CLEO-c Measurement of the Pseudoscalar Decay Constant f_{D_s} & the Ratio f_{D_s}/f_{D^+}

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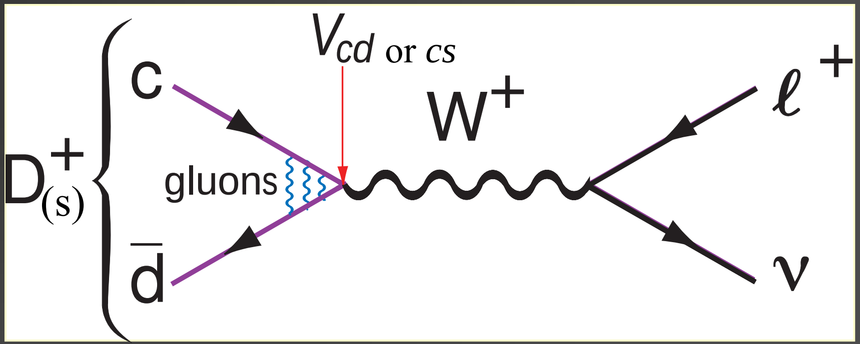
Leptonic Decays: $D_{(s)} \to \ell^+ \nu$

- Introduction: Pseudoscalar decay constants
- c and $\bar{q}$ can annihilate, probability is $\propto$ to wave function overlap
- Example :



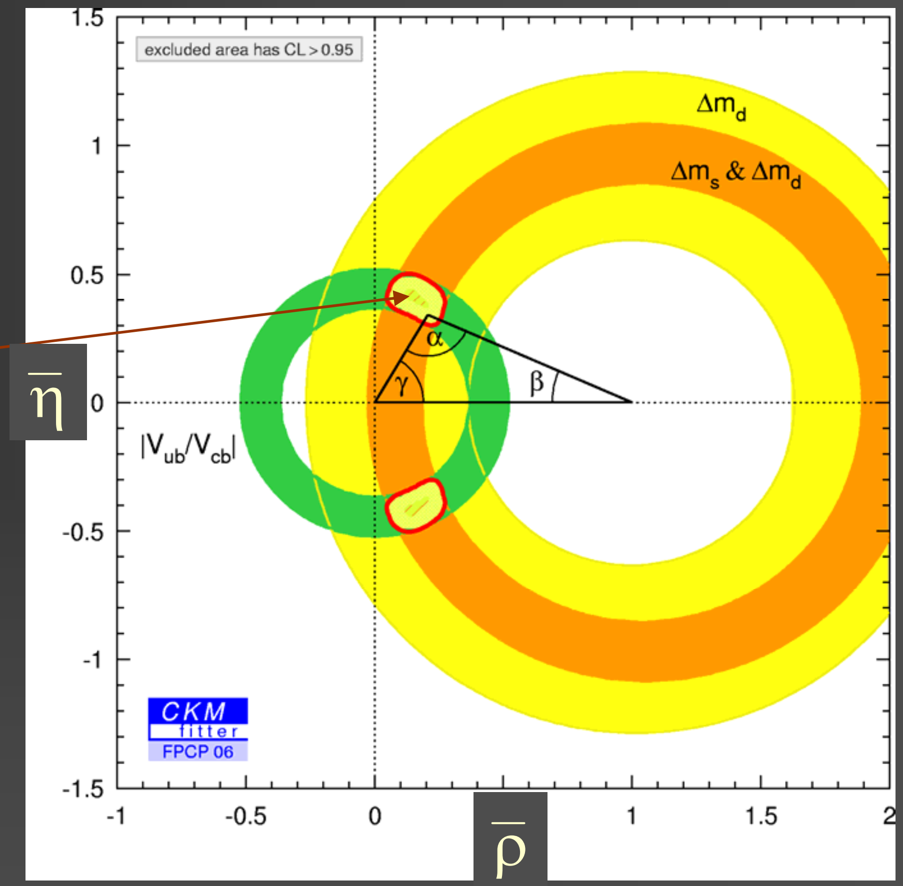
In general for all pseudoscalars:

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

Calculate, or measure if V_{Qq} is known

Goals in Leptonic Decays

- Test theoretical calculations in strongly coupled theories in non-perturbative regime
- f_B & f_{Bs}/f_B needed to improve constraints from Δm_d & $\Delta m_S/\Delta m_d$. Hard to measure directly (i.e. $B \to \tau^+\nu$ measures $V_{ub}f_B$), but we can determine f_D & f_{Ds} using $D \to \ell^+\nu$ and use them to test theoretical models (i.e. Lattice QCD)



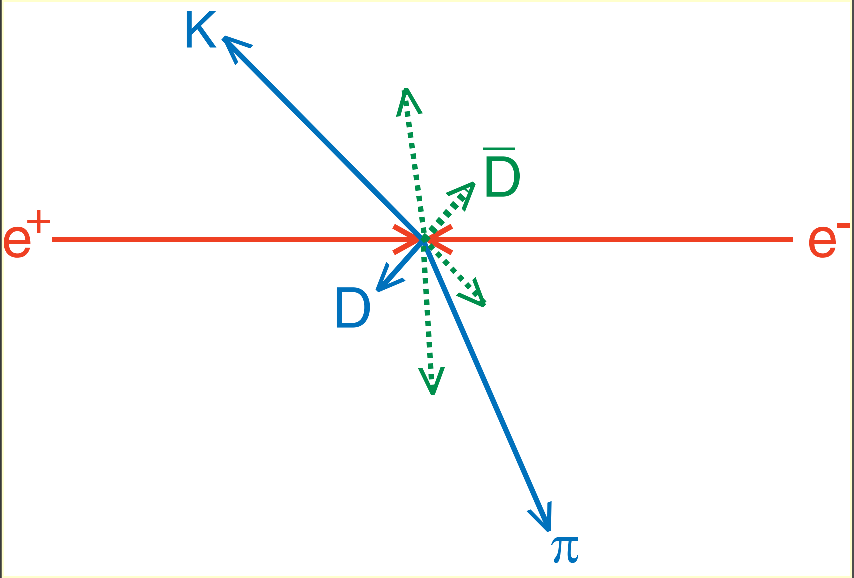
Constraints from V_{ub}, Δm_d, Δm_s & $B \to \tau^+\nu$

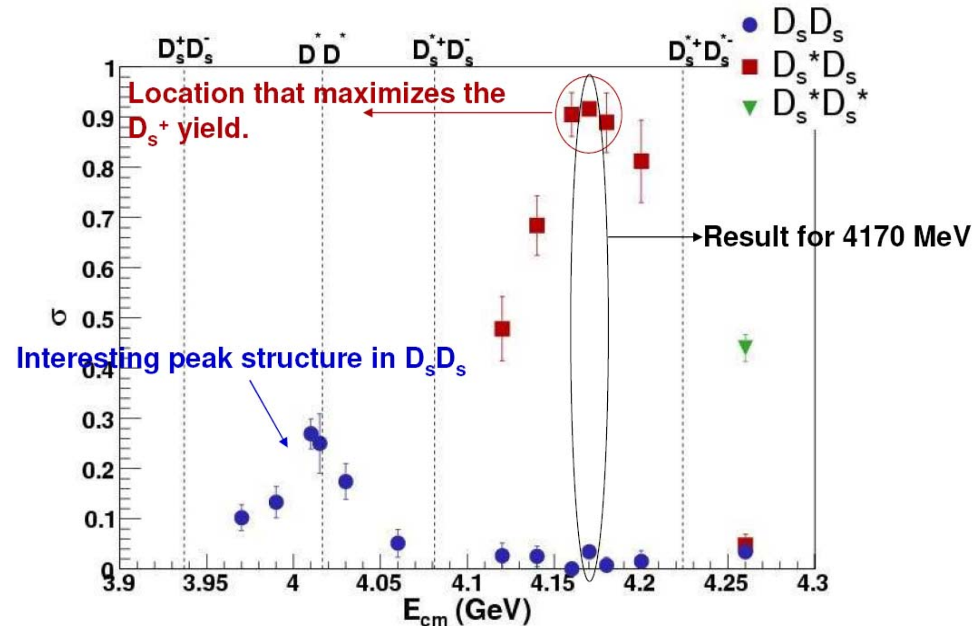
Experimental methods

- $D\bar{D}$ production at threshold: used by Mark III, and more recently by CLEO-c and BES-II.
  - Unique event properties
    - ➢Only $D\bar{D}$ not $D\bar{D}x$ produced
  - Large cross sections:

$\sigma(D^o\bar{D}^o) = 3.72\pm0.09$ nb
$\sigma(D^+D^-) = 2.82\pm0.09$ nb } World Ave
$\sigma(D_SD_S{}^*) = \sim0.9$ nb
Continuum ~14 nb

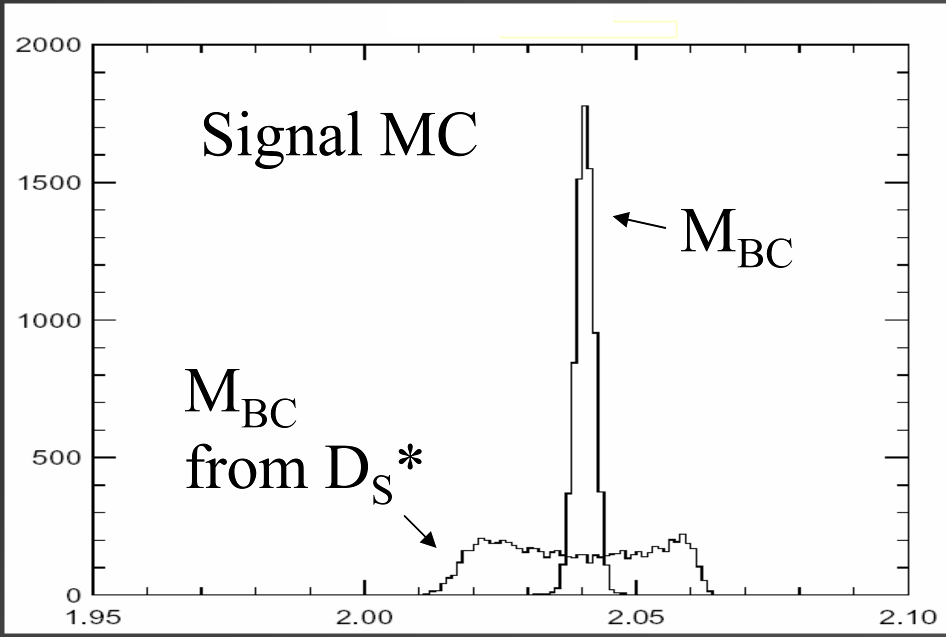
  - Ease of B measurements using "double tags"
  - $\mathcal{B}_A$ = # of A/# of D's





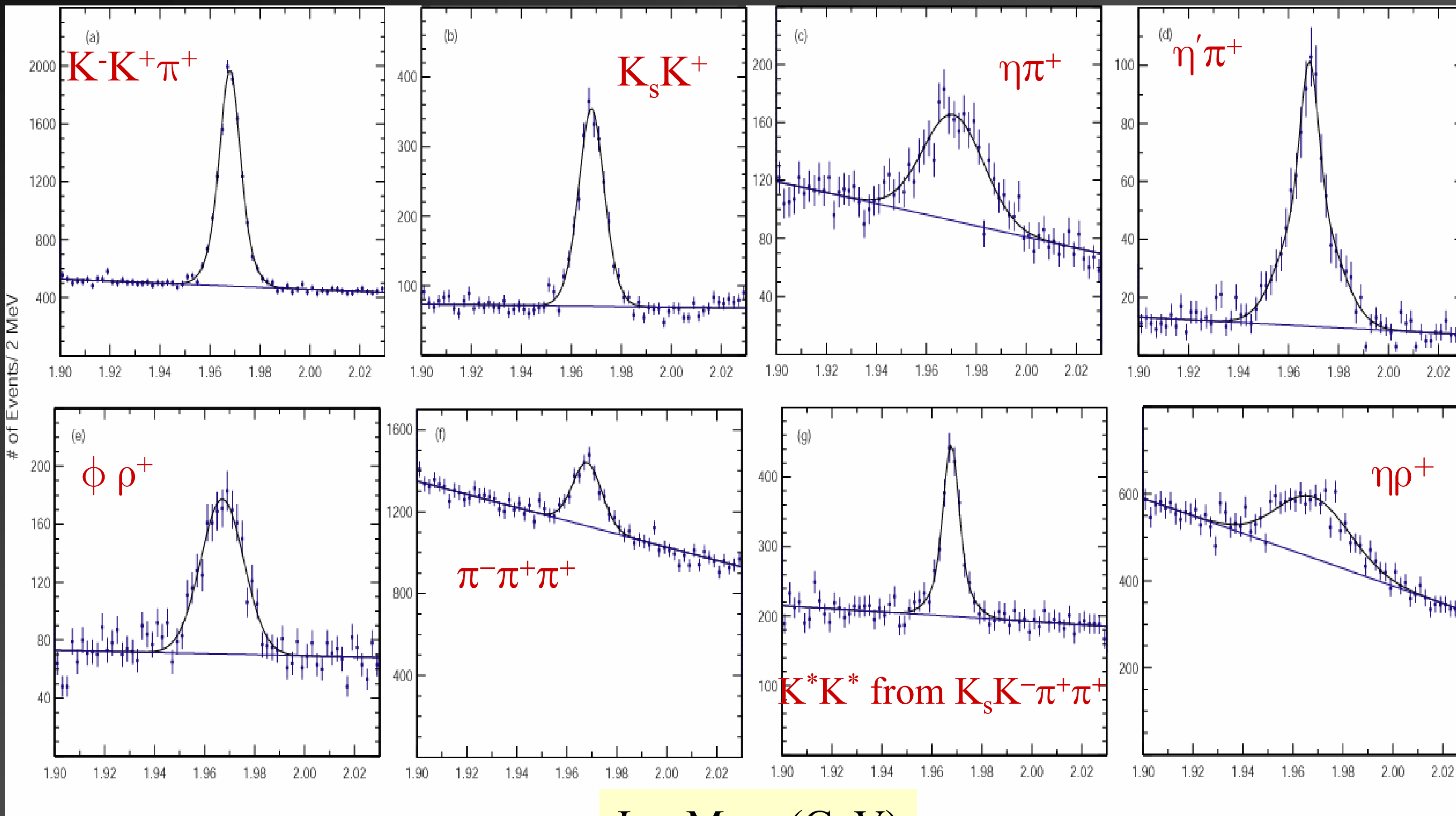
CLEO D_S^+ Results at 4170 MeV

- Since $e^+e^- \rightarrow D_S^* D_S$, the D_S from the D_S^* will be smeared in beam-constrained mass.
- $$M_{BC}^2 = E_{beam}^2 - \sum_i \vec{p}_i^{\,2}$$
- $\therefore$ cut on M_{BC} & plot invariant mass (equivalent to a p cut)
- We use ~200 pb^{-1} of data



Beam Constrained Mass (GeV)

Invariant masses



Inv Mass (GeV)

Total # of Tags = 19,185±325 (stat)

New Measurements of f_{D_s}

- Two separate techniques
- (1) Measure $D_S^+ \rightarrow \mu^+\nu$ along with $D_S \rightarrow \tau^+\nu$, $\tau \rightarrow \pi^+\nu$. This requires finding a D_S^- tag, a γ from either $D_s^{*-} \rightarrow \gamma\, D_s^-$ or $D_s^{*+} \rightarrow \gamma\, \mu^+\nu$. Then finding the muon or pion using kinematical constraints
- (2) Find $D_S^+ \rightarrow \tau^+\nu$, $\tau \rightarrow e^+\nu\nu$ opposite a D_s^- tag

Measurement of $D_S^+ \rightarrow \mu^+ \nu$

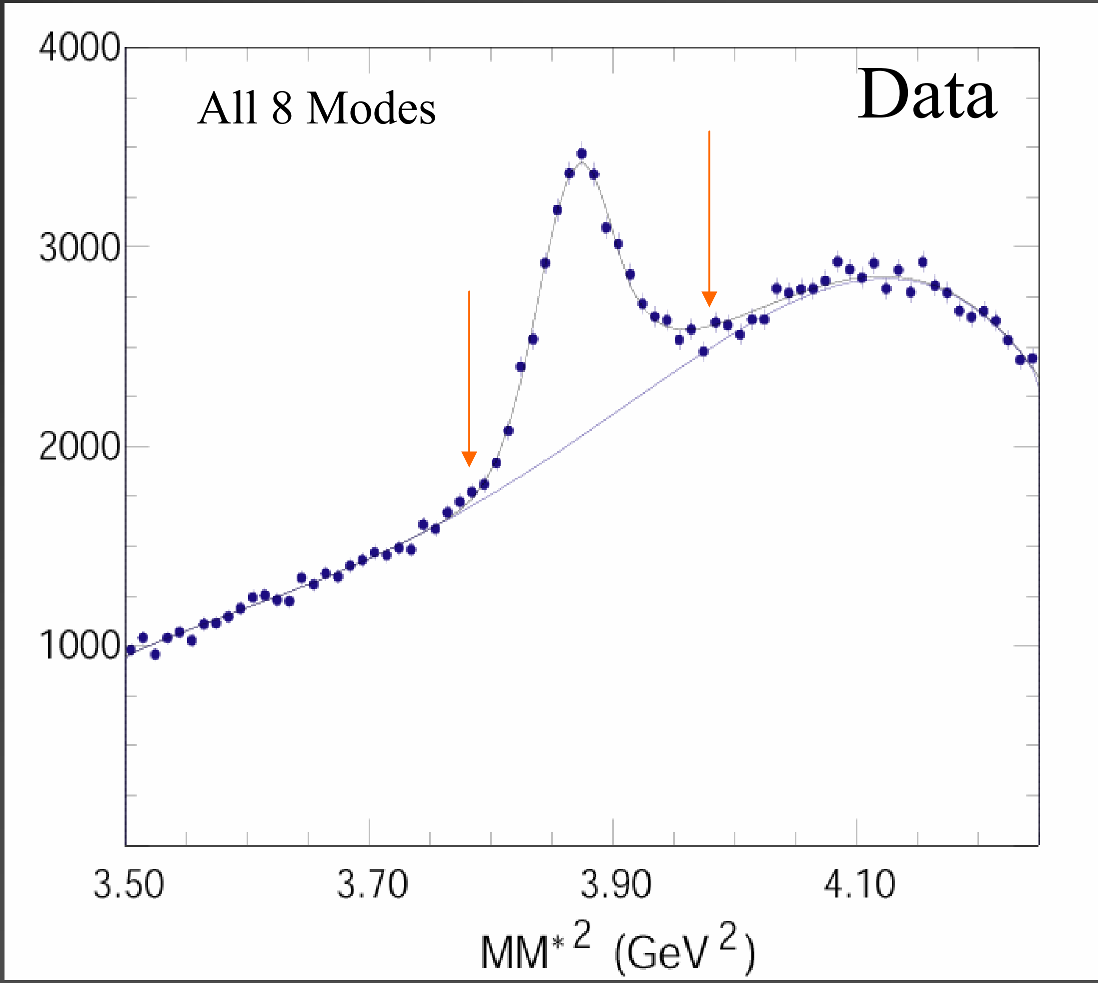
- In this analysis we use $D_S^* D_S$ events where we detect the γ from the $D_S^* \rightarrow \gamma D_S$ decay
- We see all the particles from $e^+e^- \rightarrow D_S^* D_S$, γ, D_S (tag) + μ^+ except for the ν
- We use a kinematic fit to (a) improve the resolution & (b) remove ambiguities
  - Constraints include: total p & E, tag D_S mass, $\Delta m = M(\gamma D_S) - M(D_S)$ [or $\Delta m = M(\gamma\mu\nu) - M(\mu\nu)$] = 143.6 MeV, E of D_S (or D_S^*) fixed
  - Lowest χ^2 solution in each event is kept
  - No χ^2 cut is applied

Tag Sample using γ

- First we define the tag sample by computing the MM*2 off of the γ & D_S tag

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

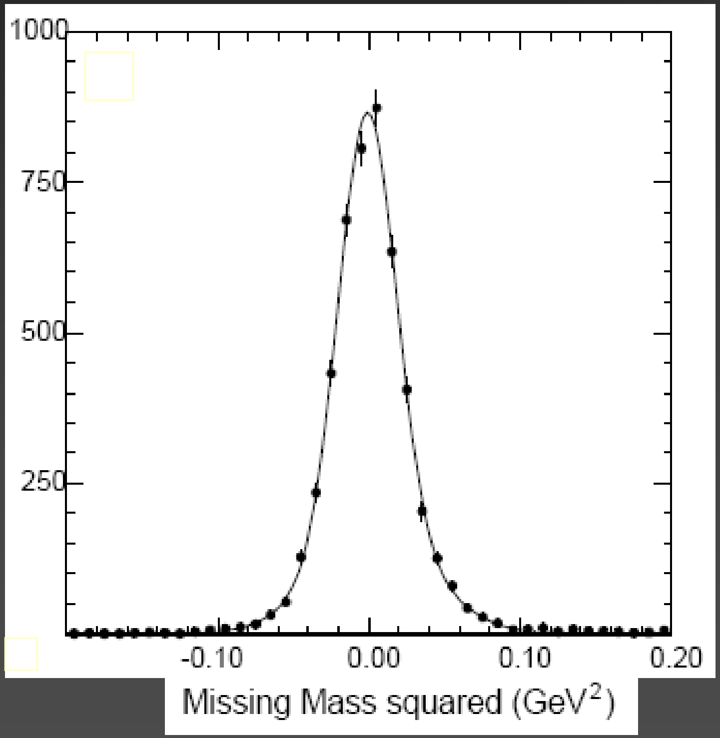
- Total of 11880±399±504 tags, after the selection on MM*2.



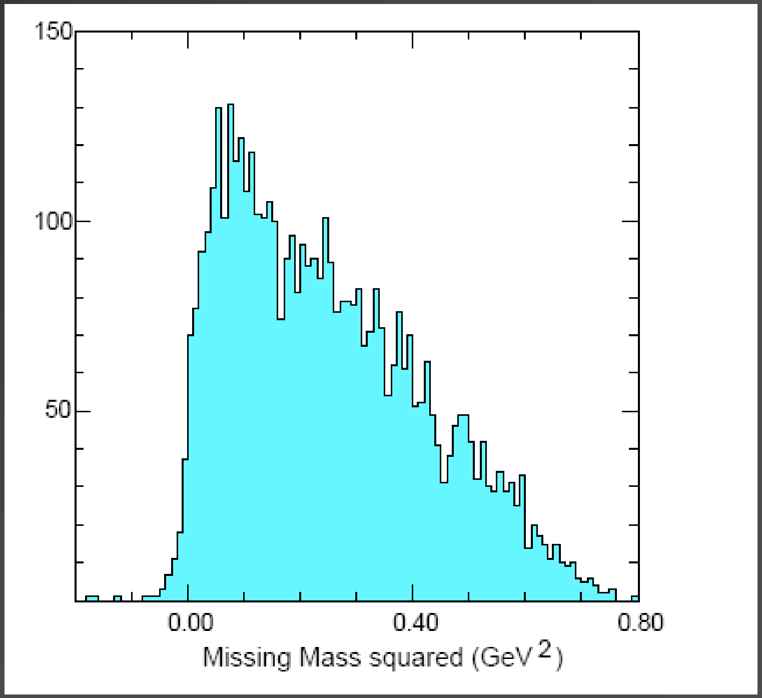
The MM^2

- To find the signal events, we compute

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



Signal μν



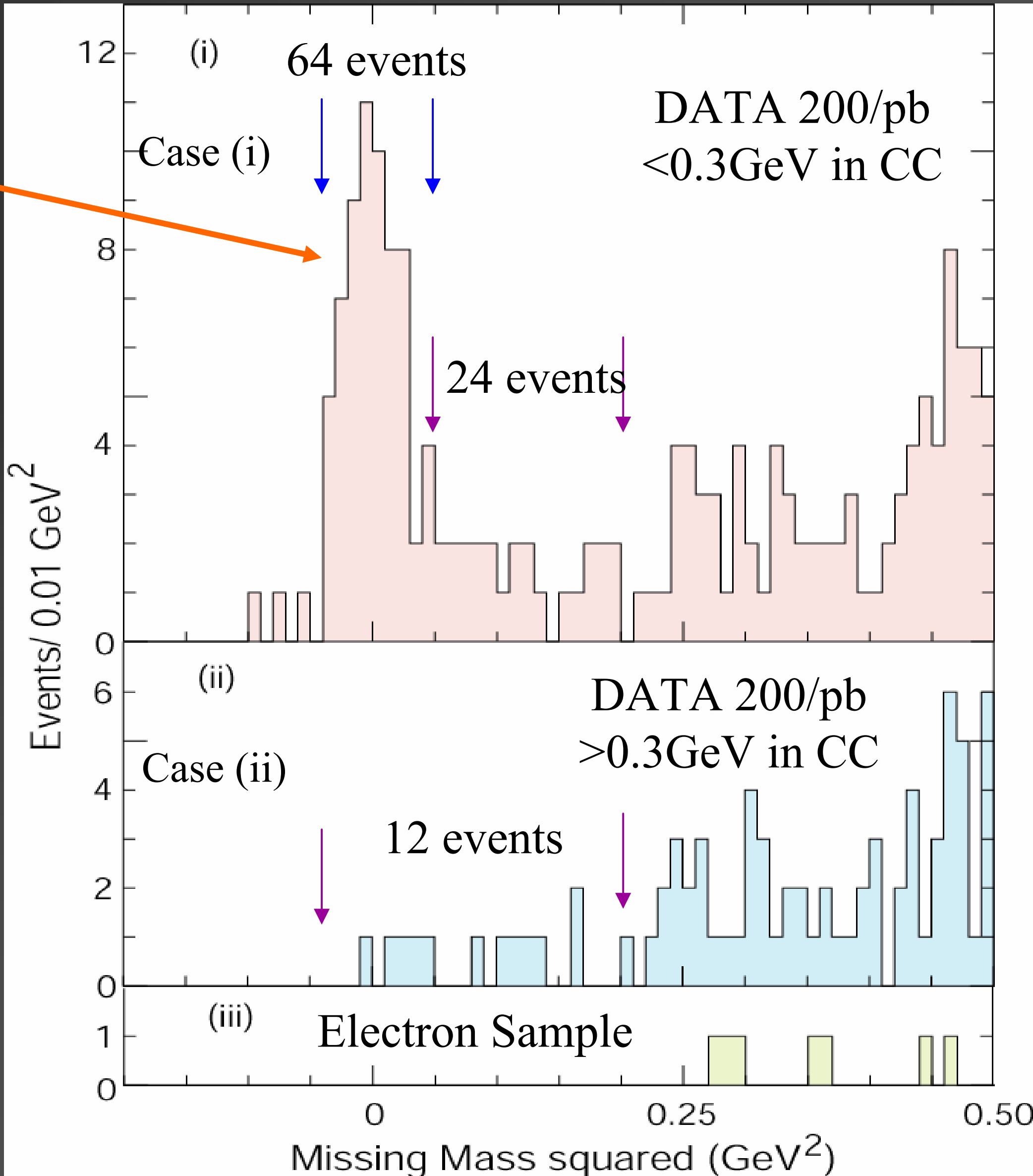
Signal τν, τ→πν

Define Three Classes

- Class (i), single track deposits < 300 MeV in calorimeter (consistent with μ) & no other γ > 300 MeV. (accepts 99% of muons and 60% of kaons & pions)
- Class (ii), single track deposits > 300 MeV in calorimeter & no other γ > 300 MeV (accepts 1% of muons and 40% of kaons & pions)
- Class (iii) single track consistent with electron & no other γ > 300 MeV

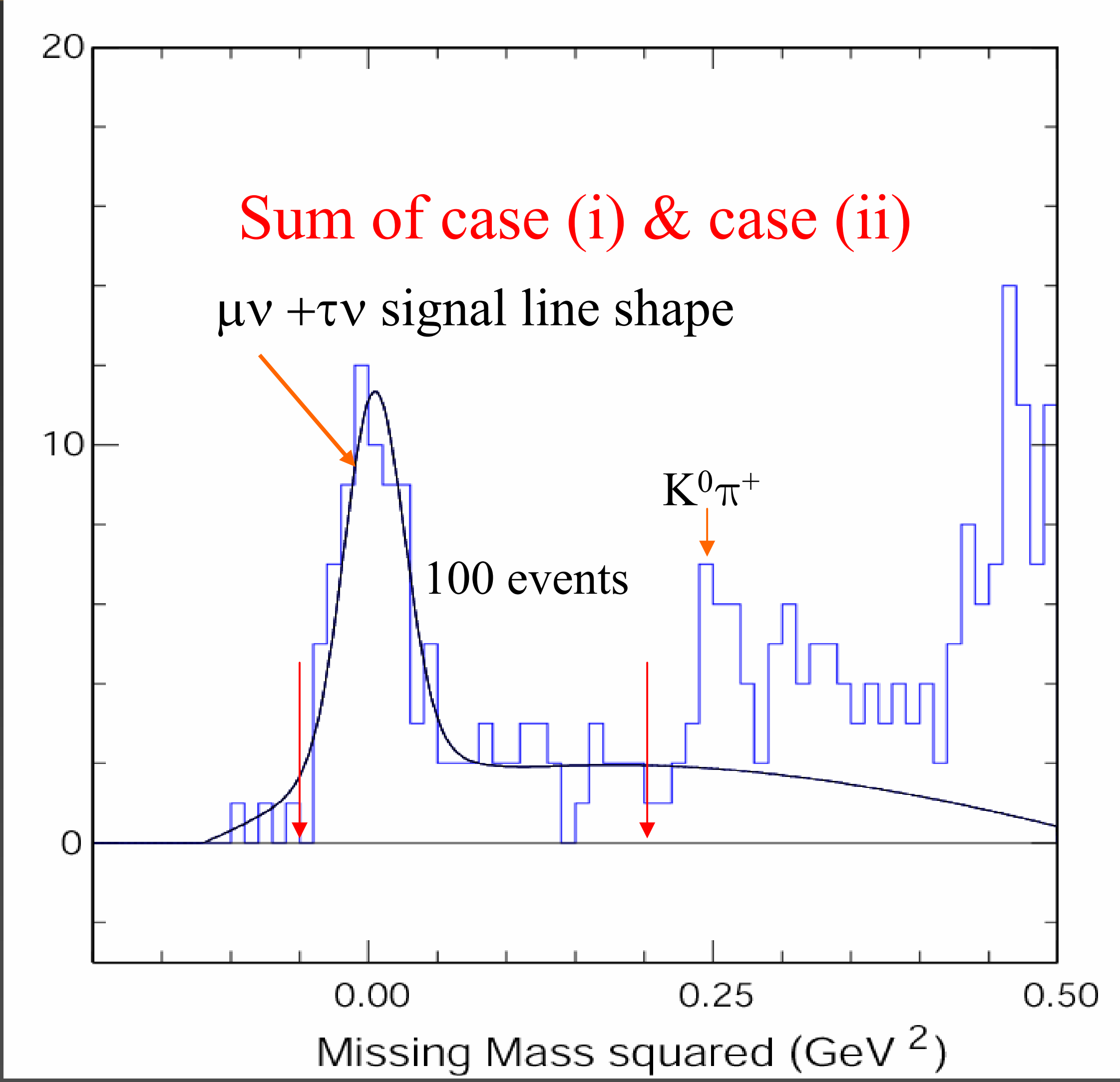
MM^2 Results from 200 pb^{-1}

- Clear $D_S^+ \to \mu^+\nu$ signal for case (i)
- Will show that events <0.2 GeV^2 are mostly $D_S \to \tau^+\nu$, $\tau \to \pi^+\nu$ in cases (i) & (ii)
- No $D_S \to e^+\nu$ seen, case (iii)



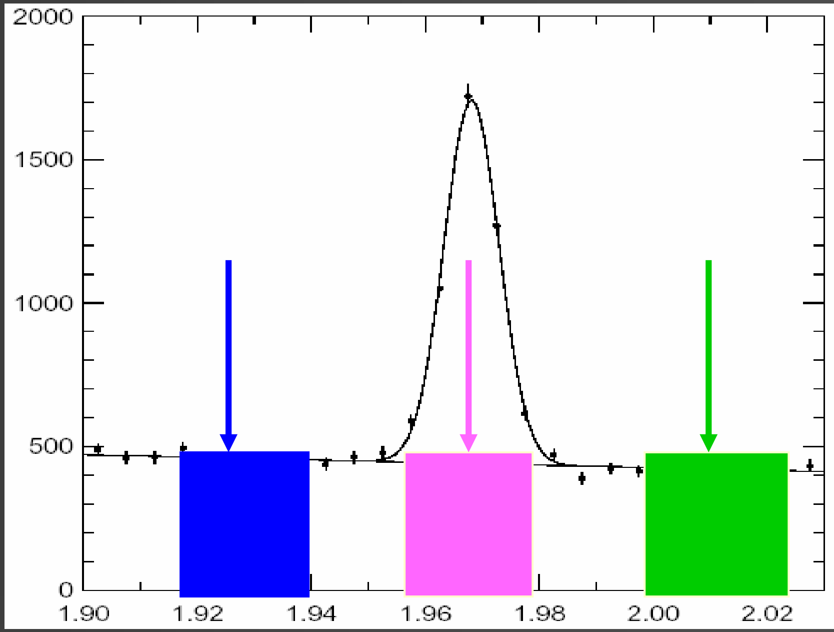
Sum of $D_S^+ \to \mu^+\nu + \tau^+\nu$, $\tau \to \pi^+\nu$

- Sum contains 100 $\mu^+\nu + \tau^+\nu$ events for $MM^2 < 0.2$ GeV^2



Background Samples

- Two sources of background
- A) Backgrounds under invariant mass peaks – Use sidebands to estimate
- In $\mu^+\nu$ signal region 2 background (64 signal)
- Total sideband bkgrnd 5.5±1.9
- B) Backgrounds from real D_S decays, e.g. $\pi^+\pi^o\pi^o$, or $D_S \rightarrow \tau^+\nu$, $\tau \rightarrow \pi^+\pi^o\nu$.... < 0.2 GeV^2, none in $\mu\nu$ signal region
- $B(D_S \rightarrow \pi^+\pi^o) < 1.1\times10^{-3}$ & γ energy cut yields <0.1 evts



Low SB region | Signal region | High SB region

Backgrounds from real D_S^+

Mode	$\mathcal{B}(\%)$	# of events case(i)	# of events case(ii)	Sum
$\pi^+\pi^0\pi^0$	1.0	0.1	0.3	0.4
$D_s^+ \rightarrow \tau^+\nu$	6.2			
$\tau^+ \rightarrow \pi^+\pi^0\nu$	1.6	0.3	0.4	0.7
$\tau^+ \rightarrow \mu^+\overline{\nu}\nu$	1.1	0	0	0
$\tau^+ \rightarrow e^+\overline{\nu}\nu$	1.1	0.2	0	0.2
Sum		0.6	0.7	1.3

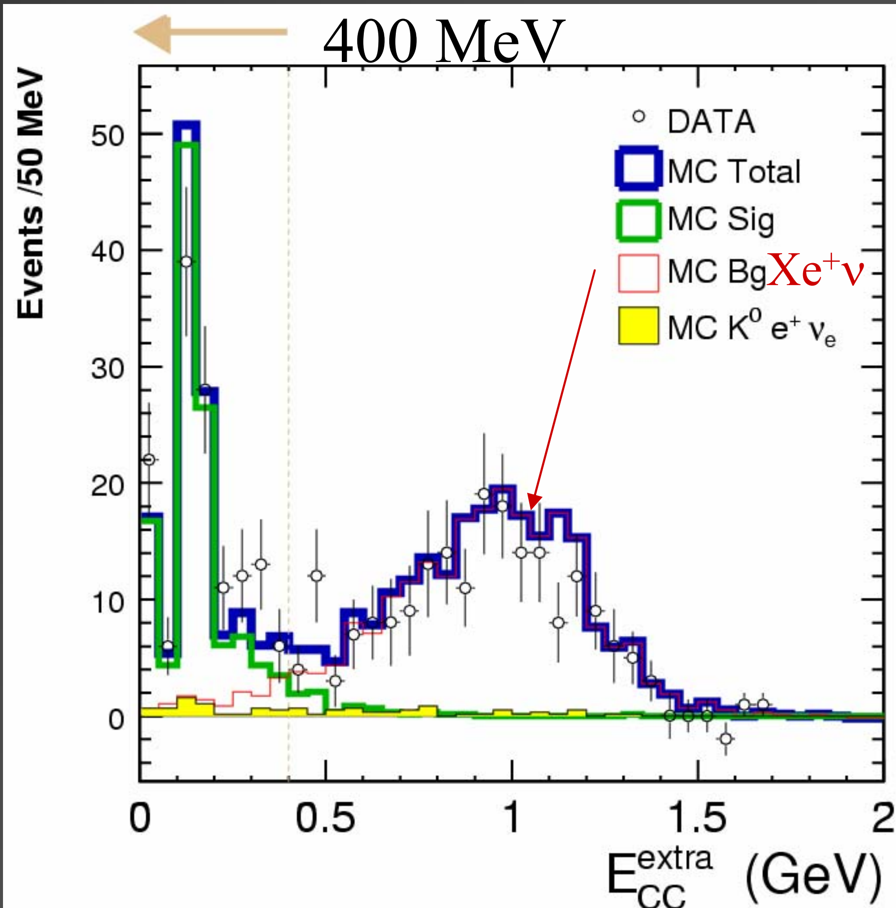
Branching Ratio & Decay Constant

- $D_S^+ \to \mu^+\nu$
  - 64 signal events, 2 background, use SM to calculate $\tau\nu$ yield near 0 MM^2 based on known $\tau\nu/\mu\nu$ ratio
  - $B(D_S^+ \to \mu^+\nu) = (0.657 \pm 0.090 \pm 0.028)\%$
- $D_S^+ \to \tau^+\nu$, $\tau^+ \to \pi^+\nu$
  - Sum case (i) $0.2 > MM^2 > 0.05$ GeV^2 & case (ii) $MM^2 < 0.2$ GeV^2. Total of 36 signal and 4.8 bkgrnd
  - $B(D_S^+ \to \tau^+\nu) = (7.1 \pm 1.4 \pm 0.03)\%$
- By summing both cases above, find

  $B^{eff}(D_S^+ \to \mu^+\nu) = (0.664 \pm 0.076 \pm 0.028)\%$
- $f_{Ds} = 282 \pm 16 \pm 7$ MeV
- $B(D_S^+ \to e^+\nu) < 3.1 \times 10^{-4}$

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

- $B(D_S^+ \to \tau^+\nu) \bullet B(\tau^+ \to e^+\nu\nu) \sim 1.3\%$ is "large" compared with expected $B(D_S^+ \to Xe^+\nu) \sim 8\%$
- Technique is to find events with an e^+ opposite D_S^- tags & no other tracks, with Σ calorimeter energy < 400 MeV
- No need to find γ from D_S^*
- $B(D_S^+ \to \tau^+\nu) = (6.29 \pm 0.78 \pm 0.52)\%$
- $f_{Ds} = 278 \pm 17 \pm 12$ MeV



f_{D_s} & f_{D_s}/f_{D^+}

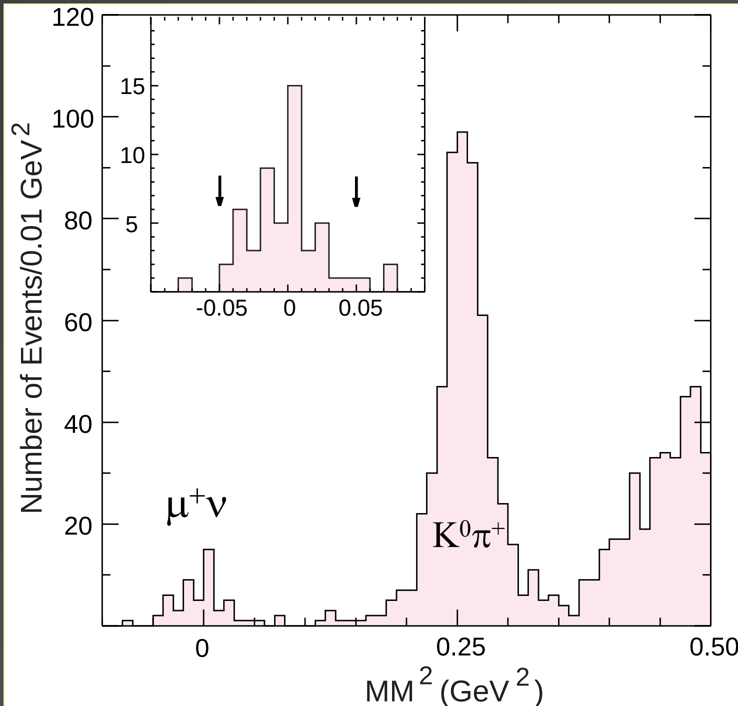
- Weighted Average: f_{Ds}=280.1±11.6±6.0 MeV, the systematic error is mostly uncorrelated between the measurements
- Previously CLEO-c measured

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

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

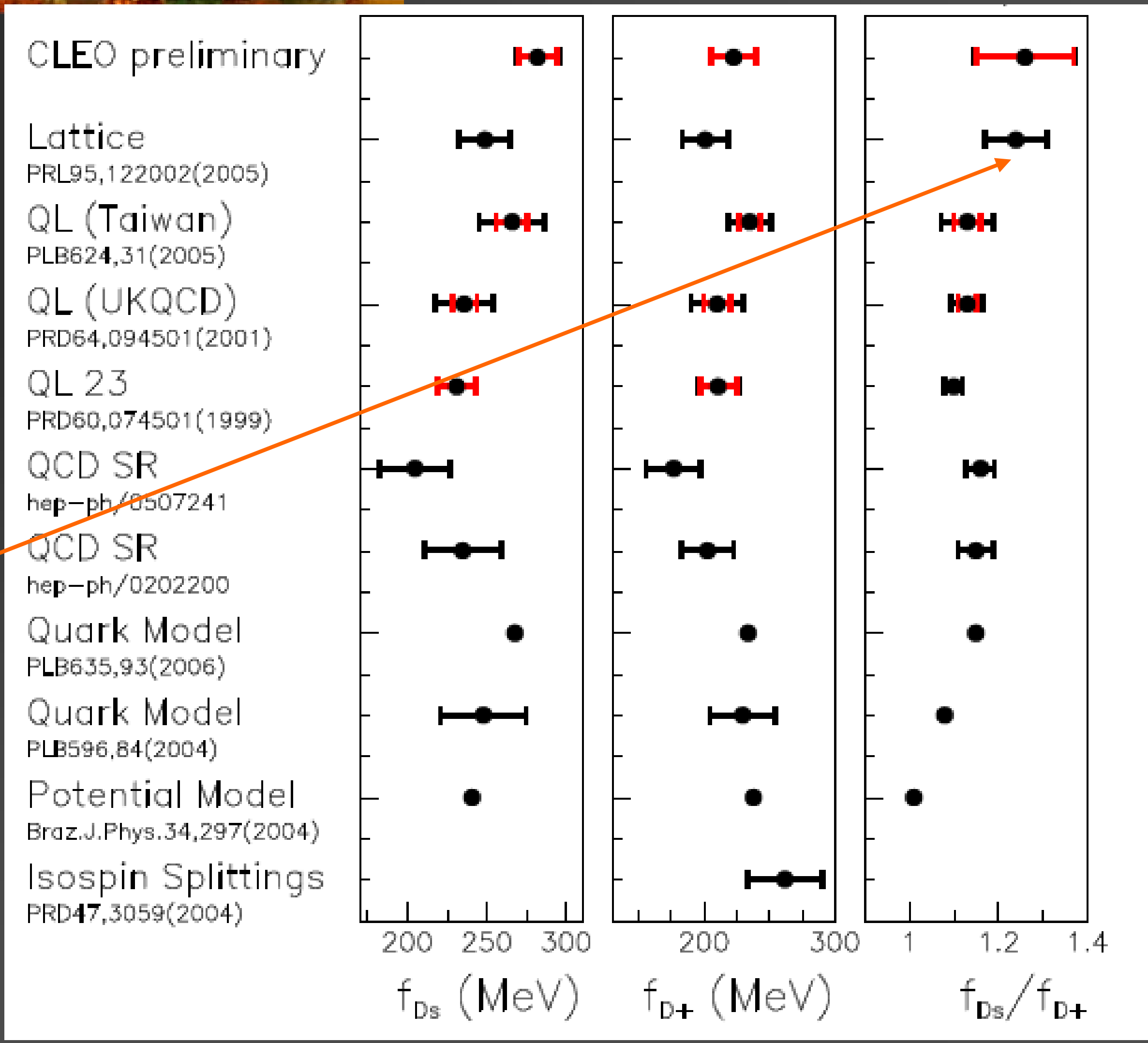
- Thus f_{Ds}/f_{D^+}=1.26±0.11±0.03
- $\Gamma(D_S^+\to\tau^+\nu)/\Gamma(D_S^+\to\mu^+\nu)$= 9.9±1.7±0.7, SM=9.72, consistent with lepton universality

$D^+\to\mu^+\nu$



Comparisons with Theory

- We are consistent with most models, more precision needed
- Using Lattice ratio find $|V_{cd}/V_{cs}|=$ 0.22±0.03



Comparison with Previous Experiments

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	-		280.1±11.6±6.0
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]	$\tau^+\nu$	$(7.0 \pm 2.1 \pm 2.0)10^{-3}$	?	$286 \pm 44 \pm 41$
L3 [33]	$\tau^+\nu$	$(7.4 \pm 2.8 \pm 1.6 \pm 1.8)10^{-3}$	?	$302 \pm 57 \pm 32 \pm 37$
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^+}

The End