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

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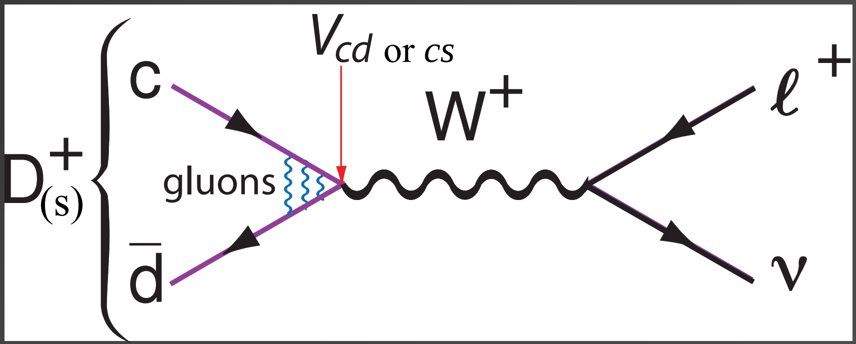
Leptonic Decays: $D \to \ell^+\nu$

Introduction: Pseudoscalar decay constants

c and $\bar{q}$ can annihilate, probability is $\propto$ to wave function overlap

Example :



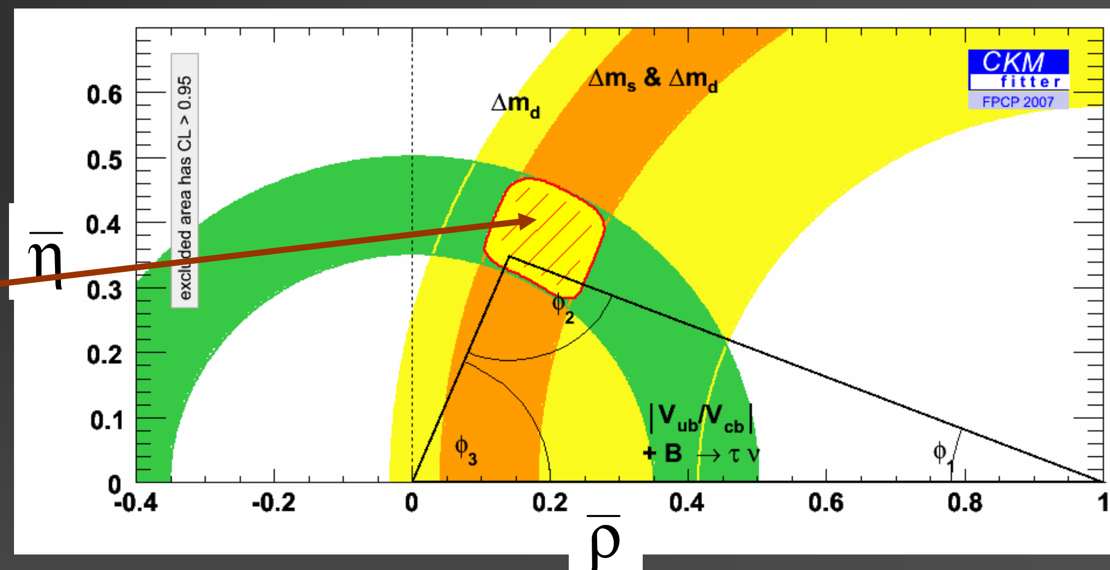
In general for all pseudoscalars:

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

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. $B \to \tau^+\nu$ gives $V_{ub}f_B$), but we can determine f_D & f_{Ds} using $D \to \ell^+\nu$ and use them to test theoretical models (i.e. Lattice QCD)



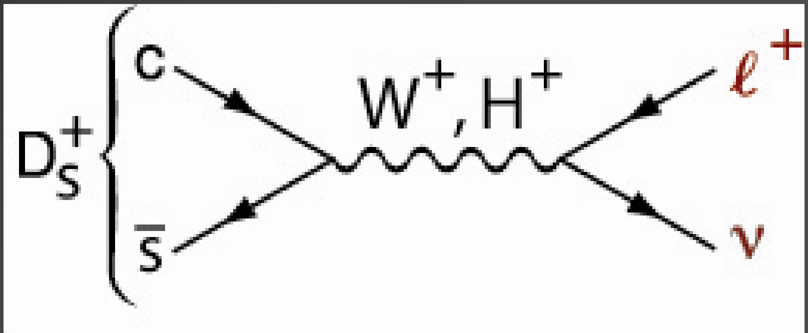
Constraints from V_{ub}, Δm_d, Δm_s & $B \to \tau^+\nu$

New Physics Possibilities

- In Standard Model

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

- Another Gauge Boson could also mediate decay, could modify ratio or change decay rates

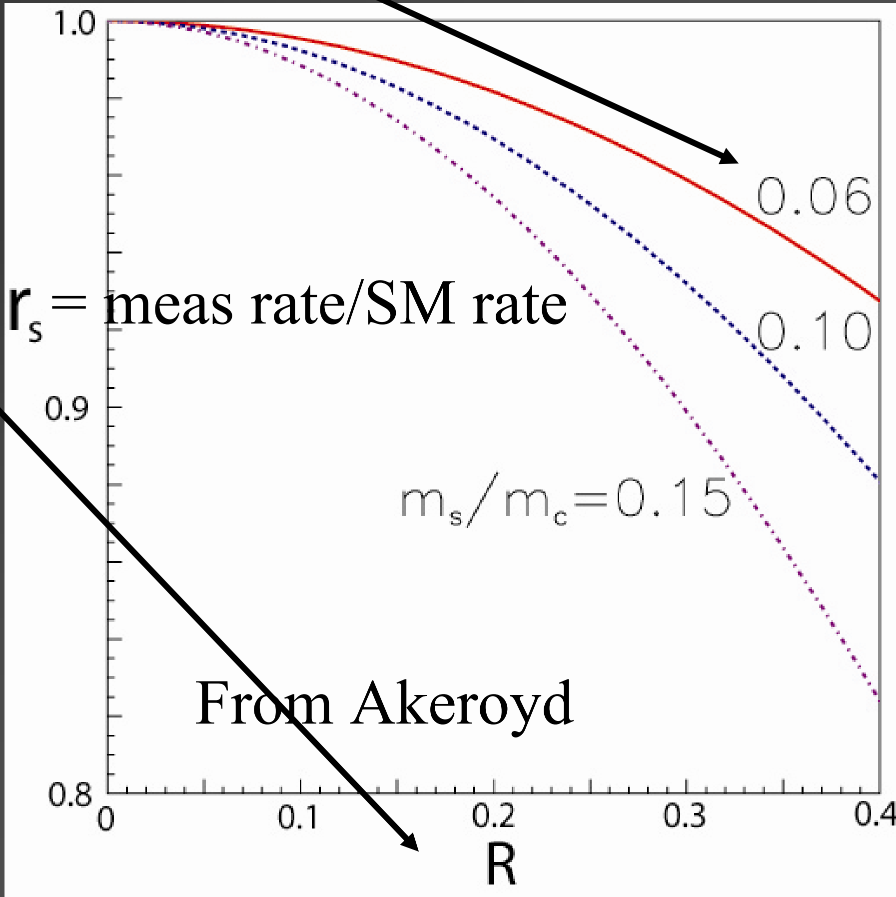


See Hewett [hep-ph/9505246] & Hou, PRD 48, 2342 (1993).

New Physics Possibilities II

- In SUSY Akeroyd calculated Leptonic decay rate as a function of m_s/m_c.
- In terms of SUSY parameter $R = \tan\beta/m_H$

See Akeryod [hep-ph/0308260]



Experimental methods

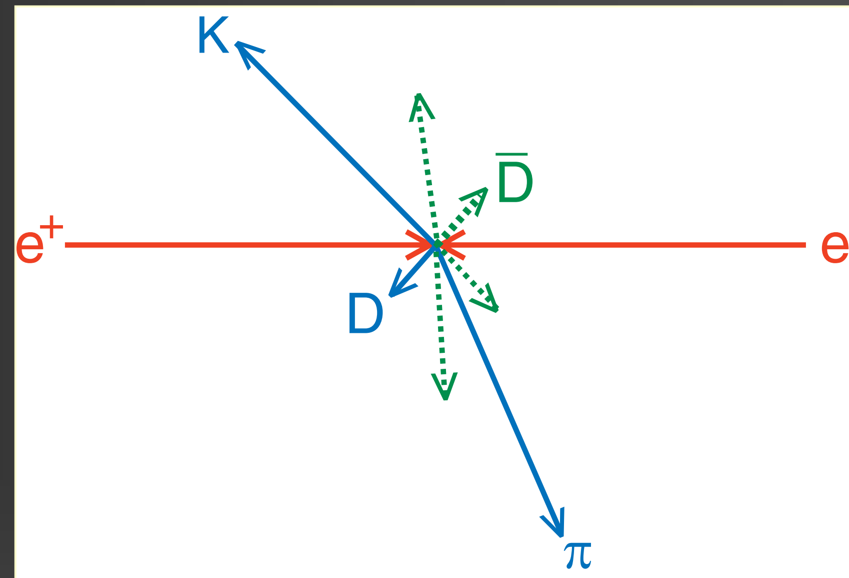
- $D\bar{D}$ production at threshold: used by Mark III, and more recently by CLEO-c and BES-II.
  - Unique event properties
  - Large cross sections:

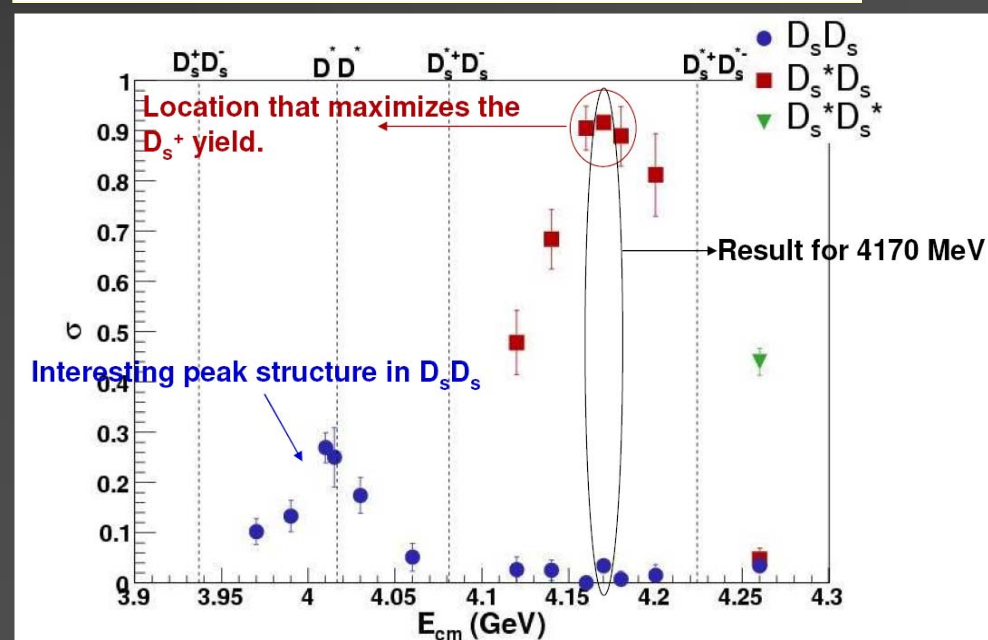
$\sigma(D^o\bar{D}^o) = 3.72\pm0.09$ nb
$\sigma(D^+D^-) = 2.82\pm0.09$ nb
World Ave

$\sigma(D_SD_S^*) = \sim 0.9$ nb

Continuum ~12 nb

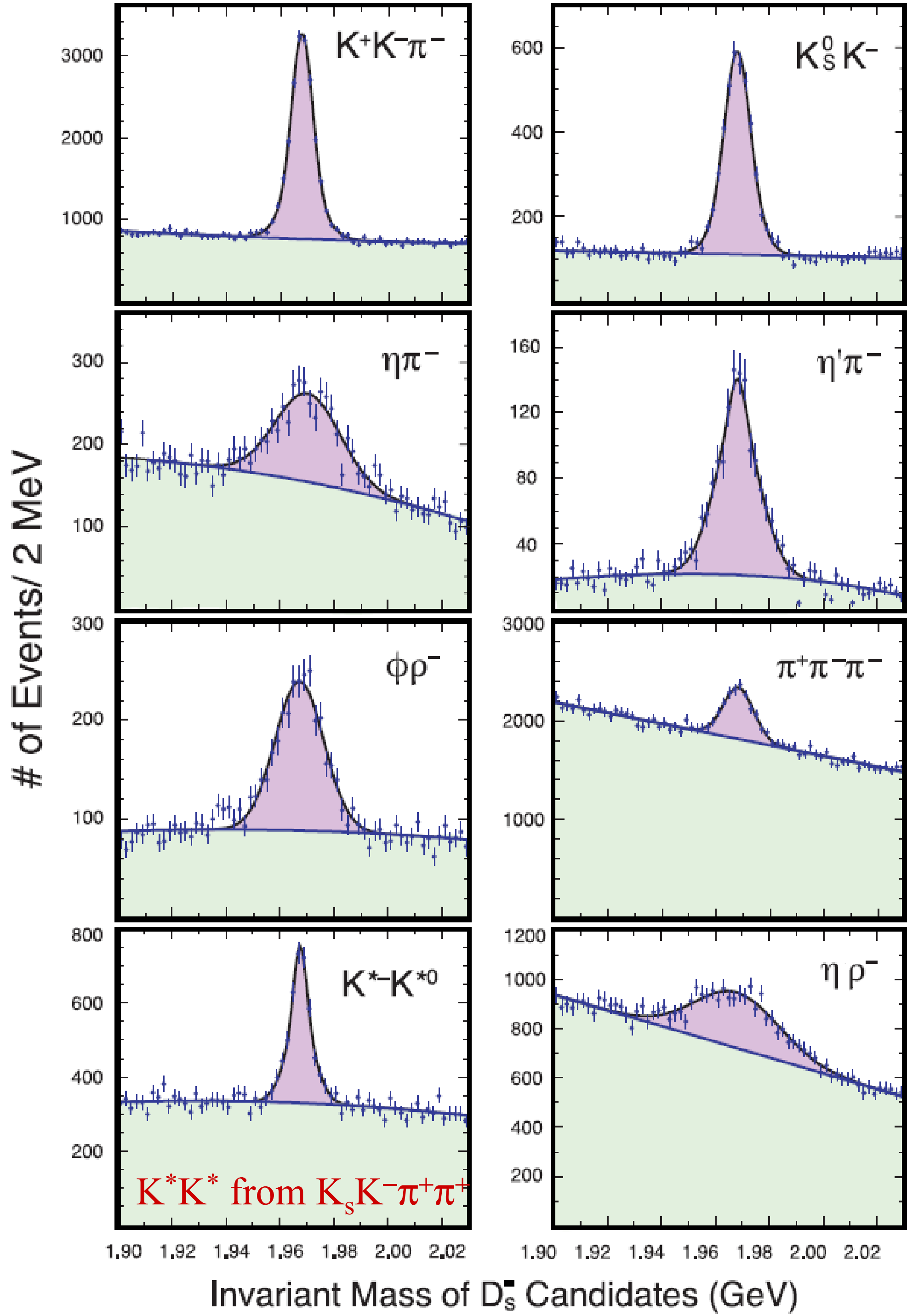
  - Ease of B measurements using "double tags"
  - $\mathcal{B}_A$ = # of A/# of D's





Invariant masses

- D_S studies done at E_{cm}=4170 MeV
- To choose tag candidates:
  - Fit distributions & determine σ
  - Cut at ±2.5 σ
- Define sidebands to measure backgrounds 5-7.5 σ
- Total # of Tags = 31,302± 472 (stat)



Measurements of f_{Ds}

- Two separate techniques
- (1) Measure $D_S^+ \to \mu^+ \nu$ along with $D_S \to \tau^+ \nu$, $\tau \to \pi^+ \nu$. This requires finding
  - a D_S^- tag,
  - a γ from either $D_S^{*-} \to \gamma D_S^-$ or $D_S^{*+} \to \gamma \mu^+ \nu$.
  - the muon or pion
  - Then inferring a single missing ν using kinematical constraints (use 314 pb^{-1}, *results are accepted for publication*)
- (2) Find $D_S^+ \to \tau^+ \nu$, $\tau \to e^+ \nu \nu$ opposite a D_S^- tag (use 195 pb^{-1}, *results are preliminary*)

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

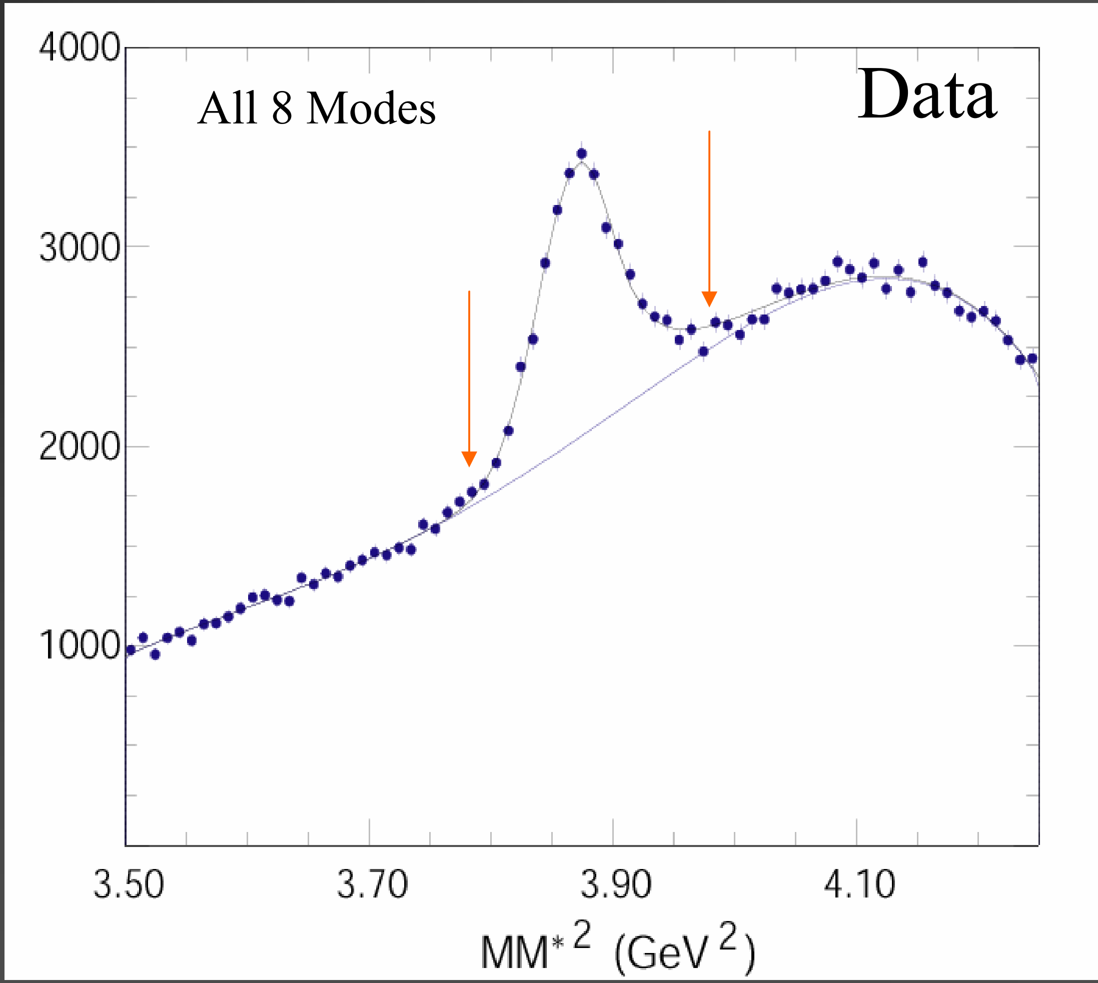
- We see all the particles from $e^+e^- \rightarrow D_S^* D_S$, γ, D_S (tag) + μ^+ except for the single ν
- We use a kinematic fit to (a) improve the resolution & (b) remove ambiguities
  - Constraints include: total p & E, tag D_S mass, $\Delta m = M(\gamma D_S) - M(D_S)$ [or $\Delta m \underset{\rightarrow}{=} M(\gamma\mu\nu) - M(\mu\nu)$] = 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.



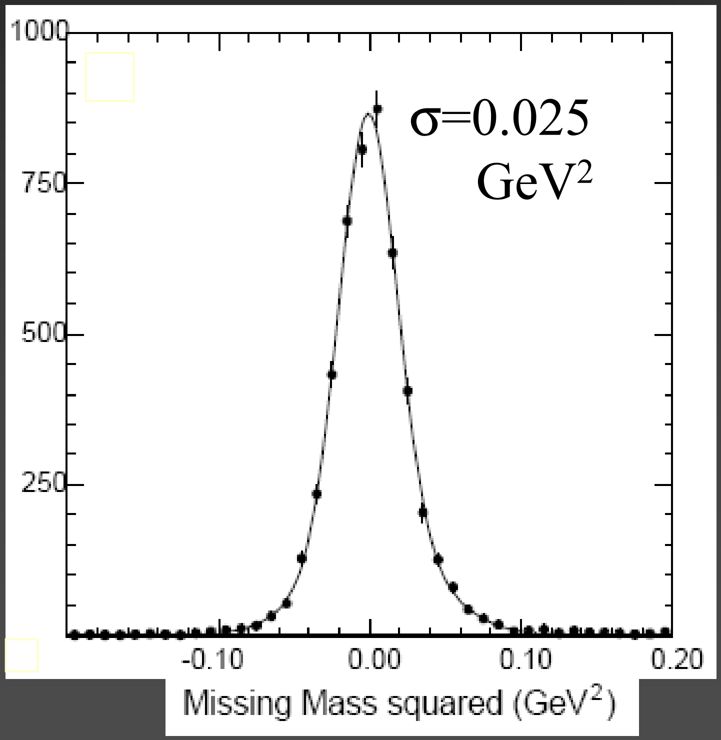
Define Three Classes

- Class (i), single track deposits < 300 MeV in calorimeter, minimum ionizing (accepts 99% of muons and 60% of kaons & pions)
- Class (ii), single track deposits > 300 MeV in calorimeter (accepts 1% of muons and 40% of kaons & pions)
- Class (iii) single track consistent with electron
- For all 3 cases require no other γ with energy > 300 MeV.

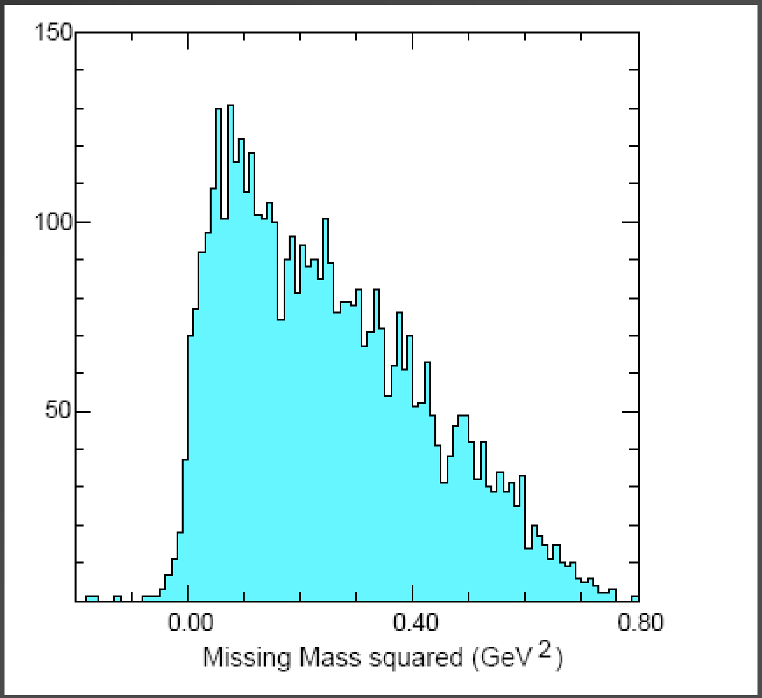
The MM^2

- To find the signal events, we compute

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



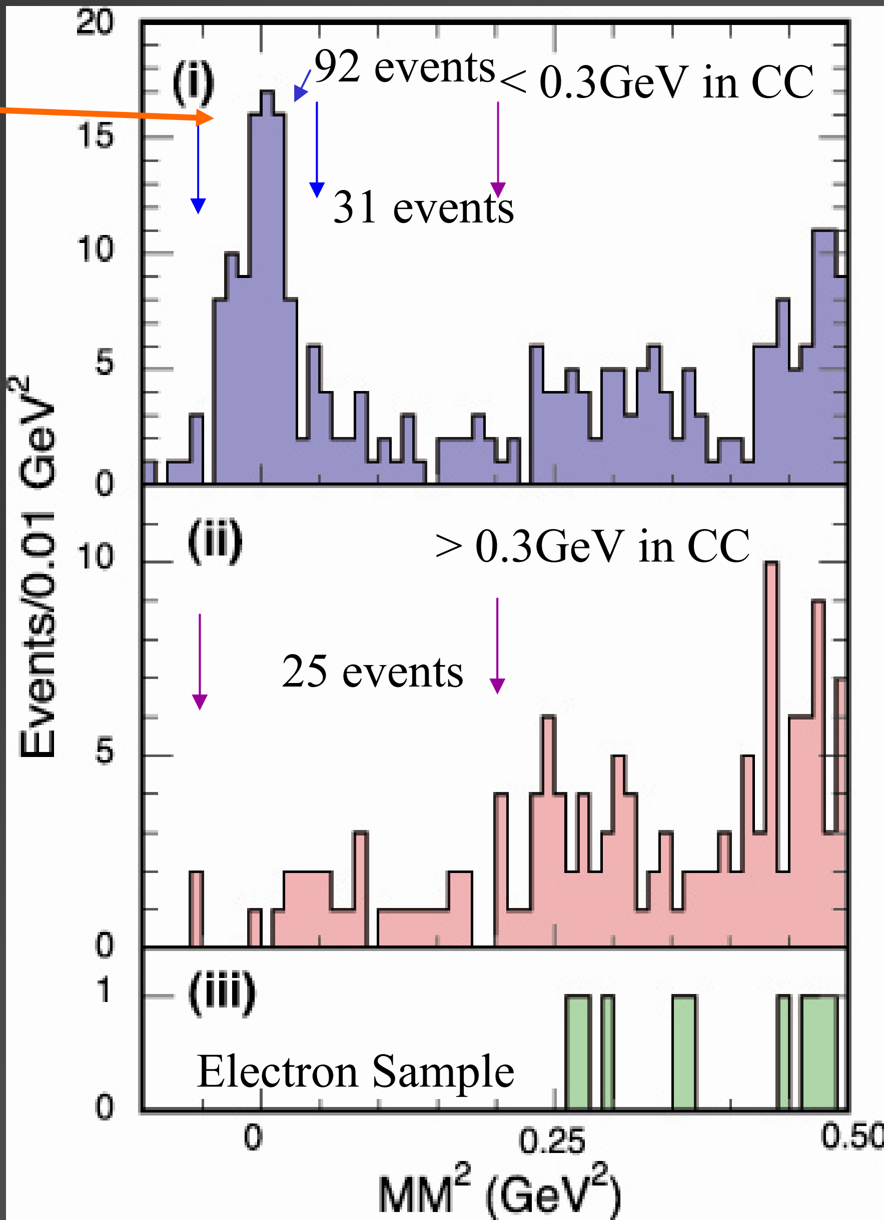
Signal μν



Signal τν, τ→πν

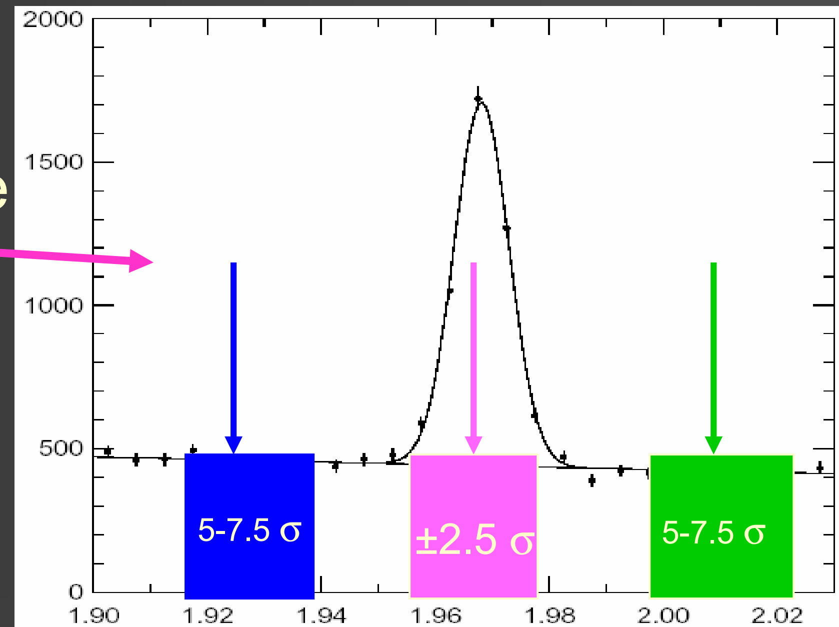
MM^2 In Data

- 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)



Background Samples

- Two sources of background
- 1) Bkgrnd under invariant mass peaks – Use sidebands to estimate
- In $\mu^+\nu$ signal region, case (i) & $|MM|^2<0.05$ GeV^2, 3.5 bkgrd, out of 92 events
- Bkgrnd for cases (i) & (ii) & $MM^2<0.20$ GeV^2= 9.0±2.3
- 2) 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
- $B(D_S \rightarrow\pi^+\pi^o) < 1.1\text{x}10^{-3}$ & γ energy cut yields <0.2 evts



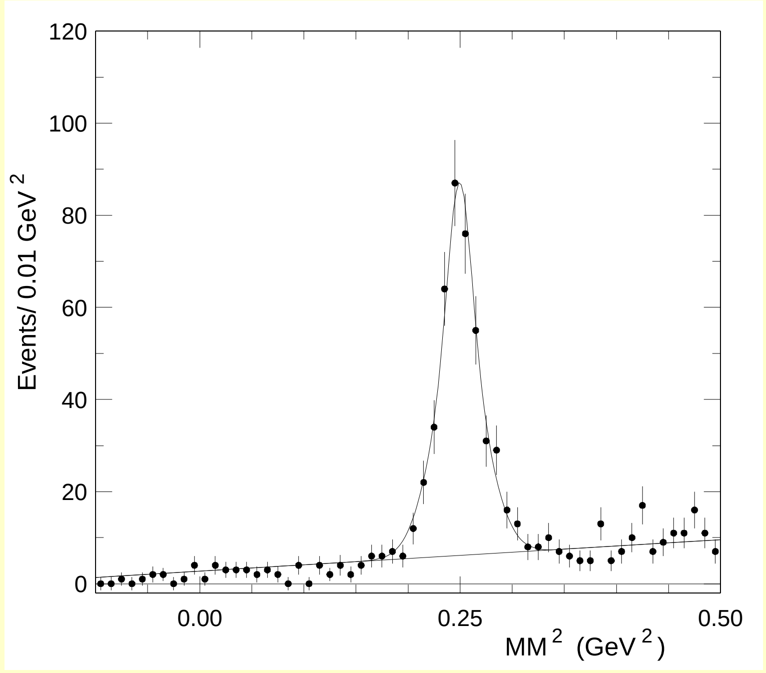
Low SB region | Signal region | High SB region

Backgrounds from real D_S^+ in $\tau\rightarrow\pi\nu$

Source	$\mathcal{B}(\%)$	# of events case (i)	# of events case(ii)	Sum
$D_s^+ \rightarrow X\mu^+\nu$	8.2	$0^{+1.8}_{-0}$	0	$0^{+1.8}_{-0}$
$D_s^+ \rightarrow \pi^+\pi^0\pi^0$	1.0	0.03±0.04	0.08±0.03	0.11±0.04
$D_s^+ \rightarrow \tau^+\nu$	6.4			
$\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}$	1.5	0.55±0.22	0.64±0.24	1.20±0.33
$\tau^+ \rightarrow \mu^+\overline{\nu}\nu$	1.0	0.37±0.15	0	0.37±0.15
Sum		$1.0^{+1.8}_{-0}$	0.7±0.2	$1.7^{+1.8}_{-0.4}$

Check: $\mathcal{B}(D_s^+ \rightarrow K^+ K^o)$

- Do almost the same analysis but consider MM^2 off of an identified K^+
- Allow extra charged tracks and showers to not veto K^o decays or interactions in EM cal
- Signal verifies expected MM^2 resolution
- Find (2.90±0.19±0.18)%, compared with result from double tags (3.00±0.19±0.10)%



Branching Ratio & Decay Constant

- $D_S^+ \to \mu^+ \nu$
  - 92 signal events, 3.5 background, use SM to calculate $\tau\nu$ yield near 0 MM^2 based on known $\tau\nu/\mu\nu$ ratio (~7 evnts)
  - $B(D_S^+ \to \mu^+ \nu) = (0.597 \pm 0.067 \pm 0.039)\%$
- $D_S^+ \to \tau^+ \nu$, $\tau^+ \to \pi^+ \nu$
  - Sum case (i) $0.05 < MM^2 < 0.2$ GeV^2 & case (ii) $-0.05 < MM^2 < 0.2$ GeV^2. Total of 56 signal and 8.6 background
  - $B(D_S^+ \to \tau^+ \nu) = (8.0 \pm 1.3 \pm 0.4)\%$
- By summing both cases above,(& use SM ratio) find

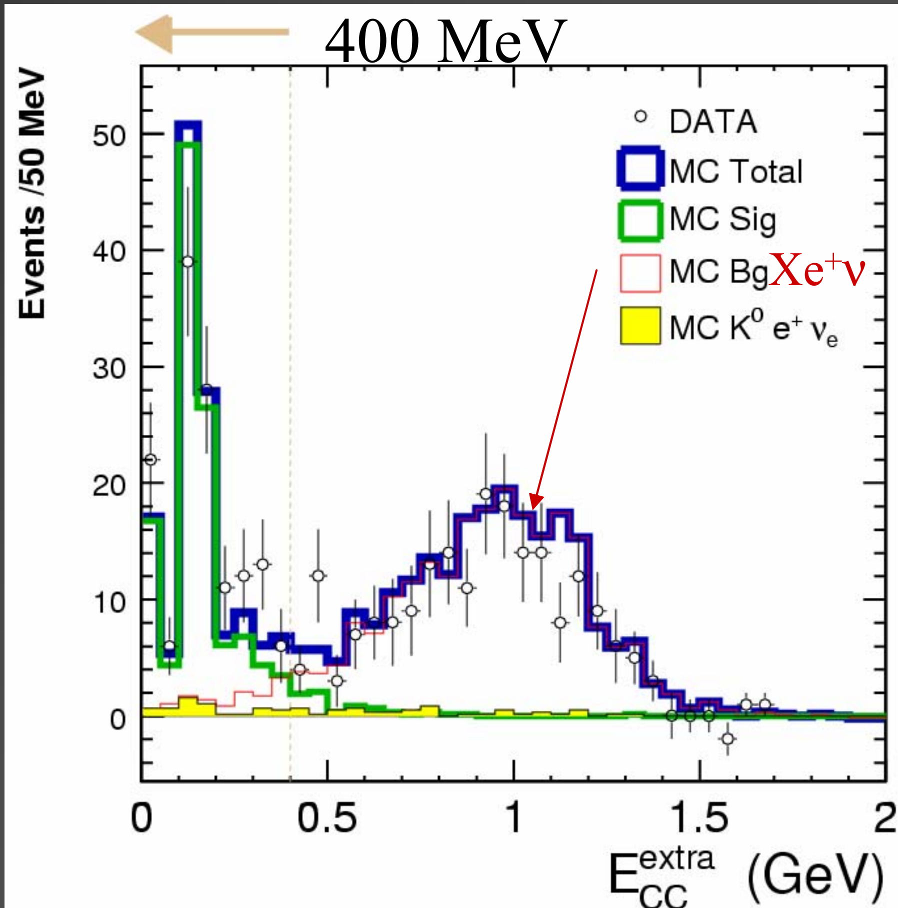
  $B^{eff}(D_S^+ \to \mu^+ \nu) = (0.638 \pm 0.059 \pm 0.033)\%$
- $f_{Ds} = 274 \pm 13 \pm 7$ MeV
- $B(D_S^+ \to e^+ \nu) < 1.3 \times 10^{-4}$

$\mathcal{B}(D_S^+ \to \mu^+ \nu)$ Systematic errors

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

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

- Use 195 pb^{-1} for this preliminary analysis
- $B(D_S^+ \to \tau^+\nu) \bullet B(\tau^+ \to e^+\nu\nu) \sim 1.3\%$ 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^*
- $B(D_S^+ \to \tau^+\nu)$ $=(6.29\pm0.78\pm0.52)\%$
- $f_{D_s}=278 \pm 17 \pm 12$ MeV



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

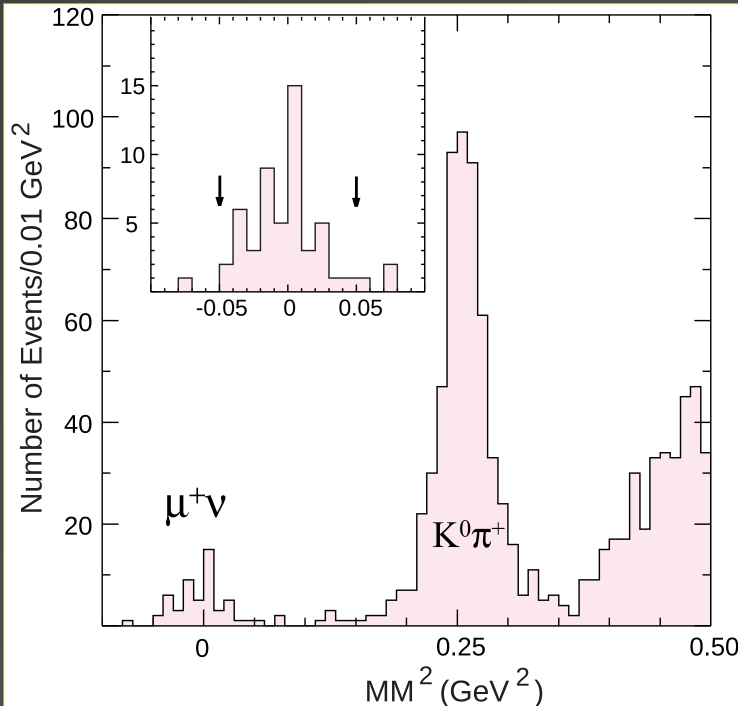
- Weighted Average: f_{Ds}=275±10±5 MeV, the systematic error is mostly uncorrelated between the measurements
- Previously CLEO-c measured

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

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

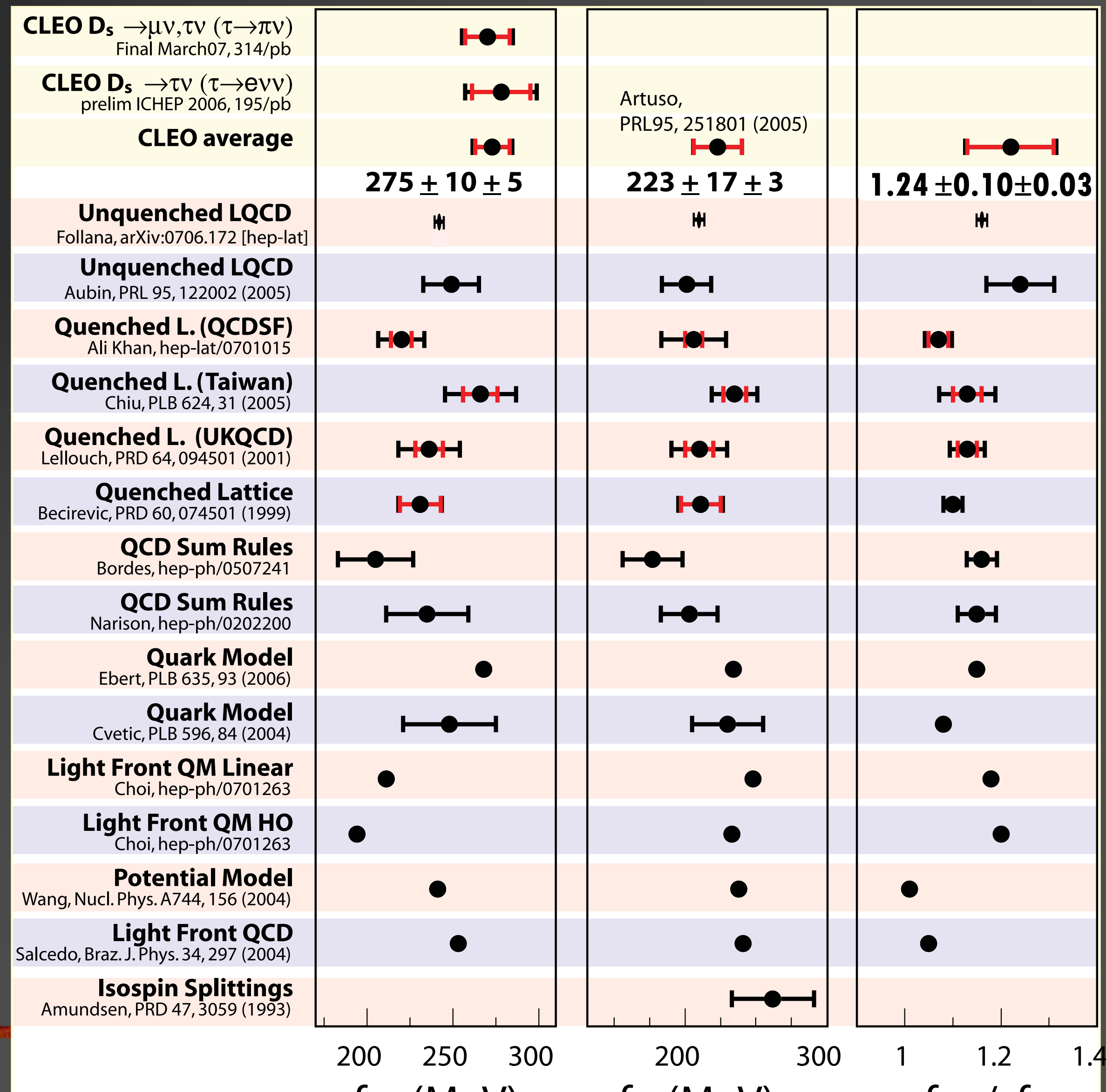
- Thus f_{Ds}/f_{D^+}=1.24±0.10±0.03
- $\Gamma(D_S^+ \to \tau^+\nu)/\Gamma(D_S^+ \to \mu^+\nu)$= 11.5±2.0, SM=9.72, consistent with lepton universality

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



Comparisons with Theory

- We are consistent with most models, more precision needed
- Using Lattice ratio find $|V_{cd}/V_{cs}|$=0.2166 ±0.020 (exp) ±0.0017(theory)



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	-		275±10±5
CLEO	$\mu^+\nu$	$(6.2 \pm 0.8 \pm 1.3 \pm 1.6)10^{-3}$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE	$\mu^+\nu$	$(8.3 \pm 2.3 \pm 0.6 \pm 2.1)10^{-3}$	3.6±0.9	$315 \pm 43 \pm 12 \pm 39$
ALEPH	$\mu^+\nu$	$(6.8 \pm 1.1 \pm 1.8)10^{-3}$	3.6±0.9	$285 \pm 19 \pm 40$
ALEPH	$\tau^+\nu$	$(5.8 \pm 0.8 \pm 1.8)10^{-2}$		
OPAL	$\tau^+\nu$	$(7.0 \pm 2.1 \pm 2.0)10^{-2}$	?	$286 \pm 44 \pm 41$
L3	$\tau^+\nu$	$(7.4 \pm 2.8 \pm 1.6 \pm 1.8)10^{-2}$	?	$302 \pm 57 \pm 32 \pm 37$
BaBar	$\mu^+\nu$	$(6.5 \pm 0.8 \pm 0.3 \pm 0.9)10^{-3}$	4.8±0.5±0.4	$279 \pm 17 \pm 6 \pm 19$

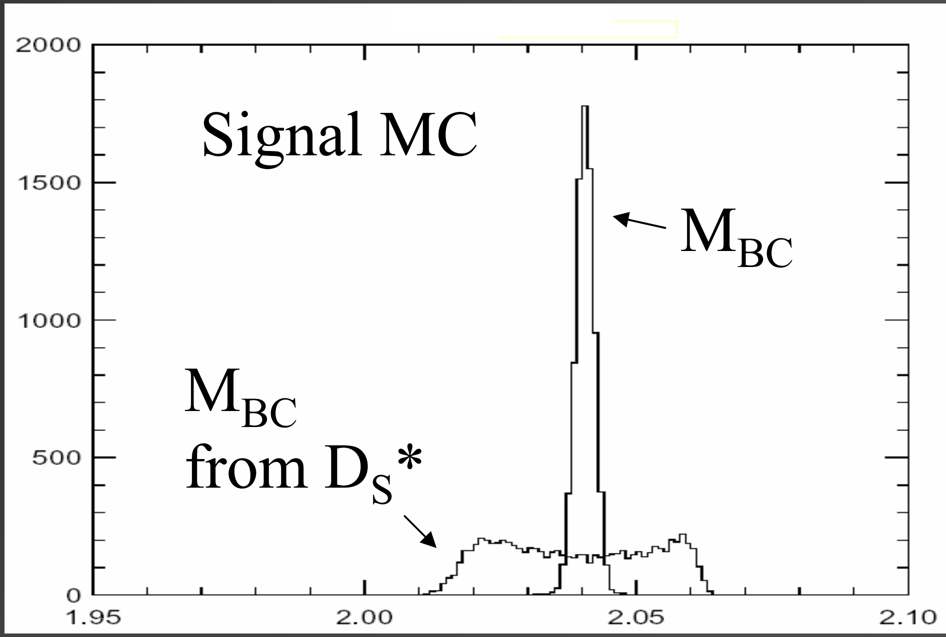
- CLEO-c is most precise result to date for both f_{D_s} & f_{D^+}

-

The End

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 314 pb^{-1} of data



Beam Constrained Mass (GeV)

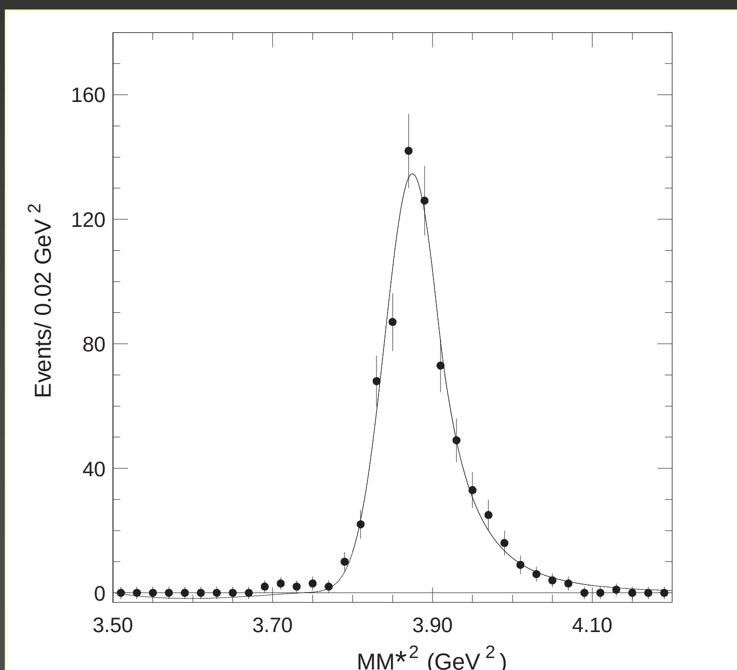
#Tags: $D_s + \gamma$

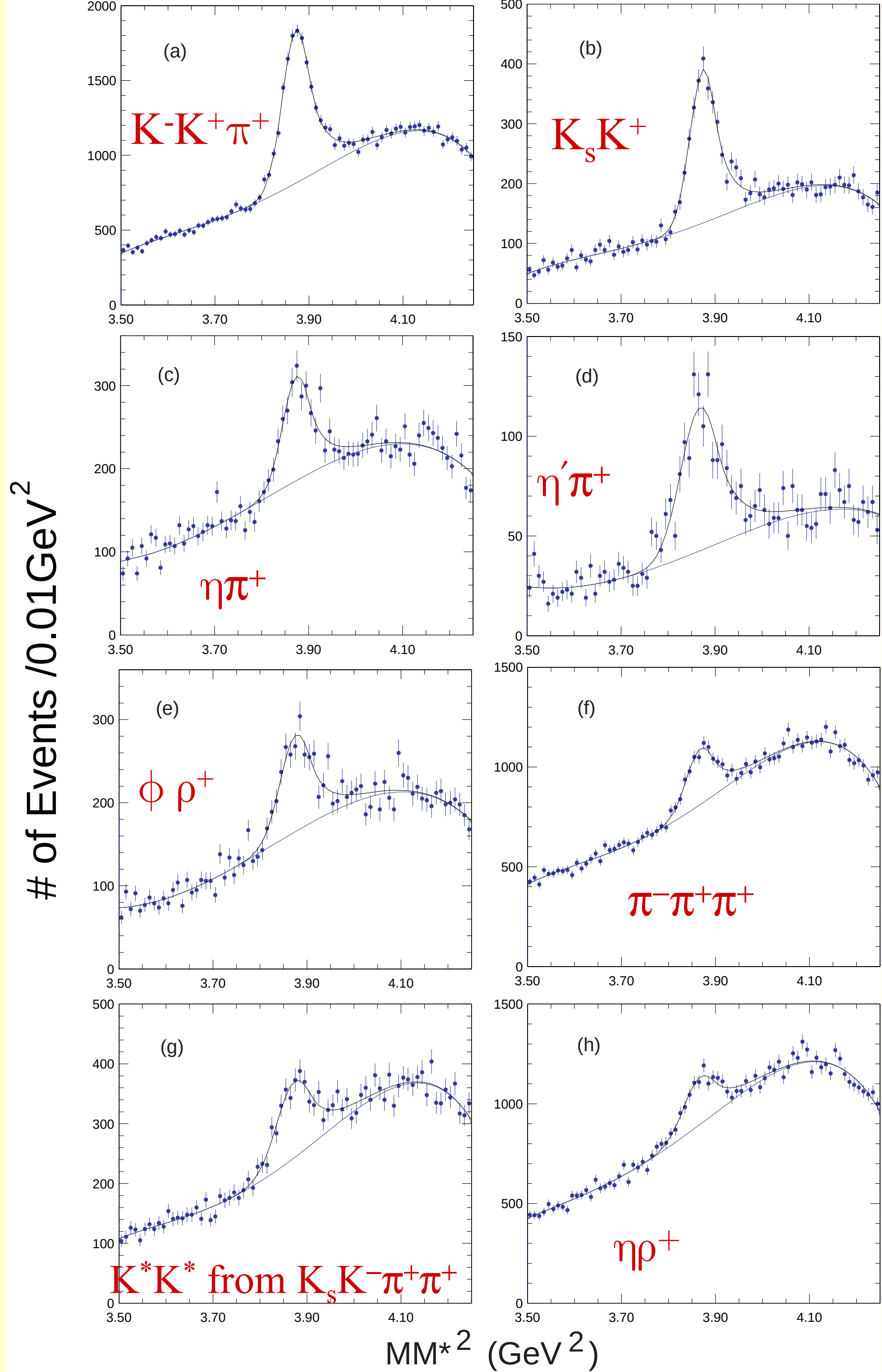
- Compute MM^{*2}

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

in each individual mode

- Use $D_S{}^*D_S$ sample to measure shape of tail





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

- As we will see, there is very little background present in any sub-sample for $MM^2 < 0.2$ GeV^2