Fermi National Accelerator Laboratory

FERMILAB-Conf-87/143-E

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The Tagged Photon Spectrometer Collaboration

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September 1987

*Contributed Paper submitted to the 1987 International Symposium on Lepton and Photon Interactions at High Energies, Hamburg, July 27-31, 1987.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

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ABSTRACT

Neutral current interactions are known from studies of K meson decays to conserve flavour to a high precision. Although flavour changing neutral currents (FCNC) are forbidden in the Weinberg-Salam model, many extensions of the Standard Model allow such processes. We present preliminary upper limits on FCNC-mediated decays of charmed particles, namely $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, $D^0 \to \mu e$ and $D^+ \to \pi^+\mu e$.

1. Introduction

The Weinberg-Salam $SU_L(2) \times U(1)$ model[1] has been remarkably successful in describing the electro-weak interactions at the energy scale of the weak vector boson M_W. The Standard Model of strong and electro-weak interactions with (fundamental or effective) gauge group $G = SU(3)_{color} \times SU_L(2) \times U(1)$ provides a very good description of the fundamental forces of nature (except gravity). However, there remain several unanswered fundamental questions, for example, the origin of the fermion masses and the mixing angles. Also unexplained is the apparent existence of three generations of fermions. Here, there exist certain regularities; all mass ratios of charged fermions belonging to the different generations (families) are large and mixing angles observed in charged current interactions are small. Also neutral current interactions are flavour conserving to a high precision[2] (recall the Glashow-Iliopoulos-Maiani model[3] introduced the charmed quark to explain the *absence* of flavour changing neutral currents in the decays of K mesons).

There exist a large number of different classes of theories which attempt to explain the mass matrix and the mixing matrix. All of them have a common feature, namely, they predict the existence of flavour-changing processes which are forbidden in the Standard Model. Among models in which FCNC processes occur naturally are[4-6]: Extended Technicolor models[5], horizontal generation-changing models [6], composite models, multiple Higgs doublet models with flavour mixing in the Higgs sector, baryon and lepton-violating low-mass Higgs in grand unified theories (GUTs), theories with heavy neutral leptons and mixing in the leptonic sector, and some of the superstrings motivated models.

Measurements, or rather limits on the partial rates into such exotic decay modes of K mesons have been the main source of constraints on the specific details of theoretical models for many years. In general, limits for the K decays are $\sim 10^4$ times more stringent than for the corresponding decays of charmed particles. However, there exist models which avoid the K limits by introducing new FCNC interactions. By intruducing different couplings to the "up-type" quarks (u,c,t) and to the "down-like" (d,s,b) quarks, the flavour non-conserving decays of charmed particles can be enhanced with respect to the corresponding decays of strange particles[7].

With half of our full data sample, we have obtained the limits on the presence of the flavour changing processes in decays of charmed particles. The decays $D^0 \to \mu^+\mu^-$ and $D^0 \to e^+e^-$ are allowed in the Standard Model, however, they are strongly suppressed. The processes $D^0 \to \mu e$ and $D^+ \to \pi^+\mu e$ are strictly forbidden in the Standard Model. It is important to look at both in limiting the FCNC because the $D^0 \to \mu e$ decay vanishes for a pure vector (or scalar) interaction and is unsuppressed for the axial vector, while the $D^+ \to \pi^+\mu e$ vanishes for a pure axial-vector (or pseudoscalar) and is unsuppressed for a vector exchange.

2. Results

This paper presents results based on the analysis of 50% of the data sample from E691, a high energy photoproduction experiment performed at the Fermilab Tagged Photon Spectrometer. The detector, a two-magnet spectrometer of large acceptance, very good resolution, particle identification (Cerenkov counters, electromagnetic and hadronic calorimetry, muon filter) and equipped with a high resolution silicon microstrip detector, has been described elsewhere[8]. The incident photons, produced via the bremsstrahlung of 260 GeV electrons, had an average tagged energy of 145 GeV. We used an open trigger based on the total transverse energy detected in the calorimeters. This accepted $\sim$ 30% of the total hadronic cross section while being $\sim$ 75% efficient for charm. The experiment recorded 10^8 events.

The electron identification used the information on the E/p ratio, the size of the signals in the electromagnetic and hadronic calorimeters, and the transverse shower shapes. The electron efficiency and the pion misidentification probability, while being position and energy dependent, had the typical values of 70% and 0.5% respectively. The muon identification was based on the size of signals from hadronic calorimeters and from muon counters located behind a steel muon filter. The muon detection efficiency was $\sim$ 85% above 12 GeV.

We required the leptons (and the π^+ in the case of the D^+ mode) to be good quality, well identified tracks. A cut on lepton momentum, $p > 12$ GeV was applied to improve the signal to noise ratio in the electron and the muon identification. The decay vertex was required to be significantly separated from the primary vertex. The actual separation cuts, measured in number of standard deviations, σ (typical value $\sim 300\mu m$), were selected independently for each of the final states studied. Both vertices were required to be of good quality. If any other track passed within 100 μm from the secondary vertex, the event was rejected. We fitted the resulting mass distributions (using a least squares algorithm) to a Gaussian, with the width determined from a Monte Carlo simulation and central value corresponding to the Particle Data Group[2] mass of the D^0 or D^+ (1864.6 MeV and 1869.3 MeV respectively), plus a background term, for which we adopted a power law shape. We constrained the central value of the amount of fitted signal to be greater or equal to zero. In this way we obtain *conservative* limits, and furthermore we avoid the problem of interpretation of fits which yield *negative* central values. From the errors returned by the fit, and after correcting for the reconstruction efficiencies, we obtain 90% confidence level limits on the number of observed events in a given mode. By comparing those to the number of events *produced* in the same data sample in $D^0 \to K^-\pi^+$ mode (or $D^+ \to K^-\pi^+\pi^+$ in the case of the D^+ mode), and assuming[9] a branching fraction of $4.2 \pm 0.4 \pm 0.3\%$ for this mode ($9.1 \pm 1.3 \pm 0.5\%$ in the case of the D^+ mode), we derive our limits on the branching fractions for the studied modes.

The mass distributions for the $\mu^+\mu^-$, e^+e^-, μ^+e^- and $\pi^+\mu e$ combinations are shown in Figures 1-4 respectively.

For $D^0 \to \mu^+\mu^-$, with a cut of 8 σ separation between the primary and decay vertices, we find 0.0 ± 4.2 events. Correcting for the efficiency of 13.1%, this translates into a limit

$BF(D^0 \to \mu^+\mu^-) < 1 \times 10^{-4}$. There exist a good upper limit[10] on the branching fraction for this mode of $BF(D^0 \to \mu^+\mu^-) < 1.1 \times 10^{-5}$.

In the $D^0 \to e^+e^-$ mode we find, with a 3 σ vertex separation cut, 0.0 ± 2.7 events. (The vertex separation cut is milder for this channel than for the $D^0 \to \mu^+\mu^-$ channel as the background is lower.) The efficiency for the cuts used was 12.0%. After all the corrections, we obtain a limit $BF(D^0 \to e^+e^-) < 8 \times 10^{-5}$.

The fit to the μ^+e^- mass distribution (a vertex separation cut of 6 σ was used here) gives 0.0 ± 3.1 events. After correcting for the 14.1% reconstruction efficiency, we measure $BF(D^0 \to \mu^+e^-) < 8 \times 10^{-5}$. There exist three measurements of the branching fraction for this lepton generation number non-conserving decay mode. The Mark III Collaboration has presented[11] a result $BF < 1.5 \times 10^{-4}$ $(90\% C.L.)$, Mark II has recently published[12] a result $BF < 2.1 \times 10^{-3}$ $(90\% C.L.)$, and the ACCMOR Collaboration has obtained[13] a limit of $BF < 1.0 \times 10^{-3}$ $(90\% C.L.)$.

For the $D^+ \to \pi^+\mu e$ mode, because of the longer lifetime, we have used the more stringent vertex separation cut of 16 σ. Reconstruction efficiency for the cuts used is 8.0%. We observe 0.0 ± 4.4 events, which translates into a limit $BF(D^+ \to \pi^+\mu e) < 2 \times 10^{-4}$.

A summary of our results and the relevant experimental details is given in Table I. We obtained preliminary results on the limits on the branching fractions for the following decay modes of charmed mesons : $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, $D^0 \to \mu e$ and $D^+ \to \pi^+\mu e$. Except for the $D^0 \to \mu^+\mu^-$ mode, our limits, based on half of the full data sample, are significantly better than the previous measurements.

3. Future improvements and developments

We have completed a detailed study of the electron identification scheme. As a result, we have not only significantly reduced the uncertainties in our knowledge of electron efficiency and backgrounds, but we have also increased the electron reconstruction efficiency itself by $\sim 25\%$, without compromising its pion rejection capabilities. A paper presenting higher sensitivity results for the rare D mesons decay modes branching fractions, based on the full data sample and the improved electron identification scheme, is in preparation. The new analysis will also take into account the possible backgrounds due to the particle misidentification. Although they are estimated to be small, properly including them in the fits could make our final limits even more stringent.

4. Acknowledgements

We gratefully acknowledge the assistance of the staff of Fermilab and of all the participating institutions. This research was supported by the U.S. Department of Energy, the National Science and Engineering Research Council of Canada through the Institute for Particle Physics, The National Research Council of Canada, and the Brasilian Conselho Nacional de Desenvolvimento Científico e Tecnológico. One of the authors (K.S.) would like to thank E. Eichten and M.H. Reno for valuable discussions.

Table I. Limits on the branching fractions for the rare D mesons decays.

decay mode	**events**	**efficiency**	**E-691 limit** (90% $C.L.$)	**existing limit** (90% $C.L.$)
$D^0 \to e^+e^-$	0.0 ± 2.7	12.0%	$< 8 \times 10^{-5}$	*none*
$D^0 \to \mu^+\mu^-$	0.0 ± 4.2	13.1%	$< 1 \times 10^{-4}$	$< 1.1 \times 10^{-5}$
$D^0 \to \mu^+e^-$	0.0 ± 3.1	14.1%	$< 8 \times 10^{-5}$	$< 1.5 \times 10^{-4}$
				$< 1.0 \times 10^{-3}$
				$< 2.1 \times 10^{-3}$
$D^+ \to \pi^+\mu e$	0.0 ± 4.4	8.0%	$< 2 \times 10^{-4}$	*none*

REFERENCES

1. S.L. Glashow, Nucl. Phys.*22*, 579 (1961); A. Salam and J.C. Ward, Phys. Lett.*13*, 168 (1964); S. Weinberg, Phys. Rev. Lett.*19*, 1264 (1967).
2. "Review of Particle Properties", Phys. Lett.*170B*, April 1986.
3. S.L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev.*D2*, 1285 (1970).
4. G.L. Kane and R.E. Shrock, "Rare K and μ Decays: Theoretical and Experimental Status and Prospects", in Proceedings, Santa Cruz 1983, Intense Medium Energy Sources of Strangeness, 123-156 and references therein; for a review, see "Flavour Mixing in Weak Interactions", Proceedings of the Europhysics Topical Conference, March 5-10, 1984, at the Ettore Majorana Center for Scientific Culture, Erice, Sicily, Italy, and references therein.
5. E. Farhi and L. Susskind, Phys. Rep.*74C*, 277 (1981); E. Eichten, I. Hinchliffe, K.D. Lane and C. Quigg, Phys.Rev.*D34*, 1547 (1986) and references therein.
6. R. Cahn and H. Harrari, Nucl. Phys.B176, 135 (1980); N.G. Deshpande, J. Gunion, D, Kosower, M.H. Reno and A. Soni, in Proceedings of the 1986 Summer Study on the Physics of the Superconducting Super Collider, Snowmass, Colorado, 1986.
7. A. Hadeed and B. Holdom, Phys. Lett.*159B*, 379 (1985); W. Buchmuller and D. Wyler, Phys. Lett.*B177*, 377 (1986); W. Buchmuller, CERN-TH-4499/86, July 1986;
8. R.J. Morrison *et al.*, in Proceedings of the VII Vanderbilt Conference, ed. R.S. Panvini and T.J. Weiler, World Scientific, Singapore 1987; J. Raab, Ph.D. thesis, University of California at Santa Barbara, 1987, and references therein. An earlier version of the detector has been described in K. Sliwa *et al.*, Phys. Rev. *D32*, 1053 (1985) and references therein.
9. J.J. Becker *et al.*, Mark III Collaboration, SLAC-PUB-4391, May 1987.
10. W.C. Louis *et al.*, Phys. Rev. Lett. *56*, 1027 (1986).
11. J.J. Becker *et al.*, Mark III Collaboration, SLAC-PUB-4194, February 1987.
12. K. Riles *et al.*, Mark II Collaboration, Phys. Rev. *D35*, 2914 (1987).
13. H. Palka *et al.*, CERN-EP/87-10 (1987);

FIGURE CAPTIONS

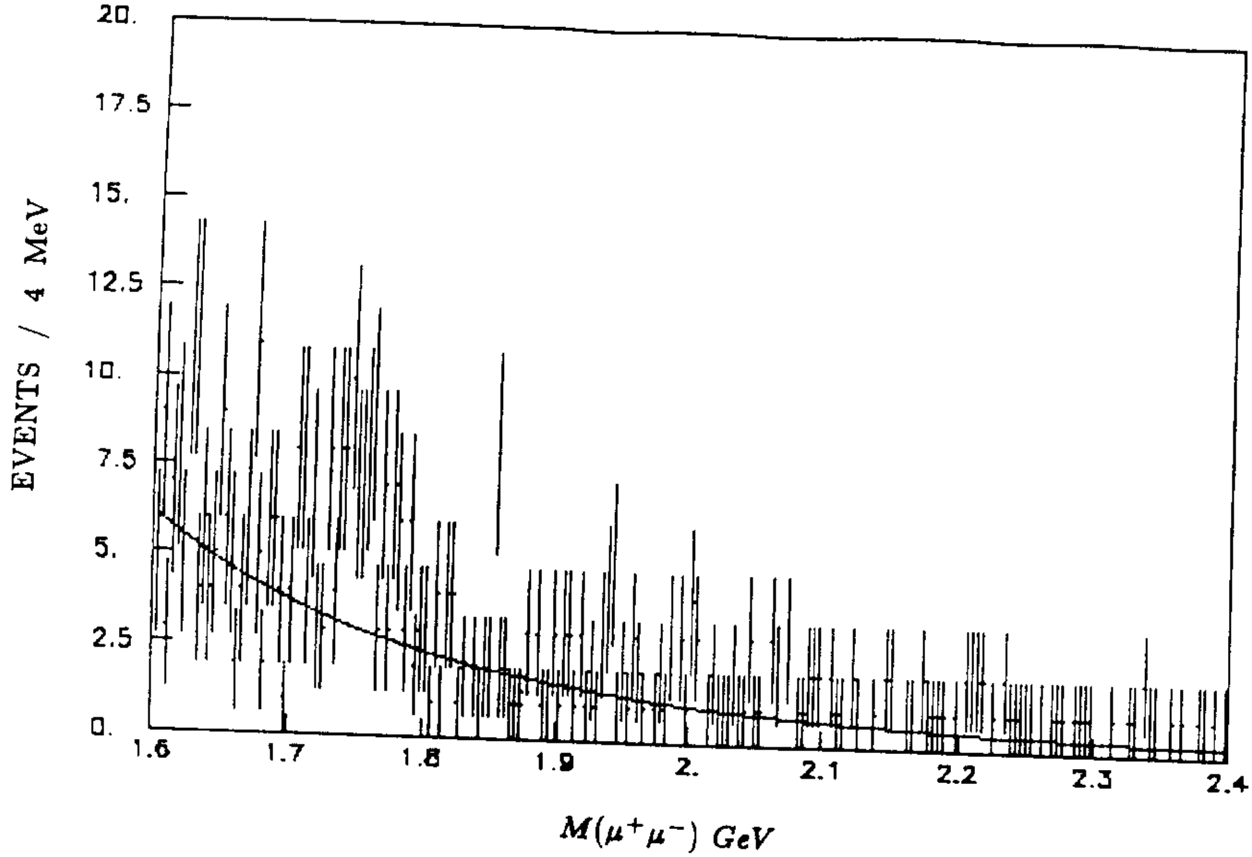
Figure 1. Effective mass distribution for $\mu^-\mu^+$ combinations.

Figure 2. Effective mass distribution for e^-e^+ combinations.

Figure 3. Effective mass distribution for $e^-\mu^+$ combinations.

Figure 4. Effective mass distribution for $\pi^\pm\mu^+e^-$ combinations.

Figure 1



20.
17.5
15.
12.5
10.
7.5
5.
2.5
0.
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
EVENTS / 4 MeV
$M(\mu^+\mu^-)$ GeV

Figure 2

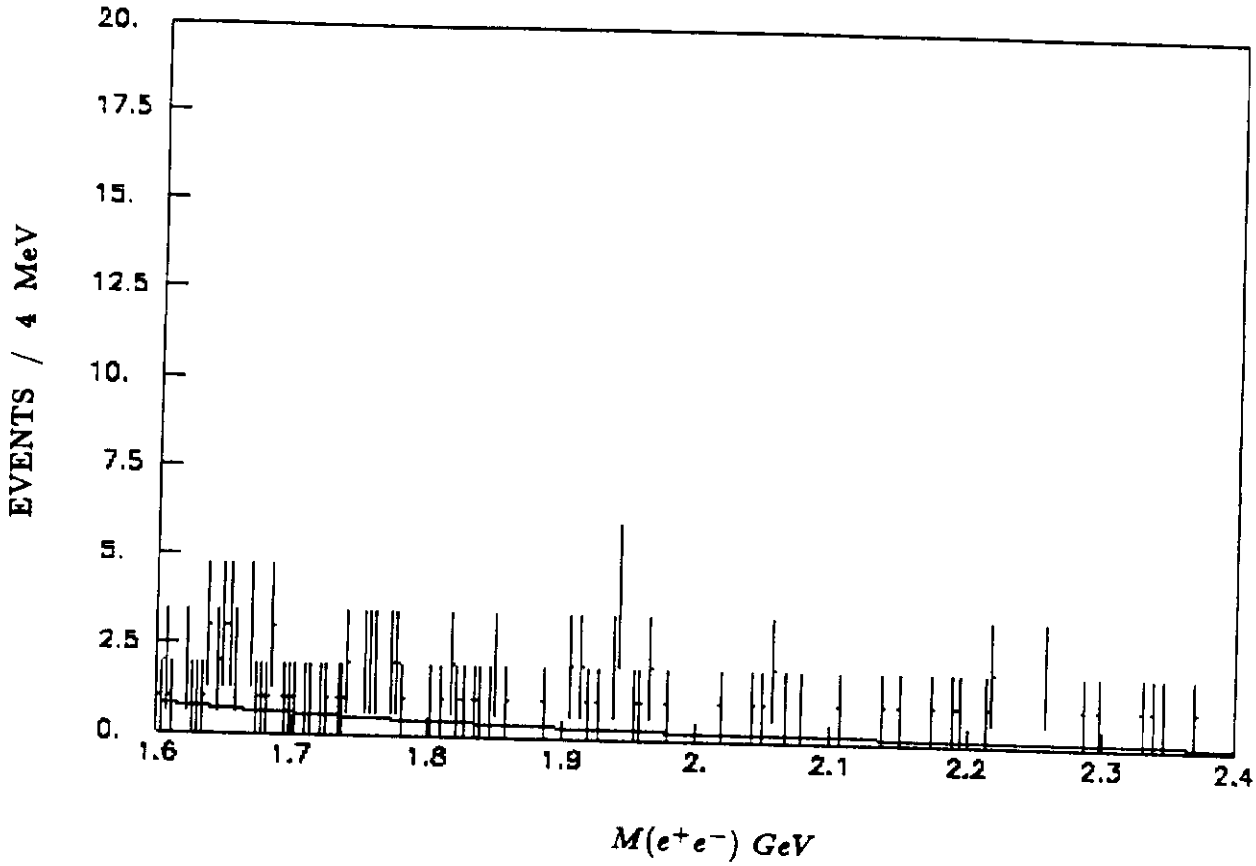

20.
17.5
15.
12.5
10.
7.5
5.
2.5
0.
EVENTS / 4 MeV
1.6
1.7
1.8
1.9
2.
2.1
2.2
2.3
2.4
$M(e^+e^-)$ GeV

Figure 3

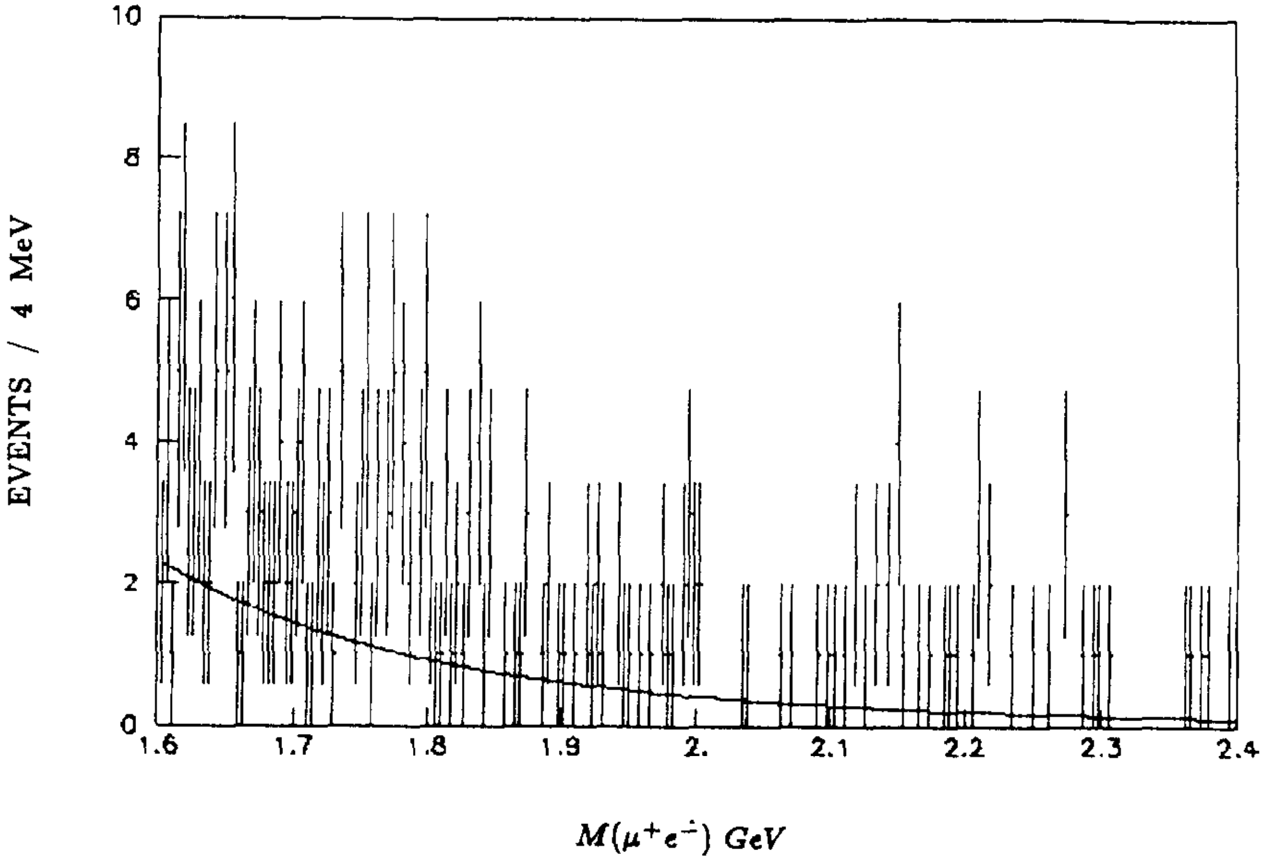
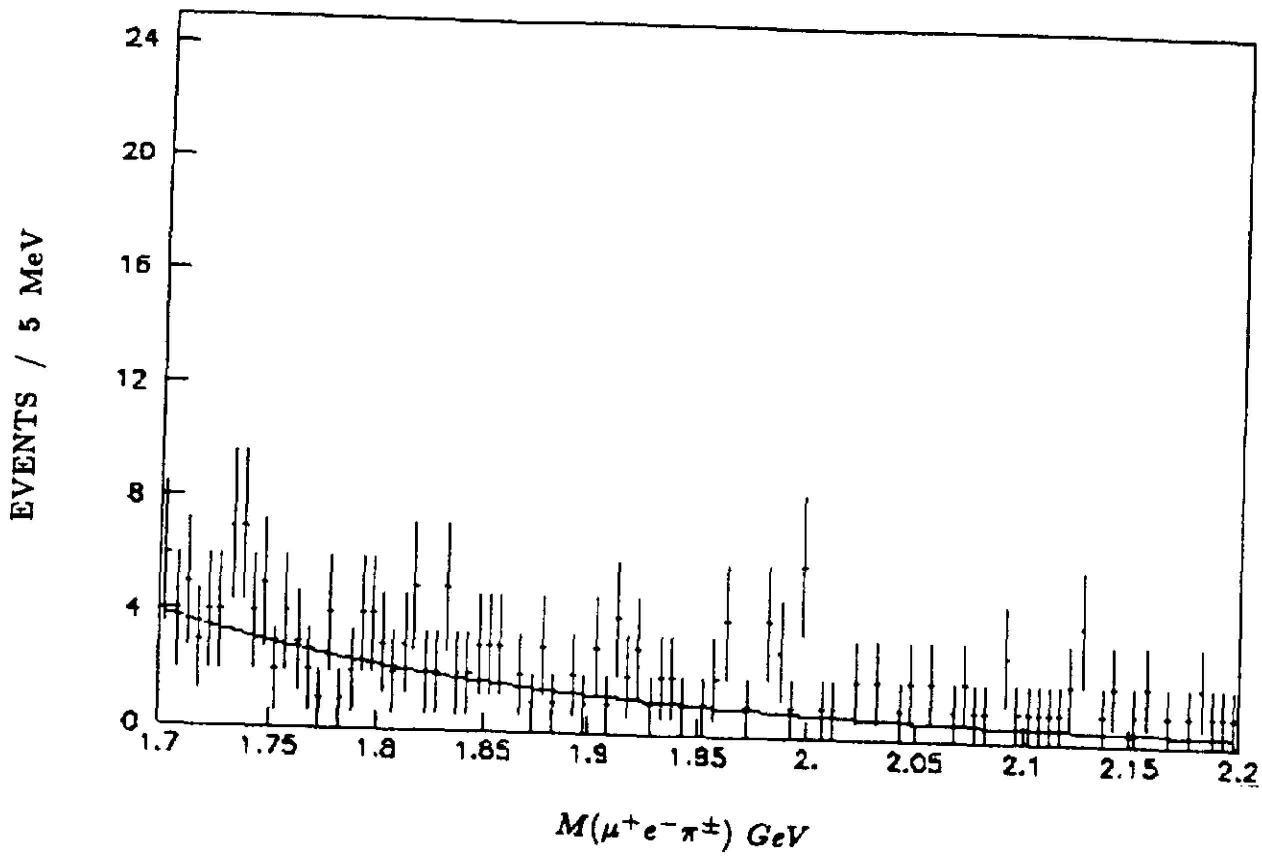


Figure 4


EVENTS / 5 MeV
0
4
8
12
16
20
24
1.7
1.75
1.8
1.85
1.9
1.95
2.
2.05
2.1
2.15
2.2
$M(\mu^+e^-\pi^\pm)$ GeV