A new calculation of light quark jet energy loss using the AdS/CFT Correspondence

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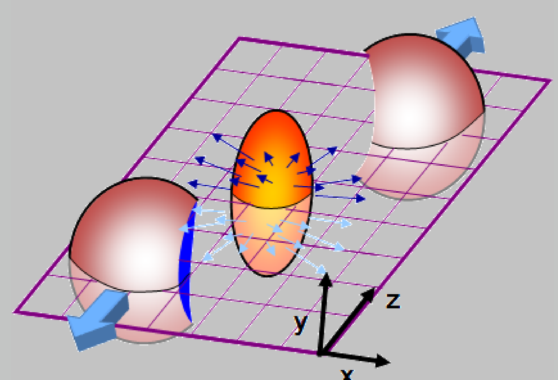
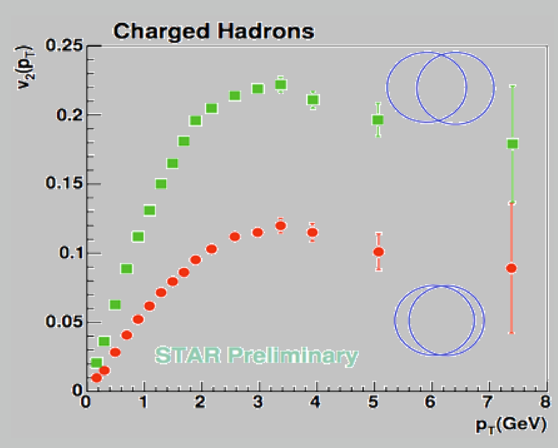
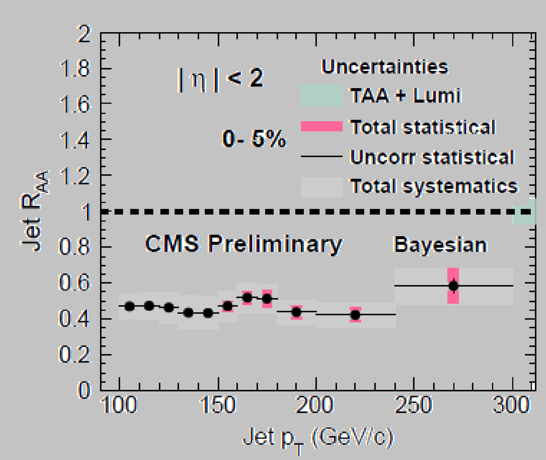
Quark-Gluon Plasma

- Quark-gluon fluid of RHIC behaves as nearly ideal, strongly coupled fluid (sQGP).
  - If produced particles interact $\longrightarrow$ Local equilibration $\longrightarrow$ produce some kind of fluid$\longrightarrow$ pressure gradients$\longrightarrow$ collective motion $\longrightarrow$ Elliptic Flow
- Rough agreement with hydrodynamic models based on perfect liquid.
  - Small shear viscosity $\longrightarrow$ Strongly interacting !
    - Hydrodynamics: $\eta/s = 0.1 \sim 0.2$
    - Naive pQCD: $\eta/s = 1$
    - N=4 SYM: $\eta/s = 1/4\pi$
  - Rapid thermalization: Less than 1 fm!
- Hard Probes:
  - Jets are produced within the expanding fireball and probe the QGP.
  - effect of hot matter on properties of jets $\longrightarrow$ Nuclear Modification Factor







AdS/CFT Correspondence

- N = 4 Super-Yang-Mills theory in 4d in large N_C and strong coupling limit $\Leftrightarrow$ A Classical supergravity on the 10d $AdS_5 \times S^5$
- Studying the theory at finite temperature $\Leftrightarrow$ Adding black hole to the geometry: AdS-Schwarzchild metric
- Fundamental quarks in theory $\Leftrightarrow$ Open strings moving in the 10d geometry

AdS-Sch metric

$$ds^2 = \frac{L^2}{u^2}\left[-f(u)\,dt^2 + dx^2 + \frac{du^2}{f(u)}\right],\ f(u) \equiv 1-(u/u_h)^4 \quad (1)$$

Hawking temperature: $T \equiv \frac{1}{(\pi u_h)}$, AdS curvature radius: $L^2 T_0 = \frac{\sqrt{\lambda}}{2\pi}$
String attached to a D7-brane ending at um $\Leftrightarrow$ Quark of mass m_Q
For light quarks, D7 brane fills all of the AdS-BH geometry $\Leftrightarrow$ Falling Strings

Light Quark in AdS-Sch

Dynamics of classical string : Polyalov Action

$$S_P = -\frac{T_0}{2}\int d^2\sigma\,\sqrt{-\eta}\,\eta^{ab}\,\partial_a X^\mu \partial_b X^\nu\,G_{\mu\nu} \quad (2)$$

Equations of motion for the embedding functions:

$$\partial_a\left[\sqrt{-\eta}\,\eta^{ab}\,G_{\mu\nu}\,\partial_b X^\nu\right] = \frac{1}{2}\sqrt{-\eta}\,\eta^{ab}\frac{\partial G_{\nu\rho}}{\partial X^\mu}\,\partial_a X^\nu \partial_b X^\rho \quad (3)$$

Choosing the world sheet metric:

$$\|\eta_{ab}\| = \begin{pmatrix} -\Sigma(x,u) & 0 \\ 0 & \Sigma(x,u)^{-1}\end{pmatrix},\ \Sigma(x,u) = \left(\frac{1-u/u_h}{1-u_c/u_h}\right)\left(\frac{u_c}{u}\right)^2 \quad (4)$$

point like initial conditions:

$$x(0,\sigma) = 0\ \ , u(0,\sigma) = u_c\ \ , t(0,\sigma) = t_c \quad (5)$$

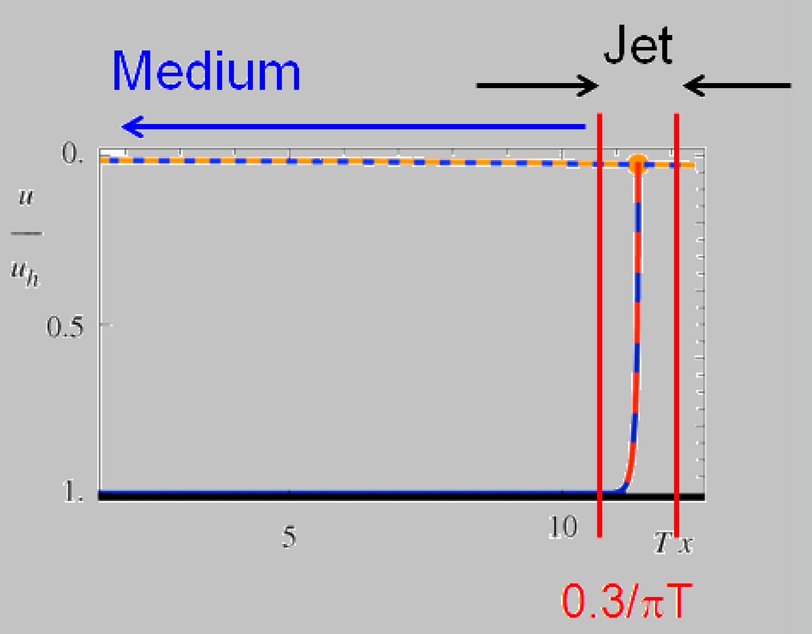
Total energy of string is conserved:

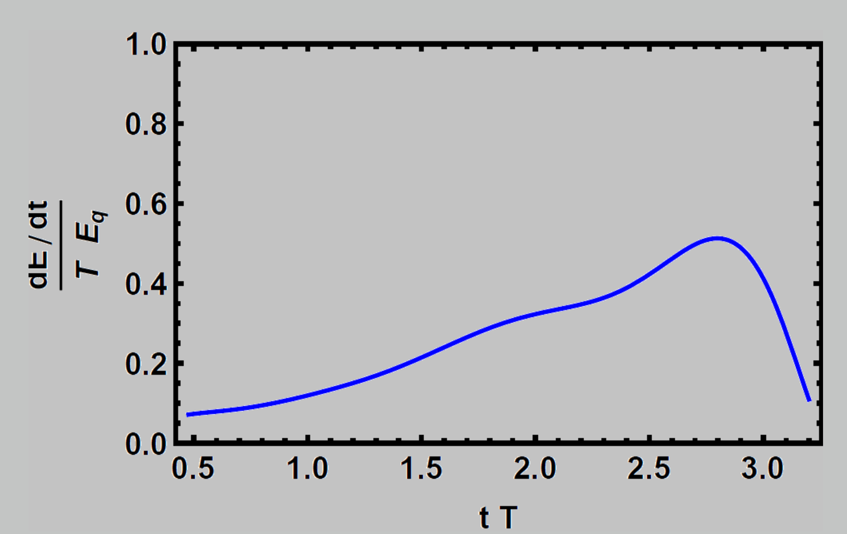
$$E_{\text{string}} = -\int_0^\pi d\sigma\,\sqrt{-\eta}\,\Pi_t^\tau(0,\sigma) \quad (6)$$

Energy Loss:

$$\frac{dp_t}{dt}(\tilde{\sigma},t) = -\frac{\sqrt{-\eta}}{\dot{t}}\left[\Pi_t^\sigma - \left(\dot{t}\,\Pi_t^\tau + t'\,\Pi_t^\sigma\right)\frac{d\sigma_\kappa}{dt}\right]_{(\sigma_\kappa(t),t)} \quad (7)$$

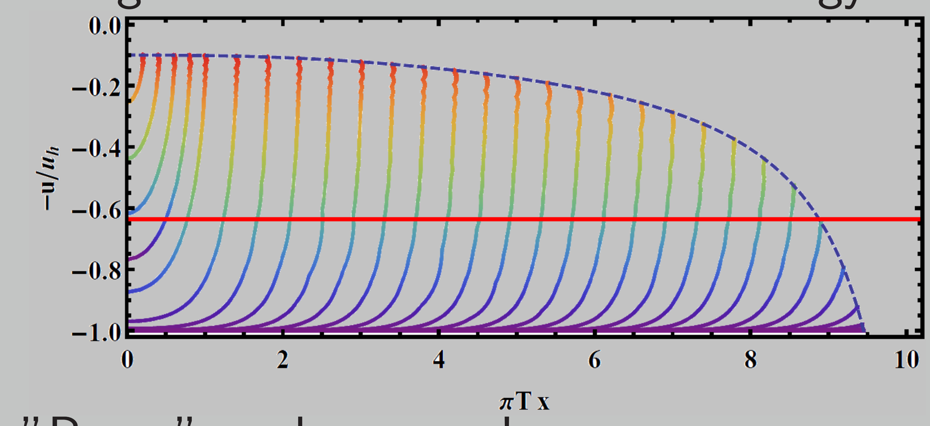
Original Jet definition:

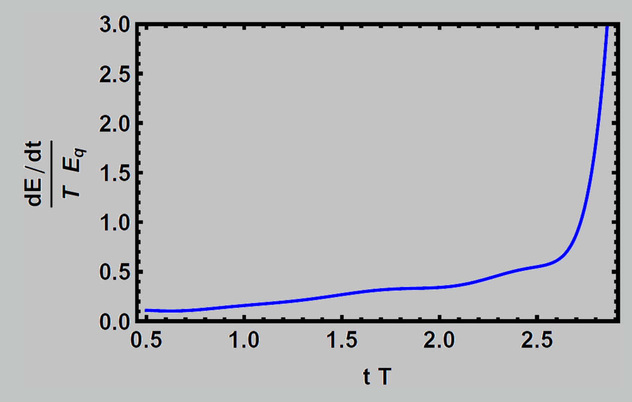




Our New Jet Prescription

Define jet by separation hard and soft scales: We define jet as a part of string which lies above a critical energy scale $\sim$ **500**MeV .





"Bragg" peak appears!

Energy Loss in a Boost-Invariant Geometry

Asymptotic boost-invariant geometry for the perfect fluid:

$$ds^2 = \frac{L^2}{u^2}\left[-\frac{\left(1-\frac{e_0}{3}\frac{u^4}{\tau^{4/3}}\right)^2}{1+\frac{e_0}{3}\frac{u^4}{\tau^{4/3}}}d\tau^2 + \left(1+\frac{e_0}{3}\frac{u^4}{\tau^{4/3}}\right)\left(\tau^2 dy^2 + dx_\perp^2\right) + du^2\right] \quad (8)$$

Dimensionfull parameter e_0 determines the energy density as $f(\tau) = e_0/\tau^{4/3}$. Rapidity y, and proper time τ are defined as:

$$x^0 = \tau\,\cosh y\quad , x^3 = \tau\,\sinh y \quad (9)$$

The metric (8) looks usual AdS-Sch metric with the horizon moving in the bulk

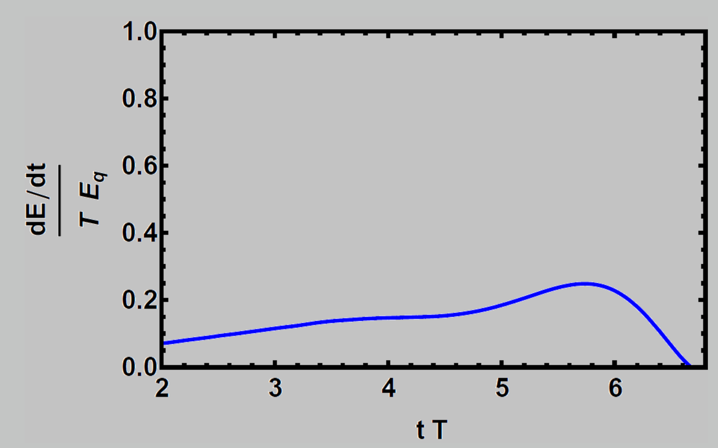
$$z_h = \left(\frac{3}{e_0}\right)^{1/4}\tau^{1/3}, \quad (10)$$

Temperature is cooling as

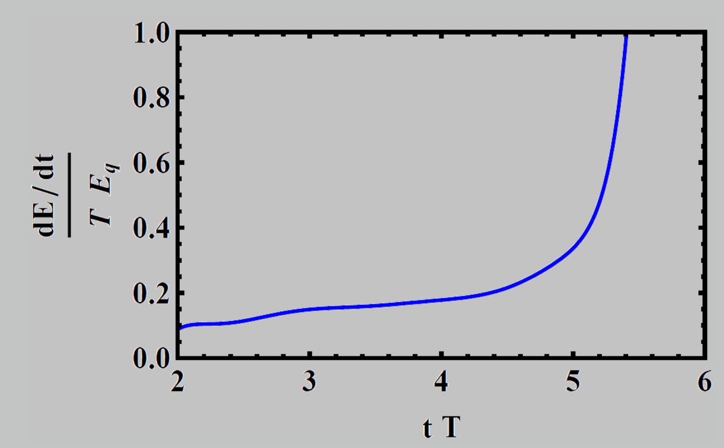
$$T(\tau) = \frac{\sqrt{2}}{\pi}\left(\frac{3}{e_0}\right)^{-1/4}\tau^{-1/3} \quad (11)$$

Next step is choosing the appropriate initial conditions, boundary conditions and stretching function for the string.

Old Prescription of Jet



Our New Prescription of Jet



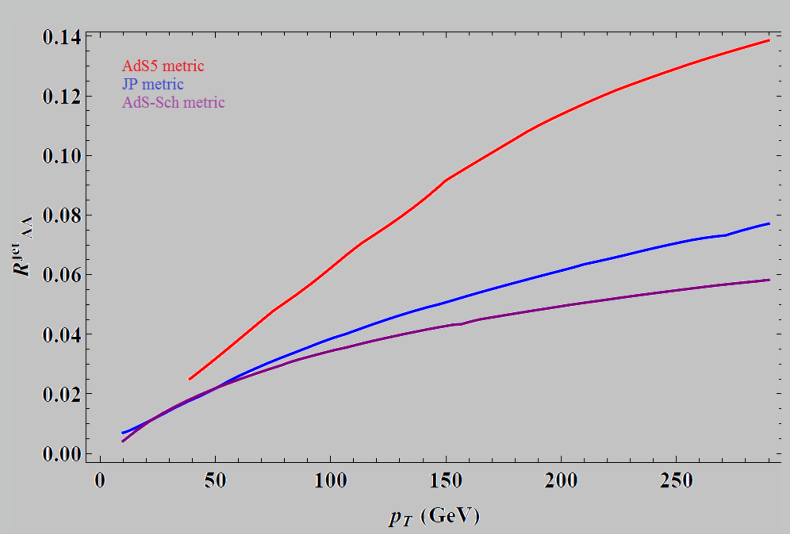
Nuclear Modification Factor

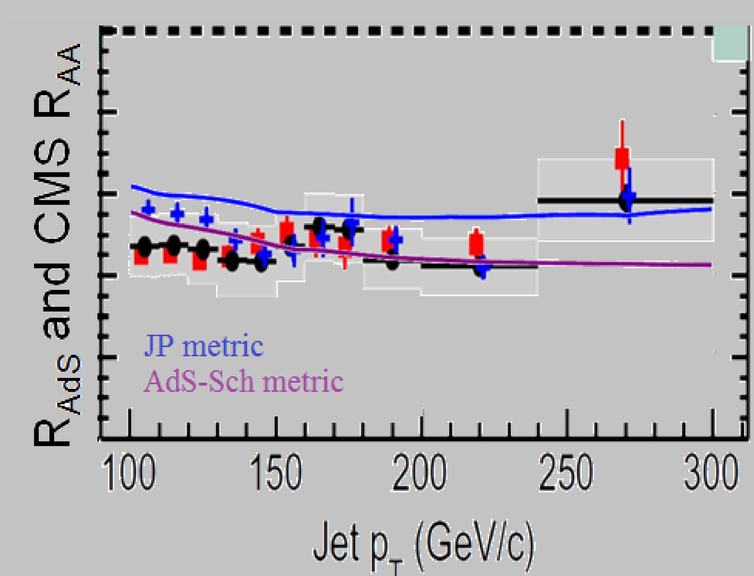
R_{AA} by assuming the power low production spectrum:

$$R_{AA}^{jet}(p_T) = \langle(\frac{p_T}{p_T^q})^{n(p_T^q)-1}\rangle_{geometrical\ average} \quad (12)$$

We define a renormalized R_{AA}

$$R_{AA}^{AdS/CFT} = \frac{R_{AA}^{jet}}{R_{AA}^{Empty\ space}} \quad (13)$$





Conclusions

- If we define the jet as a part of string above the energy scale **500**MeV, Bragg peak appeared!
- If we consider the JP metric, an expanding plasma, the thermalization time and stopping distance for light quark are larger than those on the AdS-Sch metric.
- Light quark energy loss is highly depends on the initial conditions of string.
- If we define the regularized R_{AA} by dividing to the $R_{AA}^{AdS_5}$, the result are in good agreement with jet data!
- Searching for a new string configuration dual to a high energetic quark in the QGP.