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Present and Future of QGP Research in High Energy Heavy Ion Collision Experiments

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As a part of the programme to explore the matter under extreme conditions in high energy heavy ion collisions, experiments at LHC have collected data in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. Results from p-p and p-Pb collisions at LHC at different centre of mass energies have been used as references to the results from Pb-Pb collisions. These results are further compared with detailed and elaborate measurements performed with Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC. The basic properties of the matter created at LHC have been found to be similar to that at RHIC, e.g., the matter in Pb-Pb collisions at LHC also behaves like a strongly coupled partonic liquid as inferred for the Au-Au collisions at top RHIC energy. However, with higher collision energy at LHC, a new set of probes in heavy ion collisions like jets and higher states of quarkonia open up new avenues in detailed understanding of the properties of the matter. Recent findings of the collective behaviour at p-Pb collisions at LHC however questions the existing theoretical understanding of the medium formation in p-Pb and Pb-Pb collisions. RHIC and LHC explore the high temperature and nearly zero net-baryon density region of the phase diagram, another extremes are being explored at the beam energy scan (BES) programme at RHIC and the upcoming CBM experiment at FAIR. The BES-I results demonstrate that at lower $\sqrt{s_{NN}}$, several findings that were interpreted as the signatures of the formation of de-confined partonic matter at top RHIC energy were found to be absent. The interpretation of these results require thorough understanding of the role of baryons in the matter created at lower $\sqrt{s_{NN}}$. The CBM experiment at FAIR aims to explore the matter created at low collision energy by the use of bulk and rare probes.

Key Words : QGP; High Energy Heavy Ion Collisions; LHC; RHIC; CBM

Introduction

Since the beginning of the high energy heavy ion collision programme at AGS, it has been a long way through experimental and theoretical investigations on the search of creation of quark gluon plasma (QGP), the de-confined state of strongly interacting matter. There were strong indications that a state of high temperature deconfined medium might have been formed in central A-A collisions at SPS energy, however, an

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order of magnitude increase in the centre of mass energy at RHIC has helped to form the matter in central A+A collisions with almost no net baryons at the midrapidity region. Another order of magnitude increase in the $\sqrt{s_{NN}}$ at LHC creates a system that could truly be compared to the baryon-free micro-second old universe. Fortunately, the simulations of QCD in lattice at $\approx$ zero μ_B could be used to give a reliable theoretical framework of understanding such a system.

As per the model of the high energy heavy ion collisions the crossing time (2R/γ, γ being the Lorentz contraction factor and R the radius of the nucleus) of two Lorentz-contracted nuclei will be shorter compared to the QCD time-scale of production of particles (Garcia, 2013). The longitudinal expansion will follow the quick equilibration (local) of the system. The initial state of the dense gluonic system of the colliding nuclei require special treatment. The medium comparable to the nuclear size will eventually undergo a 3-dimensional expansion. The expanding medium that could be studied using hydrodynamical evolution will undergo chemical and kinetic freezeout when the inelastic and elastic processes respectively will stop. The probes emanating from different periods of the evolution are to be measured to understand the space-time evolution of the system. Even though this model of heavy ion collisions inspired by Bjorken (Bjorken, 1983) was formulated during the SPS programme, the underlying assumptions are however justified only at RHIC energy region and beyond. In the discussions to follow, mainly due to the similarity in collision time-scales in two cases, we have clubbed RHIC and LHC in the same bracket in terms of the nature of the media that might have been formed. It will be interesting to study the properties of the medium at even higher collision energy like at the top LHC energy ($\sqrt{s_{NN}}$ = 5.5 TeV) or even beyond. With increasing collision energy, higher momentum transfer in the collisions and the associated particle production leads to enhanced fraction of harder processes that could be described by perturbative QCD. However, the associated softer processes responsible for production of the bulk of the particles of low transverse momenta (p_T) coupled to the conversions of hard partons into softer particles due to interaction with media make the interpretation of the particle spectra at RHIC and LHC energies nontrivial. It has turned out that the intermediate p_T region is even more interesting.

By now, more than a decade-old dedicated experimental programme at RHIC with STAR, PHENIX, PHOBOS and BRAHMS (Adcox *et al*., 2005) has provided detailed information using the probes from various stages of the collision. ALICE, CMS and ATLAS (Aamodt *et al*., 2008) have been contributing in understanding the matter created in the heavy ion collisions at LHC. Comparatively young heavy ion collision programme at LHC has started with the exploration of the probes that have been mastered at RHIC and going beyond. At this point of time therefore, it will be useful to first compare the basic properties of the media as have been inferred from the results at two $\sqrt{s_{NN}}$ regions and then look for new findings at higher collision energies at LHC. We give here a list of major observables at RHIC and their interpretations in terms of the properties of the medium, (i) particle multiplicity and its centrality and $\sqrt{s_{NN}}$ dependence help to understand the particle production mechanism in the collsions and provides an estimate of the entropy of the medium. The rapidity density (ρ) of produced charged particles gives an estimate of the energy density achieved after a specified formation time at the mid-rapidity region of the collision. The estimated energy density is crucial to justify the condition of forming a deconfined medium (ii) penetrating probes created early in the collisions like thermal spectra of direct photons, various quarkonia states could give an estimate of the initial temperature of the system (iii) ratios and spectra of the particles could be used to infer on the freezeout parameters (kinetic and chemical freezeout temperatures T_{kin} and T_{ch}) and the baryon chemical potential (μ_B) (Andronic *et al.*, 2006). The latter is important to the validity of comparing the medium with the baryon free microsecond old universe. The identified particle spectra could be used to study the collectivity of the system in terms of a common velocity called radial velocity (β), (iv) the collective properties could be studied further by various components (mainly the 2^{nd} component called v_2 have been studied at RHIC) of the Fourier decomposition of the azimuthal distribution of the produced particles. These observations along with their interpretations using hydrodynamics lead us to conclude about the nature of the medium in terms of the shear viscosity to entropy (η/s) ratio. The scaling of the flow components with the number of constituent quarks inform us about the constituents of the matter, (v) the energy loss of the energetic partons inside the medium at RHIC measured using the leading particles of the corresponding jet provides the information on the gluon rapidity density of the medium at midrapidity. The formulation of a medium with partonic degrees of freedom could be inferred from the high opacity of the medium to the energetic partons. The flavour dependence of the energy loss could be discussed in terms of the coupling among the constituents of the medium. The leading particle measurement has been complimented by detailed investigations of correlations between particles of high transverse momenta. (vi) the dissociation of charmonia has been a classic signal to the deconfinement transition due to Debye screening, with increase in collision energy, higher quarkonium states could also be explored to study the binding energy dependence of the melting. Several detailed reviews exist in the literature on the results of RHIC and LHC (Steinbeg, 2012; Garcia, 2013).

Of all the observables listed above, the accesibility of a number of them like higher states of quarkonia depends strongly on collision energy and therefore prominent only at LHC. In the discussions to follow, we give a list of the properties of the medium inferred from RHIC data and then compare them with similar observations at LHC energy. We also discuss the observables that are exclusive to LHC energy. As recent results from p-Pb (and p-p) collisions at LHC have brought new challenges to the understanding of the field, we discuss these surprising observations in the following discussions.

The other extreme when compared to RHIC and LHC is the region of low energy collisions leading to complete (or partial) stopping of the baryons creating regions of net-baryon densities several times higher as compared to the normal nuclear matter density. Parallels are being drawn to the core of super-heavy neutron stars (e.g. neutron stars weighing two times the solar mass) which is believed to be made of quark matter in the interior. Unfortunately, due to technical problems, lattice QCD has severe limitations in investigating such media of high baryon-chemical potential. In absence of clear theoretical guidelines, experimental investigations of such a medium takes us back to the SPS and AGS regions of collision energy. There were investigations at SPS like strangeness enhancement, $\sqrt{s_{NN}}$ dependence of the K^+/π^+ ratio (horn), broadening of the mass spectra of the ρ^0 mesons that require the invocation of the formation of chirally symmetric and deconfined media. For drawing robust conclusions on the superdense media, apart from making use of the low colliding energies at RHIC (BES), new facilities like FAIR and NICA with dedicated experimental setups like CBM and MPD are coming up. For a complete picture of the ongoing activities in this field of research, we give a brief description of this area as well.

The article is organised as follows, in the next section we discuss the main observations and their interpretations at RHIC. Section-3 discusses comparable results at LHC energy. In section-4, we discuss the surprises exclusive at LHC to be followed by discussions on investigating the high density matter in section-5.

RHIC Results

RHIC started taking data in 2000, so far it has delivered collisions for p-p, d-Au, Cu-Cu , U-U, Au-Au and Cu-Au systems at different energies. While p-p and d-Au have been used mostly as reference systems (except recent post-LHC investigations to look for collective properties of the medium formed in d-Au collisions at RHIC), the major task of the search of QGP has been performed in central Au-Au collisions. The energy range for Au-Au collisions covered so far include, $\sqrt{s_{NN}}$ of 200 GeV, 130 GeV, 62.4 GeV, 39 GeV, 27 GeV, 19.6 GeV, 11.5 GeV and 7.7 GeV. Roughly speaking, in the range of $\sqrt{s_{NN}}$ = 200-39 GeV we explore matter at high temperature and the lower collision energy is for creating media of high net-baryon density. Scanning a large range of $\sqrt{s_{NN}}$ gives access to the search of several landmarks in the phase diagram like the critical point, the junction between the cross-over transition at low μ_B to the first order transition at higher μ_B. As per the literatures available so far, a partial list of the parameters describing the media created at the central AuAu collisions at top RHIC energy and in central PbPb collisions at LHC energy are given in Table 1.

Based on various probes used to study the medium, following conclusions have been drawn,

- Spectra of the penetrating probes like direct photons or dileptons, the product of photon-conversion inside the medium have been fitted using models with hydrodynamical expansion to extract the initial

Parameter Name	Value (RHIC)	value (LHC)
T_i (MeV)	221±19±19	304 ± 51 MeV
T_{ch}	162 MeV	156-158 MeV*
T_{kin}	95 MeV	95± 5
μ_B	10 MeV	1 MeV (fixed in fit)
Radial velocity (ρ_B)	.60c	(.65± .02)c
ρ_{max}/(Npart*.5)	3.95	8.3 ± .4
Energy density (GeV/fm^3)	5.38 GeV/fm^3	14 GeV/fm^3
freezeout volume (fm^3)	150 fm^3	300 fm^3
Life time	4 fm/c	10 fm/c

Table 1: **Medium properties at RHIC and LHC. Pl. note that, at LHC, T_{ch} = 164 MeV reproduces multistrange ratios and T^{ch} = 156 MeV can explain p/π and Λ/π ratio**

temprature (T_i). The equilibrium is assumed to have been reached. The observed photon spectra has an excess beyond pQCD estimate at p_T = 1-3 GeV/c. This excess thermal photons is interpreted as radiation from sQGP. It is however essential to check that photons from later stages of evolution and decay do not get mixed up with the excess thermal direct photons (Adare *et al.*, 2010). This temperature could also be extracted using another set of initially produced particles e.g, quarkonia. It should be mentioned that excessively large v_2 of thermal photons seemingly contradict the results.

- p_T spectra of produced particles shows three distinct regions of origin (a) low p_T (upto $\approx$ 2 GeV/c): thermal spectra and radial flow (b) intermediate p_T: coalescence of thermal and shower partons and (c) high ($p_T > 4$ GeV/c): jet fragmentation.

- The near-flat rapidity distributions of produced particles around mid-rapidity justifies the use of Bjorken's model in describing the system. The energy density estimated using this model is significantly higher than the requirement suggested by lattice simulation for the phase transition to take place.

- The ratio of yields of proton and antiproton at midrapidity has been found to be close to unity at top RHIC energy showing the creation of a medium with no net-baryon. The ratios of yields of particle species consisting of light and strange flavours could be fitted using the thermal model allowing to extract a common set of chemical freezeout parameters (T_{ch} and μ_B) (Andronic *et al.*, 2006). The good quality of fits at RHIC gives credence to the use of thermal model in describing the system and extraction of parameters.

- The blast-wave model, as hydro-inspired formalism of the evolution of the system could be used to fit the spectra of identified particles in the light and strange sectors. The kinetic freezeout parameters i.e., T_{kin} and radial flow velocity (β) were thus extracted (Abelev *et al*., 2009b). The AuAu collisions at RHIC shows high degree of collectivity.

- Large ellpitic flow (v_2) in semicentral collisions is one of the most talked about measurements at RHIC. v_2, the measurement of elliptic flow represents the conversion of spatial anisotropy to the momentum anisotropy via rescattering (Ollitraut, 1993). Large v_2 and its centrality dependence at RHIC lead to the conclusion of the system to equilibrate early and reach hydro limit for the first time. v_2 data have been analysed using viscous hydrodynamics to extract the transport co-efficients like shear viscosity to entropy ratio (η/s) of the medium. The extracted η/s close to the lower quantum bound of 1/(4π) have led to the conclusions that the system behaves like a perfect liquid. Low η/s suggests that the medium could be described as a strongly coupled system. Another important observation related to v_2 at intermediate p_T of 2-4 GeV/c is its scaling with the number of constituent quarks (NCQ scaling). This scaling is interpreted as the flow of individual partons as opposed to that of hadrons (Ackermann *et al*., 2001).

- At RHIC, due to high $\sqrt{s_{NN}}$, a large fraction of particles of high p_T will be produced by hard processes i.e., due to high momentum transfer. These particles known as jet fragments shed light on the passage of the partons through the medium before fragmentation (time of fragmentation is longer than the time required to pass through the medium). Two sets of measurements (Adler *et al*., 2002) using high p_T particles have shed light on the properties of the produced medium, (i) R_{AA}, defined as the ratio of the particle spectra (charged and identified) in central A-A collisions to the p-p reference spectra normalised for the number of binary collisions shows large suppression at high p_T and (ii) the azimuthal correlations of high p_T particles at RHIC showed expected two peak structures characteristics of back to back di-jets on transverse plane. However, even though clear two-peak structures have been observed in p-p, d-Au and peripheral Au-Au collisions at top RHIC energy, the yield at the away-side shows considerable centrality and path length dependent reduction. These observations show that the partons passing through the medium are quenched and two parameters characterising the medium have been extracted. They are q-hat, the energy loss per unit length and the maximum rapidity density of gluons showing the density of the medium. The extracted high gluon density (dN_g/dy $\approx$ 1400) leads to a conclusion that the medium to be partonic. One important feature of R_{AA} at RHIC is R_{AA} (light mesons) $<$ R_{AA} (strange mesons) $<$ R_{AA}(baryons).

- R_{AA} shows that photons are not quenched (Afanasiev *et al.*, 2012): the observation is on expected line, high density medium quenches strongly interacting quark and gluon jets, direct photons are however penetrating probes and do not get quenched.

- R_{AA} of heavy favour: It is expected that the radiative processes, the main mechanism of energy loss inside the medium, should be reduced considerably due to dead-cone effect. However, the comparable to light flavour quenching for heavy flavour as observed using open charm is a surprising observation.

- 2-dimensional ($\delta\eta - \delta\phi$) correlation functions at high p_T have been extracted to study the modifications of the near and away side peaks and thereby the fragmentation function. The observations that while the near-side peak, arising primarily due to partons fragmenting from the surface, remains mostly unaffected, the away side peak reduces as a result of the modifications of the fragmentation functions of the partons passing through the bulk of the medium. The observation of the away side peak, shows that the jets from the surface fragment in vacuum, away-side jet gets quenched while passing through the medium and quenched particles softens the spectra.

- Correlations at large $\delta\eta$ in Au-Au collisions showed ridge structure which was believed to be due to the remnants of quenched partons, but currently it is understood to be the result of higher harmonics structure of the azimuthal distributions of the particles, a manifestation of the varying-shapes of the initial geometry of the collisions. This could also explain the hump observed in the away-side of the triggered correlation functions.

- Correlations at large $\delta\eta$ in d-Au collisions showed ridge structure that could be explained as an effect of initial state of the dense gluonic systems of the incoming nuclei.

- Quarkonia: Charmonium suppression is one of the classic signatures of QGP formation (Matsui and Satz, 1986). Initial observation was that the J/ψ suppression is comparable to that at SPS, however, after the reference p-A and A-A data in SPS are taken at the same collision energy, the suppression observed at RHIC is concluded to be higher than that at SPS (Adare *et al.*, 2012). It should be mentioned that data from d-Au collisions have been used at RHIC as reference. The detailed investigations show the presence of different contributions in J/ψ suppression, i.e., (a) directly produced J/ψ is smaller in number compared to the feeddown contributions from higher resonances. The suppression might therefore be the effect of melting of higher states (b) with increase in collision energy, number of open pairs of thermalised charm quarks are enhanced. These quarks could therefore be contributing to the recombination process to produce more J/ψ showing smaller net suppression (Braun-Munzinger *et al.*, 2000).

LHC Results

LHC programme has started taking data in 2010 and has collected data with p-p, p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}}$ ranging from 900 GeV to 7 TeV (p-p) , 5.02 TeV (p-Pb) and 2.76 TeV for Pb-Pb. The $\sqrt{s_{NN}}$ at LHC heavy ion collisions for the data taken so far is about 10 times higher than the top RHIC energy. It is therefore interesting to study the effect of higher beam energy on basic properties of the medium. We have enlisted the major results at LHC in comparison with that at RHIC in table-1. Following points may be emphasized from the data.

- It is seen that at higher collision energy a medium of higher temperature, larger size, longer lifetime and of higher rapidity density has been formed (Tserruya, 2011; Abelev *et al.*, 2009a; Aamodt *et al.*, 2011; Abelev *et al.*, 2012a; Milano, 2013), (Aad *et al.*, 2012a). The system also shows collectivity with somewhat higher radial flow velocity.

- v_2 is about 25% higher at LHC compared to RHIC, mainly due to larger average p_T as the $v_2(p_T)$ looks similar in two cases (Aamodt *et al.*, 2010). The medium at LHC shows η/s reaching close to quantum limit suggesting the medium to be strongly coupled. Near-validity of the NCQ scaling at LHC shows that the constituents of the medium to be partonic.

- One avenue that was inaccessible at RHIC because of low energy and can be accessed at LHC is the study of jets: with higher $\sqrt{s_{NN}}$, it is expected that the fraction of hard collisions is to increase significantly. The jets at LHC will be of higher energy, thereby enabling them to be reconstructed directly from data. At LHC energy therefore, we could study the jets itself and not their representative in the form of leading particles (Aad *et al.*, 2010). Jets have been reconstructed at LHC and it shows a quenching with q-hat higher than that at RHIC and showing larger dN_g/dy. R_{AA} of jets is p_T-independent, they however remain back to back on transverse plane. Dijets show clear asymmetry with one jets getting suppressed at higher centrality. The study of the azimuthal correlation reveals the fate of the lost energy of the partons. It is seen that the lost energy of partons is distributed among soft particles away from the core of the away-side jet. These fragments can only be observed if the lower p_T cut-off is kept sufficiently low. In addition to the tomography of jets, photon jets as reconstructed well at LHC shows no quenching. Photon jets used for calibration helps to know the energy-dependent quenching more precisely. Jets with W and Z bosons are not quenched at LHC (Aad *et al.*, 2012b). The study of modifications of fragmentation functions show similar conclusions.

- In quarkonia sector, it was said that the dissociation of states depends on their binding energy. Higher order states are to dissociate early. In addition to that, at LHC J/ψ has the complication from feeddown and regeneration. It appears that at LHC, effect of regeneration plays a larger role as it is seen that R_{AA} is larger at low p_T decreasing at higher p_T and the overall R_{AA} is higher compared to that at RHIC (Abelev *et al.*, 2012b). At LHC, ψ' and Υ of different states have been measured showing stronger suppression.The R_{AA} values of different states of Υ have been measured to be, for 1S: 0.56 $\pm$ 0.08 (stat) $\pm$ 0.07 (sys), for 2S: 0.12 $\pm$ 0.04 (stat) $\pm$ 0.02 (sys) and for 3S: 0.03 $\pm$ 0.04 (stat) $\pm$ 0.01 (sys). It has been observed that $R_{AA}(\Upsilon(1S)) > R_{AA}(J/\psi) > R_{AA}$ (Υ (2S) $> R_{AA}(\Upsilon(3S))$. Hadrons with heavy flavours also show suppression at LHC as large as light-flavoured hadrons (Abelev *et al.*, 2012c).

- Another topic which came into prominence at LHC is the study of higher order moments (v_n) of the azimuthal distributions. In RHIC era, it was believed that only v_1 and v_2 are having importance from hydrodynamical point of view and higher order moments will be absent or could not be detected. However, in post-LHC era, it has come to notice that the higher order moments could be generated as the hydrodynamical response of the initial fluctuations generated in the pre-equilibrated state of the medium. Subsequently, at LHC, v_3, v_4 ..upto v_6 have been measured to be finite. Reanalysis of RHIC data also gave values of higher order moments. As mentioned earlier, the observed ridge in near side and double-hump in away-side in A+A collisions appear after subtraction of higher order v_n (Adare *et al.*, 2011).

  In view of the above mentioned discussions on properties like collectivity, response of the medium to the energetic partons and the heavy flavours, it could be concluded that the matter produced at LHC is similar to that at RHIC albeit of higher values of some parameters like temperature, lifetime among others.

Surprises at LHC

LHC data have thrown several surprises already. The most prominent ones are (a) observation of ridge in high multiplicity pp collisions at $\sqrt{s}$ = 7 TeV (Khachtryan *et al.*, 2010) and p-Pb data at $\sqrt{s_{NN}}$ = 5.02 TeV (b) observation of large v_2 and of mass ordering of various moments in pPb collisions (Chatrchyan *et al.*, 2013), (Aad *et al.*, 2013).

pp and pPb are the systems believed to exhibit no final state effect and can act as references for A-A systems. It has therefore been expected that, any observation related to collective effects will be absent in p-p and p-A. Two cases might however be treated somewhat differently, as in p-Pb, when proton passes through an incoming Pb nucleus, it traverses a system of saturated gluons. The outgoing particles from such a collision will shed light on the dense gluonic system. Models based on such a picture, known as color glass condensate (CGC) can produce ridge-like structure as seen in LHC data. In p-p however, only in high multiplcity events such structures are seen (Khachtryan *et al.*, 2010). Protons are believed to be clusters of partons which might be able to form CGC structures. If we define impact parameter in pp collisions, the high-multiplicity events correspond to central pp collisions having higher probability of gluon saturation (Dusling *et al.*, 2013).

The scenario has become more complicated after the measurement of finite v_2 and more importantly the mass ordering of v_2 in p-A collisions which can only be explained using hydrodynamics (Aad *et al.*, 2013). The observation that p-A shows collectivity gets its support from the baryon-meson ordering and NCQ scaling of v_ns at intermediate p$_T$. This observation raises several questions, (a) is there collectivity in p-A, if yes, is it same as observed in A-A? However, absence of jet-quenching raises the question of the way the dense medium which leads to hydro-like system might have been created. (b) Does the azimuthal anisotropy parameter v_2 need a relook in its hydrodynamic interpretation? (c) some other phenomena common in p-A and A-A driving v_2 but not related to the collective properties of the medium created? This issue is something which needs to be looked into by the community in more details. The observations on average p$_T$, Λ/K_s^0 (Abelev *et al.*, 2013) in p-Pb collisions draw similar conclusions.

Low Energy Collisions Creating High Net-Baryon Density

A renewed effort has started experimentally to study the colliding heavy ions at a relatively lower energy i.e., $\sqrt{s_{NN}} <$ 39 GeV to E$_{lab}$ = 2 AGeV. The first energy range is covered at RHIC beam energy scan (BES) programme and the fixed target experiment at SPS (NA61) covers the lower energy domain. Two major upcoming experimental programmes in the low energy domain are CBM@FAIR and MPD@NICA.

The aim of these experiments is to explore the medium with high net-baryon density. Transport calculations like HSD, UrQMD gave the estimate of net-baryon density to be upto 10-15 times the saturated nuclear density. At such high density, the nucleons are believed to overlap with each other to form a phase of partons. Some other models explaining the neutron star mass of twice the solar mass requires the quark matter as the ingredient at the core of the star (Orsaria *et al.*, 2014).

Data from BES at STAR shows that major signatures showing the transition at top RHIC energy vanishes or shows interesting structure around $\sqrt{s_{NN}}$ of 20 GeV and below. The results include (a) jet quenching, (b) NCQ scaling, (c) negative v_1 (d) separation of v_2 in particles and antiparticle (Xu *et al.*, 2013) and (d) net-proton higher order moments (Adamczyk *et al.*, 2013). However, given the fact that the system at lower energy becomes baryon-rich, the interpretations of these results in terms of switching off of the partonic signatures seen at high temperature medium are to be reevaluated. One limitation at BES is it p$_T$ reach which must be enhanced for several physics conclusions to be drawn.

CBM is a dedicated fixed target experimental programme at FAIR giving special emphasis on rare probes. The beam energy to be accessible for full version of FAIR (SIS300) ranges from 90 GeV for proton and 45 AGeV for N=Z nuclei. For Au ions, the beam energy will be 35 AGeV. The corresponding values at the start version of FAIR (SIS100) will be 30 GeV proton and 10 AGeV Au ions. High intensity (10^{11}/sec) Au-beams will help to take data at high interaction rate upto 10 MHz. This new generation experiment will make use of the advanced detector systems that will handle such high rates and related harsh radiation environment. The list of physics goals and the corresponding observables at CBM are listed below.

- Equation of state at neutron star densities: (a) collective flow of hadrons, (b) particle production at threshold energies
- Onset of chiral symmetry restoration at high ρ_B: in-medium modifications of vector mesons
- New phases of strongly interacting matter: (a) excitation function and flow of lepton pairs (b) excitation function and flow of strangeness K, Λ, Ω
- Deconfinement phase transition at high ρ_B: (a) excitation function and flow of charmonia and open charm (b) anomalous suppression of charmonia
- Exotica (strange matter): (a) production of hypernuclei (b) strange meta-stable objects.

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