The Role of Jet Quenching in the $\bar{p}/\pi^- \geq 1$ Anomaly at RHIC

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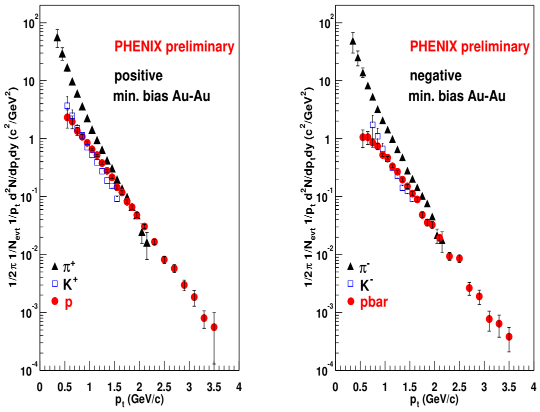
The observed quenching of the high p_T particle spectra and the large $\bar{p}/\pi^-$ ratio as a function of p_T are found to be consistent with non-abelian energy loss of fast partons in a plasma of initial gluon rapidity density $dN^g/dy \simeq 800 - 1000$ and possibly novel baryon dynamics.

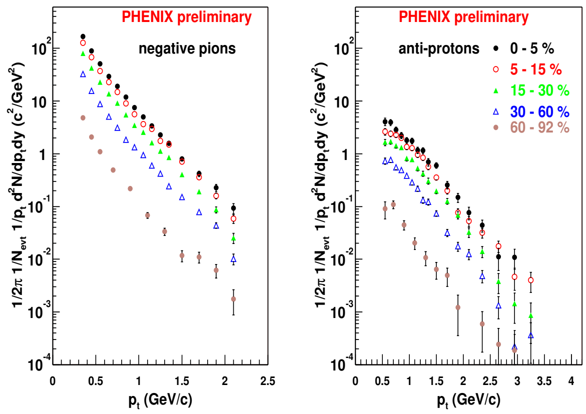
- I.V. and M. Gyulassy, [nucl-th/0104066]; Work in progress
- M. Gyulassy, P. Levai and I.V., Phys. Rev. Lett. **85** 5535 (2000)
- M. Gyulassy, P. Levai and I.V., Nucl. Phys. **B594** 371 (2001); Work in progress

Ivan Vitev

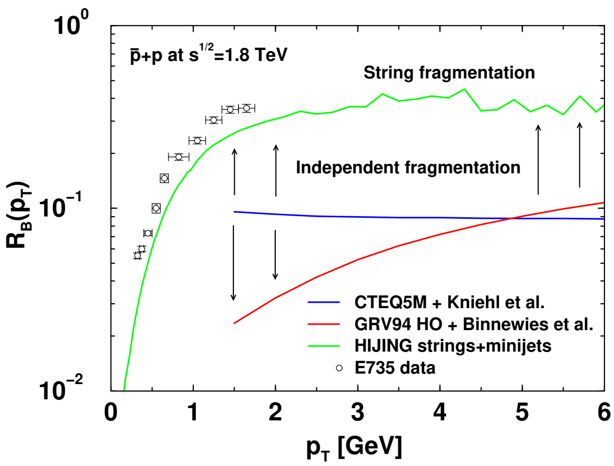
Recent RHIC Results on Baryon and Meson Production

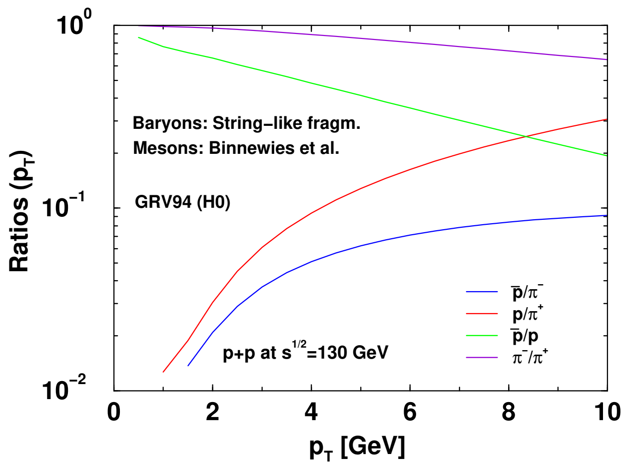
Figures by: J. Velkovska for the PHENIX Collaboration [nucl-ex/0105012]





PQCD predictions are shown for comparison. In spite of the large uncertainties PQCD expects $R_B(p_T) \leq 0.5$





Comparison to the Fermilab E-735 data at $\sqrt{s} = 1.8$ TeV is made with various fragmentation and structure functions. The baryon/meson ratio is computed at $\sqrt{s}_{NN} = 130$ GeV

The Physics of the Baryon Non-perturbative Component

Recall the Regge trajectories $J = \alpha(0) + \alpha'(0)\, M_J^2$, where $\alpha(0)$ controls the s/s_0 scaling of the cross sections and $\alpha'(0)$ controls the $\langle p_{\rm T}^2 \rangle$

On the example of string fragmentation in $\bar{q}q$ pairs:

$$\kappa = \frac{1}{2\pi\alpha'}, \quad \sqrt{\langle p_{\rm T}^2 \rangle_{q,\bar{q}}} \propto \sqrt{\kappa}$$

Observable hadron spectra $\propto$ initial quark and gluon distributions

$$\frac{dN^h}{dy d^2\mathbf{p}_{\rm T}} \sim \exp\left[-\frac{p_{\rm T}}{T}\right], \qquad \sqrt{\langle p_{\rm T}^2 \rangle_h} \propto T$$

Conjecture: that the mean observable hadron $p_{\rm T}$ is proportional to the topological parton configuration mean $p_{\rm T}$.

Baryon Junction dynamics may lead to a decrease in α' and an increase in the baryon inverse slopes, i.e.

$$\alpha'_B \simeq \frac{1}{3}\alpha'_R \quad \Rightarrow \quad T_B \simeq \sqrt{3}\, T_\pi$$

Baryon transport dynamics also predicts $dN^B/dy \sim dN^p/dy - dN^{\bar{p}}/dy = Z\beta \cosh(1-\alpha_B(0)y)/\sinh(1-\alpha_B(0)Y_{max})$. At $\sqrt{s} = 130$ AGeV $dN^B/dy \simeq 11$ (15)

Phenomenological Soft "Non-perturbative" Component

Soft non-perturbative ansatz.

$$\frac{dN_s(\mathbf{b})}{dyd^2\mathbf{p}_\mathrm{T}} = \sum_{\alpha=\pi,K,p\cdots} \frac{dn_s^\alpha}{dy}(\mathbf{b}) \frac{e^{-p_\mathrm{T}/T_0^\alpha(\mathbf{b})}}{2\pi T_0^{\alpha\,2}(\mathbf{b})}$$

We take $T^\pi \approx 0.220$ GeV, $T^p \approx 0.400$ GeV. Note that in accord with the assumed Regge trajectory for the baryon Junction it follows: $T_B \simeq \sqrt{3}\,T_\pi$

$dn_s^{tot}/dy \approx 600$ suggested by the data. If similar string dynamics drives the soft pp and AA then particle ratios can be inferred from the E-735 data: $K^-/\pi^- \simeq 11\%$ (15%), $\bar{p}/\pi^- \simeq 7\%$ (8%). Charge and strangeness conservation $\pi^+/\pi^- \simeq 1$ (1), $K^+/K^- \simeq 1$ (1.1), $\cdots$ one estimates dn_s^α/dy

$$E\frac{dN_{AB}(\mathbf{b})}{d^3p} = N_{part}(\mathbf{b})\frac{dN_s(\mathbf{b})}{dyd^2\mathbf{p}_\mathrm{T}} + T_{AB}(\mathbf{b})\frac{d\sigma_h(\mathbf{b})}{dyd^2\mathbf{p}_\mathrm{T}}$$

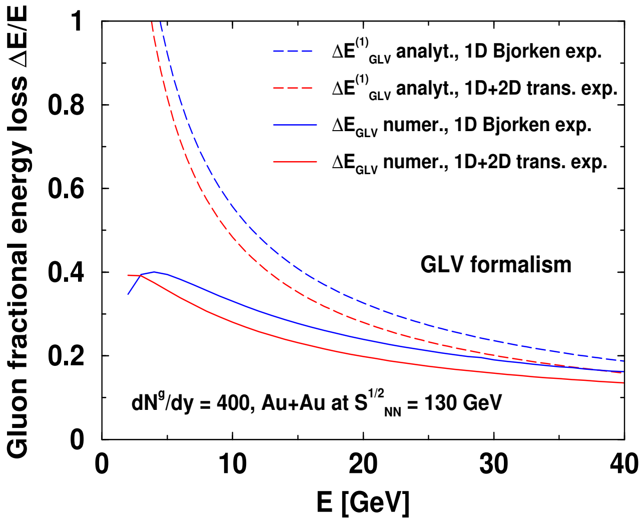
In peripheral collisions there lower density and somewhat larger string and Junction size lead to a slight decrease of the mean soft inverse slopes. Approximate $\Delta T^\pi = -0.010$ GeV, $\Delta T^K = -0.025$ GeV, $\Delta T^p = -0.050$ GeV at $\mathbf{b} = 12$ fm.

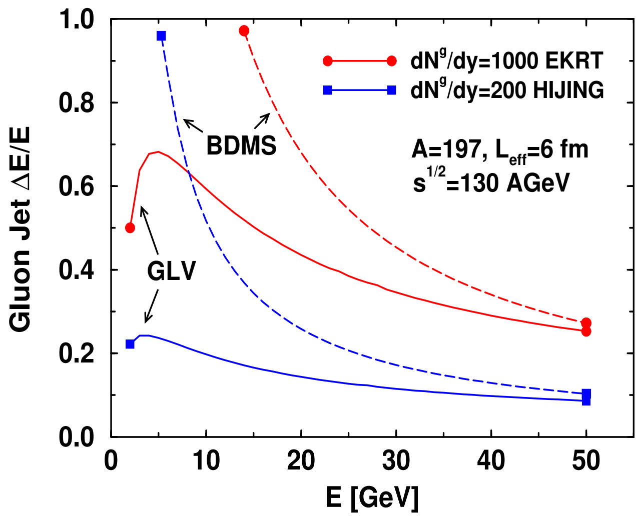
GLV Formalism - Finite Kinematics versus Asymptotic Energy Loss

$$\Delta E_{\alpha=1}(L) = \frac{9C_R\pi\alpha_s^3}{4}\left(\frac{1}{A_\perp}\frac{dN^g}{dy}\right) L \log\frac{1}{x_c}$$

$$\Delta E_{3\mathrm{D}} \approx \frac{\delta}{1+\delta v_\perp}\Delta E_{1\mathrm{D}} \quad \text{includes transverse exp.}$$

$v_\perp$ - transverse expansion velocity, δL - duration of the E-loss phase: With $L \simeq 6$ fm, $\delta \approx 1.5$ and $v_\perp = 0.6$ $\Delta E_{3\mathrm{D}} \simeq 80\% \Delta E_{1\mathrm{D}}$





The finite $E \leq 20 - 30$ GeV domain is simply out of reach for the asymptotic approximations in both GLV and BDMPS but computable numerically through the GLV solution

The analytically predicted $\sim 20\%$ reduction of ΔE is numerically confirmed for $E > 5$ GeV

PQCD Calculable Hadron Distributions

Fine-tune on $p\bar{p}$ UA1 data at $\sqrt{s} = 200$ GeV

$$
\begin{aligned}
E_h \frac{d\sigma_h^{pp}}{d^3p} \quad = \quad & K \sum_{abcd} \int dz_c dx_a dx_b \int d^2\mathbf{k}_{\mathrm{T}a} d^2\mathbf{k}_{\mathrm{T}b} \\
& f(\mathbf{k}_{\mathrm{T}a}) f(\mathbf{k}_{\mathrm{T}b}) f_{a/p}(x_a, Q_a^2) f_{b/p}(x_b, Q_b^2) \\
& D_{h/c}(z_c, Q_c^2) \frac{\hat{s}}{\pi z_c^2} \frac{d\sigma^{(ab\to cd)}}{d\hat{t}} \delta(\hat{s} + \hat{u} + \hat{t})
\end{aligned}
$$

Energy loss leads to rescaling of the hadron/parton momentum fractions

$$
z_c' = \frac{p_h}{p_c - \Delta E_c(p_c, \phi)} \,, \qquad z_g = \frac{p_h}{\Delta E_c(p_c, \phi)/N_g}
$$

A modified fragmentation function that has the feedback of the soft radiated gluons included

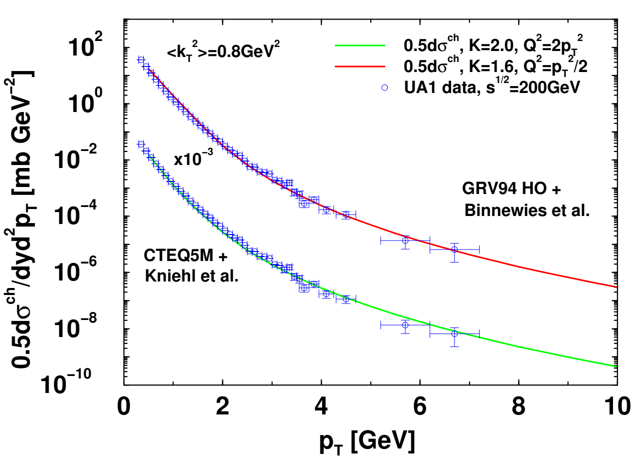
$$
z_c D'_{h/c}(z_c, Q_c^2) = z_c' D_{h/c}(z_c', Q_{c'}^2) + N_g z_g D_{h/g}(z_g, Q_g^2)
$$

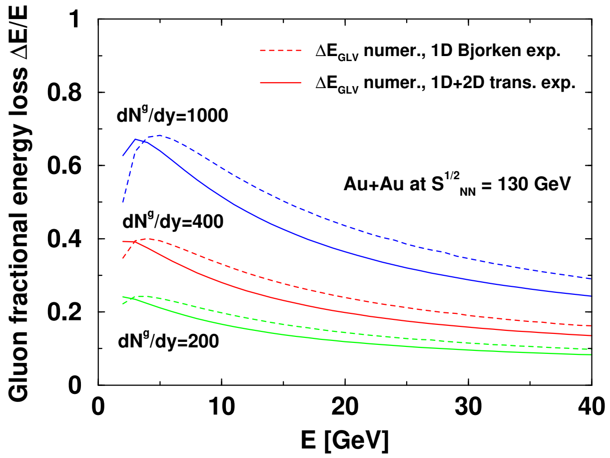
The sum rule $\int_0^1 dz \;\; z D'(z) \; = \; 1$ is automatically satisfied

Analytically and numerically shown (M. Gyulassy, P. Levai): E-loss fluctuations ($\Delta E_c \to \int \; dP_{\omega_c} f(...\omega_c...)$) can be absorbed in density renormalization factor $\sim \otimes 2 - 2.5$

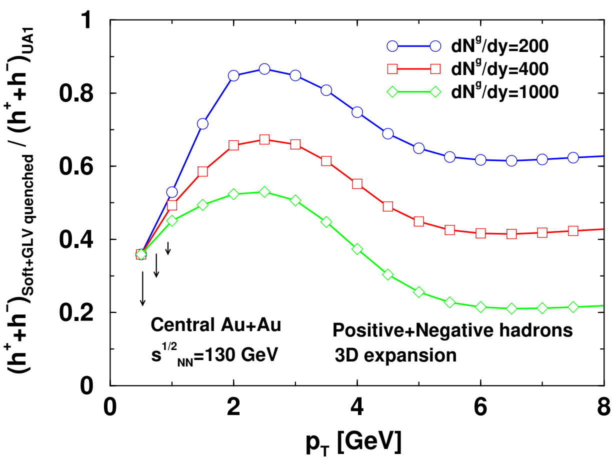
Observables Consistent with Jet Quenching

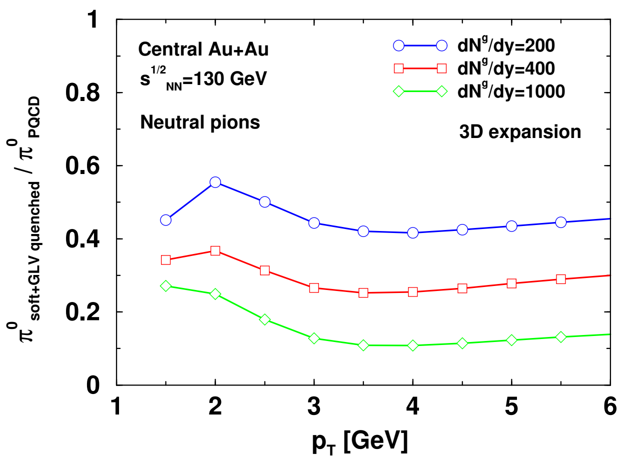
The UA1 fit is provided for reference. The density dependent energy loss is also illustrated





The suppression of the high $p_{\rm T}$ tails of hadronic spectra are signals of of non-abelian energy loss of fast partons. ($dN^g/dy \sim 2.5 \otimes 400 \simeq 1000$ in accord with estimates from the baryon/meson ratios)

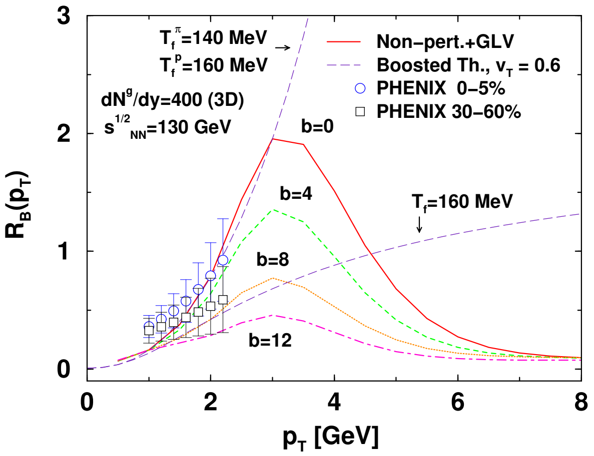


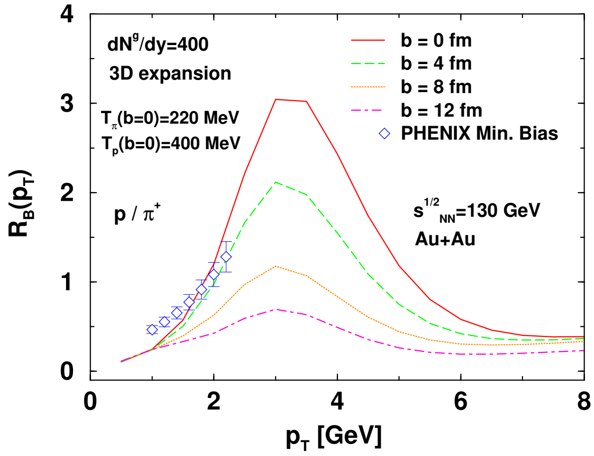


The apparent difference ~ 2 of the suppression of π^0 and h in the moderate $p_T = 2 - 4$ GeV may be caused by the strong baryon junction component

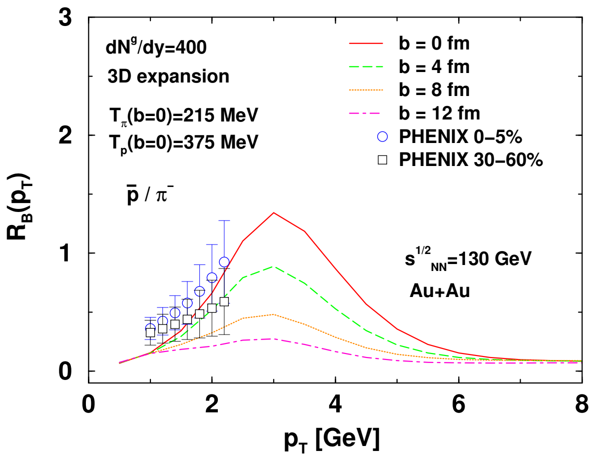
Anomalous Baryon/Meson Ratio

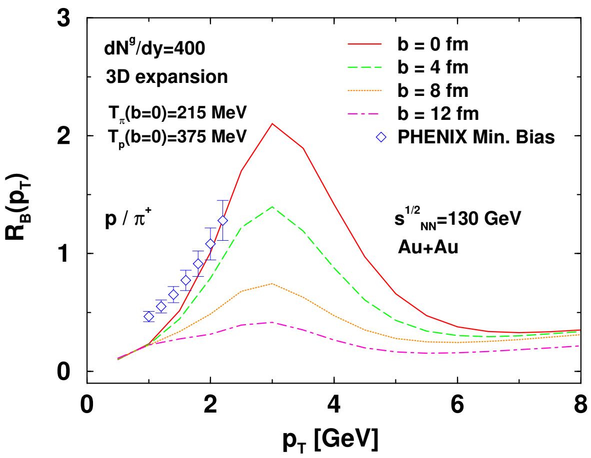
The anomalously large $\bar{p}/\pi^-$ and p/π^+ ratios are computed in the hybrid soft+GLV quenched model. In contrast boosted thermal source computation is shown to give monotonically growing ratios





Deviations from the suggested mean inverse slopes are studied. Our fits to the $\bar{p}/\pi^-$ and p/π^+ ratios inferred preliminary PHENIX data are shown for comparison





With better statistics the predicted characteristic p_T and impact parameter $\mathbf{b}$ behavior of t R_B may actually be studied in the experimentally accessible p_T region

Conclusions

- We extend the GLV formalism to include a more realistic Bjorken expanding (1D) plasma and 1D+2D expansion ($v_\perp$). We drive the energy loss problem by the initial plasma densities and use hadronic observables to obtain estimates of the properties of the hot and dense matter.
- We propose an ansatz that smoothly couples the low $p_{\rm T}$ non-perturbative phenomenological region (with the essential baryon Junction component included) with the high $p_{\rm T}$ PQCD computable region.
- The suppression of the high $p_{\rm T}$ hadronic spectra $dN^{\rm ch}/dyd^2\mathbf{p}_{\rm T}$ and the anomalously large baryon/meson ratios are consistent with jet quenching and possibly novel non-perturbative baryon Junction component. We predict specific p_T and $\mathbf{b}$ behavior of those ratios.
- Energy loss fluctuations do not change the shape of the spectra because of the non-divergent approximately constant shape of $\Delta E/E$. All corrections can be absorbed in a trivial renormalization of the initial density $\sim 2-2.5$.
- Comparison to data with the fluctuations taken into account then suggests that $dN^g/dy \sim 1000$.