Calculating dilepton production from pions interacting with a disoriented chiral condensate

Research Experience for Undergraduates
Summer 2008

Shawn Witham, Kent State University

Dr. Ralf Rapp, Xingbo Zhao, TAMU Cyclotron

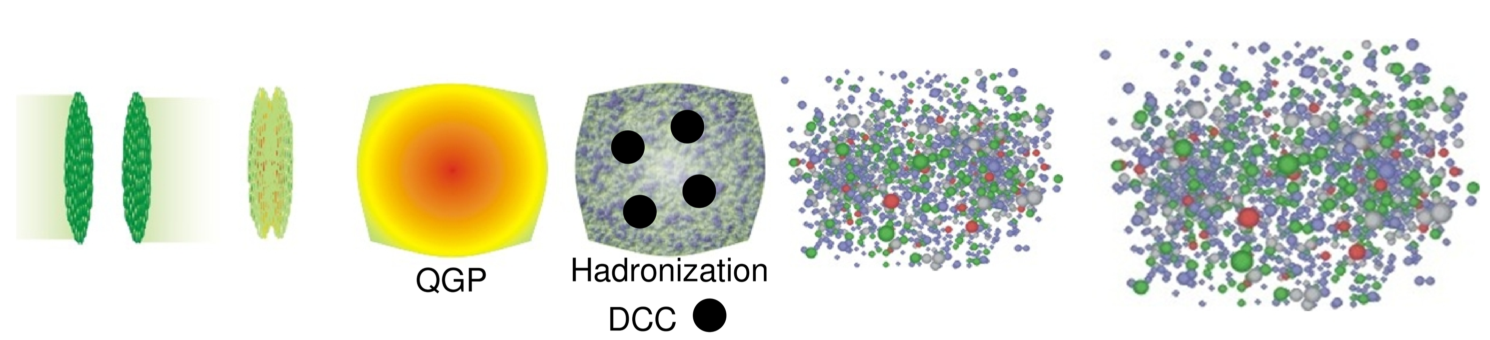
Cyclotron Institute
Texas A&M University

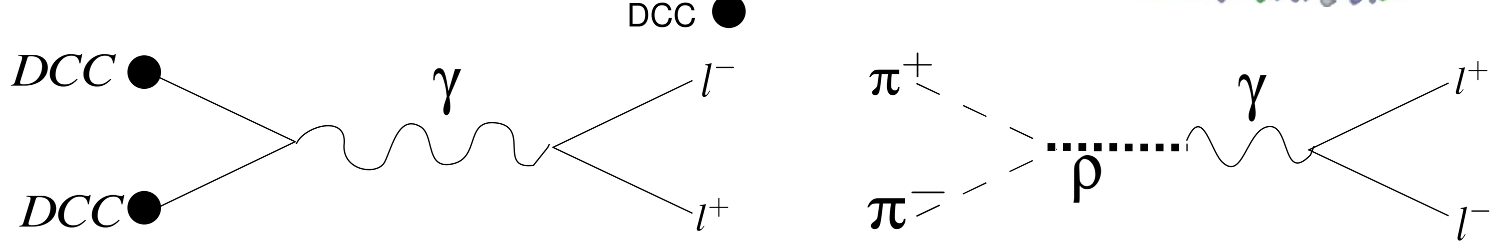
Introduction

In high energy heavy-ion collisions chiral symmetry is spontaneously broken when the quark-gluon plasma phase transitions to a hot hadron gas. It is theorized that, during this phase transition, there exists a product called a disoriented chiral condensate (DCC). By studying the effects of DCC's, more information about hadronic formation, non-equilibrium dynamics of high energy physics, and the tendency for chirality to be broken can be used to better understand current research in fundamental physics. In this project, dilepton invariant mass specta are calculated from the interactions of pions and DCC. The calculations are performed for vacuum and "in medium" situations. These theoretical calculations are done by using numerical quadrature in FORTRAN and other various computational methods.

Background

- A quark-gluon plasma is formed after a high energy collision and lasts for approximately 5 fm/c. Chiral symmetry is restored and quarks and gluons are free to move about the collision zone.
- The QGP phase transitions into a hot hadron gas and chiral symmetry is spontaneously broken where the quarks recombine to form hadrons.
- During the phase transition, it is theorized that there may lie regions where the chiral order parameter is misaligned from its normal value in isospin space. This is known as a disoriented chiral condensate (DCC).
- The DCC is able to interact with pions formed from the QGP. This interaction then emits a virtual photon which decays into a pair of leptons, commonly known as a dilepton.
- By studying the information from the resulting dileptons, one could know more about:
  1.) hadron formation from quarks and gluons
  2.) non-equilibrium dynamics in high energy physics
  3.) chiral symmetry restoration and breaking





Methods

•All calculations were done in FORTRAN and plotted with gnuplot.

•A Gauss-Legendre numerical quadrature method was used, and adapted for multidimensional integration.

•For the time evolution of the DCC fireball, τ is assumed to begin at 5 fm/c after the collision and end at approximately 9.4 fm/c.[1,2]

•A Bjorken cylindrical expansion of the DCC is also used in the fireball evolution calculations.[2]

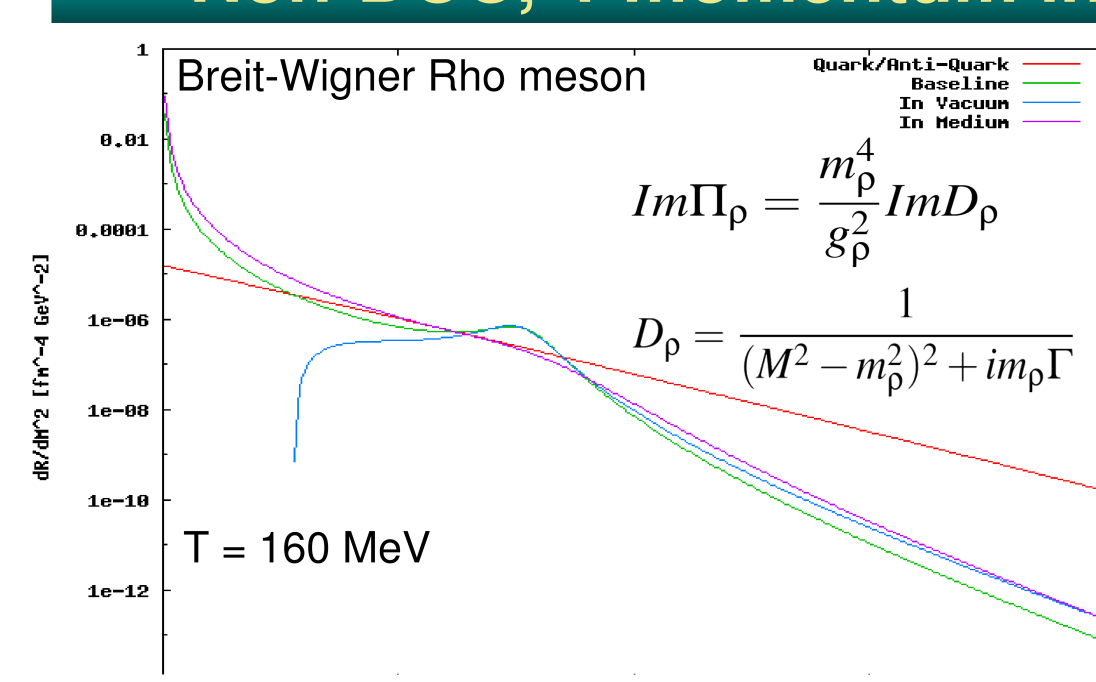
l^- l^+ Production Equations

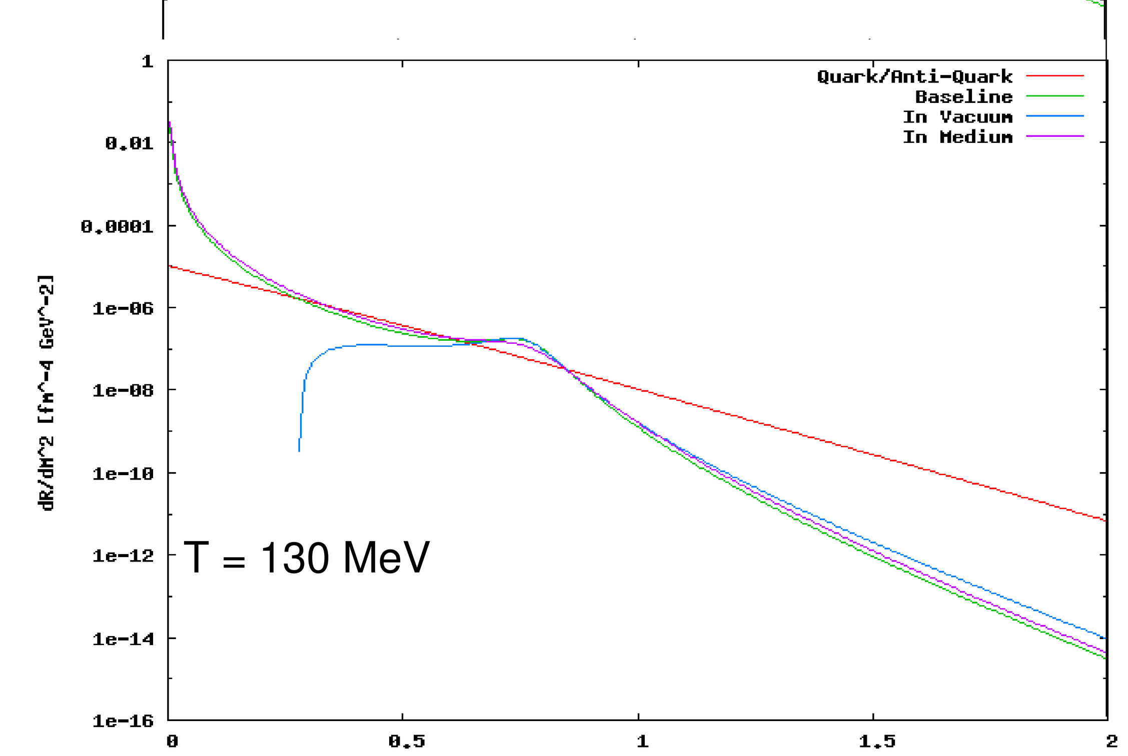
Dilepton production equation where f^{Bose} is the Bose factor, ImΠ is the electromagnetic correlation function, M is invariant mass, α is the electromagnetic coupling constant, and q_0 is the energy[3]:

$$\frac{dR^{therm}_{l^-l^+}}{d^4q} = \frac{-\alpha^2}{\pi^3 M^2} f^{Bose}(q_o,T) Im\Pi(M,q,T)$$

$$f^{Bose} = \frac{1}{(e^{\frac{q_o}{T}}-1)} \qquad q_o = \sqrt{M^2+q^2} \qquad p_\pi = \sqrt{\frac{1}{4}M^2 - m_\pi^2}$$

Non-DCC, 4-momentum integration





•T = 160 MeV is the formation temperature of the event collision.

•T = 130 MeV is the freeze out temperature of the collision.

•For Baseline gamma, ImΠ calculations are with a fixed width. γ = 150 MeV.

•For a more realistic Gamma width:
1) In vacuum, where no interaction with outside medium is possible.
2) In medium, where the medium effects are accounted for.

DCC Fireball Evolution & Dileptons

When incorporating the effect of the disoriented chiral condensate, the evolution of the volume and temperature of the expanding fireball has to be accounted for:

$$\frac{dN}{dMdy} = \int d^2qM \int_{\tau_o}^{\tau_f} d\tau \frac{dN(T)}{d^4xd^4q} V(\tau)$$

Where T is the temperature evolution function:

$$T(\tau) = T_o\left(\frac{\tau_o}{\tau}\right)^{\frac{1}{3}}$$

Where V is the fireball volume evolution function:

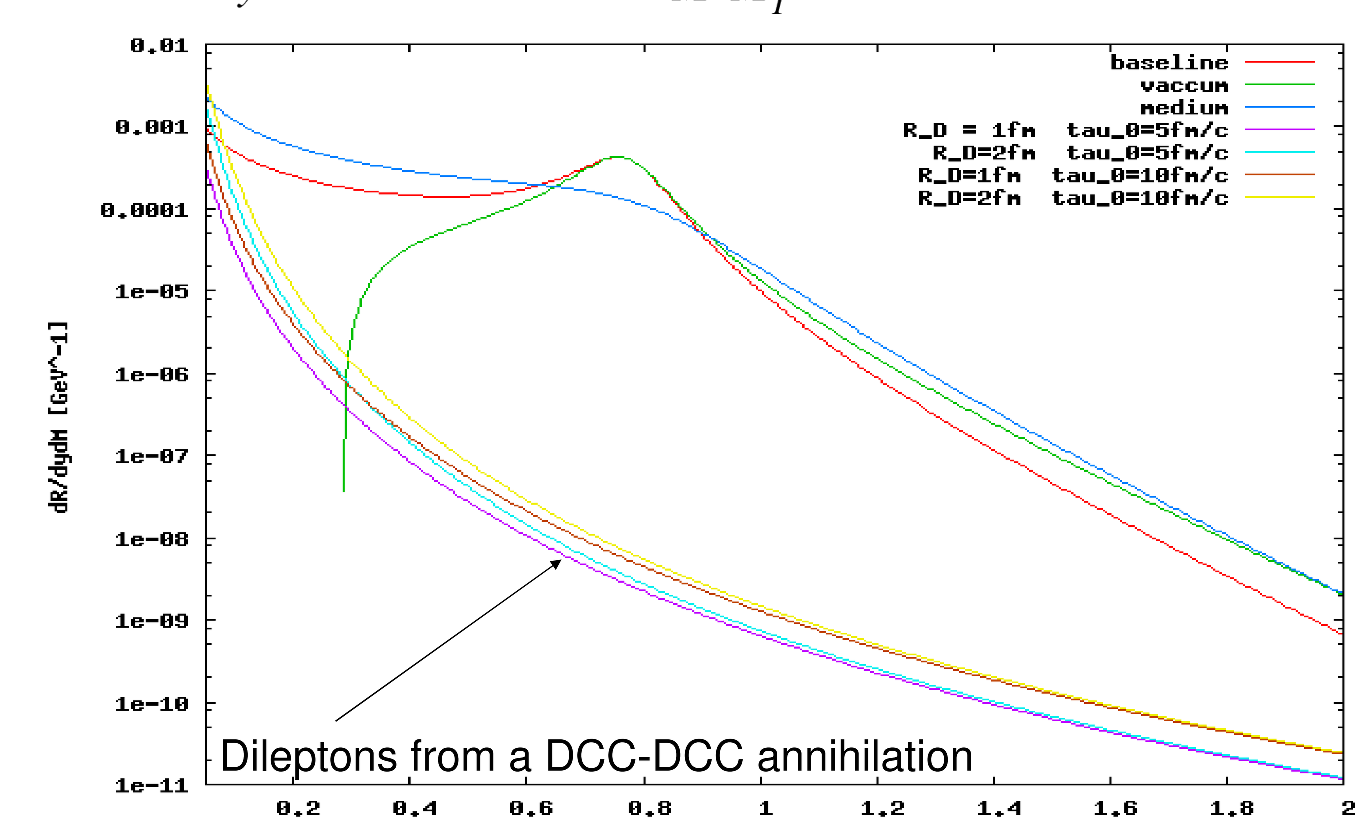
$$V(\tau) = V_o\left(\frac{\tau}{\tau_0}\right)$$

Numerically integrating dN/d^4xd^4q over space-time evolution gives the plot below with the baseline, vacuum, and in medium width comparison.

$$\Gamma_{vac} = \frac{g_\rho^2}{6\pi}\frac{p_\pi^3}{M^2} \qquad \Gamma_{med}(T(\tau)) = \left(\frac{T(\tau)}{T_{base}}\right)^4 \gamma$$

Also plotted is the dilepton production eqn. from Huang-Wang's DCC-DCC annihilation situation[2]:

$$\frac{dN}{dM^2dydM} = \frac{\alpha^2}{24}(\pi R_D^2)^2 f_\pi^4 a_3^2 \frac{Bq_T^2}{M^3 M_T^2} exp\left[\frac{-q_t^2 R_d^2}{2}\right]\left[J_0^2(M_T\tau_0) + N_0^2(M_T\tau)\right]$$



Conclusions & Future Work

• The baseline calculations have been made for comparison to the full DCC-pion implementation.

• Accurate, easy to use, and accessible computer programs have been made to integrate multidimensional integral functions.

• Implementing a DCC correlator and making a comparison with baseline calculations is a necessary next step.

• Devising a theoretical method to test the existence of DCC would be extraordinary!

Literature Cited

[1] Kluger, Y., Koch, V., Randrup, J., Wang, X. 1998. "Dileptons from disoriented chiral condensates." Phys. Rev. C, Vol. 57:1, 280-290.
[2] Huang, Z., Wang, X. 1996. "Dilepton and Photon Productions from a Coherent Pion Oscillation." Phys. Rev. B, Vol. 383:4, 457-462
[3] Rapp, R. 2003. "Dileptons in High-Energy Heavy-Ion Collisions." Pramana, Vol. 60:4, 675-686.