SLAC-PUB-4997
June 1989
(T/E)

AN EXPERIMENTAL REVIEW OF THE DECAYS OF THE D_s MESON

Rafe H. Schindler

Stanford Linear Accelerator Center, Stanford CA.

In this paper I review the current experimental knowledge of the decays of the D_s meson. I compare D_s properties to those predicted from recent comprehensive D meson decay models that are based on the better measured charmed isodoublet (D^0, D^+).

1. INTRODUCTION

Currently, there is a wealth of information on charged and neutral D meson decays that leads to a semi-quantitative picture of the pattern of the weak-hadronic process, and hence their relative lifetimes. QCD nonleptonic enhancement democratically increases Γ_{had} (D^0,D^+) and $\Gamma_{had}(D_s)$ leaving semileptonic inclusive branching ratios below 20%. Interference reduces $\Gamma_{had}(D^+)$, making making the D^+ semileptonic branching ratio larger than the D^0. Finally, there may be a small nonspectator contribution to $\Gamma_{had}(D^0)$ which lowers the semileptonic D^0 branching fraction further. This last point is the least well established, and a prime reason to study D_s decays.

2. SEMILEPTONIC D_s DECAYS

The only current experimental information on semileptonic (SL) D_s decays is a limit from MARKIII: [1]

$$Br(D_s \to e^+ X) < 25\ \% \text{ at } 90\%\ CL$$

Taking $\Gamma_{had}(Ds) = \Gamma_{tot}(D_s) - 2\Gamma_{SL}(D_s) - \Gamma_{PL}(D_s)$, (where PL = pure leptonic) and assuming <2 % for Γ_{PL} and < 50% for Γ_{SL}, we find that $\Gamma_{had} > 0.46\Gamma_{tot}$. Using the lifetimes [2] and SL branching fractions for other charmed mesons, we find:

$$\Gamma_{had}(D^0) = 20 \times 10^{11}\ sec^{-1}$$
$$\Gamma_{had}(D^+) = 6 \times 10^{-11}\ sec^{-1}$$
$$\Gamma_{had}(D_s) > 11 \times 10^{-11}\ sec^{-1}$$

Thus we conclude that the hadronic width of the D_s is large like the D^0 and distinct from the D^+.

3. HADRONIC DECAYS

The weak hadronic decays of the D_s are now summarized in Table I.[3] Because of a lack of absolute normalization, all experiments have been referenced to the $B(\phi\pi^+)$.

3.1 The Two and Three-Body Decays

The 2-body psuedoscalar-psuedoscalar decays have two new additions from MARKIII, for $\bar{K}^0K^+$ and $\bar{K}^0\pi^+$. The 3-body

TABLE I. RELATIVE HADRONIC BRANCHING RATIOS OF D_s MODES TO $\phi\pi^+$

$D_s \to \bar{K}^0K^+$	MARKIII	0.92±0.32±0.20
	CLEO	0.99±0.17±0.06
$D_s \to \bar{K}^0\pi^+$	MARKIII	<0.21 at 90% CL
$D_s \to \bar{K}^{*+}K^0$	CLEO	1.2 ±0.21±0.07
$D_s \to \bar{K}^{*0}K^+$	MARKIII	0.84±0.30±0.22
	CLEO	1.05±0.17±0.06
	E691	0.87±0.13±0.05
	ARGUS	1.44±0.37
$D_s \to \rho^0\pi^+$	ARGUS	<0.22 at 90% CL
	E691	<0.08 at 90% CL
$D_s \to S^*\pi^+$	E691	0.28±0.10±0.03
$D_s \to \eta\pi^+$	MARKII	3.0±1.1
	MARKIII	<2.5 at 90% CL
	E691	<1.5 at 90% CL
$D_s \to \eta'\pi^+$	MARKII	4.8±2.1
	NA14'	5.7±1.5
	MARKIII	<1.9 at 90% CL
$D_s \to \omega\pi^+$	E691	<0.5 at 90% CL
	E564	seen
$D_s \to \bar{K}^{*0}K^{*+}$	NA32	2.3±1.2
$D_s \to \phi\pi^+\pi^0$	E691	2.4±1.0±0.5
	NA14'	<2.6 at 90% CL
$D_s \to (K^+K^-\pi^+)_{NR}$	E691	0.25±0.07±0.05
	NA32	0.96±0.32
$D_s \to (\pi^+\pi^-\pi^+)_{NR}$	E691	0.29±0.09±0.03
$D_s \to (\pi^+\pi^+\pi^+\pi^-\pi^-)_{NR}$	E691	<0.29 at 90% CL
$Ds \to \phi\pi^+\pi^+\pi^-$	E691	0.42±0.13±0.07
	NA32	0.39±0.17
	ARGUS(a)	1.11±0.37±0.28
	ARGUS(b)	0.41±0.13±0.11
$D_s \to (K^+K^-\pi^-\pi^0)_{NR}$	E691	<2.4 at 90% CL
$D_s \to (K^+K^-\pi^+\pi^-\pi^+)_{NR}$	E691	<0.32 at 90% CL
	NA32	0.11±0.07

*Work supported by the Department of Energy, contracts DE-AC03-76SF00515

Invited talk Presented at the 12th International Workshop on Weak Interactions and Neutrino, Ginosar, Israel, April 9–14, 1989

$K\bar{K}\pi$ final states have one recent measurement from NA14' and a final measurement from MARKIII. The results from NA32 and E691 are however the most sensitive here, being able to extract the resonant and non-resonant content from the Dalitz plot. There is at present a small disparity in the non-resonant 3-body contribution.

The 3-body $\pi^+\pi^+\pi^-$ decays are intriguing since they may shed light on the issue of an annihilation contribution to D_s decays. The ARGUS group first set a limit of 22% on the $D_s \to \rho^0\pi^+$ contribution (relative to $\phi\pi^+$). Subsequently, E691 has observed a signal in $\pi^+\pi^+\pi^-$, with a resonant breakdown of 28% $S^*\pi^+$, 29% non-resonant, and a limit of 8% $\rho^0\pi^+$. The stringent limit on $\rho^0\pi^+$ suggests a small annihilation contribution (see conclusions) while the large fraction that goes through $S^*\pi^+$ is a spectator contribution. That leaves only the non-resonant $\pi^+\pi^+\pi^-$ to be explained. The small statistics at present precludes fitting for additional wide resonances (eg: f_2 (1270), which may be of additional spectator origin.

3.2 Decays with η, η' and ω.

Four recent experiments (MARKII, E691, MARKIII, and NA14') have now searched for $\eta\pi^+$, $\eta'\pi^+$ and/or $\omega\pi^+$. Two experiments claim to observe a large signal, and two only set limits.

The first recent evidence[4] for $D_s \to \eta\pi^+$ and $\eta'\pi^+$ came from MARKII at PEP. They found that $D_s \to \eta\pi^+$ relative to $\phi\pi^+$ is 3 ± 1.1 providing $Br(D_s \to \phi\pi^+) = 4\%$. Similarly, they obtain the $\eta'\pi^+$ relative to $\phi\pi^+$ of 4.8 ± 2.1 (see Fig. 1a and 1b). Note that if the $\phi\pi^+$ branching fraction is smaller than 4%, the ratio will increase in proportion.

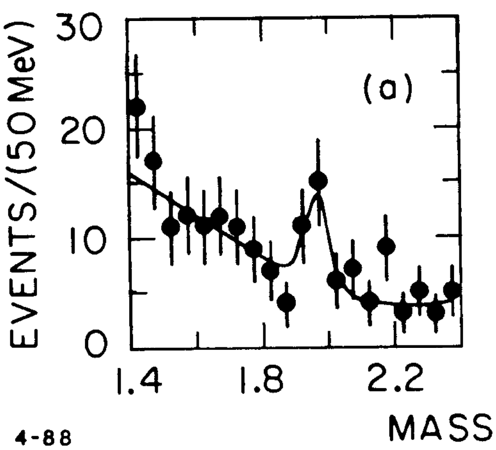

FIGURE 1
(a) $D_s \to \eta\pi^+$ from MARKII.

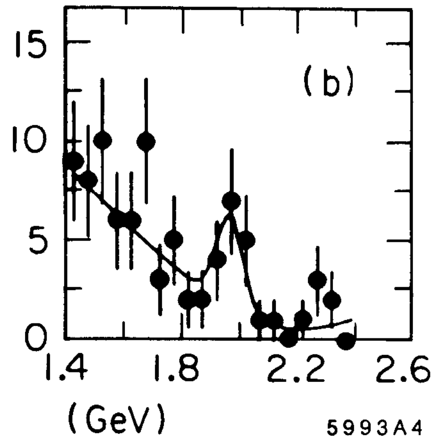

FIGURE 1
(b) $D_s \to \eta'\pi^+$ from MARKII.

NA14', [5] a new photoproduction experiment recently claimed evidence for a large $\eta'\pi^+$ signal, requiring the η' to decay via the $\gamma\rho^0$ channel directly. They find 38 ± 10 events, as seen in Fig. 2. This corresponds to a ratio of 5.7 ± 1.5 relative to $\phi\pi^+$. [6]

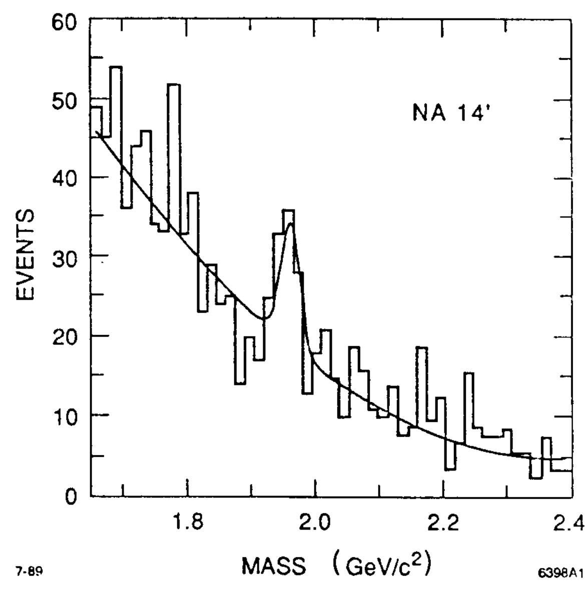

FIGURE 2
$D_s \to \eta'\pi^+$ from NA14' (photoproduction) where the $\eta' \to \gamma\rho^0$.

E691 has looked for events with $(\pi\pi\pi)^+\pi^0$ combinations where the $\pi^+\pi^-\pi^0$ make an η or an ω. This analysis results in a limit of <3.2 for the D_s-> $\eta\pi^+$ and <0.5 for the D_s->$\omega\pi^+$, both relative to D_s-> $\phi\pi^+$ at 90% CL. To improve efficiency by about 10X, they also looked for the Ds-> $\pi\pi\pi(\pi^0)$miss, obtaining a limit on $\eta\pi^+$ < 1.5 times $\phi\pi^+$ at 90% CL. Figures 3a-c and 4a-b shows the E691 analysis.

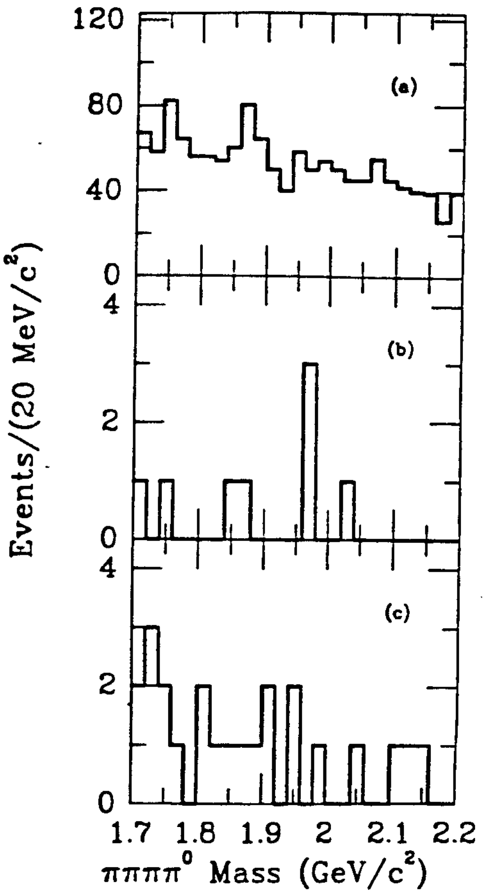

FIGURE 3

(a) Inclusive $\pi^+\pi^-\pi^+\pi^0$ from E691. (b) D_s-> $\eta\,\pi^+$ from E691. (c) D_s-> $\omega\pi^+$ from E691.

MARKIII previously presented a preliminary result[7] on the D_s->$\eta\pi^+$. This channel has now been reanalyzed and the D_s->$\eta'\pi^+$ channel added; differences result from improved detector constants, fitting techniques and background simulation. Figs. 5a and 6a show the 2C fit results for $\eta\pi^+$ where the η decays to $\pi\pi\pi^0$ or $\gamma\gamma$. While there are indications of a signal (16.6±6.1 events) in Fig. 5a yielding σ.br=44 ±16±12 pb, the result of Fig. 6a is a limit of σ.br < 42.5 pb. at 90% CL. MARKIII then quotes a combined limit of 66 pb at 90% CL , or a ratio of $\eta\pi^+$ to $\phi\pi^+$ < 2.5 at 90% CL. The D_s->$\eta'\pi^+$ is shown in Fig. 7a, where again the MARKIII does a 2C fit, with η'->$\eta\pi^+\pi^-$, and η>$\gamma\gamma$. This results in a limit for D_s->$\eta'\pi^+$ relative to $\phi\pi^+$ < 1.9 at 90% CL.

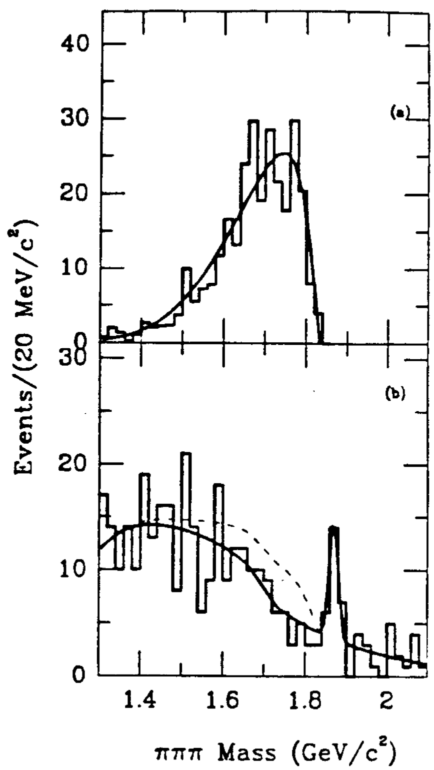

FIGURE 4

(a) Monte Carlo $\pi^+\pi^-\pi^+$ from D_s->$\eta\pi^+$ (E691). (b) Data with missing π^0. Dashed curve shows what a signal of D_s-> $\eta\,\pi^+$ would look like with 1.5X the $\phi\pi^+$ branching ratio.

4. MULTIBODY DECAYS

Only a few multibody decays of the D_s have thus far been observed. The interest of course in ascertaining the amount of vector-vector component arises because the quasi-2-body decays of the D^0 and D^+ appear to occupy a significant fraction of their hadronic widths.

E691, NA32 and NA14' have looked at decays such as $K\bar{K}\pi\pi$, E691 sees $\phi\pi^+\pi^0$ at a larger rate than NA14' (see Table I), however neither can say anything about the $\phi\rho^+$ or the $K^{*+}\bar{K}^{*0}$ content. Only a limit on the non-ϕ part is obtained. NA32 sees 5.2±2.4 events in $K^{*+}\bar{K}^{*0}$ after cutting on the K^*.

Finally, ARGUS, E691 and NA32 see signals in $\phi\pi^+\pi^+\pi^-$ and perhaps some evidence for non-resonant $K\bar{K}\pi^+\pi^+\pi^-$.

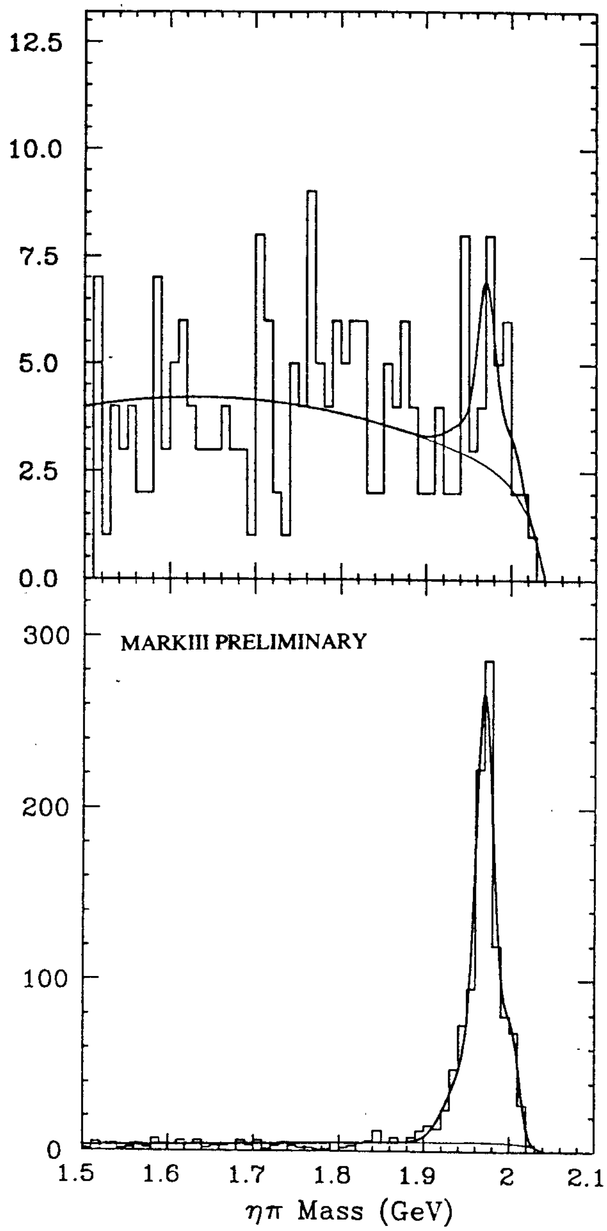

FIGURE 5

(a) Data for $D_s \to \eta\pi^+$ with $\eta \to \pi^+\pi^-\pi^0$ from MARKIII. (b) Monte Carlo.

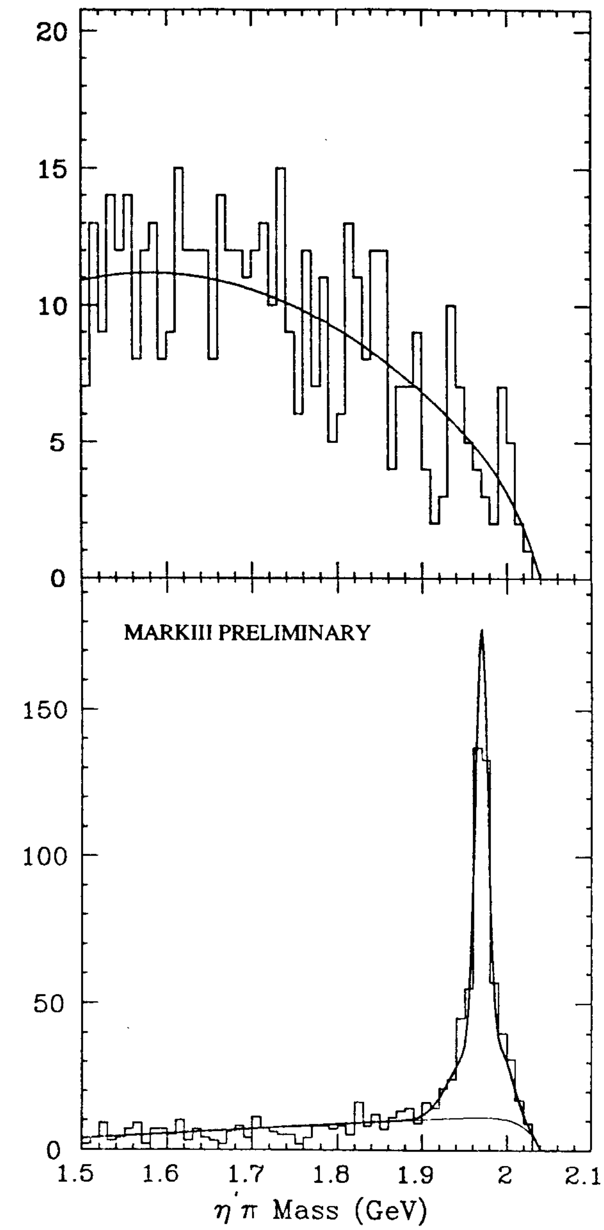

FIGURE 6

(a) Data for $D_s \to \eta\pi^+$ with $\eta \to \gamma\gamma$ from MARKIII. (b) Monte Carlo.

5. D_s ABSOLUTE BRANCHING RATIO

All high energy experiments that observe $D_s \to$ final state (i) in e^+e^-, measure the cross section for D_s production ($\sigma(D_s)$) times the branching ratio B(i). To extract a branching ratio B(i), requires knowledge of $\sigma(D_s)$. Typically, experiments (TASSO, CLEO, ARGUS and HRS) have taken observed D production (where an absolute Br scale is available[8]) and assumed some fraction to be Ds (typically 15%), or taken the total cross section, and assumed some fraction to be $c\bar{c}$ (using the quark model), and some fraction of that to be D_s (again 15%). All of

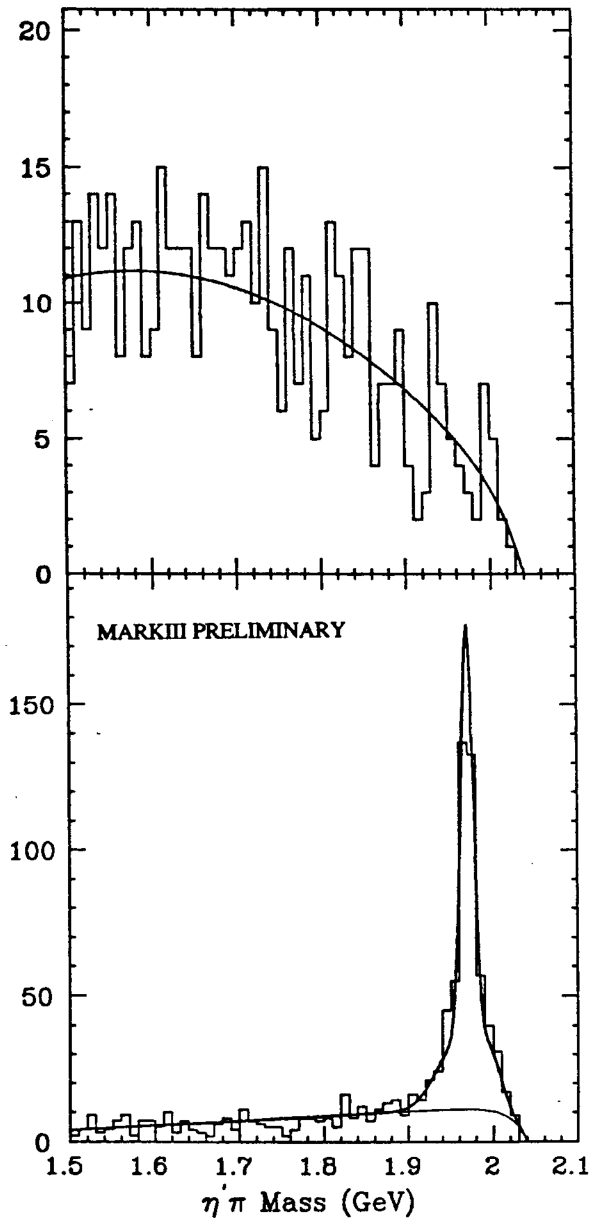

FIGURE 7

(a) Data for $D_s \to \eta' \pi^+$ with $\eta' \to \pi^+\pi^-\eta$ and $\eta \to \gamma\gamma$ from MARKIII. (b) Monte Carlo.

these descriptions are *ad-hoc*, and employ corrections for fragmentation to unseen D mesons; they lead to $B(\phi\pi^+)$ varying between about 2% and 3.3%, with errors (which do not include theoretical assumptions) of about 0.5%.

Recently, CLEO[9] has done a subtraction measurement, to obtain $\sigma(D_s)$ by removing from the charm cross section, the separate measurements of $\sigma(D^0)$, $\sigma(D^+)$ and $\sigma(\Lambda_c)$ as well. The result is $Br(D_s \to \phi\pi^+) = 2.0 \pm 1.0$ %

The MARKIII has presented preliminary results of a double tag technique that allows the model independent determination of an upper limit on $Br(D_s \to \phi\pi^+)$. At E_{cm}=4.14, D_s production is primarily $\bar{D}_s D_s^*$. Thus, by kinematically fitting this reaction with many different known final state channels of the D_s assumed to be recoiling off a $D_s \to \phi\pi^+$, or any other channel, and applying the constraints of current measurements (see Table I) for the ratios of these channels to $\phi\pi^+$, it is possible to set a limit on $Br(\phi\pi^+)$. This is completely analogous to the previous MARKIII analysis of absolute D meson branching fractions.[8] Figure 8 shows a plot of 18 possible pairings of D_s decays among the channels $\phi\pi^+$, $\bar{K}^0K^+$, $S^*\pi^+$, $\bar{K}^{*0}K^+$, $\phi\pi^+\pi^+\pi^-$, and $\phi\pi^+\pi^0$. The preliminary result is that:

$$Br(D_s \to \phi\pi^+) < 5.9\% \text{ at } 90\% \text{ CL.}$$

It is anticipated that when the full use of all channels is made, the limit can be reduced to about 4%.

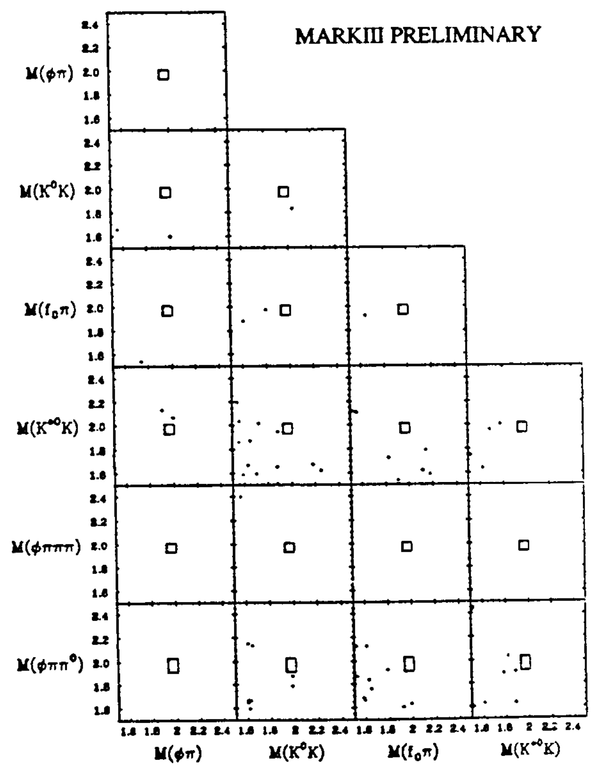

FIGURE 8

MARKIII analysis of D_s absolute branching ratios. Points show data, rectangles indicate the expected signal regions.

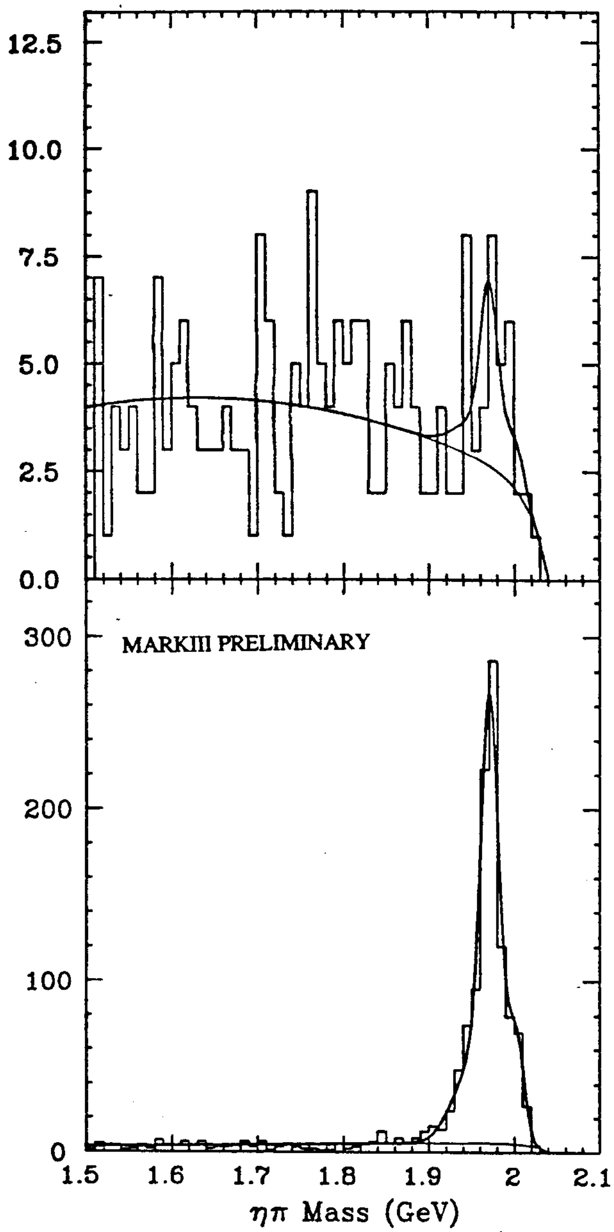

FIGURE 5

(a) Data for D_s-> $\eta\pi^+$ with η -> $\pi^+\pi^-\pi^0$ from MARKIII. (b) Monte Carlo.

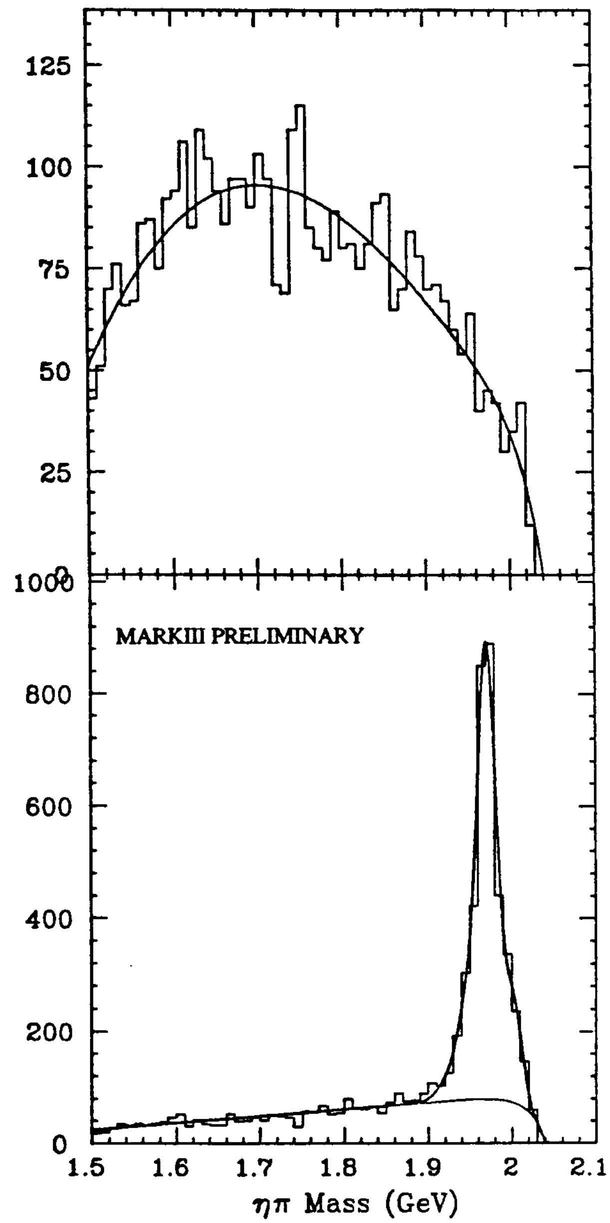

FIGURE 6

(a) Data for D_s-> $\eta\pi^+$ with η -> $\gamma\gamma$ from MARKIII. (b) Monte Carlo.

5. D_s ABSOLUTE BRANCHING RATIO

All high energy experiments that observe D_S-> final state (i) in e^+e^-, measure the cross section for D_S production ($\sigma(D_s)$) times the branching ratio B(i). To extract a branching ratio B(i), requires knowledge of $\sigma(D_s)$. Typically, experiments (TASSO, CLEO, ARGUS and HRS) have taken observed D production (where an absolute Br scale is available[8]) and assumed some fraction to be Ds (typically 15%), or taken the total cross section, and assumed some fraction to be $c\bar{c}$ (using the quark model), and some fraction of that to be D_S (again 15%). All of

6. CONCLUSIONS

Several observations can now be made about the pattern of D_s decays. First, as in D^0 and D^+ decays, the non-resonant part of the total width appears small. The visible higher multiplicity decays also appear to be small. There is no evidence for a large vector-vector contribution. The balance of the observed decays seem to be PP or PV. The decays that would reveal a large non-spectator contribution appear largely absent ($\rho^0\pi^+$ and $\omega\pi^+$), just as in the D^0 meson case.

Examining Table I, one sees that measurements thus far suggest that the total fraction of D_s decays that can be accounted for is less than about 50% if the semileptonic decays are taken to be 16%. The early measurements of MARKII and NA14' suggested a large $\eta\pi^+$ and $\eta'\pi^+$ contribution, however these have been subsequntly ruled out. Where then are the D_s decays ?

While many discreet models of charm decay exist, there are currently two theoretical models which are presumed comprehensive, in the prediction of large numbers of charm decay final states. The model of Bauer, Stech and Wirbel[10] is a phenomenological model that incorporates the short distance QCD behaviour in the Wilson coefficients c_+ and c_- and the long range effects by adding one additional parameter ξ. The model assumes that factorization is valid, dropping non-factorizable terms. This is largely justified by the 1/N expansion work of Buras, Gerard and Ruckl.[11] Potential model wave functions are used, as well as hadronic form factors, however there is no systematic treatment of SU(3) flavor breaking or final state interactions. The possibility of annihilation-like effects (dropped because they are higher orderin 1/N) are added only *by hand* assuming rescattering as an effective final state interaction. In the case of D^0 and D^+ decays, the greater part of the total widths are explained by the quasi two-body decays in this picture.

A less phenomenological but still comprehensive approach is the QCD Sum Rule method of Blok and Shifman.[12] There are no free parameters and non-factorizable pieces are retained, as are annihilation components. The method still ignores SU(3) breaking and final state interactions, however there is some evidence from D decays that final state interactions arise naturally in this approach. It too treats only the quasi two-body decays at the present time.

The results of the two models are shown in Table II, indicating general agreement in predicting many of the two-body decays observed. Interestingly, neither model would predict large η or η' contributions to the two-body channels. The major discrepancy in the Bauer-Stech- Wirbel model is the level of vector-vector decay, which experimentally appears small in the D_s, just as in the D meson cases, yet is predicted to be large in the model, for some channels.

One of the interesting conclusions that arises from the Blok and Shifman model, is the fact that given the experimental lifetime of the D_s, only about half the decays can be accounted for in the picture. If that continues to hold up, then it suggests that the large bulk of the D_s decays are multibody, and contain many neutrals, thus potentially making the D_s an extremely difficult experimental challenge to ultimately understand.

TABLE II. THEORY ESTIMATES FOR HADRONIC BRANCHING RATIOS OF D_s MODES TO $\phi\pi^+$

MODE	EXPT.	Bauer *etal*	Blok *etal*
$D_s \to \bar{K}^0 K^+$	1.00	0.47	0.43
$D_s \to \bar{K}^0 \pi^+$	<0.2 at 90% CL	0.09	
$D_s \to \bar{K}^{*0} K^+$	0.9	0.84	0.74
$D_s \to \rho^0 \pi^+$	<.08 at 90% CL	0.19	<0.03-0.06
$D_s \to \eta \pi^+$	<1.5 at 90% CL	1.0	1.0
$D_s \to \eta' \pi^+$	<1.9 at 90% CL	0.6	0.6
$D_s \to \omega \pi^+$	<0.5 at 90% CL	0.0	0.15-0.30
$D_s \to \bar{K}^{*0} K^{*+}$	2.3±1.2	1.2	-
$D_s \to \phi \rho^+$	2.4±1.1	6.3	-

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy under Contract number DE-AC03-76SF00515.

REFERENCES

[1] D. Pitman, Proceedings of the XVIth SLAC Summer Institute, SLAC REPORT 336, Ed. E. Brennan.

[2] Review of Particle Properties, Phys. Lett. B204 (1988).

[3] J.C.Anjos *et al.*, FNAL-PUB-89/23-E (1989).
J.C.Anjos *et al.*, Phys. Rev. Lett. 62 (1989), 125.
H.Albrecht *et al.*, Phys. Lett. B153 (1985), 343.
S. Barlag *et al.*, CERN EP/88 103 (1988).
M. Alvarez *et al.*, CERN-EP/88-148 (1988).
H.Albrecht *et al.*, Phys. Lett. B179 (1986), 398.
J.C.Anjos *et al.*, Phys. Rev. Lett. 60 (1988), 897.
J. McKenna, Ph.D. Thesis, U. Toronto (1987), unpublished.
J. Adler *et al.*, SLAC-PUB-4952 (1989).
G. Wormser *et al.*, Phys. Rev. Lett. 61 (1988), 1057.
G. Wormser , talk at XXIV Rencontres de Moriond, March (1989).

[4] G. Wormser etal., Phys. Rev. Lett. 61 (1988), 1057.

[5] G. Wormser, XXIVth Rencontres de Moriond, Les Arcs, France (1989).

[6] While preparing this paper, NA14' presented a revised analysis, giving the $\eta'\pi^+$ ratio of 6.9±2.4±1.4, relative to

$\phi\pi^+$. Talk presented by G. Wormser at the III [rd] Heavy Flavor Symposium, Cornell, (1989).

[7] I.E.Stockdale, Proc. of the Int. Symposium on Production and Decay of Heavy Flavors, Stanford, (1987).

[8] J. Adler *etal.*, Phys. Rev. Lett. 60 (1988) , 89.

[9] Private communication, S. Stone CLEO Collaboration. Also, presented by G. Gladding at the Intl. Symp. on Heavy Flavor Physics, Cornell, June 1989

[10] M. Bauer, B. Stech, and M. Wirbel, Z. Phys. C34 (1987), 103 . and B. Stech, Heidelberg Preprint HD-THEP-87-18.(1987).

[11] A. J. Buras, M. Gerard, and R. Ruckl, Nucl. Phys. B268, 16 (1986).

[12] B. Yu. Blok and M. A. Shifman, Sov. J. Nucl. Phys. 45 (1987) ,135 ; 45 (1987), 301; 45, 522 (1987); 767 (1987), 46.