Search for the FCNC Decay $D^0 \to \mu^+\mu^-$

Text for the blessed web page – CDF note 6273

The CDF Collaboration

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Abstract

We present a search for the flavor changing neutral current (FCNC) decay $D^0 \to \mu^+\mu^-$. With 69pb^{-1} of two-track trigger (TTT) data we set an upper limit on the branching ratio of

$$\mathcal{B}(D^0 \to \mu^+\mu^-) \leq 2.4 \times 10^{-6} \text{ at } 90\%\text{CL, and}$$

$$\mathcal{B}(D^0 \to \mu^+\mu^-) \leq 3.1 \times 10^{-6} \text{ at } 95\%\text{CL.}$$

This is nearly a factor of 2 improvement over the previous best limit of 4.1×10^{-6}.

1 Description

For the FCNC decay $D^0 \to \mu^+\mu^-$, the Standard Model predicts $\mathcal{B}(D^0 \to \mu^+\mu^-) \sim 10^{-13}$. The present experimental limit is 4.1×10^{-6} from BEATRICE (4.2×10^{-6} from E771), 7 orders of magnitude from the prediction.

New physics can substantially enhance this mode. In charm meson decays we are constraining couplings to up-type quarks not necessarily constrained by B decays. $D^0 \to \mu^+\mu^-$ presents and immaculate and unexplored region to search for new physics.

We use the TTT data for a clean analysis (all information can be determined from the data). The limit on the branching ratio is computed as:

$$\mathcal{B}(D^0 \to \mu^+\mu^-) \leq \frac{N_{\mathrm{CL}}(D^0 \to \mu^+\mu^-)}{N(D^0 \to \pi^+\pi^-)} \frac{\epsilon(D^0 \to \pi^+\pi^-)}{\epsilon(D^0 \to \mu^+\mu^-)} \mathcal{B}(D^0 \to \pi^+\pi^-)$$

where:

- $N_{\mathrm{CL}}(D^0 \to \mu^+\mu^-)$ is the 90% limit on the number of observed decays,
- $N(D^0 \to \pi^+\pi^-)$ is the number of D^0 reconstructed in the normalization mode,
- $\epsilon(D^0 \to \pi^+\pi^-)/\epsilon(D^0 \to \mu^+\mu^-)$ is the ratio of efficiencies between the signal and normalization modes, 1.012 ± 0.045, and
- $\mathcal{B}(D^0 \to \pi^+\pi^-)$ is the branching ratio of the normalization mode, $(1.43 \pm 0.07) \times 10^{-3}$

We performed a "blind" analysis. The selction cuts were optimized on a kinematically similar but statistically independent set of events. We normalize to the kinimatically similar decay $D^0 \to \pi^+\pi^-$. We select events that satisfy a D^* requirements, with both D^0 tracks fiducial to the CMU, and satisfying

- projected decay length $L_{xy} < 0.45\,\mathrm{cm}$,
- impact parameter of the D^0 $|d_{xy}| < 0.015\,\mathrm{cm}$, and
- angular separation at the CMU $\Delta\phi_{\mathrm{CMU}} > 0.085$.

1371 $D^0 \to \pi^+\pi^-$ events satisfy these requirements.

We divide our background estimate into two parts:

- $D^0 \to \pi^+\pi^-$ misidentification, and
- combinatorics (all other sources).

Using an overall π misID probability of 1.3% yields 0.22 ± 0.02 expected misID background. Five events in a 150MeV high mass sideband yields 1.5 ± 0.7 expected combinatoric background. Total expected background is 1.7 ± 0.7 events.

With these values, our sensitivity (expected limit for 1.7 observed events) is 3.9×10^{-6}.

We now "unblind" the search window and find zero events. This gives $N_{\mathrm{CL}} \leq 2.3$ at 90% confidence level, and $N_{\mathrm{CL}} \leq 3.0$ at 95% confidence level.

2 Blessed Numbers

This section summarizes the numbers which have been blessed for this analysis.

2.1 Fit results

p_T range	π^+	π^-	K^+	K^-
2.0 to 2.5	1.35 ± 0.23	0.89 ± 0.18	1.88 ± 0.25	0.83 ± 0.19
2.5 to 3.0	1.09 ± 0.20	1.29 ± 0.19	2.08 ± 0.24	1.19 ± 0.20
3.0 to 3.5	1.06 ± 0.18	1.00 ± 0.18	2.57 ± 0.26	1.62 ± 0.22
3.5 to 4.0	1.11 ± 0.21	1.29 ± 0.21	3.13 ± 0.31	1.38 ± 0.22
4.0 to 4.5	0.99 ± 0.24	0.86 ± 0.22	3.84 ± 0.40	1.24 ± 0.24
4.5 to 5.0	1.30 ± 0.30	1.98 ± 0.36	4.16 ± 0.47	1.57 ± 0.30
5.0 to 5.5	1.22 ± 0.36	1.20 ± 0.39	5.20 ± 0.62	1.95 ± 0.40
5.5 to 6.0	1.61 ± 0.49	1.48 ± 0.45	4.25 ± 0.70	2.56 ± 0.56
6.0 to 6.5	1.27 ± 0.49	2.60 ± 0.67	4.53 ± 0.82	2.33 ± 0.57
6.5 to 7.0	2.26 ± 0.76	3.12 ± 0.83	4.43 ± 0.90	2.67 ± 0.74
7.0 to 7.5	1.24 ± 0.71	1.12 ± 0.65	3.51 ± 0.97	4.43 ± 1.09
7.5 to 8.0	2.31 ± 1.04	2.44 ± 1.00	4.07 ± 1.20	3.15 ± 1.11
8.0 to 8.5	4.02 ± 1.51	0.00 ± 0.26	6.67 ± 1.73	2.42 ± 1.08
8.5 to 9.0	2.24 ± 1.30	0.84 ± 1.31	5.61 ± 1.82	1.86 ± 1.06
9.0 to 10.0	2.04 ± 1.01	2.43 ± 1.09	5.07 ± 1.49	3.41 ± 1.39
10.0 to 15.0	4.85 ± 1.52	3.31 ± 1.15	6.00 ± 1.29	2.65 ± 1.01

Table 1: Probability (in percent) to misidentify a $\pi^\pm$ or $K^\pm$ as a muon for the p_T bins listed.

2.2 Systematic errors

The uncertainties on the number of events in the normalization mode, the ratio of efficiencies, and the branching ratio to the normalization mode are included in the limit following the procedure outlined by Cousins&Highland. All of the mentioned uncertainties are of order 5%, and have a negligible effect on the limit.

2.3 Final result

$$\begin{aligned}
\mathcal{B}(D^0 \to \mu^+\mu^-) &\leq \frac{N_{CL}(D^0 \to \mu^+\mu^-)}{N(D^0 \to \pi^+\pi^-)} \frac{\epsilon(D^0 \to \pi^+\pi^-)}{\epsilon(D^0 \to \mu^+\mu^-)} \mathcal{B}(D^0 \to \pi^+\pi^-) \qquad (1) \\
&\leq \mathcal{B}(D^0 \to \mu^+\mu^-) \leq \frac{2.3}{1345} \frac{1.43 \times 10^{-3}}{1.012} \\
&\leq 2.4 \times 10^{-6} \text{ at90\%CL}
\end{aligned}$$

This result improves on the existing best limits by almost a factor of 2 (4.1×10^{-6} from BEATRICE, and 4.2×10^{-6} from E771 at 90% confidence level).

Our 95% CL limit is $\mathcal{B}(\mathrm{D}^0 \to \mu^+\mu^-) \leq 3.1 \times 10^{-6}$

3 Blessed Figures

The following figures have been blessed for the $D^0 \to \mu^+\mu^-$ search. More text can be found in CDF note 6273.

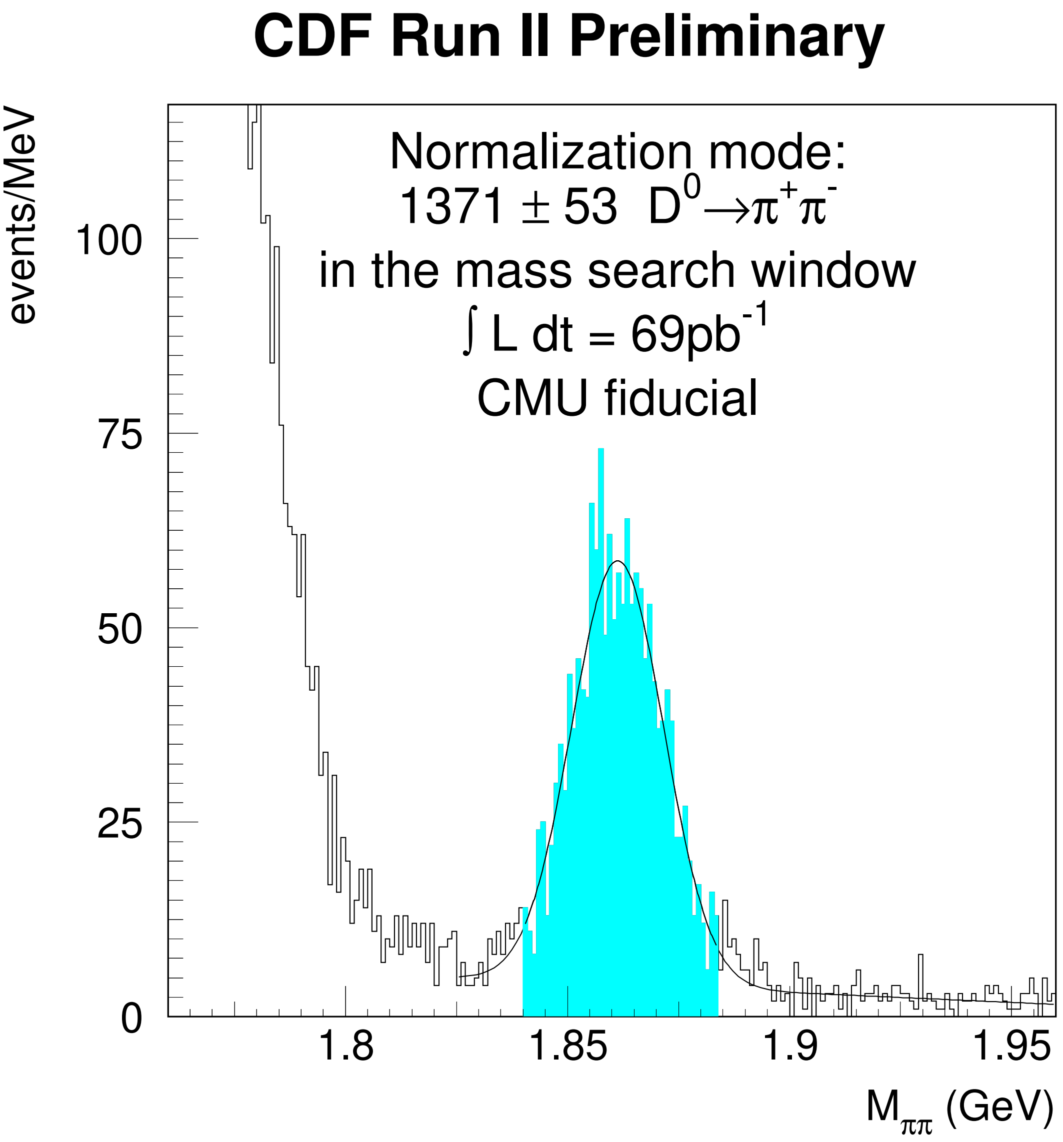

Figure 1: The calculation of the normalization. Both tracks are assigned the pion mass and required to project into a CMU chamber (CMU fiducial). The fit is to a Gaussian plus linear function, and we count the events in the range 1.840 to 1.882GeV.

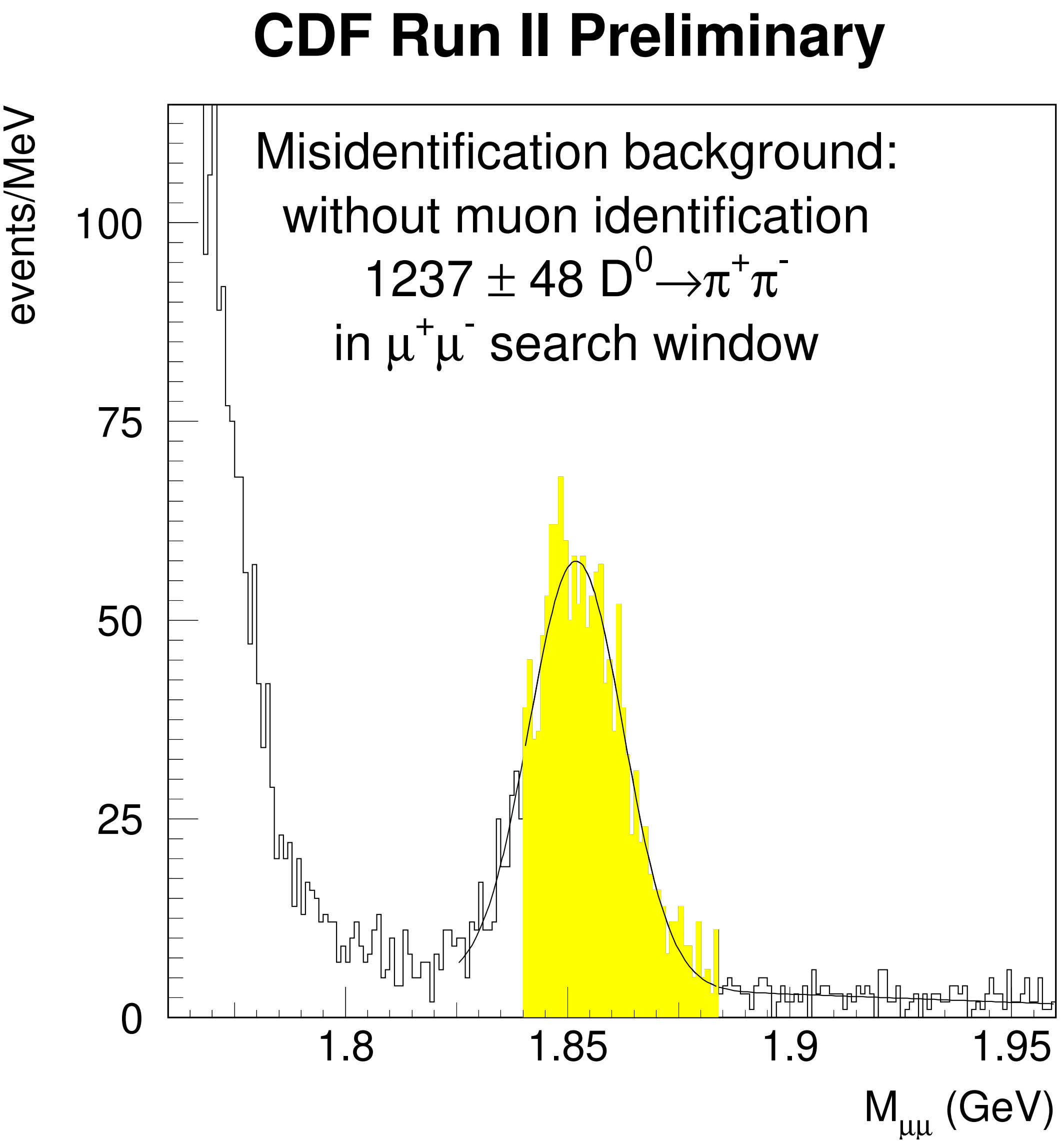

Figure 2: The misidentification background is determined from the number of $D^0 \to \pi^+\pi^-$ events that fall into the search window when reconstructed as $D^0 \to \mu^+\mu^-$, times the square of the average pion misID probability.

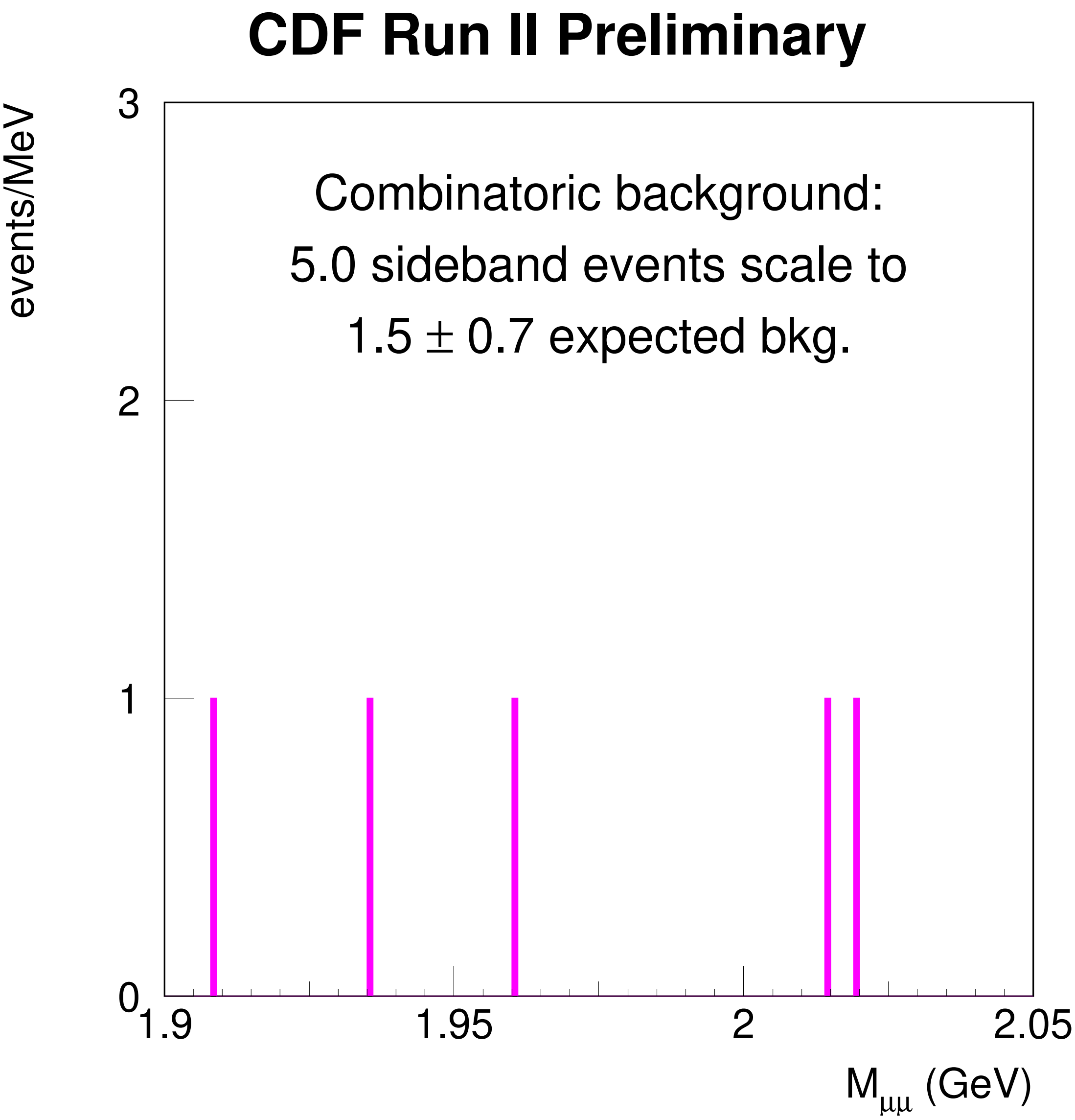

Figure 3: The combinatoric background is determined from the number of dimuon events in a 150MeV wide high mass sideband. We assume the background is linear in mass, and scale by the ratio of the search window width to the sideband width.

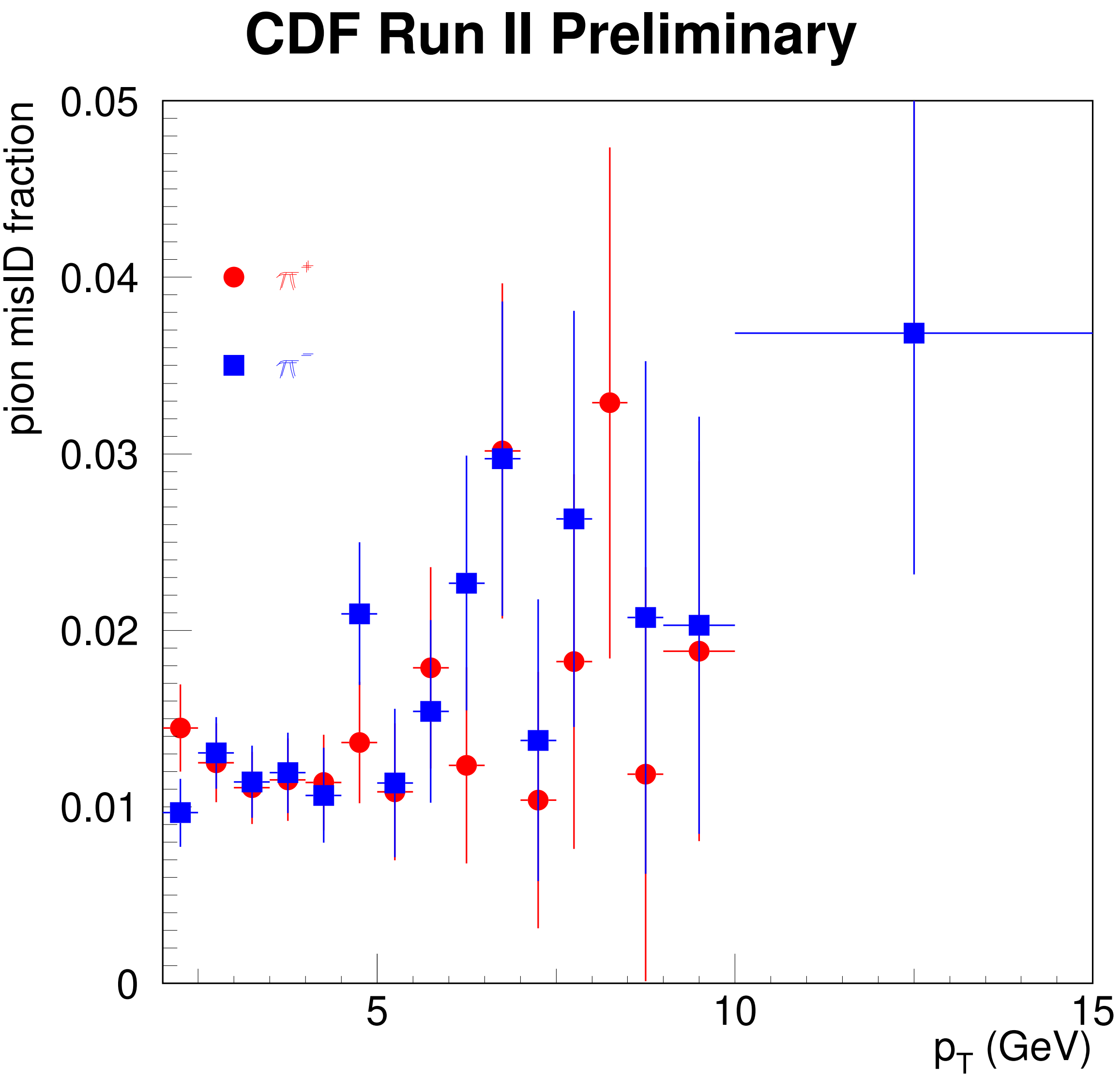

Figure 4: Using D* tagged $D^0 \to K^-\pi^+$ decays we determine the probability that a pion is misidentified as a muon. The p_T dependence is shown, and the average probability is 1.3%.

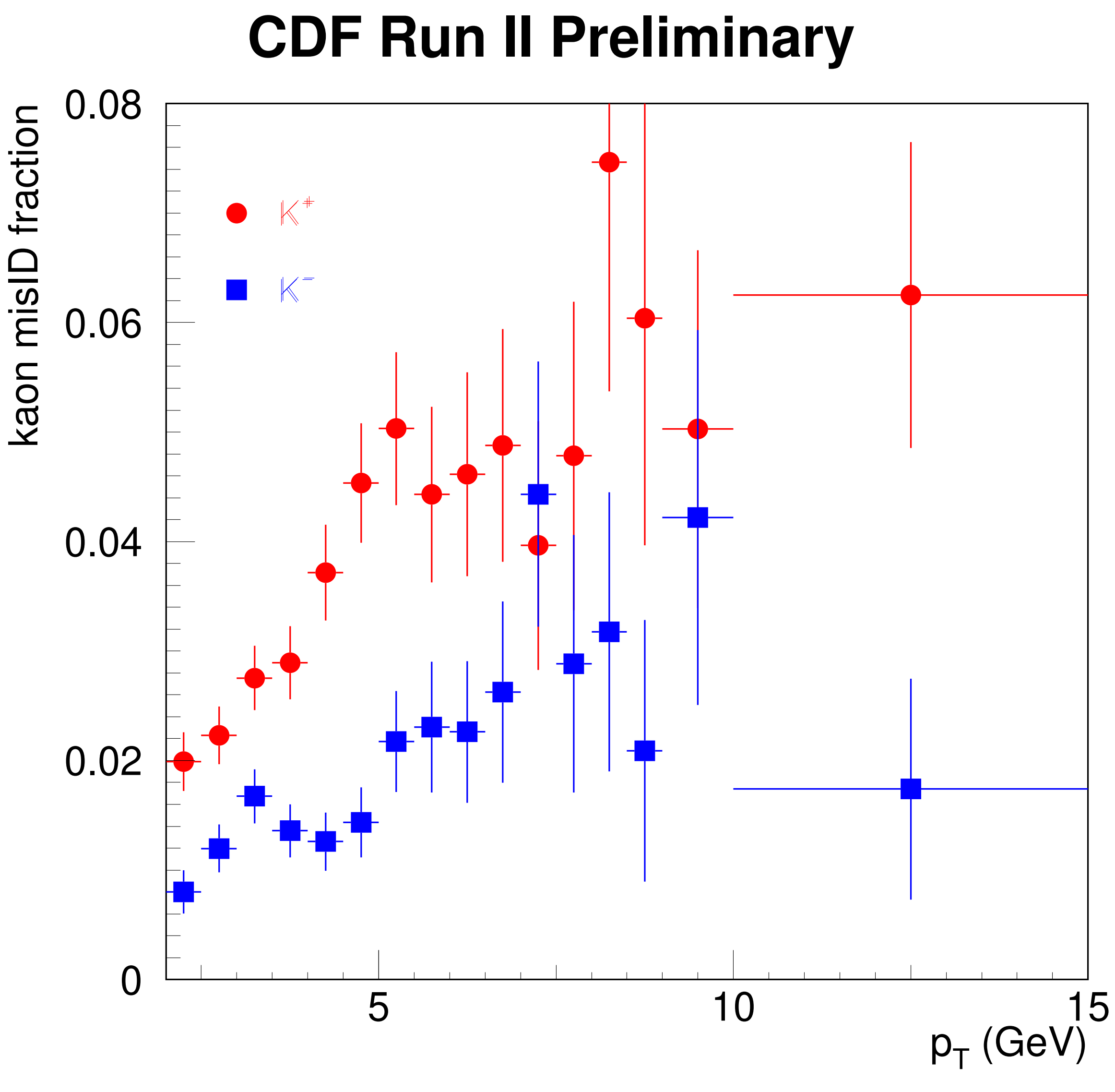

Figure 5: We performed the same misidentification analysis with the kaons. Note that the K^+ misidentification probability is significantly higher than the K^- owing to the smaller K^+ interaction cross section.

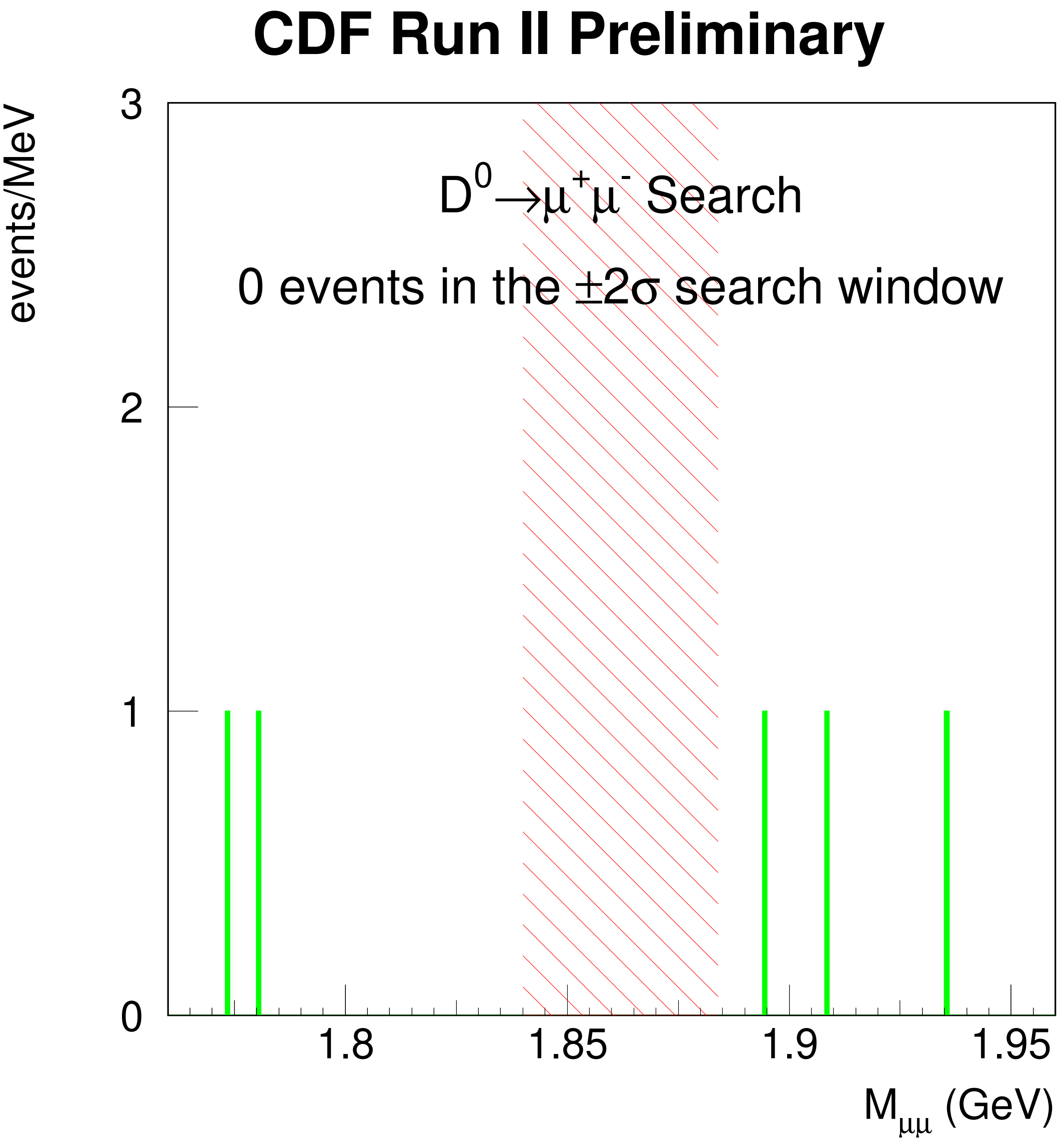

Figure 6: The unblinding of the search window (red hatched region) reveals zero events.