Charm Decays at Threshold

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What We Hope to Learn

- Purely Leptonic Charm Decays $D\to\ell^+\nu$: Check QCD calculations including Lattice (LQCD)
- Semileptonic decay rates & form-factors: QCD checks and the reverse, use QCD to extract V_{cq}
- Hadronic Charm Decays
  - Engineering numbers useful for other studies
    - B→Charm is dominant, so knowing lots about charm is useful, e.g. absolute $\mathcal{B}$'s, resonant substructure, phases on Dalitz plots, especially versus CP eigenstates
  - Learn about Strong Interactions, esp. final state interactions
- Charm Mixing & CP Violation
  - Can we see new physics? SM mixing & CP violation is small, so new effects don't have large SM background as in the K or B systems
- ALL RESULTS SHOWN HERE ARE FROM CLEO-C

  ALMOST ALL ARE *PRELIMINARY.* Exceptions will be noted
- *Due to lack of time, many interesting results are omitted*

Absolute Charm Meson Branching Ratios & Other Hadronic Decays

D^o, D^+ & D_S

Experimental methods

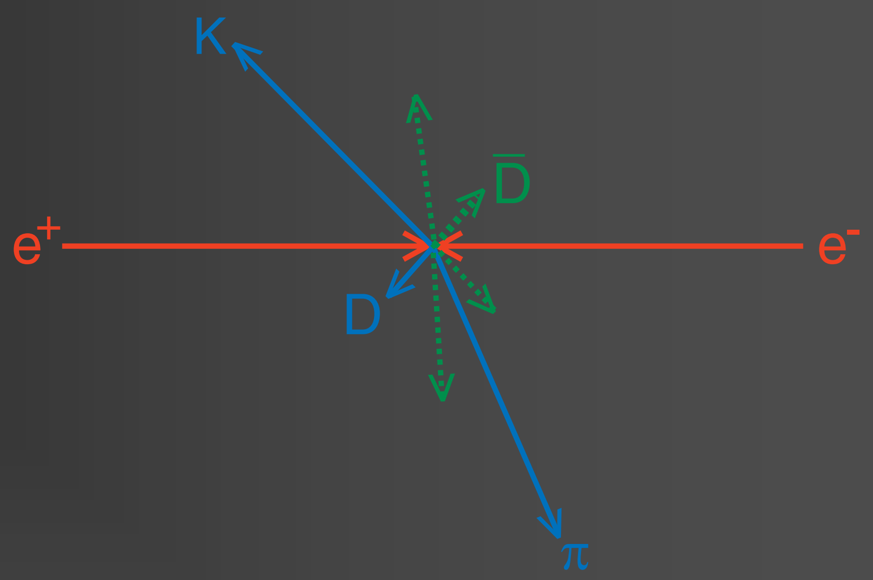
- $D\bar{D}$ production at threshold: used by Mark III, and more recently by CLEO-c and BES-II.
  - Unique event properties
    - Only $D\bar{D}$ not $D\bar{D}x$ produced
  - Large cross sections:

$\sigma(\bar{D}^o D^o)$ = 3.72±0.09 nb
$\sigma(D^+D^-)$ = 2.82±0.09 nb
(World Ave)

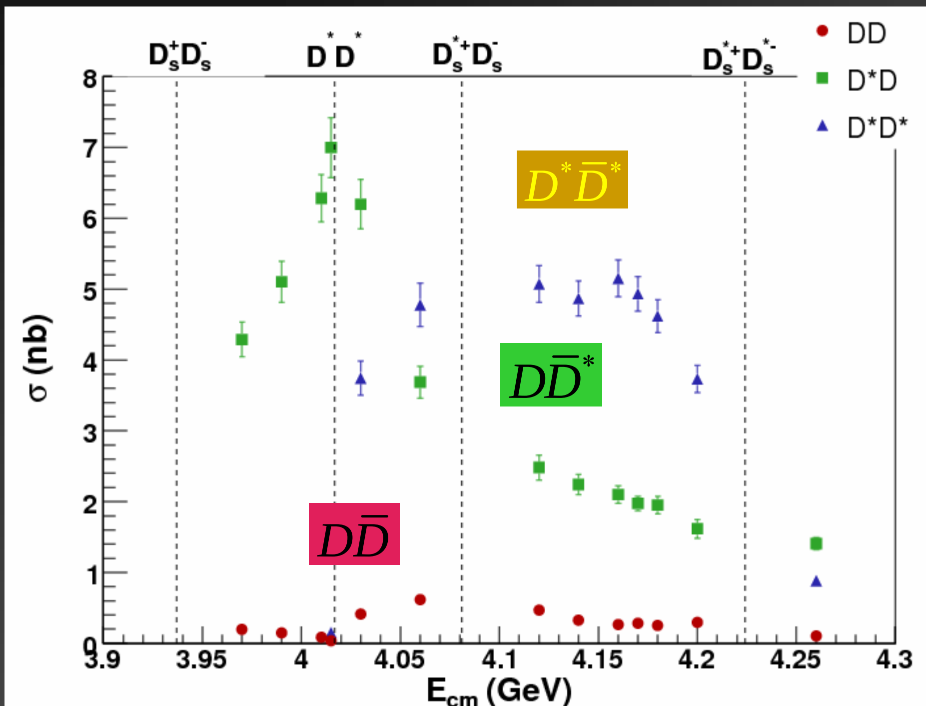
$\sigma(D_S D_S^*)$ = 0.9 nb

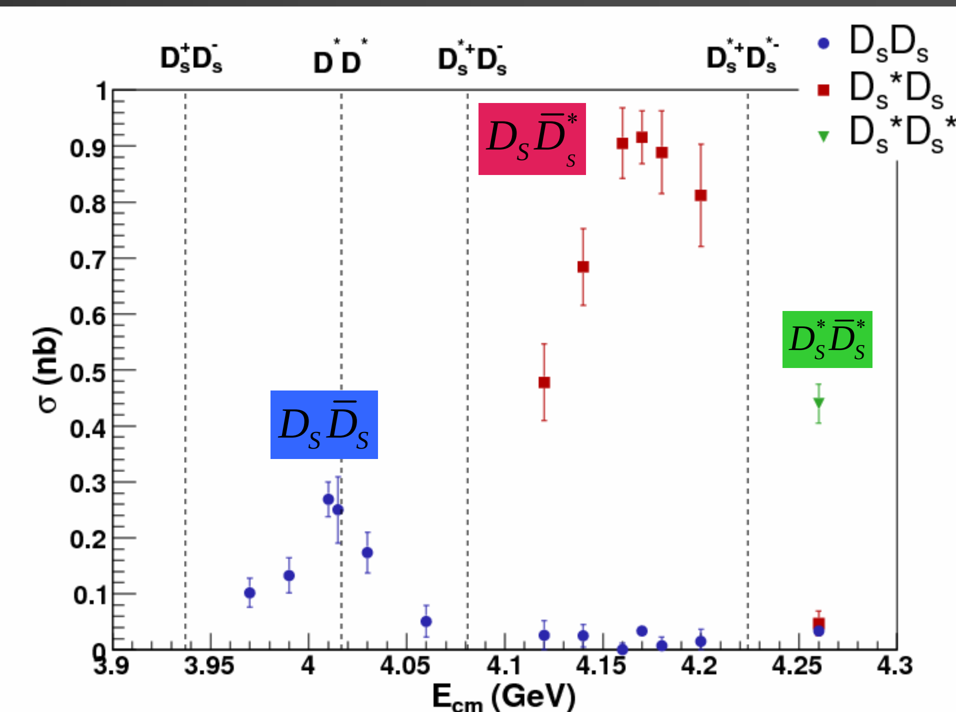
Continuum ~14 nb

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



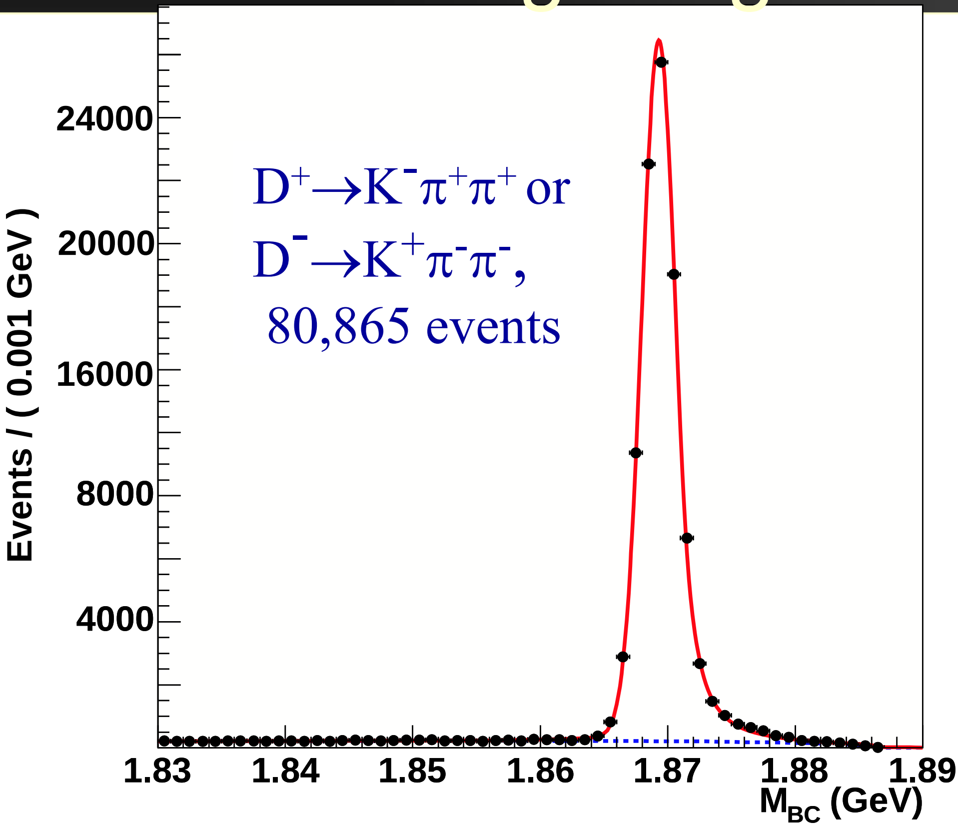
Charm Cross-Sections



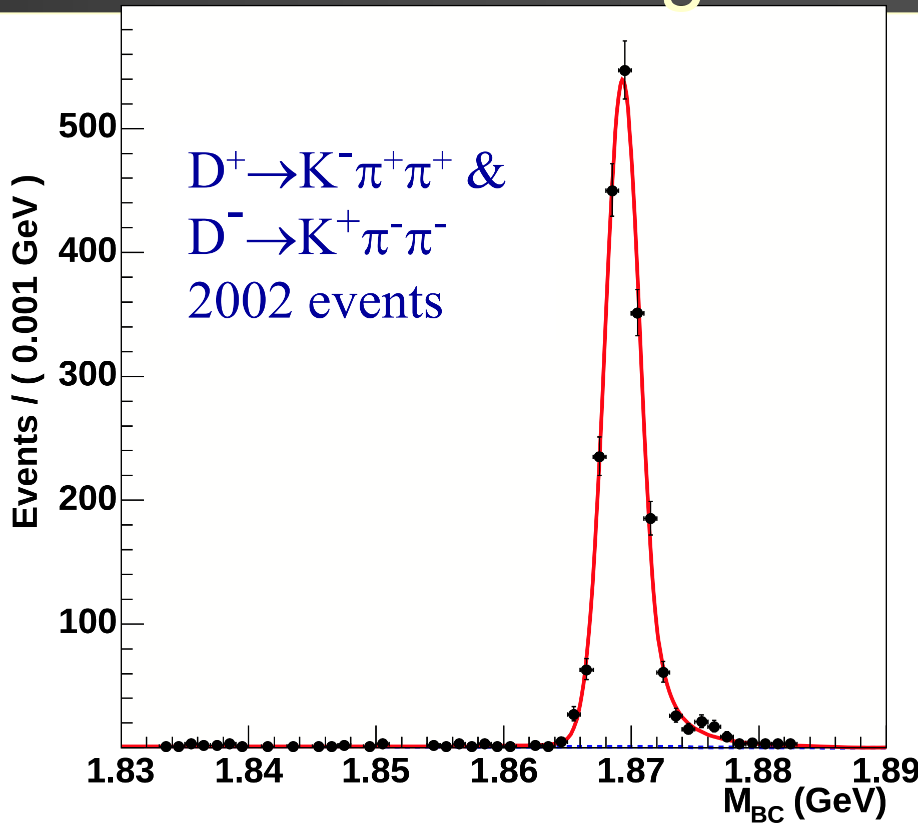


$D^+ \to K^- \pi^+ \pi^+$ at the ψ'' (CLEO-c)

Single tags



Double tags



$$M_D^2 = \sum E_i^2 - \sum \vec{P}_i^2 = E_{beam}^2 - \sum \vec{P}_i^2$$

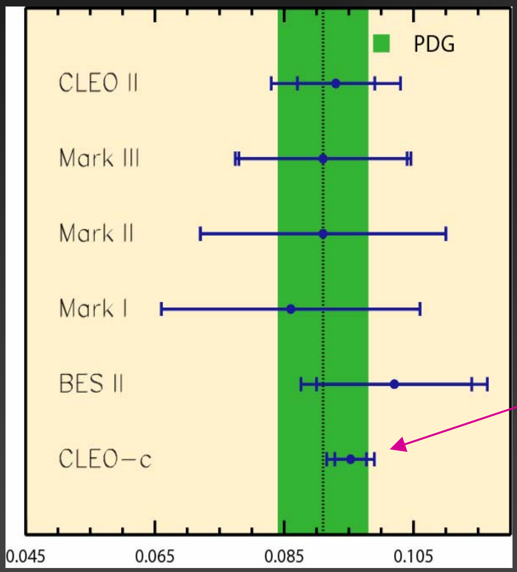
281 pb^{-1} of data at $\psi(3770)$

Absolute $\mathcal{B}$ Results for D^+ & D^o 57 pb^{-1}

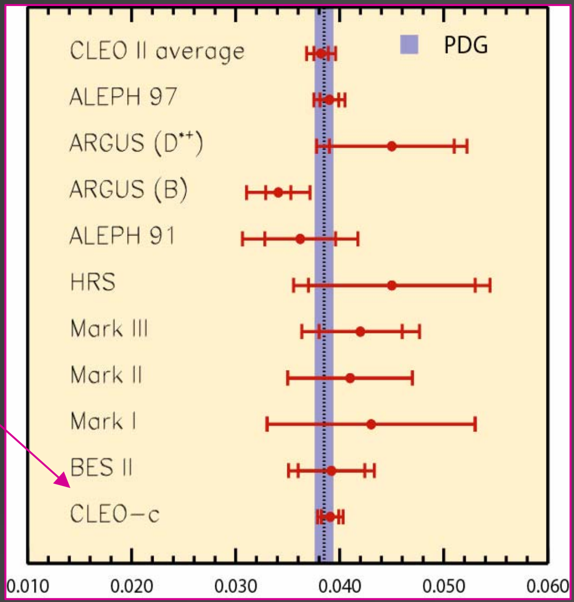
$\mathcal{B}(D^+ \to K^- \pi^+ \pi^+)$

Not preliminary

$\mathcal{B}(D^o \to K^- \pi^+)$



CLEO-c
(not in average)



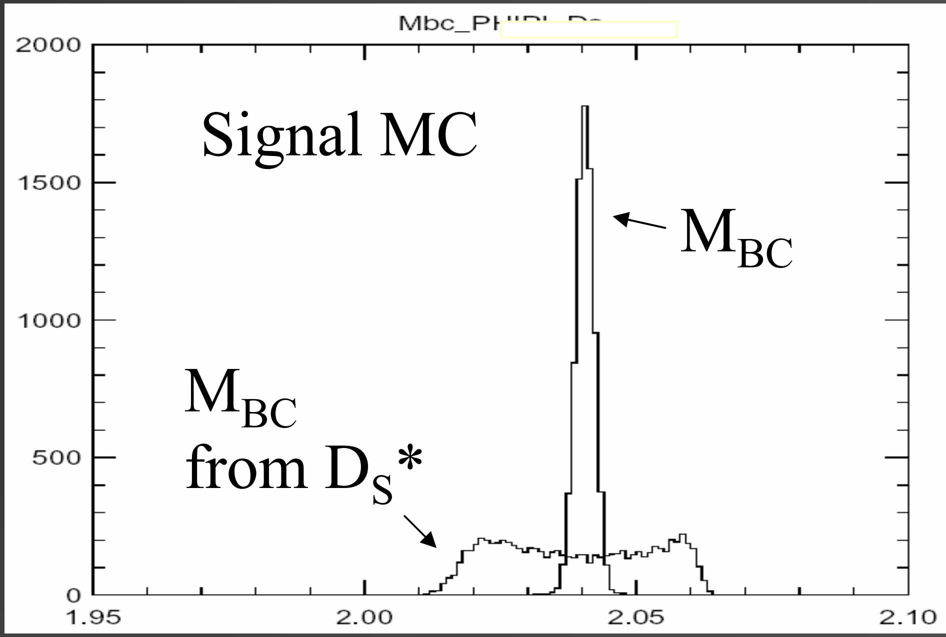
$\mathcal{B}$ (%)	Error(%)	Source
9.52 ±0.25±0.27	3.9	CLEO-c
9.2±0.6	6.5	PDG
9.43 ±0.31	3.3	World avg

$\mathcal{B}$ (%)	Error(%)	Source
3.91±0.08 ±0.09	3.1	CLEO-c
3.81±0.09	2.4	PDG
3.85 ±0.07	1.9	World avg

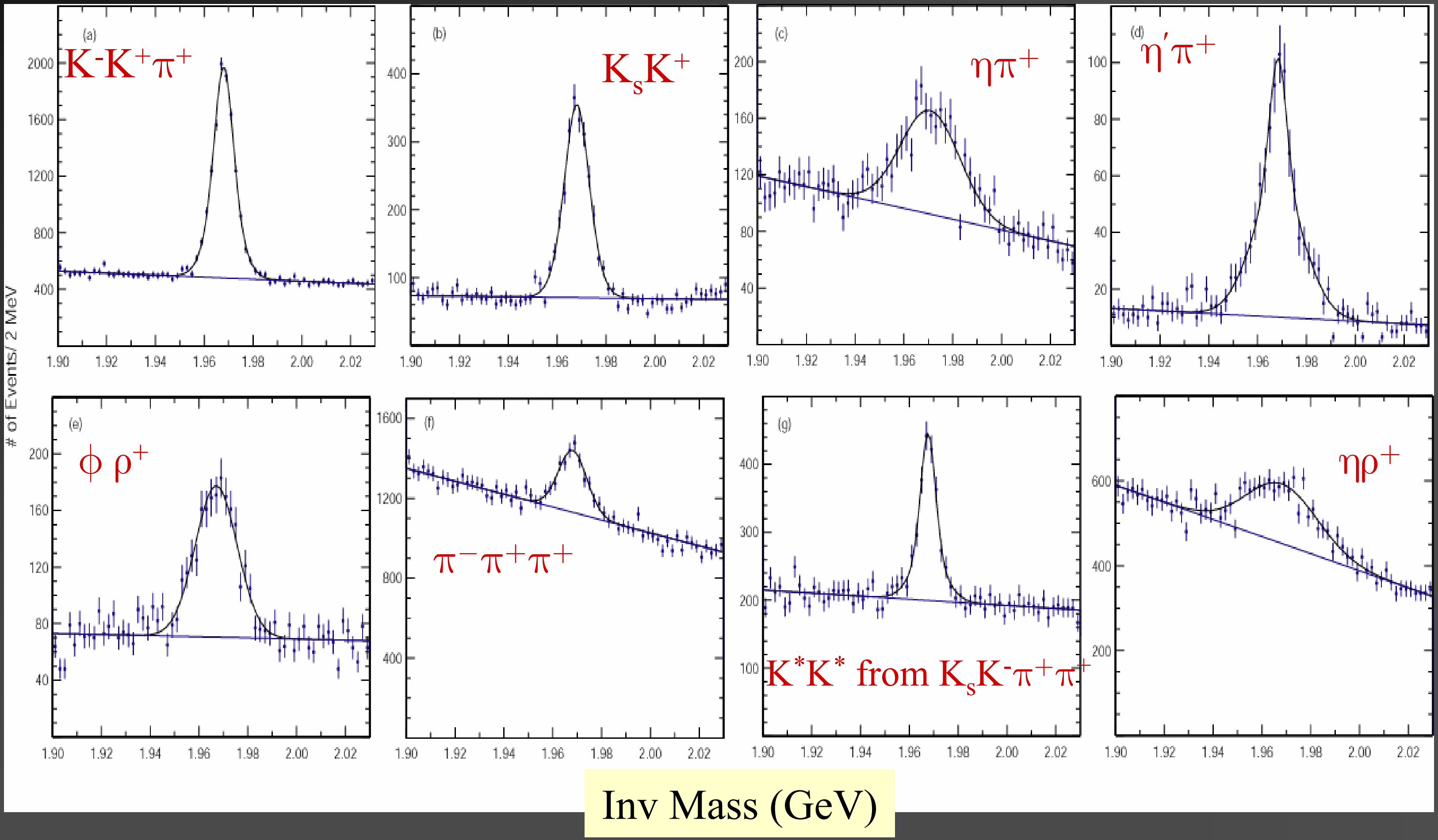
For 281pb^{-1} (systematics limited):
2.2% projected error 1.8% projected error

CLEO D_S^+ Results at 4170 MeV

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



Invariant masses



Total # of Tags = 19185±*325* (stat)

Single & Double D_S^+ Tags in 200 pb^{-1}

Single tags

	$K_S K^+$	$K^- K^+ \pi^+$	$K^- K^+ \pi^+ \pi^0$	$\pi^+ \pi^+ \pi^-$	$\pi^+ \eta$	$\pi^+ \eta'$
D_s^+	1054.8 ± 39.4	4315.8 ± 88.8	1159.7 ± 84.5	969.5 ± 79.5	547.0 ± 49.8	361.8 ± 23.4
D_s^-	927.8 ± 37.3	4349.7 ± 88.7	1250.6 ± 84.4	946.7 ± 77.7	569.8 ± 49.7	371.5 ± 23.6

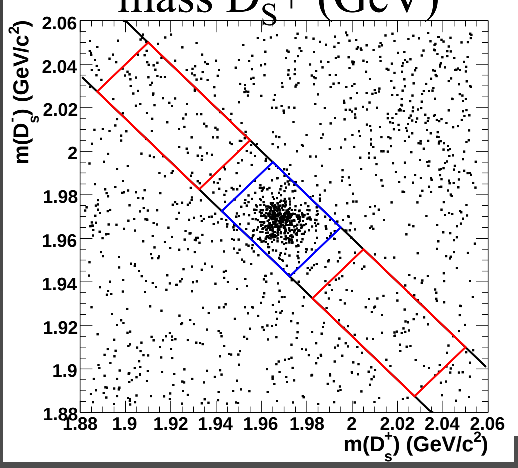
Double tags

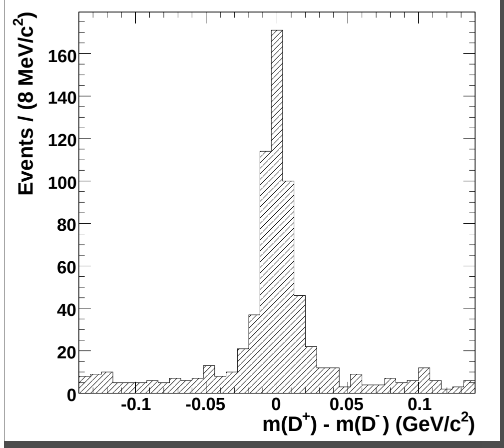
	$K_S K^-$	$K^+ K^- \pi^-$	$K^+ K^- \pi^- \pi^0$	$\pi^- \pi^- \pi^+$	$\pi^- \eta$	$\pi^- \eta'$
$K_S K^+$	7.7	27.0	18.7	7.3	4.0	5.0
$K^- K^+ \pi^+$	18.0	104.7	43.7	30.7	12.0	8.0
$K^- K^+ \pi^+ \pi^0$	8.7	35.7	14.0	13.3	1.0	5.7
$\pi^+ \pi^+ \pi^-$	3.3	22.7	16.0	13.3	4.7	4.0
$\pi^+ \eta$	0.0	10.0	2.7	6.0	1.0	1.7
$\pi^+ \eta'$	3.0	10.0	3.0	3.7	1.0	0.0

- Modes: Different selection criteria than other analyses
- Clean double tag signal

mass D_S+ (GeV)

mass D_S^- (GeV)

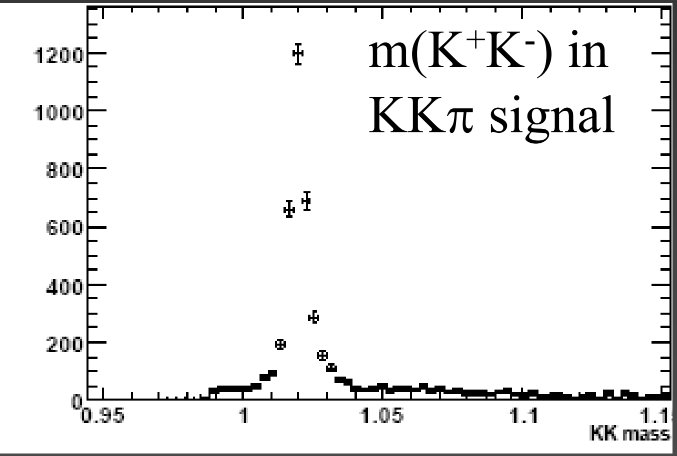


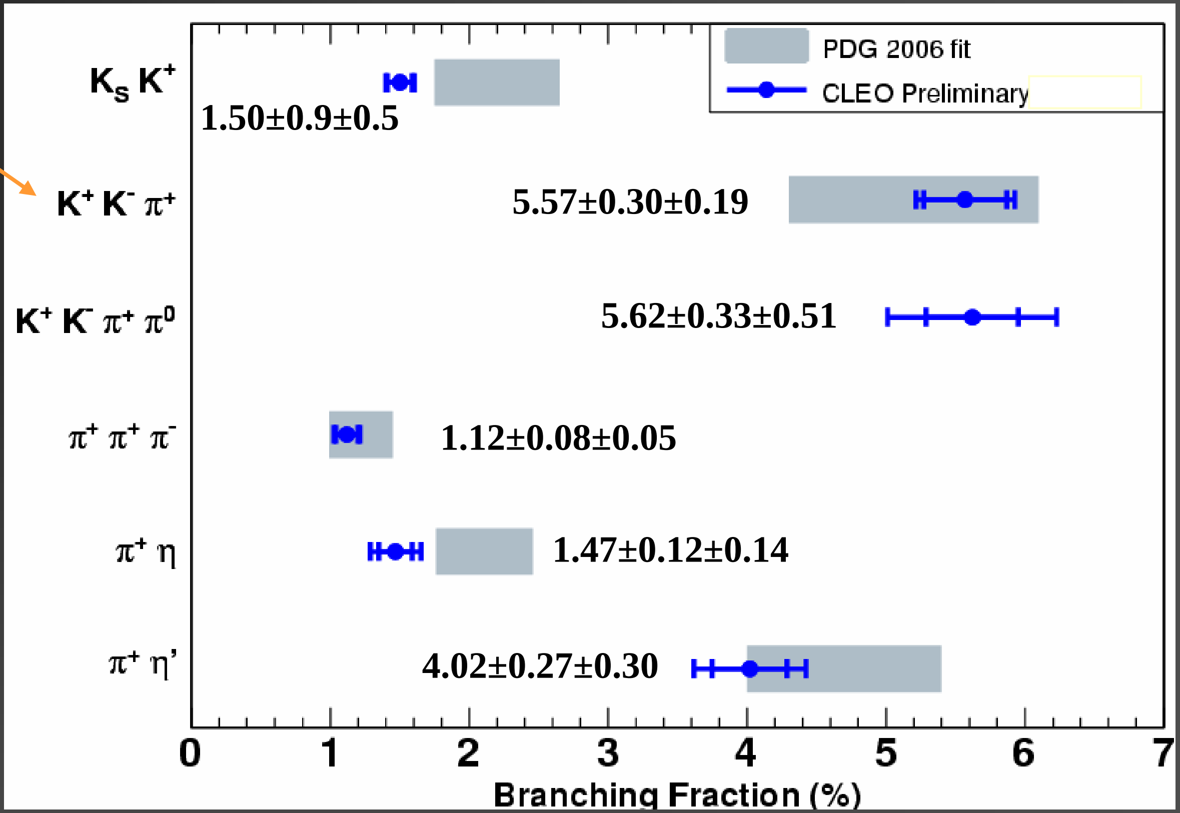


mass D_S^+-mass D_S^-

Absolute $\mathcal{B}$ Results for D_S^+ 200 pb^{-1}

- About ±6% error
- $D_S \rightarrow \phi\pi^+$ is difficult to quote because of interferences in $KK\pi$ Dalitz plot – K^*K, $f_0\ \pi$, etc…



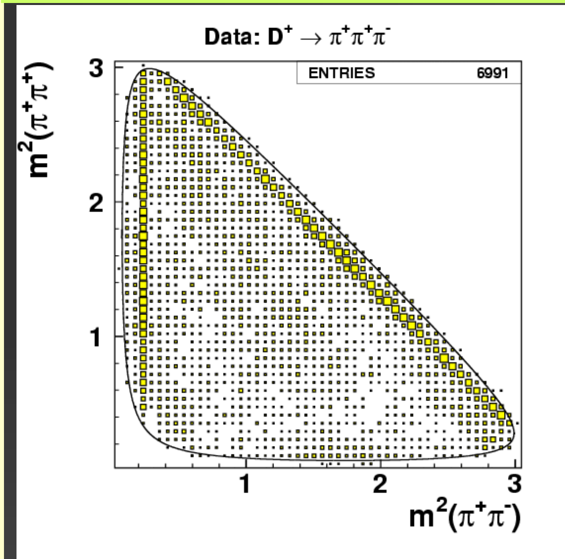


- Partial branching fraction ±10 MeV around m(ϕ): **1.98±0.12±0.09 %** ±20 MeV around m(ϕ): **2.25±0.13±0.12 %** (need x2 for $\phi \rightarrow K^+K^-$)

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

Mode	Fit Values		
	Relative Amplitude	Phase (degrees)	Fit Fraction (%)
$\rho(770)\pi^+$	1.0	0	20.0±2.3±0.9
$f_0(980)\pi^+$	1.4±0.2±0.2	12±10±5	4.1±0.9±0.3
$f_2(1270)\pi^+$	2.1±0.2±0.1	237±6±3	18.2±2.6±0.7
$f_0(1370)\pi^+$	1.3±0.4±0.2	-21±15±14	2.6±1.8±0.6
$f_0(1500)\pi^+$	1.1±0.3±0.2	-44±13±16	3.4±1.0±0.8
σ pole	3.7±0.3±0.2	-3±4±2	41.8±1.4±2.5
	Limits on Other Contributing Modes		
$\rho(1450)\pi^+$	0.9±0.5	51±22	<2.4
$f_0(1710)\pi^+$	1.0±1.5	-17±90	<3.5
$f_0(1790)\pi^+$	1.0±1.1	23±58	<2.0
Non-resonant	0.17±0.14	-17±90	<3.5
I=2 $\pi^+\pi^+$ S-wave	0.17±0.14	23±58	<3.7

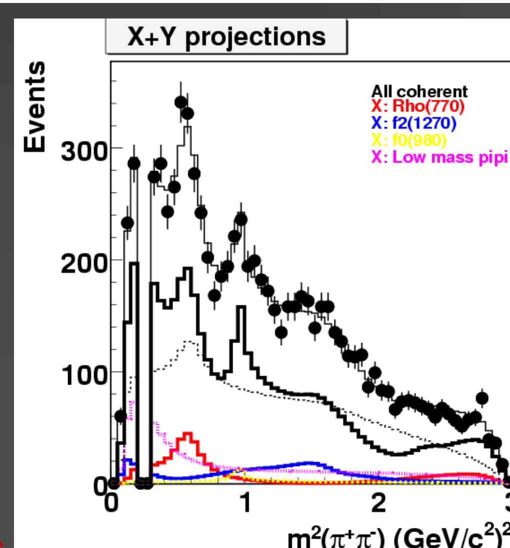
Likelihood Fit including: Amplitude, phase, spin-dependent PW (*ie*. BW), angular distribution, Blatt Weiskopf angular momentum penetration factor.

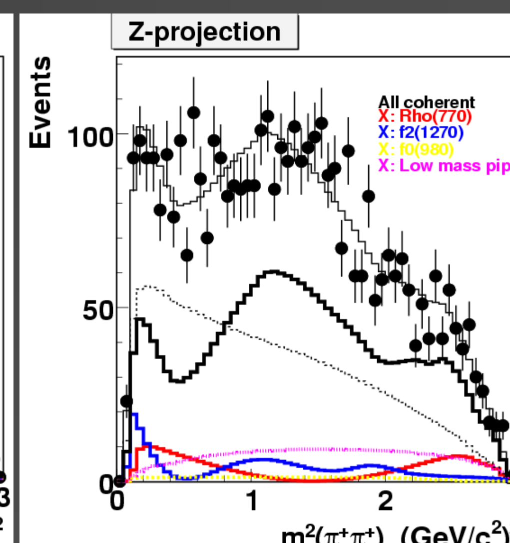


- $281 pb^{-1}$, untagged
- Signal and background box in ΔE, m_{BC}
- Dalitz plot statistics:
- $N(\pi^-\pi^+\pi^+) \sim 2600$
- $N(K_s\pi^+) \sim 2240$
- $N_{back} \sim 2150$

- ❑ Consistency with E791
  - E791 BW s Fit Fraction = **(46.3±9.0±2.1)%**
- ❑ σ pole provides a good description of the DP

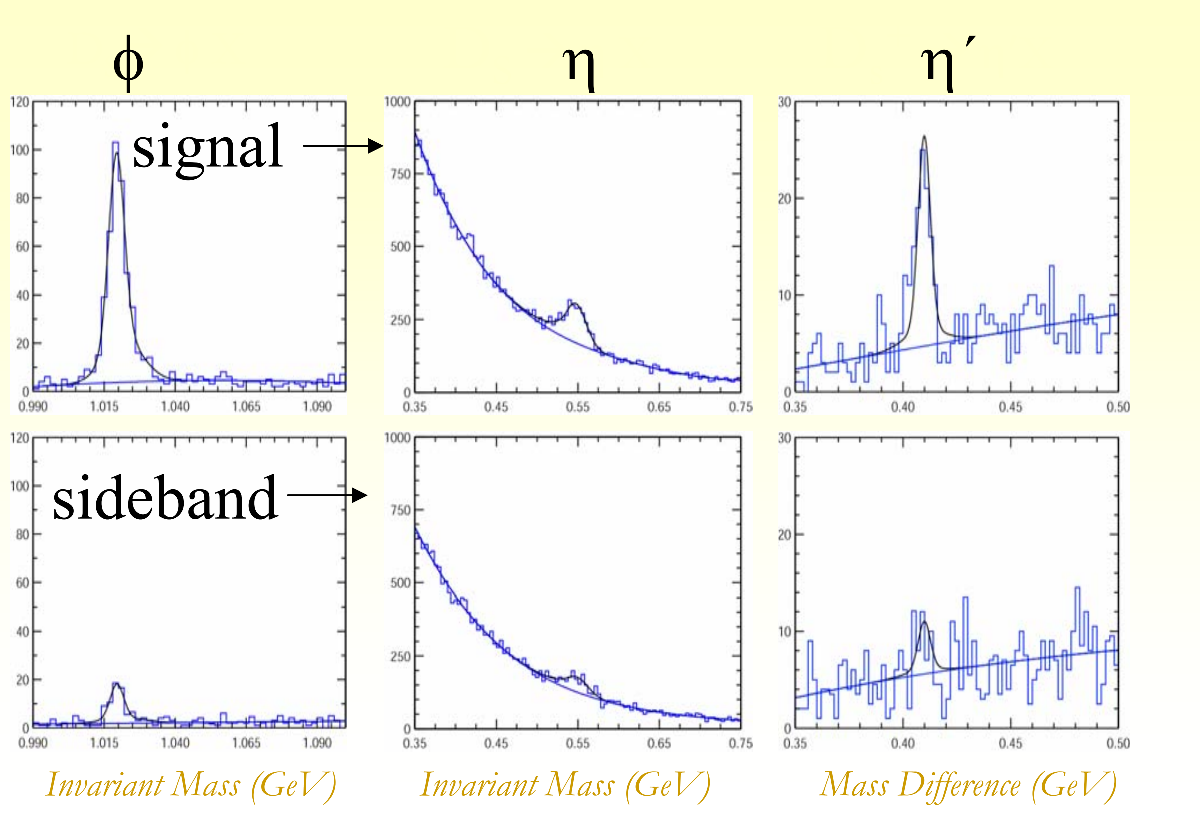
$$Pole_A(s) = \frac{1}{s - s_A}, \quad \text{where, } s_\sigma = (0.47 - i0.22)^2 \text{ GeV}^2$$





Inclusive $D_{(s)}$ Hadronic Decays

- Inclusive $s\bar{s}$ rates expected to be higher for D_s^+ than D^0/D^+.
- CLEO-c measurements with 281 pb^{-1} D^0/D^+ (3770 MeV) and 200 pb^{-1} D_s^+ (4170 MeV).
- Fully reconstruct one $D_{(s)}$, search for η, η', ϕ on the other side
- Much larger rates for D_S as anticipated



$\mathcal{B}$	ϕ (%)
D^0	1.0±0.1±0.1
D^+	1.1±0.1±0.2
D_s^+	16.1±1.2±0.6

$\mathcal{B}$	η (%)
D^0	9.4±0.4±0.6
D^+	5.7±0.5±0.5
D_s^+	23.7±3.1±1.9

$\mathcal{B}$	η' (%)
D^0	2.6±0.2±0.2
D^+	1.0±0.2±0.1
D_s^+	8.7±1.9±0.7

Less than ½ of D_S decays end up in $s\bar{s}$ mesons

η includes feed-down from η'.

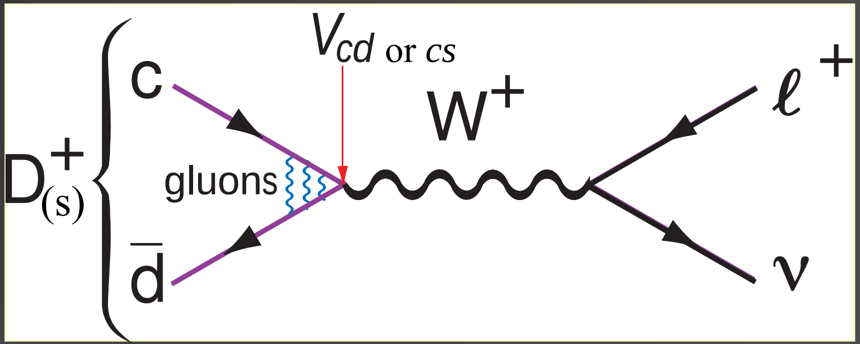
Leptonic & Semileptonic Decays

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

Introduction: Pseudoscalar decay constants

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

Example :



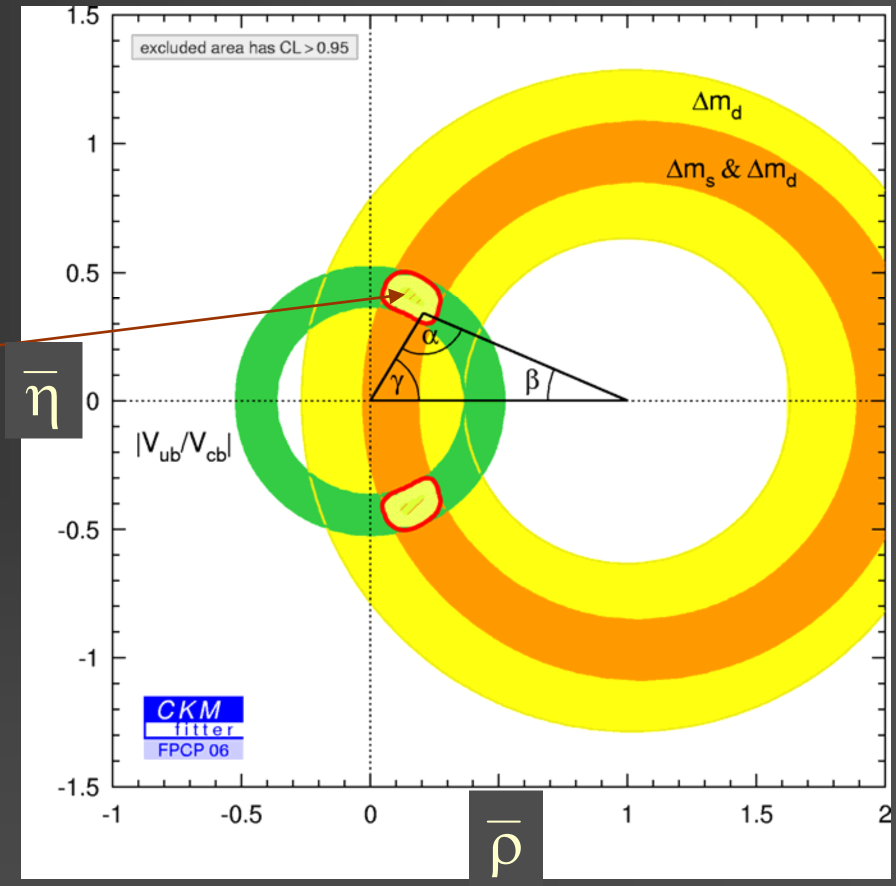
In general for all pseudoscalars:

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

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



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

New 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 $D_s^{*+} \to \gamma\, \mu^+\nu$. Then finding the muon or pion using kinematical constraints
- (2) Find $D_S^+ \to \tau^+\nu$, $\tau \to e^+\nu\nu$ opposite a D_s^- tag

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

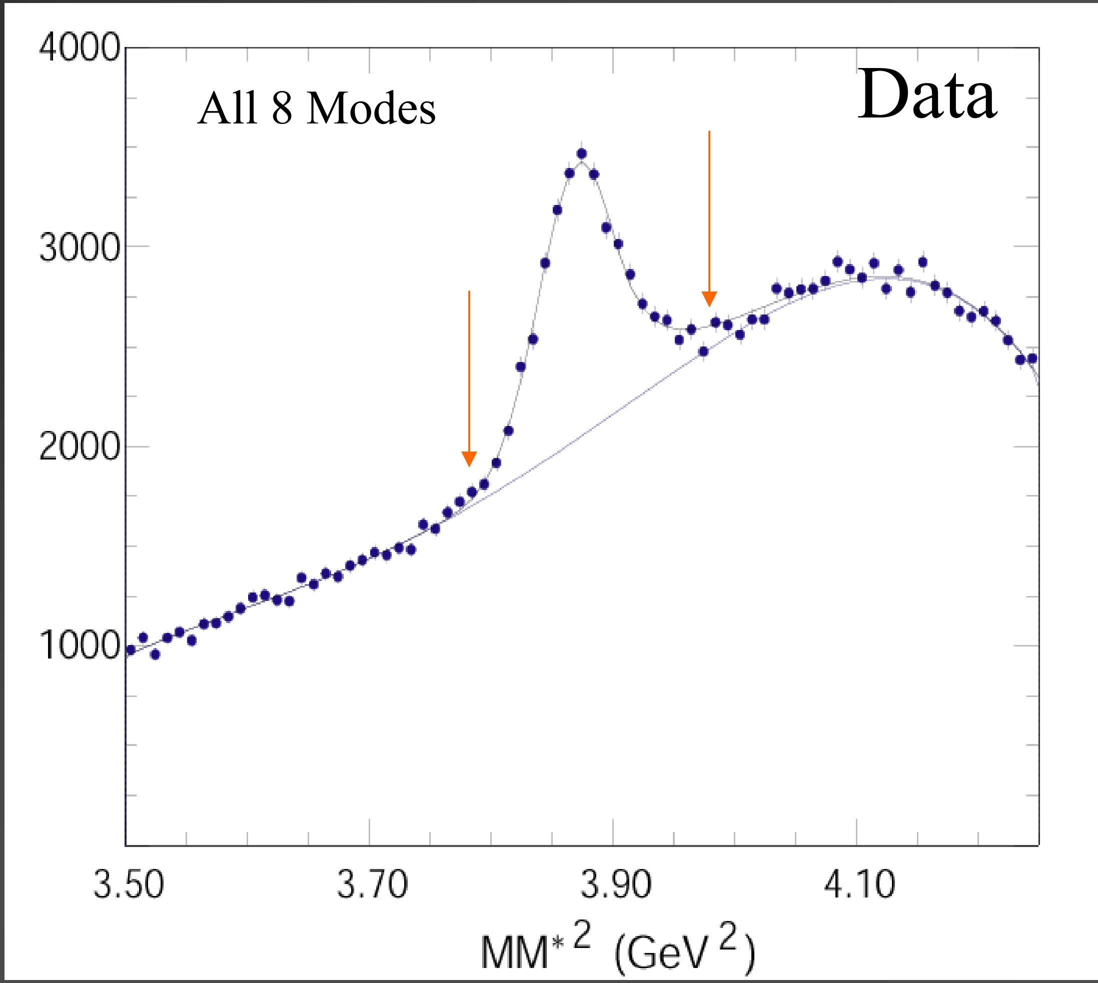
- In this analysis we use $D_S^* D_S$ events where we detect the γ from the $D_S^* \to \gamma D_S$ decay
- We see all the particles from $e^+e^- \to D_S^* D_S$, γ, D_S (tag) + μ^+ except for the ν
- We use a kinematic fit to (a) improve the resolution & (b) remove ambiguities
  - Constraints include: 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

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

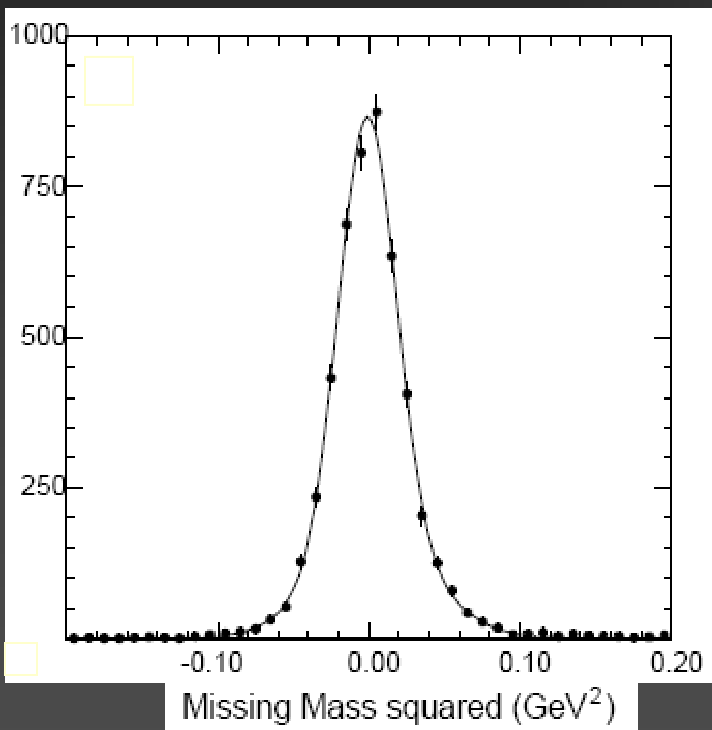
- Total of 11880±399±504 tags, after the selection on MM*2.



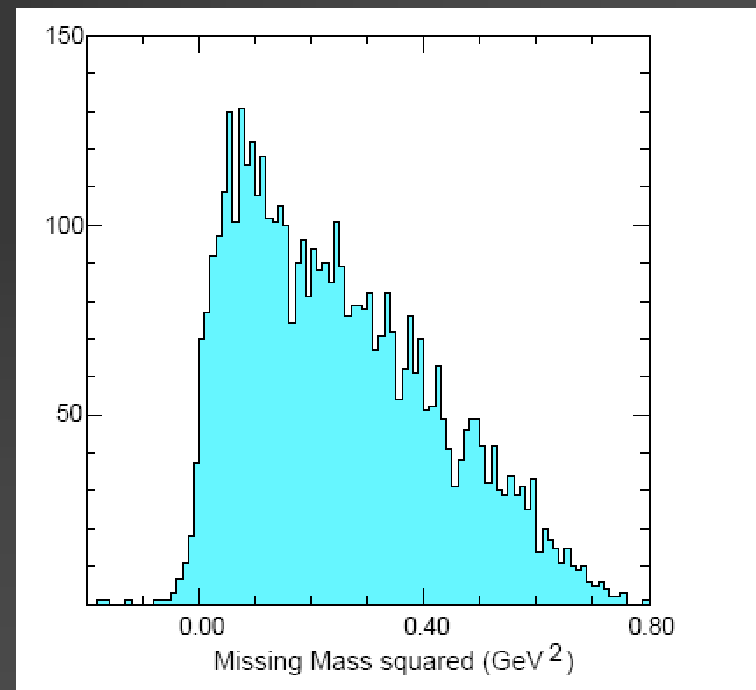
The MM^2

- 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 $\mu\nu$



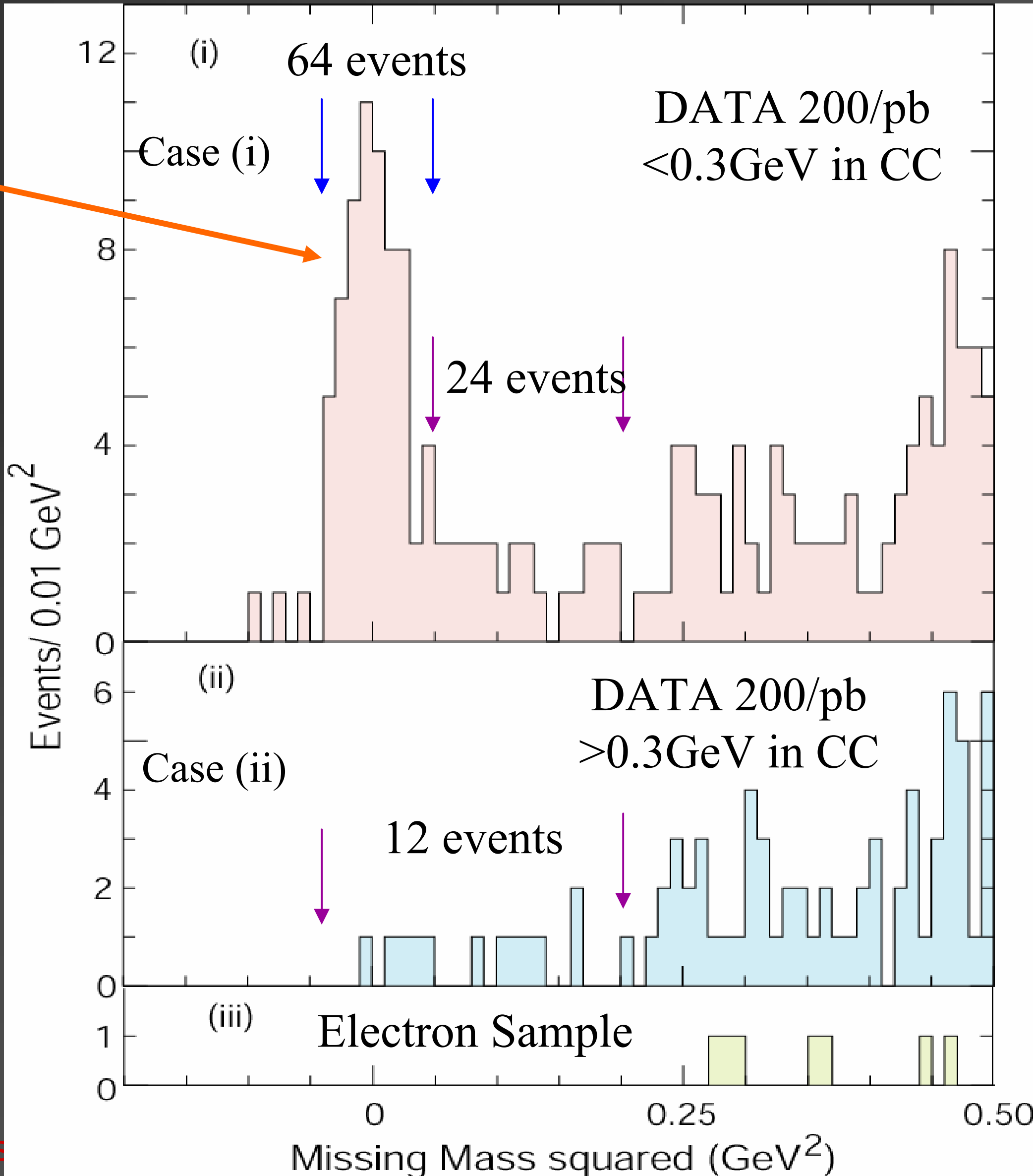
Signal $\tau\nu$, $\tau\rightarrow\pi\nu$

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

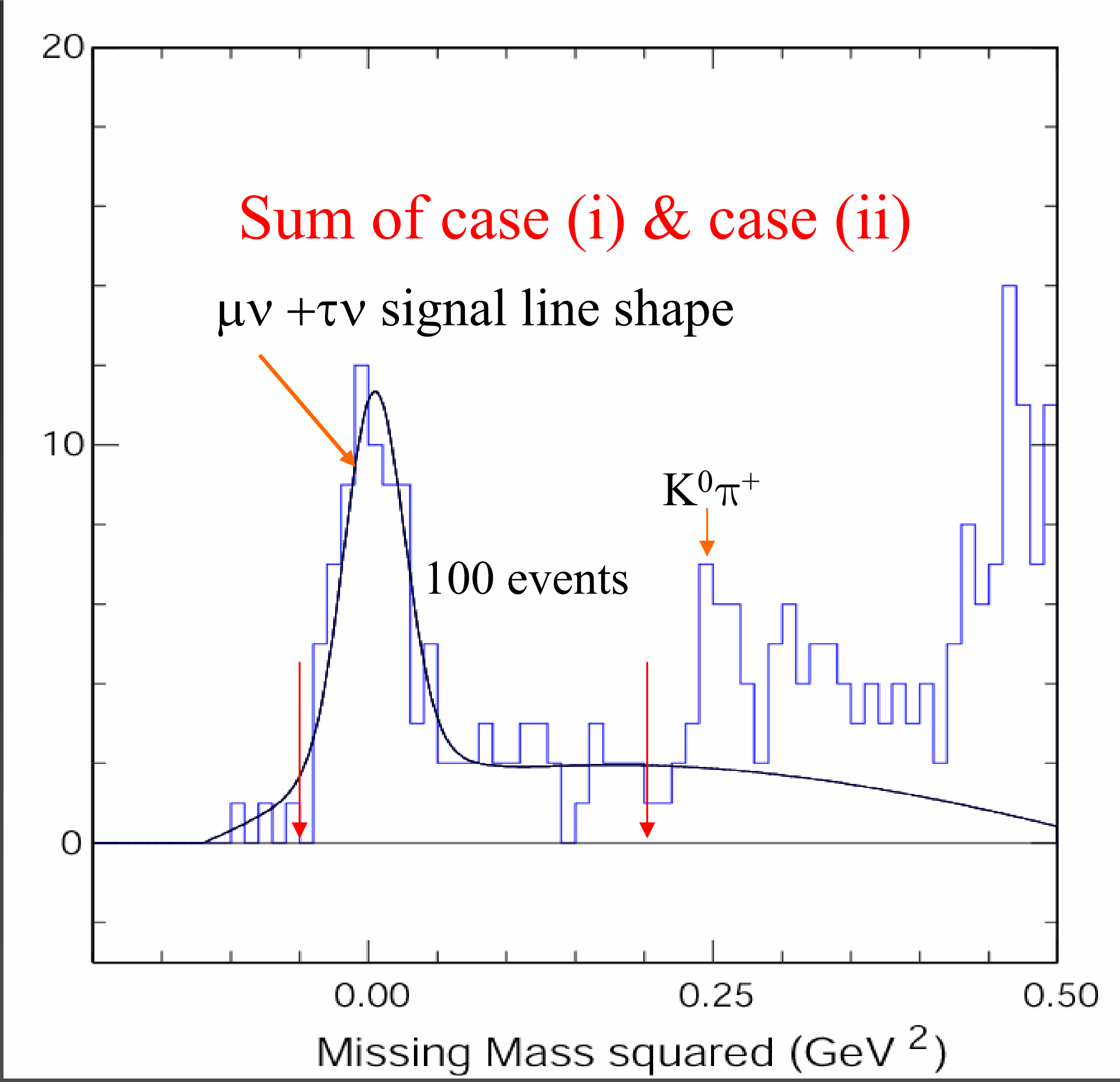
MM^2 Results from 200 pb^{-1}

- 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 $D_s^+ \to \mu^+\nu + \tau^+\nu$, $\tau \to \pi^+\nu$

- Two sources of background
- A) Backgrounds under invariant mass peaks – Use sidebands to estimate
- In $\mu^+\nu$ signal region 2 background (64 signal)
- Sideband bkgrnd 5.5±1.9
- B) Backgrounds from real D_S decays, e.g. $\pi^+\pi^o\pi^o$, or $D_S \to \tau^+\nu$, $\tau \to \pi^+\pi^o\nu$.... < 0.2 GeV^2, none in $\mu\nu$ signal region. Total of 1.3 additional events.
- $B(D_S \to \pi^+\pi^o) < 1.1\text{x}10^{-3}$ & γ energy cut yields <0.1 evts
- Total background < 0.2 GeV^2 is 6.8 events, out of the 100



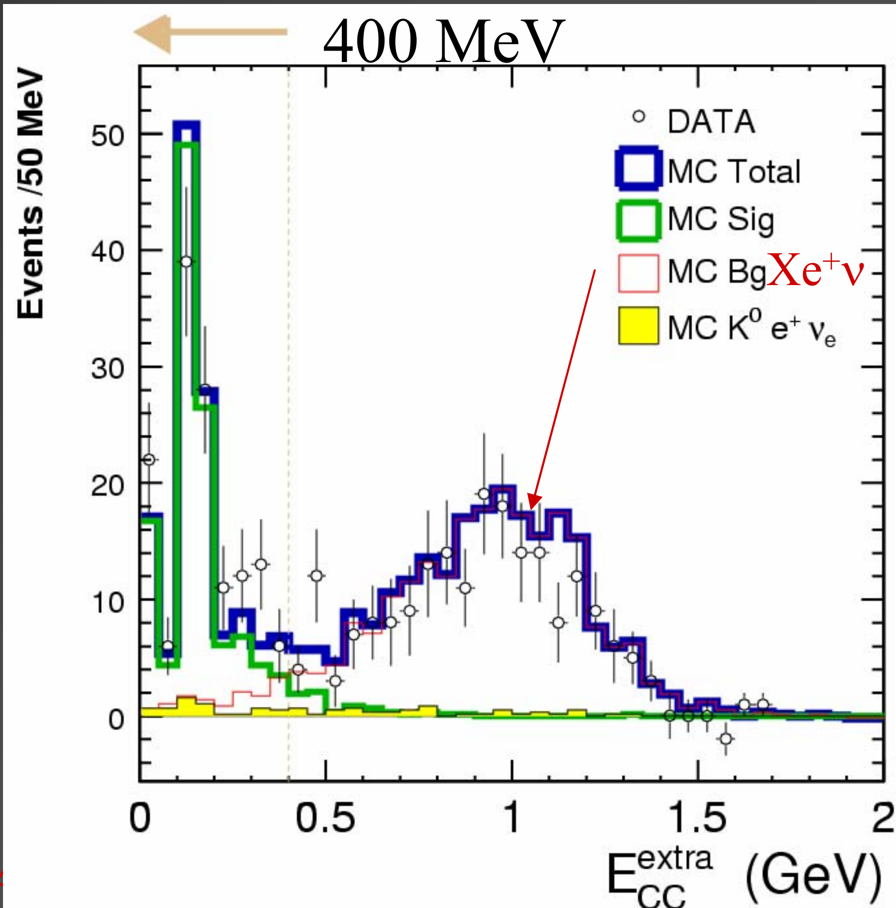
Branching Ratio & Decay Constant

- $D_S^+ \to \mu^+ \nu$
  - 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^*
- $B(D_S^+ \to \tau^+\nu)$ $=(6.29\pm0.78\pm0.52)\%$
- $f_{Ds}=278 \pm 17 \pm 12$ MeV



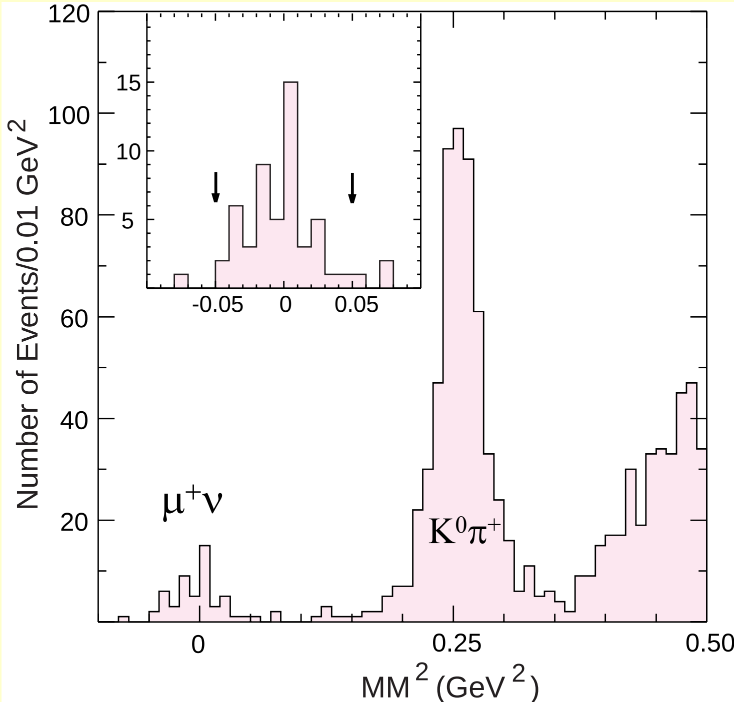
f_{D_s} & f_{D_s}/f_{D^+}

- Weighted Average: f_{Ds}=280.1±11.6±6.0 MeV, the systematic error is mostly uncorrelated between the measurements *(More data is on the way & systematic errors are being addressed)*
- Previously CLEO-c measured

$D^+ \rightarrow \mu^+ \nu$

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

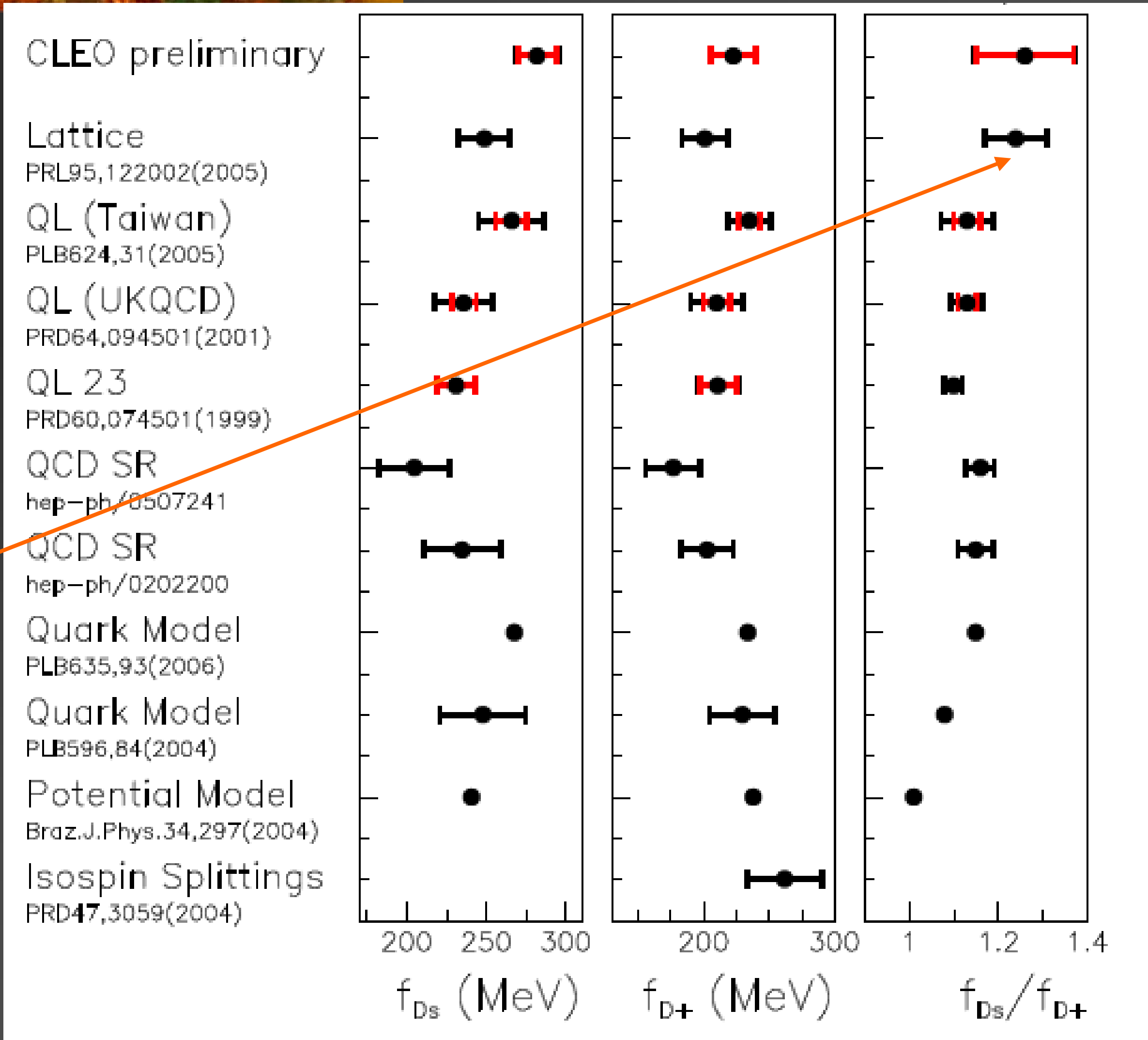
† M. Artuso et al., Phys .Rev. Lett. 95 (2005) 251801



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

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.

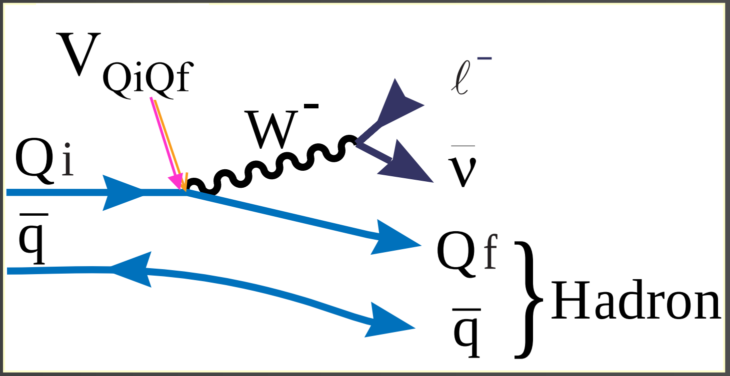
Exp.	Mode	$\mathcal{B}$	$\mathcal{B}_{\phi\pi}$ (%)	$f_{D_s^+}$ (MeV)
CLEO-c	combined	-		280.1±11.6±6.0
CLEO [30]	$\mu^+\nu$	$(6.2 \pm 0.8 \pm 1.3 \pm 1.6)10^{-3}$	3.6±0.9	$273 \pm 19 \pm 27 \pm 33$
BEATRICE [31]	$\mu^+\nu$	$(8.3 \pm 2.3 \pm 0.6 \pm 2.1)10^{-3}$	3.6±0.9	$315 \pm 43 \pm 12 \pm 39$
ALEPH [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^+}

Goals in Semileptonic Decays

- Either take V_{cq} from other information and test theory, or use theory and measure V_{cq}
  - V_{cs} use $D \rightarrow K(K^*)\ell\nu$ to measure form-factor shapes to distinguish among models & test lattice QCD predictions
  - V_{cd} use $D \rightarrow \pi(\rho)\ell\nu$
- V_{cd} & V_{cs} with precise unquenched lattice predictions, + V_{cb} would provide an important unitarity check
- V_{ub} use $D \rightarrow \pi\ell\nu$ to get form-factor for $B \rightarrow \pi\ell\nu$, at same v•v point using HQET (& $\rho\ell\nu$)

Exclusive Semileptonic Decays



- Best way to determine magnitudes of CKM elements, in principle is to use semileptonic decays. Decay rate $\alpha|V_{QiQf}|^2$
- This is how V_{us} (λ) and V_{cb} (A) have been determined
- Kinematics: $q^2 = \left(p_D^\mu - p_{hadron}^\mu\right)^2 = m_D^2 + m_P^2 - 2E_P m_D$
- Matrix element in terms of form-factors (for D→Pseudoscalar $\ell^+ \nu$

$$\left\langle P(P_P)\middle|J_\mu\middle|D(P_D)\right\rangle = f_+(q^2)(P_D+P_P)_\mu + f_-(q^2)(P_D-P_P)_\mu$$

- For ℓ = e, $f\_(q^2) \to 0$: $\frac{d\Gamma\left(D\to Pe\nu\right)}{dq^2} = \frac{\left|V_{cq}\right|^2 P_P^3}{24\pi^3}\left|f_+(q^2)\right|^2$

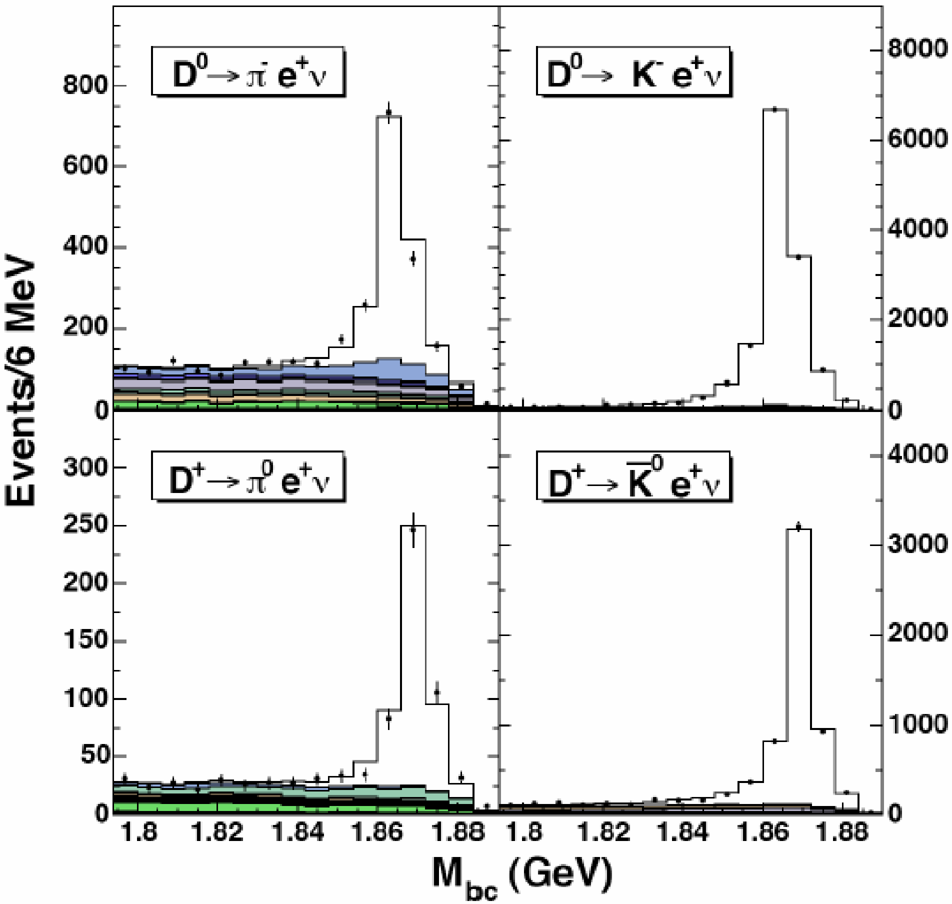
Form-Factor Parameterizations

- In general $$f_+(q^2) = \frac{f_+(0)}{1-\alpha}\frac{1}{1-q^2/m^2_{pole}} + \frac{1}{\pi}\int_{(M_D+m)^2}^{\infty} dq'^2 \frac{\mathrm{Im}(f(q'^2))}{q'^2-q^2}$$
- Modified Pole $$f_+(q^2) = \frac{f_+(0)}{\left(1-q^2/m^2_{pole}\right)\left(1-\alpha\, q^2/m^2_{pole}\right)}$$
- Series Expansion $$f_+(q^2) = \frac{1}{P(q^2)\phi(q^2,t_0)}\sum_{k=0}^{\infty} a_k(t_0)[z(q^2,t_0)]^k$$

$$t_\pm \equiv \left(M_D \pm m_{\pi(K)}\right)^2, \quad z(q^2,t_0) = \frac{\sqrt{t_+-q^2}-\sqrt{t_+-t_0}}{\sqrt{t_+-q^2}+\sqrt{t_+-t_0}}$$

Hill & Becher, Phys. Lett. B 633, 61 (2006)

Untagged D→K(or π) e ν (281/pb)



Fit Results with 281pb-1
-2lnL = 255.8 for 253 d.o.f

Neutrino Reconstruction

We use the whole event to reconstruct the event missing four-momentum (P_{miss}). This can be associated with a neutrino if the missing mass is consistent with zero.

$$P_{miss} = P_{event} - \sum P_{charged} - \sum P_{neutral}$$

Reconstruction Variables

$$\Delta E = E_{K(\pi)} + E_e + |\mathbf{p}_{miss}| - E_{beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - (\mathbf{p}_{K(\pi)} + \mathbf{p}_e + \varsigma \mathbf{p}_{miss})^2}$$

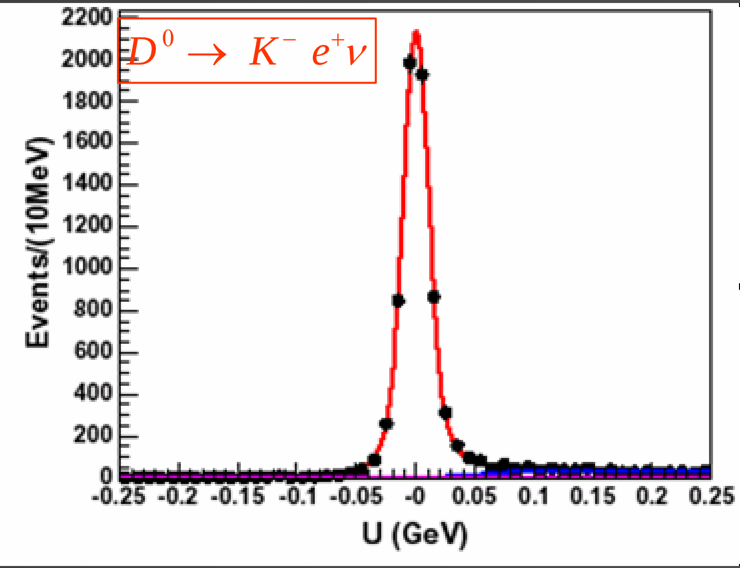
ς is a correction to $\mathbf{p}_{miss}$ such that:

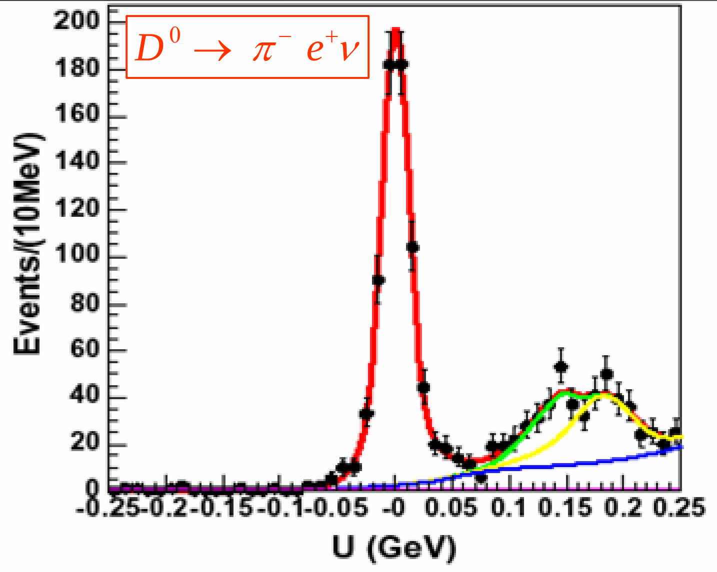
$$E_{K(\pi)} + E_e + \varsigma|\mathbf{p}_{miss}| - E_{beam} \equiv 0$$

New Tagged Results for 281 pb^{-1}

- Use $U \equiv E_{miss} - |\vec{p}_{miss}|$
- Branching Ratios

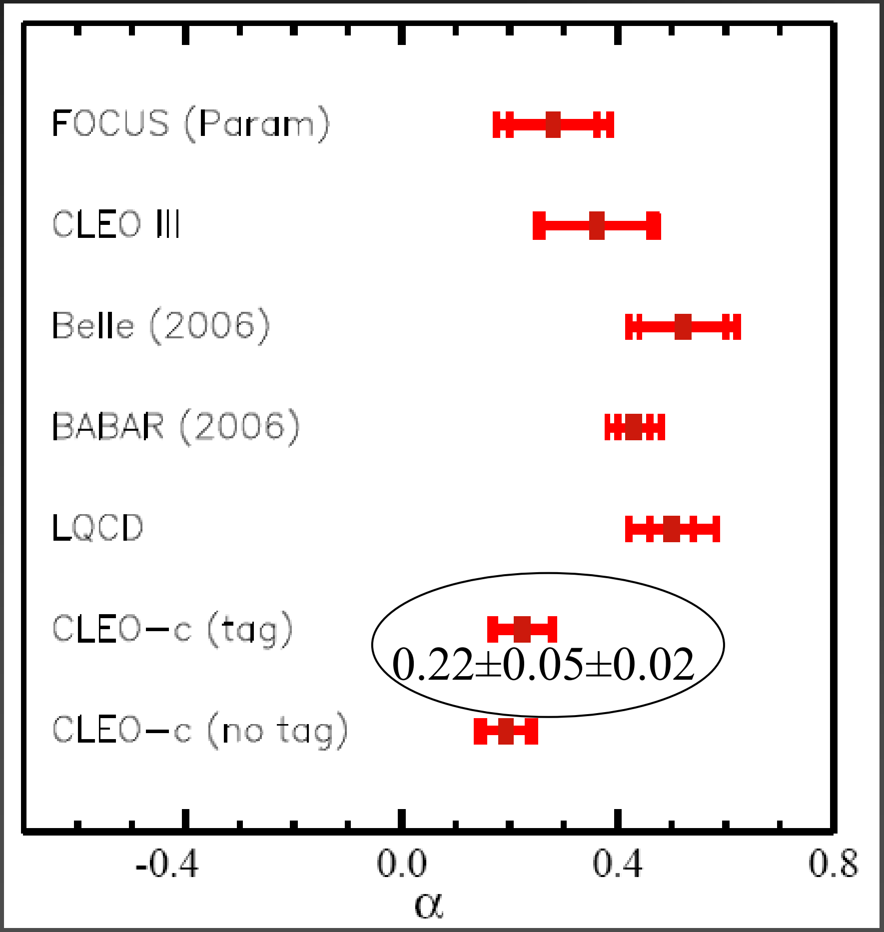
Mode	Tagged (%)	Untagged(%)
D^o		
$K^- e^+ \nu$	3.58±0.05±0.05	3.56±0.03±0.10
$\pi^- e^+ \nu$	0.31±0.01±0.01	0.30±0.01±0.01
D^+		
$K^o e^+ \nu$	8.86±0.17±0.20	8.70±0.13±0.27
$\pi^o e^+ \nu$	0.40±0.03±0.03	0.38±0.03±0.02



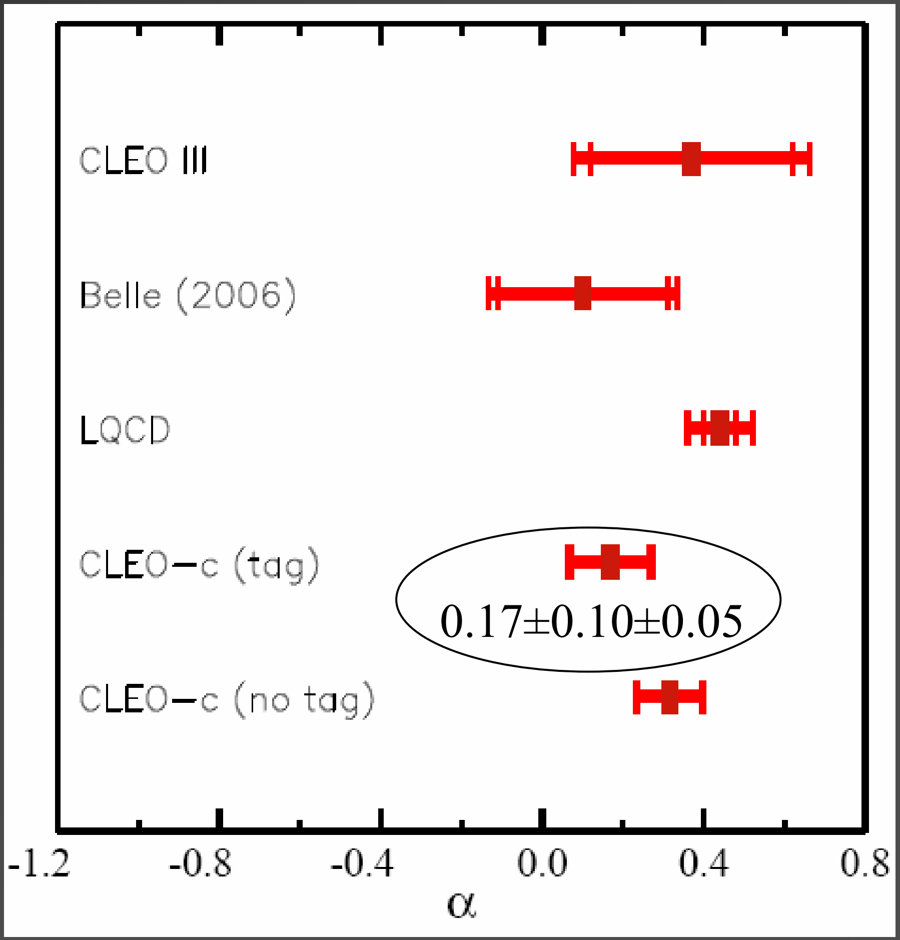


Form Factors: Tagged

$D \to K e^+ \nu$



$D \to \pi e^+ \nu$



Form-Factors Compared to Lattice

Lattice predictions*

$D\rightarrow\pi e\nu$

$f_{+}(0)=0.64\pm0.03\pm0.06$

$\alpha=0.44\pm0.04\pm0.07$

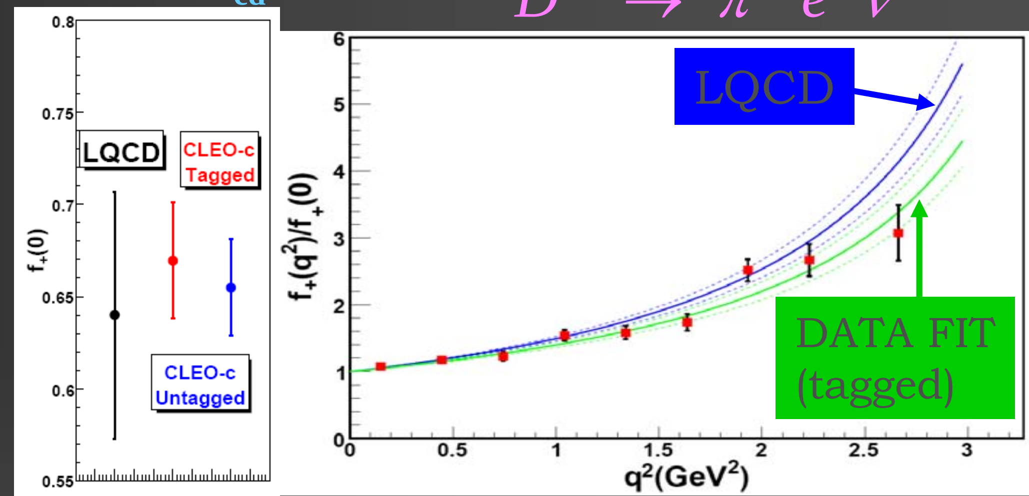
$D\rightarrow K e\nu$

$f_{+}(0)=0.73\pm0.03\pm0.07$

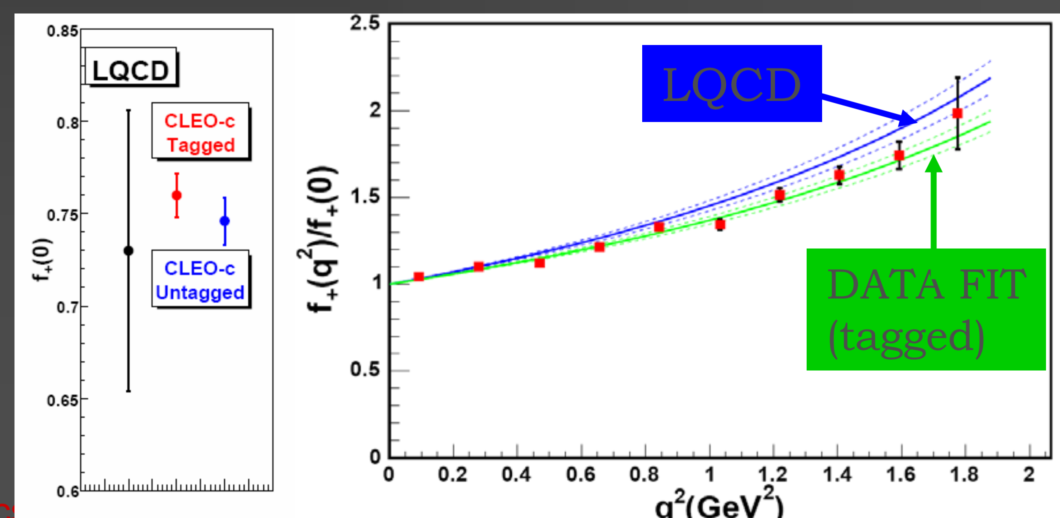
$\alpha=0.50\pm0.04\pm0.07$

*C. Aubin *et al.*, PRL **94** 011601 (2005)

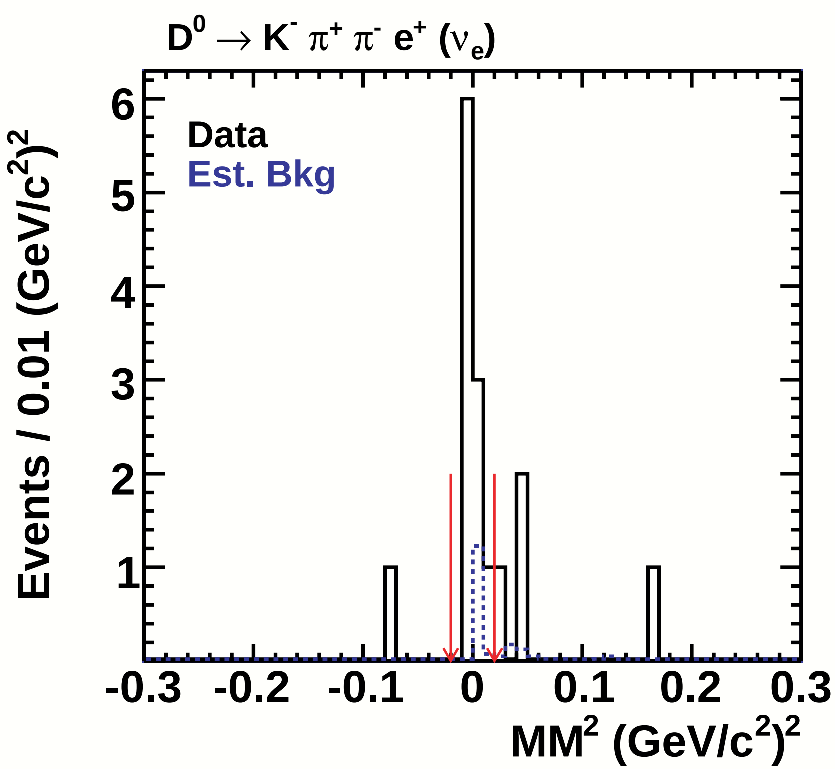
Assume V_{cd} = 0.2238 $\quad D^0 \rightarrow \pi^- e^+ \nu$

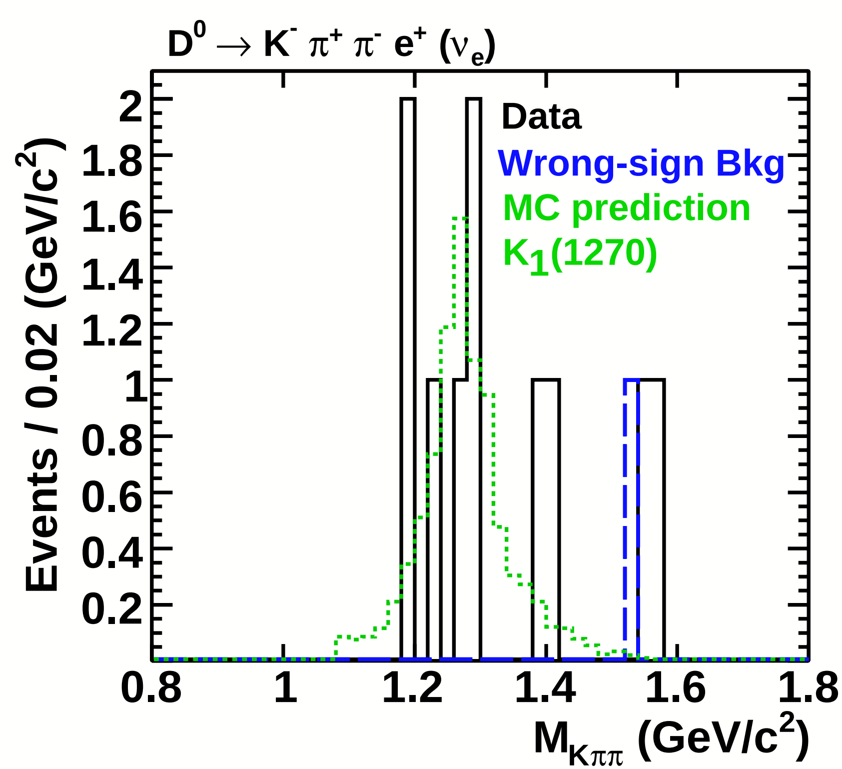


Assume V_{cs} = 0.9745 $\quad D^0 \rightarrow K^- e^+ \nu$



Discovery of D°→Kππ e⁺ν





- $B(D^o \rightarrow K_1(1270)e^+\nu)*B(K_1(1270) \rightarrow K^-\pi^+\pi^-) = (2.2^{+1.4}_{-1.0} \pm 0.2)x10^{-4}$ consistent with ISGW2 prediction

TCQA: The Quantum Correlation Analysis

C = –1

$e^+e^- \rightarrow \gamma^* \rightarrow D^0\bar{D}^0$

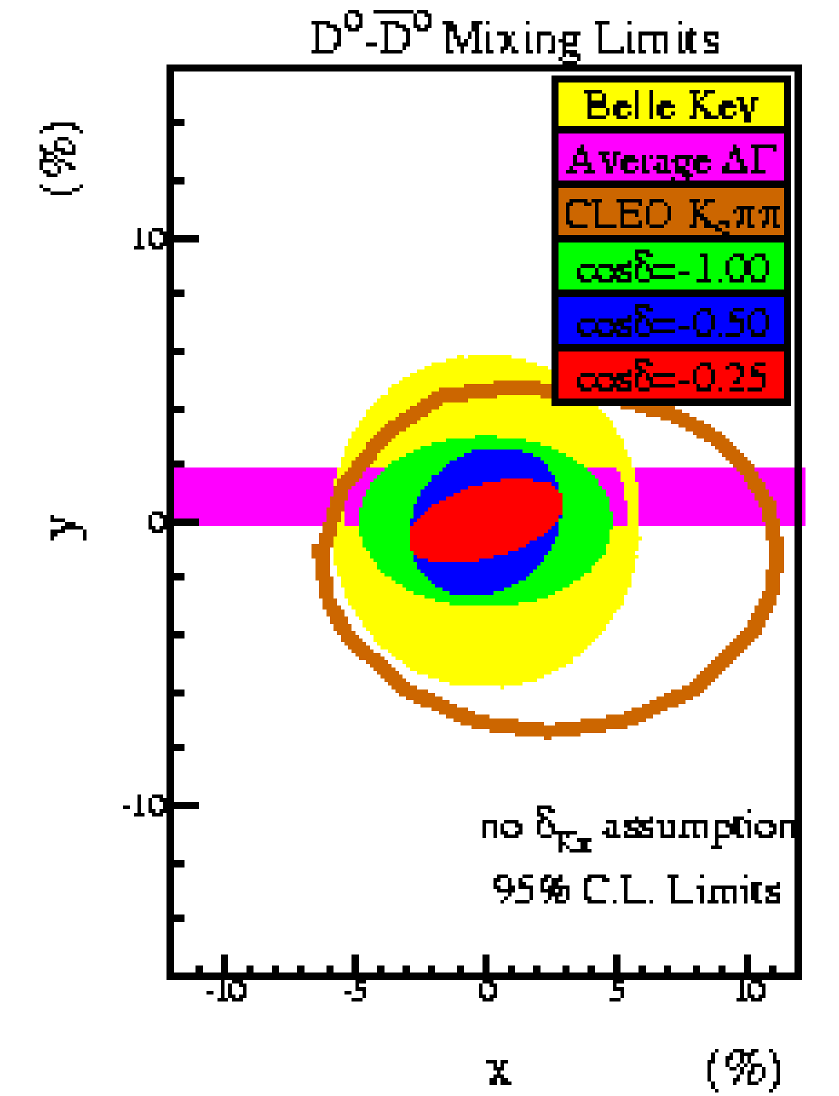
interference	$K^-\pi^+$	$K^+\pi^-$
	$K^+\pi^-$	$K^-\pi^+$
forbidden by Bose symmetry	$K^-\pi^+$	$K^-\pi^+$
	$K^-\pi^+$	$K^+l^-\nu$
	$CP+$	$K^+l^-\nu$
	$CP-$	$K^+l^-\nu$
	$K^-l^+\nu$	$K^+l^-\nu$
maximal constructive interference	$CP+$	$CP-$
forbidden by CP conservation	$CP+$	$CP+$
	$CP-$	$CP-$

- Because of quantum correlation between D^0 and D^0, not all final states allowed. This affects:
  - total rate
  - apparent branching fractions
- Two entangled causes:
  - Interf. between CF and DCSD
  - D mixing: single tag rates depend on $y = \mathcal{B}(CP+)-\mathcal{B}(CP-)$.
- Can exploit coherence to measure DCSD and mixing.

From D. Asner & W. Sun [hep-ph/0507238]

Sensitivity with 1 fb^{-1}

- Sensitivities are comparable with present experiments
- Statistical errors dominate y, but are the ~= to systematic errors for x
- Can also use D°D°* events at higher energies



Sensitivities versus Increased Statistics

- Decay constants: statistics limited
  - D^+ 7.5% for 281 pb^{-1} at 3770.
    Ultimate systematic limit may be ~1%
  - D_S 4.1% for 200 pb^{-1} at 4170. Ultimate systematic limit may be ~2%
- Dalitz analyses e.g. $D^o \rightarrow CP$ vs. $D^o \rightarrow K_S \pi^+ \pi^-$
  - Statistics starved until at least~10 fb^{-1}
- Semileptonic Decays
  - Branching ratios of Cabibbo favored & suppressed modes will be well known with 1 fb^{-1}
  - Form-factors will need 10 fb^{-1}
  - Rare modes will be statistics starved for a long time
- The Quantum Correlation Analysis will give some results with 1 fb^{-1}, needs 100x

Conclusions

- Beginning to see accurate absolute B

  $B(D^o \to K^- \pi^+) = (3.85 \pm 0.0.07)\%$ *not preliminary*

  $B(D^+ \to K^- \pi^+ \pi^+) = (9.43 \pm 0.31)\%$ *not preliminary*

  $B(D_S \to K^+ K^- \pi^+) = (5.57 \pm 0.36)\%$ *preliminary*

- $f_{D^+} = (222.6 \pm 16.7^{+2.3}_{-3.4})$ MeV *not preliminary*
- $f_{Ds} = 280.1 \pm 11.6 \pm 6.0$ MeV *preliminary*
- $f_{Ds}/f_{D^+} = 1.26 \pm 0.11 \pm 0.03$ *preliminary*
- Accurate semi-leptonic form-factors confronting QCD
- Much much more to do – Best wishes to BES

The End

Untagged: Form-Factor Results

Simp. Pole

$$f^+(q^2) = \frac{f^+(0)}{\left(1 - q^2/m^2_{pole}\right)}$$

Decay Mode	$\lvert V_{cx}\rvert f^+(0)$	m_{pole}
$D^0 \to \pi^{\pm} e\nu$	$0.146 \pm 0.004 \pm 0.003$	$1.87 \pm 0.03 \pm 0.01$
$D^0 \to K^{\pm} e\nu$	$0.736 \pm 0.005 \pm 0.010$	$1.98 \pm 0.03 \pm 0.02$
$D^{\pm} \to \pi^0 e\nu$	$0.152 \pm 0.007 \pm 0.004$	$1.97 \pm 0.07 \pm 0.02$
$D^{\pm} \to K^0 e\nu$	$0.719 \pm 0.009 \pm 0.012$	$1.97 \pm 0.05 \pm 0.02$

Mod. Pole

$$f^+(q^2) = \frac{f^+(0)}{\left(1 - q^2/m^2_{pole}\right)\left(1 - \alpha\, q^2/m^2_{pole}\right)}$$

Decay Mode	$\lvert V_{cx}\rvert f^+(0)$	α
$D^0 \to \pi^{\pm} e\nu$	$0.142 \pm 0.005 \pm 0.003$	$0.37 \pm 0.09 \pm 0.03$
$D^0 \to K^{\pm} e\nu$	$0.734 \pm 0.006 \pm 0.010$	$0.19 \pm 0.05 \pm 0.03$
$D^{\pm} \to \pi^0 e\nu$	$0.151 \pm 0.008 \pm 0.004$	$0.12 \pm 0.17 \pm 0.05$
$D^{\pm} \to K^0 e\nu$	$0.718 \pm 0.009 \pm 0.012$	$0.20 \pm 0.08 \pm 0.04$