Electromagnetic Radiation at RHIC 2

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Introduction: Why measure electromagnetic radiation?

The measurement of electromagnetic (EM) radiation gives direct access to two of the most important phenomena in high temperature QCD: chiral symmetry restoration and the black body radiation reflecting the temperature of the system. EM radiation is measured via photons and dileptons. Dileptons can be either in the electron or muon channel. Such final states give access to the earliest moments of a collision since photons and leptons do not interact strongly and are essentially free to escape from the system once they are formed. This is in contrast to hadrons which come from the later stages of the interaction. The relative small size of α_{EM} in contrast to α_S which leads to the sensitivity of EM radiation to the early stages of the system, also lead to major practical problems – the low rate, and the huge backgrounds arising from decays of hadrons – most notably dalitz decays of the π^0 . In addition correlated charm decays into leptons overwhelm other sources of di-leptons at higher masses. In this discussion, I will treat charm as a background; however the measurement of charm itself is a critical part of the RHIC program. I will also concentrate on the di-electron channel for masses below 3 GeV.

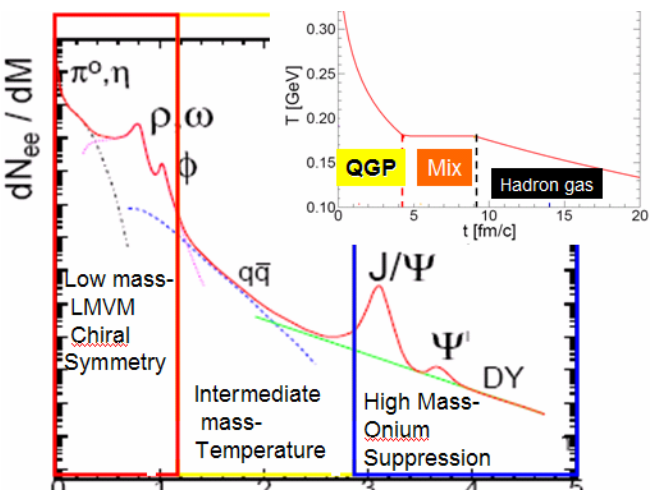

Figure 1: Different regions of the dielectron mass spectrum as in heavy ion collisions. The inset shows the time evolution of the temperature.

The di-electron mass spectrum is typically divided into three regions, as show in figure 1. The low mass region is dominated by the decays of mesons – hence is sensitive to the decays of low-mass vector mesons (LMVM) – the ρ, ω and ϕ. A broadening or dropping of the spectral function of the LMVM would be the signature of chiral symmetry restoration. Measurements of the A_1 (see talk by P. Fachini in this session) would be particularly nice to compare to the ρ since the masses of the two states should be equal when chiral symmetry is restored. A schematic of the time evolution of the system is shown in the inset of figure 1. The LMVM in the spectrum is primarily from the mixed and hadron gas phases. It is during the mixed phase when chiral symmetry is still restored that changes in mass and width will occur. In the intermediate mass region between 1 and 3 GeV quark-antiquark annihilations and other thermal photons should be measurable. The spectrum measured would be a sum of radiation from the various stages of the collision – it is expected that the earliest stages would dominate since the strength of the radiation increases with increasing temperature. Hence such radiation will be indicative of the initial temperature at which the QGP[1] is formed.

A new idea

We know that the system thermalizes rather quickly – within the first Fermi or so – from flow measurements. Typical perturbative QCD calculations cannot account for this. There are several hypothesis to account for this rapid thermalization – one of the most intriguing comes from

[1] The name QGP should be taken generically. Within our present understanding it should be understood as sQGP.

Kharzeev and Tuchin[2] who use gravity and blackholes as a paradigm. Hawking predicted that blackholes emit radiation because of the quantum mechanical tunneling of pairs through the event horizon with a characteristic temperature $T=g_{Blackhole}/2\pi$ where $g_{Blackhole}$ is the acceleration due to gravity at the event horizon. The equivalence principle tells us that gravity is equivalent to an accelerating reference frame – hence Unruh[3] pointed out that accelerating objects should also emit radiation with $T=a/2\pi$. At ordinary values of a, e.g. $a=g_{Earth}$ the predicted temperature is far too small to be detected. However, during a high energy collision of heavy ions, the accelerations are enormous due to the color fields of the quarks and gluons. Kharzeev and Tuchin argue that this acceleration is equal to the saturation momentum, Q_{Sat} as calculated in the colored-glass condensate picture. Q_{Sat} can be directly related to the centrality and energy of the collisions.[4] This then allows one to calculate the predicted temperature of the emitted radiation as a function of centrality and beam energy as shown in Figure 2. Such a mechanism would account for the rapid thermalization time since $\tau_{therm} \sim 1/Q_{Sat} \sim 0.2$ fm. The system would be born into a high temperature, chirally symmetric phase. As shown in figure 2, this also would imply that the system reaches T_C (assuming 170 MeV from the lattice) in 200 GeV Au-Au collisions for low values of N_{Part}. One of the intriguing ways to check this theory is that systems at different energies and centralities should radiate at the same energy- e.g. an Au-Au peripheral collision at 200 GeV should give the same T as Cu-Cu central collisions at 200 GeV and Au-Au central collisions at 60 GeV.

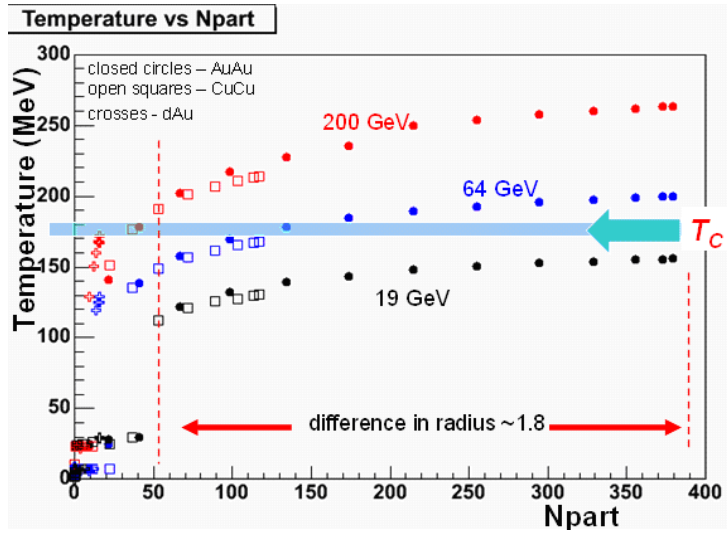

Figure 2: Initial temperature for heavy ion collisions as a function of species, centrality and energy as predicted using the model of Kharzeev and Tuchin.

How will we measure electromagnetic radiation?

The dielectron spectrum gives us experimental access to both the temperature and chiral symmetry restoration. Figure 4 shows the dielectron mass spectrum as predicted by Rapp[5] for the PHENIX acceptance. As was mentioned before, it is in the mass region between 1 and 3 GeV where the thermal radiation from the QGP dominates, aside from the contribution from correlated charm. At lower masses the low mass vector meson spectrum can be measured. Note that for the vector mesons, charm will not be a problem. One can see that there is a huge combinatorial background – largely from π^0 dalitz decays. PHENIX will be installing a large Cerenkov detector in a field free region which is blind to hadrons below about 4 GeV. Installation and commissioning should occur in the next 2 years. A cut on pairs with a small opening angle will reject a 90% of electrons from π^0 dalitz decay and photon conversions.

[2] Kharzeev Tuchin hep/ph/0501234
[3] Unruh Phys. Rev. D 14, 870(1976)
[4] Kharzeev, Nardi – Physics Letters B 507 (2001) 121-128
[5] Rapp – hep-ph/0010101, nucl-th/0409054

After making the initial di-electron spectrum, one will make a cut using the HBD reducing the background by about a factor of 100. A mixed event technique is ued to subtract the remaining combinatorial background. This then leaves us with the real di-electron spectrum show in light blue in figure 2. At this point the spectrum at low mass should be dominated by the relevant decays from the ρ, ω and ϕ. In order to access the thermal di-leptons an intermediate masses, however the correlated charm background must be directly measured and subtracted. A new vertex detector is being planned for PHENIX which will allow such a measurement. The charm can then be subtracted leaving us with the relevant di-electron spectrum shown in red which will be a sum of thermal radiation from the QGP, thermal radiation from the hadron gas, and decays of the low mass vector mesons. Theory will then be used to disentangle the spectrum to yield the mass spectrum of the vector mesons and the temperature of the system.

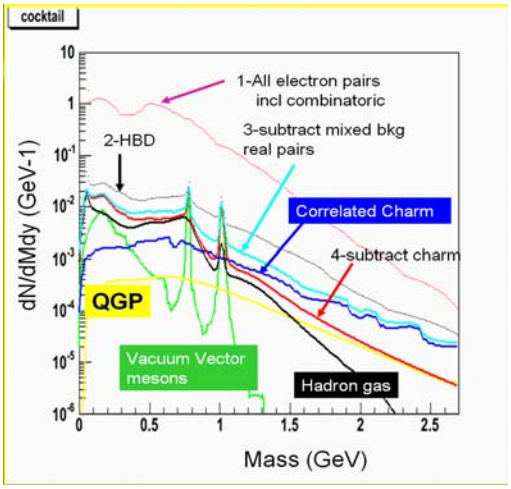

Figure 3: The dielectron system with various compnents and cuts. The yellow and black lines are from thermal radiation form the QGP and hadron gas respectively. The green line is from low mass vector mesons, including dalitz decays.

Since one is subtracting large backgrounds using either mixed events or a measured charm spectrum which is used to generate a correlated charm background – the available statistics is a crucial factor. Figure 4-left shows the subtracted spectrum using RHIC II statistics of 15/nb and 2M charm decays with a p_T>1 GeV and a DCA giving about a 1.5% measurement of the charm spectrum at 2 GeV. The thermal spectrum (assuming 50 MeV bins) can be measured to a few percent. Figure 4-right shows a similar spectrum for RHIC I statistics and a 45% measurement of charm at 2 GeV.

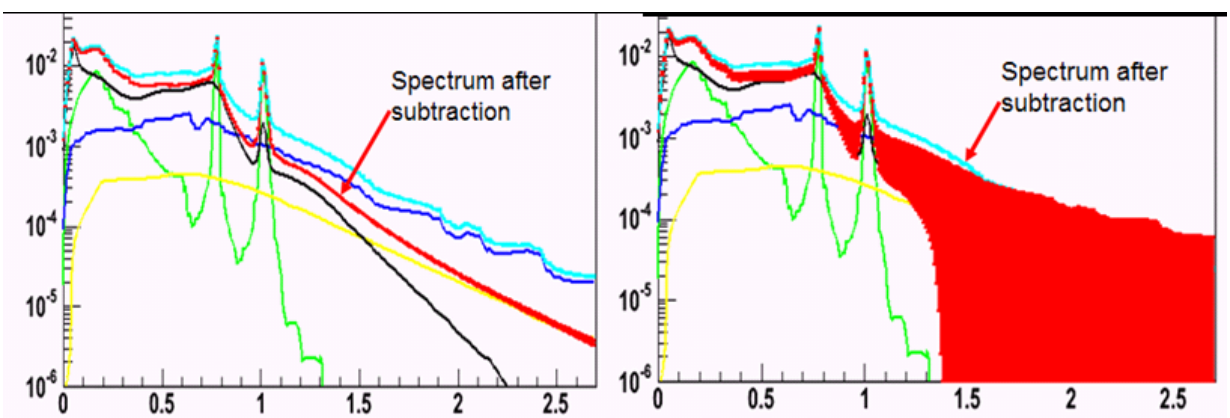

Figure 4: Subtracted spectrum after cuts where the thickness of the red line indicates the statistical error bars. The left panel shows the case for RHIC 2 and a 1.5% measurement of charm at 2 GeV, while the right panel shows the case for RHIC 1 statistics and a 45% measurement of charm at 2 GeV.

In order to obtain a complete understanding of the temperature evolution of the system and to pinpoint quantities such as the phase transition temperature – it will be important to measure at high statistics, for a variety of energies and beam species. Only this, together with upgraded detectors will make these measurements possible.