D_s^+ Semileptonic Decays at a τ – Charm Factory*

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Abstract

Preliminary studies of semileptonic D_s^+ decays have been made. The analysis relies on a large sample ($\approx 10^6$) of tagged hadronic D_s^+ events. The Monte Carlo study involved specific decay channels, $D_s^+ \rightarrow \phi e^+ \nu_e$ and $D_s^+ \rightarrow K^0 e^+ \nu_e$, at a center-of-mass energy of 4.03 GeV. Background events due to other D_s^+ modes and to D^0 and D^+ decays are examined. The possibility of signal reconstruction at a center-of-mass energy of 4.14 GeV is investigated.

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The present state of semileptonic decays could best be described as poor. A single measurement/upper limit of the inclusive decay $D_s^+ \to e^+X$[1] has been made by the Mark III experiment[2] using a sample of about 75 tagged hadronic events. Of this sample, fewer than 10 events contain electron candidates. Measurements of D_s^+ semileptonic decays are not likely to be made with the present fixed target data; future measurements may be possible.[3]

A quantum leap will be made at a tau-charm factory. Not only will a precise measurement of the inclusive decay rate be made, but measurements of specific semileptonic decay channels, for example $D_s^+ \to \phi e^+\nu_e$, will be possible. The number of expected number of signal events *per channel* ranges from 500 to 2000.

In the understanding of the Kobayashi-Maskawa matrix, measurements of individual matrix elements as well as of ratios of the matrix elements are significant. A comparison of the matrix elements V_{cd} and V_{cs} may be made through two approaches. The first involves the comparison of reactions with like initial states and different final states, for example, $D^0 \to \pi^- e^+\nu_e$and $D^0 \to K^- e^+\nu_e$, which has been made with present data.[4] The branching ratios for these two reactions are related by:

$$\frac{B(D^0 \to K^- e^+\nu_e)}{B(D^0 \to \pi^- e^+\nu_e)} = \left|\frac{V_{cs}}{V_{cd}}\right|^2 \left[\frac{f_+^K(0)}{f_+^\pi(0)}\right]^2 \left[\frac{\int (m_{D_s^*}^2/(m_{D_s^*}^2 - t))^2 (E_K^2 - m_K^2)^{3/2} dt}{\int (m_{D^*}^2/(m_{D^*}^2 - t))^2 (E_\pi^2 - m_\pi^2)^{3/2} dt}\right],$$

where $f_+(0)$ are the form factors at zero momentum transfer and the integrals account for the t-dependence of the form factors.

The second approach is to compare reactions with different initial states and identical final states, for example the comparison of $D_s^+ \to K^0 e^+\nu_e$ with $D^+ \to$

$\overline{K^0}e^+\nu_e$. (In fact the final states do differ slightly due to phase space.) The branching ratios for these reactions are related by:

$$\frac{B(D^+ \to \overline{K}^0 e^+\nu_e)}{B(D_s^+ \to K^0 e^+\nu_e)} = \left|\frac{V_{cs}}{V_{cd}}\right|^2 \left[\frac{f_+^{\overline{K}}(0)}{f_+^K(0)}\right]^2 \left[\frac{\int(m_{D_s^*}^2/(m_{D_s^*}^2 - t))^2(E_{\overline{K}}^2 - m_{\overline{K}}^2)^{3/2}dt}{\int(m_{D^*}^2/(m_{D^*}^2 - t))^2(E_K^2 - m_K^2)^{3/2}dt}\right]$$

The extraction of V_{cd}/V_{cs} will require an accurate knowledge of the form factors. Several authors have addressed this topic;[5–9] one would presume that the predictions for the form factors will become more refined as further experimental data is available.

The example of $D_s^+ \to K^0e^+\nu_e$ and $D^+ \to \overline{K^0}e^+\nu_e$ can of course be extended to many more decay channels containing electrons or muons. For instance, comparisons of $D_s^+ \to \overline{K^*}^0\ell^+\nu_\ell$ with $D^+ \to K^{*0}\ell^+\nu_\ell$, (where ℓ is a lepton), would provide similar information on the ratios of Kobayashi-Maskawa matrix elements. Finally, with considerable statistics available in a broad range of specific decay channels, a knowledge of the matrix elements V_{cd} and V_{cs} themselves should be possible.

Monte Carlo Studies

At the tau-charm factory, it is estimated that there will be $\approx 8.3 \times 10^5$ tagged hadronic D_s^+ decays.[10] About 10^5 of these tags would be $D_s^+ \to \phi\pi^+$.

For this workshop, events were generated for the semielectronic decays channels:

$$D_s^+ \to \phi e^+\nu_e;\ D_s^+ \to K^+K^-e^+\nu_e;\ D_s^+ \to K^0e^+\nu_e;\ \text{and}\ \mathrm{D_s^+} \to \phi\pi^0\mathrm{e}^+\nu_\mathrm{e}.$$

Ten thousand events per channel were generated opposite the hadronic decay $D_s^+ \to \phi\pi^+$. The tagging efficiency for this hadronic mode is $\approx 13\%$, if one requires

2 well-identified kaons and restricts M_{KK} to be within 10 MeV/c^2 of the mass of the ϕ. Events were generated with a center-of-mass energy of 4.03 GeV, and the modest version of the tau-charm detector.[11] In particular, the electromagnetic calorimeter energy resolution is $8\%/\sqrt{E}$. For $D_s^+ \to \phi e^+ \nu_e$, events were generated with a center-of-mass energy of 4.14 GeV as well. At 4.14 GeV, the dominant D_s^+ production process is $e^+e^- \to D_s^+ D_s^{*-}$.[12]

The analysis proceeds similarly for all the semileptonic channels. The tagged D_s^+ is first reconstructed; the recoil tracks are then studied. The extraction of the signal relies upon the use of the variable $U \equiv E_{missing} - P_{missing}$, where $E_{missing}$ is the calculated missing energy using the known center-of-mass energy, and $P_{missing}$ is the calculated missing momentum. The measured four-momenta for all the tracks used in the tag and those in the recoil which correspond to the semileptonic decay channel of interest are used in the calculations of $E_{missing}$ and $P_{missing}$.

For events containing a single undetected massless particle, U will be 0. The spread in its value reflects the detector resolution. On the other hand, U will not be zero if there is more than one undetected massless particle or if $E_{missing}$ or $P_{missing}$ has been miscalculated due to unreconstructed (charged or neutral) tracks.

We begin with a study of $D_s^+ \to \phi e^+ \nu_e$ under several possibilities. Figure 1a illustrates the cleanliness of the above technique. U is plotted for the case when both K^+ and K^- have been identified using TOF; their invariant mass is required to lie within 10 MeV/c^2 of the mass of the ϕ; and the electron has been identified using the electromagnetic calorimeter. The spread in the value of U about zero has a half-width of $\approx$ 8 MeV/c^2. The number of events in the plot ($\approx$ 450) is comparable to the expected number of reconstructed events at a tau-charm factory for this specific semileptonic signal opposite this particuliar hadronic tag.

The same reaction has been studied for a slightly different analysis criterion, namely, that only one of the kaons be well-identified. All other requirements remain the same as in the previous case. Such events would not be uncommon: many of the kaons, being of low momenta, may decay in flight. The distribution of the variable U, shown in Figure 1b, has broadened considerably. The half-width is ≈ 25 MeV$/c^2$ and the distribution has far-reaching tails. This clearly demonstrates the importance of tracking close to the interaction point so that tracks of decaying particles may be correctly reconstructed. For this channel, the increase in statistics which results from the loosening of the requirement on kaon identification is roughly 50%.

The reaction $D_s^+ \to \phi\pi^0 e^+\nu_e$ is studied as a background to the process $D_s^+ \to \phi e^+\nu_e$, for the case of an undetected π^0. For this analysis, U is calculated using the tracks which form the tag, and the ϕ and the electron. No requirements are yet imposed on the presence (or lack thereof) of photons in the event. The resulting U distribution is shown in Fig. 2; its peak is shifted from zero (as expected). Already, there is no significant overlap between these events and those in Fig 1a. Rejection of events with one or more photons would eliminate most of these events.

Background to semileptonic D_s^+ decays may arise from D decays. D^0 and D^+ may be produced directly, $e^+e^- \to D^+D^-$, $D^0\overline{D^0}$, or from D^* which are also produced at this center-of-mass energy. A preliminary study was made of this potential source of background. A total of 40000 events of the type $D^*\overline{D^*}$, $D\overline{D^*}$, and $D\overline{D}$ were generated, where the D^* and D decay according to measured branching ratios. Of the 40000 events, less than 20 events passed the tagging criteria for $D_s^+ \to \phi\pi^+$. Of these, none had values for U within the signal region for $D_s^+ \to \phi e^+ \nu_e$.

The analysis of $D_s^+ \to K^0 e^+ \nu_e$ proceeds similarly. The electron is identified by the electromagnetic calorimeter. The K^0 is reconstructed as $K_s^0 \to \pi^+\pi^-$, with M_{KK} required to be in the range $0.492 - 0.504$ GeV/c^2. Again U is calculated using the center-of-mass energy, the tag tracks, the electron and the K^0. The resulting U distribution is shown in Fig. 3. The half-width is ≈ 8 MeV/c^2.

Finally, events were generated for $D_s^+ \to \phi e^+ \nu_e$ with a center-of-mass energy of 4.14 GeV. At this energy, the dominant production mechanism is $e^+e^- \to D_s^{*+} D_s^-$, $D_s^{*+} \to D_s^+ \gamma$. For the analysis, one reconstructed photon is required in addition to the other tracks for the purpose of calculating U. The distribution for U is shown in Fig. 4. The half-width has broadened to ≈ 20 MeV/c^2 and the efficiency for reconstruction of this particular channel decreases by $\approx 25\%$.

The reconstruction of specific D_s^+ semileptonic decays will be easily accessible with the estimated number of tagged D_s^+ events at a tau-charm factory. There are several important factors concerning the detector design and the resulting approach to data analysis which should be mentioned. For the case of an "average" detector, by imposing strong requirements on such things as particle identification, one will obtain clear signals, at the cost of efficiency. On the other hand, with good track reconstruction close to the interaction point and optimal resolution on the event missing energy, maximal numbers of clean signal events will be had, without the need to impose strict kinematic requirements. For $D_s^+ \to \phi e^+ \nu_e$, the increase in statistics is $\geq 50\%$. As demonstrated by the plots of U, a center-of-mass energy below D_s^* threshold is clearly favoured for reconstruction of D_s^+ semileptonic decays. The ability to reject events containing extra photons would be extremely useful.

To summarise, there will be a huge step forward in the domain of semileptonic D_s^+ decays, for which data is severely lacking. For $D_s^+ \to \phi e^+ \nu_e$, roughly 2000 events should be reconstructed. For the Cabibbo-suppressed decay $D_s^+ \to K^0 e^+ \nu_e$, a few hundred events are expected to be reconstructed. The Monte Carlo work performed so far addresses only a few of the many possible semileptonic channels. A study of semimuonic decay channels and those containing photons, such as $D_s^+ \to \eta \ell^+ \nu_\ell$, would be useful.

REFERENCES

1. Throughout this paper, reference to a state implies its charge conjugate state as well.
2. D. Pitman, Proceedings of the SLAC Summer Institute on Particle Physics (1988) 209.
3. M. Witherell, these Proceedings.
4. J. Adler, *et al.,* Phys. Rev. Lett. 62 (1989) 62.
5. M. Wirbel, B. Stech, and M. Bauer, Z. Phys. C 29 (1985) 637.
6. C.A. Dominguez and N. Paver, Phys. Lett 207B (1988) 499.
7. N. Isgur, D. Stora, B. Grinstein and M. Wise, Phys. Rev. D 39 (1989) 799.
8. G. Peter Lepage and Stanley J. Brodsky, Phys. Rev. D 22 (1980) 2157.
9. B.F.L. Ward, these Proceedings.
10. T. Browder, these Proceedings.
11. J. Kirkby, these Proceedings.
12. G. Blaylock *et al.,* Phys. Rev. Lett. 58 (1987) 2171.

Figure Captions

1. a) U, ($\equiv E_{missing} - P_{missing}$), for the decay $D_s^+ \rightarrow \phi e^+ \nu_e$, for the selection criteria described in the text. b) U for the same channel with looser particle identification requirements, as described in the text.
2. U for $D_s^+ \rightarrow \phi \pi^0 e^+ \nu_e$, where the π^0 has not been reconstructed.
3. U for $D_s^+ \rightarrow K^0 e^+ \nu_e$.
4. U for $D_s^+ \rightarrow \phi e^+ \nu_e$, for center-of-mass energy of 4.14 GeV.

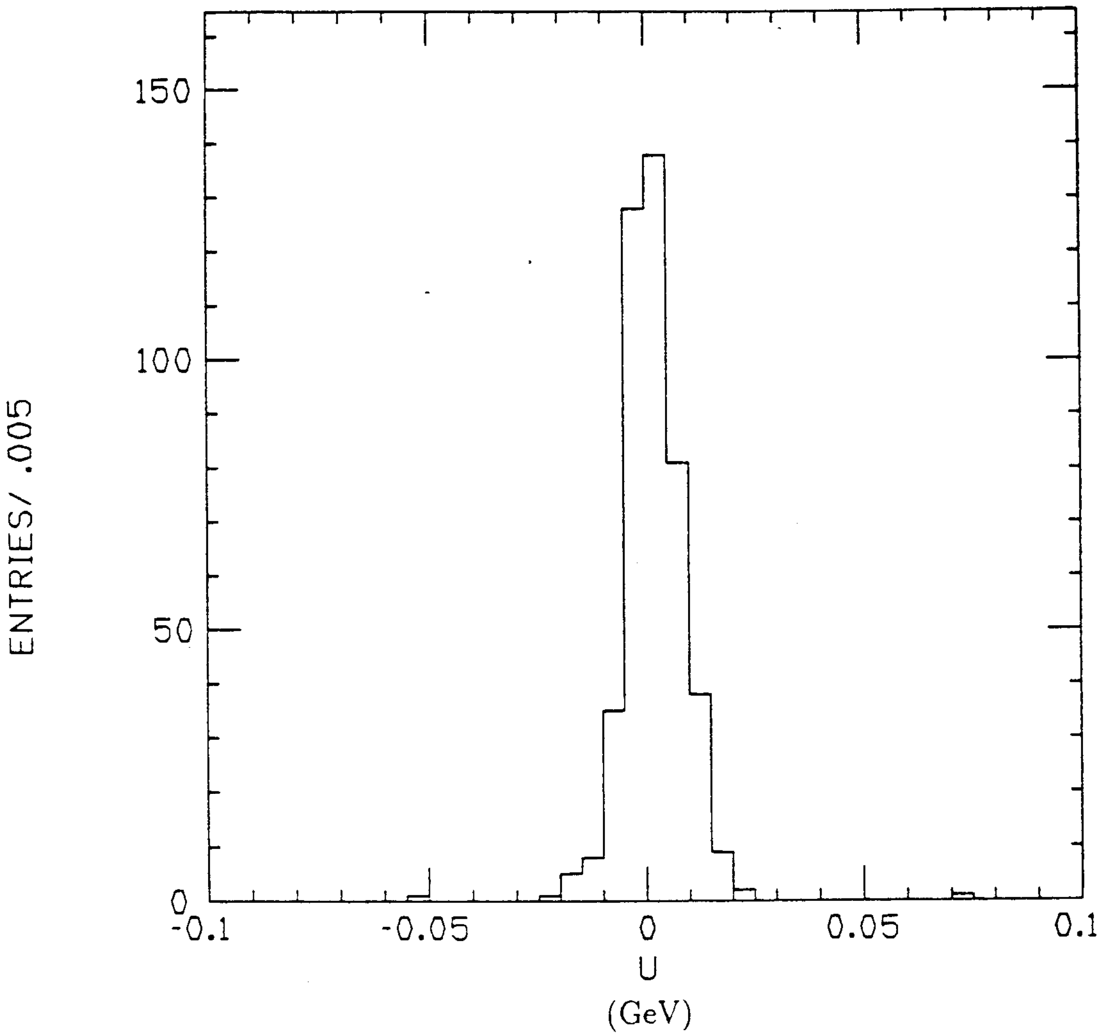

FIGURE 1(a)

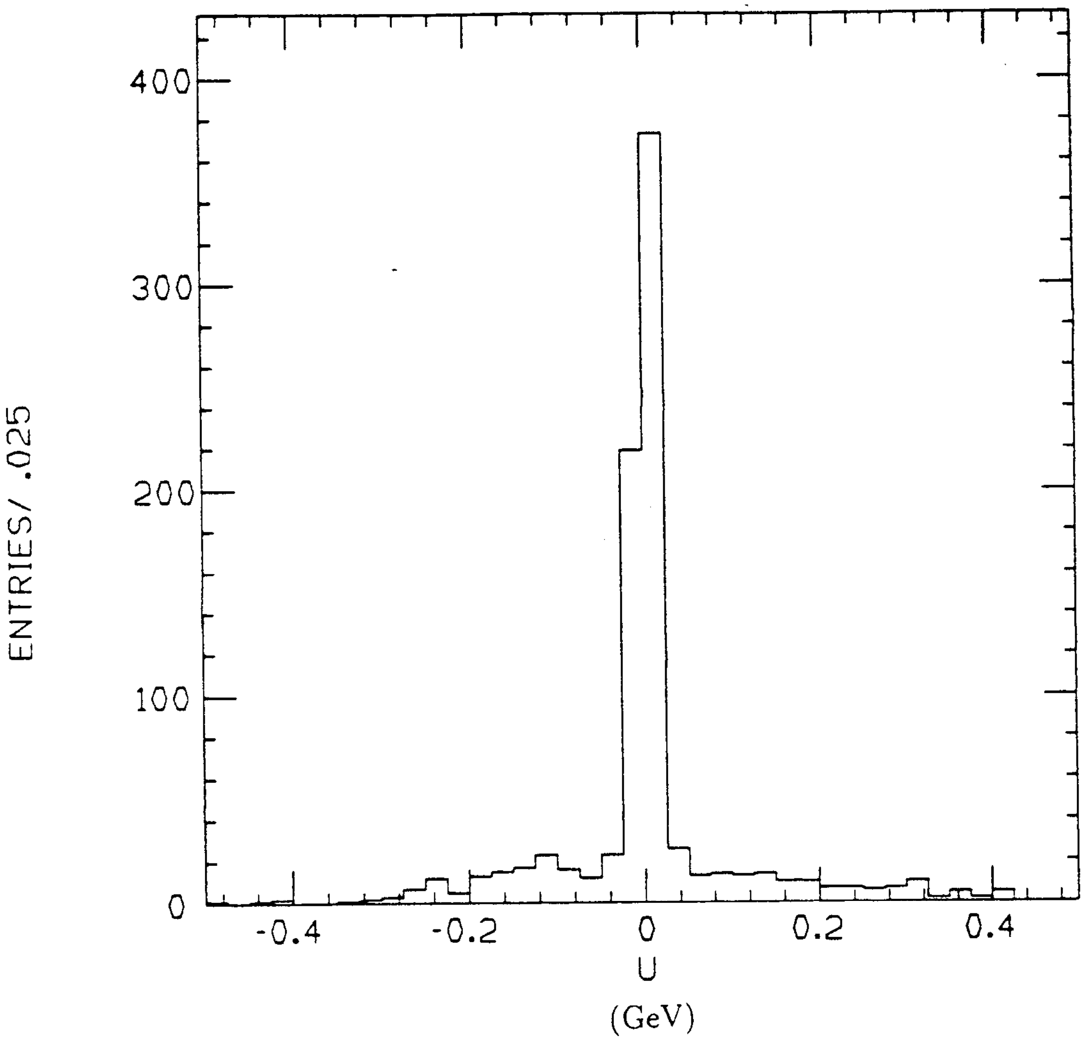

FIGURE 1(b)

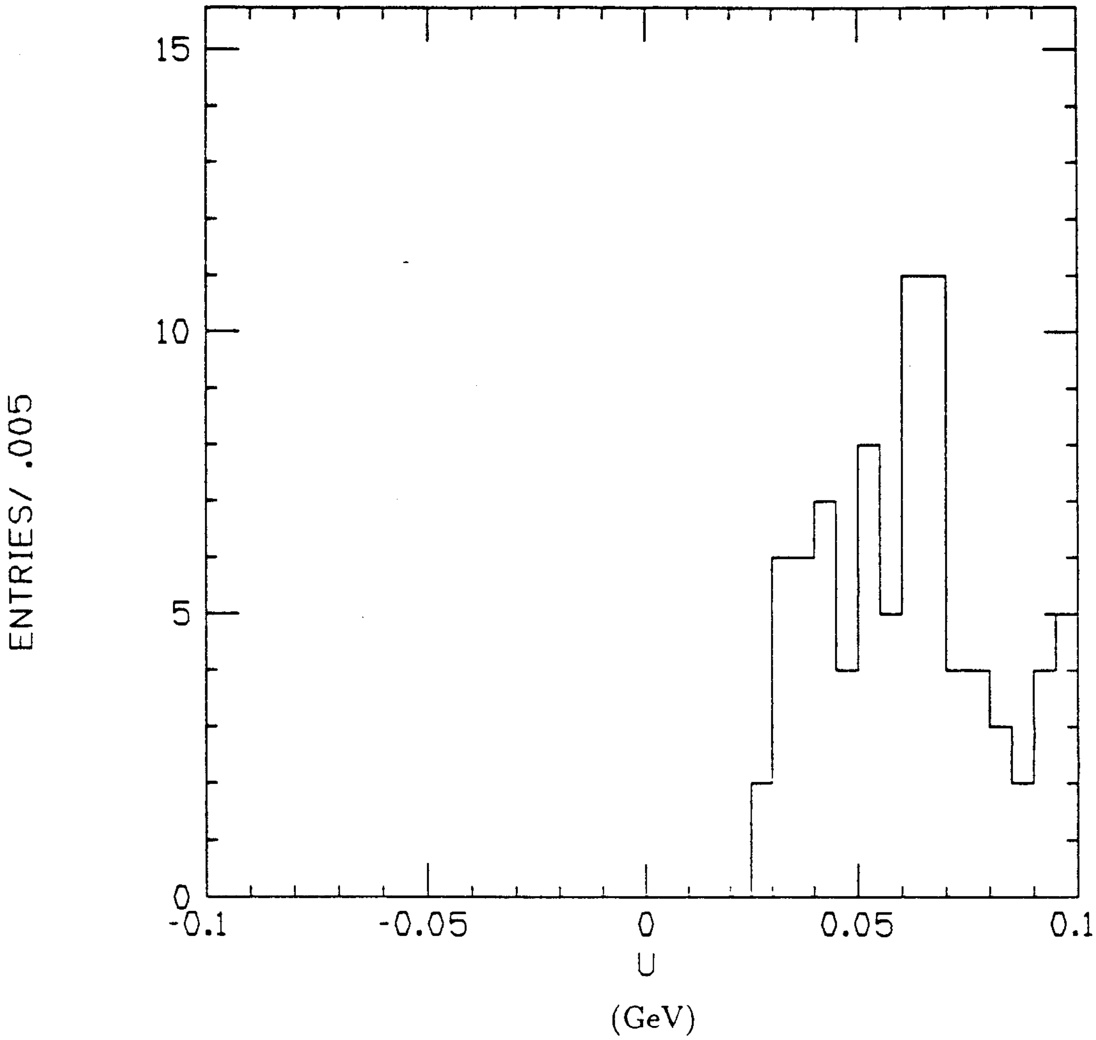

FIGURE 2

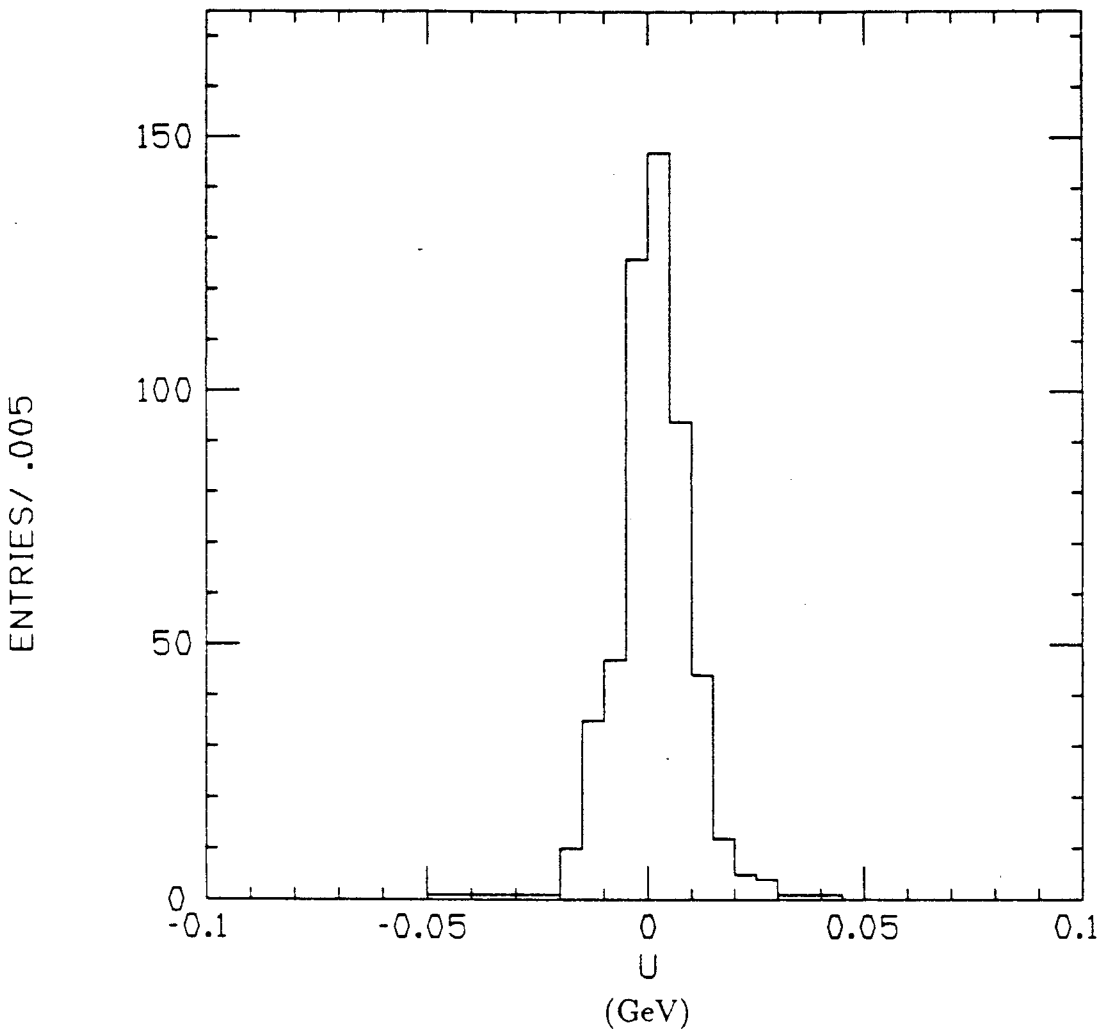

FIGURE 3

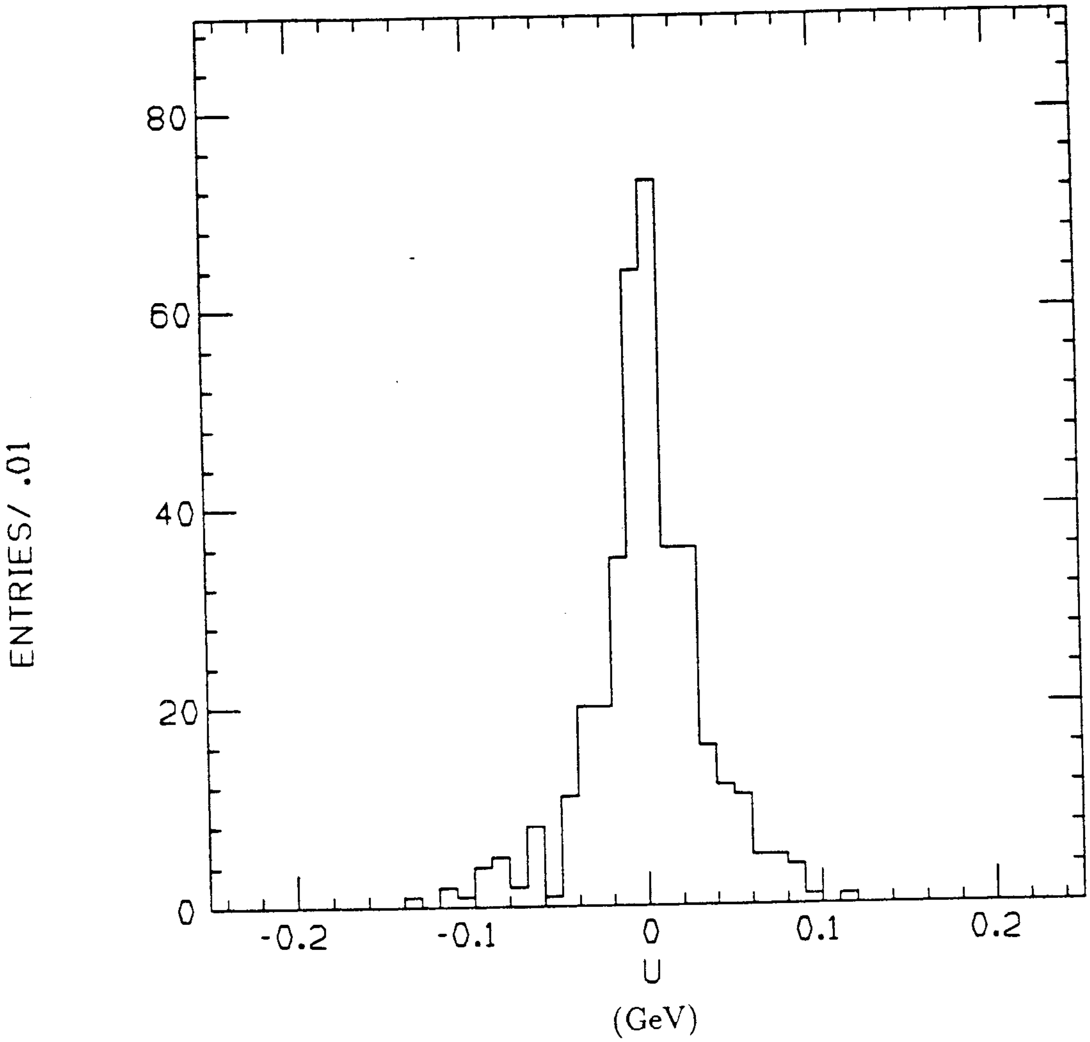

FIGURE 4