Results on $D_{(s)}$ Pure-Leptonic Decays from experiments near DD threshold

L. L. Jiang

(For BESIII Collaboration)

Institute of High Energy Physics, Beijing

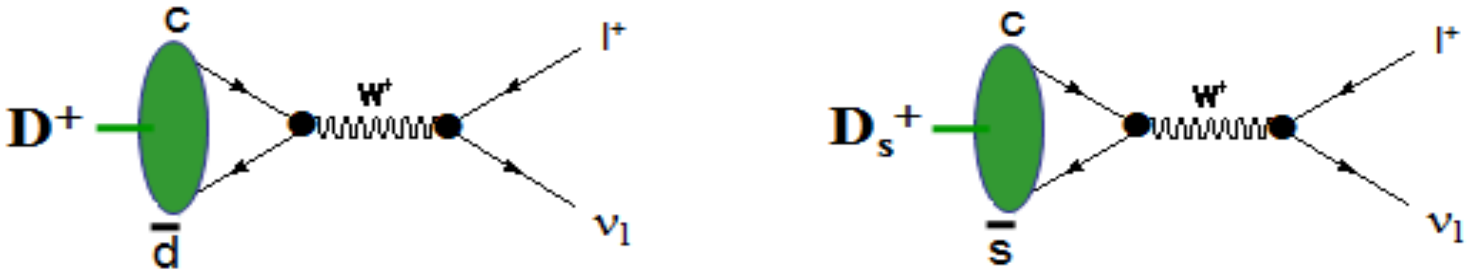
7th International Workshop on the CKM Unitarity Triangle, Cincinnati, Ohio, USA Sep. 28-Oct. 2, 2012

Outline

- Introduction
- D^+ leptonic decays
- D_S^+ leptonic decays
- Summary

Introduction

Leptonic decays of $D_{(S)}^+$ play an important role in understanding of the SM of particle physics.



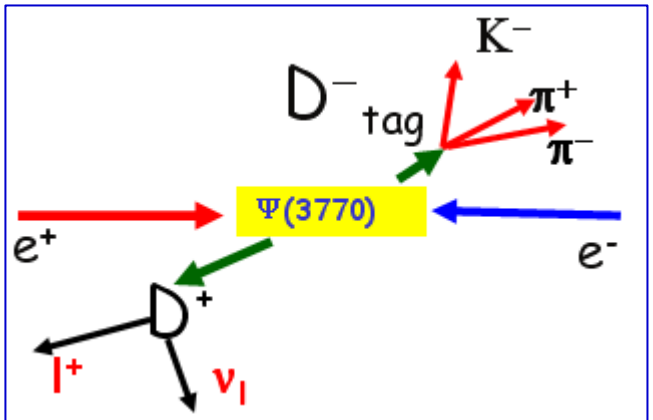
$$B(D_{(s)}^+ \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 \tau_{D_{(s)}^+} |V_{cd(s)}|^2 f_{D_{(s)}^+}$$

f_D can be calculated or measured and measurements of f_D provide critical test of theory to calculate f_B, f_{Bs}

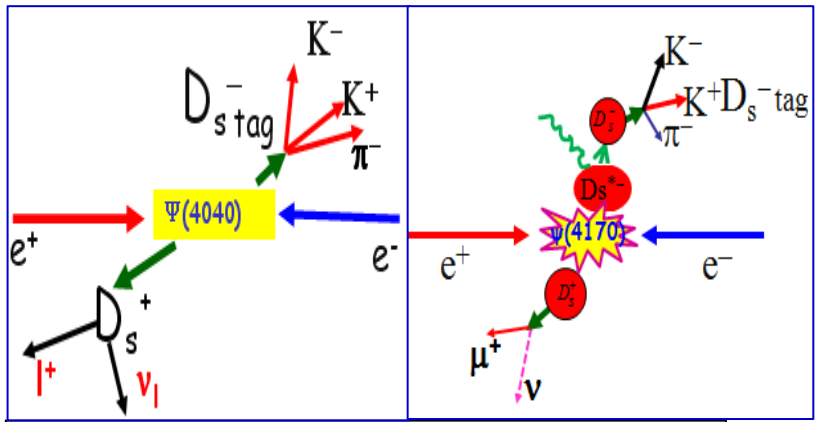
Improve determination of $|V_{td}|$, $|V_{ts}|$ from B^0B^0, Bs^0Bs^0 mixing experiment needing f_{B+}, f_{Bs+} as input.

Experiments near threshold

Taking the advantage of the $D^+D^-(D_s^+D_s^-)$ production, one can absolutely measure the branching fraction for $D_{(s)}^+ \rightarrow l^+\nu$



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



BES-I, CLEO-c and BES-III

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

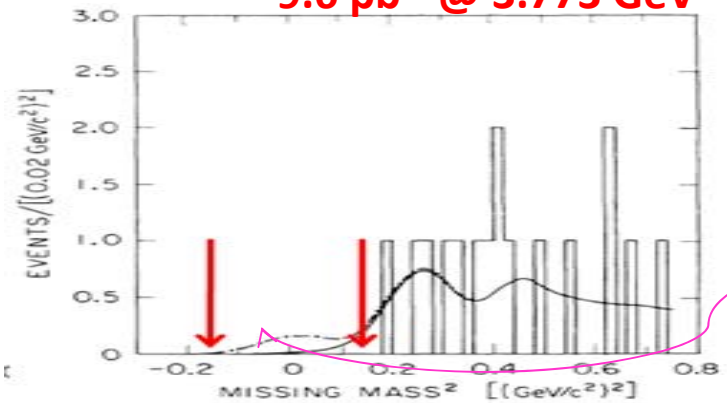
$$M^2_{\rm miss} = (E_{\rm beam} - E_{\mu^+})^2 - (-\vec{p}_{D^-_{tag}} - \vec{p}_{\mu})^2$$

D^+ leptonic decays

In 1988, MARK-III first searched for the decay of $D^+ \to \mu^+ \nu_\mu$.

MARK-III

9.6 pb^{-1} @ 3.773 GeV



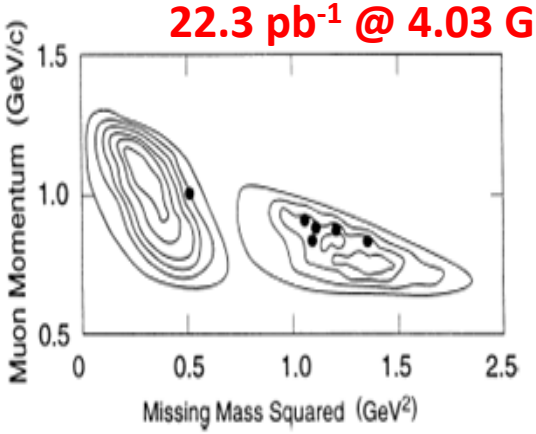
No signal event was found

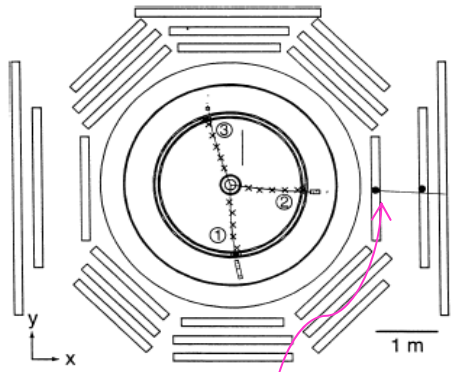
PRL60, 1375(1988)

MARK-III did not observe signal for this decay, they set an upper limit on decay constant f_{D^+}<290 MeV

BES-I

22.3 pb^{-1} @ 4.03 GeV





PLB429, 188 (1998)

$$N^{PRD}_{D^+} = 10082$$

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

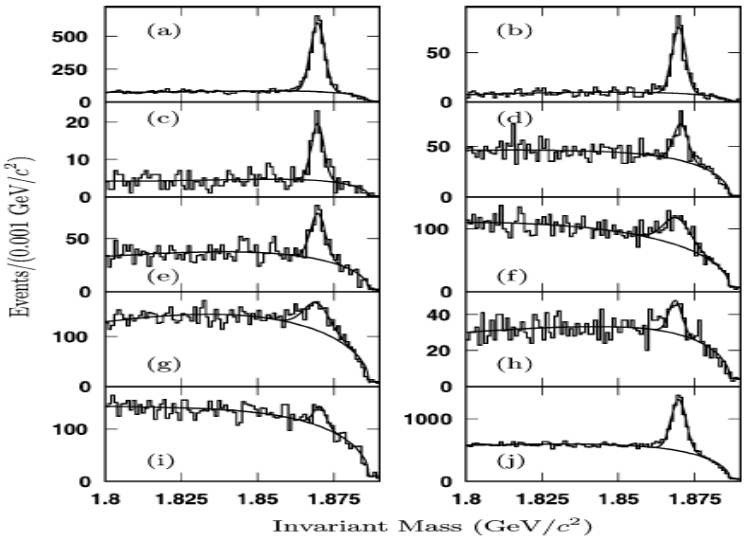
$$B(D^+ \to \mu^+ \nu) = (0.08^{+0.16+0.05}_{-0.05-0.02})\%$$

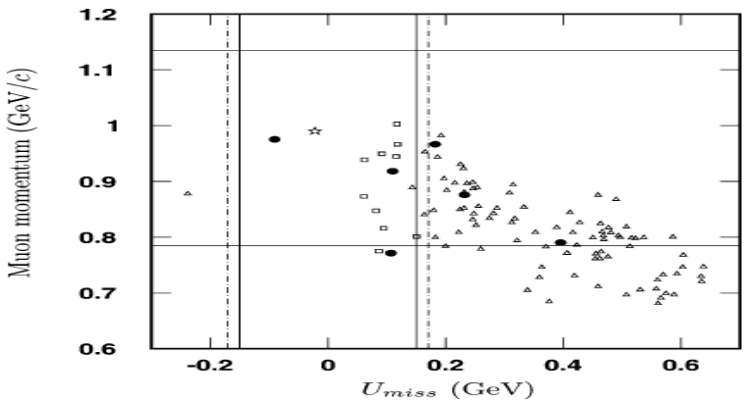
$$f_{D^+} = (300^{+180+80}_{-150-40})\ \text{MeV}$$

One signal event observed

D^+ leptonic decays @ BES-II

33 pb^{-1} @ 3.773 GeV





PLB610, 183 (2005)

9 single tag modes

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

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

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

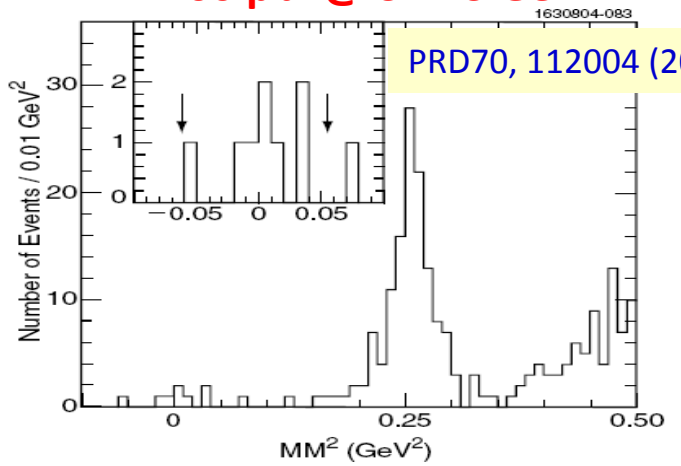
$$f_{D^+} = (371^{+129}_{-119} \pm 25)\ \text{MeV}$$

The results were first reported at '04 Electroweak Interactions & Unified Theories

D^+ leptonic decays @ CLEO-c

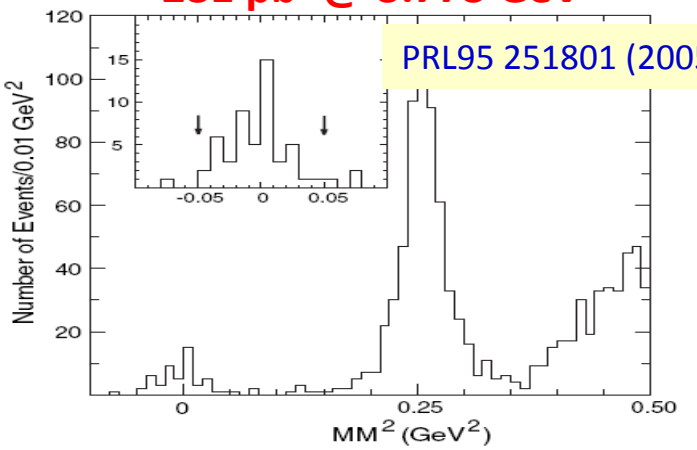
60 pb^{-1}@ 3.773 GeV

PRD70, 112004 (2004)



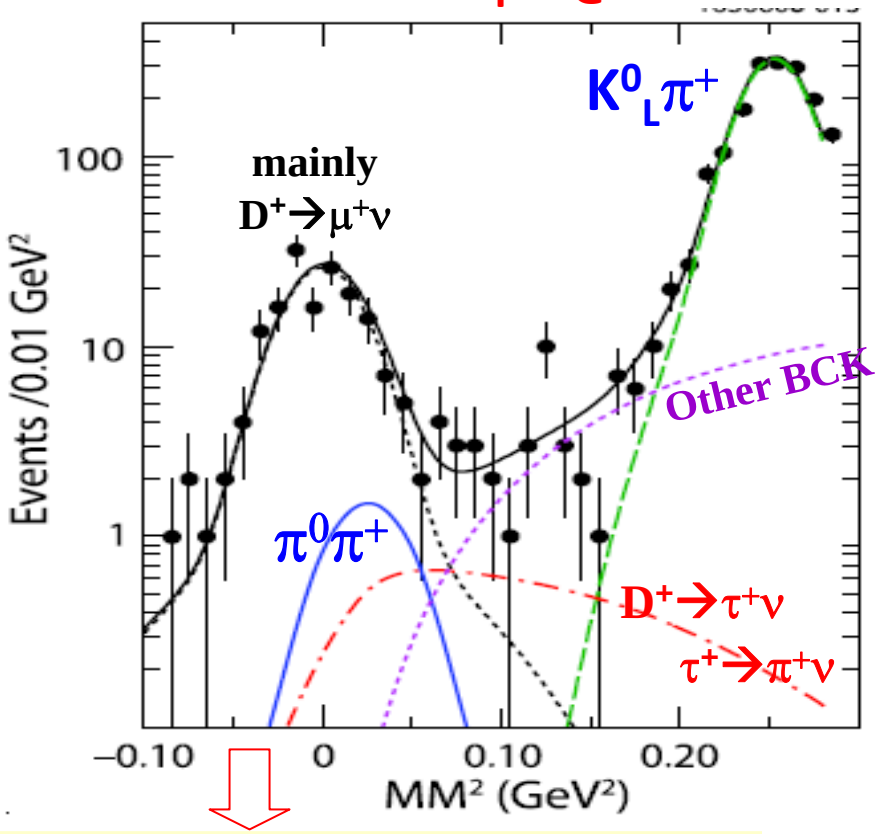
281 pb^{-1}@ 3.773 GeV

PRL95 251801 (2005)



PRD78, 052003(2008)

818 pb^{-1}@ 3.773 GeV



Supersed the previous results

D^+ leptonic decays @ CLEO-c

PRD78, 052003(2008)

Results:

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

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

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

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

Other background events : 2.4 ± 1.0

37.4 background Events

$$Br(D^+ \to \mu^+\nu) = (0.0382 \pm 0.0032 \pm 0.0009)\%$$
$$f_{D^+} = (205.8 \pm 8.5 \pm 2.5)\ \text{MeV}$$

Without fixing the backgroun number from $D^+ \to \tau^+\nu_\tau$

$$Br(D^+ \to \mu^+\nu) = (0.0393 \pm 0.0035 \pm 0.0009)\%$$
$$f_{D^+} = (207.6 \pm 9.3 \pm 2.5)\ \text{MeV}$$

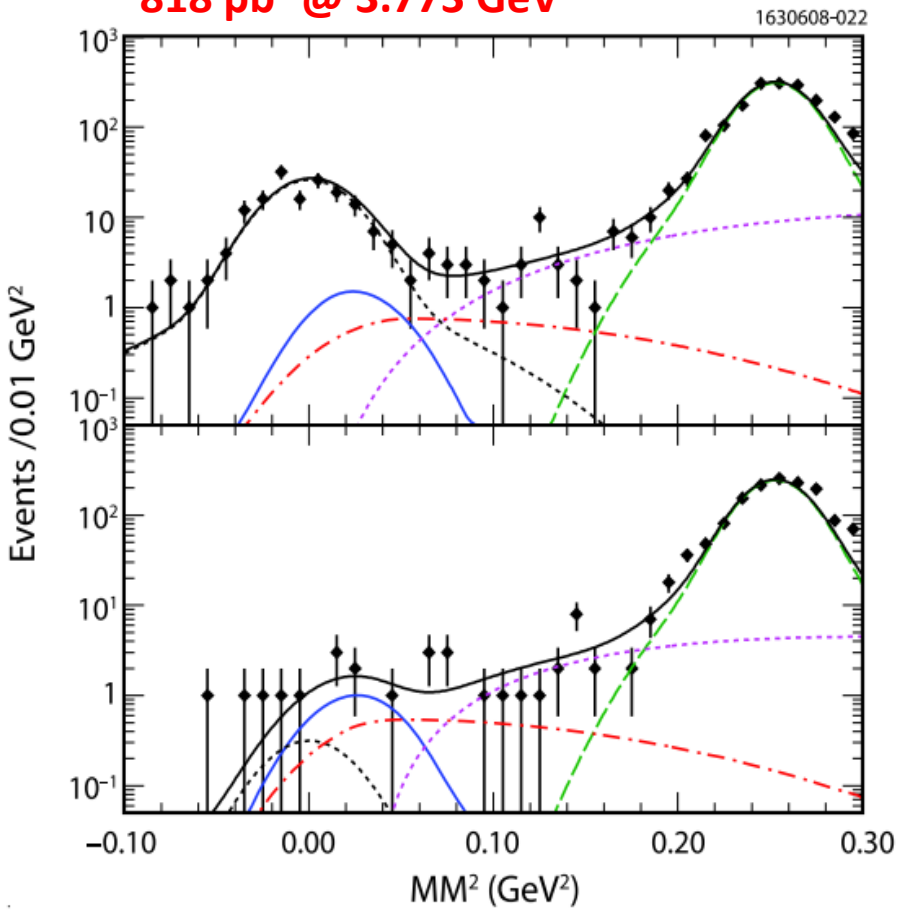
More reliable*

***For detail, see arXiv:1209.0085v1[hep-ex]**

D^+ leptonic decays @ CLEO-c

PRD78, 052003(2008)

818 pb^{-1}@ 3.773 GeV



$$N_{D^-_{tag}} = 460055 \pm 787$$

$$N_{D^+ \to \tau^+ \nu} = 27.8 \pm 16.4$$

$$Br(D^+ \to \tau^+ \upsilon_\tau) < 1.2 \times 10^{-3}$$

$$Br(D^+ \to e^+ \upsilon_e) < 8.8 \times 10^{-6}$$

D^+ leptonic decays @BES-III

The selected single tag channels:

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

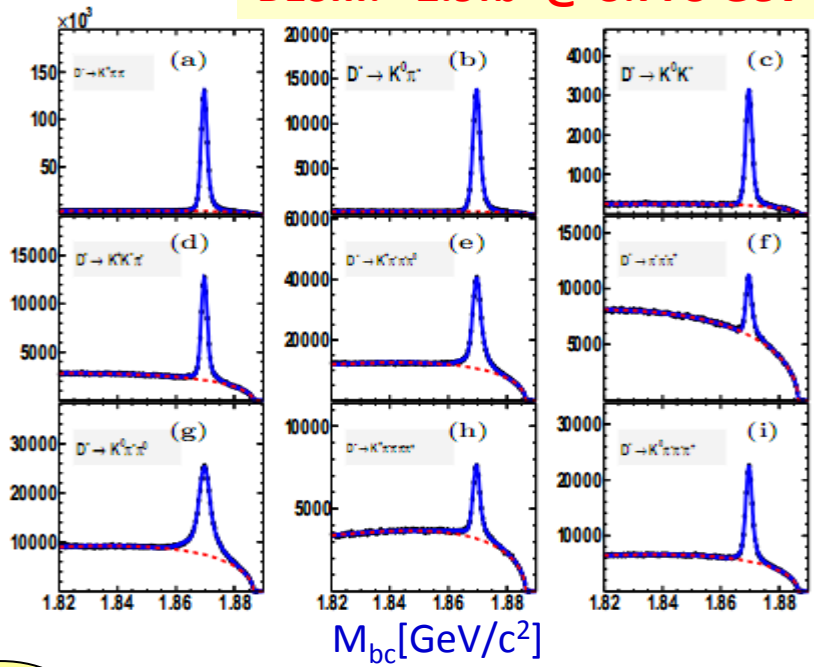
$D^- \to K^0\pi^-$ $\quad D^- \to \pi^-\pi^-\pi^+$

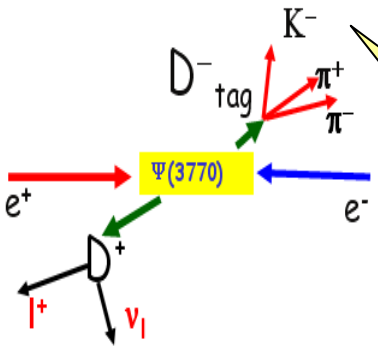
$D^- \to K^0K^-$ $\quad D^- \to K^0\pi^-\pi^0$

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

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

BESIII: ~2.9fb^{-1}@ 3.773 GeV



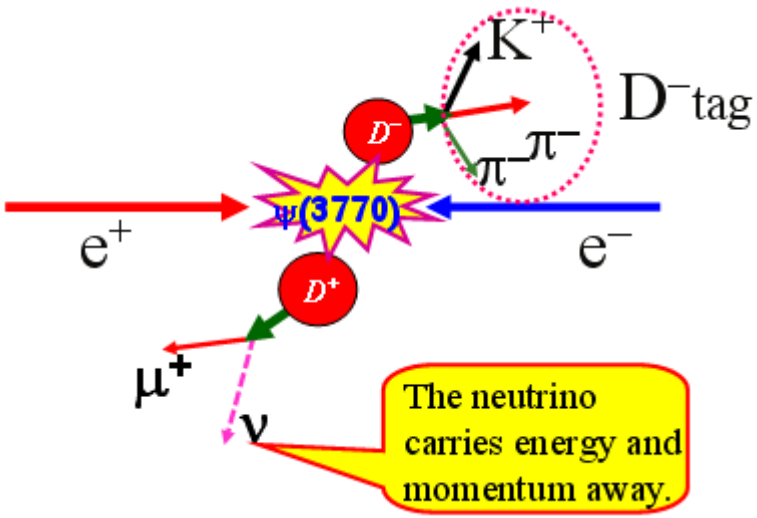


9 singly tagged D⁻ modes are used to accummulate the D⁺D⁻ events

$$N_{D^-_{tag}} = 1565953 \pm 2327$$

Selection of $D^+ \to \mu^+\nu$ @BES-III

In the side recoiling against the singly tagged D^-, BES-III select the purely leptonic decay events for $D^+ \to \mu^+\nu$



they require:

One identified charged μ^+

No isolated photon

$$E_{\text{miss}} = E_{\text{cms}} - \sum_i E_i$$

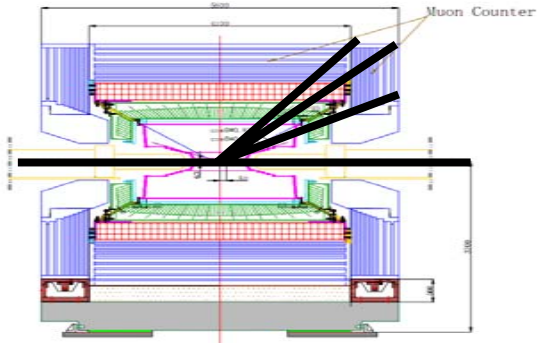
$$\vec{p}_{\text{miss}} = -\sum_i \vec{p}_i$$

$$M^2_{miss} = E^2_{miss} - P^2_{miss}$$

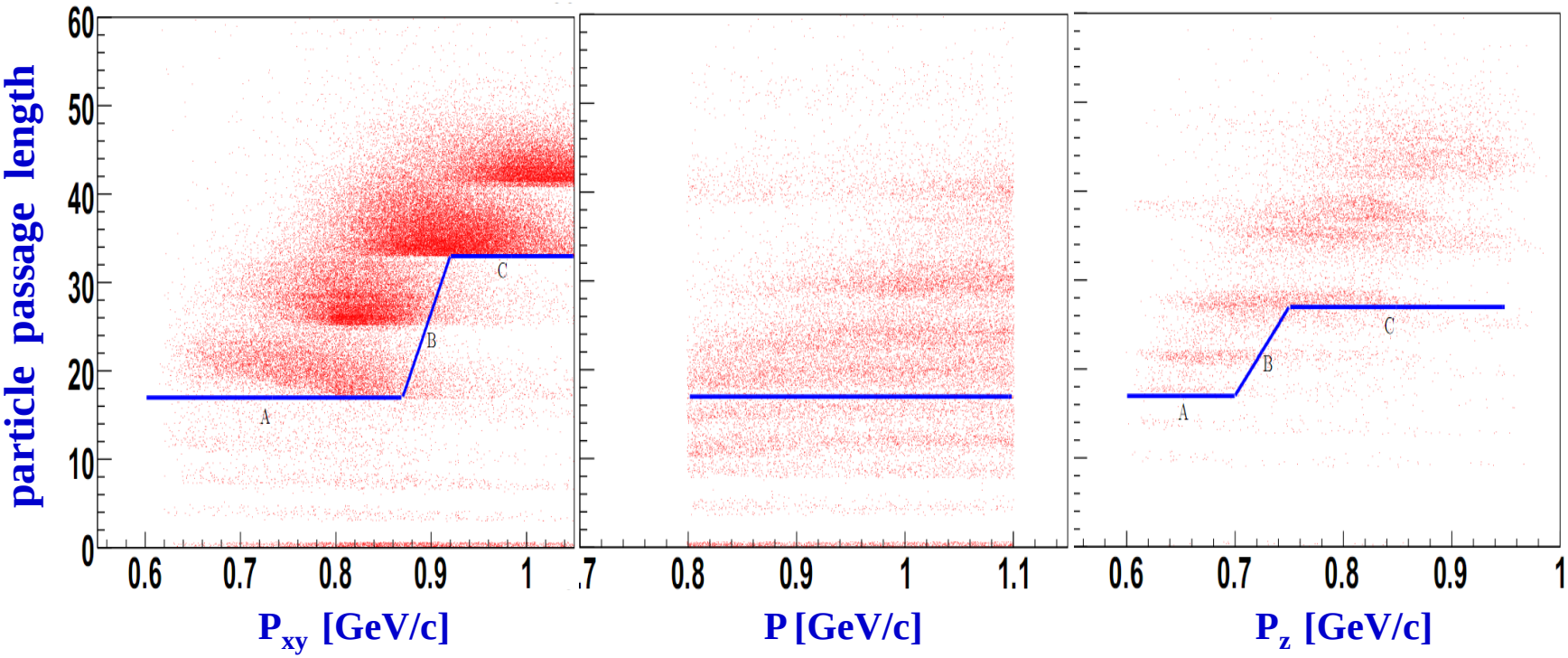
The expected value of M^2_{miss} for the events of the singly tagged D^- v.s. $D^+ \to \mu^+\nu$ should be ~0

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

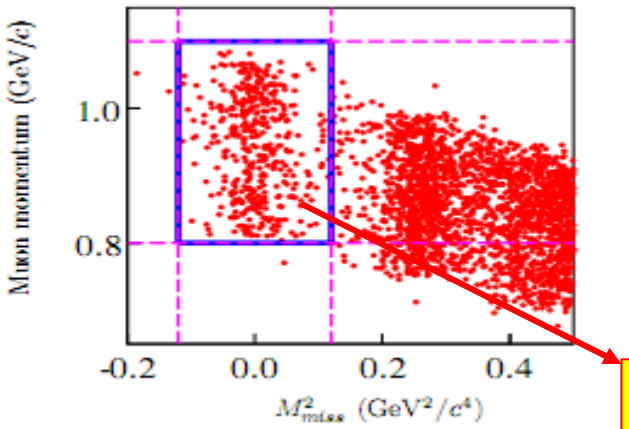
Muon can be well identified with the passage length of a particle going through the MUC at the BES-III experiment

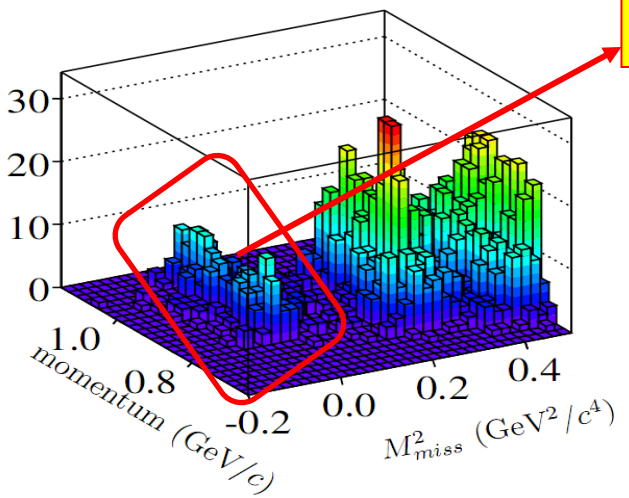


Particle passage length in MUC VS momentum



Selection of $D^+ \to \mu^+\nu$ @BES-III





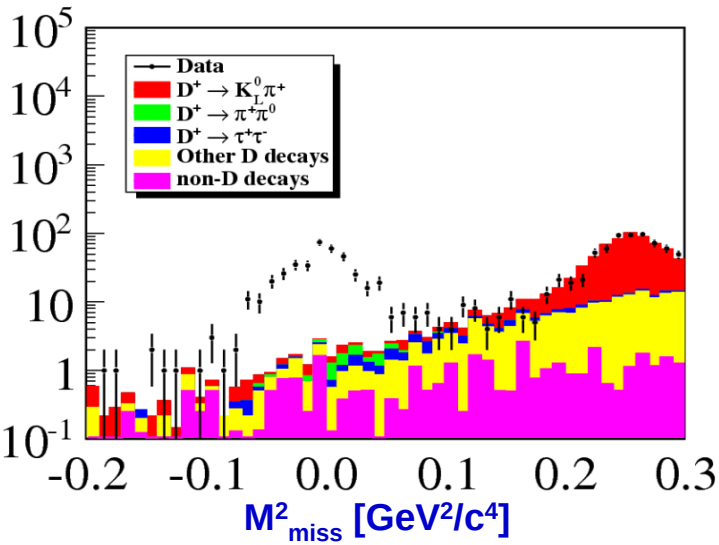
425 Candidates for $D^+ \to \mu^+\nu$

The remained bg are estimated by MC simulation.

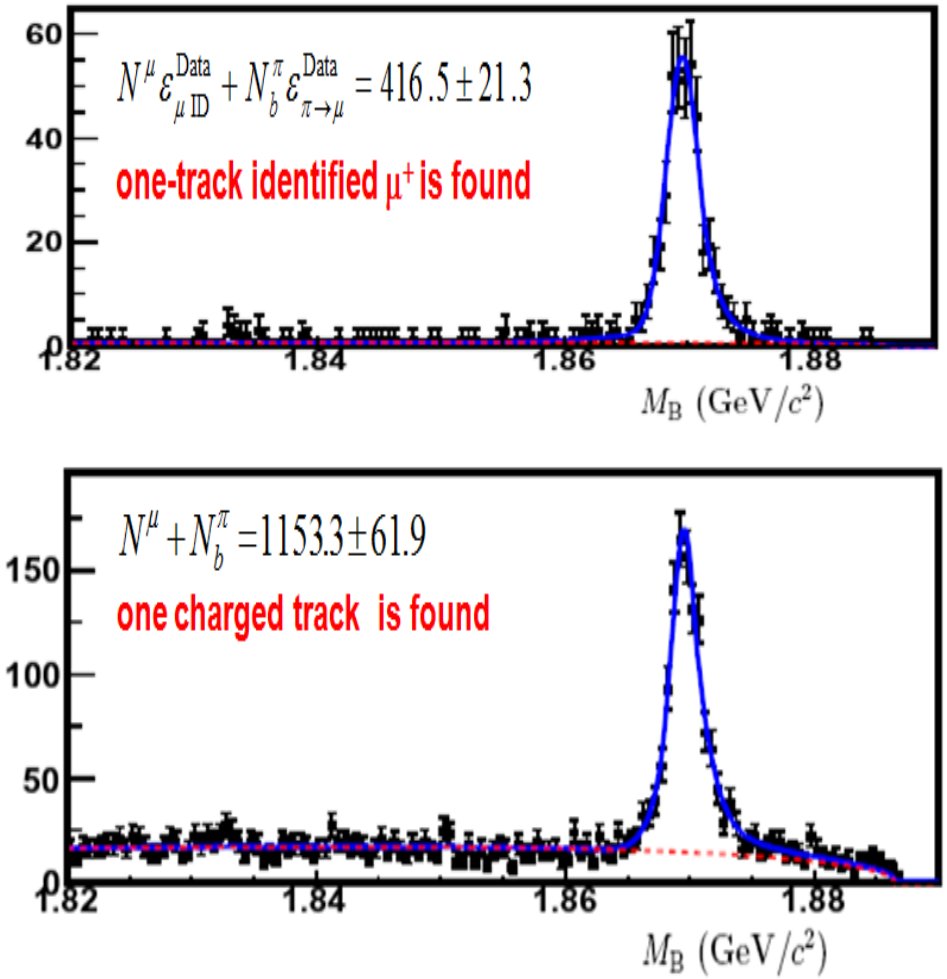
The remained bg are estimated by MC simulation.

Estimated with Monte Carlo

Source mode	Number of events
$D^+ \to K^0_L\pi^+$	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 are 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.

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

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

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

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

Based on the observed number of $D^+ \to \mu^+\nu_\mu$, the branching fraction is measured to be

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

Which is related to f_{D+} and V_{cd} by

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

f_{D+} = (203.91±5.72±1.97) MeV (**$|V_{cd}|=|V_{us}|$=0.2252±0.0007**)

$|V_{cd}|$ = 0.2249±0.0060±0.0044 (**f_{D+} = 207±4 MeV (from LQCD)**

Those results were first reported at Charm2012.

Average of Br. & f_D

Experiment	$B(D^+ \to \mu^+ \nu_\mu)$ $(\times 10^{-4})$	Average
CLEO-c	$(3.93 \pm 0.35 \pm 0.09)$*	(3.79 ± 0.19)
BES-III(PRLMNRY)	$(3.74 \pm 0.21 \pm 0.06)$	

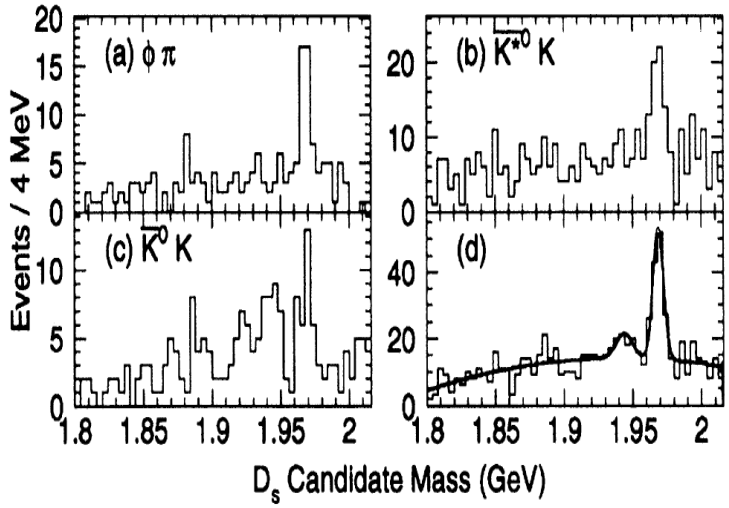
Experiment	f_D (MeV)	Average
CLEO-c	$(207.6 \pm 9.3 \pm 2.5)$	(205.3 ± 5.1)
BES-III(PRLMNRY)	$(203.91 \pm 5.72 \pm 1.97)$	

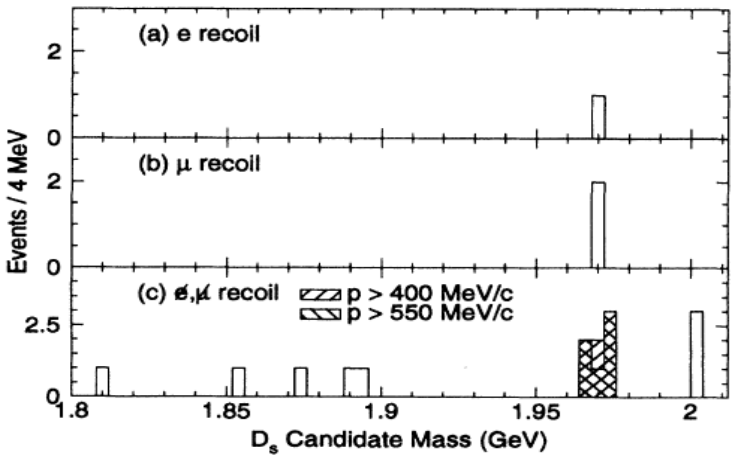
At present, the error is still dominated by statistics, needing more data to be taken at 3.773 GeV to reduce the error.

*For detail, see arXiv:1209.0085v1[hep-ex]

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

22.3 pb^{-1} @4.03 GeV





PRL74, 4599 (1995)

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

3 singly tagged Ds^- modes

94 singly tagged Ds^-

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

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

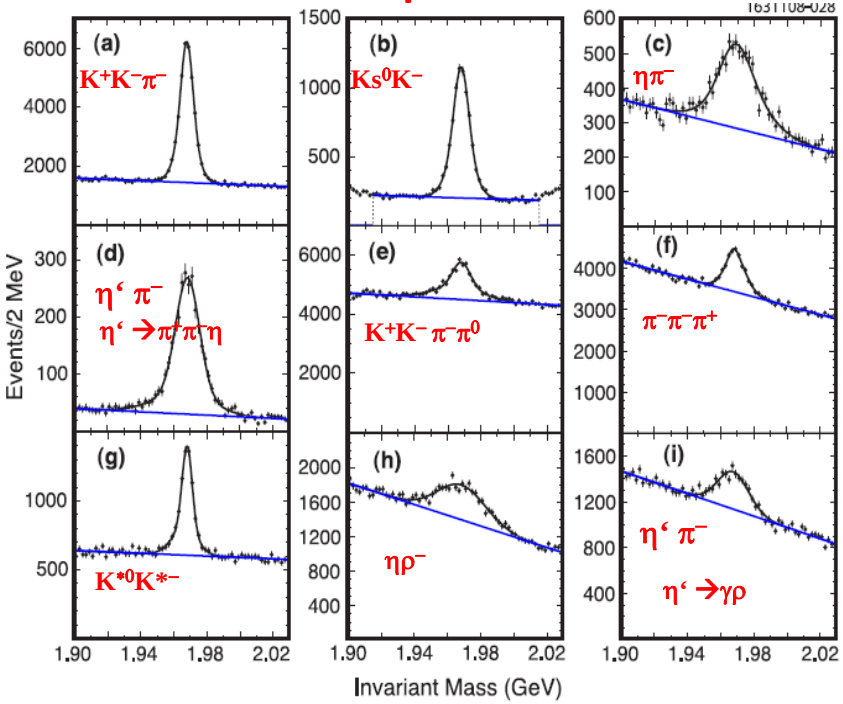
$$f_{D_S^+} = 430\ ^{+150\ +40}_{-130\ -0.40}\ \text{MeV}$$

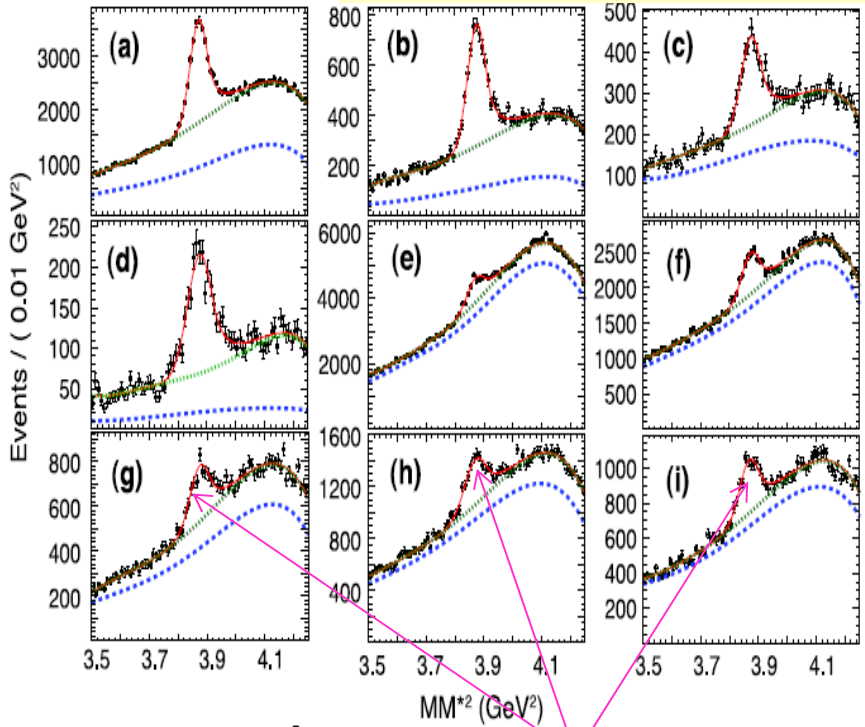
It was the first absolute measurement.

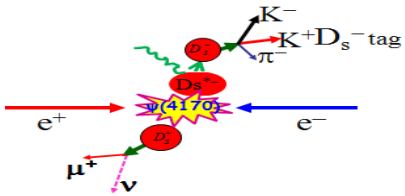
$Ds^+ \rightarrow l^+\nu$ at CLEO-c

600 pb^{-1} @ 4.170 GeV

PRD79, 052001 (2009)







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

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

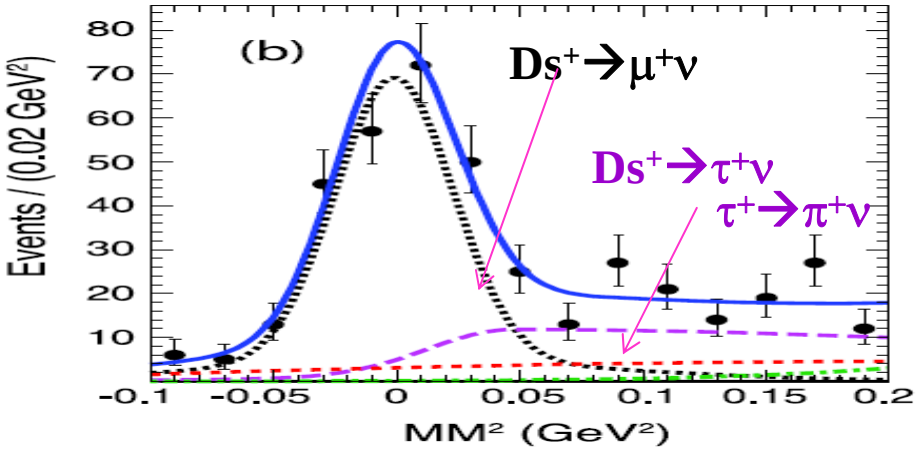
MM^{*2} is the missing mass-squared recoiling against the γDs^-

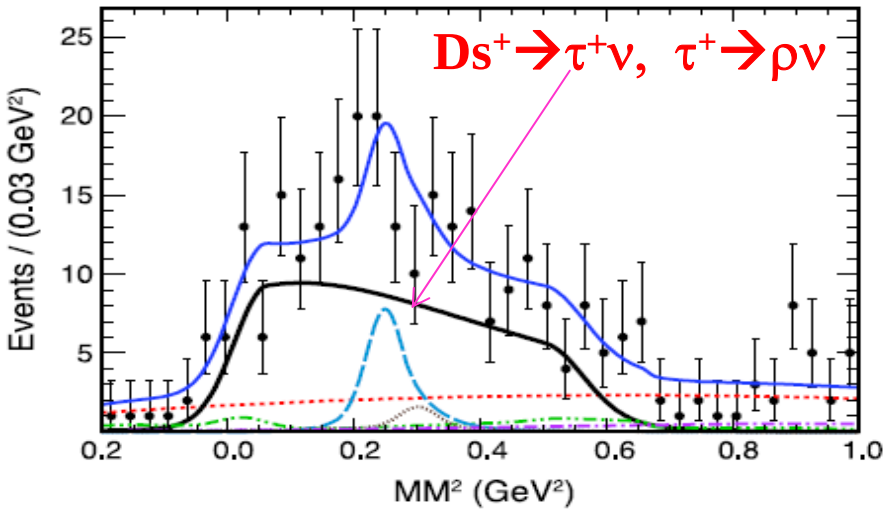
These peaks indicate that the Ds*- are well reconstructed

N_{tag} = 43859±436

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

600 pb-1 @4.17GeV





PRD79, 052001 (2009)

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

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

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

PRD80, 112004 (2009)

$$B(D_s^+ \rightarrow \tau^+\nu) = (5.52 \pm 0.57 \pm 0.21)\%$$

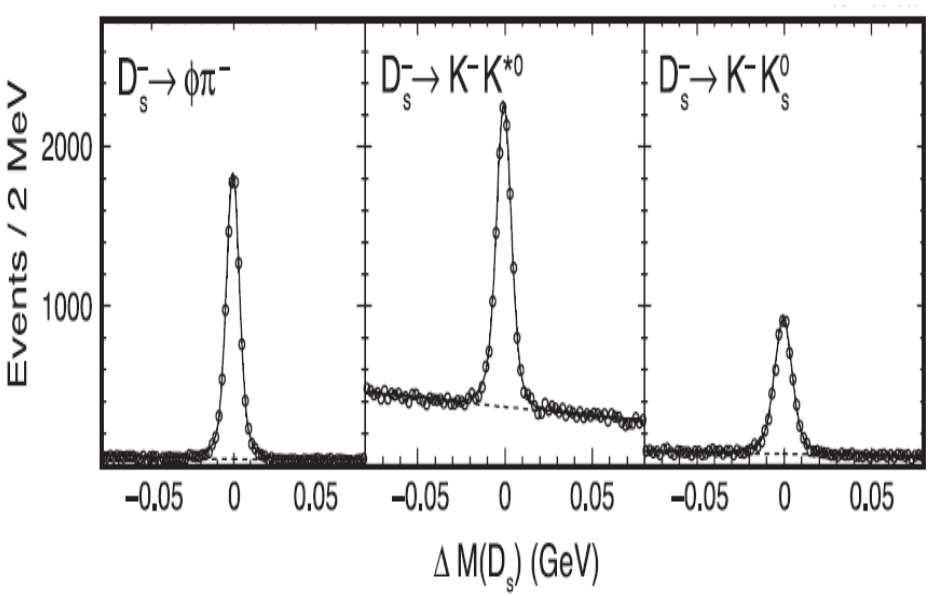
$$f_{D_s^+} = 257.8 \pm 13.3 \pm 5.2 \text{ MeV}$$

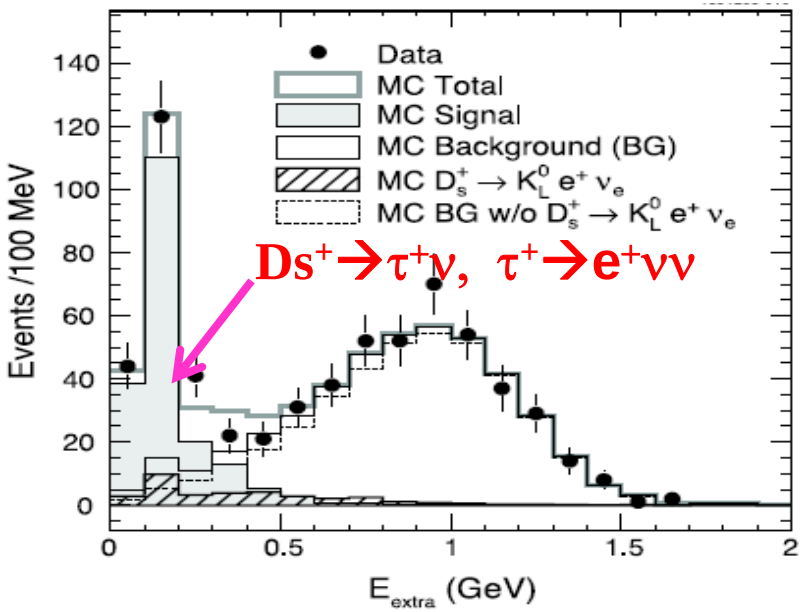
Absolute measurement.

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

600 pb-1 @4.17GeV

PRD79, 052002 (2009)





Three cleanest single tag Ds mode were used

Tag mode	n_{ST}^S	n_{ST}^B	s	n_{ST}
$D_s^- \rightarrow \phi\pi^-$	10459	807	0.980	9668.1 ± 106.1
$D_s^- \rightarrow K^-K^{*0}$	18319	7381	1.000	10938.0 ± 160.3
$D_s^- \rightarrow K^-K_S^0$	7135	1409	0.999	5727.8 ± 92.4
Total				26333.9 ± 213.3

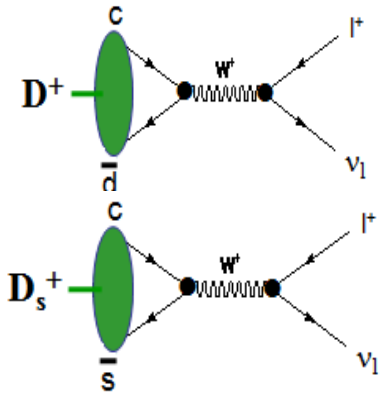
E_{extra} is the total energy of rest of the event measured in the electromagnetic calorimeter

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

Absolute measurement.

Summary and Future Perspective

- MARK-III, BES-I, BES-II, CLEO-c and BES-III have measured the $f_{D(s)}$.
- The best precise measurement from BES-III:



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

$$f_{D^+} = (203.91 \pm 5.72 \pm 1.97)\ \text{MeV}$$

$$|V_{cd}| = (0.222 \pm 0.006 \pm 0.005)$$

- Experimental value of f_D is with precision of 2.5%. More data is needed.
- **In future,**
  - The results of pure-leptonic decay for $D^+ \to \tau^+ \nu_\tau$ and $D^+ \to e^+ \nu_e$ will be presented with the largest $\psi(3770)$ data in the world.
  - The results of pure-leptonic decay for $D_s^+ \to \mu^+ \nu_\mu$ and $D^+ \to \tau^+ \nu_\tau$ will be presented with the data taken with BESIII @ 4.01 GeV .

The end!