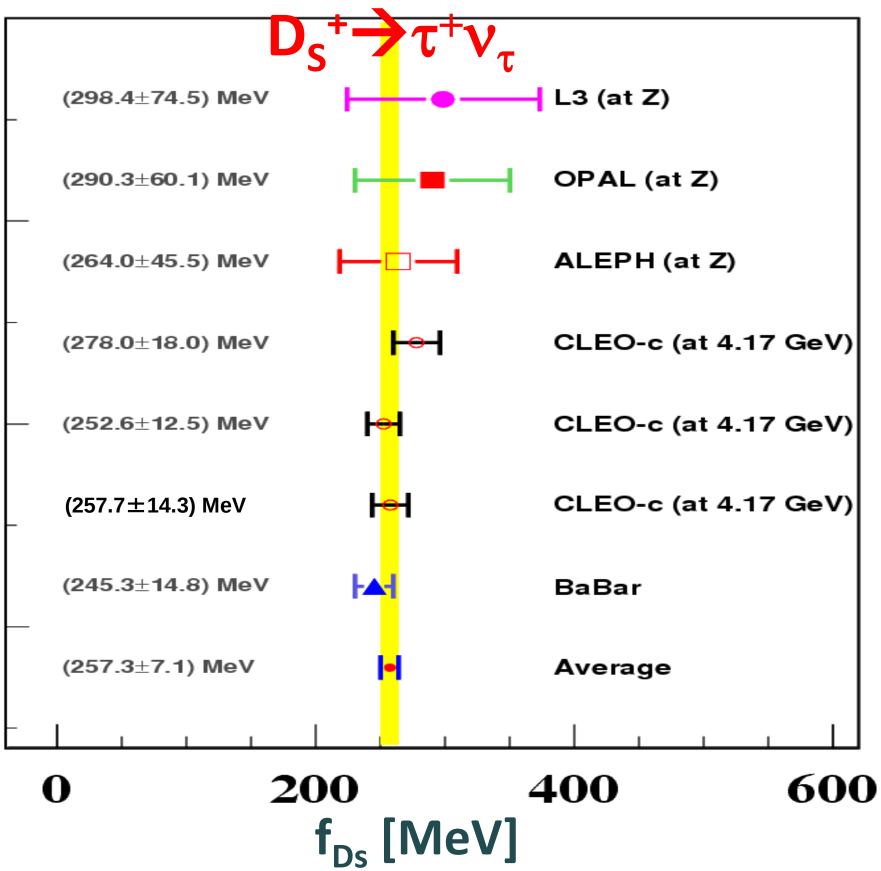
$B(D_S^+\rightarrow\tau^+\nu_\tau) = (0.572\pm0.031)\%$

$B(D_S^+\rightarrow\tau^+\nu_\tau) = (5.45\pm0.30)\%$

Comparison of the measured f_{Ds}

Based on the measured branching factions of D_S^+ leptonic decays (after radiative correction), and with inputs of D_S^+ mass, lepton mass, D_S^+ lifetime and $|V_{cs}|$=0.97345 from CKMfiter, we calculate the f_{Ds} .



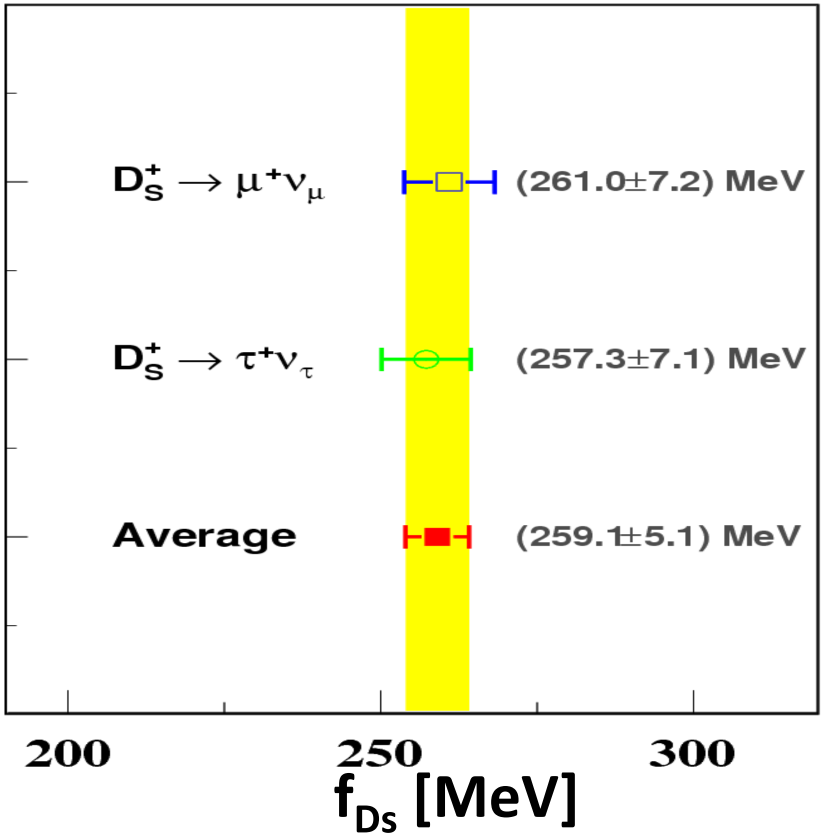


$$f_{D_S^+} = (261.0 \pm 7.2)\ \text{MeV}$$

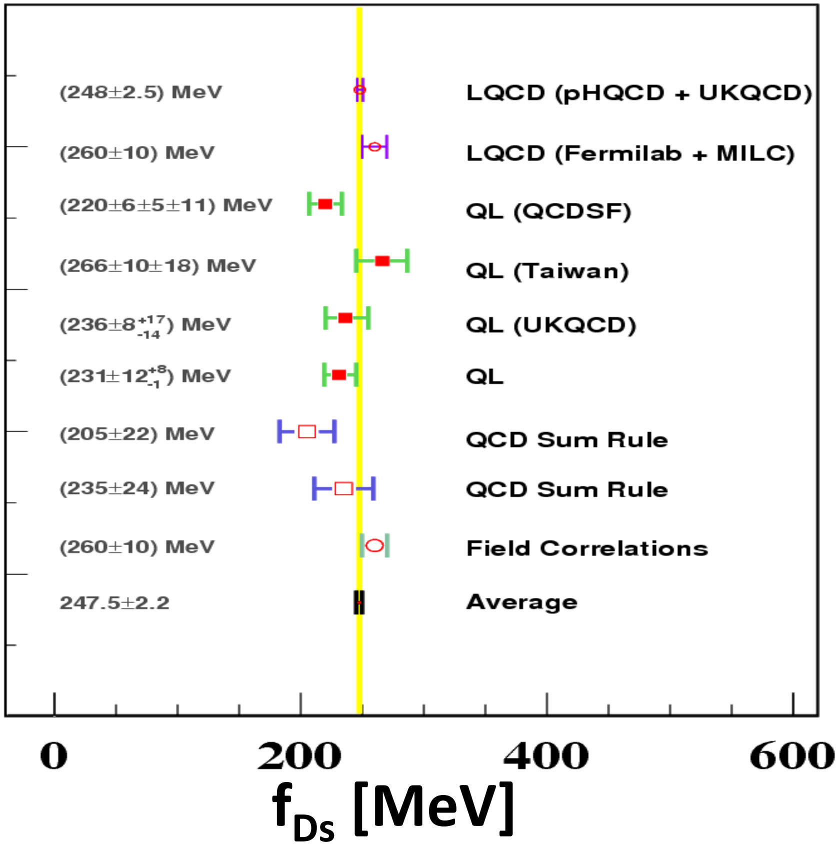
$$f_{D_S^+} = (257.3 \pm 7.1)\ \text{MeV}$$

Measured & calculated f_{Ds}

f_{Ds} measured at different experiments



Calculations of f_{Ds}



$f_{Ds}=(259.1\pm5.1)$ MeV (Weighted Average)	$f_{Ds}=(247.5\pm2.2)$ MeV (Weighted Average)

The measured f_{Ds} is 2.09σ larger than the one expected by theories.

Comparison of f_{Ds}/f_D

Experiments

Weighted Average

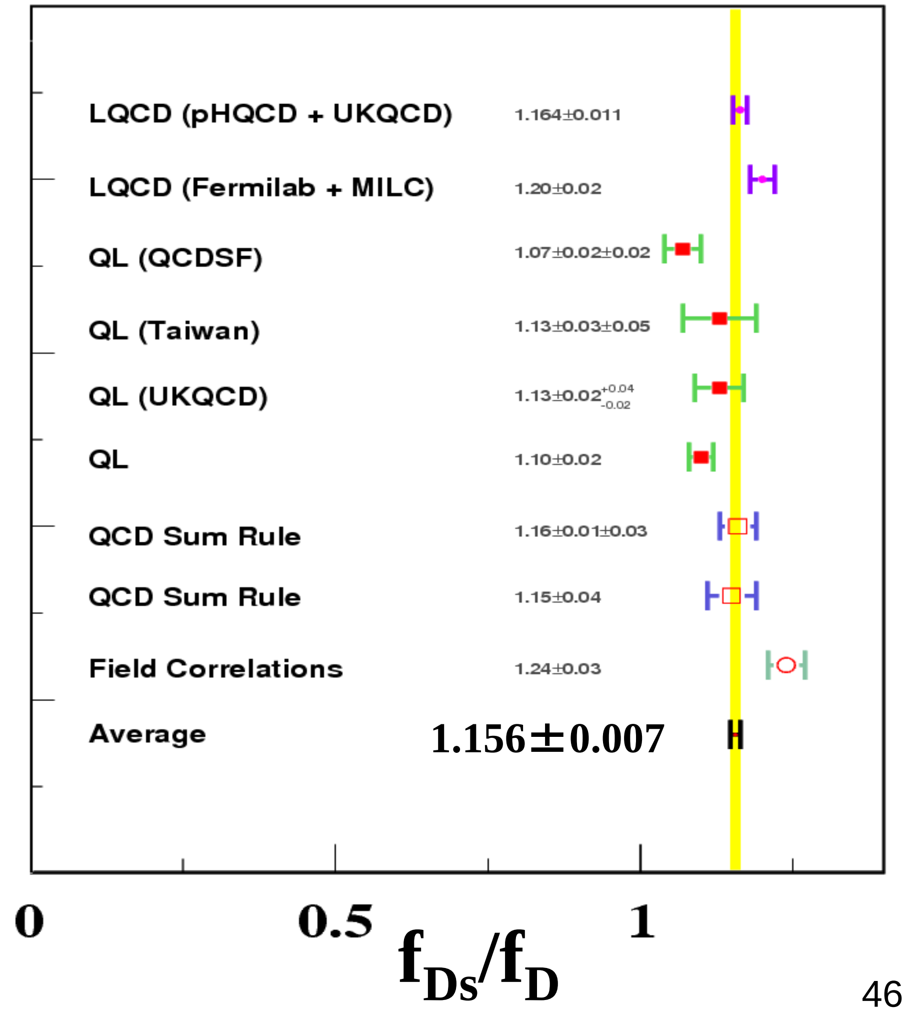
$f_{Ds}=(259.1\pm5.1)$ MeV

$f_D=(204.5\pm5.0)$ MeV

$f_{Ds}/f_D=(1.267\pm0.040)$

The measured ratio of the f_{Ds}/f_D is 2.7σ larger than that predicted by theoretical calculations

Theoretical calculations



Determination of $|V_{cs}|$ and $|V_{cd}|$

$$\Gamma(D^+_{(s)} \to l^+ \upsilon_l) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \left|V_{cd(s)}\right|^2 m_l^2 m_{D^+_{(s)}} \left(1 - \frac{m_l^2}{m^2_{D^+_{(S)}}}\right)^2$$

$f_{D(Ds)}$ can be well calculated (LQCD, …)

$\Gamma[D_{(s)}{}^+ \to l^+ v]$ can be well measured

One can extract CKM matrix elements $|V_{cs}|$ and $|V_{cd}|$

CKM matrix element $|V_{cd}|$

The $|V_{cd}|$ could be extracted with

$$\Gamma(D^+ \to l^+ \upsilon_l) = \frac{G_F^2 f_{D^+}^2}{8\pi} |V_{cd}|^2 m_l^2 m_{D^+} (1 - \frac{m_l^2}{m_{D^+}^2})^2$$

Inserting the quantities

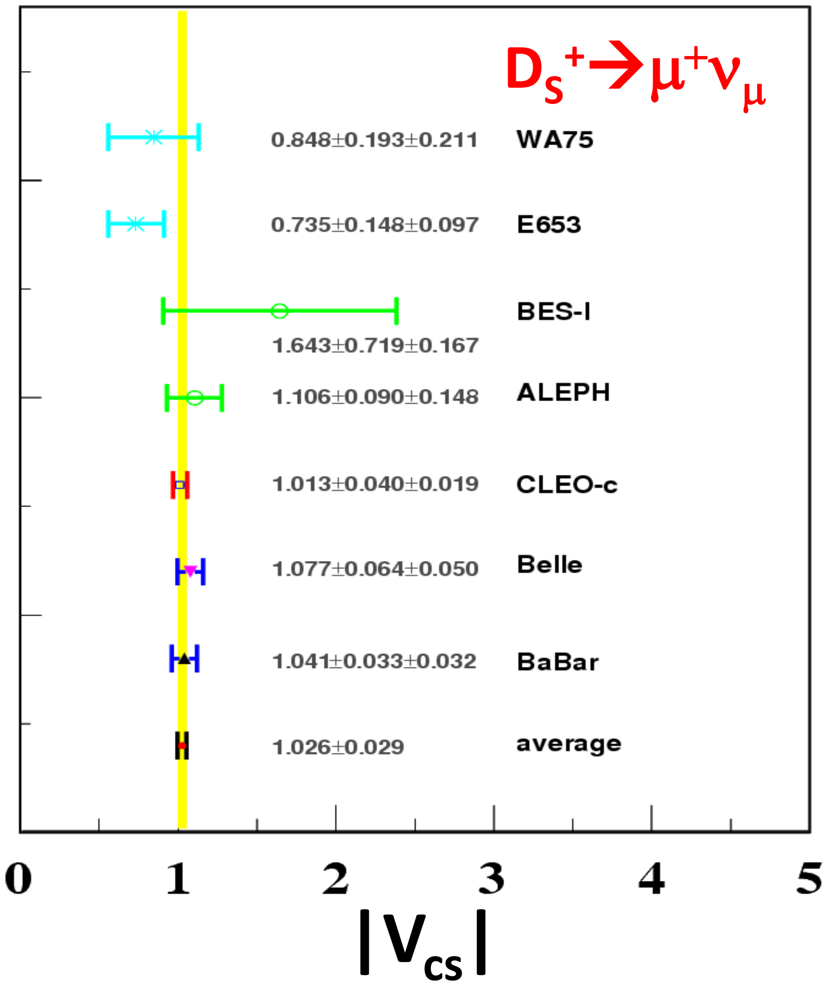
τ_{D+} = (1040±7) fs,
M_{D+} = (1896.60±0.16) MeV
$M_{\mu+}$ = (105.658±0.000) MeV
f_{D+} = 207±4 MeV (from LQCD)

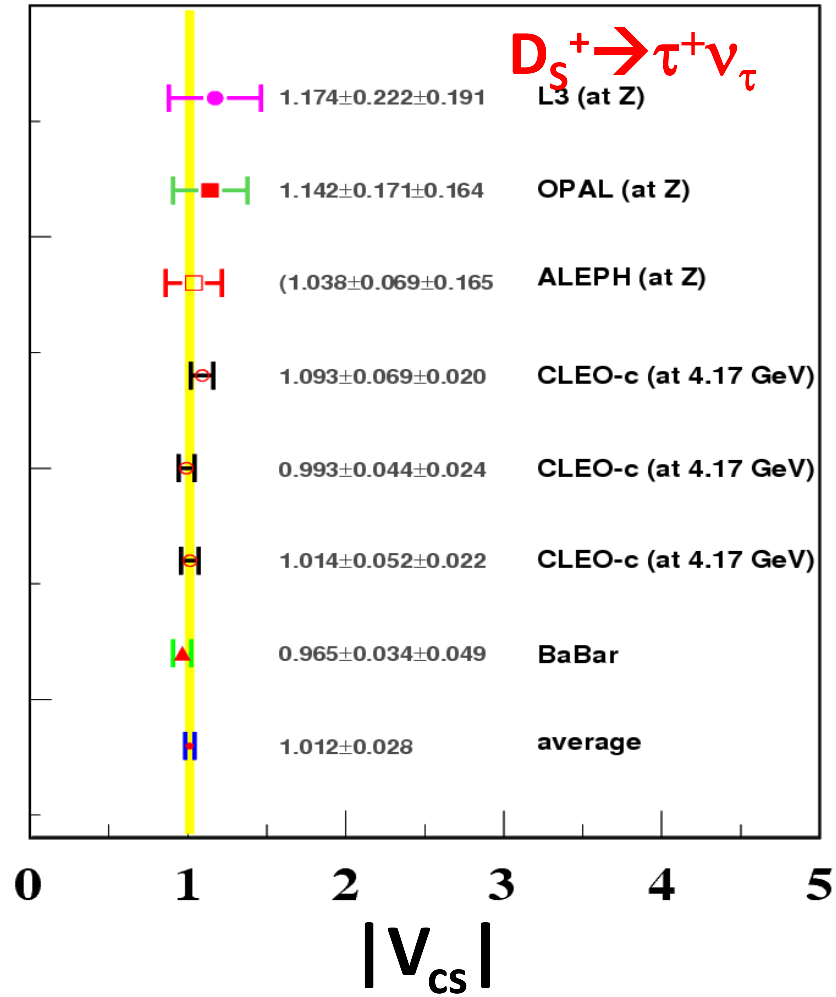
yields

$|V_{cd}|$ = (0.222±0.006±0.005) (BES-III **Preliminary**)

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

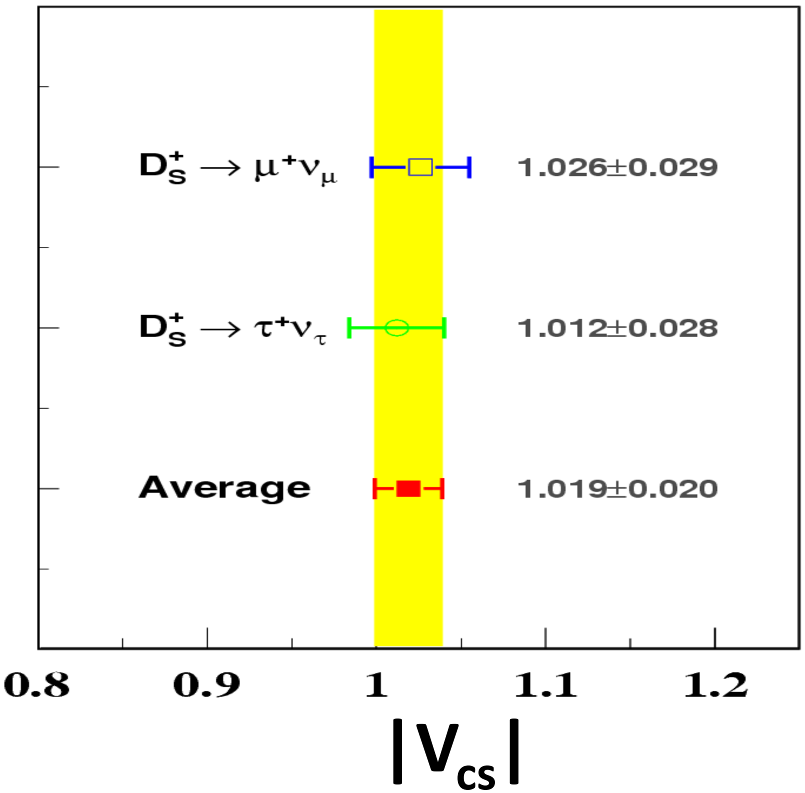
CKM matrix element $|V_{cs}|$

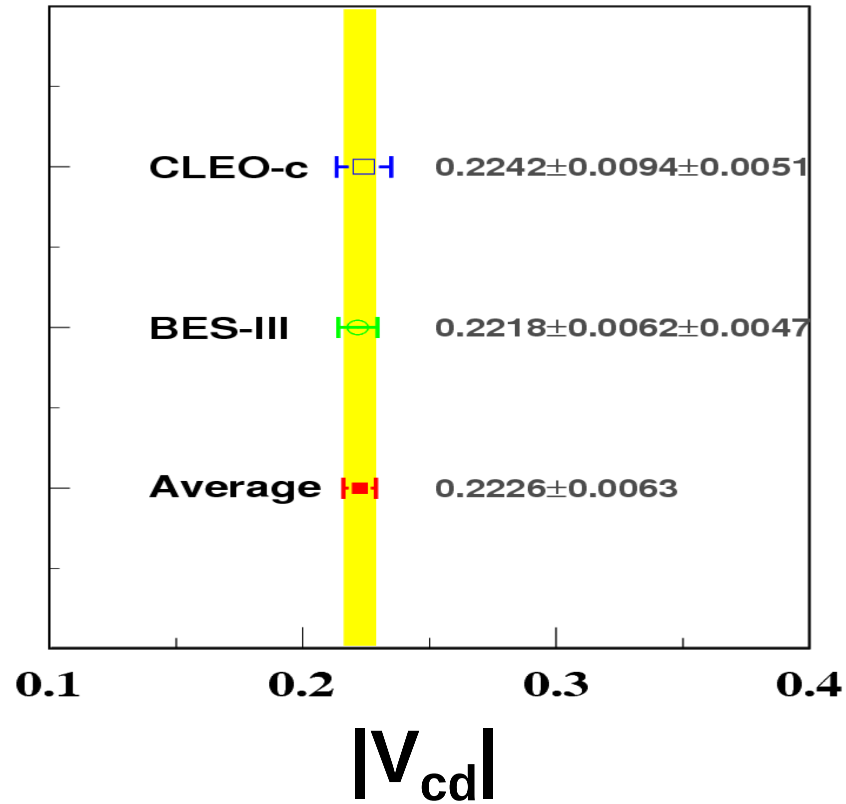




In the calculation we use f_{Ds}=(247.5±2.2) MeV (the average of calculations)

$|V_{cs}|$ & $|V_{cd}|$





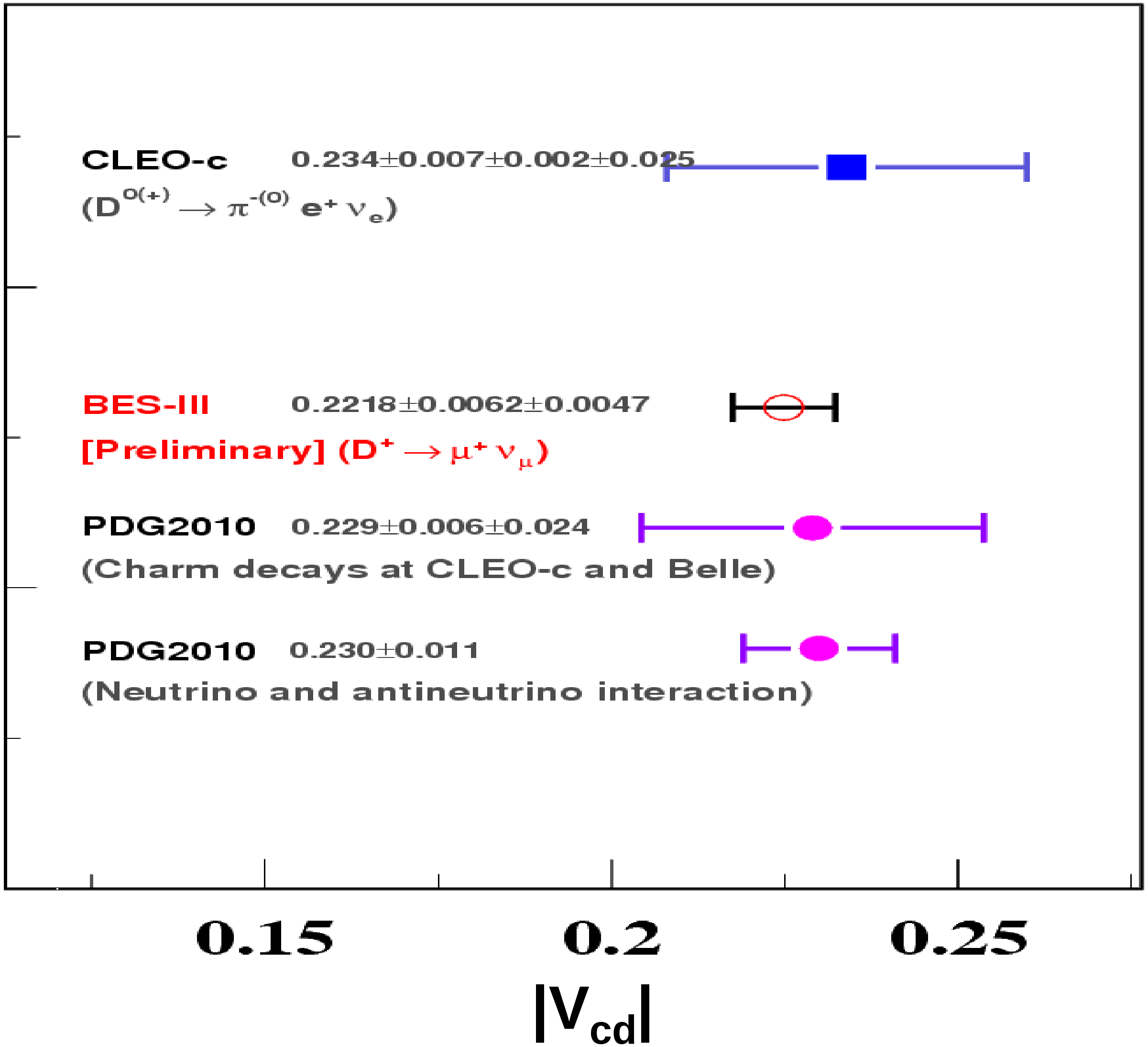
$|V_{cs}|=1.019\pm0.020$

$|V_{cd}|=0.223\pm0.006$

From D_s^+ leptonic decays

From D^+ leptonic decays

Comparison of $|V_{cd}|$



The most precise determination of $|V_{cd}|$ is from the BES-III

Discussions of $|V_{cd}|$ & $|V_{cs}|$

Carefully comparing these CKM matrix elements obtained by analyzing $D_{(s)}^+$ leptonic decays with these obtained by analyzing D meson semileptonic decays provide some useful information about New Physics

Effects of nonstandard leptonic decay of D_S^+ would enhance D_S^+ leptonic decay rate, resulting in a larger $|V_{cs}|$ than that obtained from D meson semileptonic decays

Accumulating Evidence for Nonstandard Leptonic Deacsy of Ds Mesons
B.A. Dobressu and A.S. Kronfeld, PRL100, 241802 (2008)

If no nonstandard leptonic decay of D^+, one would obtain the same values of $|V_{cd}|$ obtained from the D^+ leptonic decays and D semileptonic decays.

Discussions of $|V_{cd}|$ & $|V_{cs}|$

$|V_{cs}|_{CKMfiter}$ = (0.973 ± 0.001) from CKMfiter

$|V_{cs}|_{DS+\rightarrow l+\nu}$ = (1.019 ± 0.020) from $D_S^+ \rightarrow l^+\nu$

$|V_{cs}|_{DS+\rightarrow l+\nu}$ is ~2.5σ larger than $|V_{cs}|_{CKMfiter.}$ Does this indicate New Physics effects?

$|V_{cd}|_{CKMfiter}$ = (0.225 ± 0.001) from CKMfiter

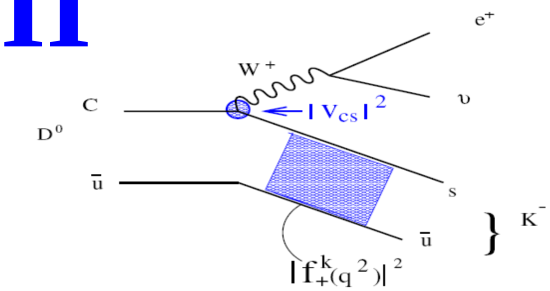
$|V_{cd}|_{D+\rightarrow l+\nu}$ = (0.223 ± 0.006) from $D^+ \rightarrow \mu^+\nu$

$|V_{cd}|_{D+\rightarrow l+\nu}$ is consistent within error with $|V_{cd}|_{CKMfiter.}$

We need to examine D semileptonic decays to measure $|V_{cd}|$ & $|V_{cs}|$ as well.

$|V_{cd(s)}|$ from D semileptonic decays at BES-III

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 |\vec{p}_{K(\pi)}|^2 |f_+^{K(\pi)}(q^2)|^2$$

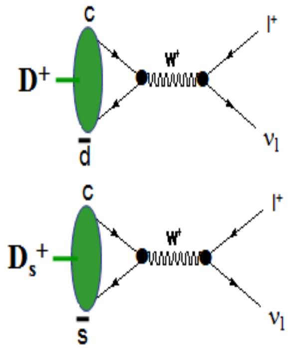


The BES-III can also determine $|V_{cs}|$ and $|V_{cd}|$ from D^0 semileptonic decays. These results will come out soon.

In BES-III Collaboration, two analysis working groups (IHEP and CMU) have been working on extracting $|V_{cs}|$ and $|V_{cd}|$ (see C.L. Liu's talk), as well as some other physical quantities related to these D meson semileptonic decays.

These would be other important results for precise test of the SM and searching for NP.

Summary



- More than 25 years studies of D leptonic decays, over 530 $D^+ \to \mu^+\nu$ events have been accumulated. We begin to precisely study hadronic vertex and test LQCD

- BES-III is the most precise results for these to date:

$$\begin{cases} Br(D^+ \to \mu^+\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4} \\ f_{D+} = (203.91 \pm 5.72 \pm 1.97)\,\text{MeV} \\ V_{cd} = (0.222 \pm 0.006 \pm 0.005) \end{cases}$$

- The world average of decay constants:

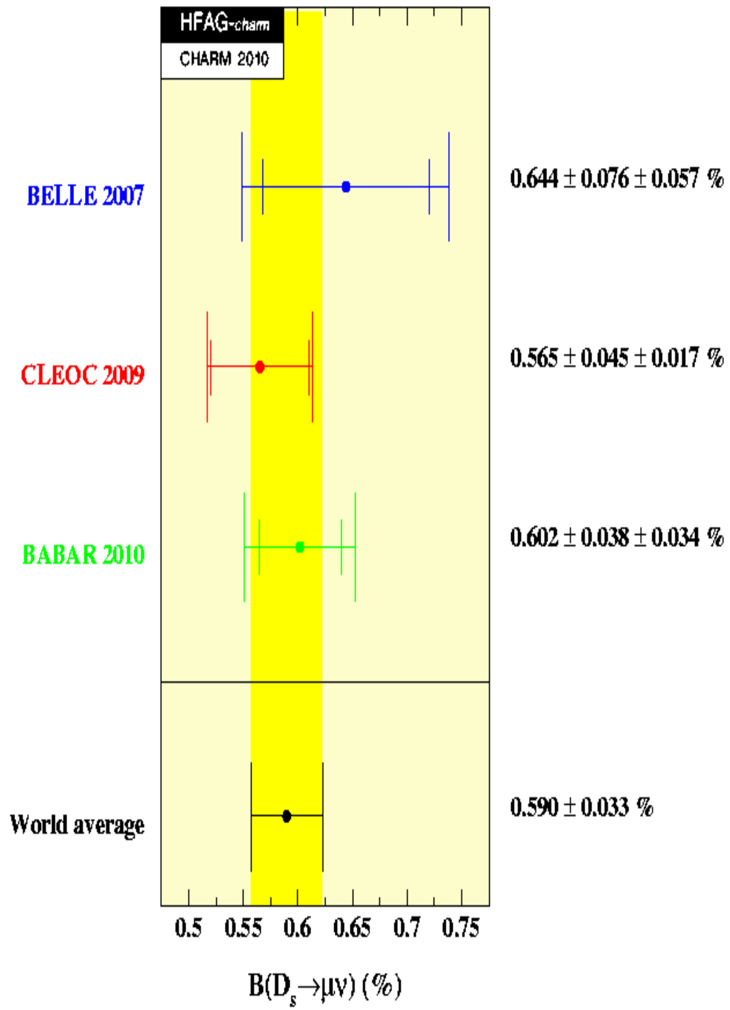
$$f_D = (204.5 \pm 5.0)\ \text{MeV}, \quad f_{Ds} = (259.1 \pm 5.1)\ \text{MeV}$$

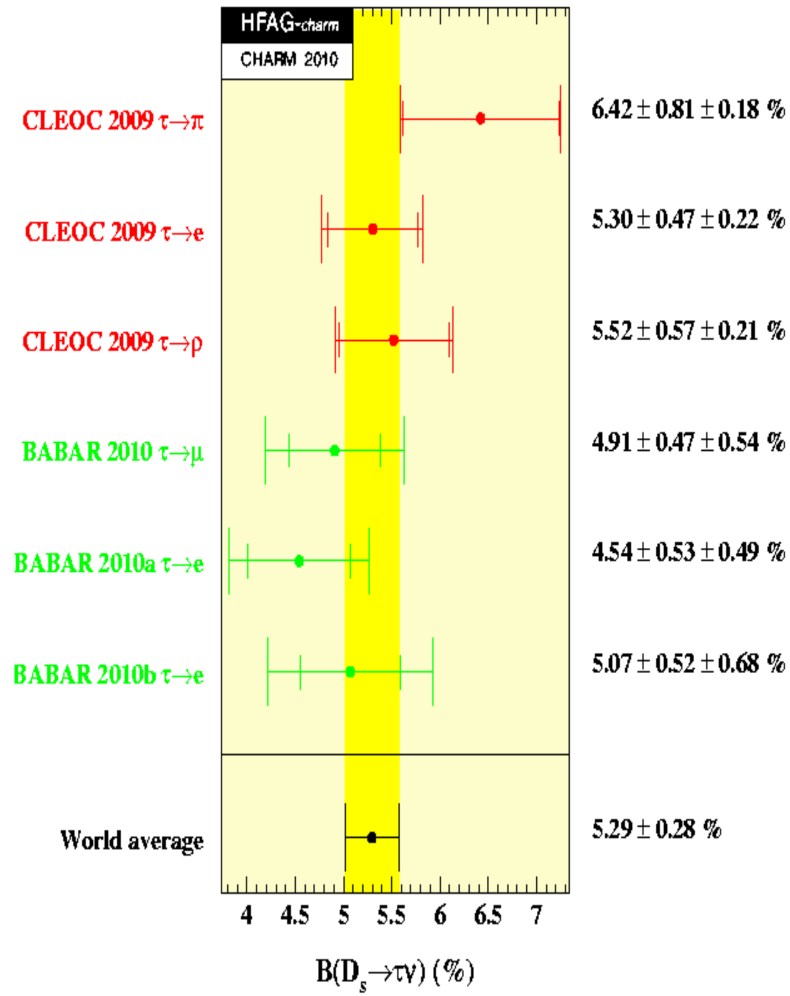
- World average f_{Ds}/f_D is 1.267 ± 0.040, which is ~2.7σ larger than $f_{Ds}/f_D = 1.156 \pm 0.008$ predicted by theories based on QCD

- Charm decay constants f_D and f_{Ds} can test LQCD, verified LQCD help extract $|V_{td}|$ and $|V_{ts}|$ from $B_{(s)}B_{(s)}$ mixing experiments. These help more precisely test SM and search for New Physics. Charm do play an important role in test of SM of particle physics.

The end!

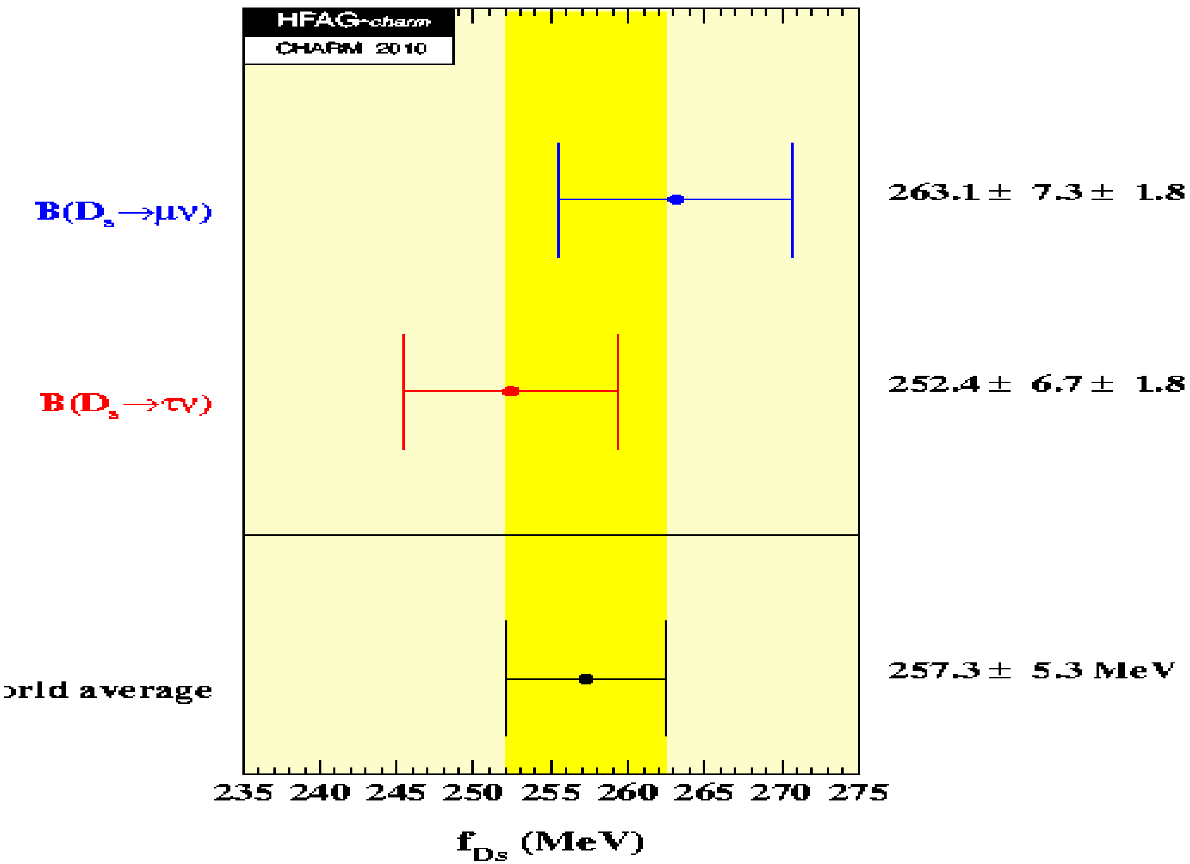
Summary for $B(Ds^+ \rightarrow l^+ \nu)$





These are taken from HFAG web page

Summary for f_{Ds+}



The World Average is: f_{Ds} = (257.3 ± 5.3) MeV

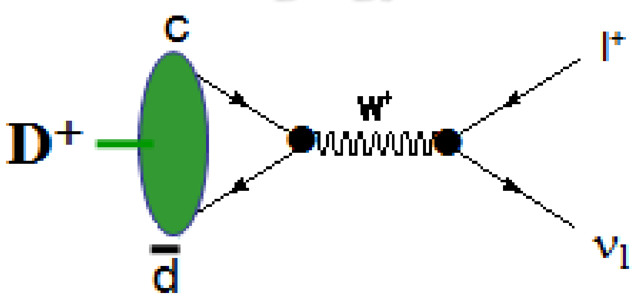
This plot is taken from HFAG web page

Decay rates & $f_{D(Ds)}$

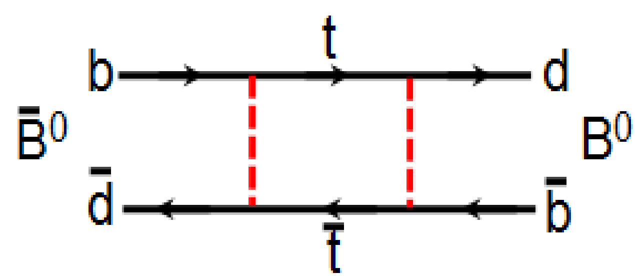
- **Measurements of branching fractions probe the hadronic vertex**

$$\Gamma_{\mathrm{SM}}(D_{(s)}^{+} \to l^{+}\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 \; f_{D_{(s)}^{+}}$$

  - **Non-perturbative QCD effects are absorbed into $f_{D(Ds)}$, $f_{D(Ds)}$ can be calculated or measured**
  - **Measurements of $f_{D(Ds)}$ provide critical test of theory to calculate f_B, f_{Bs}**

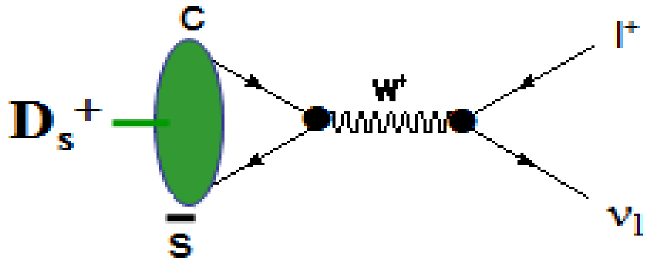


Measured f_{D+} tests LQCD f_{D+} ➔ better calculated f_{B+}

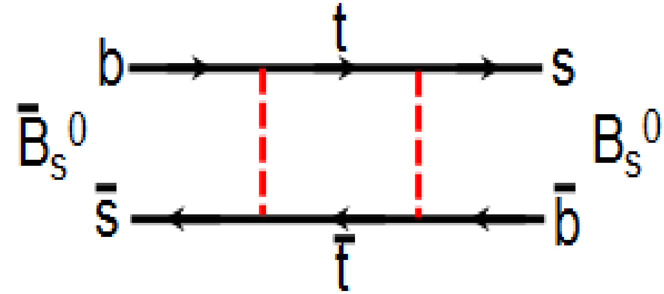


Improve determination of |V_{td}| from B^0B^0 mixing experiment, needing f_{B+} as input

Decay rates & $f_{D(Ds)}$



Similarly, measured f_{Ds+} tests LQCD calculated f_{Ds+} ➔ better calculated f_{Bs+}



Improve determination of $|V_{ts}|$ from Bs^0Bs^0 mixing experiment, needing f_{Bs+} as input

Two decay constants ($f_{D(Ds)}$ ➔ $f_{B(Bs)}$) affect

- $|V_{ub}|$ extracted from $B^+ \to l^+ v$
- $|V_{td}|$ extracted from Δm_d in B^0B^0 mixing
- $|V_{ts}|$ extracted from Δm_s in $B_s^0B_s^0$ mixing

These are used to constraint the unitary triangle

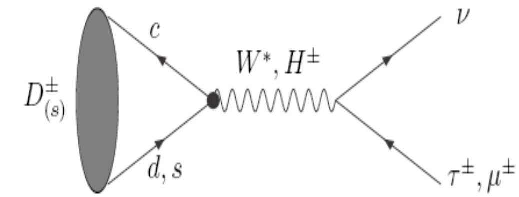
➢ **Two decay branching fractions determine**

- $|V_{cd}|$ extracted from $D^+ \to l^+ v$
- $|V_{cs}|$ extracted from $D_s^+ \to l^+ v$

➢ New Physics in $D_{(s)}^+$ leptonic decays

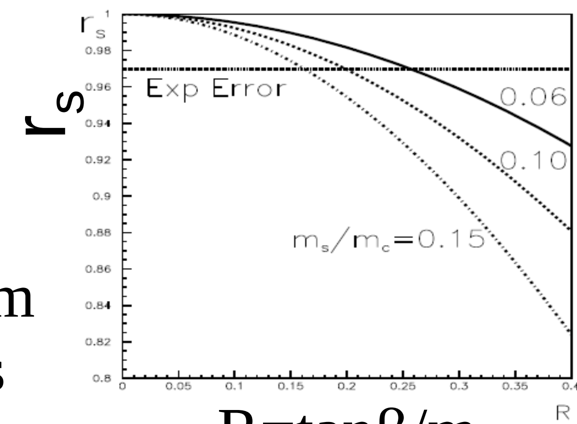
J.L. Hewett, hep-ph/9505246;
A.G. Akeroyd, hep-ph/0308260

Interference between $W^{\pm}$ and $H^{\pm}$ suppresses $D_s^+ \to l^+\nu$, but it does not suppressed $D^+ \to l^+\nu$



$$\Gamma(D_{(s)}^+ \to l^+\nu) = \Gamma_{SM}(D_{(s)}^+ \to l^+\nu)\,r_s$$

$$r_s = \left[1 - m_{D_{(s)}^+}^2 R^2 \left(\frac{m_{d(s)}}{m_{d(s)} + m_c}\right)\right]^2$$



R=tanβ/m_H

R=tanβ/m_{H}, where tanβ is the ratio of vacuum expectation values of the two Higgs doublets

➢ If tanβ is large, it is possible to observe deviation from lepton universality in these decays

Wei-Shu Hou, PRD48, 2342(1993)

$$\frac{\Gamma(D_{(s)}^+ \to \tau^+\nu)}{\Gamma(D_{(s)}^+ \to \mu^+\nu)} = \frac{m_{\tau^+}^2 (1 - m_{\tau^+}^2 / m_{D_{(s)}}^2)^2}{m_{\mu^+}^2 (1 - m_{\mu^+}^2 / m_{D_{(s)}}^2)^2}$$

Ratio expected to be 2.67 (9.76) from SM