Energy density and path-length dependence of the fractional momentum loss in heavy-ion collisions at $\sqrt{s_{\rm NN}}$ from 62.4 to 5020 GeV

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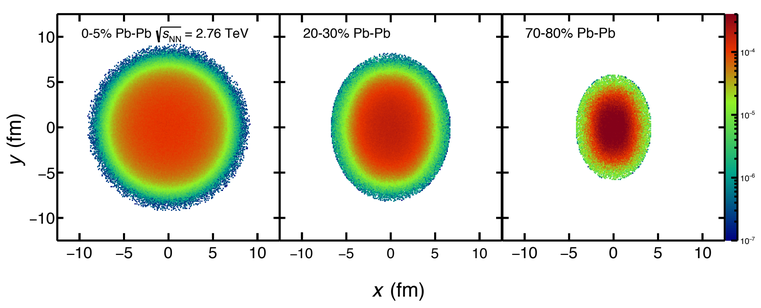
Introduction

- At large transverse-momenta, yields are mainly suppressed by medium-induced gluon radiation accompanying multiple scattering [1]. To model these effects, a convolution of the vacuum (pp) production cross section of the particle with energy $p_{\rm T}+\epsilon$ with the distribution $D(\epsilon)$ that describes the additional energy loss ϵ in the final state is used and the quenching effect can be modeled by the substitution: $\frac{{\rm d}^2\sigma_{AA}(p_{\rm T})}{{\rm d}y{\rm d}p_{\rm T}} = \frac{{\rm d}^2\sigma_{\rm pp}(p_{\rm T}+\delta_{p_{\rm T}})}{{\rm d}y{\rm d}p_{\rm T}}$
- The shift in momenta is: $\delta_{p_{\rm T}} \approx (p_{\rm T}\omega_{\rm c})^{1/2}$. Considering $\omega_{\rm c} = \hat{q}L^2/2$, $\hat{q}$ being the transport coefficient and that the ideal estimate from pQCD calculation is $\hat{q} \propto \epsilon^{3/4}$ [2], with ϵ the energy density of the system, one would expect: $\delta_{p_{\rm T}} \approx p_{\rm T}^{1/2}\epsilon^{3/8}L$.
- $\delta_{p_{\rm T}}$ can be related with the fractional momentum loss ($S_{\rm loss}$) and that a linear relation between $S_{\rm loss}$ and $\epsilon^{3/8}L$ is required in order to describe the behavior of the $R_{\rm AA}$ at high $p_{\rm T}$.

Methodology

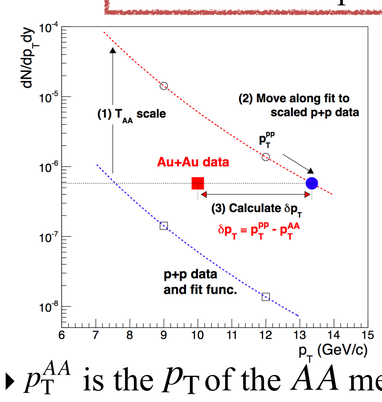
Characteristic path length



- Glauber MC → $N_{\rm part}$ distributions.
- $A_{\rm T} \propto \sigma_x\sigma_y$.
- Scattering centers were generated randomly according to the $N_{\rm part}$ distributions.
- $L \propto \sigma$, with σ being the RMS of the distance distribution that a parton travels from the scattering center to the edge of the area.

Fractional momentum loss

$S_{\rm loss}$ measure of parton energy loss [3]



$$S_{\rm loss} \equiv \delta p_{\rm T}/p_{\rm T} = \frac{p_{\rm T}^{\rm pp} - p_{\rm T}^{AA}}{p_{\rm T}^{\rm pp}}$$

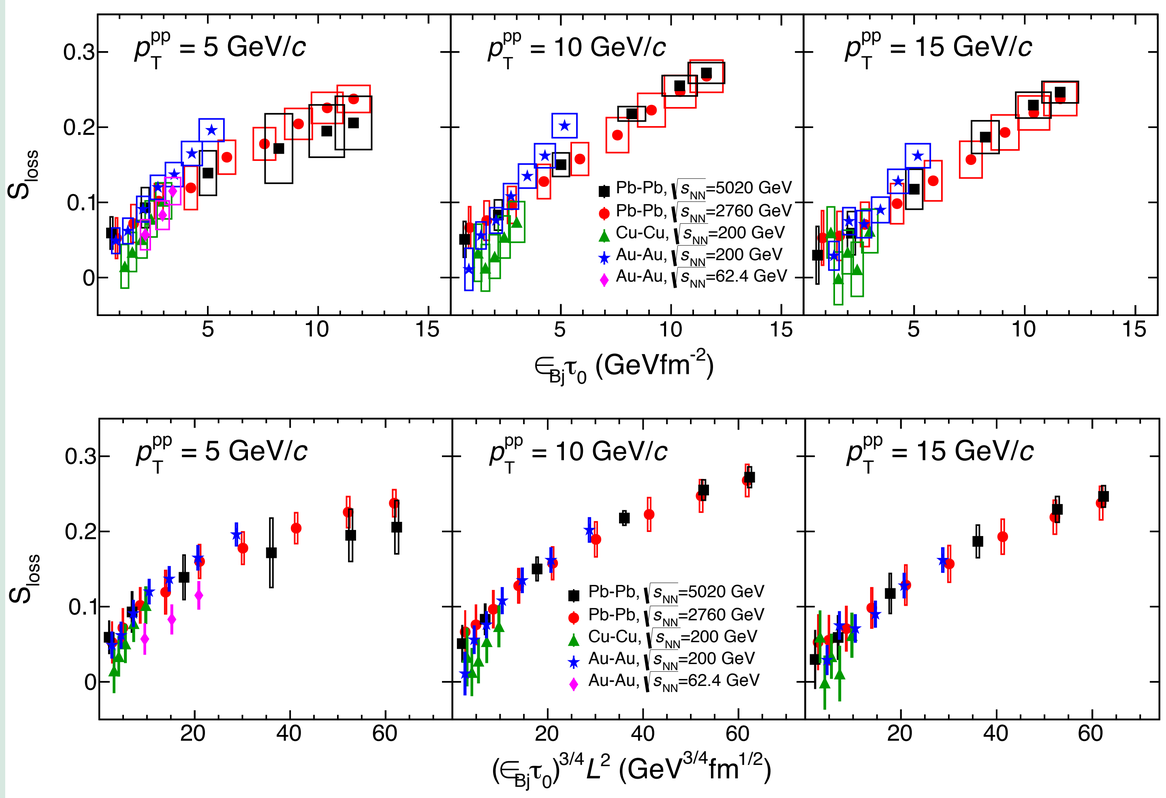
- $p_{\rm T}^{AA}$ is the $p_{\rm T}$ of the AA measurement.
- $p_{\rm T}^{\rm pp}$ corresponds to the pp measurement at the same yield of AA.
- The pp measurement was scaled by the mean number of binary collisions $\langle N_{\rm coll}\rangle$ of the corresponding centrality class.

Bjorken energy density

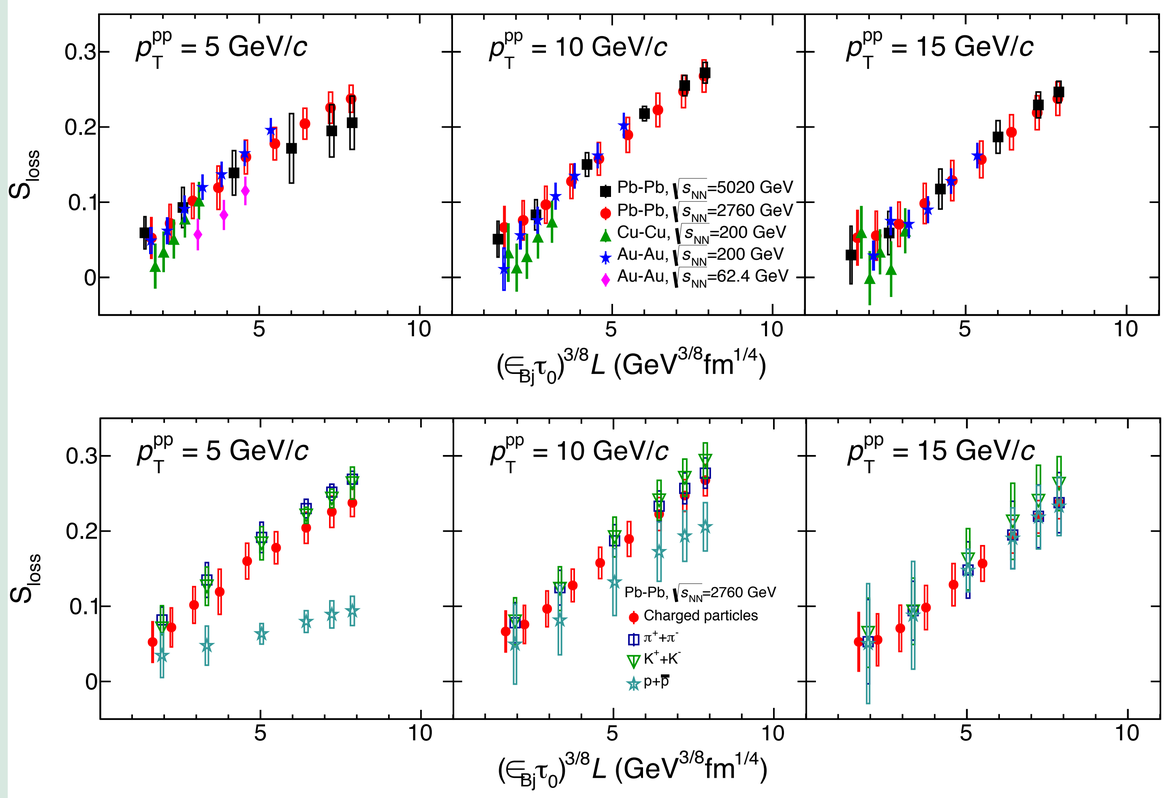
$$\epsilon_{\rm Bj} = \frac{1}{\tau_0 A_{\rm T}}\left\langle \frac{{\rm d}E_{\rm T}}{{\rm d}y} \right\rangle$$

- Mean transverse energy per unit rapidity.
- Proper time (model dependent) when the QGP is equilibrated.
- The values for $\epsilon_{\rm Bj}\tau_0$ at $\sqrt{s_{\rm NN}} = 62.4$ and 200 GeV are reported in [3].
- The corresponding value at $\sqrt{s_{\rm NN}} = 5.02$ TeV is extrapolated using the fact that $\langle {\rm d}E_{\rm T}/{\rm d}\eta\rangle/\langle N_{\rm ch}/{\rm d}\eta\rangle$ vs. $\langle N_{\rm part}\rangle$ is nearly energy independent from RHIC to run I LHC energies [4].

Results



- $s_{\rm loss}$ vs. $\epsilon_{\rm Bj}\tau_0$ is linear only for $p_{\rm T}^{\rm pp} > 10$ GeV/c.
- $s_{\rm loss}$ vs. $(\epsilon_{\rm Bj}\tau_0)^{3/4}L^2$ fails to reproduce a scaling. Furthermore, $(\epsilon_{\rm Bj}\tau_0)^{3/4}L^2 \approx 0$ does not yield a fractional momentum loss equal to zero.



- A scaling is observed for $p_{\rm T}^{\rm pp} \geq 10$ GeV/c.
- A decrease of around 20% from $p_{\rm T}^{\rm pp} \approx 10 \rightarrow 15$ GeV/c is consistent with the fact that at hight transverse-momentum $S_{\rm loss} \propto 1/\sqrt{p_{\rm T}}$.

Conclusions

- For all the transverse-momentum values which were explored, $5 < p_{\rm T} < 10$ GeV/c, the fractional momentum loss was found to increase linearly with $(\epsilon_{\rm Bj}\tau_0)^{3/8}L$. Moreover, this behavior is not observed if the scaling variable is changed to $\epsilon_{\rm Bj}\tau_0$ or $(\epsilon_{\rm Bj}\tau_0)^{3/4}L^2$.
- A universal (linear) functional form was found to describe the data from the different colliding systems which were analyzed.
- The same linear behavior was also observed for identified charged particles (pions, kaons, and protons).

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[3] A. Adare *et al.* (PHENIX Collaboration), Phys.Rev. C **93**, 024911(2016).
[4] J. Adam *et al.* (ALICE Collaboration), Phys. Rev. C **94**, 034903(2016).