Time of Flight Performance

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1 Introduction

The Time Of Flight (TOF) system in STAR provides particle identification (PID), improving the particle species separation achievable with the baseline detector substantially. In this note the algorithms used in the simulation and reconstruction programs along with their performance are briefly reported.

2 TOF Algorithms

2.1 Monte Carlo

The full STAR Monte Carlo program, based in the GEANT package, is used to simulate the detector response to particles produced in heavy ion collisions. The TOF time resolution is 0 according to the results obtained in a test beam [1] using the expression: $\sigma_t = \alpha\sqrt{z_t}$, where z_t stands for the distance from the particle impact to the phototube cathode and $\alpha = 30$ ps/$cm^{1/2}$.

2.2 Reconstruction

The information resulting from the Monte Carlo simulation is run through the STAR analysis shell (TAS). The PID is 0 by the CPI module and can be summarized in the following steps:

1. Extrapolation of tracks out to TOF barrel and back to the vertex. Tracks have to fulfill the following conditions to be further considered in the analysis:
    (a) Extrapolate to the TOF.
    (b) Originate at the main vertex.

[1] ***In-beam tests of proximity mesh dynode tubes for the STAR TOF subsystem***, S. Ahmad, B. E. Bonner, W. Gere, G. S. Mutchler, P. Rambo, S. Toshkov, E. Platner, H. J. Crawford and J. M. Engelage, Nuclear Instruments and Methods **A 330**, 416 (1993).

(c) Hit a TOF counter that has fired.

2. The length of the track from the interaction point to the TOF, L, is calculated.

3. The time provided by the TDC is corrected to take into account the light trajectory inside the scintillator. The corrected time, t_c, is obtained from the raw time, t_r, through the expression: $t_c = t_r - z_t v_s$ where a value v_s=75 ps/cm is obtained from the beam tests.

4. The particle velocity is obtained using the equation:

$$1/\beta = ct_c/L = c(t_r - z_t v_s)/L \quad (1)$$

As can be noted, the ability to separate the different particle species depends on the accuracy to determine the various quantities in equation (1). In the following section, resolution of some relevant quantities are presented.

3 Resolutions

Figure 1 shows the distance between the reconstructed impact using the TPC tracks and the real particle hit obtained from Monte Carlo information. The first plot presents the distance in rϕ, ϕ being the azimuthal angle. The second distribution represents the distance along the axis parallel to the beam, z. Both distributions are fitted with a double gaussian. The width of the narrower gaussian, taken as the resolution, is 0.21(0.24) cm for the rϕ(z) distribution.

Figure 2 depicts the difference between the corrected reconstructed time, t_r, and the real time obtained from the Monte Carlo. The distribution is fitted with a gaussian. The width of the distribution is 71 ps.

Figure 3 shows the 0 between the reconstructed track length and the real track length from the Monte Carlo. The reconstruction algorithm assumes that all tracks come from the main vertex. The Monte Carlo length is taken from the track origin to the back plane of the TOF. Reconstructed length is taken from (0,0) in the plane perpendicular to the beam to the front plane of the TOF. This difference in the calculation of the reconstructed and simulated lengths explains why the distribution is not centered at zero. The resolution in the track length determination is 0.8 cm.

4 Particle Identification Capabilities

In the base line detector, PID is done using the fact that pions, kaons, and protons are not minimum- ionizing in the energy range of the STAR acceptance and thus exhibit different energy loss while traversing the SVT and the TPC. Figure 4.a shows the expected energy loss curves as measured in the TPC in the momentum range 0-3 GeV/c for pions, kaons and protons. The plots in figure 4.1 were obtained by running the STAR GEANT Monte-Carlo program to simulate detector response and energy loss processes in the detector. From this figure, one can see that it is possible to distinguish kaons and pions below 600 MeV/c knowing their momentum and energy loss.

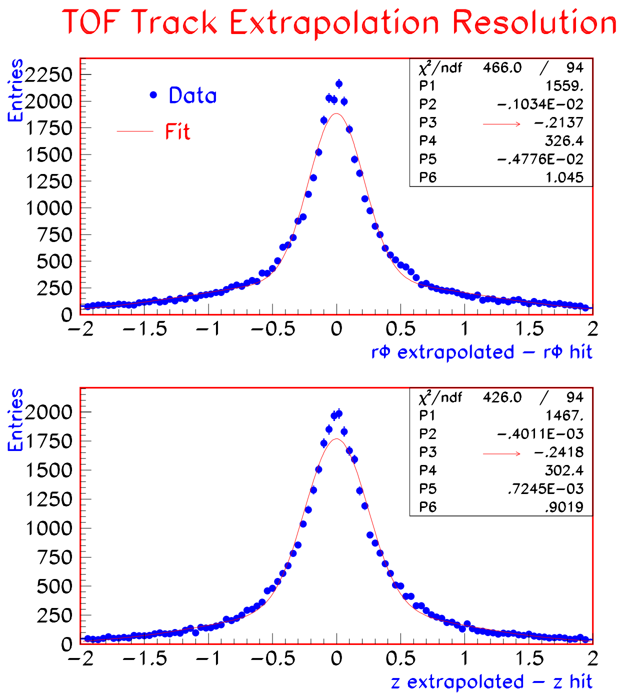

Figure 1: The distance between the reconstructed impact and the real hit from Monte Carlo (a) in rϕ and (b) along the beam axis (z). Reconstructed impacts are obtained from extrapolation of TPC tracks. The line is a double gaussian fit to the distribution.

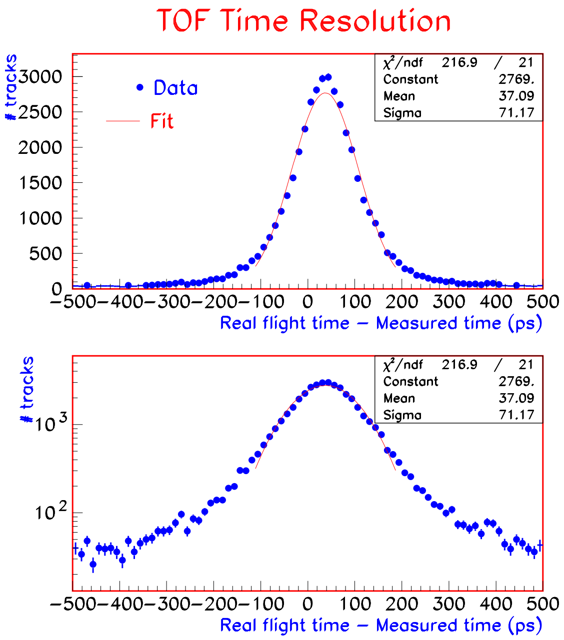

Figure 2: The difference between the corrected reconstructed time and the real impact time obtained from Monte Carlo. The upper(lower) plot is in linear(log) scale. The line represents a gaussian fit

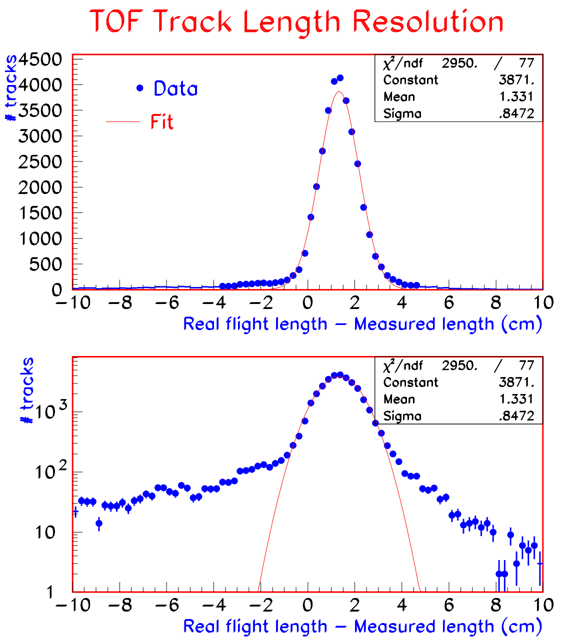

Figure 3: The difference between the reconstructed length and the real track length obtained from Monte Carlo. The upper(lower) plot is in linear(log) scale. The line represents a gaussian fit

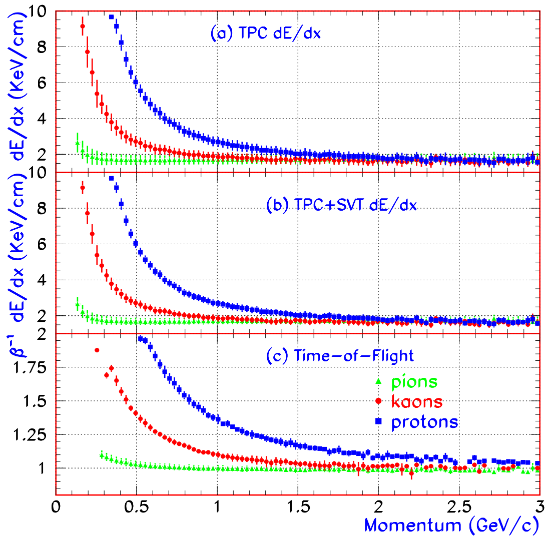

Figure 4: Particle identification distributions for a) dE/dx in the TPC alone, b) dE/dx for TPC+SVT (see text for explanation), and c) Time-of- flight information. Plotted is the mean value of the measured quantity as a function of particle momentum. The error bars are one standard deviation of the distribution at the measured momentum.

To perform the PID from the TPC energy loss curves, functions of the Bethe-Bloch form (i.e., β^{-2}) are fit to these curves. From these functions one can calculate the difference between the average expectation for a pion, kaon, etc. at that momentum, and the measured energy loss for a given particle. Knowing the width of the dE/dx distribution, from this difference a probability that a given particle belongs to each of the three species can be derived. At low momenta, where the pion/kaon separation is large, it is sufficient to take the highest probability hypothesis as the PID. Above 350 MeV/c, however, the pion and kaon dE/dx distributions overlap and the contamination (i.e. pions misidentified as kaons and vice- versa) becomes large. One can recover better efficiency while maintaining low contamination by allowing more kaons from the high dE/dx side of the distribution to be tagged as kaons and more pions from the low dE/dx side of the pion dE/dx distribution to be tagged as pions, while cutting very hard on dE/dx values which lie in the overlap region. Using a method similar to this, one can get the efficiency and contamination distributions shown in Figure 5 a and b, plotted as a function of p_t. From these figures we see that proton identification from energy loss in the TPC is feasible to $p_t \approx$1.2 GeV/c, while kaon identification is only feasible to $\approx$600 MeV/c.

Particles also experience energy losses while traversing the Silicon Vertex Tracker (SVT). The measured energy losses in this detector can be used as in the TPC for PID. Figure 4.b shows the TPC dE/dx distributions with the resolution improved by $\sqrt{2}$, which would be the effect on the PID capability if the SVT dE/dx information were equal to that of the TPC. This is an optimistic view given the fact that the momentum and dE/dx resolution in the SVT are likely to be worse than in the TPC. From the

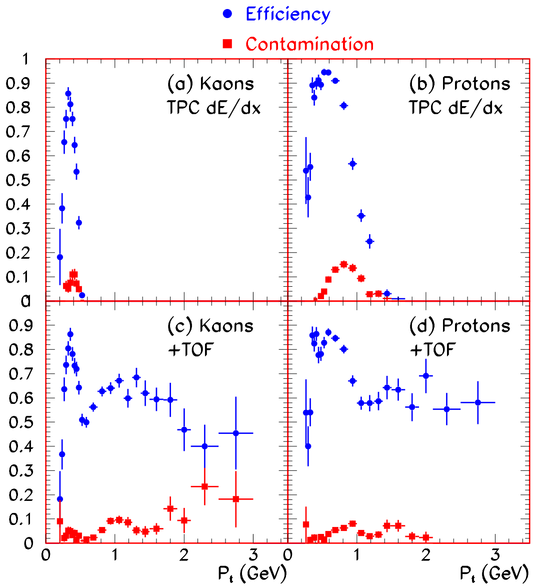

Figure 5: Efficiency and contamination levels for particle identification plotted as a function of transverse momentum for kaons and protons. Efficiency is defined as the total number of correctly tagged particles divided by the total generated in the Monte-Carlo. Contamination is defined as the number of incorrectly tagged particles divided by the number of correctly tagged particles. Figures (a) and (b) are for TPC dE/dx particle identification only, and (c) and (d) are obtained with combined dE/dx and time-of-flight information.

	Contamination <10%	Contamination <50%
dE/dx π/K	<0.35	<0.65
+TOF π/K	<1.5	<2.0
dE/dx K/p	<0.7	<1.5
+TOF K/p	<2.5	<3.0

Table 1: Upper limit in the 0 range where particle separation is possible with TPC dE/dx and TOF.

curves in Figure 4.b, we see that the separation for the different species is only slightly better, improving the upper limit for separation by ≈100 MeV/c.

The addition of a TOF system to the STAR detector will enhance PID capability in the momentum range covered by dE/dx in the TPC, and extend the useful range to 3 GeV/c. Figure 4.c shows $1/\beta$ vs. p for pions, kaons, and protons. The excellent separation for the different particle species allows one to identify the particle at much higher momenta than using dE/dx alone.

PID from the TOF information is done in a similar way to that described above for the dE/dx information. Figures 5 (c) and (d) show efficiency and contamination for a combined TOF and dE/dx PID as a function of p_t.

Table 4 presents the momentum ranges where the different species can be separated with TPC dE/dx and with TOF. Two levels of maximum allowed contamination are considered.