High p_T Physics with the TOF

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1 Physics Motivation

The search for the Quark Gluon Plasma (QGP) is one of the main purposes of the Relativistic Heavy Ion Collider (RHIC) being built at BNL. An intense research program has recently been carried out in relativistic heavy ion collisions, and number of QGP signatures have been proposed. Some of these signatures, like strangeness enhancement and the J/Ψ suppression, were observed experimentally. After the initial excitement created in the community by these observations, many models that do not include QGP formation were shown to explain the data. As a consequence, the importance of understanding the properties of the hadronic matter before making any statements concerning the creation of the QGP was realized. The determination of the temperature, density, transverse and longitudinal flow and source volume reached in the collision are essential ingredients to understand the dynamics of the hadronic matter.

1.1 Transverse Mass

The temperature of a static thermalized particle source can be obtained from the $(1/m_T)dn/dm_T$ distribution of the emitted particles. This simple picture is modified in reality by the presence of resonances and transverse flow. Resonances tend to modify the m_T spectrum at low momentum, especially for light particles, like pions, while transverse flow increases the transverse mass. In this context, the measurement of the m_T spectrum for pions, kaons and protons in a large m_T range is very important in order to understand the characteristics of the hot hadronic matter produced after the collisions of heavy ions for pions, kaons and protons in a large m_T range [1].

[1]For an analysis of $(1/m_T)dn/dm_T$ data to extract temperatures and flow velocities see, e.g. E. Schnedermann, J. Sollfrank and U. Heinz, Phys. Rev. **C 48** (1993) 2463.

In STAR, the meaningful m_T range for pions, kaons and protons in which precise measurements are available is extended significantly by the inclusion of the TOF system. This is illustrated in Figure 1, where $(1/m_T)dn/dm_T$ is plotted for the different particle species with and without the information provided by the TOF system. As apparent from this Figure, the TOF system expands the measurable range of m_T considerably. It is important to note that the slopes of these distributions vary with m_T. The temperatures extracted from the inverse slopes of these distributions may therefore be difficult to interpret in the absence of the TOF information.

1.2 Particle Correlations

Particle correlation measurements have been widely used to extract the source size at freeze-out. Most commonly pions are used to form the interferometric correlation functions. However, the presence of abundant resonances tend to distort the source radius extracted from the pion correlation, 0 for low momentum pairs. The situation improves when analyzing kaon correlations and/or high momentum pairs.

Kaon interferometry has also being used to deduce the size of the kaon emitting source. Kaons are less sensitive to resonances and the lifetime of the source can be extracted from it [2]. In addition the study of interferometry as a function of transverse momentum provides useful information about particle flow. 0, the presence of QGP droplets in hadronic matter has been predicted to produce characteristic features in the kaon correlation function [3]. The presence of the TOF system will significantly extend the p_T range where kaon interferometry can be studied.

The ability of the TOF to study kaon interferometry has been 0 with the full Monte Carlo simulation in STAR. Special events with 1000 correlated kaon pairs with a flat p_T distribution and a momentum difference between 0-300 MeV were generated and run through the Monte Carlo and reconstruction chains.

The correlation distribution was studied as a function of the $Q = \sqrt{-qq}$, q being defined as $q = q_1 - q_2$, where q_i is the 1 of particle i, i=1,2. The uncorrelated distribution was built using tracks belonging to different events. The correlation function was obtained by dividing the correlation distribution by the uncorrelated one.

Figure 2 shows the correlation functions obtained after reconstruction in different bins in p_T of the particle pair. Without the TOF system only pairs with a p_T below 1 GeV can be reconstructed. With the TOF the correlation function can be obtained in different p_T bins as shown in the plot. The width of the reconstructed correlation function increases when going to large p_T, reproducing the behavior of the input correlation function.

1.3 Strangeness Enhancement

The K/π ratio does not by itself provide a signature for QGP formation. However, it has been proposed that the variation of this ratio with temperature and chemical

[2] J.Boltz et al., Phys. Lett. **B 300** (1993) 404.
[3] S.Pratt et al., Phys. Rev. Lett. **68** (1992) 1109.

potential in the presence of a QGP could be unique [4]. A very precise study of the ratio as a function of transverse momentum, which can only be achieved with the information of the TOF system, will shed light on the origin of possible enhancements to this ratio.

The production cross section of the ϕ-meson can be measured inclusively from the decay $\phi \rightarrow K^+K^-$. The measurement of the yield of the ϕ, which is an ss pair, places more stringent constraints on the origin of the observed flavor composition than the K/π ratio. The production rate is also expected to be extremely sensitive to changes in the quark masses [5], due to the chiral transition at high energy densities which is predicted by lattice QCD calculations. Moreover shifts in the ϕ-meson mass and width have been predicted in a hot hadronic medium [6] In fact the E859 Collaboration has reported a shift in the ϕ-meson as a function of reaction centrality [7]. In order to understand these effects a careful and systematic study of the ϕ production is needed. The particle yield as a function of p_T is one of most basic tools to understand the production mechanism of any particle.

The ϕ p_T distribution with/without the proposed TOF system is shown in Figure 3. As can be observed, studying the p_T dependence without the TOF system appears to be problematic.

1.4 Jet quenching

When the QGP is formed in a heavy=ion 0, most of the particles produced in this new state of the matter must undergo freeze-out and hadronization processes before reaching the experimental apparatus. Unfortunately, most of the particles that are detected may have lost all memory of the primordial QGP. In principle, only jets and leptons are predicted to retain any memory of the transient QGP. The study of jets is 1 interesting since RHIC will be the first heavy ion machine with a high enough energy to produce them. However the experimental challenges that jet detection presents in AuAu collisions are substantial.

The TOF system can provide a unique tool to study jet quenching by measuring the ratio of high p_T proton/antiproton spectra. Protons are mainly produced in quark jets, while antiprotons are predominantly generated in gluon jets. Since gluons lose more energy in the QGP than quarks, p and $\bar{p}$ should be affected differently. Therefore, modified p_T spectra are expected at 1 where the production mechanism is the same for both particles [8]. This effect is illustrated in Figure 4 obtained with the Monte Carlo program HIJING which includes a jet quenching algorithm [9]. The plot shows the ratio

$$(dn/dp_T)_{AuAu}/(dn_dp_T)_{pp}$$

[4]S.Uddin and C.P. Singh, Phys. Lett. **B 278** (1992) 357.

[5]R.D. Pisarski and F. Wilczek, Phys. Rev. **D 29** (1984) 338; T. Hatsuda and T. Kunihiro, Phys. Lett. **B 185** (1987) 304; E.V. Shuryak, Nucl. Phys **A 525** (1991) 3c.

[6]M. Asakawa, C.M. Ko (Texas A-M), 1994. Nucl. Phys. **A 572 (1994) 732.**

[7]Y. Wang et al. ***Multiplicity Dependence of the Mass of the ϕ-meson from Si+Au Collisions at 14.6 GeV/c*** in Quark Matter '95, January 95, 0 (California).

[8]X.-N. Wang to be published, private communication.

[9]X.-N. Wang and M. Gyulassy, Phys. Rev. **D 44** (1991) 3501.

for protons and antiprotons with and without jet quenching, where $(dn/dp_T)_{AuAu}$ and $(dn_d p_T)_{pp}$ are the number of particles produced in central AuAu and proton-proton collisions respectively. Jet quenching is reflected mainly in the antiproton ratio.

Other mechanisms due to the presence of QGP have been also proposed for the suppression of high p_T nucleons [10]. 0 processes have been predicted to suppress intermediate-p_T antiproton production in heavy ion collisions. This could be used as a probe of the space-time evolution of the reaction [11]. The TOF system will allow the study of such antiproton spectra, which are potentially very interesting.

1.5 Open Charm

The possibility of using the TOF in combination with a vertex detector is investigated in this section. $D^0(D^{\pm})$ mesons branching ratio into charged kaons is around 50%(30%). Due to the high D mass these kaons tend to have a large p_T. In the present STAR design only the TOF will be able to identify them.

Kaons produced in a sample of 850 Hijing central AuAu were selected and split into primary and secondary from charm decays (charm kaons). Then they were run through the full Monte Carlo and simulation chains. The present study considers a production of 1(0.5) $D^0(D^{\pm})$ per unit rapidity.

The minimum distance of the reconstructed tracks to the main vertex was calculated for both kaon samples. We will refer to this quantity as offset. Because of technical difficulties a vertex gas detector was consider instead of the SVT. The main difference between both detector is the very low multiple scattering in the gas detector. However this difference should be smaller for large momentum particles.

Figure 5.a and b show the offset distribution for kaons with no p_T cuts and with p_T >1.3 GeV respectively. As can be seen the use of a high pt cut reduces the background from primary kaons by nearly two orders of magnitude. This cut in high pt kaons **can only be achieved with the TOF system**. When high p_T kaons are used a signal to background ratio of 1/4 is obtained for particles with an offset larger than 300 microns. These results seem to indicate that a D production measurement could be possible using the TOF system combined with a light vertex detector. Even if the results look promising, a careful understanding of the tail will be necessary with real data. However such an understanding at the level of 10% should be achievable by comparing different reactions, like pp, SiSi, AuAu, etc. Nevertheless further studies are necessary to reach a more definite conclusion.

[10]W.Geist, Phys. Lett. **B 211** (1989) 233.
[11]S.Gavin et al., Phys. Lett. **B 234** (1990) 175.

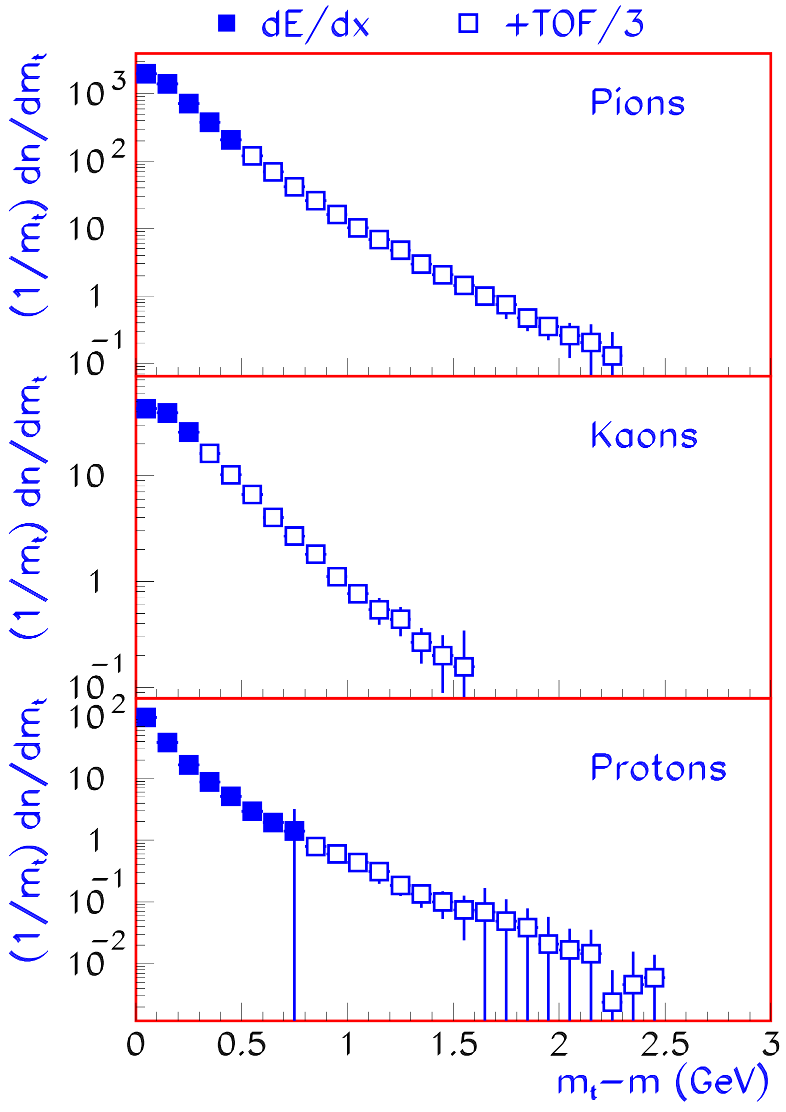

Figure 1: Invariant cross sections versus the transverse mass for pions, kaons and protons from the full simulation of the STAR detector for central AuAu collision using the Hijing model for particle production. The shaded points show the region that can be measured using only dE/dx from the TPC for PID. The open points are obtained with inclusion of the TOF system.

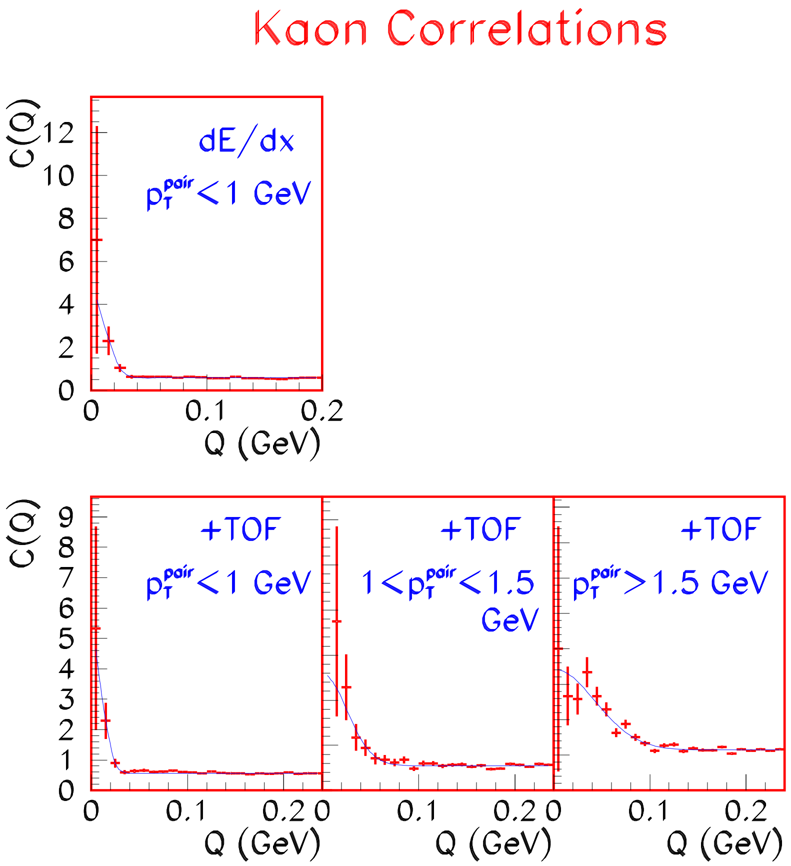

Figure 2: Kaon correlation functions in three p_T^{pair}, (transverse momentum of the particle pair) bins from the full simulation of the STAR detector using special events with correlated kaons for particle production. Correlations with $p_T^{pair} > 1$ GeV cannot be obtained with only the TPC. The upper plot is obtained using only the dE/dx from the TPC for PID. The lower plots are obtained with inclusion of the TOF system.

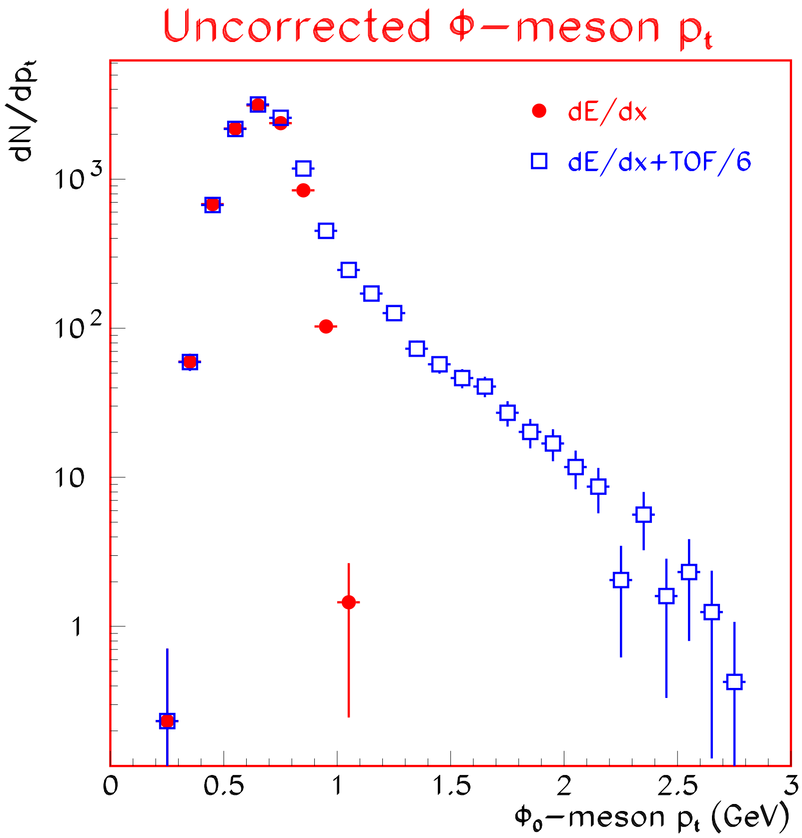

Figure 3: The ϕ meson p_T spectrum using only dE/dx from the TPC (solid points), and including a one-sixth patch of the TOF system (open points). The distributions are not corrected for the detection efficiencies or the geometrical acceptance.

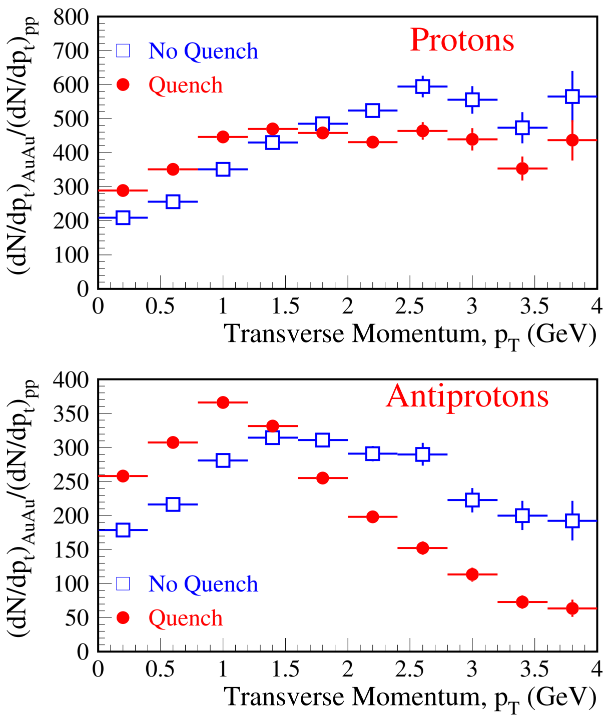

Figure 4: Particle production ratio in Central AuAu relative to proton-proton collisions as a function of pt for protons and antiprotons obtained using HIJING with (solid circles) and without (open squares) jet quenching.

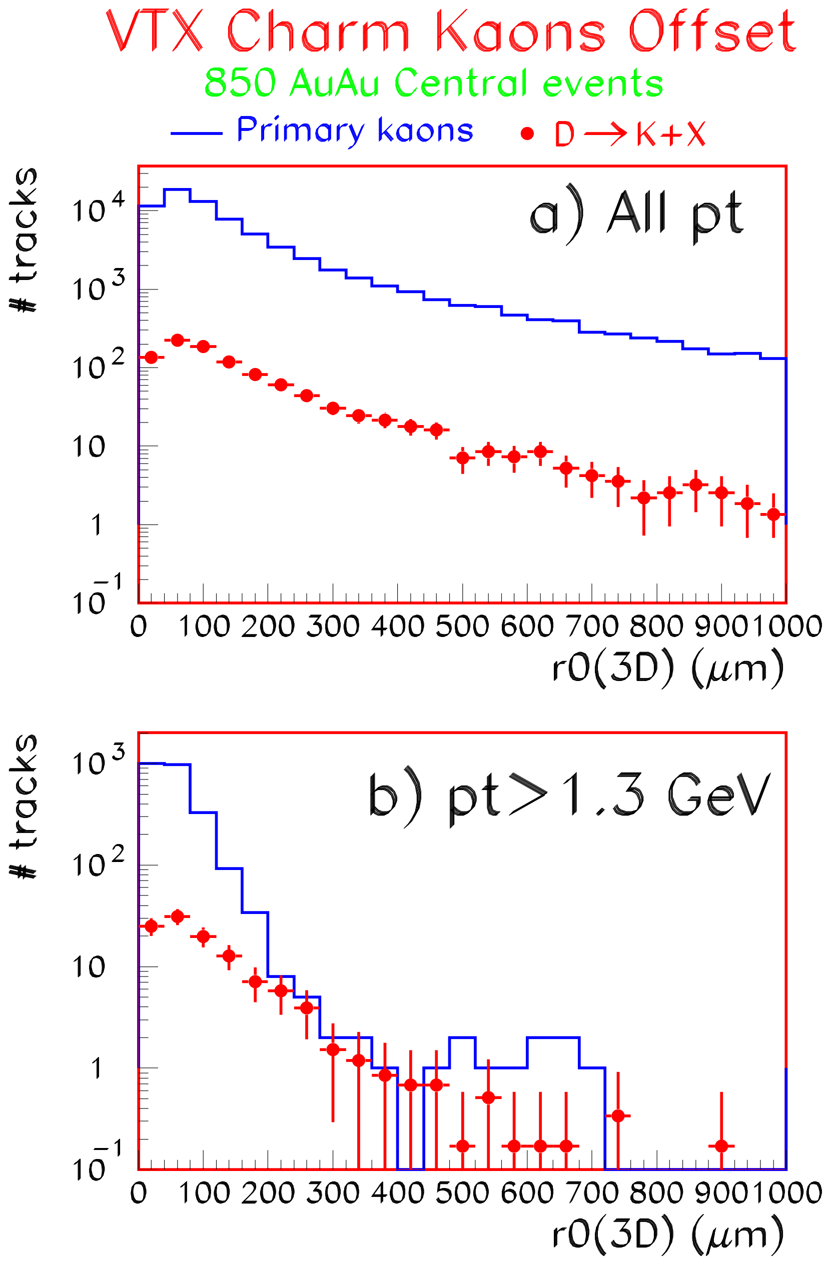

Figure 5: VTX Offset distributions of primary and charm (from D decay) Kaons (a) with no p_T restriction and (b) with p_T >1.3 GeV. The plots were obtained using the STAR full Monte Carlo and reconstruction chains for 850 Hijing central AuAu events.