SYNOPSIS

At very high energy densities, exceeding approximately 1 GeV/fm$^3$, quantum chromodynamics predicts a phase transition from ordinary hadronic nuclear matter to a new state of matter where the degrees of freedom are quarks and gluons. Matter at such high energy density can be produced in laboratory conditions by colliding heavy nuclei at relativistic energies at the Relativistic Heavy Ion Collider (RHIC) and recently at the Large Hadron Collider (LHC). This state of matter exhibits very strong coupling between its constituents and is thus called the strongly coupled Quark-Gluon Plasma (sQGP).

The quark gluon matter presumably with local thermal equilibrium expands hydrodynamically and undergoes a phase transition to hadronic matter which further cools till the multiple scatterings among particles are sufficient to keep them as one system. The hadrons then decouple from the system and their spectra would reflect the condition of the system at the time of freeze-out. Hadrons (pions, kaons and protons) form the bulk of particles produced and are usually the first and easiest to be measured in a heavy ion collision experiment. Traditionally, statistical model has been used at SPS and RHIC energies to infer the conditions at freezeout using measured hadron ratios as input. Alternatively one can consider full transverse momentum ($p_T$) spectra of hadrons in heavy ion collisions. The bulk and collective effects show up in the low and intermediate $p_T$ regions of hadron spectra while the high $p_T$ region above 5 GeV/$c$ consists of particles from jets which are produced in hard interactions.

Experimental measurement of strange meson

The particle spectra in heavy-ion collisions are modified due to presence of the medium and are quantified by the “nuclear modification factor” ($R_{AB}$) defined as:

$$R_{AB} = \frac{d^2N_{AB}/p_T dydp_T}{N_{\text{coll}} \times d^2N_{pp}/p_T dydp_T},$$

(1)
where the numerator is the of particle production in $A+B$ (heavy ion) collisions, measured as a function of $p_T$ and rapidity ($y$), $d^2N_{pp}/p_Tdydp_T$ is the yield of the same process in $p+p$ collisions and $N_{coll}$ is the number of nucleon-nucleon collisions in the $A+B$ system. $R_{AB}$ different from unity is a manifestation of medium effects.

In central Au+Au collisions at RHIC, $R_{AB}$ of hadrons reaches a maximum suppression of a factor of $\sim 5$ at $p_T \sim 5$ GeV/c. The high $p_T$ suppression is found to be independent of the particle type, mesons or baryons, and their quark flavor content. In the intermediate $p_T$ range ($2 < p_T < 5$ GeV/c), mesons containing light quarks ($\pi$, $\eta$) exhibit suppression, whereas protons show very little or no suppression. Measurements of particles with different quark content provide additional constraints on the models of collective behavior, parton energy loss and parton recombination. Experimental measurements of particles containing strange quarks are important to find out whether flow or recombination mechanisms boost strange hadron production at intermediate $p_T$ and to understand their suppression at high $p_T$. In heavy ion collisions, the $\phi$ meson shows at high $p_T$ the same suppression as particles containing only $u$ and $d$ quarks, however at intermediate $p_T$ it is less suppressed than the $\pi$ meson. On the other hand, the $\eta$ meson, which has a significant strange quark content, is suppressed at the same level as $\pi$ meson in the $p_T$ range from 2–10 GeV/c.

The main part of this thesis concentrates on the measurements of the nuclear modification factor of strange meson $K^{*0}$ at PHENIX experiment. The $K^{*0}$ meson spectra for different centralities are measured in the $p_T$ range from 1.1 GeV/c up to 8 GeV/c in Cu+Cu collisions via $K^{*0} \rightarrow K^+\pi^-$. The measurements extend the momentum coverage of the previously published results by the STAR collaboration. These measurements are further combined with the $K^0_S$ meson ($K^0_S \rightarrow \pi^0(\rightarrow \gamma\gamma)\pi^0(\rightarrow \gamma\gamma)$) measurements over the $p_T$ range of 3–12 GeV/c. This gives strange meson $R_{AB}$ over a wider $p_T$ range.

The PHENIX detector consists of global, tracking and PID detectors. The event information is obtained from the Beam Beam Counters (BBC), located at $|\eta| < 0.35$ and covering $2\pi$ in azimuth. The track reconstruction and momentum determination are done with the
help of the Drift Chambers (DC) and first layer of the Pad Chambers (PC). The second and third layers of PC help to suppress contribution of the secondary tracks originating from the decay of long-lived particles or from the interaction of tracks with the detector material. The Time of Flight (TOF) detector identifies charged hadrons.

The $K^{*0}$ meson invariant mass is reconstructed via $K^{*0} \rightarrow K^\pm \pi^\mp$ which has a branching ratio of $\sim 67\%$. The Minimum Bias triggered samples are used for the $K^{*0}$ meson study. The charged kaons and pions are identified by the TOF in PHENIX. The TOF detector has a small acceptance and has limitation in identification of particles. This limitation leads to the measurement of $K^{*0}$ in low $p_T$ region. To increase the extent of measurement up to high $p_T$, unidentified tracks with opposite charge are also included in the analysis. The unidentified tracks are required to have associated hits in PC3 and EMCal to do away the contribution originating from secondary tracks. Depending on the track selection criteria, three different techniques are used to reconstruct the $K^{*0}$ invariant mass distribution.

1. **Fully Identified**, where both the tracks are identified as kaons and pions via the TOF.
2. **Kaon Identified**, where one of the tracks is identified as kaon via the TOF and the other PC3-matched track is given the mass of pion.
3. **Unidentified**, where both the tracks are PC3-matched tracks. The invariant mass spectra is obtained by the combinatorial method. The total invariant mass distribution for charged kaon-pion consists of the both signal and background. The uncorrelated background is removed by the event-mixing technique. The correlated part of the background is mainly dominated by the mis-identified track pairs. Two of the most dominating processes are: $\phi \rightarrow K^+K^-$ and $K^0_S \rightarrow \pi^+\pi^-$. These are estimated and removed from the obtained invariant mass spectra. The contribution of residual background is also removed and the raw yield for $K^{*0}$ is obtained by bin-counting. The raw yield is then divided by acceptance to get the corrected yield.

The invariant transverse momentum spectra and nuclear modification factors of $K^{*0}$ are obtained for different centralities in the Cu+Cu system and are combined with the
\(K^0\) meson results. In the Cu+Cu collisions system, no nuclear modification is observed in peripheral collisions within the uncertainties of the measurement. In central Cu+Cu collisions both mesons show suppression. In the range \(p_T = 2-5\) GeV/c, the strange mesons show an intermediate suppression between the more suppressed \(\pi^0\) and the nonsuppressed baryons. This behavior provides a particle species dependence of the suppression mechanism and provides additional constraints to the models attempting to quantitatively reproduce nuclear modification factors. At higher \(p_T\), all particles, \(\pi^0\), strange mesons and baryons, show a similar level of suppression.

**Systematics of hadron spectra in \(p+p\) and heavy-ion collisions**

Phenomenological studies are done for the charged pion transverse momentum spectra for different collisional energies and also for different event-multiplicities (at LHC energies) in \(p+p\) collisions using Tsallis distribution. The Tsallis distribution describes a system in terms of two parameters; temperature and \(q\) which measures deviation from thermal distribution. It has been shown that the functional form of the Tsallis distribution in terms of parameter \(q\) is the same as the QCD-inspired Hagedorn formula in terms of power \(n\). Both \(n\) and \(q\) are related and describe the power law tail of the hadron spectra coming from QCD hard scatterings.

The Tsallis parameter \(n\) decreases with increasing \(\sqrt{s}\) and starts saturating at LHC energies. The value of \(T\) also reduces slowly from SPS energies to LHC energies. It means that the spectra at SPS energies have large softer contribution and as the collision energy increases more and more contribution from hard processes are added. The \(p_T\) integrated pion yield increases with increasing \(\sqrt{s}\) and becomes 10 times when going from SPS to highest LHC energy. The Tsallis parameters are also obtained as a function of event multiplicity for all three LHC energies which can be described by the same curve. The variation of \(n\) and \(T\) as a function of multiplicity is very similar to the variation which we find as a function of \(\sqrt{s}\). It means that events with higher multiplicity have larger contribution from hard processes.
The value of $n$ for high multiplicity events at 7 TeV is $\sim 4$ which is depictive of production from point quark-quark scattering. The $p_T$ integrated pion yield distribution for the three LHC energies shows that as the energy increases, more and more high multiplicity events are added in the sample with mean of the distribution shifting towards higher multiplicity.

The transverse momentum spectra of charged pions measured in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are analysed using the modified Tsallis distribution. All the spectra used in this analysis are well described by this distribution. The parameter $q$ of the modified Tsallis distribution suggests similar thermalization characteristics for systems at RHIC and LHC energies. The kinetic freeze-out temperature and transverse flow velocity are extracted from pion $p_T$ spectra. The kinetic freeze-out temperature is also obtained from a model independent method using the measurement of HBT radii and particle multiplicity.