D^0 Detection In STAR Using D^{*+} Kinematics

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March 22, 1994

Abstract

In this note we examine the possibility of using the $D^{*+} \rightarrow \pi^+ D^0$ decay kinematics to reduce the background from reconstructed D^0 candidates. This technique has been used by the most of the detectors at high energy e^+e^- storage rings to get a clean D^0 signal.

The technique relys on the fact that $M(D^{*+}) - M(D^0) = M(\pi^+) + 5.8MeV$. The small Q value means the phase space of the π^+ will be restricted to a small volume. Selecting only D^0s that also reconstruct to a D^{*+} (with the addition of a π^+) should reduce the D^0 background. For thermal Ds at mid-rapidity the allowed π^+ phase space is large enough that there is a significant random occupancy for central Au-Au events. For higher energy Ds the D^{*+} decay kinematics become more restrictive and it is suggested that examining this regime would be worth a follow up study.

1 Signals and Backgrounds

To claim a D^0 signal we would normally make a plot of reconstructed mass and note an excess of counts in a window around the D^0 mass. There will almost certainly be background counts in the window, and we can estimate the number of background counts by fitting a polynomial through 'side-bands' on either side of the D^0 peak. If we call the number of real D^0s per event S_{D^0}, the number of estimated background D^0s per event B_{D^0}, and the number of events N we will require

$$NS_{D^0} > 3\sqrt{NB_{D^0}}$$

or

$$N > 9\frac{B_{D^0}}{S_{D^0}^2}$$

before we would claim observation of a signal. (No matter how small the signal we only need enough events!) A reasonable criterion for a cut is that it decreases $B_{D^0}/S_{D^0}^2$.

2 D^0 signatures in STAR

2.1 Naive Evolution of c Quarks

For every c quark produced in a Au-Au collision we assume it picks up a $\bar{u}$ or $\bar{d}$ quark at random (50% neutral, 50% positive) with a random spin configuration (75% spin one excited state, 25% spin 0 ground state). There are also the charge conjugate states produced by the $\bar{c}$ quarks which should have the same characteristics and are implicitly assumed throughout this note (just change the sign of the electric charge and/or put bars above all the charmed mesons).

All of the D^{*0} mesons decay through the D^0. The branching ratio $D^{*+} \rightarrow \pi^+ D^0$ is 0.55 and the rest of the D^{*+} chain goes through the D^+. This means about 20% of the c quarks produced will go through the chain $D^{*+} \rightarrow \pi^+ D^0$. Adding up the numbers we expect about 70% of the c quarks will end up in D^0 mesons with the remainder showing up in D^+ mesons.

An attractive decay of the D^0 is to $K^-\pi^+$. This branching ratio is about 0.037. (Note the decay $D^0 \rightarrow K^+\pi^-$ has recently been observed and is two orders of magnitude smaller.) The D^0 has a mass of 1.8645 GeV so in its rest frame the K and π have momenta of 0.861 GeV/c. We assume the c quark is produced by a thermal source, implying the D^{*+} will have a kinetic energy peaking in the $0.5GeV$ to $1.0GeV$ range. Our signature is thus high momentum $K^-\pi^+$ pair with invariant mass near the D^0 mass and a low momentum π^+ which in combination with the candidate D^0 has an invariant mass near the D^{*+}.

2.2 Minimum Phase Space Containing D^{*+} Decay Products

Requiring the D^0 to have come from a D^{*+} will reduce the possible D^0s by a factor of 3.5. To make this cut worthwhile we have to be able to reduce the background by at least a factor of 10. An excellent discussion of using the D^{*+} decay kinematics in a high energy physics experiment can be found in [1]. In STAR we have a much more serious soft π background, so the emphasis of this note is on the soft π^+ from the D^{*+} decay.

We have made some simple calculations of D^{*+} kinematics to determine what cuts will restrict the phase space while not eliminating the signal. We assume the D^{*+} has no average helicity, which means the π^+ comes out at a random angle in the D^{*+} center of mass. In figures 1 to 4 we plot the laboratory angle between the π^+ and D^{*+} and the π^+ momentum as a function of center of mass opening angle. Plots 1 and 3 are for D^{*+} kinetic energies from 100 MeV to 1 GeV in 100 MeV steps. Plots 2 and 4 are for D^{*+} kinetic energies from 1 GeV to 10 GeV in steps of 1 GeV.

We see that for low $E(D^{*+})$ the π^+ can come out at an appreciable laboratory angle. Even if the D^{*+} has 900 MeV of kinetic energy the π^+ opening angle can be 15° in the lab. A cone of 15° contains $\frac{1}{60}$ of the solid angle and will contain something like 35 particles in a RHIC central Au-Au collision, half of which will have the correct charge. If we make a cut on opening angle that is less than the maximum opening angle we will have very poor efficiency. For example, if we take a cone of 5° we are down to about 4 random particles but only have about 10% of the π^+ we are looking for. It is better to cut in a narrow ring near the maximum lab opening angle. The ring from 15° to 14° will only contain about 4 random particles in our central Au-Au collisions but will still contain about 30% of the π^+ we are looking for.

Our first cut is thus a two dimensional cut in the plane of $\pi^+ D^{*+}$ opening angle versus D^{*+} energy. The efficiency of this cut will depend on the D^{*+} energy unless some care is taken in choosing the width of the angular range as a function of D^{*+} energy. We expect from 1 to 10 random particles to pass this cut for every D^0 candidate with kinetic energy below 1 GeV. This is not a particularly great reduction of candidates. An independent cut can be made in the π^+ momentum versus D^{*+} plane. This will reduce the number of candidate π^+ per D^0 to less than 1. (This momentum cut is equivalent to the ΔM cut discussed in [1].)

2.3 Simple Monte Carlo to Confirm Phase Space Cut

I have written a simple kinematic program to check the efficiency of these cuts. I generated 100,000 D^{*+}s assuming a Maxwell-Boltzmann (non-relativistic) distribution with isotropic direction in the lab. I decay the D^{*+} to $\pi^+ D^0$ isotropically in the D^{*+} frame and the D^0 to $K^-\pi^+$ isotropically in the D^0 frame.

In figure 5 I plot the $\pi^+ D^{*+}$ opening angle versus D^{*+} energy after requiring all three particles were within the SVT coverage. In this plot the D^{*+} temperature was picked to be 500 MeV. I find 63% of the generated events have the K^- and π^+ from the D^0 decay within the SVT coverage and 55% of the events also have the π^+ from the $D^{*+} \rightarrow \pi^+ D^0$ decay within the SVT coverage. Figure 6 is the same plot as figure 5 but only for events which pass both of my two dimensional cuts. About 16% of all generated events pass all the cuts. If I increase the temperature to 1000 MeV the overall efficiency rises to 20%. Adjusting the cuts will affect these efficiencies, but we need to examine the backgrounds first.

3 Backgrounds to D^0s in Central Au-Au Collisions

I have used ten central Au-Au Fritiof events as representative of the background. I use the track information from the GEANT KINE banks. To be considered a candidate the track had to come from the primary vertex and have left a hit in layer three of the SVT. I assume that for all particles below $p = 500 MeV/c$ we can identify K^- and π^+. For higher momenta we must use tracks twice, once as a K and once as a π. In figure 7 I plot the invariant mass of all pairs of tracks that are within 150 MeV of the D^0 mass. We expect a mass resolution of something like $15 MeV$ and our D^0 bin should be something like $\pm 1\sigma$ around the D^0 mass. This gives a background of 2500 candidates per event. Figure 8 shows the invariant mass of all candidates passing both our two dimensional cuts. The background is reduced by an order of magnitude.

I show the effects of my cuts on the π^+ from the D^{*+} decay in figures 9 to 12. Figures 9 and 10 show the $\pi^+ D^{*+}$ opening angle before and after the opening angle cut. Figures 11 and 12 show the π^+ momentum before and after the π^+ momentum cut, both plots after the opening angle cut.

4 Discussion

4.1 Required Number of Events (Assuming D^{*+} temperature of 500 MeV)

First we forget about the D^{*+} and take the background from figure 7. Assume two c quarks per event on average. Our expected observed signal per event would be

$$S_{D^0} = 2 \times 0.7 \times 0.037 \times 0.63 = 0.033$$

Our background per event is

$$B_{D^0} = 2500$$

To obtain a statistically significant signal we would need

$$N > 9 \frac{B_{D^0}}{S_{D^0}^2} = 21 \times 10^6$$

While this seems like a tremendous number of events it is one event per second for two thirds of a year. A 3 σ signal should be quite believable, but all we would then know about D^0 production would be the rate, and that would have large errors.

Including the D^{*+} cut both our background and our signal decrease. Again assuming two c quarks per event we find

$$S_{D^0} = 2 \times 0.2 \times 0.037 \times 0.16 = 0.0024$$

and

$$B_{D^0} = 225$$

requiring

$$N > 10\frac{B_{D^0}}{(S_{D^0})^2} = 400 \times 10^6.$$

This actually is a tremendous number of events. The signal to background ratio with and without the D^{*+} cut is just about the same, but the statistical power is much worse.

It should be emphasized that a small increase in the number of c quarks per event can lead to a significant reduction in the number of events required to observe a signal. Doubling the number of c quarks will decrease the number of events we need by a factor of four.

4.2 We need higher energy D^{*+}s

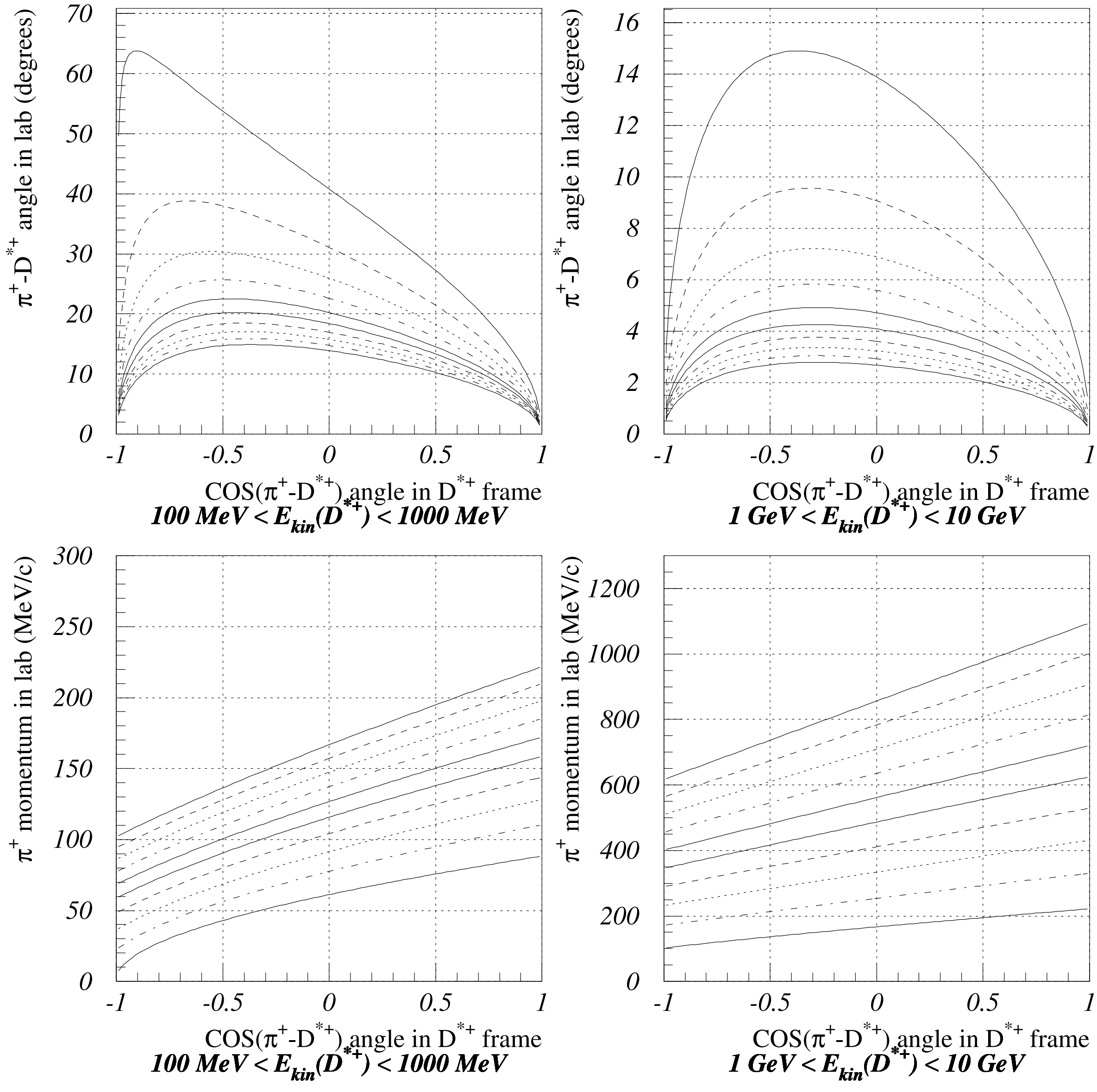
It is clear that for low energy D^0s at mid-rapidity the D^{*+} kinematics is not a big help. This is because the $\pi^+ D^{*+}$ opening angle can be quite large for low energy D^{*+}s. Even when we select a narrow cone we have a non-negligible chance to find a π^+ of the right momentum. One can reduce background by picking a lower multiplicity system. We expect the D^0 combinatorial background to scale with the square of the multiplicity, and the D^{*+} background to scale as the cube of the multiplicity. To make a significant difference in the required number of events to observe a signal we would need a substantial reduction in the multiplicity. This system would probably not be interesting from a plasma point of view, and if it is interesting we will study it in NA49.

The more likely way to reduce the combinatorial background is to pick more energetic Ds. This would allow one to look for a secondary vertex and would also make the $\pi^+ D^{*+}$ opening angle smaller, increasing the efficacy of that cut. At mid-rapidity this is selecting the high energy tail of the D distribution. An alternative is to go to higher rapidity and use a combination of SVT, TPC and external TPCs in reconstructing Ds. It may be useful to put the interaction point near one end of the SVT so the decay products don't have to come out at such a large angle with respect to the beam.

It is worthwhile to follow up on the idea of selecting higher energy Ds. This study should examine both the D^{*+} decay kinematics and the secondary vertex reconstruction of the D^0 decay. It is expected that within a couple of months the STAR event reconstruction chain will be stable enough that studying the secondary vertex reconstruction efficiency, including multiple Coulomb scattering and tracking efficiencies, should be possible.

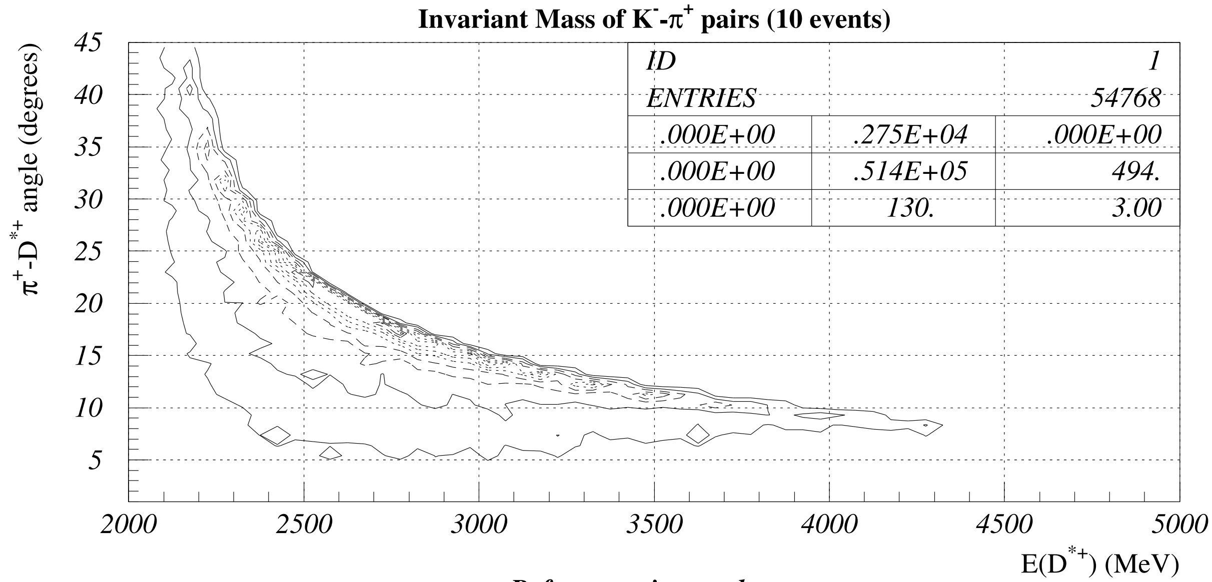
References

[1] D. Cinabro *et al.*, CLEO Collaboration, Phys. Rev. Lett. **72**, 1410 (1994)

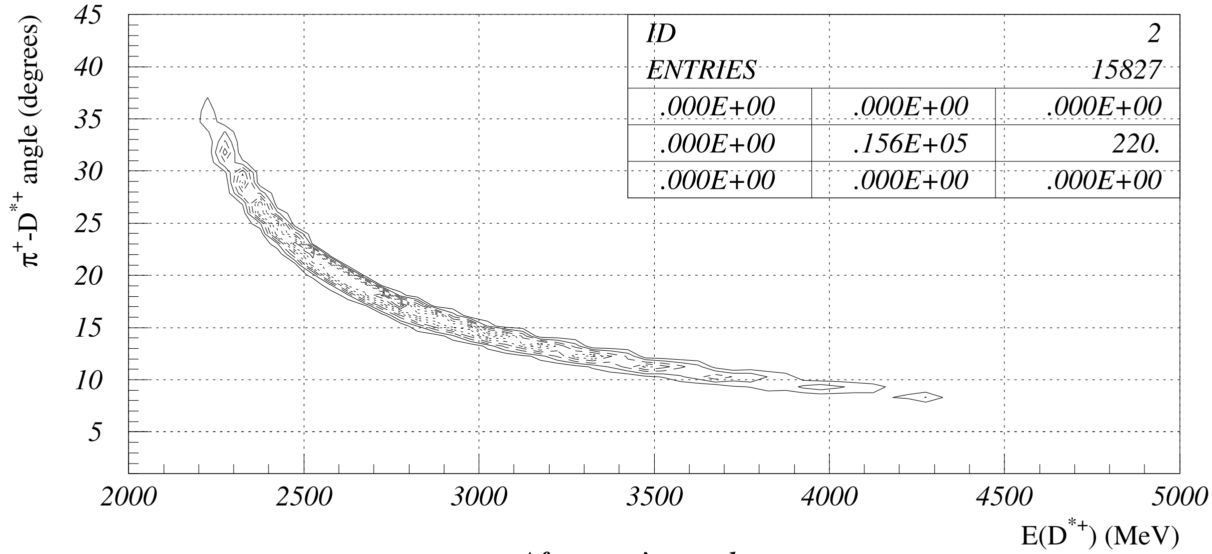


Figures 1 through 4

Figures 1 and 2 show the π^+ D^{*+} laboratory opening angle as a function of the center of mass opening angle. Figures 3 and 4 show the π^+ laboratory momentum as a function of the center of mass opening angle. In figures 1 and 2 the D^{*+} kinetic energy increases in equal steps from top to bottom. In figures 3 and 4 the D^{*+} kinetic energy increases in equal steps from bottom to top.



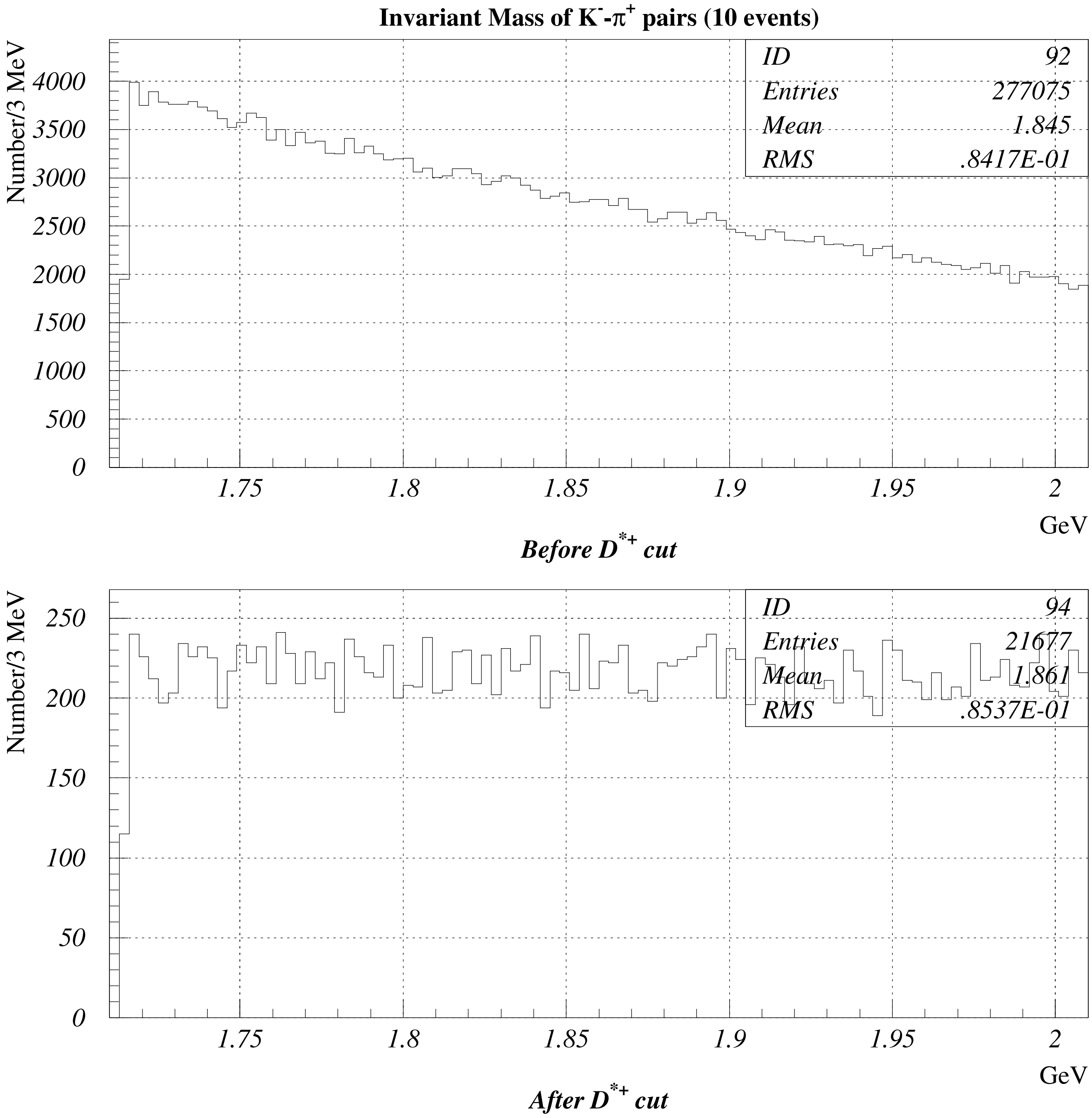
Before opening angle cut



After opening angle cut

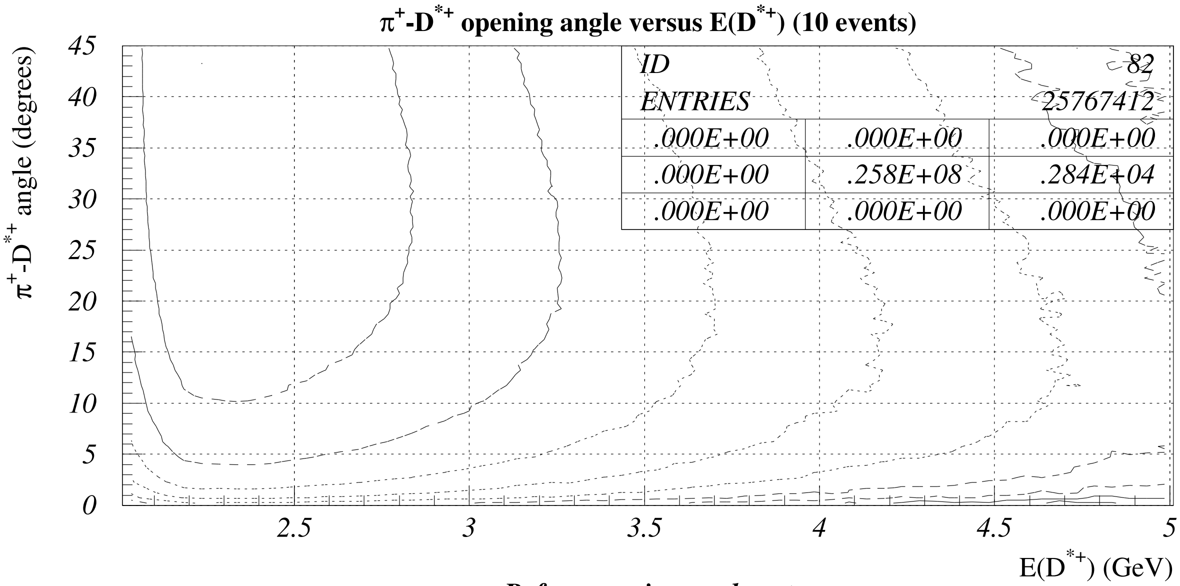
Figures 5 and 6

Figures 5 and 6 show the π^+ D^{*+} laboratory opening angle versus the D^{*+} kinetic energy. This D^{*+} sample was generated assuming a 500 MeV temperature. Figure 5 is for events in which the bachelor π^+ from the D^{*+} decay and the $K^-\pi^+$ from D^0 decay all are within the SVT acceptance. Figure 6 are those events from figure 5 which pass the opening angle cut described in the text.

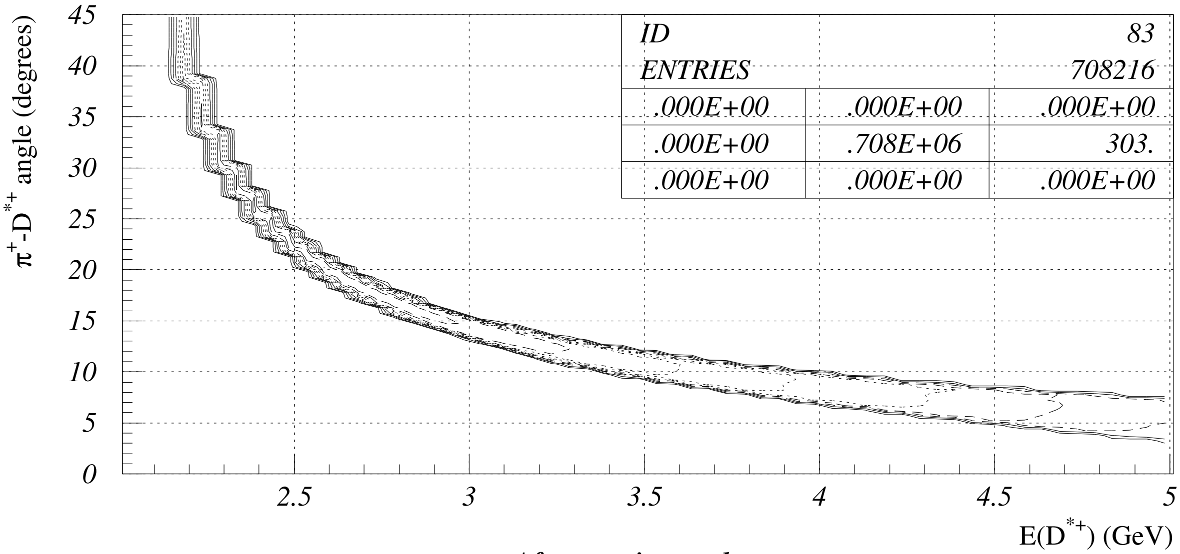


Figures 7 and 8

Figures 7 and 8 show the invariant mass for D^0 candidates from 10 central Au-Au Fritiof events. Figure 7 is for all $K^-\pi^+$ pairs within 150 MeV of the D^0 mass. Figure 8 is the subset of figure 7 candidates that also had a π^+ satisfying the $D^{*+} \rightarrow \pi^+ D^0$ kinematics discussed in the text.



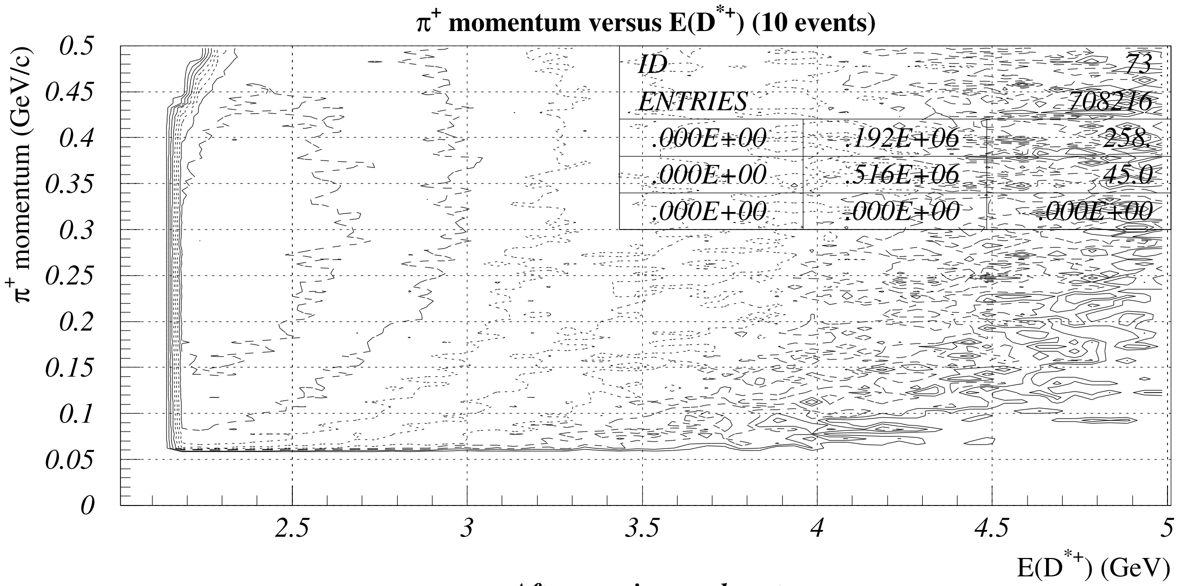
Before opening angle cut



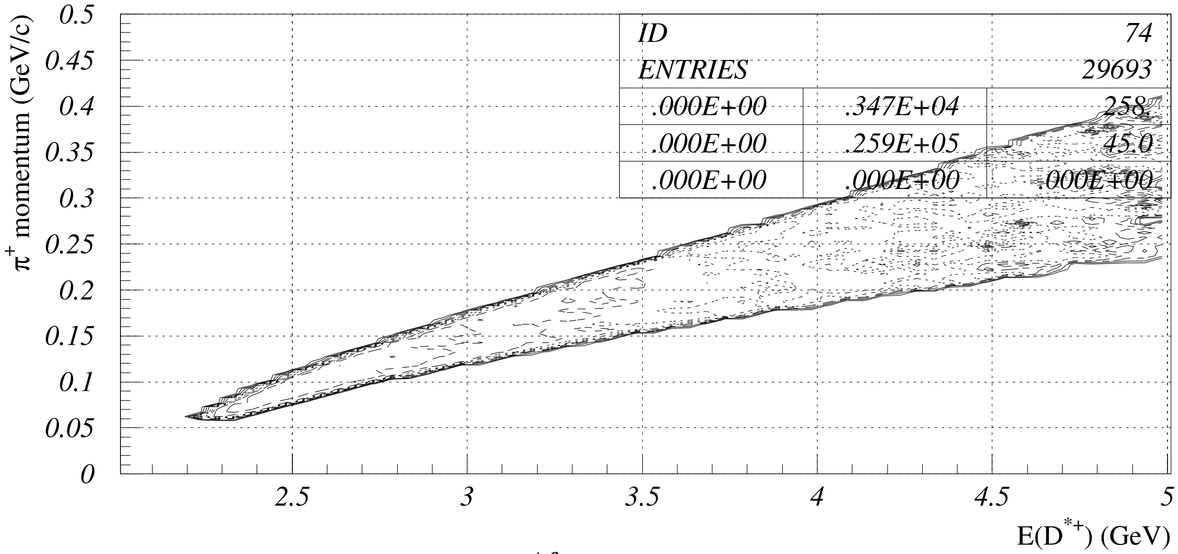
After opening angle cut

Figures 9 and 10

Figures 9 and 10 show the $\pi^+ D^{*+}$ opening angle versus D^{*+} energy for D^0 candidates from 10 central Au-Au Fritiof events. The z-scale is logarithmic. Figure 9 is before the opening angle cut and figure 10 is after the opening angle cut.



After opening angle cut



After momentum cut

Figures 11 and 12

Figures 11 and 12 show the π^+ momentum versus D^{*+} energy for D^0 candidates from 10 central Au-Au Fritiof events. The z-scale is logarithmic. Figure 11 is before the momentum angle cut and figure 12 is after the momentum angle cut. Both figures are after the opening angle cut.