SLAC – PUB – 4607
March 1988
(T/E)

EVIDENCE FOR D_s DECAY TO $\eta\pi$ FROM MARK III*

JEAN-CLAUDE BRIENT**
Representing the Mark III Collaboration†

ABSTRACT

This paper presents the evidence for a decay mode of the D_s state, obtained using the Mark III detector at the e^+e^- storage ring SPEAR. We report the observation of the decay $Ds^+ \to \eta\pi^+$ in two channels ($\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$). The product branching fraction is measured to be $\sigma(e^+e^- \to D_s^+ D_s^{*-} + c.c.) \times B(D_s^+ \to \eta\pi^+) = 80 \pm 20 \pm 25$ pb and $74 \pm 19 \pm 25$ pb for the $\gamma\gamma$ and $\pi^+\pi^-\pi^o$ channels, respectively. These values are approximately twice the rate of $D_s \to \phi\pi$.

Invited Talk presented at the XXIII Rencontre de Moriond: Current Issues in Hadron Physics, Les Arcs, France, March 13–19, 1988

---

* Work supported in part by the Department of Energy, under contracts DE-AC03-76SF00515, DE-AC02-76ER01195, DE-AC03-81ER40050 and DE-AM03-76SF00034.

** On leave of absence from LAPP-Annecy, France.

† The Mark III Collaboration: D. Coffman, G. P. Dubois, G. Eigen, J. Hauser, D. G. Hitlin, C. G. Matthews, J. D. Richman, W. J. Wisniewski, Y. Zhu, *California Institute of Technology, Pasadena, CA 91125.* M. Burchell, D. E. Dorfan, J. Drinkard, C. Gatto, R. P. Hamilton,◇ C. A. Heusch, L. Köpke, W. S. Lockman, R. Partridge, J. Perrier, H. F. W. Sadrozinski, M. Scarlatella, T. L. Schalk, A. Seiden, A. J. Weinstein, R. Xu, *University of California at Santa Cruz, Santa Cruz, CA 95064.* J. J. Becker, G. T. Blaylock, B. I. Eisenstein, T. Freese, G. Gladding, J. M. Izen, S. A. Plaetzer, C. Simopoulos, A. L. Spadafora, I. E. Stockdale, J. J. Thaler, B. Tripsas, A. Wattenberg, *University of Illinois at Urbana-Champaign, Urbana, IL 61801.* J. Adler, T. Bolton, J. C. Brient, K. O. Bunnell, R. E. Cassell, D. H. Coward, K. F. Einsweiler, C. Grab, U. Mallik, R. F. Mozley, A. Odian, D. Pitman, R. H. Schindler, W. Stockhausen, W. Toki, F. Villa, S. Wasserbaech, N. Wermes, D. Wisinski, *Stanford Linear Accelerator Center, Stanford, CA 94305.* J. S. Brown, T. H. Burnett, V. Cook, A. L. Duncan, A. Li, R. Mir, P.M. Mockett, B. Nemati, L. Parrish, H. J. Willutzki, *University of Washington, Seattle, WA 98195.*

◇ Deceased.

We report the observation of the decay $D_s \to \eta\pi$, both in the decay $\eta \to \pi^+\pi^-\pi^o$ and in the decay $\eta \to \gamma\gamma$. The data sample represents an integrated luminosity of (6.30 ± 0.46) pb^{-1} at $\sqrt{s} = 4.14$ GeV, collected with the Mark III detector at SPEAR. The dominant D_s production process at this energy has been found to be:[1] $e^+e^- \to D_s\overline{D_s^*}$ + c.c. . For this reason, in D_s analysis, the recoil mass is constrained to be at 2.109 GeV/c², the mass of the D_s^*:[1]

$$D_s^+ \to \eta\pi^+ \quad , \quad \eta \to \pi^+\pi^-\pi^o \quad .$$

The analysis proceeds in two steps. First, a set of selections are applied to have correct topology and kinematics for the candidate combinations. The photons pairs for the π^o are selected by a 1C fit (π^o mass constraint, $\chi^2 < 6$). The charged tracks must have TOF information consistent with a pion hypothesis to be used. To reduce the number of entries in the global kinematic fit, the $\pi^+\pi^-\pi^o$ mass must be less than 800 MeV/c², and the $\pi^+\pi^-\pi^o\pi^\pm$ system must have a mass greater than 1.6 GeV/c², and a recoil mass within 80 MeV/c² of the D_s^* mass. For all combinations passing the above cuts, a 1C fit is performed where the recoil mass to $\pi^+\pi^-\gamma\gamma\pi^\pm$ is constraint to the D_s^* mass, with a cut on the probability of the fit at 1%. To reject fake showers and some backgrounds resulting from D^* decays, the fit photon energy must be larger than 120 MeV. To reject further the background, we require that the mass of the η candidates ($\pi^+\pi^-\gamma\gamma$ after the recoil mass constraint fit) shift from the $\pi^+\pi^-\pi^o$ mass by less than 40 MeV/c². This rejects fake π^o due to the 1C fit pulling the photon momenta away from the values obtained in the direct π^o fit.

The scatter plot of $M(\pi^+\pi^-\gamma\gamma)$ versus $M(\pi^+\pi^-\gamma\gamma\pi^\pm)$ is shown in figure 1. There is an excess of events near the intersection of the η and D_s regions. The $\pi^+\pi^-\gamma\gamma$ mass is shown in figure 2(a), for events where $M(\pi^+\pi^-\gamma\gamma\pi^\pm)$ is in the D_s region (1.94–2.00 GeV/c²). In this figure, a peak is observed at the η mass, with mass and resolution consistent with Monte Carlo [distribution shown in figure 2(b)]. As can be seen in figure 1, no evidence for η production is observed outside the D_s region. Selecting events in the η region (± 40 MeV/c²) for $M(\pi^+\pi^-\gamma\gamma)$, figure 3 shows the $(\pi^+\pi^-\gamma\gamma\pi^\pm)$ spectrum. On this figure, the curve corresponds to a fit of a Gaussian signal (with resolution $\sigma = 25$ MeV/c², from Monte Carlo) and a background shape from *a D^* Monte Carlo*. The fitted D_s mass is 1974. ± 7 MeV/c² (statistical errors only). The fitted signal corresponds to 13.7 ± 3.5 events, and statistical significance of 5 σ.[2] This corresponds to:

$$\sigma(e^+e^- \to D_s^+D_s^{*-} \ + \ c.c.) \times B(D_s^+ \to \eta\pi^+) \ = \ 74 \ \pm \ 19 \ \pm \ 25 \text{ pb} \quad .$$

The systematic error (± 25 pb) comes from Monte Carlo statistical error, selection efficiency, choice of background shape, and the integrated luminosity:

$$D_s^+ \to \eta\pi^+, \ \eta \to \gamma\gamma \quad .$$

In a first step, photons involved in a possible π^o are tagged and not used for the η candidates. For this, a π^o is defined as a pair $\gamma\gamma$ with a raw mass within ± 40 MeV/c² of the π^o mass. Now, using the remaining photons, the η candidates are selected by a 1C fit (η mass constraint, $\chi^2 < 6$), while the raw $\gamma\gamma$ mass is required to be greater than 400 MeV/c². $\eta\pi$ candidates with mass greater than 1.6 GeV/c², and recoil mass within 200 MeV/c² of the D_s^* mass, are selected. A 1C fit is performed, where the recoil to $\gamma\gamma\ \pi$ is required to have the D_s^* mass. Then a 2C fit is performed where both the recoil mass and η mass are constrained. Figure 4 shows the $\gamma\gamma$ mass (1C fit D_s^* constraint), for the data after the 2C fit [figure 4(a)], and for the Monte Carlo after the 2C fit [figure 4(b)]. A selection of the

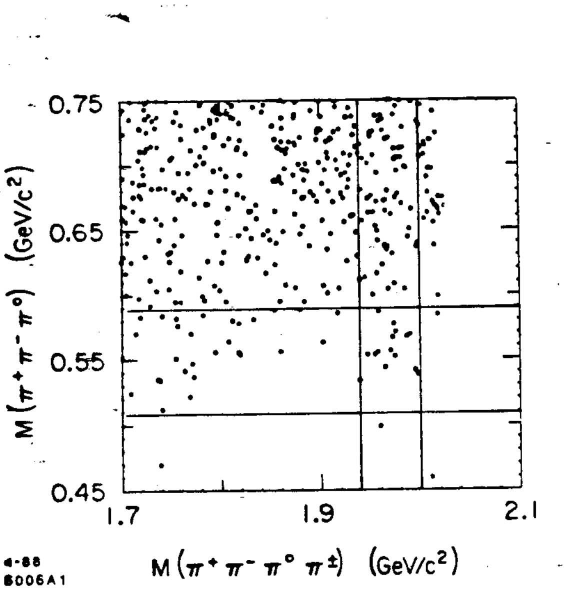

Fig. 1. Scatter plot of $M(\pi^+\pi^-\gamma\gamma\pi^\pm)$ versus $M(\pi^+\pi^-\gamma\gamma)$ for the results of the 1C D_s^* fit. The lines indicate the D_s and η regions described in the text.

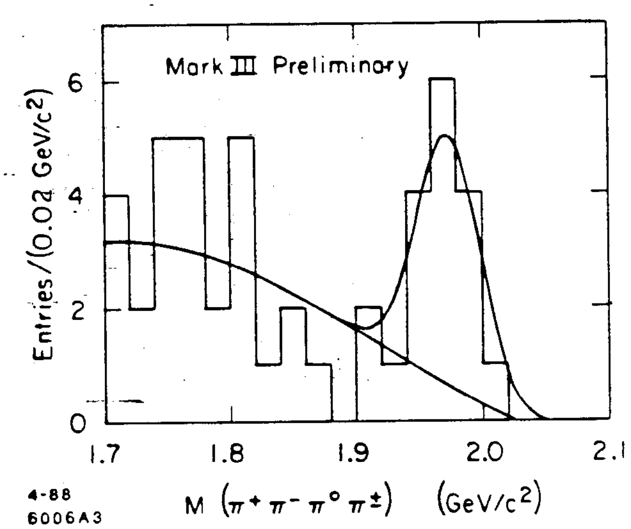

Fig. 3. The $\pi^+\pi^-\gamma\gamma\pi^\pm$ mass after selecting η region for $\pi^+\pi^-\gamma\gamma$ mass for the data.

η region ($\pm$20 MeV/c^2) on this distribution is very useful to reject background. (Rejected events correspond to the dashed area.) The final selection is to take only symmetric decays of the $\eta \to \gamma\gamma$ ($|\cos(\theta_{\gamma\eta})| < 0.5$), and symmetric decays of the $D_s^+ \to \eta\pi^+$ ($|\cos(\theta_{\pi\eta})| < 0.5$),

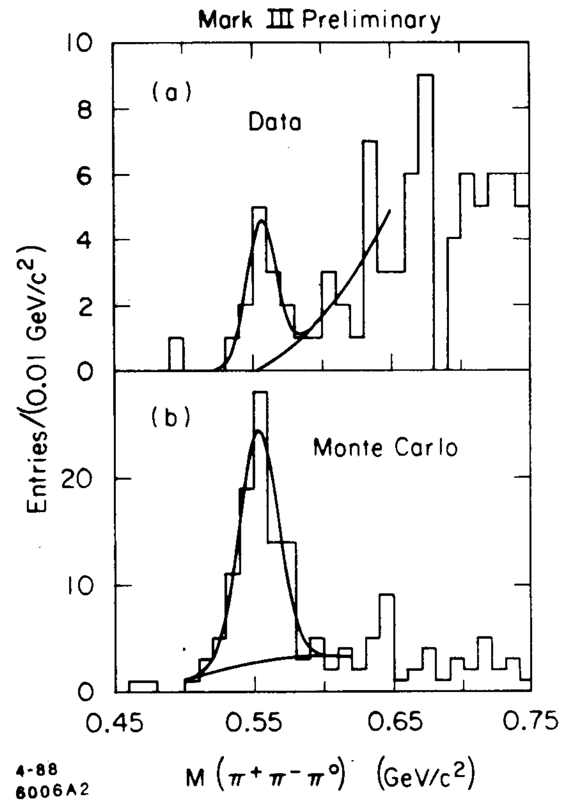

Fig. 2. The $\pi^+\pi^-\gamma\gamma$ mass after cut on $\pi^+\pi^-\gamma\gamma\pi^\pm$ mass, for data (a) and Monte Carlo (b). The curves are the results of fits: $m(\eta) = 554 \pm 2$ MeV and $\sigma(\eta) = 14 \pm 2$ MeV for the Monte Carlo, and $m(\eta) = 557 \pm 4$ MeV and $\sigma(\eta) = 11 \pm 3$ MeV for the data.

where $\theta_{\gamma\eta}$ is the angle between one photon and the η, in the η rest frame, and $\theta_{\pi\eta}$ is the angle of the η and the $\eta\pi$ system, in the $\eta\pi$ rest frame. After all the cuts, the $\eta\pi$ mass spectrum is shown in figure 5. Figure 6 shows our first estimate of the background shape, namely the "η side bands" in the recoil mass constraint fit. Figure 7 shows $\eta\pi$ mass spectrum after the "η side bands" subtraction. A clear peak is observed, corresponding to a mass of 1970 $\pm$ 5 MeV/c^2, a mass resolution of 20 MeV (to be compared with 21 MeV/c^2 predicted using the Monte Carlo), and 18.0 $\pm$ 4.5 events. In fact, since the η mass is used as a constraint in the 2C fit, the "side band" procedure is not fully correct

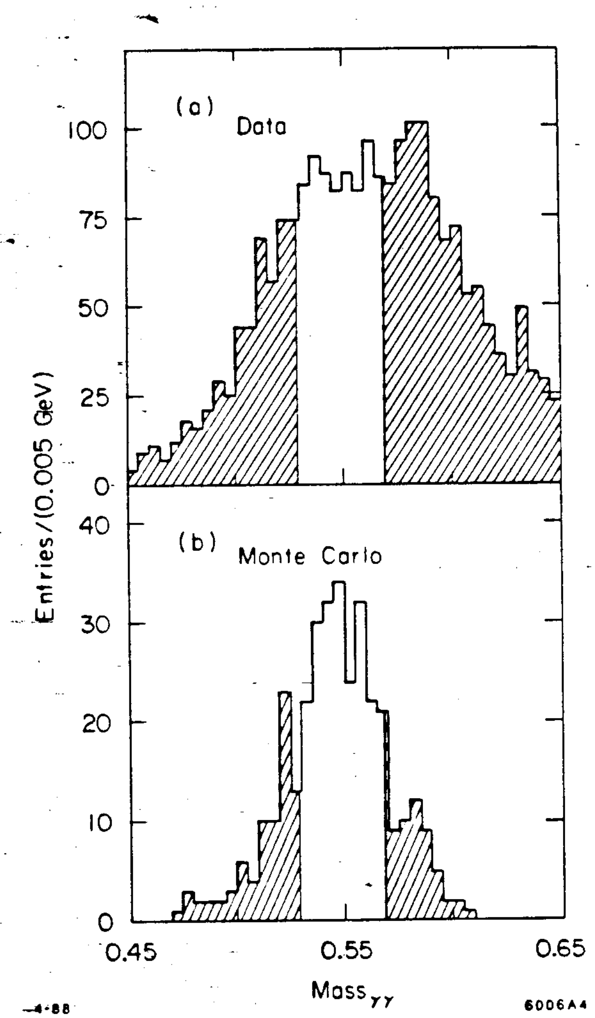

Fig. 4. $\gamma\gamma$ mass from the 1C D_s^* fit, after the 2C fit (D_s^* and η constraint), for the data (a) and the Monte Carlo (b).

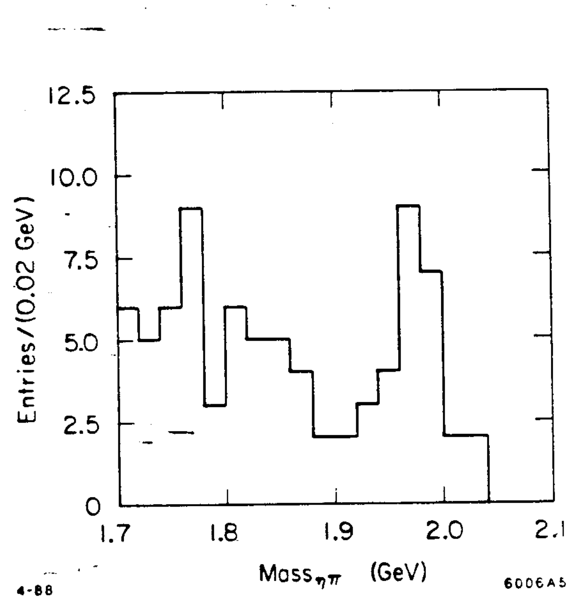

Fig. 5. The $\eta\pi^{\pm}$ mass from the 2C fit, after all the cuts described in the text.

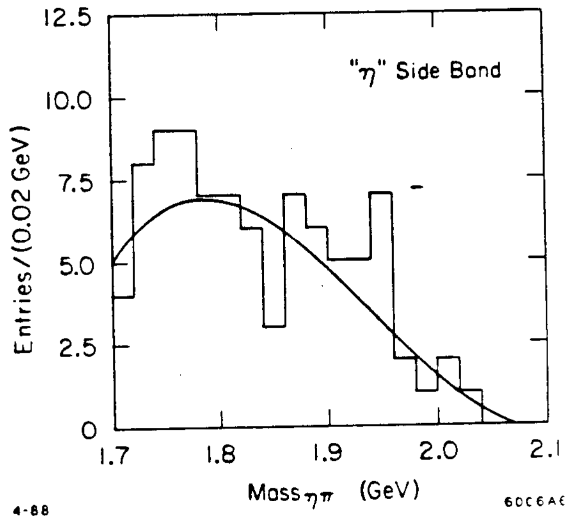

Fig. 6. The $\eta\pi^{\pm}$ mass from the 2C fit, after all the cuts, but for the "η side band" in the 1C D_s^* fit. The curve is the result of the fit of a polynomial background.

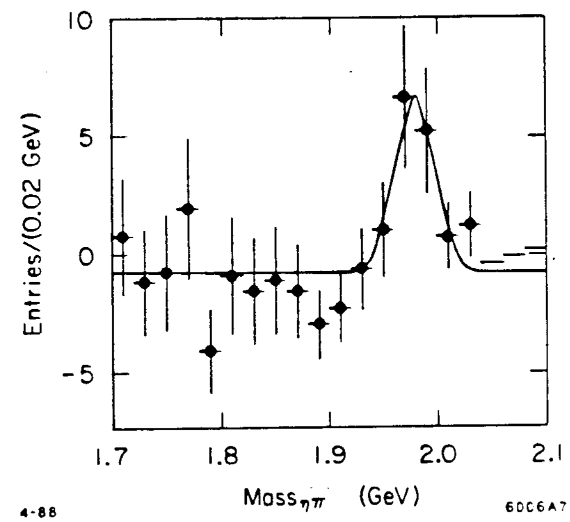

Fig. 7. The $\eta\pi^{\pm}$ mass (2C fit), after subtracting the background curve obtained on the "η side band."

in this case. To have a more accurate estimate of the background, we have made a "mixing" sample combining η candidates with charged pions from different events. The analysis is then performed as on the real data sample. Figure 8 shows the $\eta\pi$ mass spectrum for the "mixing" sample, where the curve represents the result of the fit of a polynomial function. Figure 9 shows the $\eta\pi$ mass spectrum for the real data, where the curve is the result of a fit using the

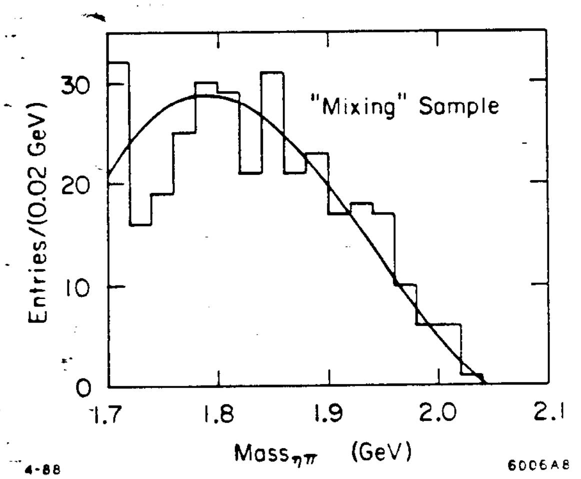

Fig. 8. The $\eta\pi^{\pm}$ mass (2C fit) for the "mixing" sample described in the text. The curve is the result of the fit of a polynomial function.

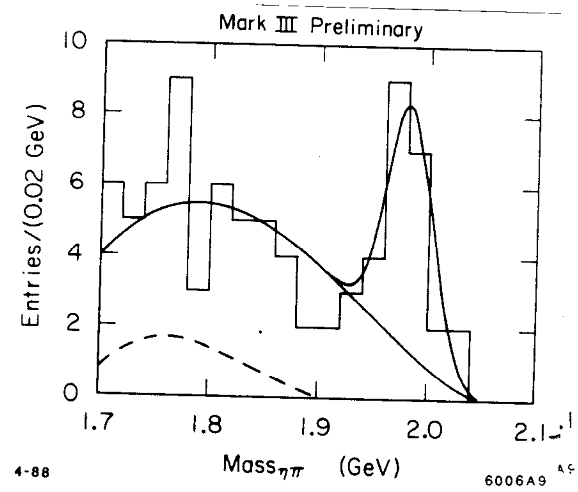

Fig. 9. Same mass spectrum as Fig. 5. The solid curve is the result of a fit using for the background the shape of the "mixing" sample, and a Breit–Wigner for the signal. The dashed line corresponds to the predicted D contribution (see text).

background shape from the "mixing" sample and a Gaussian signal. The fitted mass is 1982. $\pm$ 7 MeV/c^2, and the mass resolution is 21 $\pm$ 4.5 MeV/c^2. The fitted number of signal events is 18.5 $\pm$ 4.6, with 5.5 σ statistical significance.[2] This corresponds to:

$$\sigma(e^+e^- \rightarrow D_s^+ D_s^{*-} \ + \ c.c.\ ) \times B(D_s^+ \rightarrow \eta\pi^+) \ = \ 80 \ \pm \ 20 \ \pm \ 25 \text{ pb} \quad .$$

The systematic error is obtained similarly to that in the 3-pion channel.

Many checks have been performed. First, no signal is observed if we change the η mass in the fit, or if we change the recoil constraint mass. Generating of the order of 5 times the number of $D\overline{D} + X$ events present in our real data, we have found that $e^+e^- \rightarrow D^*\overline{D^*}$ is the dominant background coming from D production. No fake peak is observed with this Monte Carlo D sample. The background shape fitted on this sample is consistent with what is found with the "mixing" sample. Moreover, using this Monte Carlo, and the value of the production cross section,[3] we predict the D contribution to the background as shown by the dashed line in figure 9. The events in the signal region have been visually scanned, and reasonable behavior is observed for each event. In conclusion, D_s^+ decays to $\eta\pi^+$ are observed in both channels $\eta \rightarrow \pi^+\pi^-\pi^o$ and $\eta \rightarrow \gamma\gamma$. The measured cross section times branching fraction is consistent for the two different channels. The branching ratio relative to $\phi\pi$ decay is found to be:

$$B(D_s^+ \rightarrow \eta\pi^+) \ = \ (2.6 \pm 0.6 \pm 0.8) \times B(D_s^+ \rightarrow \phi\pi^+) \quad .$$

Various models predict 1.1[4] and 1.[5] for this ratio. It is interesting to note that B($D_s^+ \rightarrow \eta\pi^+$) B($D_s^+ \rightarrow \overline{K^0}K^+$) is found to be in reasonable agreement with the expectations of these two models.

REFERENCES

1. J. Adler et al., Phys. Rev. Lett. **58**, 2171 (1987).
2. The statistical significance of signals are obtained by the variation of the likelihood function with or without signal.
3. J. Adler et al., SLAC–PUB–4518, January 1988, to be published in Physics Letters B.
4. B. Y. Blok et al., Sov. J. of Nucl. Phys. **45(3)**, 522 (1987).
5. M. Bauer et al., Z. Phys. C **34**, 103 (1987).