Fermi National Accelerator Laboratory

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ABSTRACT

We have observed the decay mode $D^0 \to K_S^0 K_S^0$. The signal was isolated by detecting both K_S^0's decaying via $K_S^0 \to \pi^+\pi^-$, and by using the well-known $D^{*+} \to D^0\pi^+$ mass difference. We have measured the branching fraction of $D^0 \to K_S^0 K_S^0$ relative to $D^0 \to K^+K^-$ and find the ratio $\frac{\Gamma(D^0 \to K^0\overline{K^0})}{\Gamma(D^0 \to K^+K^-)}$ to be 0.4±0.3.

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The $D^0 \to K^0\overline{K^0}$ decay channel allows an interesting investigation of the effects of final state interactions in the weak decay of the charmed meson. The $D^0 \to K^0\overline{K^0}$ decay is expected to occur primarily via the W exchange diagrams shown in Figure 1. Since the Cabibbo factors have opposite signs, one might expect a near-complete cancellation of the two amplitudes, and thus a very small branching fraction for the decay. However, a recent calculation[1] predicts a relatively large branching fraction due to final state rescattering, with the ratio $\frac{\Gamma(D^0 \to K^0\overline{K^0})}{\Gamma(D^0 \to K^+K^-)} = 0.5$. Previous experimental information[2] on $D^0 \to K^0\overline{K^0}$ was only in the form of a limit which could not differentiate between near-complete cancellation and a sizeable contribution from final state rescattering. We report the first direct observation of $D^0 \to K^0\overline{K^0}$, and a measurement of $\frac{\Gamma(D^0 \to K^0\overline{K^0})}{\Gamma(D^0 \to K^+K^-)}$.

The measurement was made using data from experiment E400 at Fermi National Accelerator Laboratory. The beam was a broadband neutron beam produced by 800 GeV/c protons incident on a beryllium target. The neutron energy spectrum had a most probable energy at approximately 80% of the incident proton momentum. The contribution to the neutral beam from photons and K_L^0's above 200 GeV was negligible.

The detector, described previously[3] , consists of an active target and vertex detector[4] , a magnetic spectrometer, gas Cerenkov system, and electromagnetic and hadronic calorimetry. The target was composed of three segments- 300μm thickness of W, 2000μm of Si, and 4000μm of Be. Immediately following the target region was the vertex detector, consisting of nine planes of MWPC's, with 250 μm wire spacing in three views. The main magnetic spectrometer consisted of two analyzing magnets with three stations of MWPC's between the magnets and two stations of MWPC's following the second magnet.

Charged particle identification was accomplished using three 34 cell Cerenkov counters, operating with pion thresholds of 2.8, 10.8, and 5.7 GeV/c respectively. The resulting momentum range over which kaons could be distinguished from pions was from 3 to 40 GeV/c. Protons could be uniquely identified in the momentum region 20 to 80 GeV/c. All tracks not explicitly identified as kaons or protons were considered as pion candidates. Finally, neutral kaons and lambdas were reconstructed if they decayed at least 18 cm downstream of the target and upstream of the center of the second magnet.

The neutron energy was obtained by summing the output of the three calorimeters. The front calorimeter was a 22 radiation length array of 120 lead glass blocks to measure electromagnetic energy. Immediately following was a second calorimeter of six absorption lengths of steel and scintillator to measure hadronic energy. Both detectors contained a beam hole of approximately 3.8 cm radius. The summed response of these calorimeters formed the minimum energy trigger. A third calorimeter, constructed of six absorption lengths of tungsten and scintillator, was used to measure energy passing through the beam hole.

For this analysis we used a sample of approximately 45 million events. The primary interaction trigger consisted of a coincidence between a target region scintillation counter and two counters in a downstream scintillator hodoscope. This trigger insured that an interaction in the target had occurred and that at least two charged particles had traversed the entire detector. Approximately ten percent of the data was recorded with this minimum bias requirement. The rest of the data was accumulated with the following additional requirements: a) a minimum energy trigger of 265 GeV, b) a minimum multiplicity of 4 charged tracks,

c) two or more charged tracks just downstream of the target, and d) at least 1 charged kaon with momentum over 21 GeV traversing the entire detector.[5,6] All triggers satisfying requirements a) through d) were analyzed by a program which found all charged tracks and a common vertex, and which performed a Cerenkov counter analysis and searched for K_S^0 and Λ candidates.

To obtain the ratio $\frac{\Gamma(D^0 \to K^0 \overline{K^0})}{\Gamma(D^0 \to K^+ K^-)}$ we describe first the $D^{*+} \to D^0 \pi^+$ with $D^0 \to K^+ K^-$ decay analysis. We then proceed to the $D^{*+} \to D^0 \pi^+$, $D^0 \to K_S^0 K_S^0$ decay analysis. We conclude with a test of our pattern recognition efficiencies for the both the neutral and charged kaons using $K^*(890)$'s.

Candidates for $D^0 \to K^+ K^-$ were formed by requiring two tracks of opposite sign consistent with our kaon definition. A third pion candidate track was then added to produce the D^{*+} candidates. Only tracks with an acceptable fit to the spectrometer hits were used. Figure 2 shows the D^0 mass from the D^{*+} candidates after requiring 144 MeV/$c^2 < (M_{D^{*+}} - M_{D^0}) <$147 MeV/$c^2$. A fit to a Gaussian signal plus a polynomial background yields 134±19 events at a mean D^0 mass of 1872±5 MeV/c^2 and a width of 18±3 MeV/c^2. This width is consistent with our detector resolution for a narrow state. The statistical significance of the fit is 6.9 standard deviations. From Monte Carlo studies this channel is found to have relatively good acceptance in the range $0 < x_f < 0.14$, with an average acceptance of approximately 5% .

We have obtained an estimate for $B \cdot \sigma$ for the $D^{*+} \to D^o \pi^+$,$D^o \to K^+ K^-$ process in the region $0 < x_f < 0.14$ by dividing the acceptance corrected event yield by the luminosity determined by counting relatively unbiased inelastic neutron interactions originating in our target. Here B $\equiv$ B($D^* \to D\pi$) $\cdot$ B($D^0 \to K^+ K^-$). The corrected event yield was found by fitting a weighted

K^+K^- invariant mass histogram for the D^{*+} candidates of Figure 2 to a Gaussian signal over a polynomial background. The combinations entering this histogram were individually weighted by the reciprocal of the D^{*+} acceptance. The acceptance was parameterized as a function of $x_f(D^{*+})$ alone, averaging over all other relevant production and decay variables. The x_f for a given combination was computed from the measured energy of a D^{*+} candidate, and the incident neutron energy as reconstructed through calorimetry. As a check, we obtained an alternative acceptance-corrected event yield using weights parameterized in terms of the measured D^{*+} energy rather than x_f. For this method, only D^{*+} candidates with 37 GeV/c $< D^{*+} <$ 92 GeV/c were used. The latter energy range was chosen to correspond to the range $x_f = 0 \rightarrow 0.14$ at our average neutron energy of 550 GeV. The event yield estimates from these two methods were found to be within 15 % of each other.

The luminosity for our sample was measured by counting the number of unbiased neutron interactions and dividing by the previously measured[7] total inelastic neutron cross section. The number of interactions was determined by counting the coincidences of the target region scintillation counter and the downstream scintillation hodoscope. The total inelastic cross section was averaged over our target materials, and corrections for triggering losses (0.85) and livetime (0.40) were made. We obtain a partial cross section of $B \cdot (\sigma(D^{*+}) + \sigma(D^{*-})) = 0.60 \pm 0.12$ μb/nucleon in the range $0 < x_f < 0.14$, where we have assumed a linear A dependence for the hadronic charm cross section. Within the kinematic region covered by our data $\frac{D^{*+}}{D^{*-}} = 1.2 \pm 0.4$, which is consistent with symmetric particle and antiparticle production. Under this symmetric production assumption , the D^{*+} inclusive production cross section is $B \cdot \sigma(D^{*+}) = 0.30 \pm .06$ μb/nucleon.

Correcting for the x_f range, we obtain the D^{*+} differential cross section under the assumption of symmetric production to be : $B \cdot \frac{d\sigma(\bar{x}_f)}{dx_f} = 2.11 \pm 0.43$ μb/nucleon at $x_f = 0.07$.

In addition to the statistical errors quoted above, we estimate a total systematic uncertainty in the cross section of $\approx 30\%$ due to errors in the luminosity ($\pm 20\%$), model dependence ($\pm 20\%$), and differences due to the parameterization of the acceptance ($\pm 10\%$). The cross section given is calculated by the first method described as $B \cdot \frac{d\sigma(\bar{x}_f)}{dx_f} = 2.11 \pm .43 \pm .63 \mu$b/nucleon for an assumed $A^{1.0}$ nuclear dependence. We note that the cross section is sensitive to the value of α assumed for the nuclear A^{α} dependence. A $\pm 10\%$ change of α about 1.0 will result in a $\pm 30\%$ change in σ.

For the channel $D^0 \rightarrow K^0_S K^0_S$, candidates were chosen from events with two cleanly identified K^0_S 's. A cleanly identified K^0_S had at least one pion from the K^0_S with no associated hits in the vertex detector and was inconsistent with a Λ hypothesis 1105 MeV/c^2< $M_{\pi p}$ < 1125 MeV/c^2(where the fastest particle was assigned the proton mass). In addition, the momentum vector of each K^0_S was extrapolated from the K^0_S decay point back to the primary vertex. The resulting impact parameter of the K^0_S at the event vertex was required to be less than .635 cm. Monte Carlo studies indicate that this K^0_S requirement does not produce any loss of events due to the finite lifetime of the D^0. Finally, to obtain a clean two K^0_S sample each K^0_S was allowed to share no more than 3 hits with the other K^0_S . Figure 3a) shows the D^0 mass from D^{*+} candidates with 143 MeV/c^2< $(M_{D^{*+}} - M_{D^0}) < 147$ MeV/c^2. A fit to a Gaussian signal plus a polynomial background yields 8.9±2.7 events for a statistical significance of 4.8 standard deviations. The curve in Figure 3a) represents the polynomial background. The shape was constrained by a fit to the $K_S^0 K_S^0$ mass distribution using all $K_S^0 K_S^0$ combinations. Figure 3b) shows the mass difference ($M_{D^{*+}} - M_{D^0}$) for the D^0 mass region 1840 MeV/c^2< $M_{K_s K_s}$ < 1900 MeV/c^2. A fit to the mass difference yields 8.3±3.3 events, in agreement with the fit to Figure 3a). The efficiency for reconstructing two K_S^0 's was found to have a peak of 3% at x_f =0.14 with acceptable efficiency in the range 0< x_f < 0.5. Our relatively good efficiency at high x_f results from our large decay volume, and the fact that Cerenkov identification of the K_S^0 decay pions is not needed. Additionally, the $K_S^0 K_S^0$ events were obtained from a larger data sample than that used to obtain the K^+K^- events. The larger sample was used to obtain the largest possible number of $K_S^0 K_S^0$ candidates.

In order to present a relatively model-independent measurement of the ratio $\frac{\Gamma(D^0 \to K^0 \bar{K}^0)}{\Gamma(D^0 \to K^+K^-)}$, both the $K_S^0 K_S^0$ and K^+K^- samples were required to be in the x_f region 0<x_f <0.14. The numbers of K^+K^- and $K_S^0 K_S^0$ candidates were corrected for detection efficiency, relative luminosity, and $K^0 \overline{K^0}$ branching fraction to $\pi^+\pi^-$ (.118). We find the ratio $\frac{\Gamma(D^0 \to K^0 \overline{K^0})}{\Gamma(D^0 \to K^+K^-)}$ to be 0.4±0.3.

To check our understanding of the relative acceptances of the K_S^0 and K^+ , we compared the state $K^{*0}(890) \to K^-\pi^+$ to the state $K^{*+}(890) \to K_S^0\pi^+$ for the x_f range -.02<x_f <+.14. In table 1 the ratio of $\frac{K^{*0}+\overline{K^{*0}}}{K^{*+}+K^{*-}}$ is presented for four bins of x_f . From isospin considerations we expect this ratio to be 1 at low x_f . A similar comparison using neutral and charged kaons produced in pp collisions has been shown[8] to agree with these expectations. After correcting for efficiency and the K^0 branching fraction to K_S^0 , the ratios for each bin are consistent with the predicted value.

In conclusion, we have observed the decay $D^0 \to K^0 \overline{K^0}$ and have compared this decay channel to $D^0 \to K^+K^-$. To evaluate the reconstruction and identification efficiencies of the charged kaons and the K_S^0 , a study of the $K^*(890)$ system was made. The results indicate that we have no major systematic errors which would affect our measurement of $\frac{\Gamma(D^0 \to K^0\overline{K^0})}{\Gamma(D^0 \to K^+K^-)}$. Finally, we note that our measured ratio, 0.4±0.3, is consistent with the theoretical estimate of reference 1.

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TABLE 1: A comparison of K^{*0} and K^{*+} cross sections as measured by this experiment. Errors are statistical only; the cross section values have a 50% systematic uncertainty which cancels out in the ratio.

x_f range	$\frac{d\sigma}{dx_f}$ (K^{*0}) (mb)	$\frac{d\sigma}{dx_f}$ (K^{*+}) (mb)	ratio
-.02 to +.02	10.1 ± 1.4	7.5 ± 2.7	$1.33 \pm .51$
+.02 to +.06	6.8 ± 0.8	6.6 ± 1.5	$1.03 \pm .24$
+.06 to +.10	5.1 ± 0.7	4.7 ± 1.1	$1.09 \pm .28$
+.10 to +.14	4.1 ± 0.7	4.1 ± 0.9	$0.99 \pm .27$

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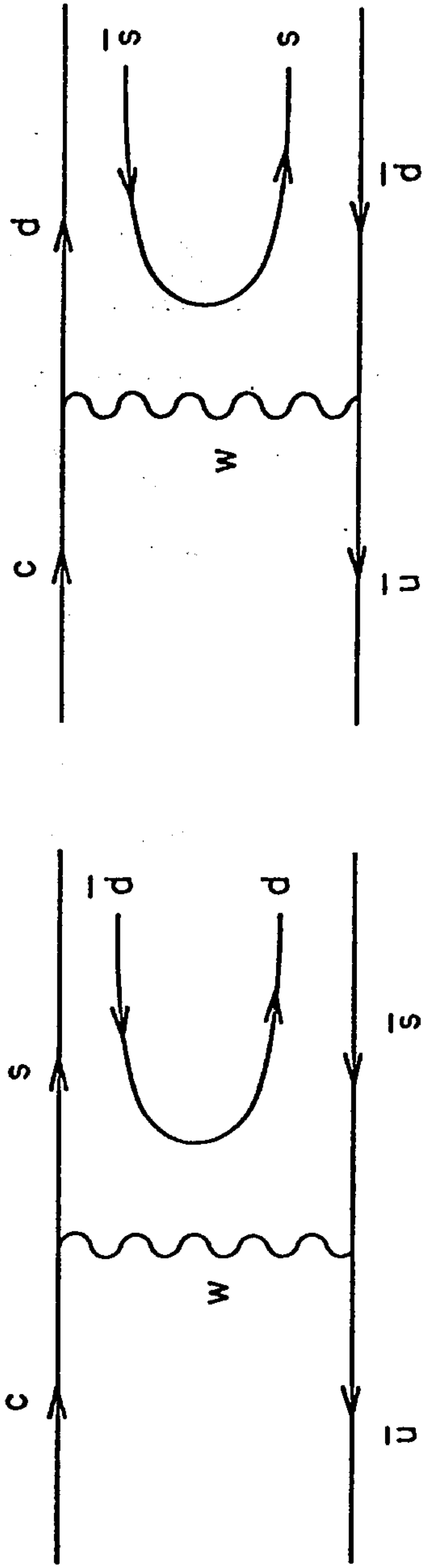
FIGURE CAPTIONS

1. Two cancelling diagrams for the decay $D^0 \to K^0\overline{K^0}$.
2. A K^+K^- mass plot cut on a $D^* - D^0$ difference between 144 and 147 MeV/c^2.
3. a) A $K_s^0K_s^0$ mass plot cut on a $D^* - D^0$ difference between 143 and 147 MeV/c^2. b) The $D^* - D^0$ plot for $1840 < M_{K_s^0K_s^0} < 1900$ MeV/c^2.



c
d
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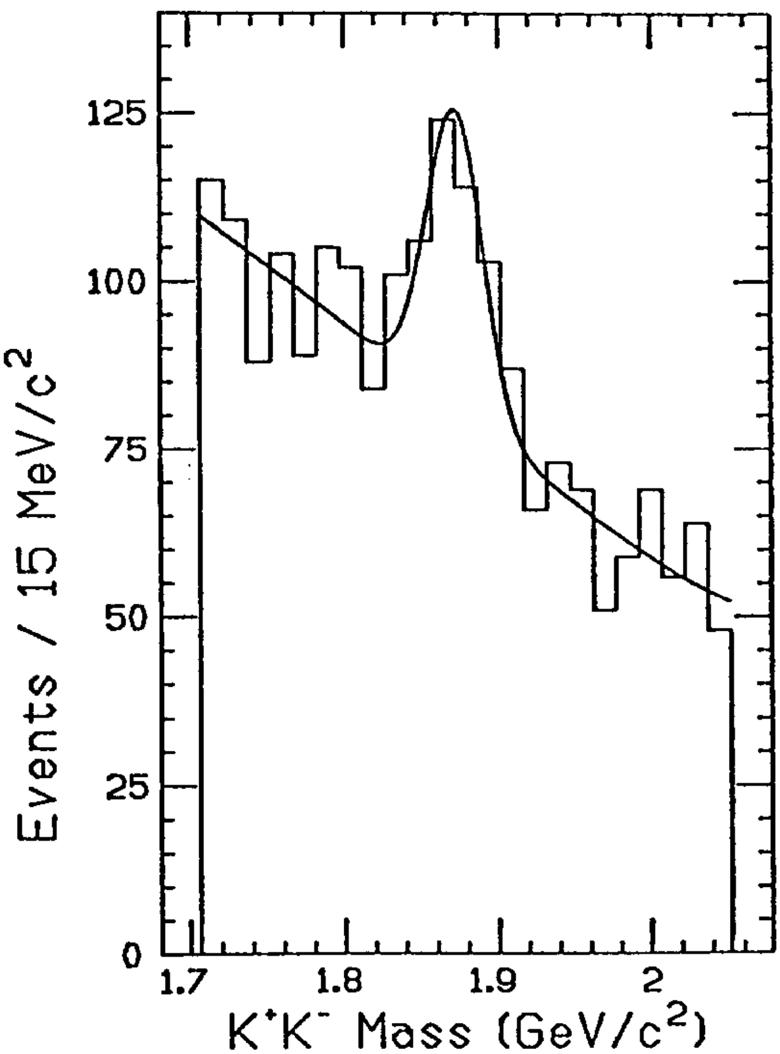
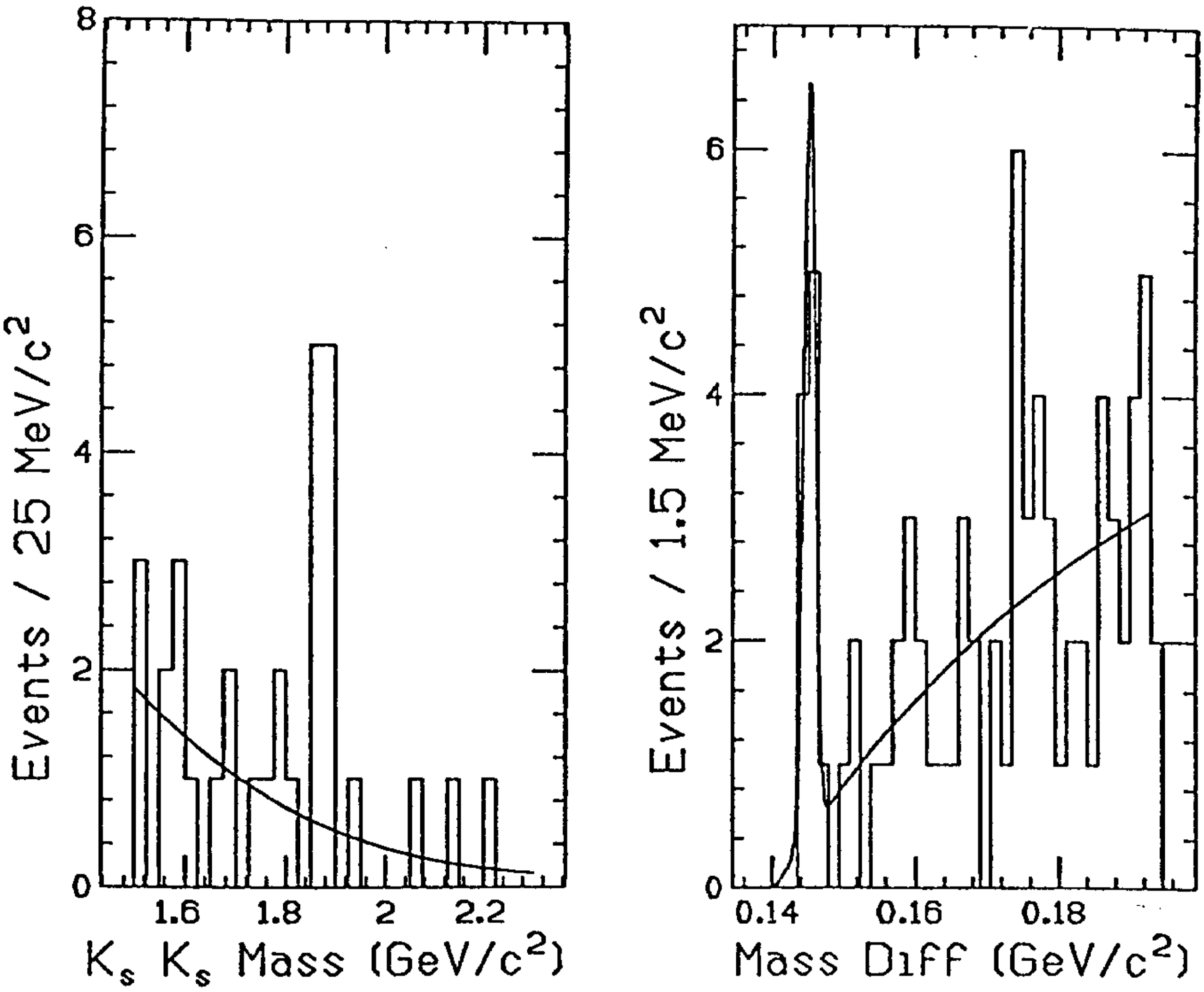


125
100
75
50
25
0
Events / 15 MeV/c²
1.7
1.8
1.9
2
K⁺K⁻ Mass (GeV/c²)


Events / 25 MeV/c²
K_s K_s Mass (GeV/c²)
Events / 1.5 MeV/c²
Mass Diff (GeV/c²)