Jet Conversion in a Hadronic Gas

Aaron Hernley
Carnegie Mellon University
Mentor: Dr. Rainer Fries
Special Thanks to Wei Liu
Cyclotron Institute REU 2008

Quark-Gluon Plasma

- Temperatures involved in heavy-ion collisions believed to be hot enough to create a Quark-Gluon Plasma (QGP)
- Quarks and gluons are unbound
  - Exhibit color degrees of freedom

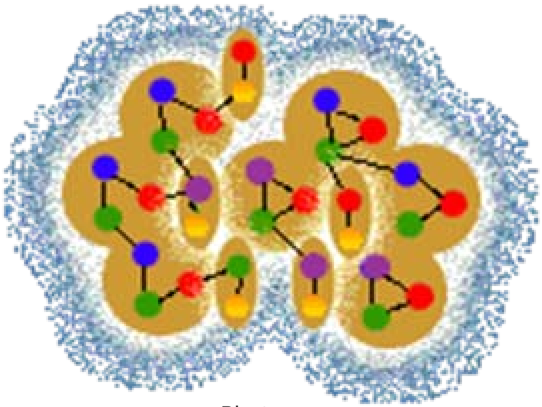


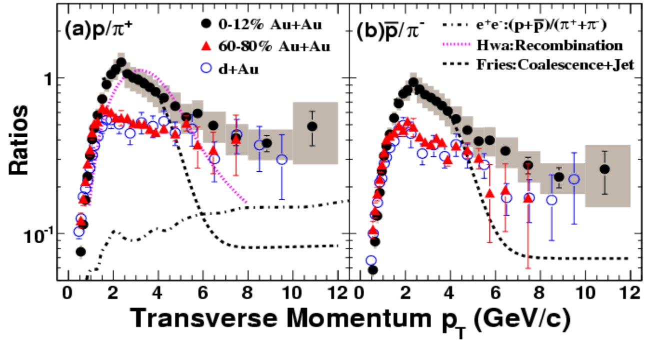
Photo source: http://www.bnl.gov/RHIC/QGP.htm

Jets

- Collisions cause jets of particles at high-p_T
- Jet is first a high energy quark or gluon
- Quark and gluon jets fragment into baryons and mesons.

Jet Quenching

- In heavy ion collisions, loss of energy of jets
  - Absorption in dense medium
  - Emission of gluon radiation
- Open Questions with theory
  - Relative suppression factor 9/4 for gluons vs. quarks not seen in data



from STAR [1]

Jet Conversion - Theory

- Jet flavor defined as flavor of leading parton
  - Not conserved in medium
  - Can be changed through inelastic or elastic scattering

$$q+\bar{q} \leftrightarrow g+g$$
$$q+g \leftrightarrow g+q$$

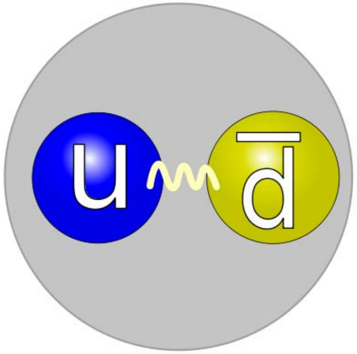
$$q+g \rightarrow \gamma+g$$
$$q+g \rightarrow \gamma+q$$

$$g+Q \leftrightarrow Q+g$$
$$g+g \leftrightarrow Q+\bar{Q}$$

- Flavor conversion in a QGP studied by Liu and Fries [3]

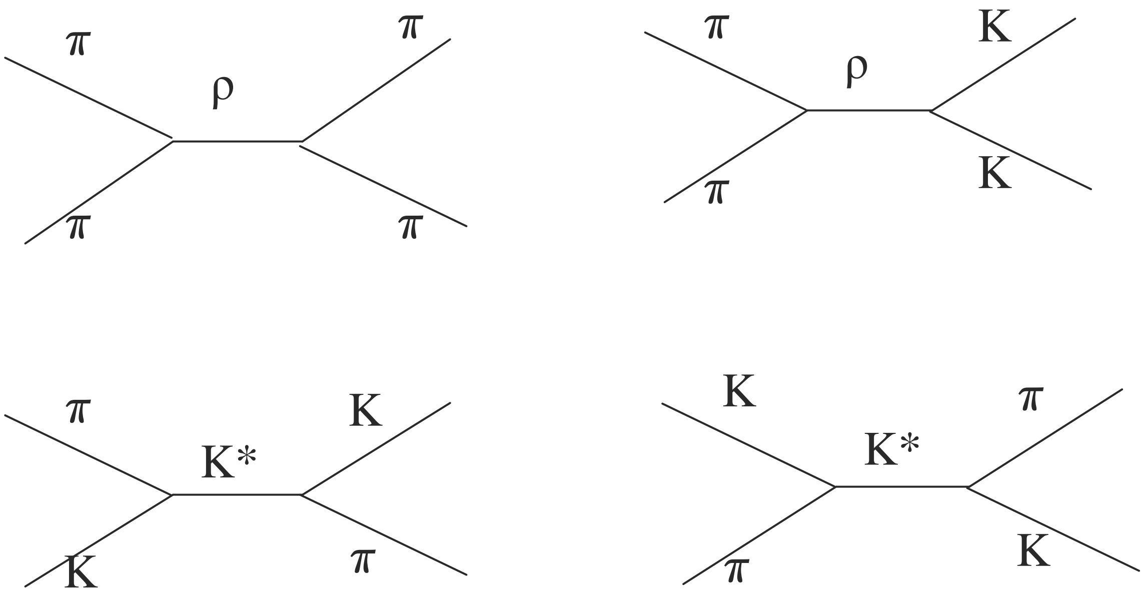
Hadronic Gas

- To check uniqueness of QGP results, need to test case of jets fragmented into hadrons in hadronic medium.
- Much less energy density than a QGP
- Main constituents are now pions and kaons



Conversion Channels

The four main channels we are concerned with are $\pi\,\pi \rightarrow \pi\,\pi$, $\pi\,K \rightarrow K\,\pi$, $K\,\pi \rightarrow \pi\,K$, and $\pi\,\pi \rightarrow K\,K$.



Interaction Lagrangian and Scattering Amplitude

- Equations of motion for propagating particles can be expressed by interaction Lagrangian.

$$\mathcal{L} = \mathcal{L}_0 + ig\mathrm{Tr}\left(\partial^\mu P\left[P, V_\mu\right]\right) - \frac{g^2}{4}\mathrm{Tr}\left(\left[P, V_\mu\right]^2\right)$$
$$+ ig\mathrm{Tr}\left(\partial^\mu V^\nu\left[V_\mu, V_\nu\right]\right) + \frac{g^2}{8}\mathrm{Tr}\left(\left[V_\mu, V_\nu\right]^2\right) \ .$$

- Can then find scattering amplitudes, $M_{12\rightarrow 34}$ for each channel.

Drag Coefficient / Conversion Width

- Drag Coefficient, γ, gives a measure of the energy loss

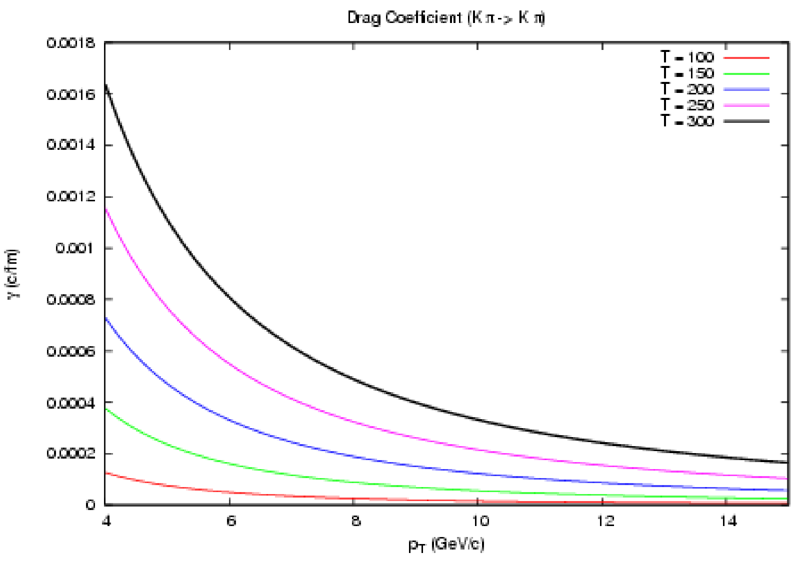
$$\gamma(|\mathbf{p}|, T) = \sum_i \left\langle \overline{|M_i|^2} \right\rangle - \frac{\sum_i \left\langle \overline{|M_i|^2 \mathbf{p} \cdot \mathbf{p}'} \right\rangle}{|\mathbf{p}|^2}$$

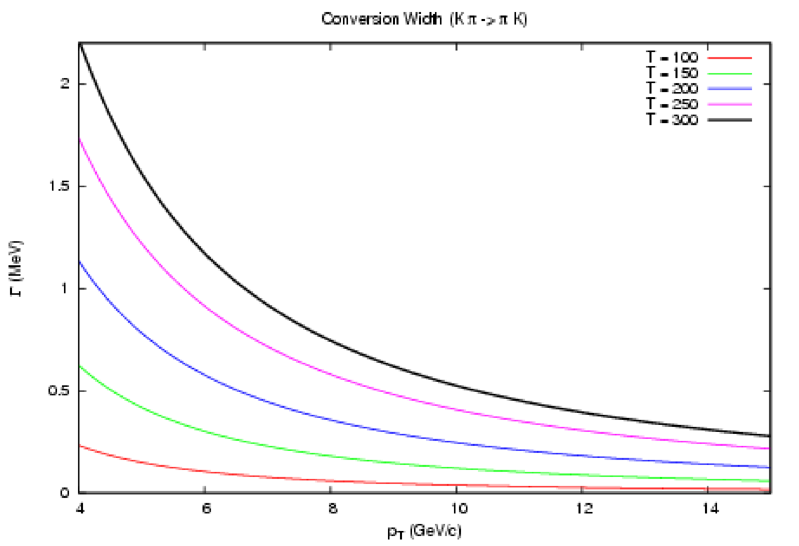
- Conversion width, Γ_c, gives probability of leading parton of jet changing its flavor

$$\Gamma_c = \frac{1}{2E_1} \int \frac{g_2 d^3p_2}{(2\pi)^3 2E_2} \frac{d^3p_3}{(2\pi)^3 2E_3} \frac{d^3p_4}{(2\pi)^3 2E_4} f(p_2)[1 \pm f(p_4)] \times \overline{|M_{12\to34}|^2} (2\pi)^4 \delta^{(4)}(p_1 + p_2 - p_3 - p_4) = \left\langle \overline{|M_{12\to34}|^2} \right\rangle$$

Extrapolation Program

- Use explicitly calculated values to create function that extrapolates γ and Γ_c, for any T and p_T.





Fireball Simulation

- Propagate jets through fireball simulation
- Code created by Dr. Wei Liu, implementing drag coefficients and conversion width functions

Nuclear Modification Factor, R_{AA}

- Useful to probe jet suppression

$$R_{AA} = \frac{\dfrac{dN^{AA}}{dp_T}}{\langle N_{coll} \rangle \dfrac{dN^{pp}}{dp_T}}$$

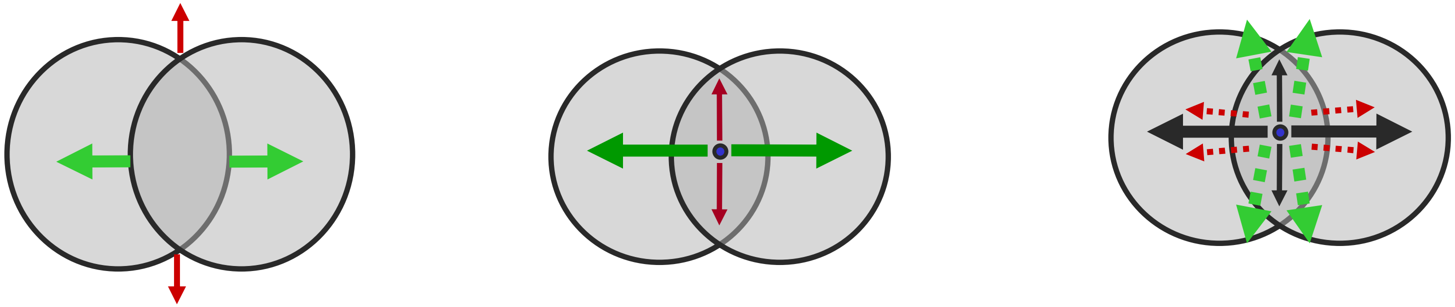
Elliptical Flow, v_2

- Azimuthal anisotropy in particle momentum, caused by having impact parameter greater than 0

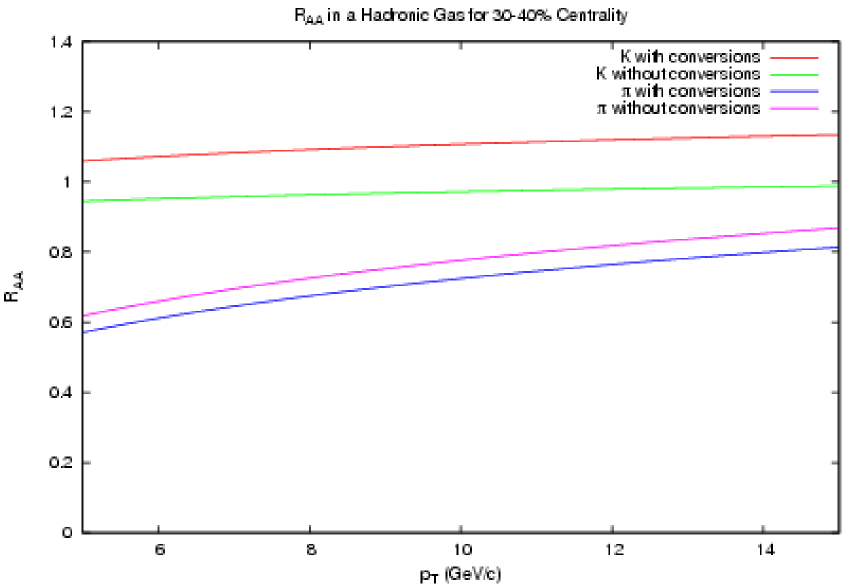
$$v_2 = \frac{\int d\varphi \frac{dN^{AA}}{dp_T d\varphi} \cos 2\varphi}{\int d\varphi \frac{dN^{AA}}{dp_T d\varphi}}$$

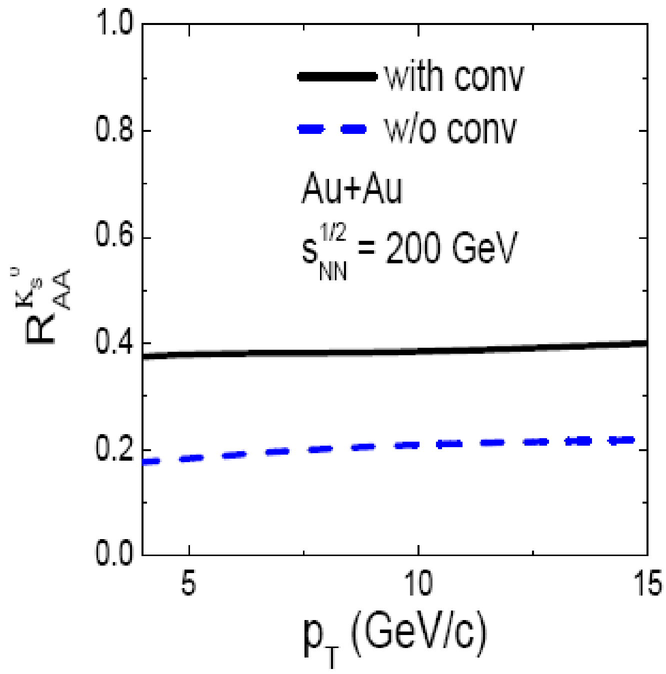
Elliptical Flow Mechanisms

- 3 mechanisms that generate anisotropy
  - Pressure gradient – from fireball itself
  - Absorption anisotropy – from jets
  - Conversion along a path – rare jets and photons



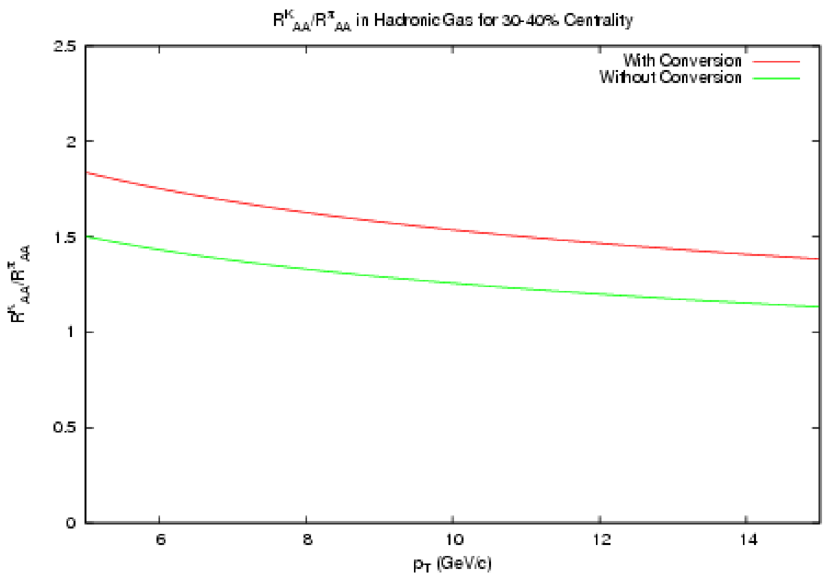
R_{AA} Comparison

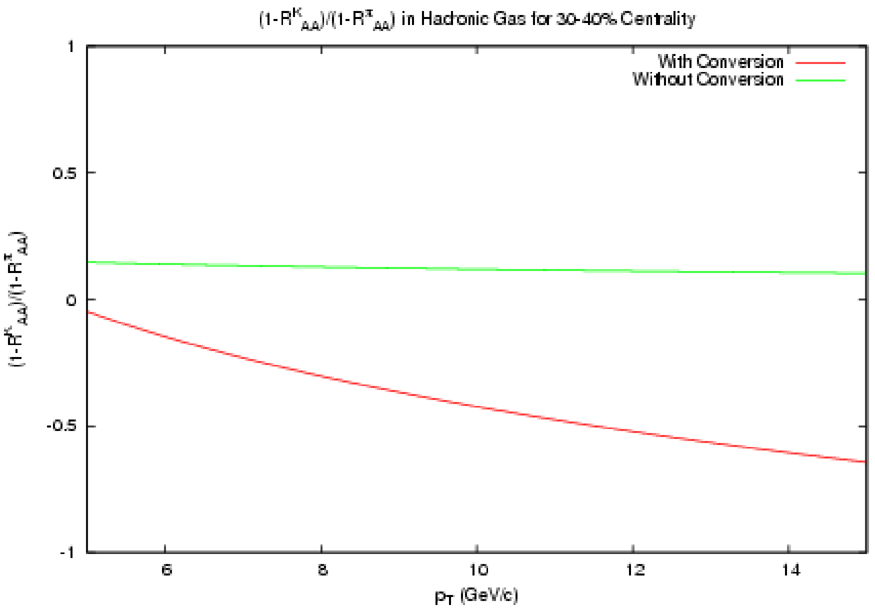




30-40% Centrality

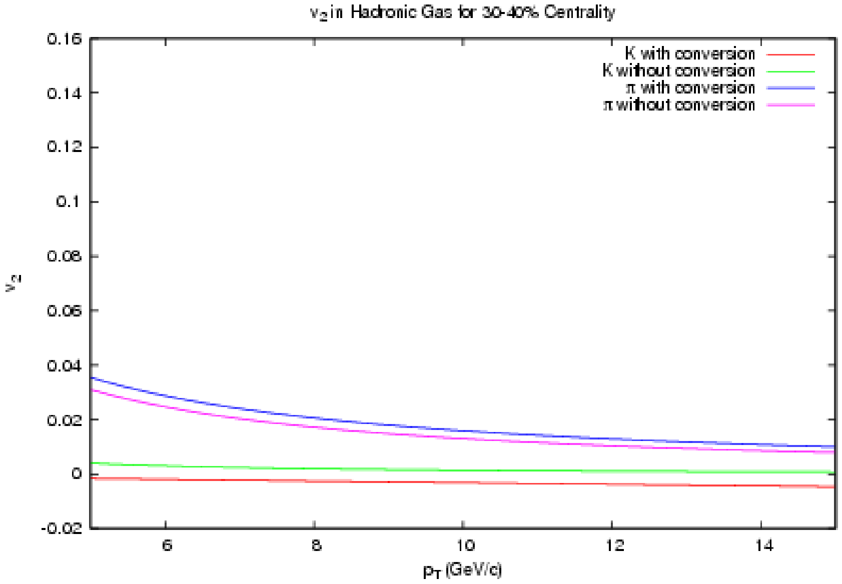
R_{AA} Double Ratio Comparison

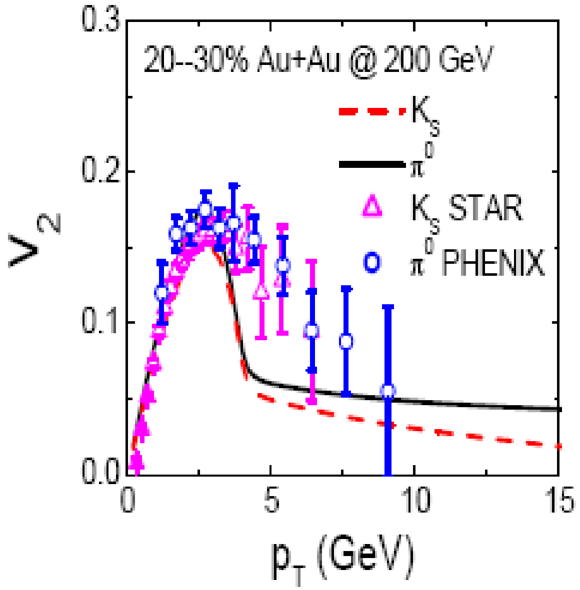




30-40% Centrality

Elliptical Flow Comparison





30-40% Centrality

Conclusions

- Much less suppression in hadronic gas than quark-gluon plasma
- K yield in hadronic gas greater than one due to net conversions overcoming small energy loss from drag
- Significant difference between the QGP and hadronic gas scenarios, which will help distinguish between the two cases
- v_2 is essentially zero in hadronic gas

Acknowledgements

- Thank you to the following:
  - Dr. Rainer Fries
  - Dr. Wei Liu
  - Dr. Sherry Yennello and the rest of the Cyclotron Institute
  - Larry May
  - Texas A&M University and the National Science Foundation

- References

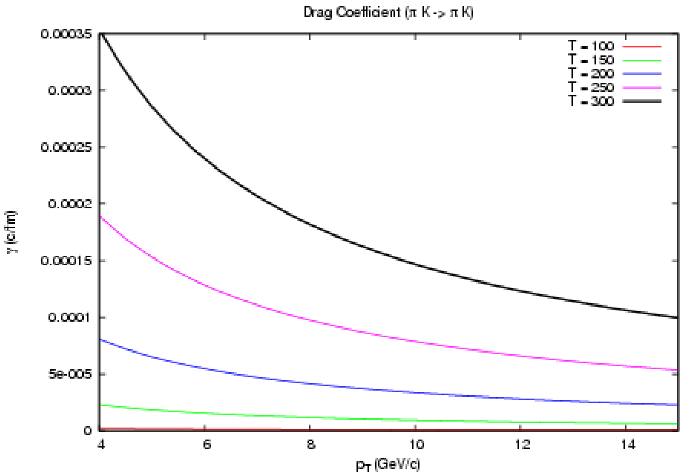
[1] B.I. Abelev et al. (STAR Collaboration), Phys. Rev. Lett. 97:152301 (2006).
[2] W. Liu, C.M. Ko, and B.W. Zhang, Phys.Rev.C75:051901 (2007).

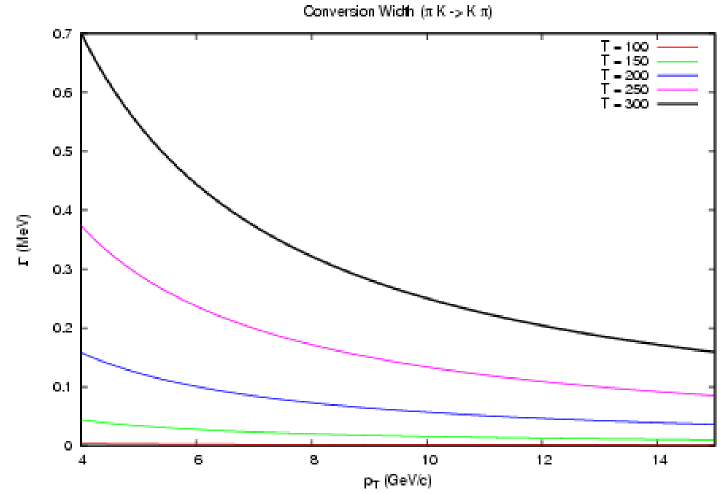
[3] W. Liu and R.J. Fries, Phys. Rev. C77:054902 (2008).

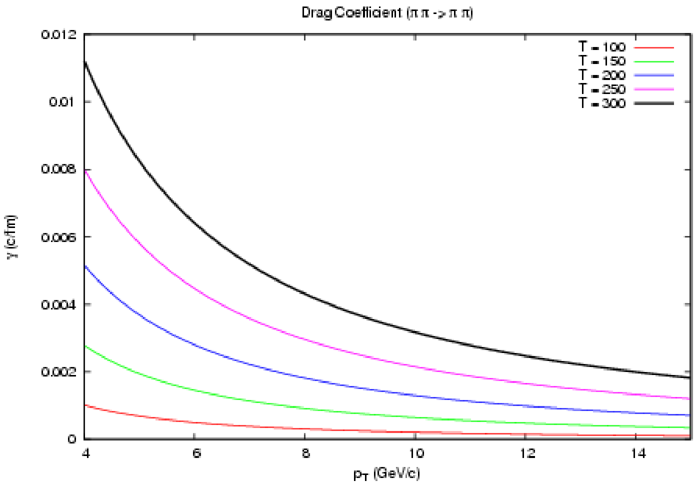
[4] Ziwei Lin and C.M. Ko, Phys. Rev. C62:034903 (2000)

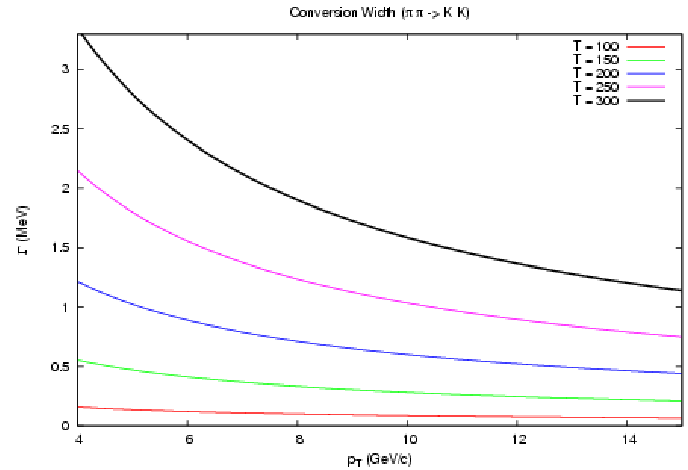
Back-Up Slides

More Extrapolation Plots

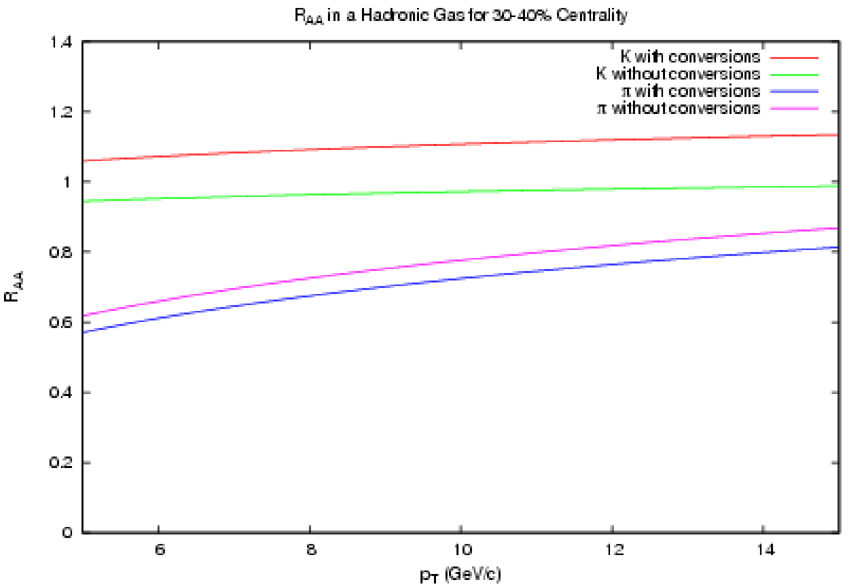


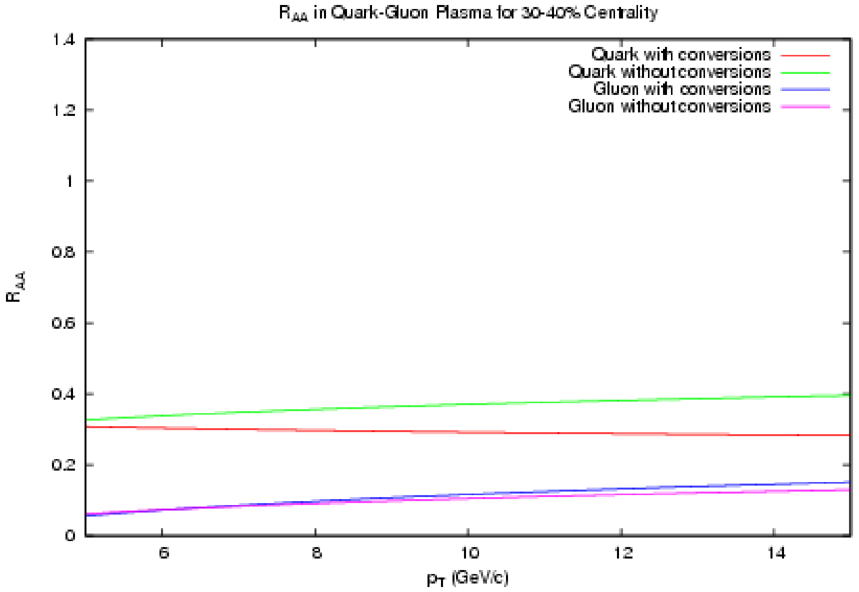






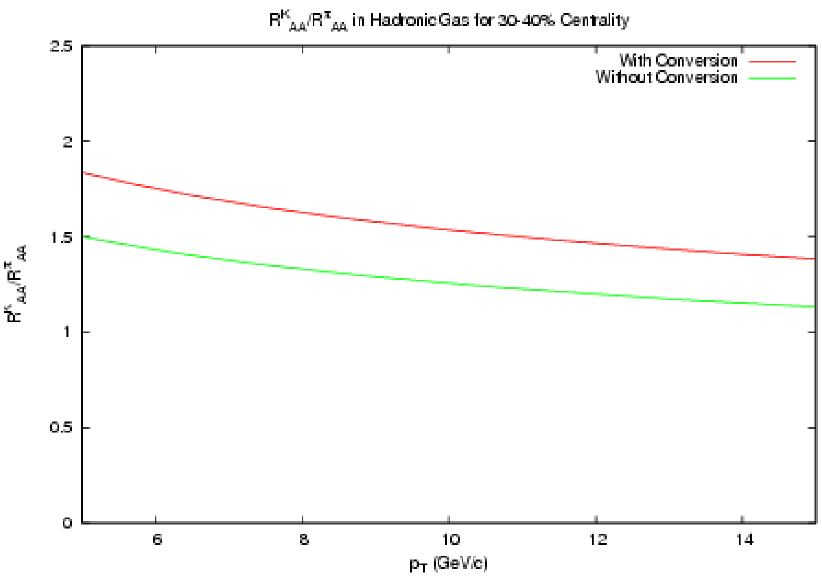
R_{AA} Comparison

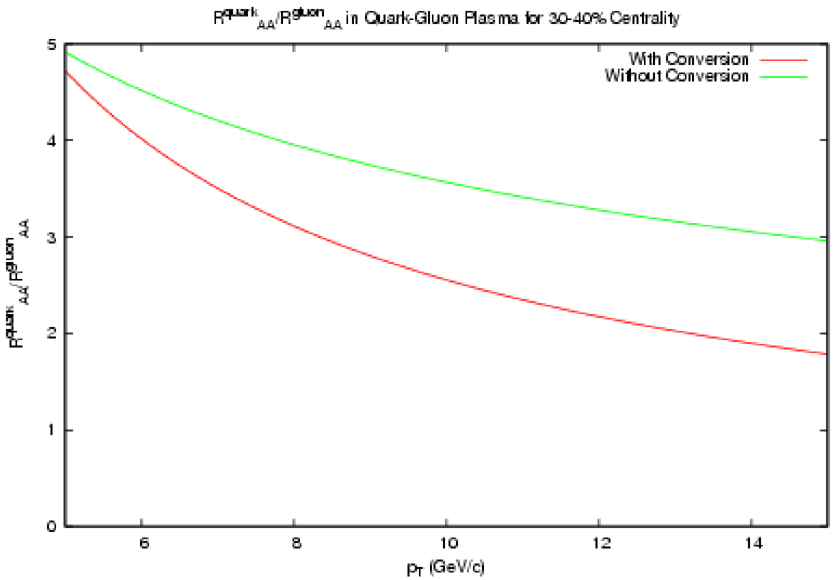




30-40% Centrality

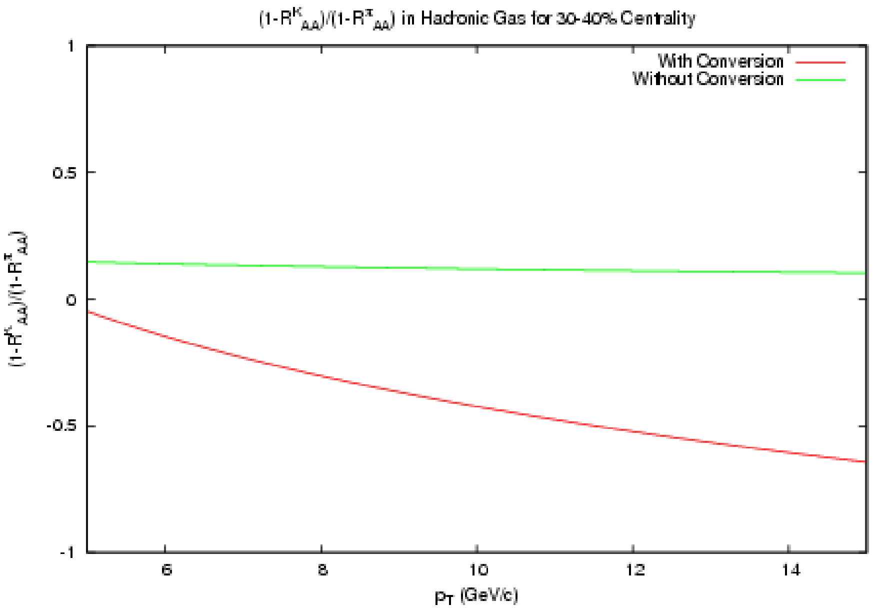
R_{AA} Double Ratio Comparison

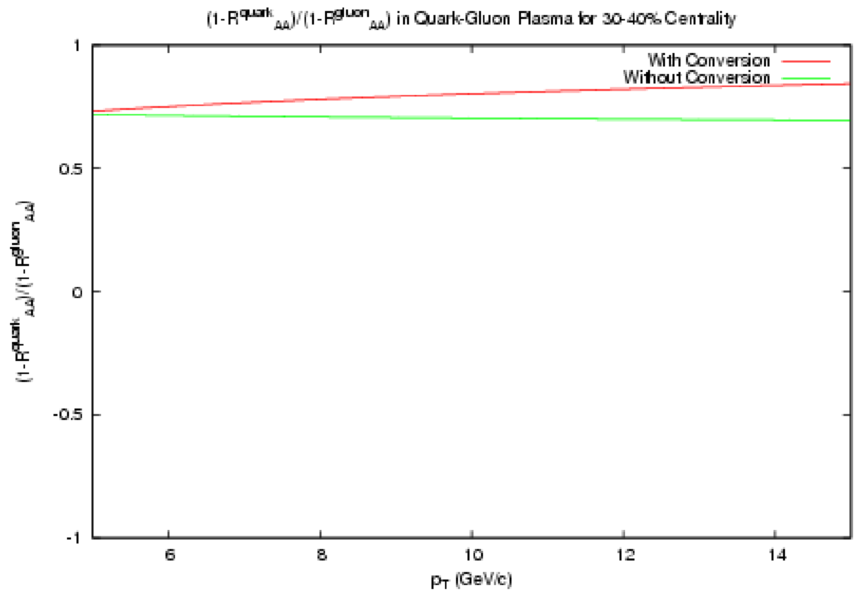




30-40% Centrality

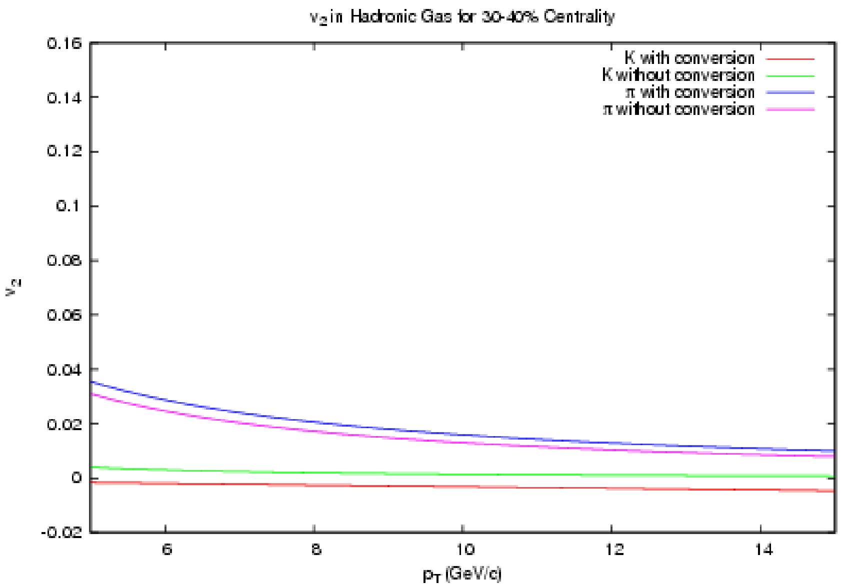
1-R_{AA} Ratio Comparison

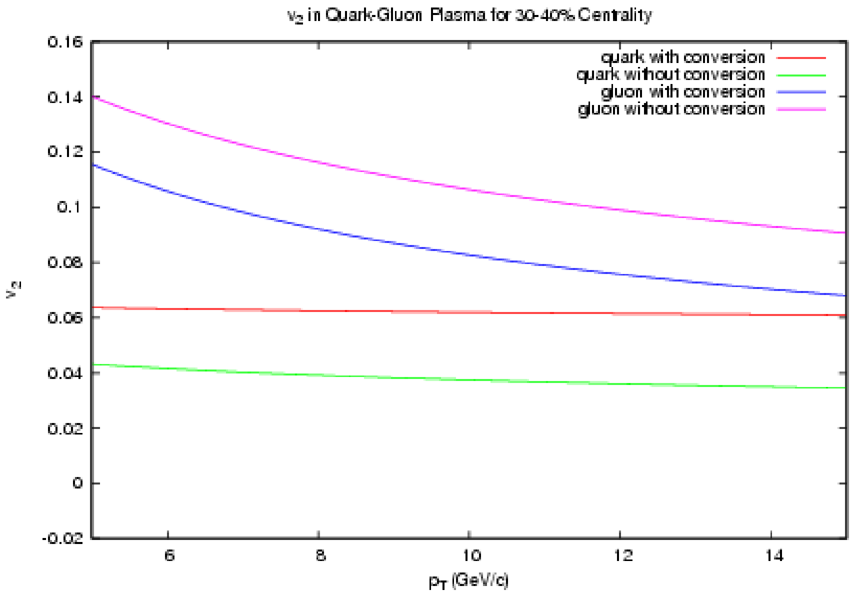




30-40% Centrality

Elliptical Flow Comparison





30-40% Centrality

0-10% Centrality Data