



Calculating dilepton production from pions interacting with a disoriented chiral condensate

Summer 2008 REU
July 31, 2008

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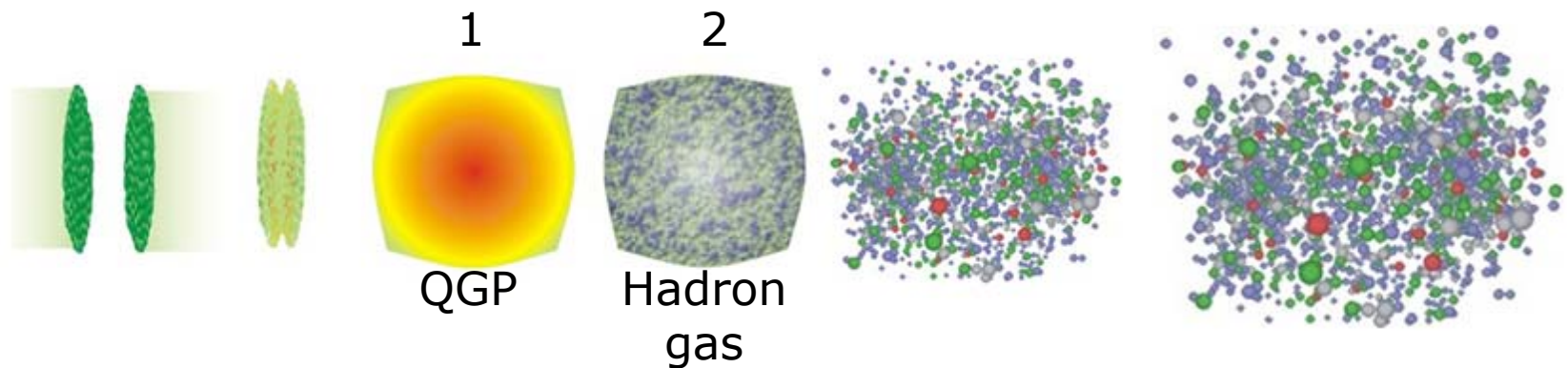
Summer Goals

- Learn numerical quadrature in FORTRAN
- Learn about high-energy heavy-ion collisions and the theory behind quark-gluon plasma(QGP)/evolution of collisions
- Create program and reproduce old results
- Incorporate a disoriented chiral condensate (DCC) evolution into calculations
- Use a DCC correlator for pion-DCC annihilation

Outline

- Background of QGP, hot hadron gas, chiral symmetry
- Benefits of studying DCC
- Results
- Conclusions and Future Work

Background



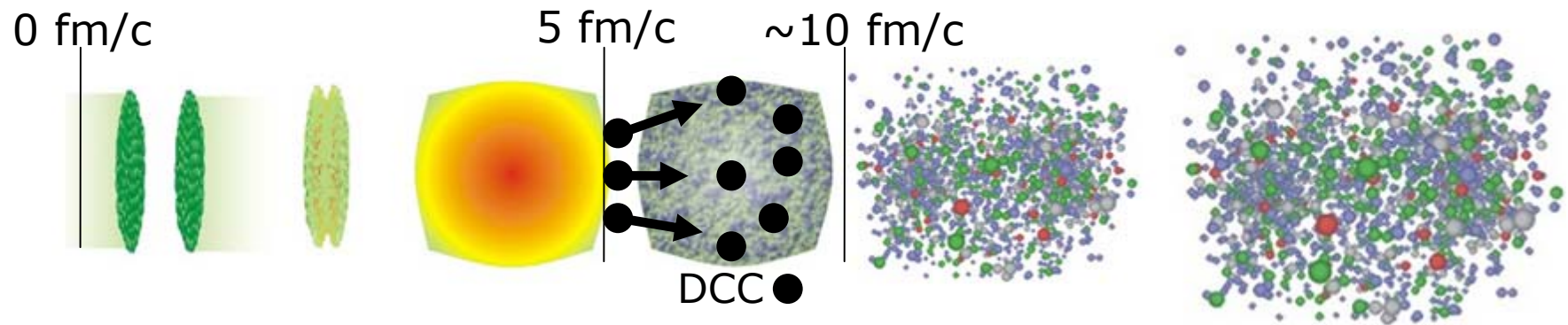
The focus of my research is the transition from phase 1 to phase 2, or from the quark-gluon plasma to the hadron gas.

At point 1, chiral symmetry is restored, and quarks and gluons are free to move about the collision zone.

At point 2, the QGP transitions into a hot hadron gas. During this transition, chiral symmetry is broken, and the quarks and gluons combine into hadrons.

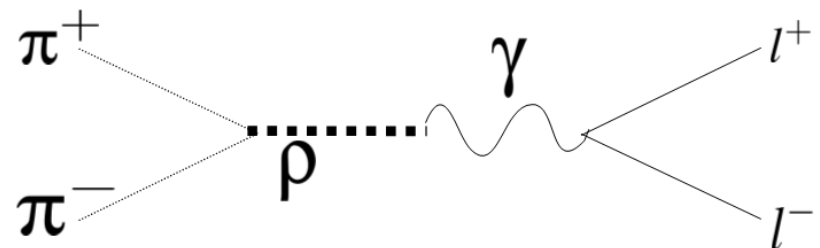
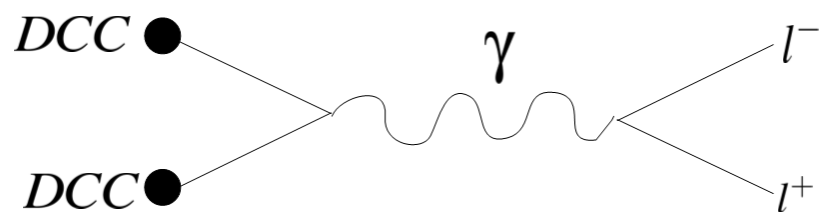
But...

The Disoriented Chiral Condensate



It is theorized that during the phase transition from the QGP to a hot hadron gas, there may lie regions where the chiral order parameter is misaligned from its normal value in isospin space...this is a disoriented chiral condensate.

The DCC is then able to interact with pions that were created in the QGP.



Chiral/Flavor Symmetry

Writing the quantum chromodynamics (QCD) Lagrangian in terms of left and right-hand spinors:

$$L = \bar{q}_L i \not{D} q_L + \bar{q}_R i \not{D} q_R + L_{gluons}$$

-The QCD Lagrangian is unchanged when a 2x2 unitary matrix is rotated on q . This is chiral and flavor symmetry.

--Chiral is left/right spin symmetry

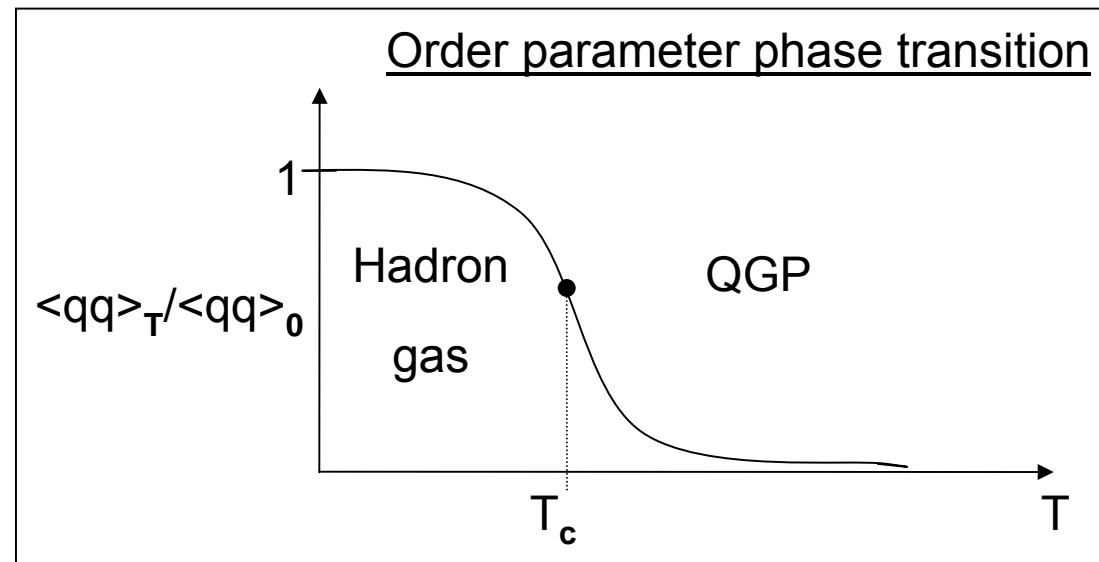
--Flavor is up/down isospin symmetry

-Also, the chiral transformations are broken when a quark condensate is formed. Isospin remains conserved.

-Isospin is a quantum number, relating to the strong force.

Chiral condensates

- The formation of a quark condensate is what breaks the chiral symmetry.
- A chiral condensate is described by an order parameter that relates to phase transitions between QGP and a hadron gas.
 - The order parameter is a characteristic that equates to the phase transition
- Quark/Chiral condensates are what gives the masses to the quarks that form hadrons.



Research: The need for DCC

- Dileptons can be used as an electromagnetic probe for the QGP/hadron transition
- Chiral symmetry restoration and breaking
- Non-equilibrium dynamics of high energy physics

Dilepton Production Equations

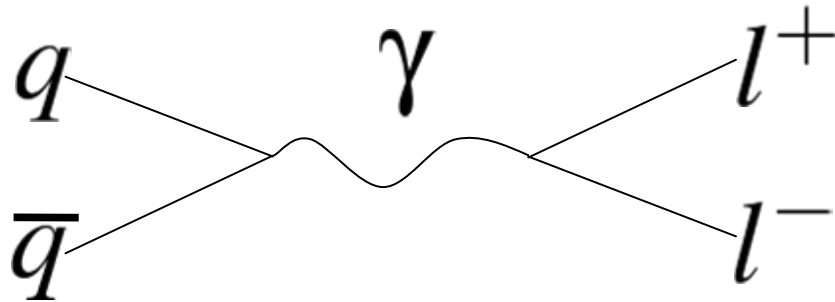
- Dilepton production is expressed through the Bose-factor, f^{Bose} , and an electromagnetic correlation function, $\text{Im}\Pi$.
- f^{Bose} is a statistical distribution of particles in thermal equilibrium.
- $\text{Im}\Pi$ is the E&M spectral function of the medium.

$$\frac{dN}{d^4x d^4q} = \frac{-\alpha^2}{\pi^3 M^2} f^{\text{Bose}}(q_0, T) \text{Im}\Pi(M, q, T)$$

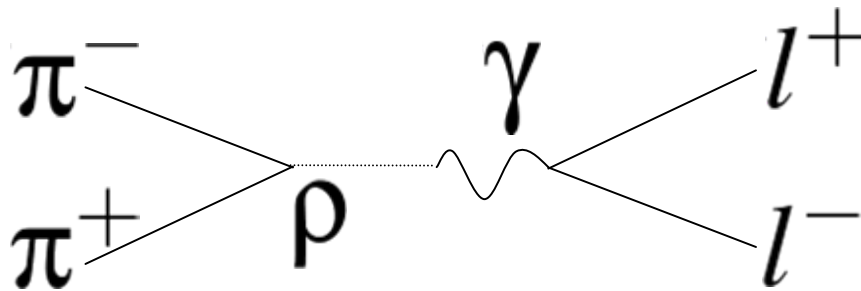
$$f^{\text{Bose}} = \frac{1}{(e^{\frac{q_0}{T}} - 1)}$$

$$q_0 = \sqrt{M^2 + q^2}$$

$q\bar{q}$ & Breit-Wigner Rho Meson



Quark/Anti-quark annihilation

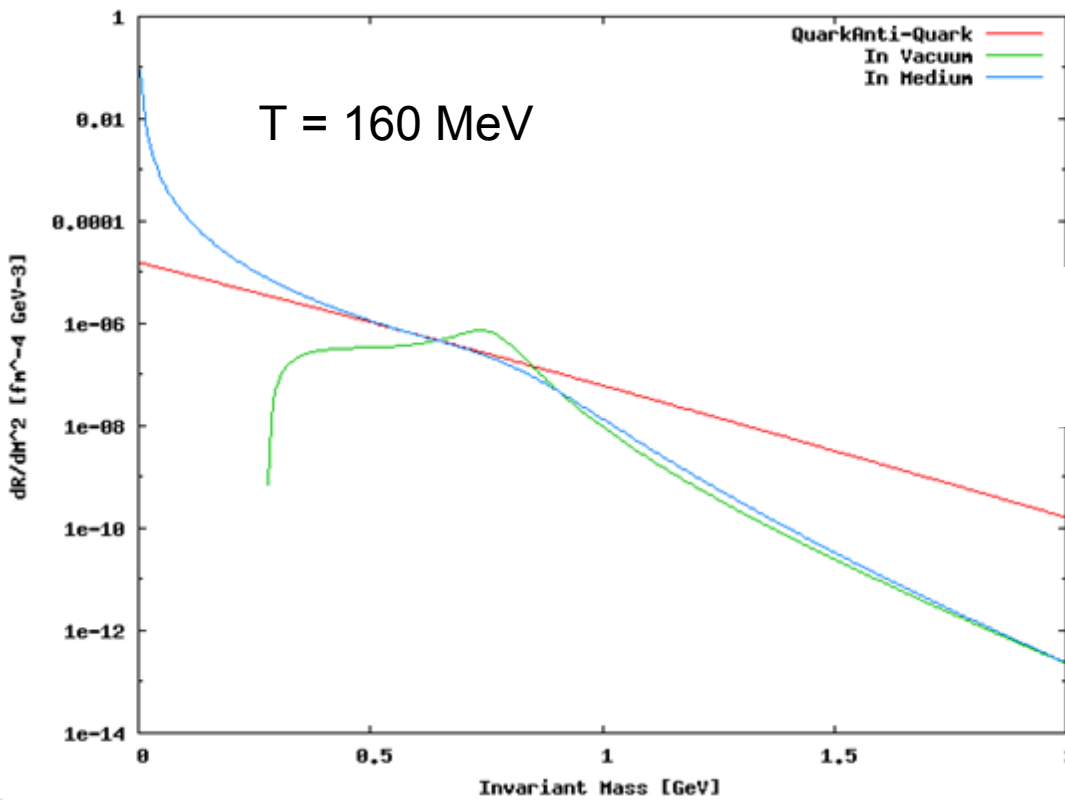


Breit-Wigner rho meson

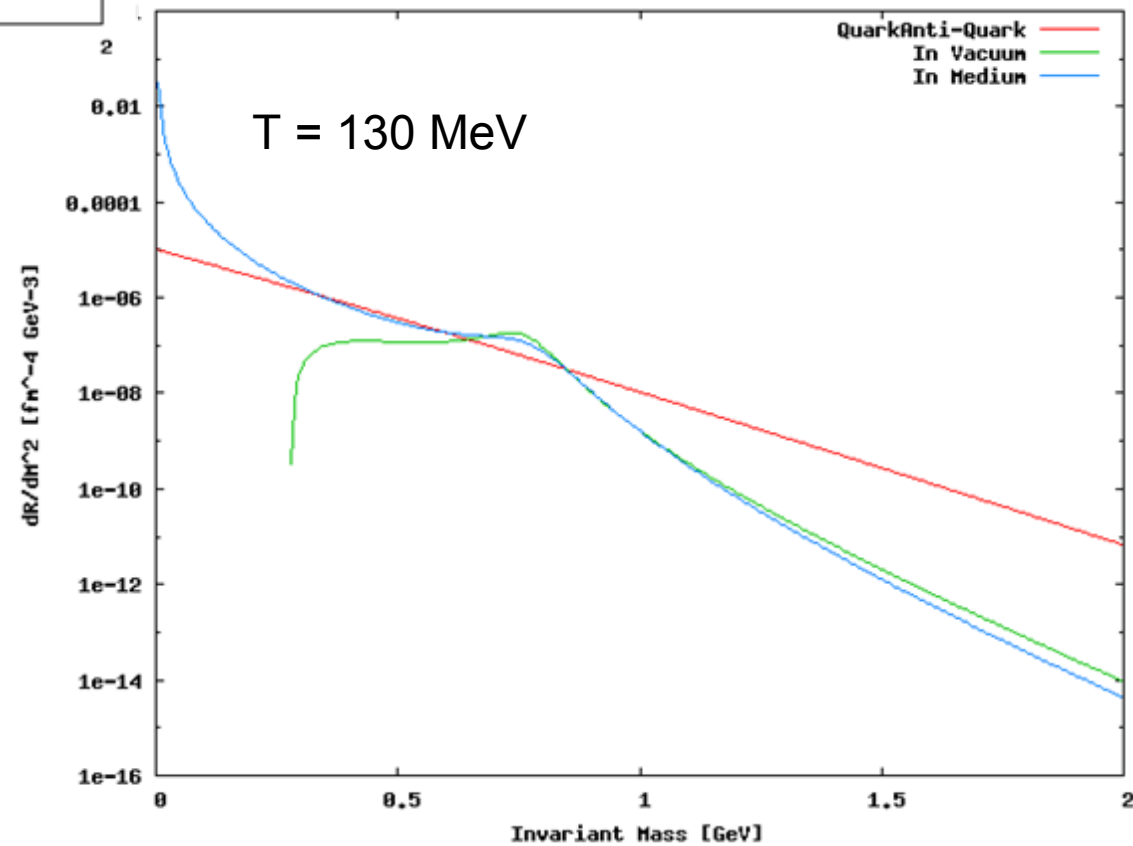
Research: Methods

- 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 10 fm/c.
- A Bjorken cylindrical expansion of the DCC is also used in the fireball evolution calculations.

Non-DCC, 3-momentum Integration



$$\frac{dR}{dM^2} = \int \frac{d^3 q}{2q_0} f^{Bose} \text{Im}\Pi$$



Fireball Evolution & Dileptons

-When incorporating the effect of the fireball, the evolution of the fireball's temperature and volume has to be accounted for:

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

-The $\text{Im}\Pi$ E&M correlator used for this was a Breit-Wigner rho meson with a fixed, in vacuum, and in medium Gamma width. Comparisons of all these are showed on future slides.

$$\text{Im}\Pi_\rho = \frac{m_\rho^4}{g_\rho^2} \text{Im}D_\rho$$

$$D_\rho = \frac{1}{(M^2 - m_\rho^2) + im_\rho\Gamma}$$

$$\Gamma_{fixed} = 150 \text{ MeV}$$

$$\Gamma_{vac} = \frac{g_\rho^2}{6\pi} \frac{p_\pi^3}{M^2}$$

$$\Gamma_{med}(T(\tau)) = \left(\frac{T(\tau)}{T_{base}} \right)^4 \gamma$$

DCC Fireball Evolution & Dileptons, con't

A space-time integration of $dN/dMdy$:

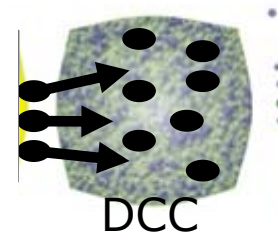
$$\frac{dN}{dMdy} = \int d^2q M \int_{\tau_o}^{\tau_f} d\tau \frac{dN(T)}{d^4x d^4q} V(\tau)$$

-Non-DCC: in medium rates as shown before

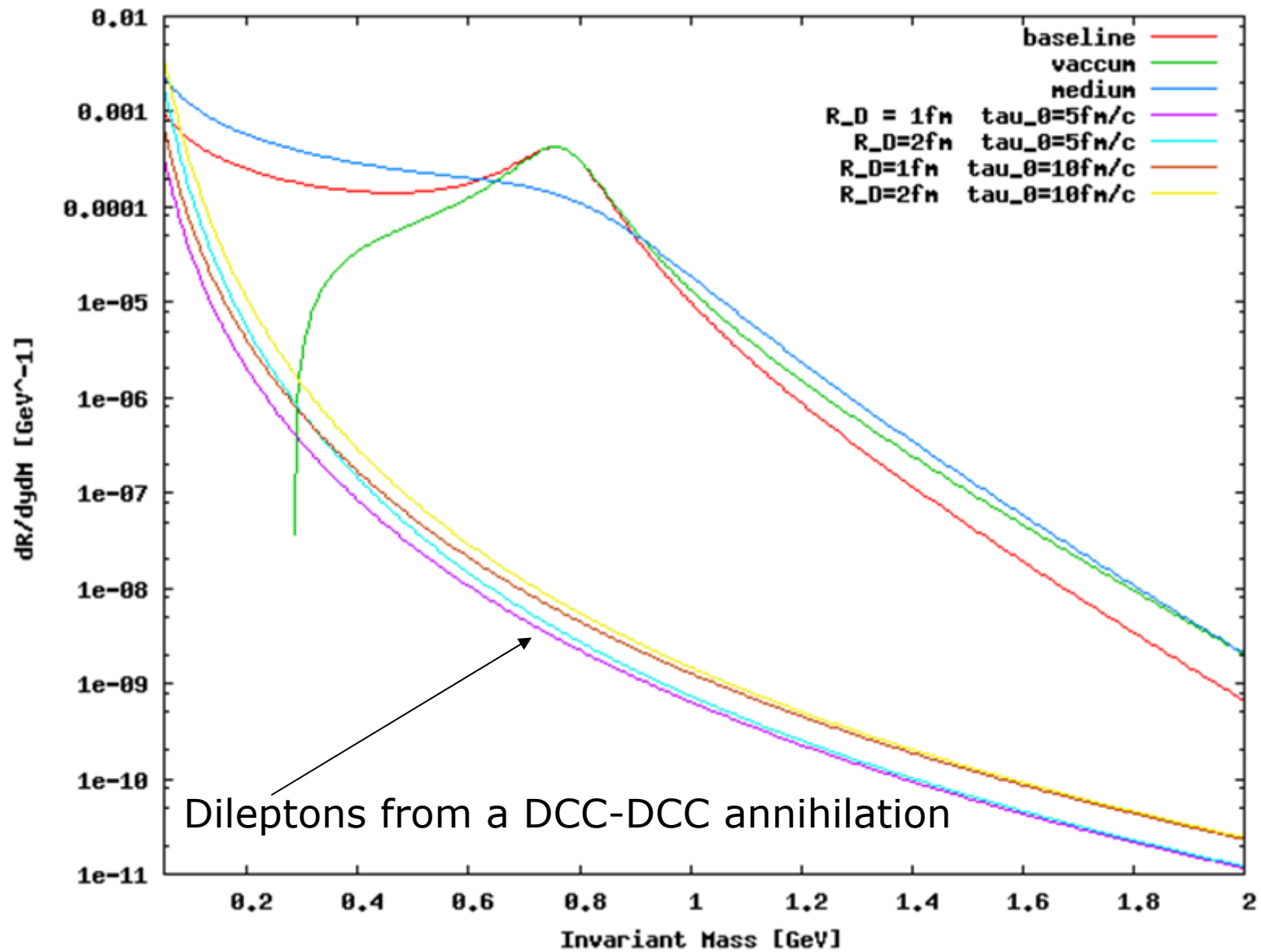
Dilepton production from a DCC-DCC annihilation [Huang-Wang '96]:

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

R_D : DCC domain size



Breit-Wigner comparison to DCC-DCC



Conclusions & Future Work

CONCLUSIONS

- Accurate, easy to use, and accessible computer programs have been made to integrate multidimensional integral functions.
- The baseline calculations have been made for comparison to the full DCC-pion implementation.
- Including the in medium effects will drown the DCC-DCC annihilation effects which therefore are much more difficult to observe.

FUTURE WORK

- Implementing the contribution of the thermal pion/DCC annihilation effects.
- Devising an theoretical method to test the existence of DCC would be extraordinary!

Acknowledgements

Special thanks to:

- Dr. Ralf Rapp and graduate student, Xingbo Zhao, for their guidance, time, and patience throughout the summer.
- Dr. Sherry Yennello and Larry May for creating and managing a fun and academically useful REU program.
- Texas A&M Cyclotron Institute for access to the resources needed to conduct research.
- The National Science Foundation for the continued funding of the Physics REU program



Cyclotron Institute
Texas A&M University



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