Fermilab E791 Collaboration

Search for Rare and Forbidden decays of D^+, D_s^+, and D^0 Charmed Mesons

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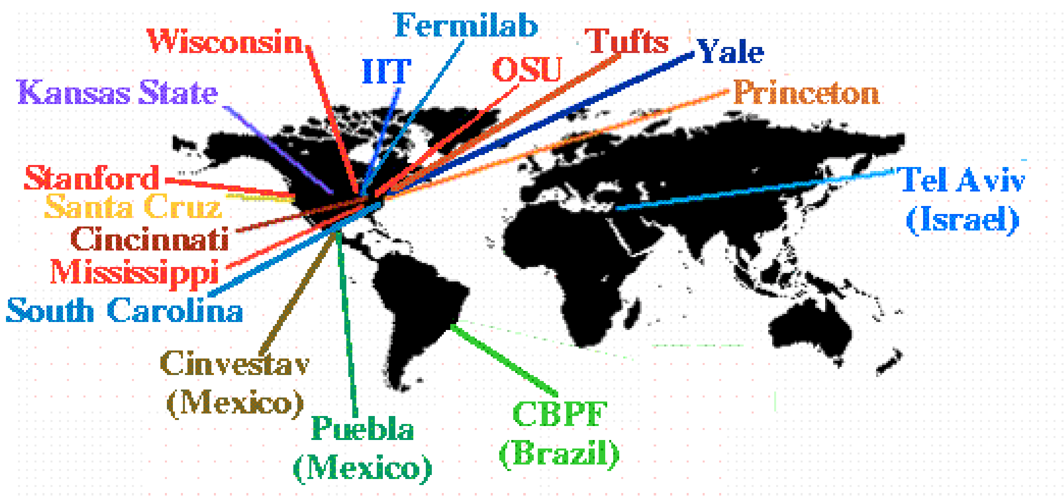
- Introduction
- Physics Motivation, Search for New Mediators
- Detector Description, Fixed Target
- Method, Blind Analysis
- Results
- Conclusion

Fermilab Wine and Cheese, October 29, 1999

The E-791 Collaboration



Centro Brasileiro de Pesquisas Fisicas (CBPF)
University of California - Santa Cruz
University of Cincinnati
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Illinois Institute of Technology
Kansas State University
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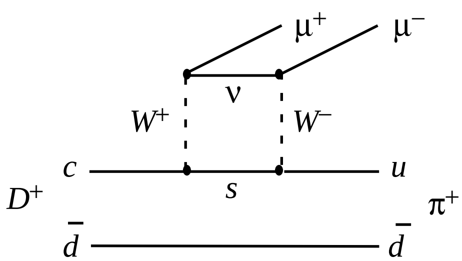
Princeton University
Universidad Autonoma de Puebla
University of South Carolina
Stanford University
Tel Aviv University
Tufts University
University of Wisconsin - Madison
Yale University

Why Search for Rare and Forbidden decays?

- Tests Standard Model and allows investigation of phenomena in mass ranges beyond those available to current accelerators

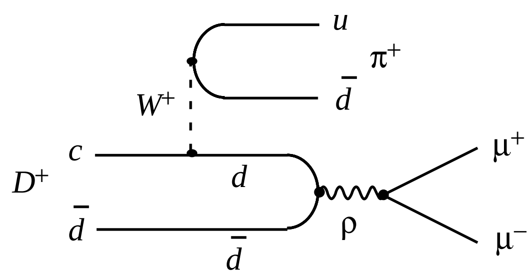
- Standard Model predicts Branching Ratio $<10^{-9}$–10^{-6}

Short Range



BR$<10^{-9}$

Long Range

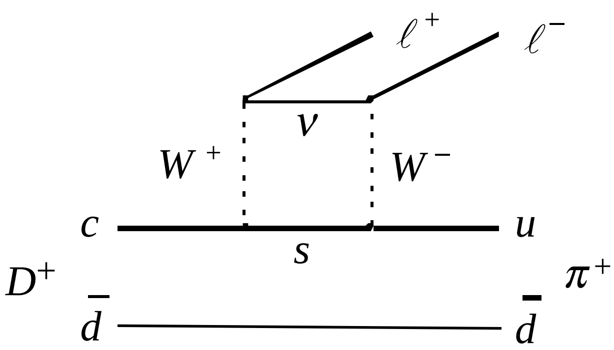


BR$<10^{-6}$

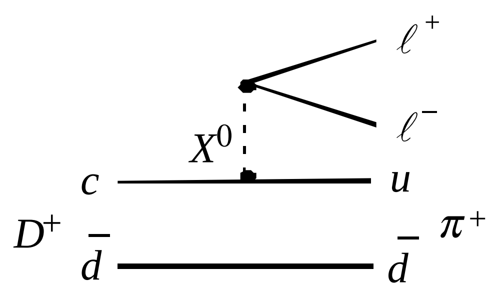
- Search for violations from Flavor Changing Neutral Currents, Lepton Number and/or Flavor Violations (via Neutrino Oscillations, Leptoquark, Horizontal Gauge Bosons, etc.?)

Feynman Diagram Examples

Standard Model



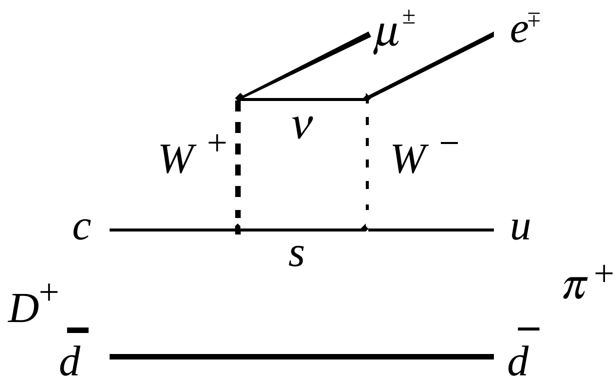
Flavor-Changing Neutral-Current



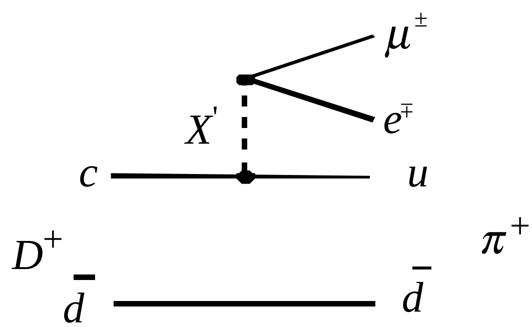
$$D^+ \rightarrow \pi^+ \ell^+ \ell^-$$

Lepton Flavor Violating Modes

Neutrino Oscillations



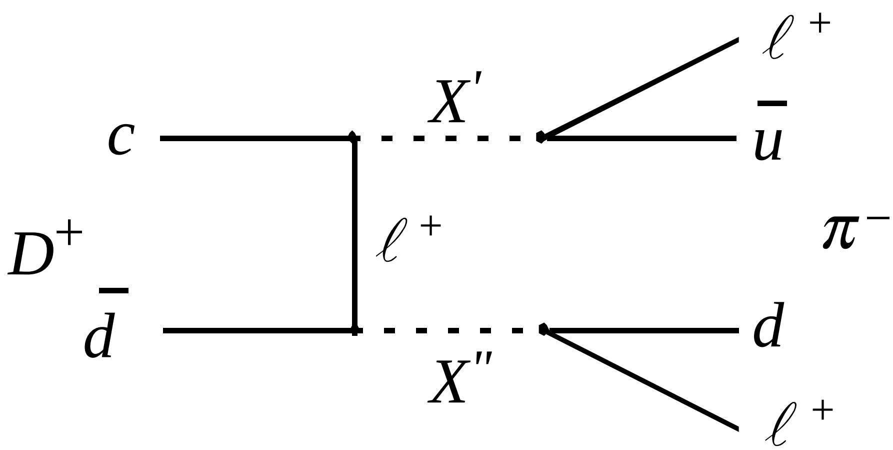
Horizontal Gauge Boson



$$D^+ \rightarrow \pi^+ \mu^\pm e^\mp$$

Lepton Number Violating Modes

Leptoquark



$$D^+ \to \pi^- \ell^+ \ell^+$$

Note: If the two leptons are a different flavor then this would be a Lepton Flavor Violating mode.

Rare and Forbidden Decay Modes

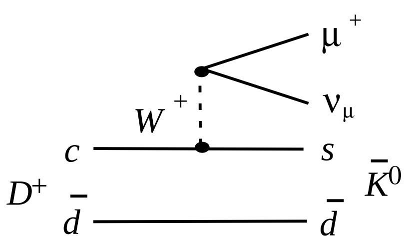
Flavor Changing Neutral Currents	**Lepton Flavor Violating**	**Lepton Number Violating**
$D^+ \to \pi^+ \mu^+ \mu^-$	$D^+ \to \pi^+ \mu^\pm e^\mp$	$D^+ \to \pi^- \mu^+ \mu^+$
$D^+ \to \pi^+ e^+ e^-$	$D^+ \to \pi^- \mu^+ e^+$	$D^+ \to \pi^- e^+ e^+$
$D^+ \to K^+ \mu^+ \mu^-$	$D^+ \to K^+ \mu^\pm e^\mp$	$D_s \to K^- \mu^+ \mu^+$
$D^+ \to K^+ e^+ e^-$	$D_s \to K^+ \mu^\pm e^\mp$	$D_s \to K^- e^+ e^+$
$D_s \to K^+ \mu^+ \mu^-$	$D_s \to K^- \mu^+ e^+$	$D_s \to \pi^- \mu^+ \mu^+$
$D_s \to K^+ e^+ e^-$	$D_s \to \pi^+ \mu^\pm e^\mp$	$D_s \to \pi^- e^+ e^+$
$D_s \to \pi^+ \mu^+ \mu^-$	$D_s \to \pi^- \mu^+ e^+$	
$D_s \to \pi^+ e^+ e^-$	$D^0 \to \mu^\pm e^\mp$	
$D^0 \to \mu^+ \mu^-$		
$D^0 \to e^+ e^-$		

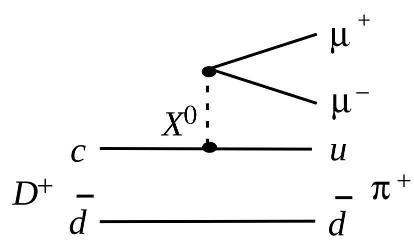
Explore New Mass Ranges

For simplicity assuming $g_{X^0,X'} = g_W$

Flavor Changing Neutral Current - Using:

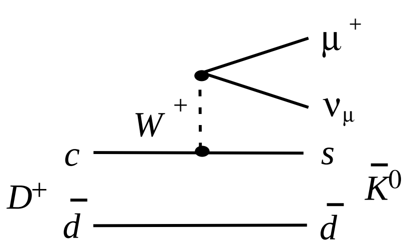
$$m_{X^0} \sim m_W \cdot \left[\frac{BR\left(D^+ \to \overline{K}^0 \mu^+ \nu_\mu\right)}{BR\left(D^+ \to \mathrm{FCNC}\right)} \right]^{1/4}$$

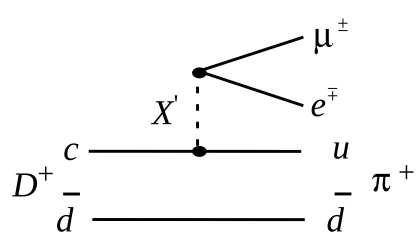




Lepton Flavor Violating - Using:

$$m_{X'} \sim m_W \cdot \left[\frac{BR\left(D^+ \to \overline{K}^0 \mu^+ \nu_\mu\right)}{BR\left(D^+ \to \mathrm{LFV}\right)} \right]^{1/4}$$

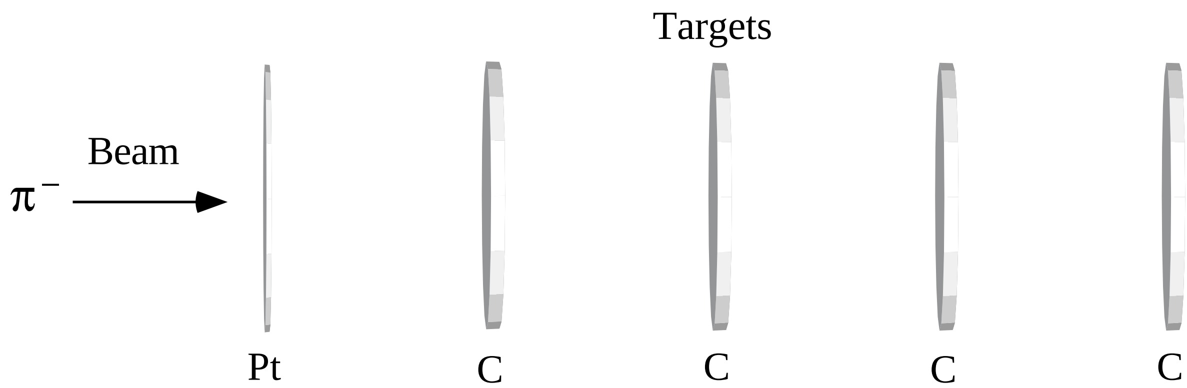




A. Schwartz, Mod. Phys. Lett. A8 (1993) 970.

Detector Description

The E791 experiment used a 500 GeV π^- beam hitting a target



The E791 Spectrometer consisted of the following detectors:

Particle Tracking Detectors

- 23 planes of Silicon Microstrip Detectors (SMDs)
- 45 planes of wire chambers (PWCs and DCs)

Momentum Measurement

- 2 dipole magnets

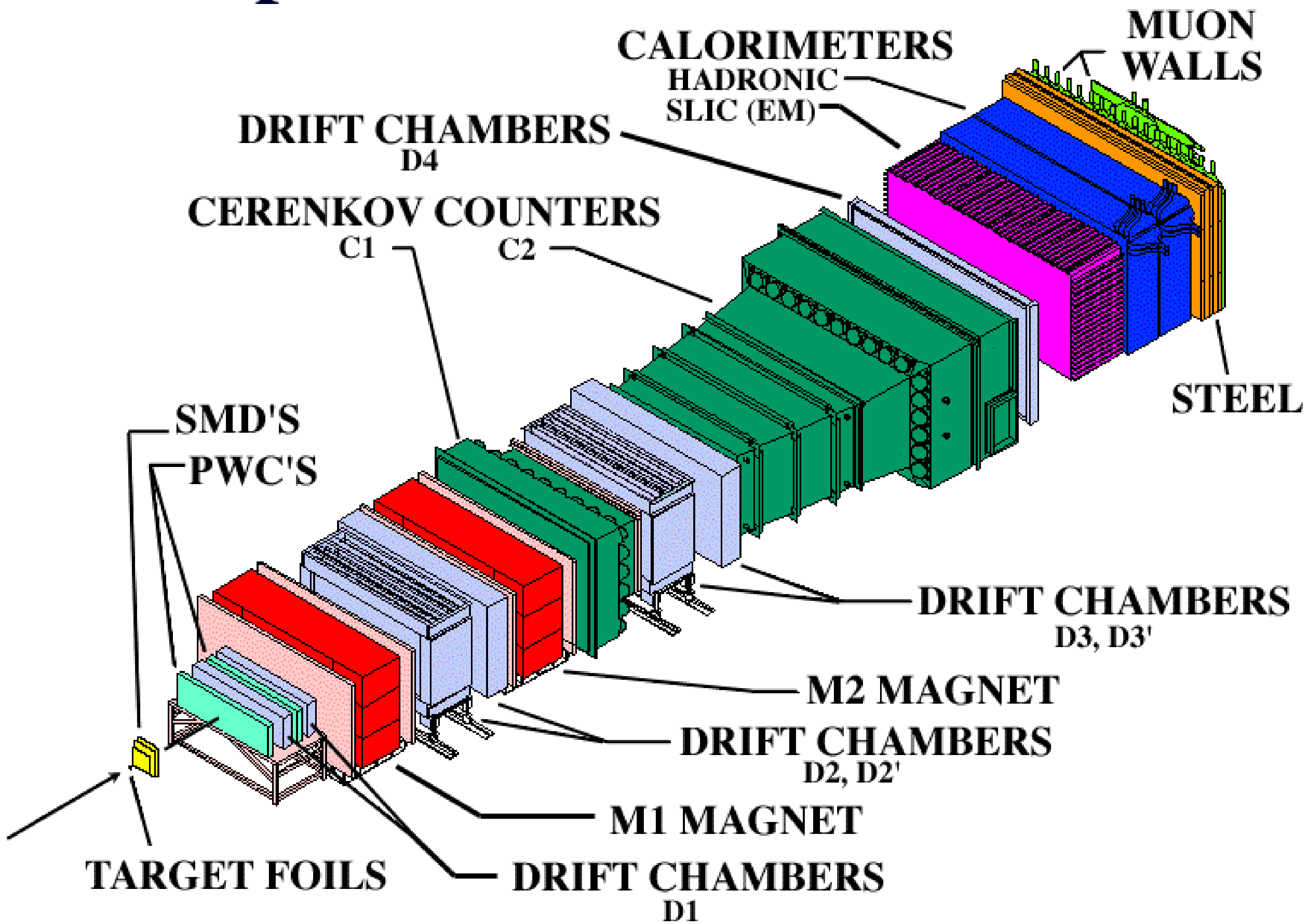
Particle Identification

- 2 multi-cell Čerenkov counters
- Muon detector

Energy Measurement

- Electromagnetic and hadronic calorimeters

E-791 Spectrometer



Electron Identification

The Segmented Liquid Ionization Calorimeter (SLIC)

Separated electrons from pions by:

1) Matching SLIC energy with Drift Chamber momentum.

2) Matching SLIC position with Drift Chamber positions.

3) Finding no energy in the Hadron Calorimeter behind the candidate electron shower.

4) Transverse energy deposition.

50-70% efficient.

Pion misidentification ~1%.

Muon Identification

16 Horizontal Scintillator strips 14 cm X 3 m with PMT/TDCs on one end.

14 Vertical Scintillator strips covering a 3m X 6m area.

Located behind ~2.5 meters of Iron (15 IL) – Stops hadronic showers.

1) Extrapolated tracks with > 8 GeV/c momentum to muon wall.

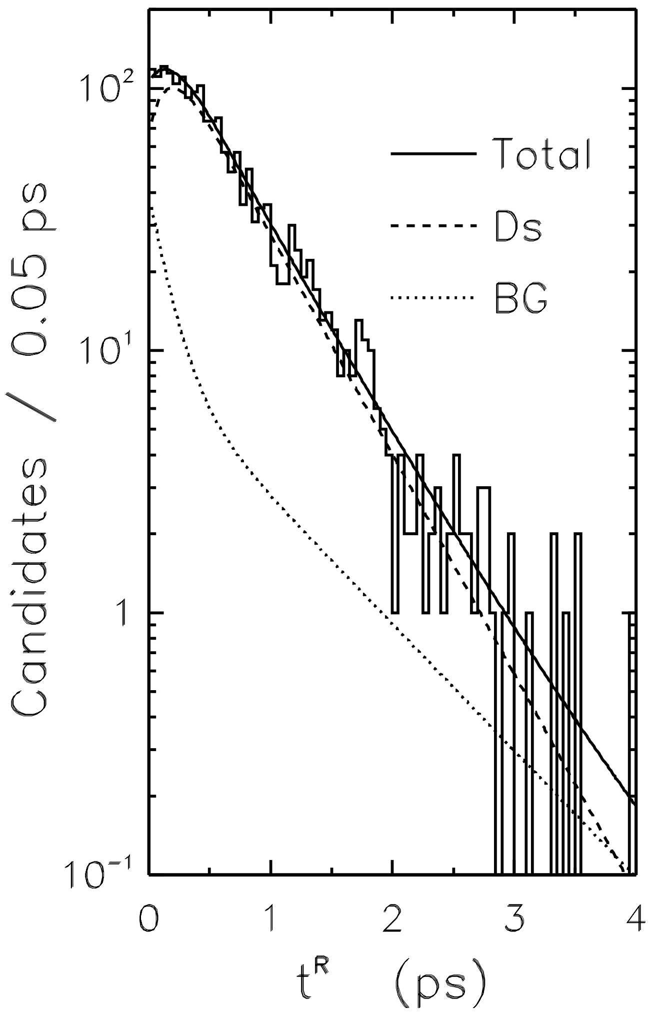
2) Did not allow candidates to share hits in a horizontal strip.

3) Used TDC information to improve horizontal resolution.

99% Efficient.

Pion misidentification rate ~1.5%.

Vertexing – D_s Lifetime



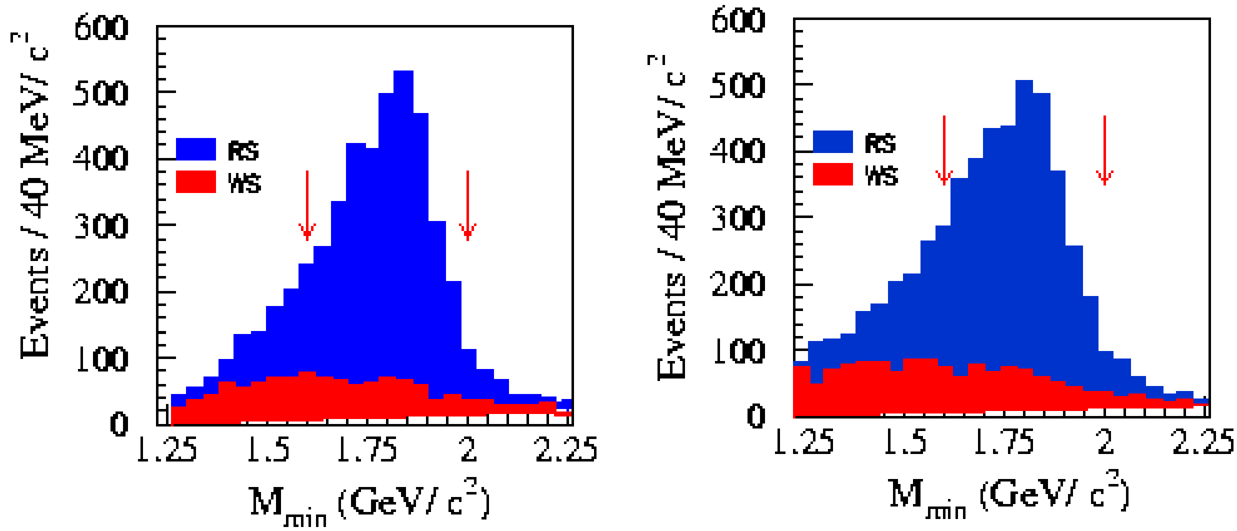
$\tau(D_s \to \phi\pi) = 0.518 \pm 0.014 \pm 0.007$ ps

$\frac{\tau(D_s)}{\tau(D^0)} = 1.25 \pm 0.04$ (6σ difference from unity)

Physics Letters **B 445** (1999) 449-454

D^+ Semileptonic measurements

$D^+ \rightarrow \overline{K}^{*0} \mu^+ \nu_\mu$ $D^+ \rightarrow \overline{K}^{*0} e^+ \nu_e$



$$M_{\text{min}} = P_t + \sqrt{p_t^2 + m_{\text{vis}}^2}$$

Combined Form-Factor results

$r_v = 1.87 \pm 0.08 \pm 0.07$ and $r_2 = 0.73 \pm 0.06 \pm 0.08$

Physics Letters **B 440** (1998) 435-441

Data Acquisition and Offline Computing System

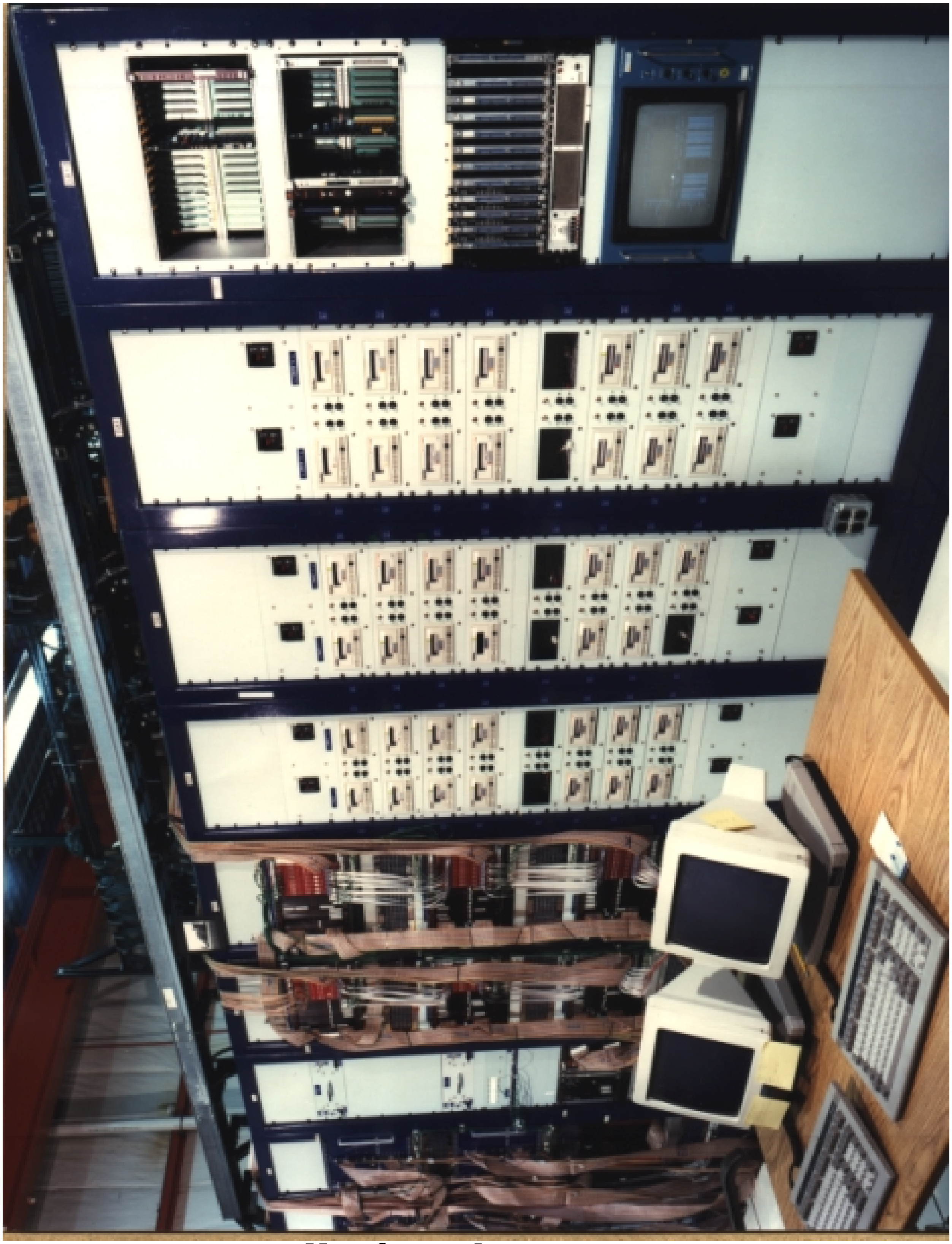
E791 used a loose transverse energy (or open Charm) trigger. More data = more Charm.

Recorded 2×10^{10} events – 50 Terabytes of raw data on 24,000 8mm tapes. (CDF 10 TB 1985-95)

Golden Convergence:

- High speed electronics – 50 μs Silicon ADCs/TDCs. (4000 events/second to tape.)
- New data storage devices – Exabyte 8mm tape drives.
- Fast reconstruction computer farms – Commercial UNIX RISC-based computers. Beginning of cheap commodity computing.

1/3 of the data was reconstructed at the University of Mississippi Computer Farm – the remainder at Kansas State University, Fermilab, and CBPF - Brazil.

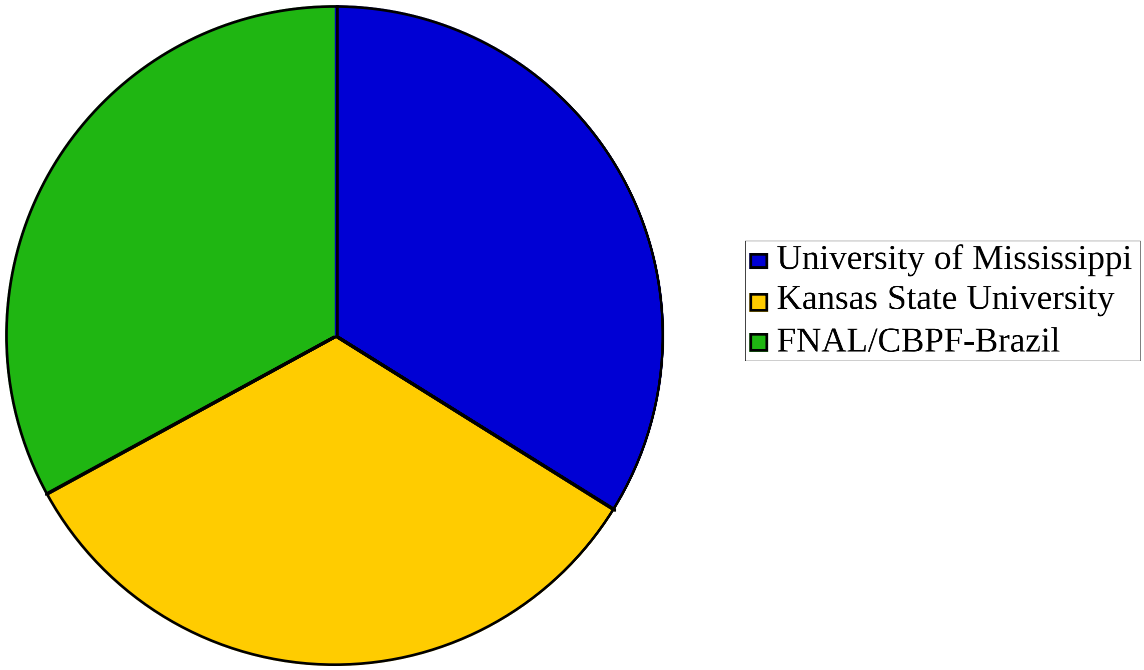


“Great Wall of Exabytes”– E791 DAQ

Mississippi Computer Farm

The computer farm, consisting of 68 DECstations, was running in the background during an E791 collaboration meeting at the University of Mississippi.

E791 Data Reconstruction



Blind Analysis Method

Method:

- Cover signal region with a "box"
- Optimize ALL cuts before opening "box"

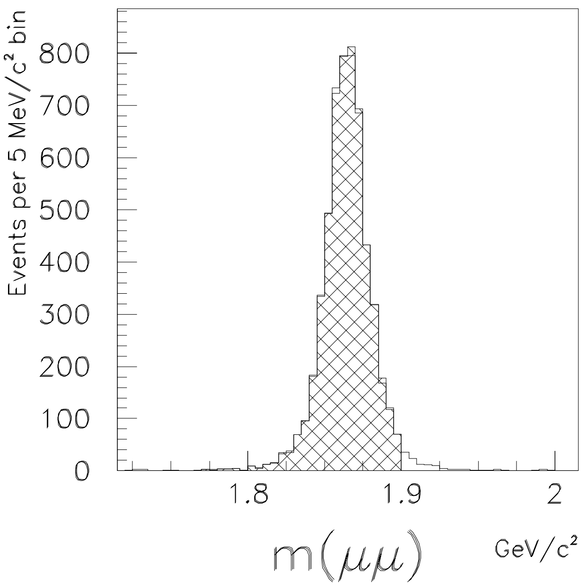
  Maximize Monte Carlo Signal/$\sqrt{\text{Data Wings}}$

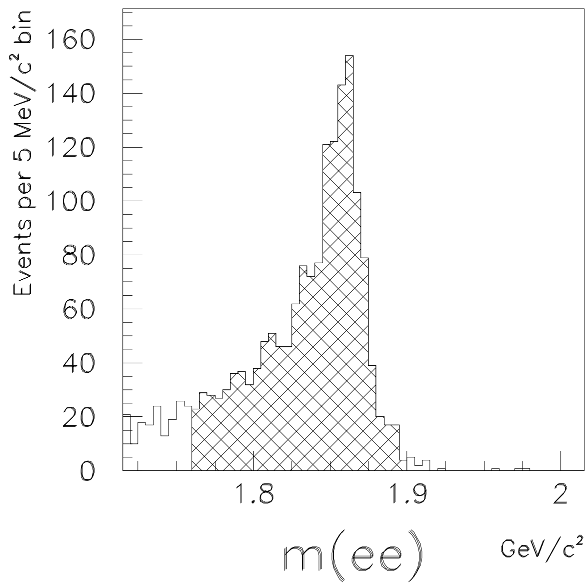
- Open "box" covering signal region

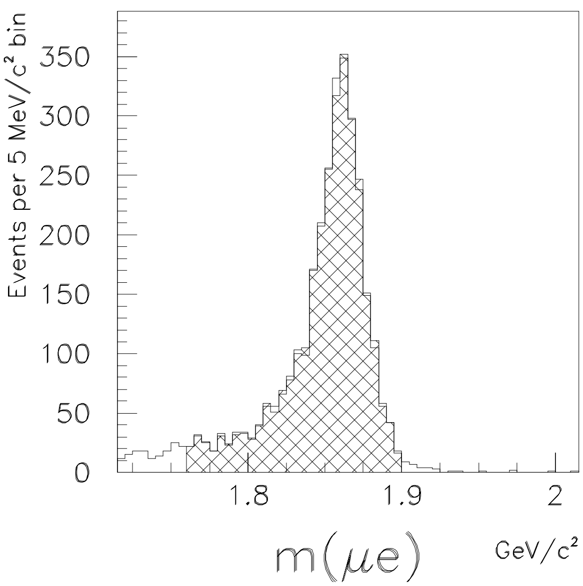
Blind Analysis Closed mass "box" widths:

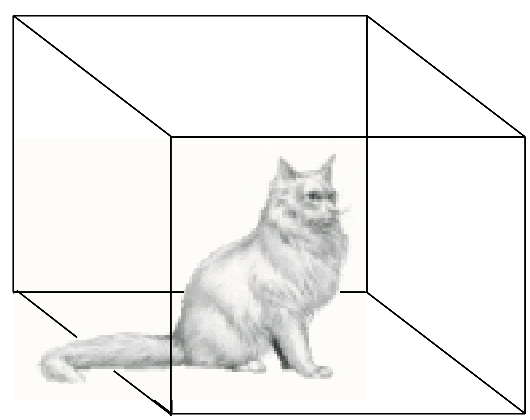
$D^+ \to h\mu\mu$	60 MeV/c^2
$D^+ \to hee$(or $h\mu e$)	120 MeV/c^2
$D_s^+ \to h\mu\mu$	40 MeV/c^2
$D_s^+ \to hee$(or $h\mu e$)	80 MeV/c^2
$D^0 \to \mu\mu$	70 MeV/c^2
$D^0 \to ee$(or μe)	140 MeV/c^2

Illustration of the closed "box" mass using D^0 Monte Carlo generated events







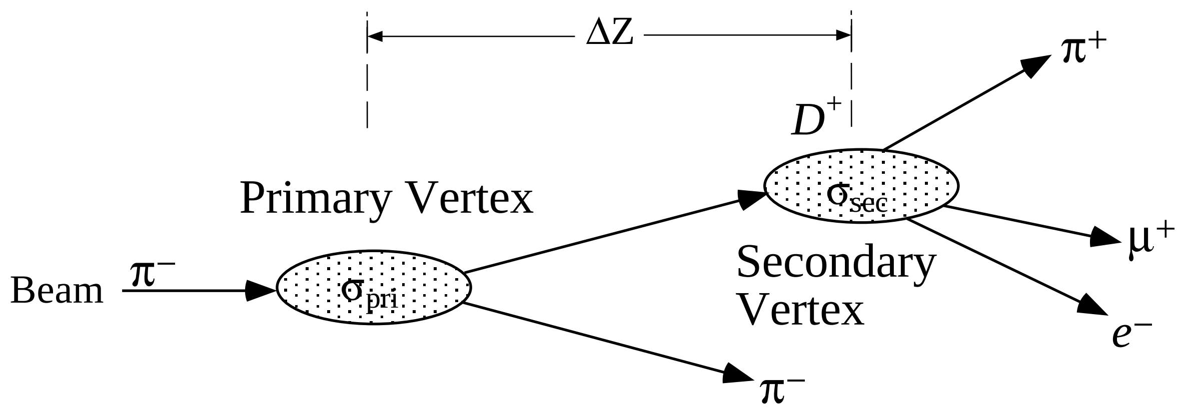


Note the asymmetry of the "box" due to the Bremsstrahlung tail

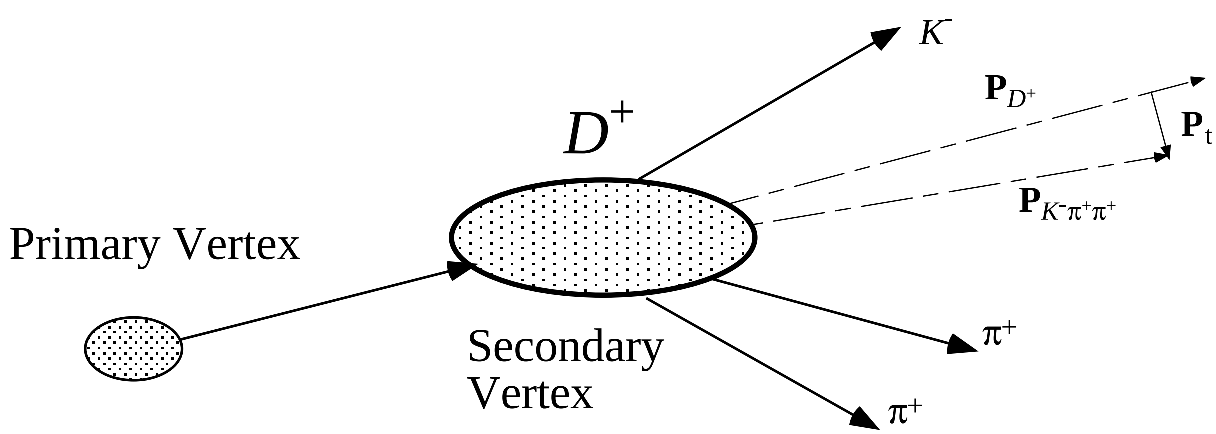
(We tried to keep tails inside the "box" but, as Schrödinger would have found out, sometimes the tails stick out a little.)

Description of the Kinematics Variables

- Vertex Separation (SDZ)



- Transverse Momentum Balance (PTB)



Kinematics Cuts

	D^+	D_s^+	D^0
Separation of Vertices	> 20 σ	> 12 σ	> 12 σ
Vertex separation from Target	> 5 σ	> 5 σ	> 5 σ
Lifetime	< 5 ps	< 3 ps	< 3 ps
Impact parameter	< 0.040 mm	< 0.040 mm	< 0.040 mm
Transverse momentum balance	< 0.20 GeV/c	< 0.25 GeV/c	< 0.30 GeV/c

Cuts were determined to maximize Monte Carlo signal $/\sqrt{\text{Background}}$. (Background is data outside the signal region.)

Other cuts:

- Removal of "reflections" due to particle misidentification
- Particle ID cuts

Branching Ratio Calculation

$$BR_X = \frac{N_X / \varepsilon_X}{N_{norm} / \varepsilon_{norm}} \cdot BR_{norm}$$

$$= \frac{N_X}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_X} \cdot BR_{norm}$$

Where the efficiency ratio $\frac{\varepsilon_{norm}}{\varepsilon_X} = \frac{N^{MC}_{norm}}{N^{MC}_X}$ is the ratio of the number of events from a Monte Carlo simulation.

If you have enough candidates to use Gaussian statistics then N_X is the number of observed events, after subtracting backgrounds. If not, you have to use Poisson statistics and make an upper limit calculation.

Monte Carlo Simulation

Used PYTHIA/JETSET[1] from Lund Monte Carlo

Mode	**# Generated**	**# Passed Cuts**	**% Yield**
$D^+ \to K^- \pi^+ \pi^+$	250,000	2,653	1. 06
$D^+ \to \pi^+ \mu^+ \mu^-$	250,000	2,706	1.08
$D^+ \to \pi^+ e^+ e^-$	250,000	816	0.33
$D^+ \to \pi^+ \mu^\pm e^\mp$	250,000	1,272	0.51
$D^+ \to \pi^- \mu^+ \mu^+$	250,000	2,088	0.84
$D^+ \to \pi^- e^+ e^+$	250,000	701	0.28
$D^+ \to \pi^- \mu^+ e^+$	250,000	976	0.39
$D^+ \to K^+ \mu^+ \mu^-$	250,000	1206	0.48
$D^+ \to K^+ e^+ e^-$	250,000	453	0.18
$D^+ \to K^+ \mu^\pm e^\mp$	250,000	664	0.27
$D^+ \to K^- \mu^+ \mu^+$	250,000	1,214	0.49
$D^+ \to K^- e^+ e^+$	250,000	421	0.17
$D^+ \to K^- \mu^+ e^+$	250,000	683	0.27
$D_s^+ \to \phi \pi^+$	250,000	1,225	0.49
$D_s^+ \to K^+ \mu^+ \mu^-$	250,000	647	0.26
$D_s^+ \to K^+ e^+ e^-$	250,000	244	0.10
$D_s^+ \to K^+ \mu^\pm e^\mp$	250,000	388	0.16
$D_s^+ \to K^- \mu^+ \mu^+$	250,000	686	0.27
$D_s^+ \to K^- e^+ e^+$	250,000	257	0.10
$D_s^+ \to K^- \mu^+ e^+$	250,000	381	0.15
$D_s^+ \to \pi^+ \mu^+ \mu^-$	250,000	1725	0.69
$D_s^+ \to \pi^+ e^+ e^-$	250,000	565	0.23
$D_s^+ \to \pi^+ \mu^\pm e^\mp$	250,000	809	0.32
$D_s^+ \to \pi^- \mu^+ \mu^+$	250,000	1588	0.69
$D_s^+ \to \pi^- e^+ e^+$	250,000	528	0.23
$D_s^+ \to \pi^- \mu^+ e^+$	250,000	911	0.32
$D^0 \to K^- \pi^+$	250,000	4,535	1.81
$D^0 \to \mu^+ \mu^-$	250,000	5,297	2.12
$D^0 \to e^+ e^-$	250,000	1,577	0.63
$D^0 \to \mu^\pm e^\mp$	250,000	2983	1.19

[1] H.-U. Bengtsson and T. Sjöstrand, Comp. Phys. Comm. 82 (1994) 74;
T. Sjöstrand, PYTHIA 5.7 and JETSET 7.4 Physics and Manual, CERN-TH.7112/93, 1995.

Upper Limit Branching Ratio Calculation

$$BR_X < \frac{N_X / \varepsilon_X}{N_{norm} / \varepsilon_{norm}} \cdot BR_{norm}$$

$$< \frac{N_X}{N_{norm}} \cdot \frac{\varepsilon_{norm}}{\varepsilon_X} \cdot BR_{norm}$$

Where $\frac{\varepsilon_{norm}}{\varepsilon_X} = \frac{N_{norm}^{MC}}{N_X^{MC}}$ and

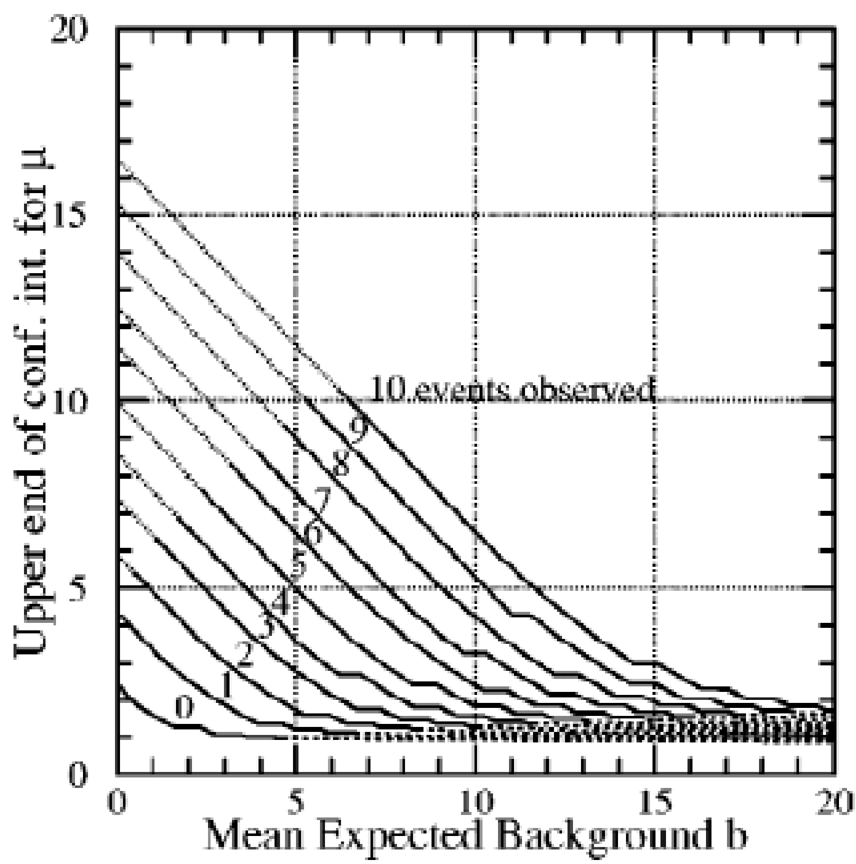
N_X is now the 90% CL upper limit prediction on the number of events.

Since there was some background, N_X is calculated using the method of Feldman and Cousins. One also has to correct N_X for systematic errors. This was done using the method of Cousins and Highland.

90% Confidence Level Upper Limit

CL=90% – No background		
n_0 (Number observed)	μ_1 (Lower Limit)	μ_2 (Upper Limit)
0	0.00	2.44
1	0.11	4.36
2	0.53	5.91
3	1.10	7.42
4	1.47	8.60
5	1.84	9.99
6	2.21	11.47
7	3.56	12.53
8	3.96	13.99
9	4.36	15.30
10	5.50	16.50

Method of Feldman and Cousins[2]



2 G. J. Feldman and R. D. Cousins Phys. Rev. D 57 (1998) 3873-3889.

Sources of Background

- Reflection Background – $K \leftrightarrow \pi, \ell$

  Gets rid of e.g.:

  $D^+ \to K^- \pi^+ \pi^+$ decays from $D^+ \to \pi^- \mu^+ \mu^+$ $(K \leftrightarrow \pi)$

  $D^0 \to K^- \pi^+$ decays from $D^0 \to \mu^- \mu^+$ $(K \leftrightarrow \ell)$

  Reflected outside of the box

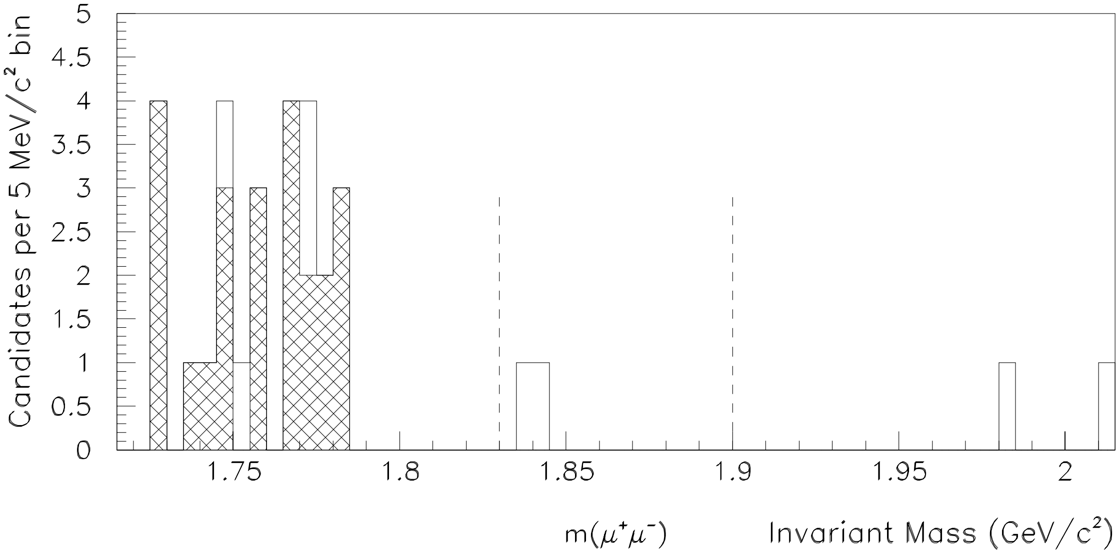
  Were explicitly removed before opening the box

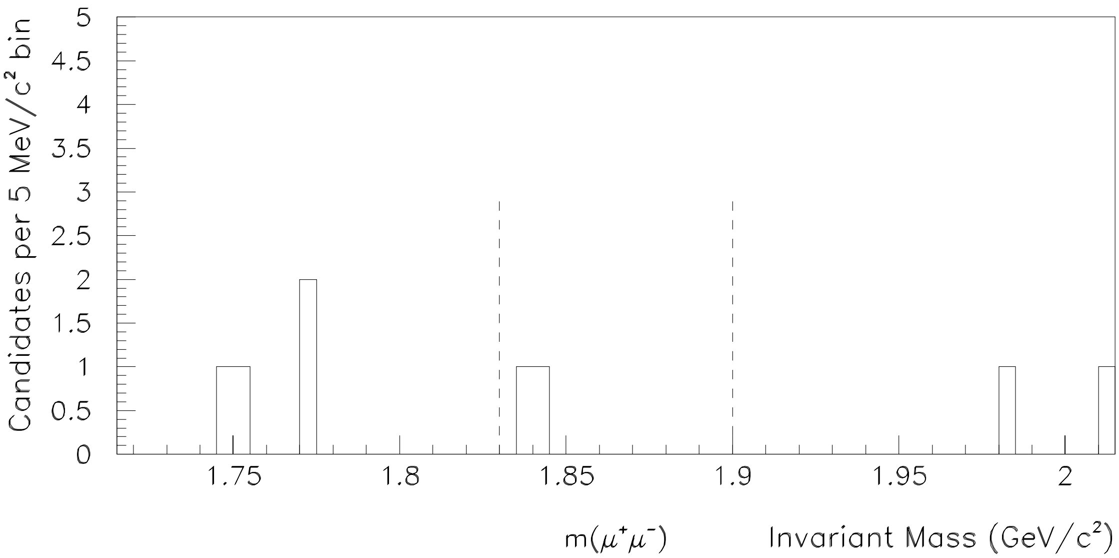
- Pion Misidentification Background – $\pi \leftrightarrow \ell$

- Combinatoric Background – Random Tracks

Reflection Background

$K \leftrightarrow \pi$ (or $K \leftrightarrow \ell$) Misidentification

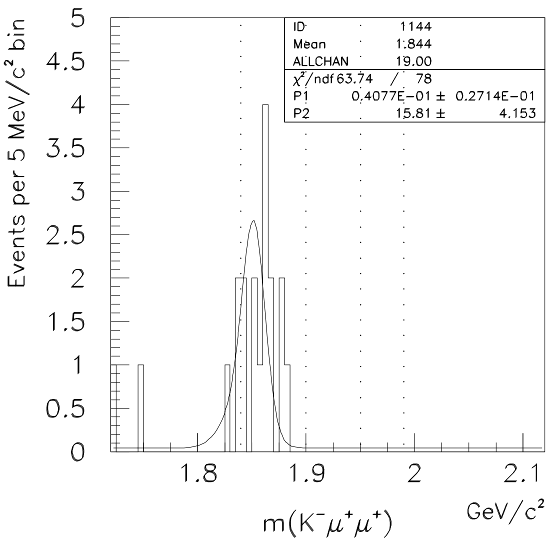


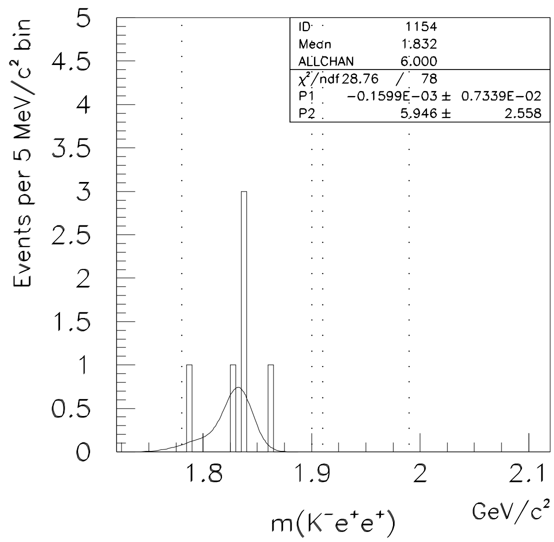


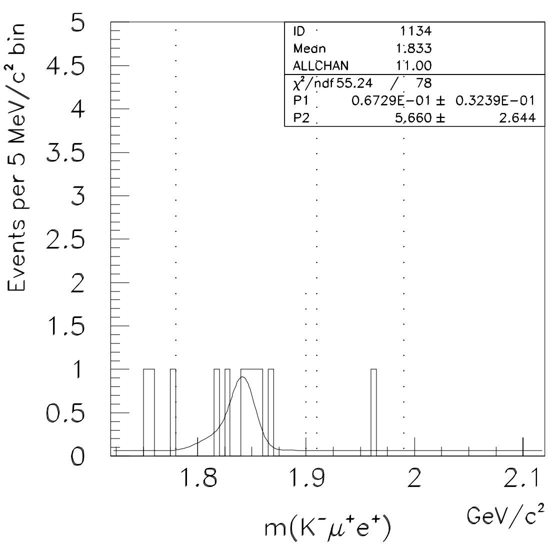
The shaded region shows events identified as coming from $D^0 \rightarrow K^- \pi^+$ that are reflected into the $D^0 \rightarrow \mu^+ \mu^-$ mass window. Thus, a Kaon is misidentified as a muon and reflected outside of the box (dashed lines).

Pion Misidentification Background

$\pi \leftrightarrow \ell$ Misidentification Rate



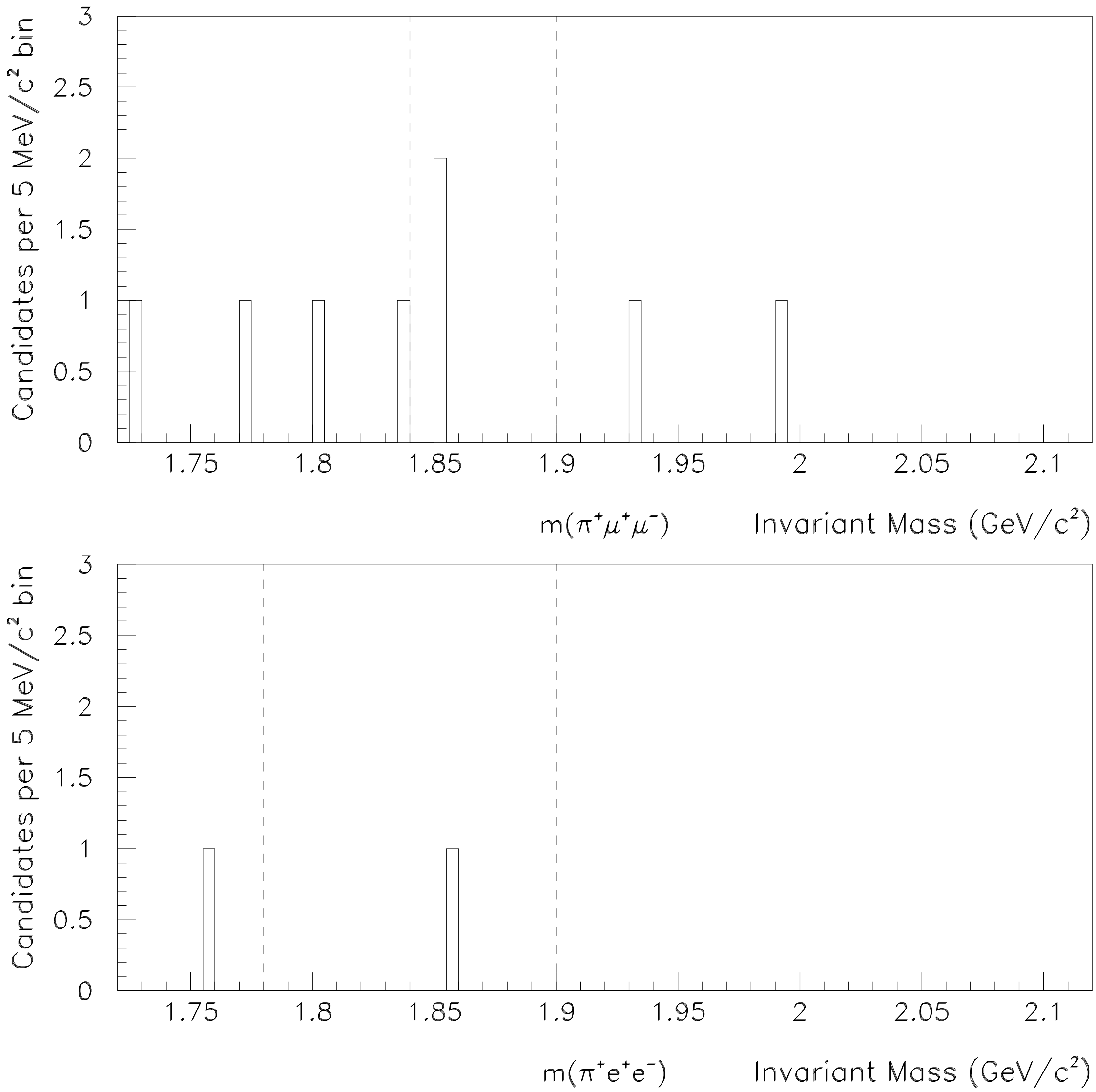




We used these misidentified $D^+ \to K^- \pi^+ \pi^+$ signals to determine the pion-lepton background misidentification rate; therefore, we did not set limits for the $D^+ \to K^- \ell^+ \ell^+$ modes.

Combinatoric Background

Random Tracks



Because there was not enough combinatoric background to characterize the shape we used a very conservative assumption to determine the combinatoric background rate. We assumed either a flat distribution (top) or no combinatoric background (bottom).

Systematic Error

Sources of the systematic errors

1) Normalization Branching Ratio from the PDG.
2) Statistical errors on the normalization fit.
3) Monte Carlo statistics of the normalization and decay modes.
4) Pion misidentification background.
5) Muon counter's and electron calorimeter's hardware performance and Monte Carlo simulations.
6) Bremsstrahlung tails.
7) Čerenkov ID efficiency.

Method of Cousins and Highland

The 90% CL upper limit prediction is corrected for the systematic error using the method described in Cousins and Highland[3]. Now $N_x = U_x + \Delta U_x$ where U_x is the uncorrected value that is calculated using the method of Feldman and Cousins. And

$$\Delta U_x = \frac{U_x + B - n}{U_x + B} \cdot \frac{U_x^2 \sigma_r^2}{2}$$

where B is the predicted background, n is the number of observed events, and σ_r is the total systematic errors.

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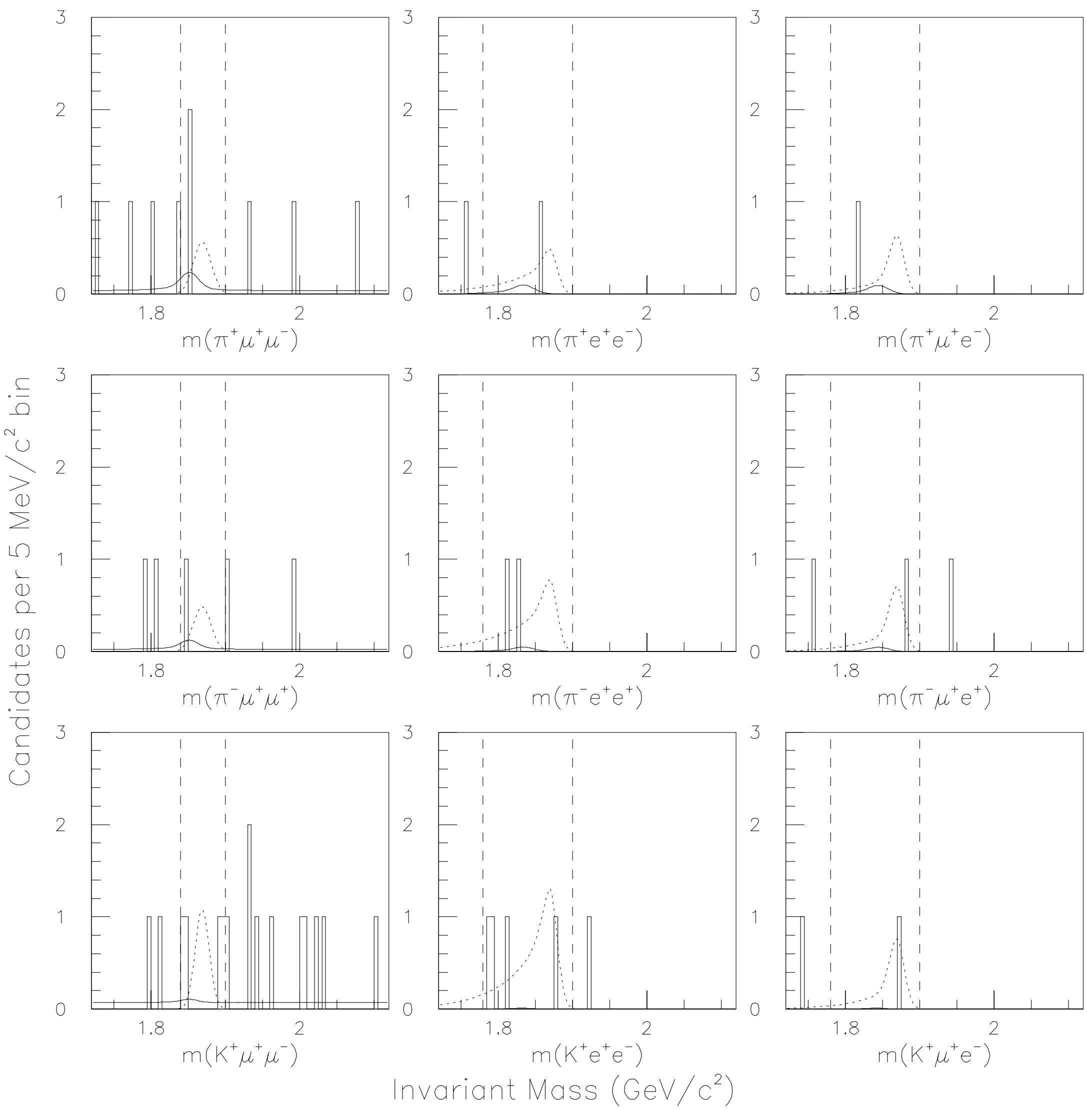
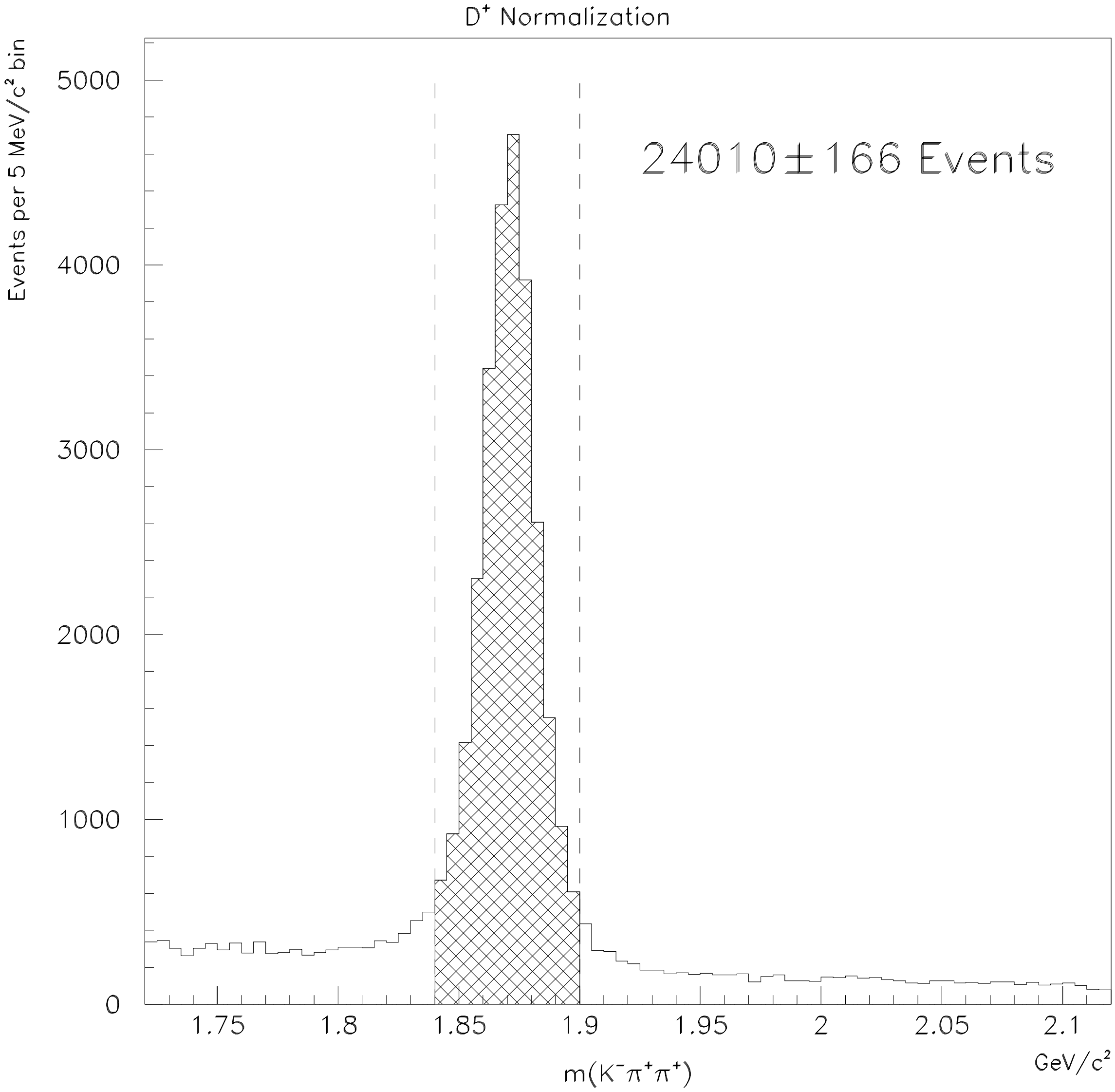
[3] R. D. Cousins and V. I. Highland, Nucl. Instr. Meth. A320 (1992) 331-335.

Systematic Error Fractions								
Mode	1	2	3	4	5	6	7	Total
$D^+ \to \pi^+ \mu^+ \mu^-$	0.067	0.007	0.027	0.051	0.033	0.022	0.020	0.099
$D^+ \to \pi^+ e^+ e^-$	0.067	0.007	0.040	0.069	0.053	0.036	0.020	0.124
$D^+ \to \pi^+ \mu^\pm e^\mp$	0.067	0.007	0.034	0.065	0.046	0.020	0.020	0.113
$D^+ \to \pi^- \mu^+ \mu^+$	0.067	0.007	0.029	0.025	0.036	0.013	0.020	0.089
$D^+ \to \pi^- e^+ e^+$	0.067	0.007	0.042	0.034	0.074	0.035	0.020	0.121
$D^+ \to \pi^- \mu^+ e^+$	0.067	0.007	0.037	0.032	0.073	0.019	0.020	0.114
$D^+ \to K^+ \mu^+ \mu^-$	0.067	0.008	0.036	0.001	0.024	0.016	0.000	0.082
$D^+ \to K^+ e^+ e^-$	0.067	0.008	0.052	0.000	0.056	0.025	0.000	0.105
$D^+ \to K^+ \mu^\pm e^\mp$	0.067	0.008	0.045	0.000	0.045	0.011	0.000	0.093
$D_s^+ \to K^+ \mu^+ \mu^-$	0.250	0.038	0.049	0.034	0.034	0.032	0.020	0.265
$D_s^+ \to K^+ e^+ e^-$	0.250	0.038	0.070	0.046	0.052	0.098	0.020	0.289
$D_s^+ \to K^+ \mu^\pm e^\mp$	0.250	0.038	0.058	0.043	0.048	0.037	0.020	0.271
$D_s^+ \to K^- \mu^+ \mu^+$	0.250	0.040	0.048	0.017	0.038	0.023	0.020	0.263
$D_s^+ \to K^- e^+ e^+$	0.250	0.040	0.069	0.023	0.053	0.084	0.020	0.282
$D_s^+ \to K^- \mu^+ e^+$	0.250	0.040	0.059	0.022	0.067	0.045	0.020	0.274
$D_s^+ \to \pi^+ \mu^+ \mu^-$	0.250	0.036	0.035	0.047	0.024	0.061	0.028	0.269
$D_s^+ \to \pi^+ e^+ e^-$	0.250	0.036	0.049	0.063	0.051	0.107	0.028	0.292
$D_s^+ \to \pi^+ \mu^\pm e^\mp$	0.250	0.036	0.044	0.060	0.131	0.067	0.028	0.303
$D_s^+ \to \pi^- \mu^+ \mu^+$	0.250	0.036	0.036	0.023	0.051	0.050	0.028	0.267
$D_s^+ \to \pi^- e^+ e^+$	0.250	0.036	0.051	0.032	0.051	0.116	0.028	0.290
$D_s^+ \to \pi^- \mu^+ e^+$	0.250	0.036	0.042	0.030	0.078	0.062	0.028	0.278
$D^0 \to \mu^+ \mu^-$	0.023	0.007	0.020	0.017	0.039	0.012	0.030	0.062
$D^0 \to e^+ e^-$	0.023	0.007	0.029	0.022	0.062	0.030	0.030	0.087
$D^0 \to \mu^\pm e^\mp$	0.023	0.007	0.024	0.021	0.040	0.014	0.030	0.066

D^+ Results

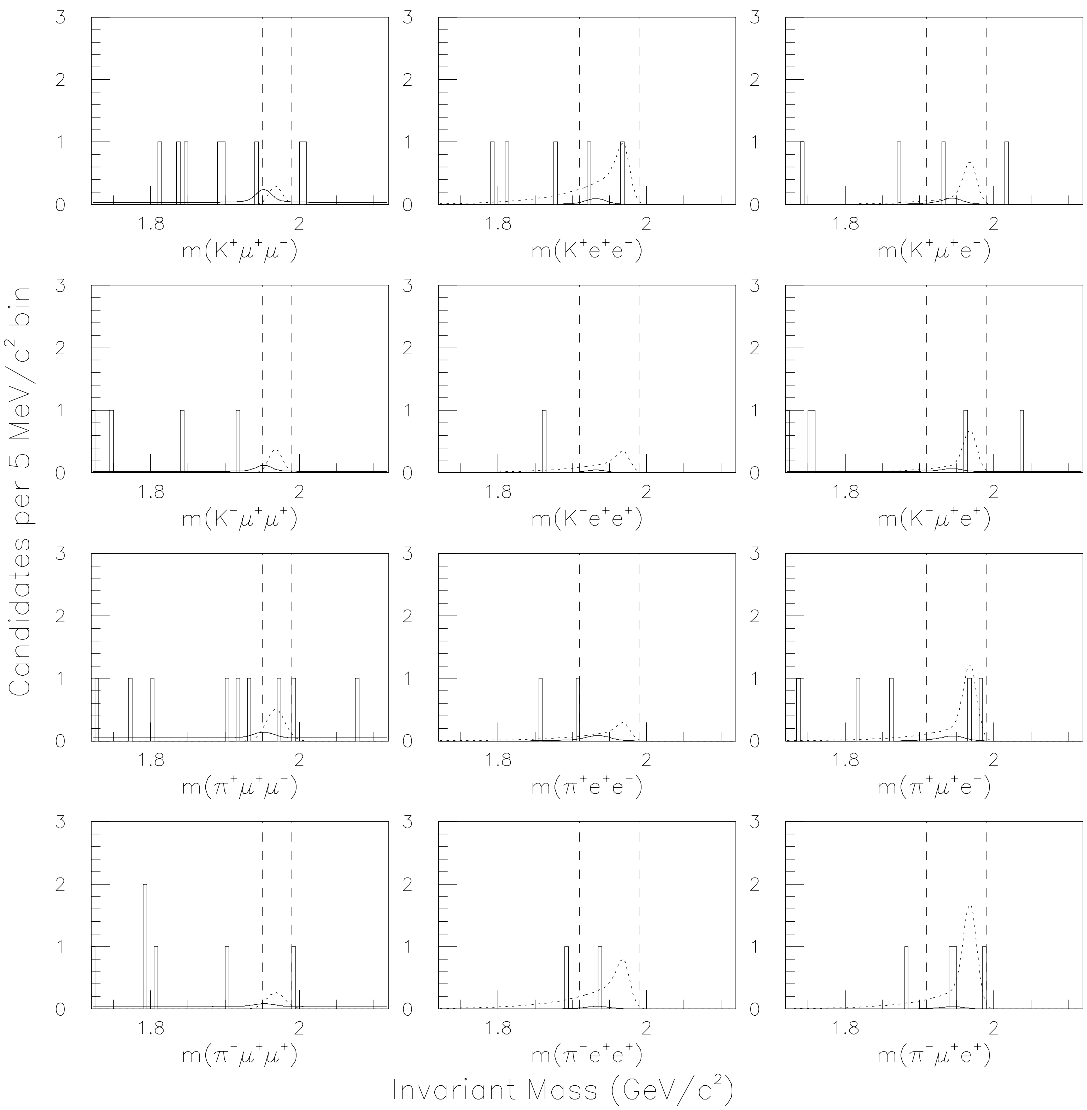


D^+ data.
Dotted line is the shape that we expect if there were the number of events predicted at 90% CL upper limit. Solid line is estimated background. Dashed lines are "box".
Bin width = 5 MeV/c^2



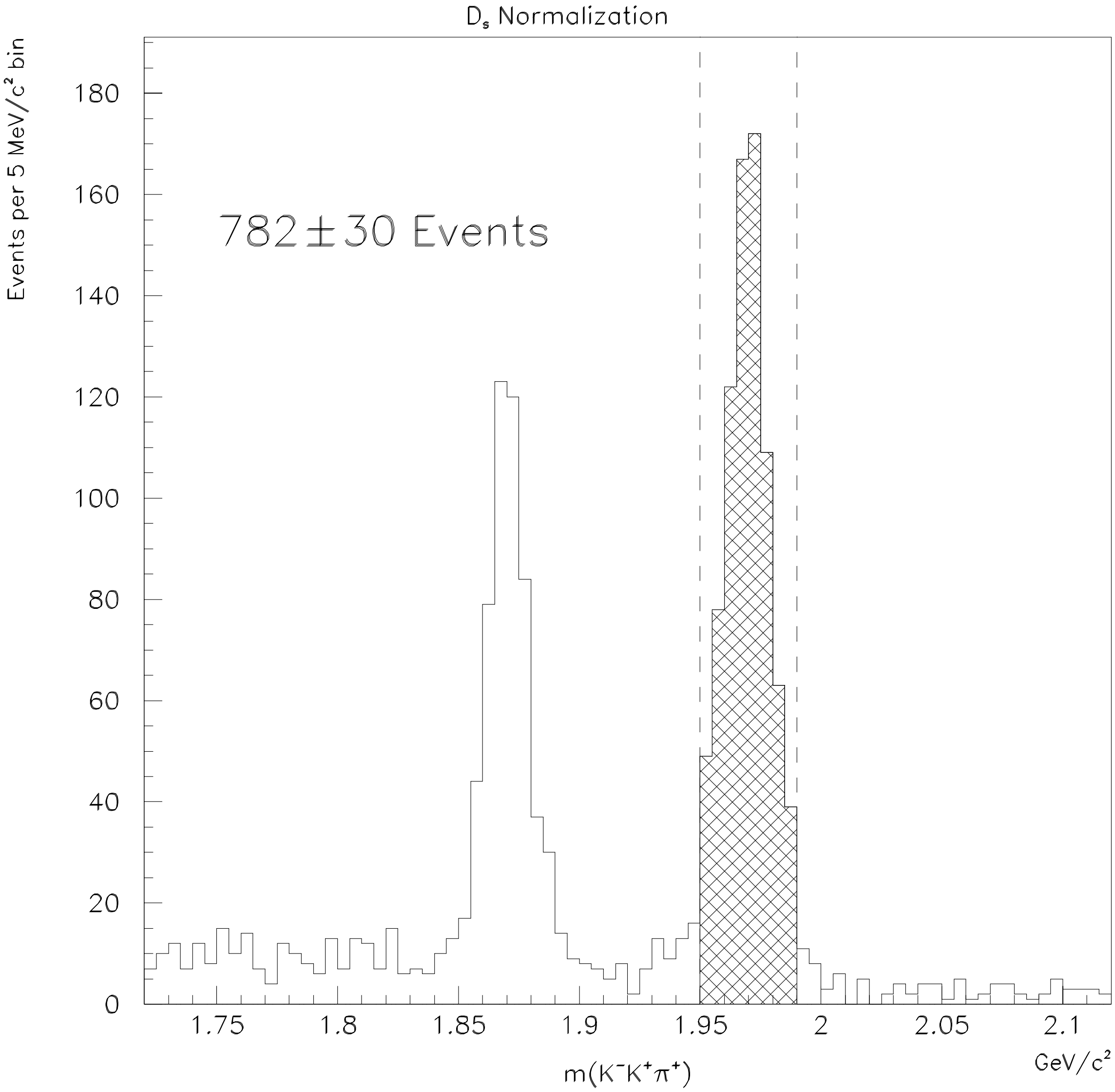
One of our Normalization Signals, $D^+ \to K^-\pi^+\pi^+$.
Dashed lines are "box". Bin width = 5 MeV/c^2

D_s^+ Results



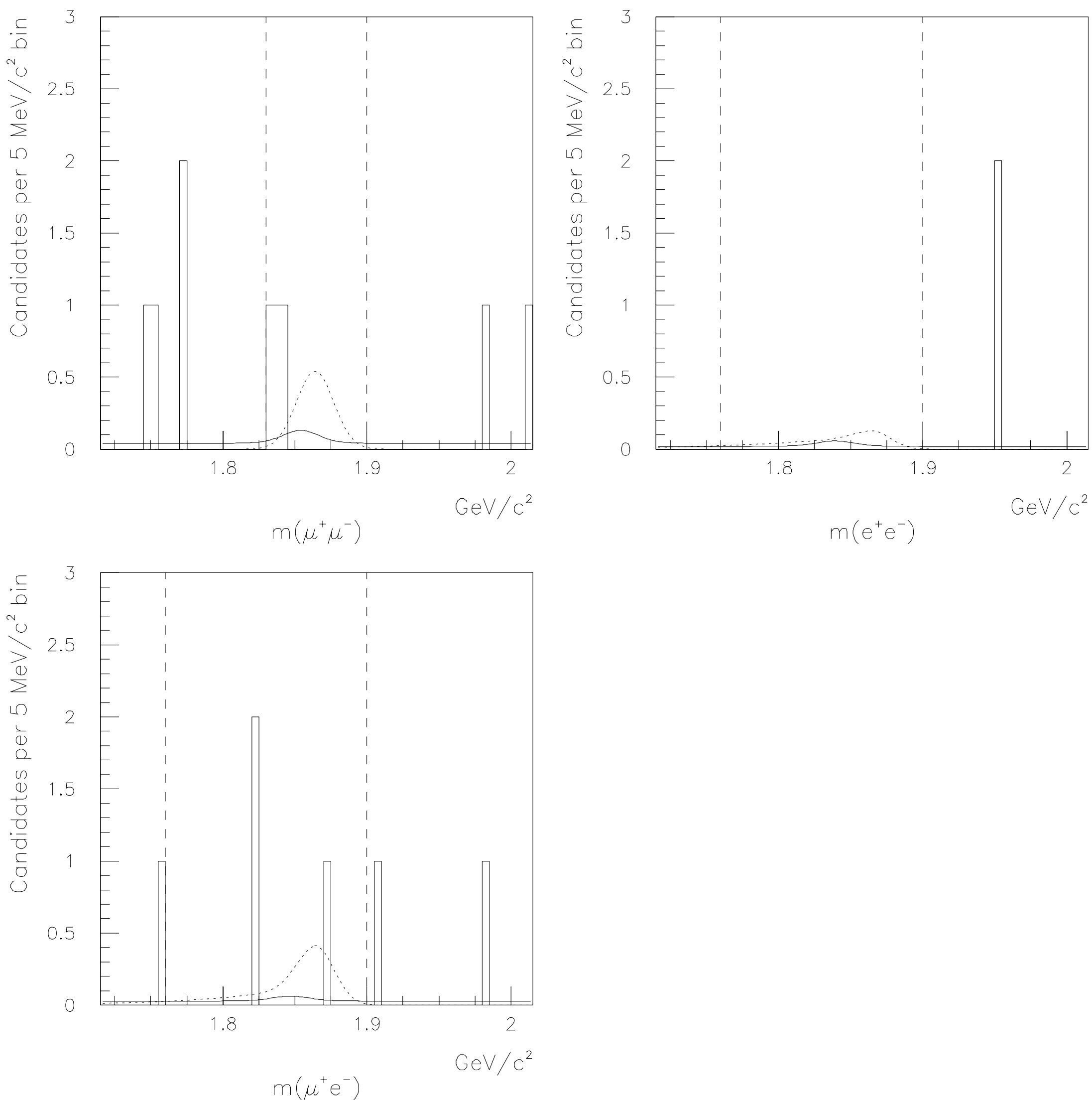
D_s^+ data.

Dotted line is the shape that we expect if there were the number of events predicted at 90% CL upper limit. Dashed lines are "box". Bin width = 5 MeV/c^2

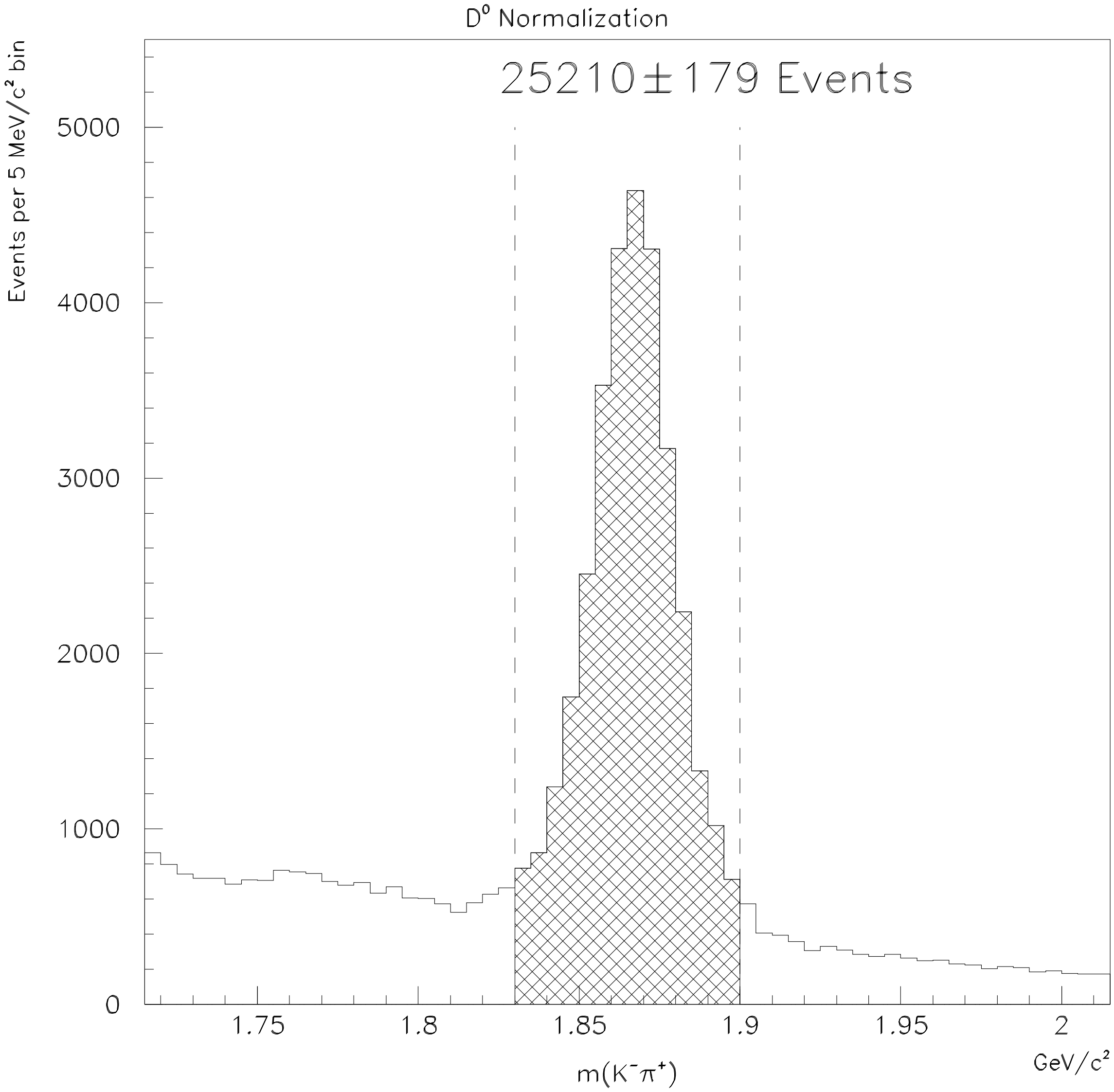


Another Normalization Signal, $D_s^+ \to \phi\pi^+ (\phi \to K^+K^-)$.
Dashed lines are "box". Bin width = 5 MeV/c^2

D^0 Results



D^0 data.
Dotted line is the shape that we expect if there were the number of events predicted at 90% CL upper limit. Dashed lines are "box". Bin width = 5 MeV/c^2

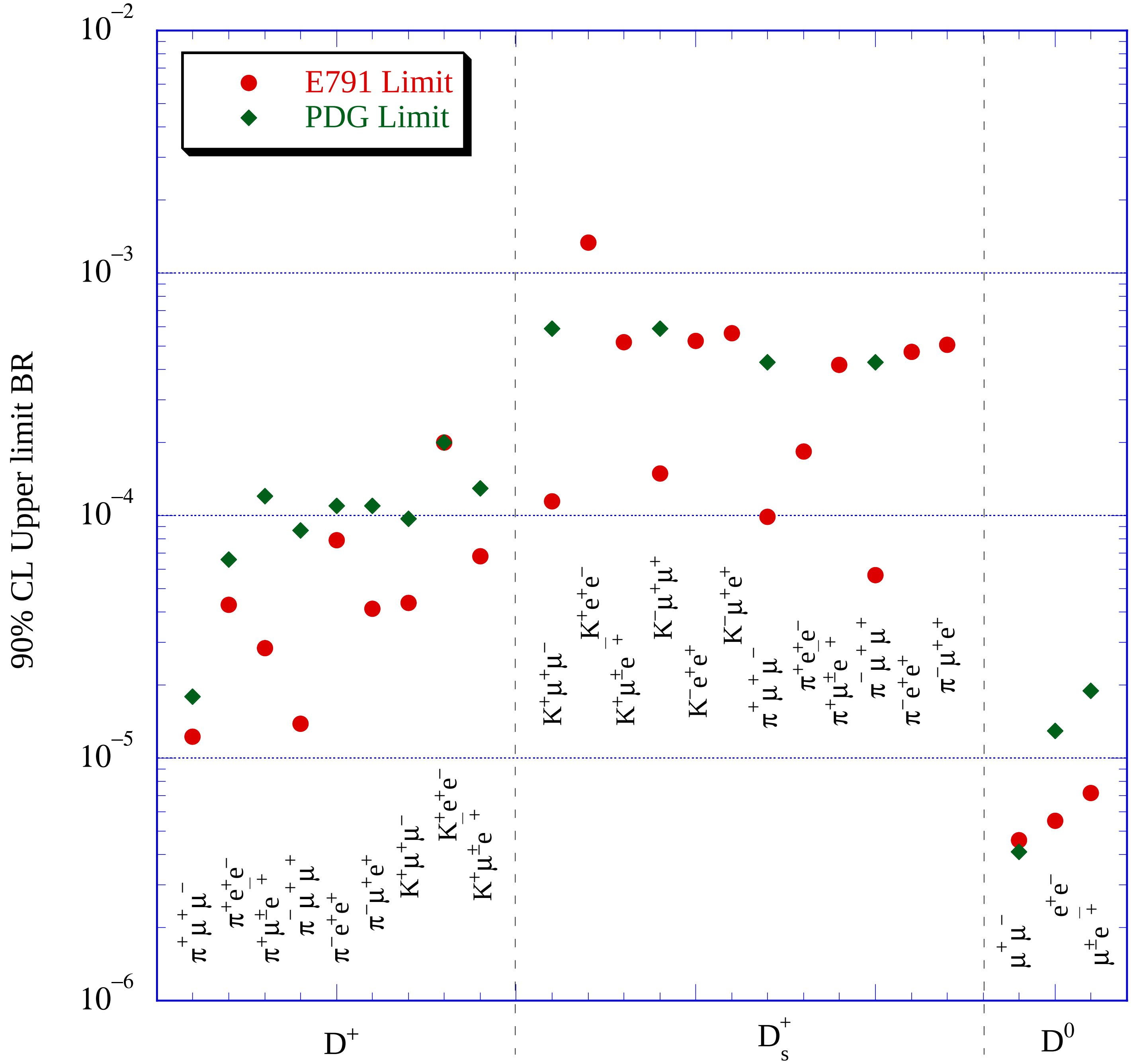


Yet another Normalization Signal, $D^0 \rightarrow K^- \pi^+$.
Dashed lines are "box". Bin width = 5 MeV/c^2

Final Results – 90% CL upper limit

Mode	E791 BR	BR (1998 PDG)	Previous Results
$D^+ \to \pi^+ \mu^+ \mu^-$	1.48×10^{-5}	1.8×10^{-5}	E791
$D^+ \to \pi^+ e^+ e^-$	5.17×10^{-5}	6.6×10^{-5}	E791
$D^+ \to \pi^+ \mu^\pm e^\mp$	3.42×10^{-5}	1.2×10^{-4}	E687
$D^+ \to \pi^- \mu^+ \mu^+$	1.67×10^{-5}	8.7×10^{-5}	E687
$D^+ \to \pi^- e^+ e^+$	9.56×10^{-5}	1.1×10^{-4}	E687
$D^+ \to \pi^- \mu^+ e^+$	4.96×10^{-5}	1.1×10^{-4}	E687
$D^+ \to K^+ \mu^+ \mu^-$	4.38×10^{-5}	9.7×10^{-5}	E687
$D^+ \to K^+ e^+ e^-$	2.00×10^{-4}	2.0×10^{-4}	E687
$D^+ \to K^+ \mu^\pm e^\mp$	6.80×10^{-5}	1.3×10^{-4}	E687
$D_s^+ \to K^+ \mu^+ \mu^-$	1.38×10^{-4}	5.9×10^{-4}	E653
$D_s^+ \to K^+ e^+ e^-$	1.61×10^{-3}		
$D_s^+ \to K^+ \mu^\pm e^\mp$	6.25×10^{-4}		
$D_s^+ \to K^- \mu^+ \mu^+$	1.80×10^{-4}	5.9×10^{-4}	E653
$D_s^+ \to K^- e^+ e^+$	6.34×10^{-4}		
$D_s^+ \to K^- \mu^+ e^+$	6.82×10^{-4}		
$D_s^+ \to \pi^+ \mu^+ \mu^-$	1.43×10^{-4}	4.3×10^{-4}	E653
$D_s^+ \to \pi^+ e^+ e^-$	2.66×10^{-4}		
$D_s^+ \to \pi^+ \mu^\pm e^\mp$	6.05×10^{-4}		
$D_s^+ \to \pi^- \mu^+ \mu^+$	8.22×10^{-5}	4.3×10^{-4}	E653
$D_s^+ \to \pi^- e^+ e^+$	6.86×10^{-4}		
$D_s^+ \to \pi^- \mu^+ e^+$	7.34×10^{-4}		
$D^0 \to \mu^+ \mu^-$	5.18×10^{-6}	4.1×10^{-6}	BEATRICE, E771
$D^0 \to e^+ e^-$	6.23×10^{-6}	1.3×10^{-5}	CLEO
$D^0 \to \mu^\pm e^\mp$	8.12×10^{-6}	1.9×10^{-5}	CLEO

Final 90% CL Results



What New Mass Regions Do We Probe?

For simplicity assuming $g_{X^0,X'} = g_W$

Flavor Changing Neutral Current - Using:

$$m_{X^0} \sim m_W \cdot \left[\frac{BR\left(D^+ \to \overline{K}^0 \mu^+ \nu_\mu\right)}{BR\left(D^+ \to \pi^+ \mu^+ \mu^-\right)} \cdot (2.2) \right]^{1/4},$$

$$m_{X^0} \geq 800 \text{ GeV}/c^2$$

Lepton Flavor Violating - Using:

Horizontal Gauge Bosons

$$m_{X'} \sim m_W \cdot \left[\frac{BR\left(D^+ \to \overline{K}^0 \mu^+ \nu_\mu\right)}{BR\left(D^+ \to \pi^+ \mu^\pm e^\mp\right)} \cdot (2.2) \right]^{1/4},$$

$$m_{X'} \geq 650 \text{ GeV}/c^2$$

A. Schwartz, Mod. Phys. Lett. A8 (1993) 970.

Conclusion

- 24 measured modes
- 8 are completely new
- 14 improved on previous results

These results have been published in Physics Letters B 462 (1999) 401-409.

E791 sees no evidence for rare or forbidden charm decays at this level of sensitivity ($\sim 10^{-5}$).