D Leptonic Decays near Production Threshold

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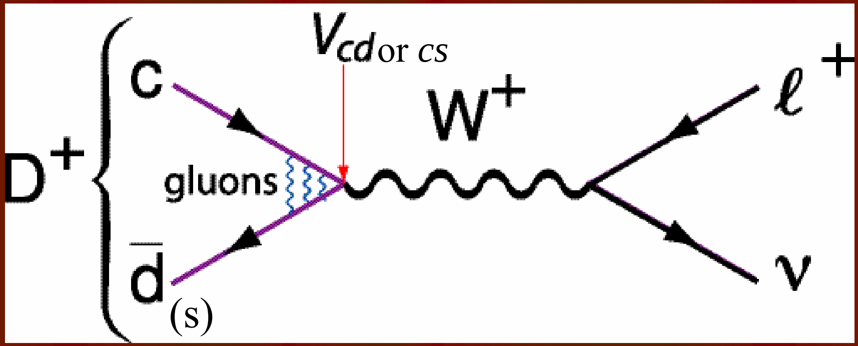
(on behalf of the CLEO Collaboration)

Introduction: $D \to \ell^+ \nu$



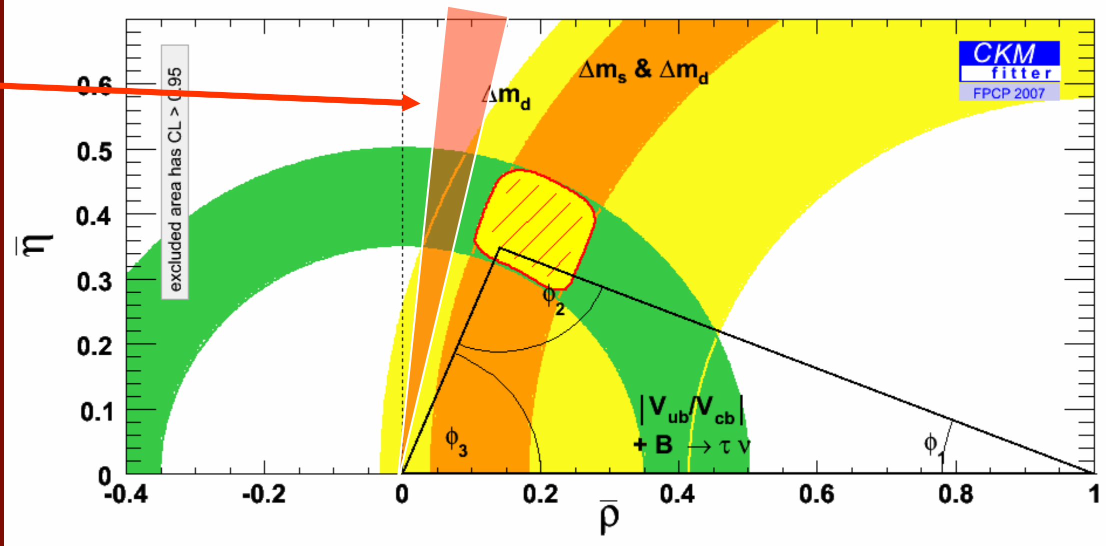
- Partial width measurement probes the hadronic vertex
  - Soft-gluon effects → Non-perturbative QCD
  - Decay constant, f_D describes the hadronic vertex, and is proportional to the wave-function overlap (Prob $\propto$ $c\bar{d}(\bar{s}) \to W$ annihilation)
- General solution (SM) for partial width

$$\Gamma(P^+ \to \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} known

Leptonic Decays in SM

- Measurement provides critical test of theory to compute f_B, f_{Bs}.
- In a few years, we will have a precision measurement (~5°) of $\gamma(\phi_3)$ by LHC*b*.
  - Expect $\sigma(\gamma)$~5° with 2 fb^{-1}
- Could provide signs of NP if γ measurement doesn't coincide with $\Delta m_{(s,d)}$ band.
- $B \to \tau^+ \nu$ gives $V_{ub} f_B$, but hard to measure directly.

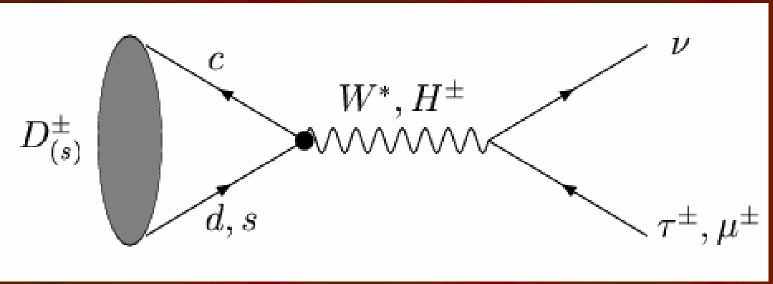


Constraints from V_{ub}, Δm_d, Δm_s & $B \to \tau^+ \nu$

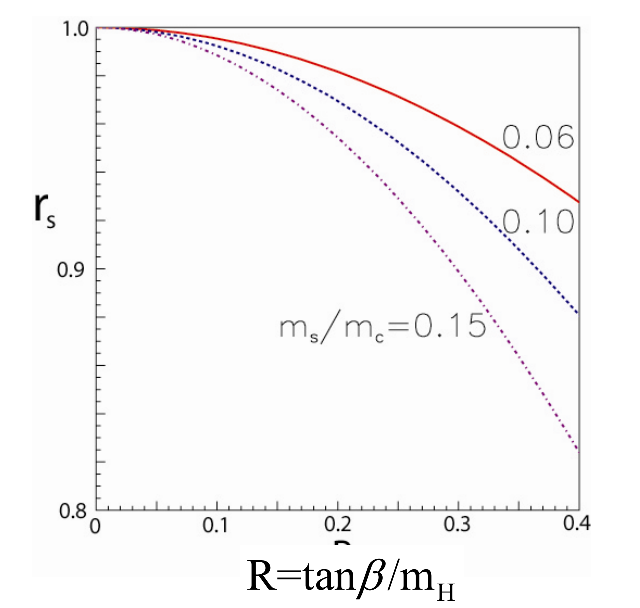
New Physics in $D_{(s)}$ leptonic decays

- Interference between $H^\pm$ and $W^\pm$ suppresses $D_s \to \ell\nu$, but NOT $D \to \ell\nu$

  Akeroyd, hep-ph/0308260



$$r_{(s)} = \frac{\Gamma}{\Gamma_{SM}} = [1 - \tan^2\beta (m_{Dq}^2 / m_{H^\pm}^2)(m_q / m_c)]^2$$
$$\equiv [1 - R^2 m_{Dq}^2 (m_q / m_c)]^2$$



- Deviations from lepton universality possible if tanβ large

  Hewett [hep-ph/9505246] & Hou, PRD 48, 2342 (1993).

$$\frac{\Gamma(P^+ \to \tau^+\nu)}{\Gamma(P^+ \to \mu^+\nu)} = \frac{m_\tau^2 \left(1 - m_\tau^2 / M_P^2\right)^2}{m_\mu^2 \left(1 - m_\mu^2 / M_P^2\right)^2}$$

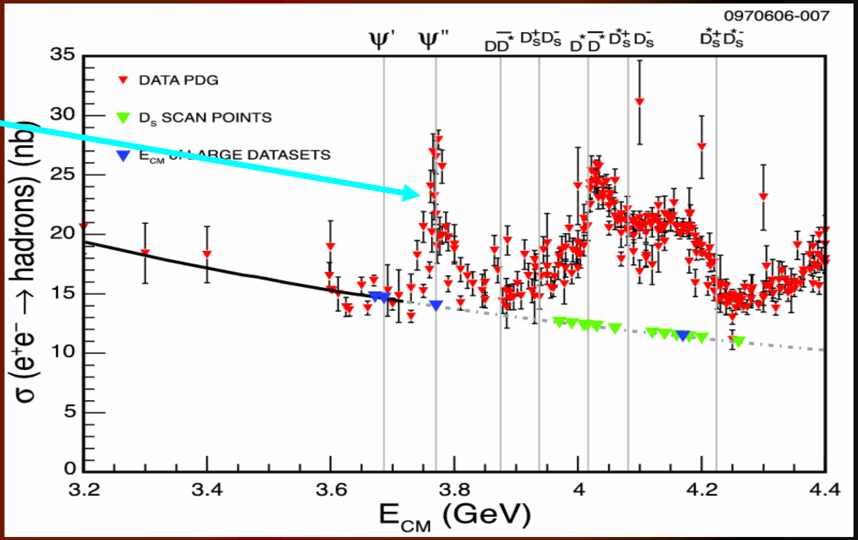
Deviations of this ratio from SM value of 9.72 would signal New Physics

D and D_s Landscape near threshold

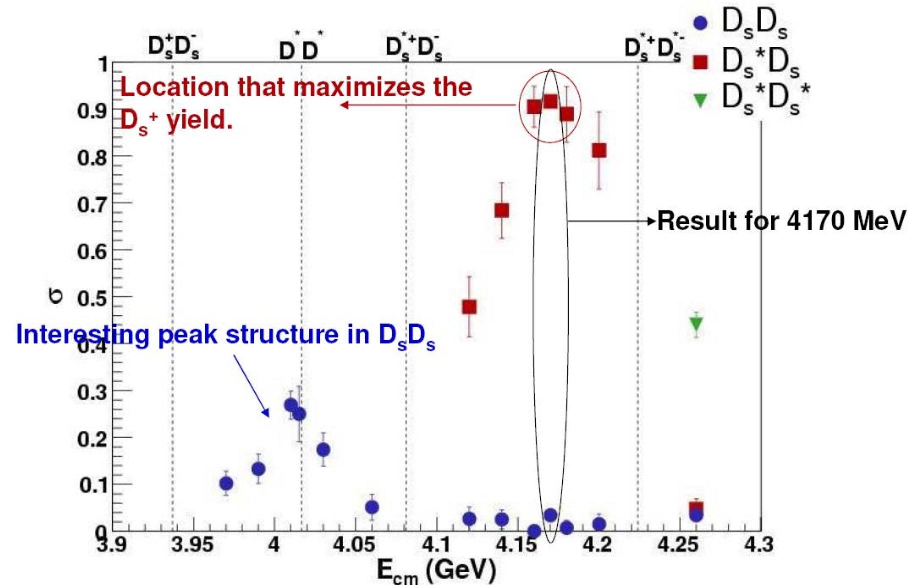
- Produce $D\bar{D}$ at $\psi(3770)$.
  - No additional particles
  - Coherent 1– state
  - Ideal for absolute BF measurements
  - Measurements from 281 pb^{-1}
    (Phys. Rev. Lett. 95, 251801 (2005))

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

  - Not reviewed in this talk

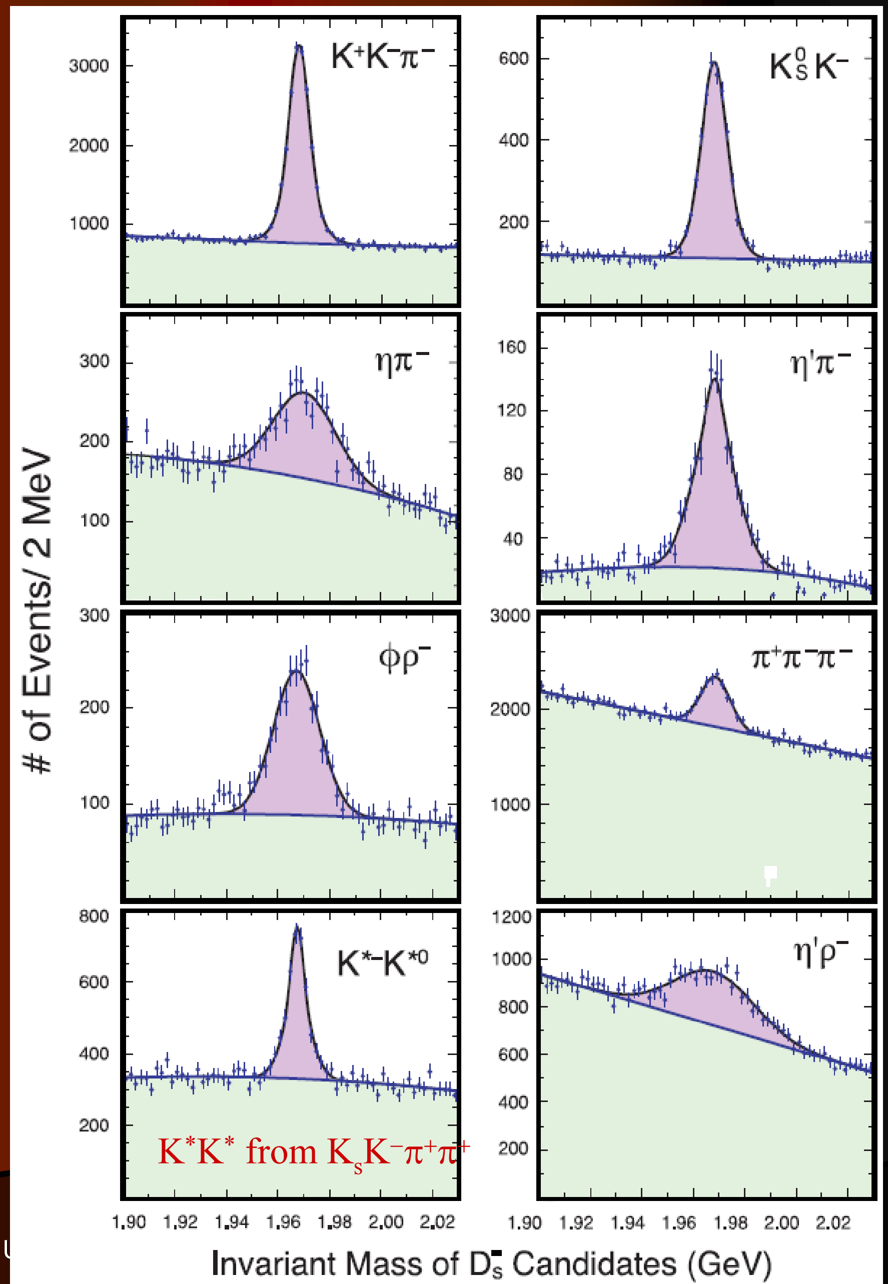


- D_s Leptonic Decays
  - Dedicated scan to find optimal energy for D_s physics (see talk by B. Lang)
    - At E_{cm} = 4170 MeV $\sigma(\bar{D}_s D_s^*)$~0.9 nb
    - Additional photon, ~100 MeV to contend with.



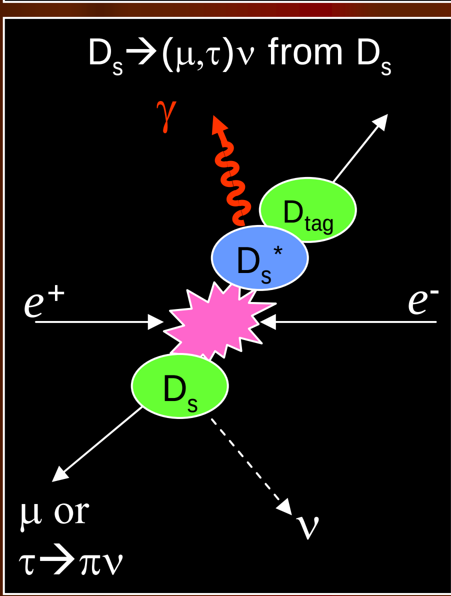
Reconstructed D_s "Tags" at 4170 MeV

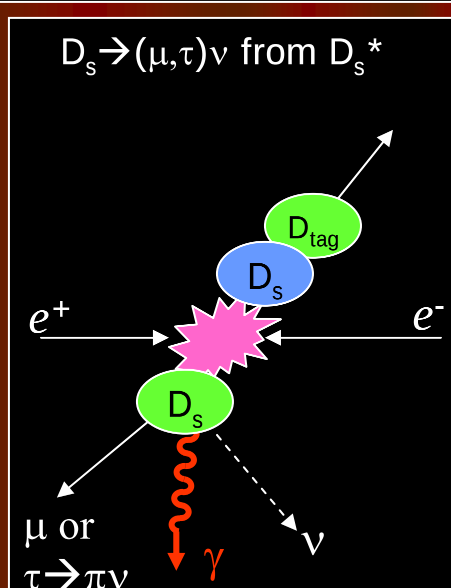
- Leptonic analyses require one fully reconstructed D_s decay ("tag").
  - 8 tag modes
- Signal region:
  - $|M_{rec}-M_{Ds}| < 2.5\ \sigma$
- Sidebands:
  - $5.0<|M_{rec}-M_{Ds}| < 7.5\ \sigma$
- Total # of Tags
  = 31,302 ± 472 (stat)



Measurements of f_{Ds}

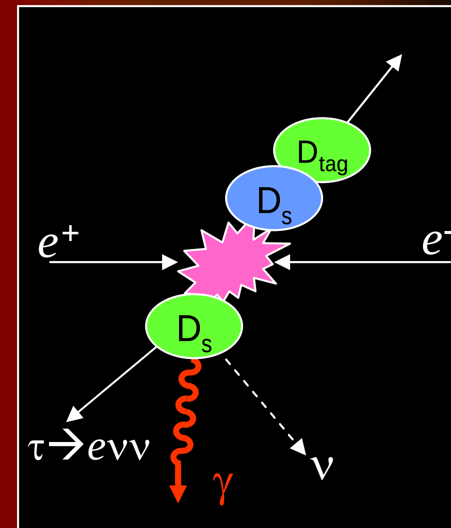
"Missing Mass" Analyses (314 pb^{-1})
Accepted to PRD arXiv:0704.0437v2





- ❑ Only one additional track, $K^{\pm}$ rejection using PID
- ❑ No additional γ with E>300 MeV
- ❑ Use (missing) mass recoiling against ($D_s^* + \mu$)

"Missing Energy" Analysis (195 pb^{-1})
Preliminary



- ❑ Only one additional track, consistent with electron hypothesis
- ❑ Signal discriminant:
  Remaining energy in calorimeter after tag and electron are removed.

Anatomy of Missing Mass Analyses

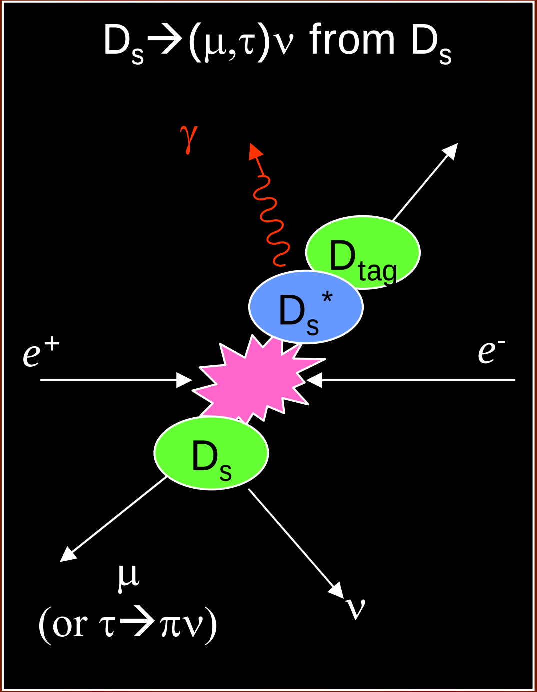
$$B(D_s^+ \to \mu^+\nu) = \frac{N_{cand} - N_{back}}{\varepsilon_\mu (N^*_{tag})}$$

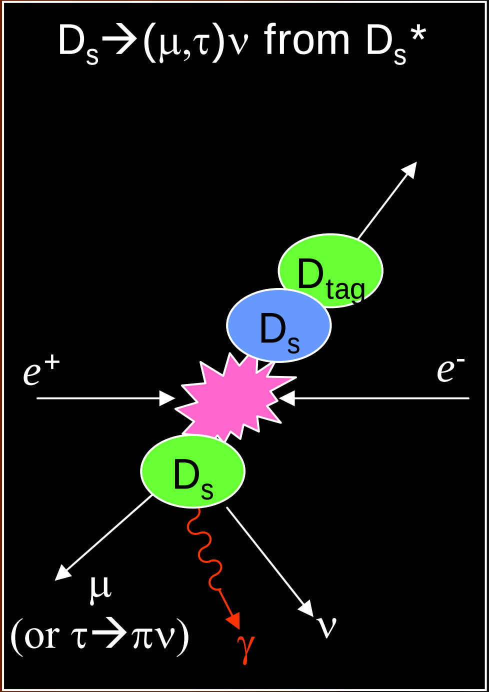
$N^*_{tag} = N(D_s^{*\pm} D_s^{\mp})$ including γ from D_s^* decay

$\varepsilon_\mu =$ muon detection efficiency

$N_{cand} = \#$ of $D_s^+ \to \mu^+\nu$ candidates

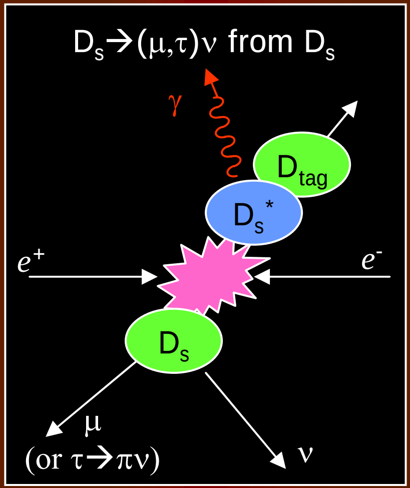
$N_{back} =$ expected background

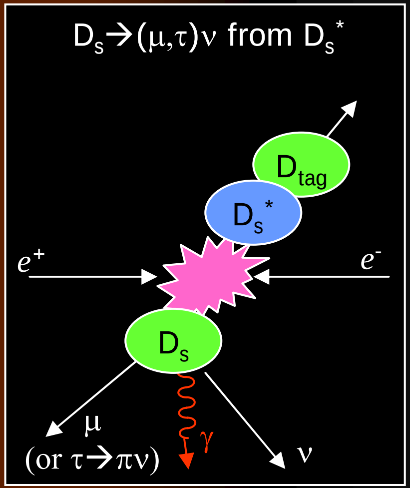




Missing Mass Analyses – N_{tag}^*

$$B(D_s^+ \to \mu^+\nu) = \frac{N_{cand} - N_{back}}{\varepsilon_\mu(\quad)}$$



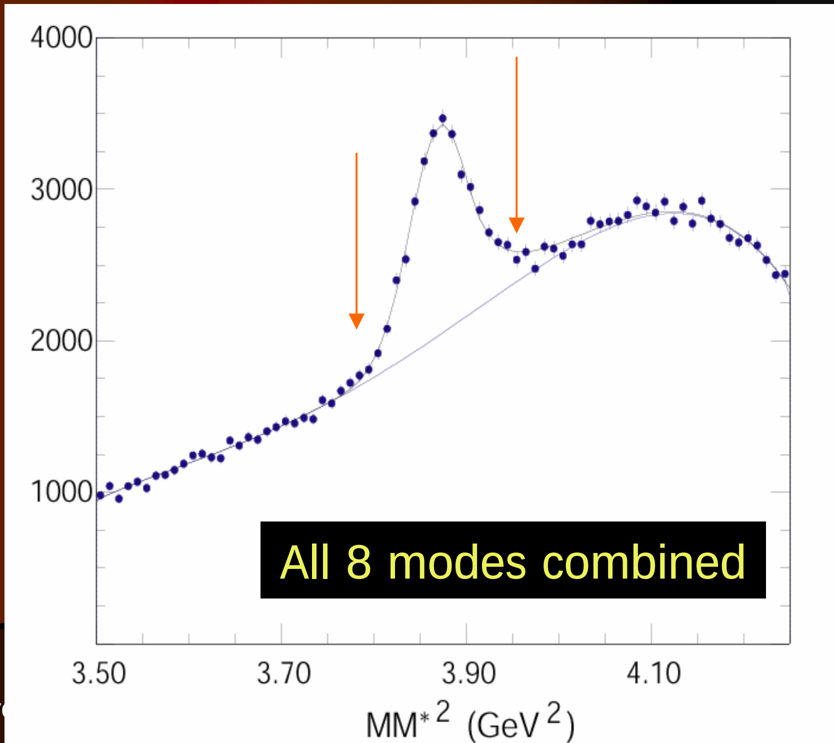


- Take each D_s tag and photon candidate and compute the recoil mass against $(D_s^{tag}+\gamma)$.

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

regardless of whether $D_s+\gamma$ forms D_s^*, recoil mass peaks at $M(D_s)^2$

- N_{tag}^* = 18645±426(stat) tags, after 2.5σ selection on MM^{*2}.



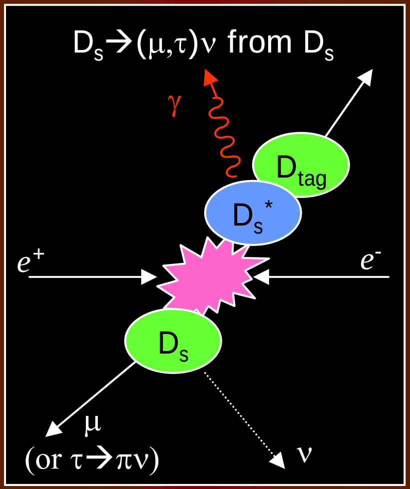
Missing Mass Analyses – Signal Side

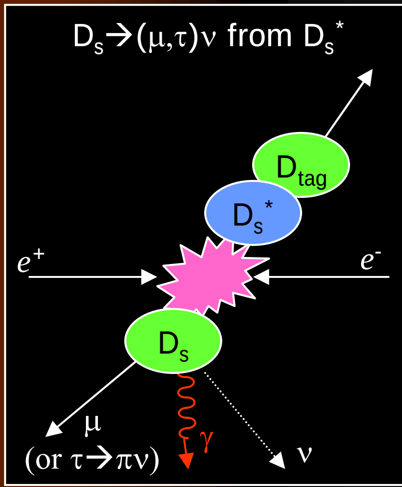
$$B(D_s^+ \to \mu^+ \nu) = \frac{N_{cand} - N_{back}}{\varepsilon_\mu (N^*_{tag})}$$

For each D_s^* candidate, perform a kinematic fit, imposing the following constraints:

$$\vec{p}_{D_s} + \vec{p}_{D_s^*} = 0$$
$$E_{D_s} + E_{D_s^*} = E_{CM}$$
$$M_{D_s^*} - M_{D_s} = 143.6 \text{ MeV}$$
$$M_{tag} = M(D_s^*)$$
$$E_{D_s^*} = \frac{E_{cm}}{2} \pm \frac{M^2_{D_s^*} - M^2_{D_s}}{2E_{cm}}$$

Two solutions for each D_s^* candidate
- γ belongs with D_s tag
- γ belongs with $D_s \to \mu\nu$ (try both)





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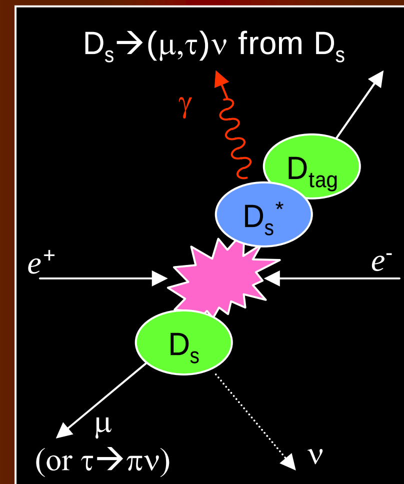
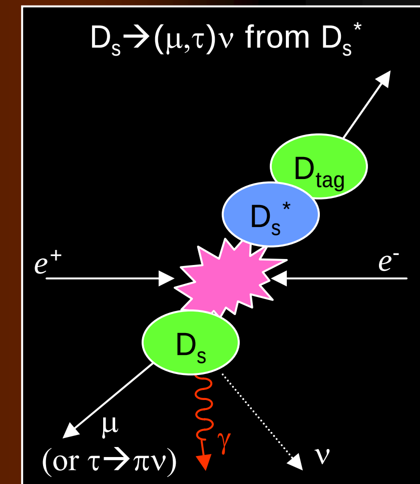
(try both)



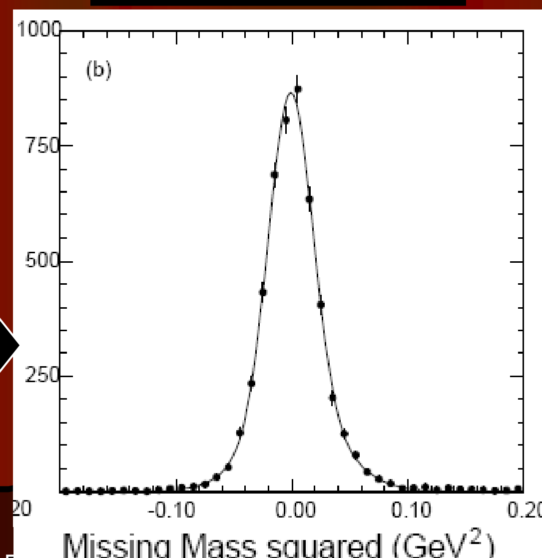


Choose solution with lowest χ^2 (but no cut), and compute:

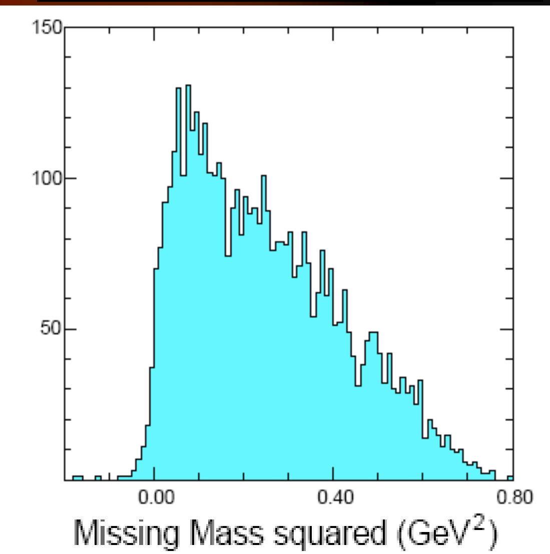
$$MM^2 = \left(E_{CM} - E_{D_s} - E_\gamma - E_\mu\right)^2 - \left(\vec{p}_{CM} - \vec{p}_{D_s} - \vec{p}_\gamma - \vec{p}_\mu\right)^2$$

Signal MC

Signal $D_s \to \mu\nu$



Signal $D_s \to \tau\nu$, $\tau \to \pi\nu$



MM^2 from CLEO-c Data

$$B(D_s^+ \to \mu^+ \nu) = \frac{N_{cand} - N_{back}}{\varepsilon_\mu (N^*_{tag})}$$

<u>Return to 3 separate cases:</u>

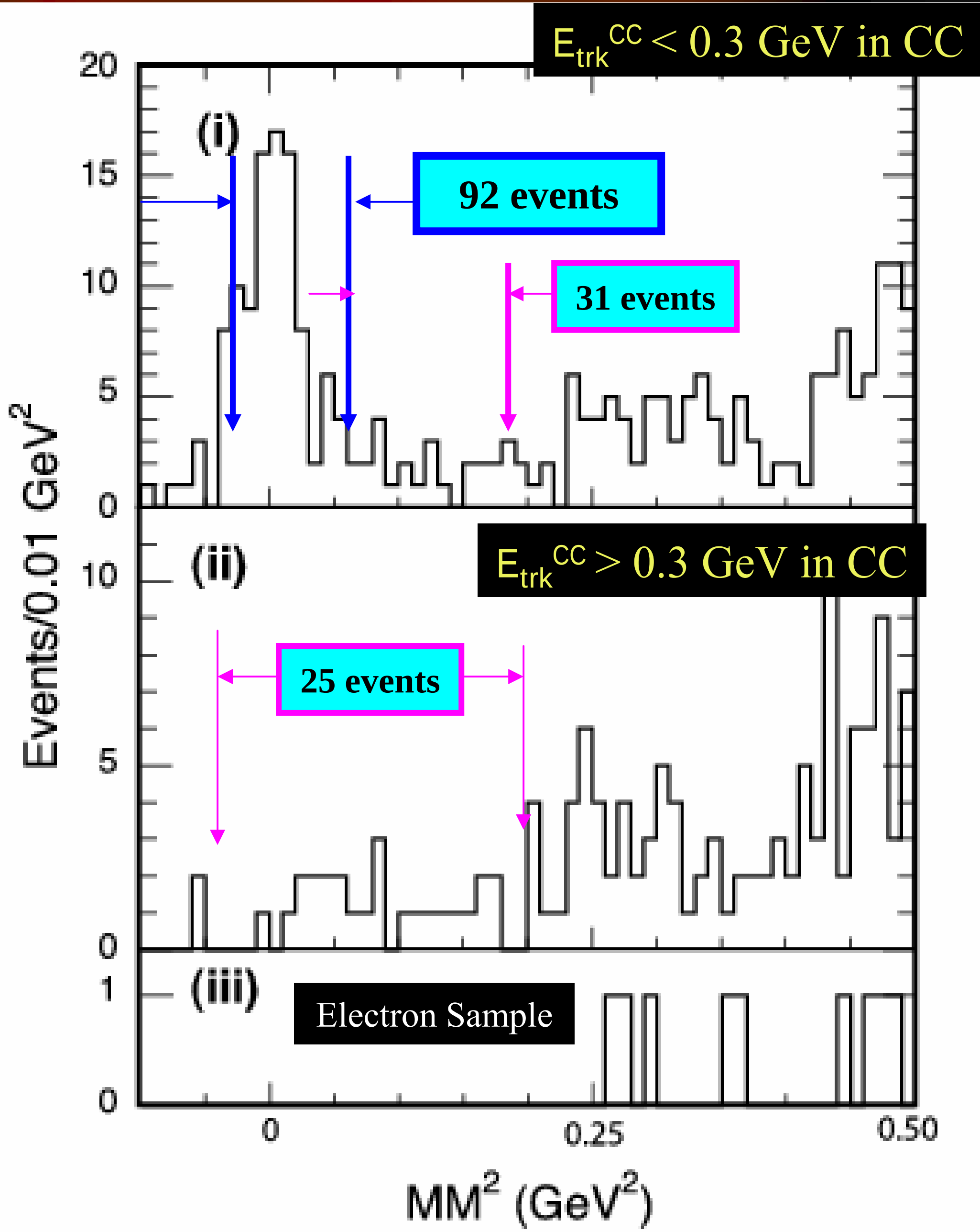
i. E_{trk}^{CC}<300 MeV

- "D→μν-like": (ε~99%)
  -0.05<MM^2<0.05 GeV^2
- "D→τν(τ→πν)-like": (ε~60%)
  0.05<MM^2<0.20 GeV^2

ii. E_{trk}^{CC}>300 MeV

- "D→τν(τ→πν)-like": (ε~40%)
  -0.05<MM^2<0.20 GeV^2

iii. Electron-like

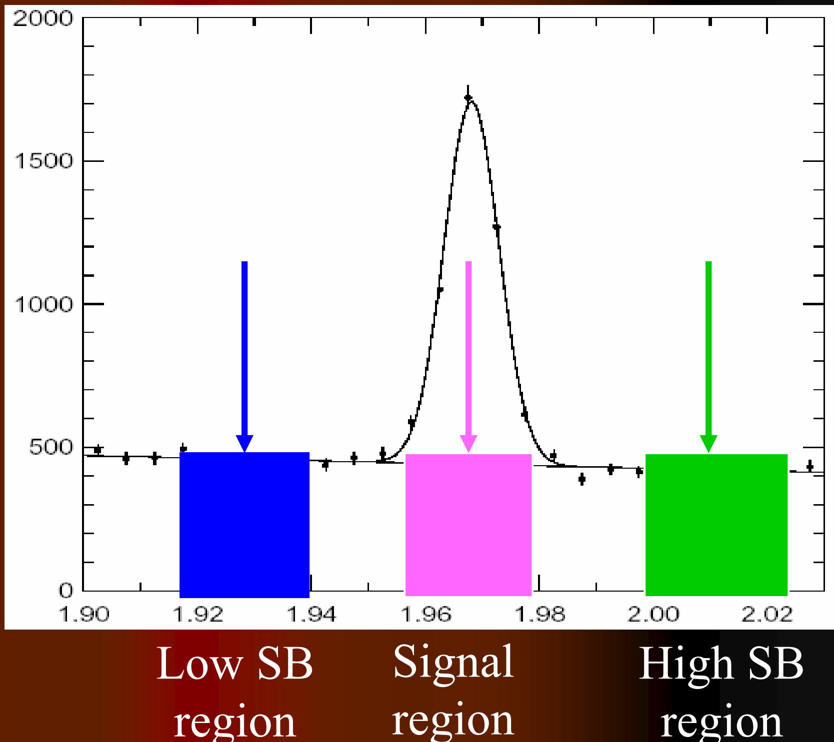


Backgrounds

- Combinatoric background under peaks:

  Use D_s cand. mass sidebands

Sample	Signal	Comb. Back.
(i) E_{trk}^{CC}<300 MeV, "$D\to\mu\nu$-like"	92	3.5±1.4
(ii) E_{trk}^{CC}<300 MeV, "$D\to\tau\nu$-like"	31	2.5±1.1
(iii) E_{trk}^{CC}>300 MeV, "$D\to\tau\nu$-like"	25	3.0±1.3
Total	148	9.0 ±1.3



- $D_s\to\tau\nu$ backgrounds from real D_s decays

Background	BF (%)	E_{trk}^{CC}<300 MeV, "$D\to\tau\nu$-like"	E_{trk}^{CC}<300 MeV, "$D\to\tau\nu$-like"
$D_s\to X\mu\nu$	8.2	$0^{+1.8}_{-0}$	0
$D_s\to X\mu\nu$	1.0	0.03±0.04	0.08±0.03
$D_s^+\to\tau^+\nu$, $\tau\to\pi^+\pi^0\nu$	1.5	0.55±0.22	0.64±0.24
$D_s^+\to\tau^+\nu$, $\tau^+\to\mu^+\nu\bar{\nu}$	1.0	0.37±0.15	0
Total		$1.0^{+1.8}_{-0.3}$	0.7±0.2

$$B(D_s^+\to\mu^+\nu)=\frac{N_{cand}-N_{back}}{\varepsilon_\mu(N^*_{tag})}$$

Negligible real D_s decay background to $D_s\to\mu\nu$

Since $B(D_s\to\pi^+\pi^0)$ <1.1×10^{-3} @ 90% CL

Branching fractions

$B(D_s^+ \to \mu^+\nu)$

$$N_{\mu\nu} = N_{tag}\varepsilon[\varepsilon_\mu B(D_s^+ \to \mu^+\nu) + \varepsilon_\tau B(D_s^+ \to \tau^+\nu; \tau \to \pi\bar{\nu})]$$

N_{tag}	$=18645\pm426\pm1081$
ε = efficiency for reconstructing μ^+/π^+	= 80.1%
ε_μ = efficiency for $E_{CC}<300$ MeV + $\lvert MM^2\rvert<50$ MeV	= 91.4%
ε_τ = efficiency for $E_{CC}<300$ MeV(60%) + $\lvert MM^2\rvert<50$ MeV(13%)	= 13.2%
$N_{\mu\nu}$ = 92 – (3.5±1.4)	= 88.5±9.7
$B(D_s^+ \to \tau^+\nu; \tau^+ \to \pi^+\bar{\nu})$	$= 1.059 \times B(D_s^+ \to \mu^+\nu)$ (SM / PDG)

$B(D_s^+ \to \mu^+\nu) = (0.597\pm0.067\pm0.039)\%$

$B(D_s^+ \to \tau^+\nu)$

	Type (i)	Type (ii)
N_{cand}	31	25
N_{back}	$3.5^{+1.7}_{-1.1}$	5.1±1.6
$\varepsilon(E_{trk}^{CC})$	60%	40%
$\varepsilon(MM^2)$req.	32%	45%

$B(D_s^+ \to \tau^+\nu) = (8.0\pm1.3\pm0.4)\%$

Combined f_{Ds}

Combine (i) and (ii).

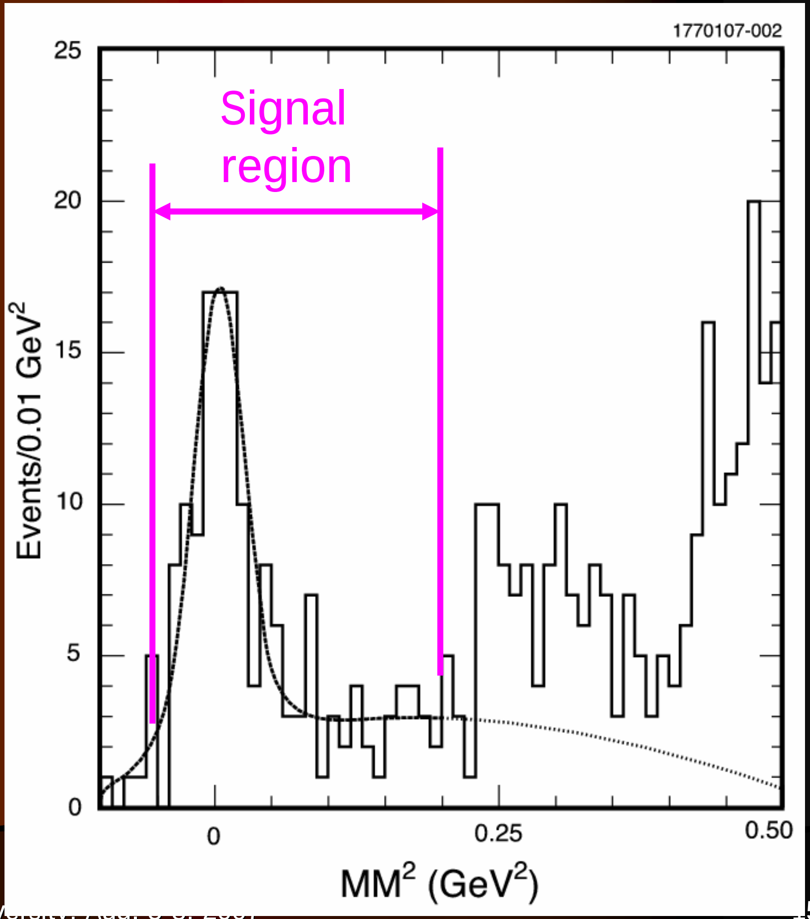
$$N_{\mu\nu} = N_{tag}\varepsilon[\varepsilon_\mu B(D_s^+ \to \mu^+\nu) + \varepsilon_\tau B(D_s^+ \to \tau^+\nu; \tau \to \pi\bar{\nu})]$$ (still applies)

ε_μ = 91.4%
ε_τ = 45.2%
$N_{\mu\nu}$ = 148 – ($10.7^{+2.9}_{-2.3}$)

Results

- $B^{eff}(D_S^+ \to \mu^+\nu)$ = (0.638±0.059±0.033)%
- f_{Ds}= 274 ± 13 ± 7 MeV
- $B(D_S^+ \to e^+\nu) < 1.3\times10^{-4}$ @90%CL

Error Source	Size (%)
Track finding	0.7
Photon veto	1
Minimum ionization*	1
Number of tags	5
Total	5.2



Missing Energy Analysis

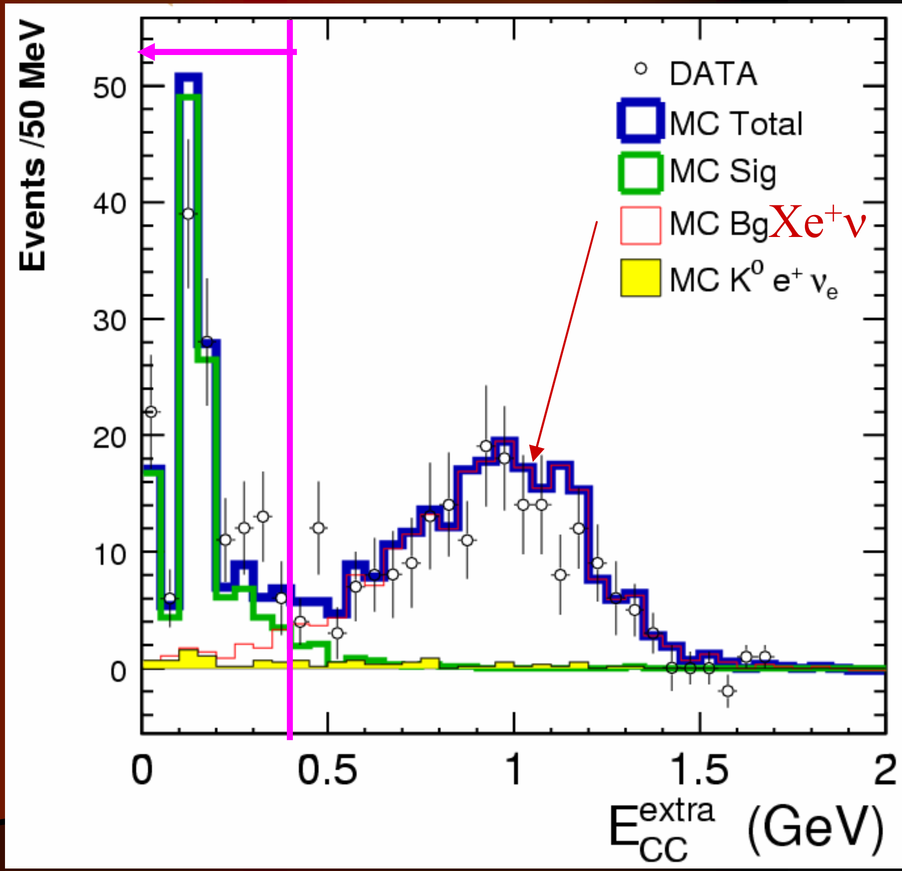
$D_S^+ \to \tau^+\nu,\ \tau^+ \to e^+\nu\nu$

(Preliminary)

- Use 195 pb^{-1} at E_{cm}=4170 MeV
- Reconstruct D_s tag, use recoil from D_s to get $N(\bar{D}_s D_s^*)$
- Require one extra electron candidate + no other tracks.
- No need to find γ from D_S^*
- Main backgrounds from $D_S^+ \to Xe^+\nu \sim 8\%$
- Discriminant is E_{CC}^{extra}: extra energy in CC left over after showers associated to reconstructed particles are removed.
- Signal region: E_{CC}^{extra} < 400 MeV
- Background obtained by scaling MC

$$N_{data}^{<400MeV} = \left(\frac{N_{MC}^{<400MeV}}{N_{MC}^{>600MeV}}\right) N_{data}^{>600MeV}$$

- $B(D_S^+ \to \tau^+\nu) = (6.29 \pm 0.78 \pm 0.52)\%$
- $f_{Ds} = 278 \pm 17 \pm 12$ MeV



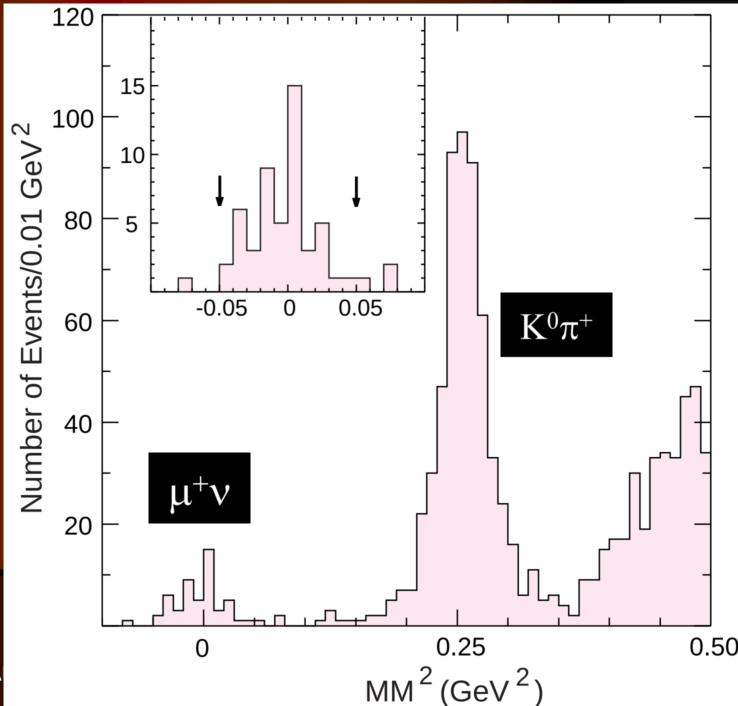
Combined results

- Weighted Average: f_{Ds}=275±10±5 MeV, the (systematic errors are mostly uncorrelated between the measurements)
- Previously CLEO-c measured

$$f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})\ \text{MeV}$$

M. Artuso et al., Phys .Rev. Lett. 95 (2005) 251801

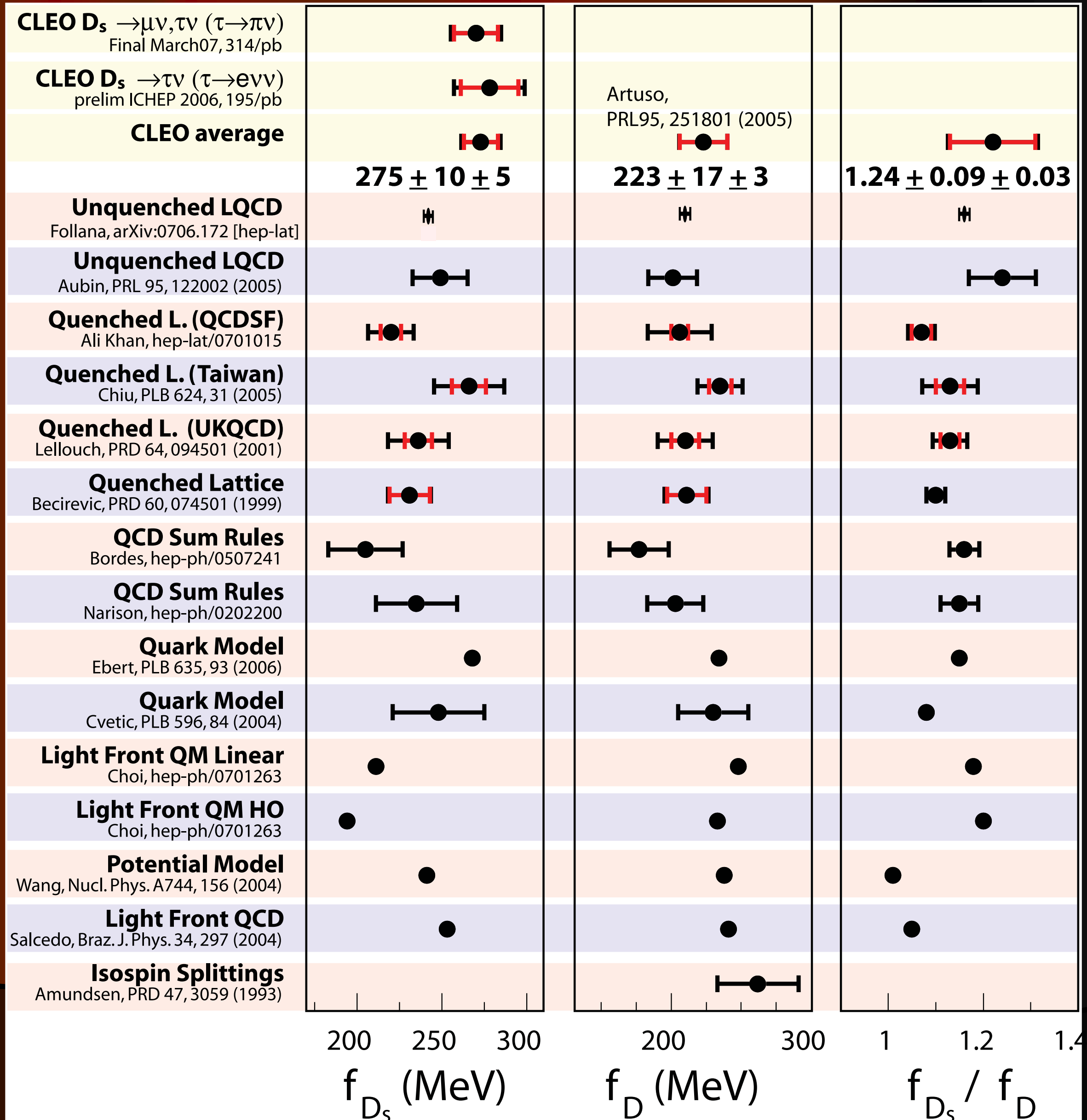
$D^+ \to \mu^+\nu$
281 pb^{-1} at $\psi(3770)$



- †Thus f_{Ds}/f_{D^+}=1.24±0.10±0.03
- $\Gamma(D_S^+ \to \tau^+\nu)/\Gamma(D_S^+ \to \mu^+\nu)$= 11.5±2.0, SM=9.72, consistent with lepton universality

Comparisons with theoretical expectations

- CLEO-c data consistent with most models, more precision needed
- Using Lattice ratio find $|V_{cd}/V_{cs}|=0.2166\pm 0.020\ (exp) \pm 0.0017 (theory)$



Comparison to previous measurements

TABLE VI: These results compared with previous measurements. Results have been updated for new values of the D_s lifetime. ALEPH uses both measurements to derive a value for the decay constant.

Exp.	Mode	$\mathcal{B}$	$\mathcal{B}_{\phi\pi}$ (%)	$f_{D_s^+}$ (MeV)
CLEO-c	combined	-		**275±10±5**
CLEO [30]	$\mu^+\nu$	$(6.2 \pm 0.8 \pm 1.3 \pm 1.6)10^{-3}$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE [31]	$\mu^+\nu$	$(8.3 \pm 2.3 \pm 0.6 \pm 2.1)10^{-3}$	3.6±0.9	$315 \pm 43 \pm 12 \pm 39$
ALEPH [32]	$\mu^+\nu$	$(6.8 \pm 1.1 \pm 1.8)10^{-3}$	3.6±0.9	$285 \pm 19 \pm 40$
ALEPH [32]	$\tau^+\nu$	$(5.8 \pm 0.8 \pm 1.8)10^{-2}$		
OPAL [34]	$\tau^+\nu$	$(7.0 \pm 2.1 \pm 2.0)10^{-2}$		$286 \pm 44 \pm 41$
L3 [33]	$\tau^+\nu$	$(7.4 \pm 2.8 \pm 1.6 \pm 1.8)10^{-2}$		$302 \pm 57 \pm 32 \pm 37$
BaBar [36]	$\mu^+\nu$	$(6.5 \pm 0.8 \pm 0.3 \pm 0.9)10^{-3}$	4.8±0.5±0.4	$279 \pm 17 \pm 6 \pm 19$

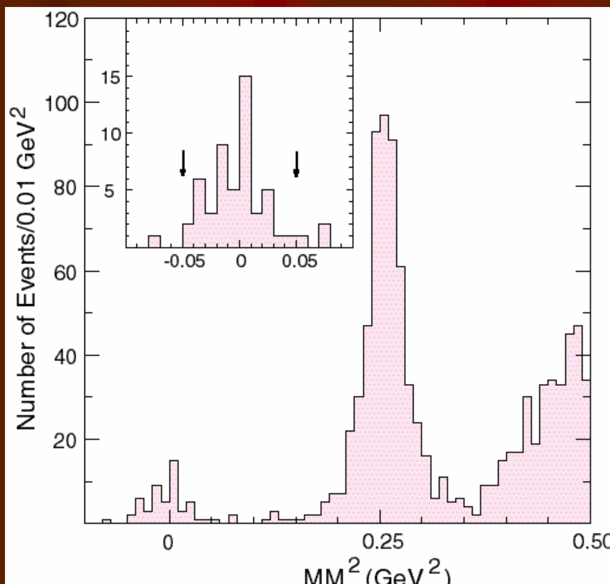
- CLEO-c is most precise result to date for both f_{D_s} & f_{D^+}

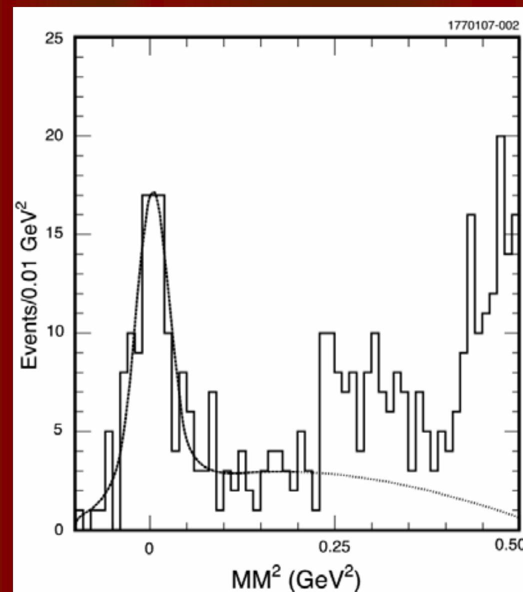
Summary

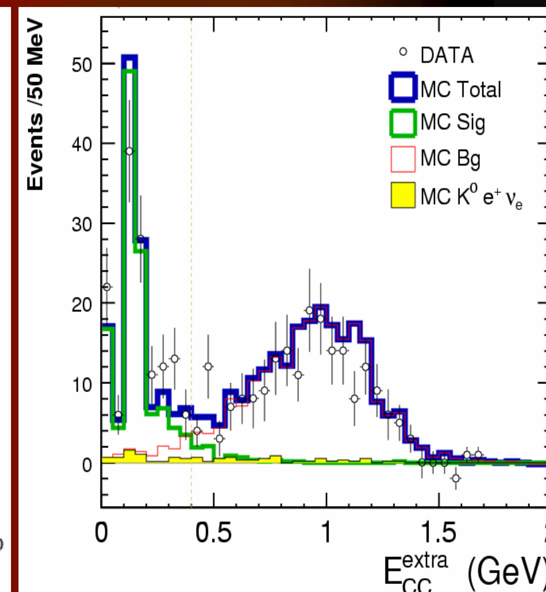
- Decay constants from CLEO-c are most precise to date

$f_{D^+}=(222.6\pm16.7^{+2.3}_{-3.4})$ MeV

$f_{D_s}=(275\pm10\pm5)$ MeV







- Expect to reach a precision of ~4.0-4.5% on these decay constants with full CLEO-c (through Apr 2008).

Backups

Missing Mass Distributions - MC

Check of resolution, procedure using $D_s \rightarrow K_s K$
- Remove extra track/shower/$K^{\pm}$ veto

- MC resolution consistent w/ data
- Find BF=(2.90±0.19±0.18)%,

  Result from double tags:
  (3.00±0.19±0.10)%

- This background is wiped out by the PID requirement on the stiff μ/π.