Jet-Energy Loss in Heavy-Ion Collisions
Where Does the Energy Loss Lose Strength?

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OUTLINE

I. Results

0. Motivation – paradox behaviors in $R_{AB}$
   - $R_{AuAu}^\pi$ seems to increase at high-$p_T$...
   - ...but, $R_{dA}^h$ and $R_{AuAu}^\gamma$ decrease at high-$p_T$?
   - Signatures for EMC effect in $dAu$ and $AuAu$ at RHIC

I. The strength of HOT quenching at high-$p_T$ at RHIC
   - What are the good parameters: L, $\lambda$, $\mu$, $\hat{q}$, ...?
   - Conservative test: GLV energy loss at high-$p_T$

II. Nuclear Modifications at LHC – results again...
   - Analysing EMC effect in high-energy $AA'$ collisions
   - Predictions for LHC at 5.5 TeV $PbPb$ collisions
Results: What do we expect for the energy loss in $PbPb$ collisions in LHC experiments?
HOT PHENIX $\pi^0$ data
- $R_{AuAu} \approx 0.2$ at low $p_T$s
- At high $p_T \sim 15 - 20$ GeV/c
  $R_{AuAu} \approx 0.4$, where this will go?

More precise PHENIX $dAu$ data
- PRL 98 (2007) 172302
- Only huge errors at high $p_T$?
- 20 – 25% suppression and slope structure at high $p_T$?
**M O T I V A T I O N – γ**

**PHENIX prelim. γ data in dAu**
- D. Peressounko, hep-ex/0609037
- Weak but, $R_{dAu}^γ ≲ 1$, so negative slope at high $p_T$.

**PHENIX prelim. γ data in AuAu**
- T. Isobe, nucl-ex/0701040
- This is a 20 – 40% effect with negative slope again.

Paradoxon: why do differ the slopes in $π^0$ and γ production?
THEORETICAL INPUT

Baseline: \( dAu \) analysis for \( \pi^0 \) and \( \gamma \) (see poster #31)

- Shadowing function has \( x \) scaling by its nature, but parameterizations differ even \( \sim 40\% \) at low-\( x \).
- Common properties at high \( x \) all has constant negative log slope.
- Multiple scattering also scales: based on E706 measurement in FNAL we found, this is \( \sim \ln(\sqrt{s}) \)

It’s time to see the energy loss...
Models for jet energy loss in heavy-ion collisions

The 'conservative' non-Abelian jet energy loss methods

– Energy loss in THICK plasma BDMS, LCPI
– Energy loss in THIN plasma GLV

New models on jet energy loss

– PQM model Loizides, Daniese, Paić
– AdS CFT for heavy quarks, see the talk of W. Horowitz
– ...

Here, I will use the ’conservative’ way with $L/\lambda$
Medium induced radiative energy loss – for $L \sim \lambda_g$


**GLV:** time-ordered pQCD (Feynman diagramms)

+ OPACITY expansion ($n = 1, 2, 3, ...$)
+ kinematical cuts

\[ M_{n_s,m,l} \text{ where } l = 2^{n_s-m} - 1 \]

Simplification of this equation:
Relative Energy Loss vs. Jet Energy

Energy dependence of GLV jet energy loss

$$\Rightarrow \Delta E_{GLV} \approx \Delta E_{GLV}^{(1)} \approx \frac{C_R \alpha_s}{N(E)} \frac{L^2 \mu^2}{\lambda_g} \log \frac{E}{\mu}$$

- $\Delta E$ is $E$-dependent
  - $N(E)$ is a numerical function, $N(E) \rightarrow 4$ at $E \rightarrow \infty$.
- $\approx E$-independent $\Delta E/E$ in $3 < \text{GeV} \; E < 10 \; \text{GeV}$
- Opacity $n = L/\lambda$
- logarithmic tail

![Graph showing $\Delta E/ \Delta E_{GLV}^{(1)}$ vs. $E$ for different $L/\lambda$ values]
GLV jet-quenching in thin plasma approximation $L \sim \lambda_g$

$$\Delta E_{GLV} \approx \frac{C_R \alpha_s}{N(E)} \frac{L^2 \mu^2}{\lambda_g} \log \frac{E}{\mu} = \frac{C_R \alpha_s}{N(E)} \frac{1}{A_{\perp}} \frac{dN}{dy} \langle L \rangle \log \frac{E}{\langle \mu \rangle}$$

Energy loss of jet decreases the $p_c$ momenta of $c$ before fragmentation:

$$\frac{D_{\pi/c}(z_c, Q'^2)}{\pi z_c^2} \rightarrow \frac{z_c^*}{z_c} \frac{D_{\pi/c}(z_c^*, Q'^2)}{\pi z_c^2}, \text{ where } z_c^* = \frac{z_c}{1 - \Delta E/p_c},$$

\[\begin{align*}
\text{Au} + \text{Au} & \rightarrow \pi^0 \text{ at 130 AGeV} \\
\text{Central Collision} & \quad \text{pQCD+shadowing} \\
& \quad + \text{multiscattering} \\
& \quad \text{GLV quenching} \\
\text{Peripheral Coll.} & \quad \text{Preliminary PHENIX data} \\
& \quad \text{pQCD} \\
& \quad L/\lambda
\end{align*}\]
Jet-tomography at midrapidity in AuAu and CuCu

Extracting opacities in all centralities for $p_T > 4$ GeV/c
(See more in P. Lévai's talk)

All of these information are summarized ⇒
Analyzing opacity dependence in midrapidity $AA'$ collisions

$L \propto A^{1/3} \propto N_{\text{part}}^{1/3}$

$\varepsilon = \Delta E/E \propto L^2 \propto N_{\text{part}}^{2/3}$

$\implies$ Suppression or enhancement is expected at LHC?
Opacity Prediction for $PbPb$ collisions at LHC

\[ L \propto A^{1/3} \propto N_{\text{part}}^{1/3} \]

\[ \varepsilon = \frac{\Delta E}{E} \propto L^2 \propto N_{\text{part}}^{2/3} \]

\[ \implies L/\lambda \text{ will NOT disappear in very peripheral collisions;} \]

\[ \implies N_{\text{part}} \text{ suggests strong suppression for LHC with } L/\lambda \approx 8 - 12; \]

\[ \implies \ldots \text{ but energy loss loses its strength at high } p_T \]
How the energy loss will look like at high energies?

Without shadowing

- General rule: \( \frac{dN}{dy} \sim \ln \sqrt{s} \)
- Central \( AuAu \) at RHIC
  \[
  \frac{1}{A_{\perp}} \frac{dN}{dy} \approx \frac{680}{\pi R_{AuAu}^2} = 5.1
  \]
- LHC: \( \frac{dN}{dy} \sim 1500 - 2000 \)
  \[
  \frac{1}{A_{\perp}} \frac{dN}{dy} \approx 10 - 15
  \]

With all nuclear effects

- Shadowing (EMC) effect will suppress again at high-\( x \)
$R_{PbPd}$ might enhance at $p_T \sim 15$ at RHIC

but, makes a maximum even at LHC energies.
SUMMARY

Latests PHENIX \( R_{AB} \) data have paradox behavior
- \( R_{AuAu}^\pi \) seems to increase at high-\( p_T \)...
- ...but, \( R_{dA}^h \) and \( R_{AuAu}^\gamma \) decrease at high-\( p_T \)?
- possible signature of the EMC effect in \( dAu \) and \( AuAu \)

I. The strength of HOT quenching at high-\( p_T \)
- Conservative test: GLV energy loss at high-\( p_T \)
- We expect a maximum of \( R_{AuAu}^\pi (p_T) \) at \( p_T \approx 15 \text{ GeV/c} \)

II. Nuclear Modifications at LHC energies – result again...
- Opacity estimated \( L/\lambda \approx 8 – 12 \) in \( PbPb \) at LHC
- Using this \( R_{AuAu}^\pi (p_T) \) were shown for LHC at 5.5 TeV \( PbPb \)

Identified high-\( p_T \) particle measurements in ALICE
- HMPID and VHMPID detectors in ALICE posters: 97 & 98