Jet quenching in pp and pA collisions

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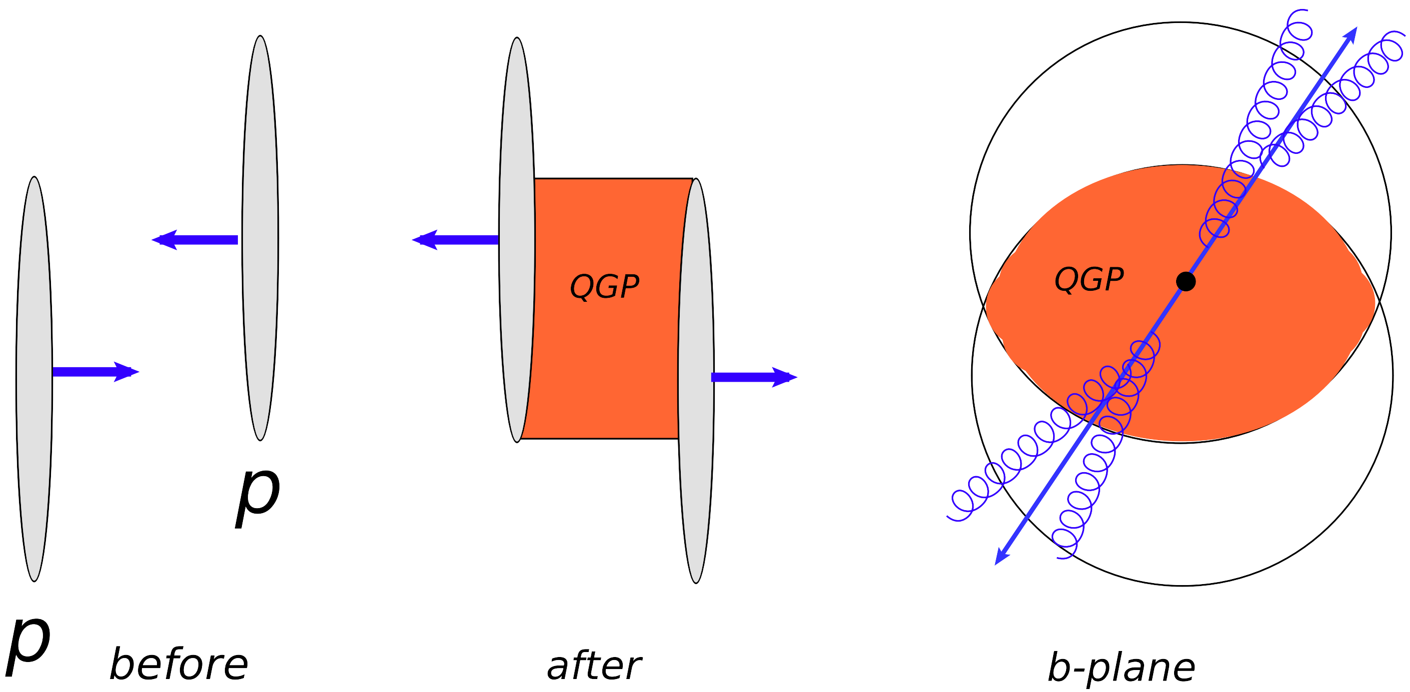
OUTLINE

- Mini-QGP in pp-collisions, underlying events and parameters of mini-fireball
- Jet quenching in QGP in LCPI approach
- Results for R_{pp} and and effect of R_{pp} on R_{AA}
- Medium modification factor for pA-collisions
- Medium modification of photon-tagged jets in pp-collisions
- Summary

Mini-QGP in pp-collisions



To fix T_0 we use the entropy/multiplicity ratio $C = dS/dy \Big/ dN_{ch}/d\eta \approx 7.67$ [B. Müller and K. Rajagopal, Eur. Phys. J. C**43**, 15 (2005)]. We write the initial entropy density as

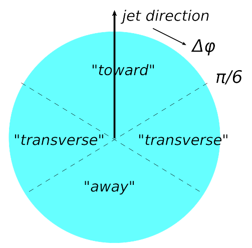
$$s_0 = \frac{C}{\tau_0 \pi R_f^2} \frac{dN_{ch}}{d\eta} \, .$$

We ignore the azimuthal anisotropy, and regard the R_f as an effective plasma radius, which includes all impact parameters. The MIT bag model says that only 25% of jets come from pp collisions with the impact parameter larger than the bag radius.

$\Rightarrow$ In jet events typically the fireball has a relatively small eccentricity (?).

Underlying events in jet production

In jet events the multiplicity of soft off-jet particles (underlying events) is enhanced by $K_{ue} \sim 2-3$ as compared to the minimum bias multiplicity [CDF Collaboration], Phys. Rev. D**65**, 092002 (2002)]. And even at RHIC energies $\sqrt{s} \sim 0.2$ TeV the UE $dN_{ch}/d\eta$ may be high enough for the QGP formation.



UE $dN_{ch}/d\eta$ grows with momentum of the leading charged jet hadron at $p_T \lesssim 3-5$ GeV and then flatten (in terms of the jet energy the plateau region corresponds to $E_{jet} \gtrsim 15-20$ GeV).

At $\sqrt{s} = 0.2$ TeV we use K_{ue} from PHENIX [J. Jia, arXiv:0906.3776] obtained by dihadron correlation method. Using the minimum bias non-diffractive events $dN_{ch}^{mb}/d\eta = 2.98 \pm 0.34$ from STAR [Phys. Rev. C 79, 034909 (2009)] we obtain in the plateau region $dN_{ch}/d\eta \approx 6.5$.

For LHC we use the ATLAS data [JHEP 1207, 116 (2012)] on the UE at $\sqrt{s} = 0.9$ and 7 TeV that give in the plateau region

$$dN_{ch}/d\eta \approx 7.5 \quad \sqrt{s} = 0.9 \text{ TeV}\,, \quad dN_{ch}/d\eta \approx 13.9 \quad \sqrt{s} = 7 \text{ TeV}\,.$$

Assuming that $dN_{ch}/d\eta \propto s^{\delta}$ we obtain the UE multiplicity density

$$dN_{ch}/d\eta \approx 10.5 \quad \sqrt{s} = 2.76 \text{ TeV}\,, \quad dN_{ch}/d\eta \approx 12.6 \quad \sqrt{s} = 5.02 \text{ TeV}\,.$$

Size and temperature of mini-fireball

One can expect that $R_f \sim R_p \sim 1$ fm. It agrees qualitatively with R_f obtained for pp collisions at $\sqrt{s} = 7$ TeV in IP-Glasma model [A. Bzdak, B. Schenke, P. Tribedy, and R. Venugopalan, Phys. Rev. C87,064906 (2013)]. R_f grows approximately as linear function of $(dN_g/dy)^{1/3}$ and then flattens. The flat region corresponds to almost head-on collisions. We take $dN_g/dy = \kappa dN_{ch}/d\eta$ with $\kappa = C45/2\pi^4\xi(3) \approx 2.13$. We use parametrization of R_f from L. McLerran, M. Praszalowicz, and B. Schenke, arXiv:1306.2350. For UE $dN_{ch}/d\eta$ in the plateau regions it gives

$$R_f[\sqrt{s} = 0.2, 2.76, 5.02, 7 \text{ TeV}] \approx [1.3, 1.44, 1.49, 1.51] \text{ fm}.$$

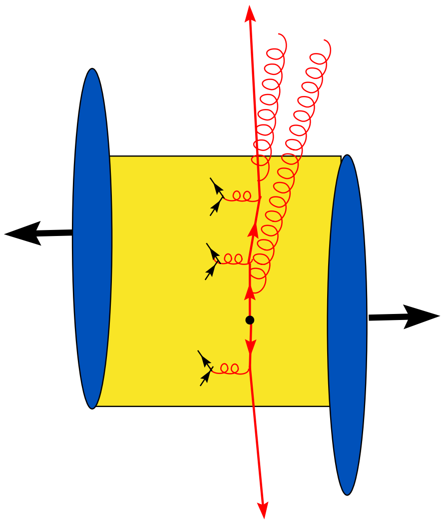
Using the ideal gas formula $s = (32/45 + 7N_f/15)T^3$ (with $N_f = 2.5$), we obtain the initial temperatures of the QGP at $\tau_0 = 0.5$ fm

$$T_0[\sqrt{s} = 0.2, 2.76, 5.02, 7 \text{ TeV}] \approx [199, 217, 226, 232] \text{ MeV}.$$

For entropy from lattice calculations T_0 will be higher by $\sim 10 - 15\%$. We ignore this difference since for jet quenching the crucial quantity is the entropy, which we take from experimental data, and the temperature is just an intermediate quantity in our calculations.
From the Drude formula and lattice σ [A. Amato *et al.* arXiv:1310.7466] one can obtain $Kn(\text{quark}) = \tau^q_{col}/\tau \sim 1$ at $\tau \sim 0.5$ fm and $Kn(\text{quark}) \sim 0.25$ at $\tau \sim 1$ fm.

Jet quenching in QGP

Radiative (Bethe-Heitler) and collisional (Bjorken) energy losses modify jet evolution. Both these mechanisms should be treated on even footing. We have not such a formalism. But $\Delta E_{coll} \ll \Delta E_{rad}$. Nevertheless, the theoretical uncertainties in the factor R_{AA} are large (about a factor of 2). For this reason α_s should be treated as a free parameter of the model. And to evaluate the medium suppression in pp collisions it is reasonable to use the information on α_s necessary for description of jet quenching in AA collisions.



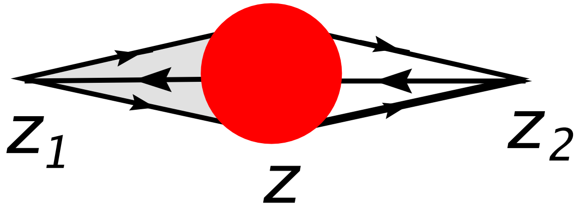
- Can we see the effect of mini-QGP on R_{AA}, say, via the variation of the light/heavy ratio?
- Does not mini-QGP scenario lead to contradiction with the LHC data $R_{pA} \approx 1$?
- Can we observe directly the effect of the mini-QGP in γ+jet events via the multiplicity dependence of the γ-tagged FF?

Induced one gluon emission in LCPI approach

$dP/dx = \int_0^L dz n(z) d\sigma_{eff}^{BH}(x,z)/dx$. The effective Bethe-Heitler cross section for $q \to g + q$ reads [BGZ (1997)]

$$\frac{d\sigma_{eff}^{BH}(x,z)}{dx} = \text{Re} \int\limits_0^z dz_1 \int\limits_z^\infty dz_2 \int d\vec{\rho}\, \hat{g}(x) \mathcal{K}_v(z_2,\vec{\rho}_2|z,\vec{\rho})\sigma_3(\rho)\mathcal{K}(z,\vec{\rho}|z_1,\vec{\rho}_1)\Big|_{\vec{\rho}_1=\vec{\rho}_2=0}$$

$x = \omega_g/E$, z is the position of the scattering center in QGP, $\sigma_3 = \sigma_{q\bar{q}g}$. For the vacuum Green's function $\mathcal{K}_v$ z_2-integration up to infinity gives the LCWF with the azimuthal quantum number $m = \pm 1$ $\psi(\vec{\rho}, x) \propto K_1(\epsilon\rho)\exp(im\phi)$ with $\epsilon^2 = m_q^2 x^2 + m_g^2(1-x)$. The result reads [BGZ (2004)]



$$\frac{d\sigma_{eff}^{BH}(x,z)}{dx} = -\frac{P_{Gq}(x)}{\pi\mu(x)} \text{Im} \int\limits_0^z d\xi \alpha_s(Q_{eff}) \frac{\partial}{\partial\rho}\left(\frac{F(\xi,\rho)}{\sqrt{\rho}}\right)\Big|_{\rho=0},$$

$\mu = Ex(1-x)$, $Q_{eff}^2 = 1.85\mu/\xi$, F is the solution to the radial Schrödinger equation for $m = 1$

$$i\frac{\partial F(\xi,\rho)}{\partial\xi} = \left[-\frac{1}{2\mu(x)}\left(\frac{\partial}{\partial\rho}\right)^2 - i\frac{n(z-\xi)\sigma_3(\rho)}{2} + \frac{4m^2-1}{8\mu(x)\rho^2} + \frac{1}{L_f}\right]F(\xi,\rho)$$

with $L_f = 2\mu(x)/\epsilon^2$, $F(\xi=0,\rho) = \sqrt{\rho}\sigma_3(\rho)\epsilon K_1(\epsilon\rho)$. We solve the Schrödinger equation backward in time to have a smooth boundary condition.

Collisional energy loss, $2 \to 2$ processes

$$\frac{dE_{col}}{dz} = \frac{1}{2Ev} \sum_{p=q,g} g_p \int \frac{d\vec{p}'}{2E'(2\pi)^3} \int \frac{d\vec{k}\, n_p(k)}{2k(2\pi)^3}$$

$$\times \int \frac{d\vec{k}'[1+\epsilon_p n_p(k')]}{2k'(2\pi)^3} (2\pi)^4 \delta^4(P+K-P'-K')\omega\langle|M(s,t)|^2\rangle\theta(\omega_{max}-\omega)$$

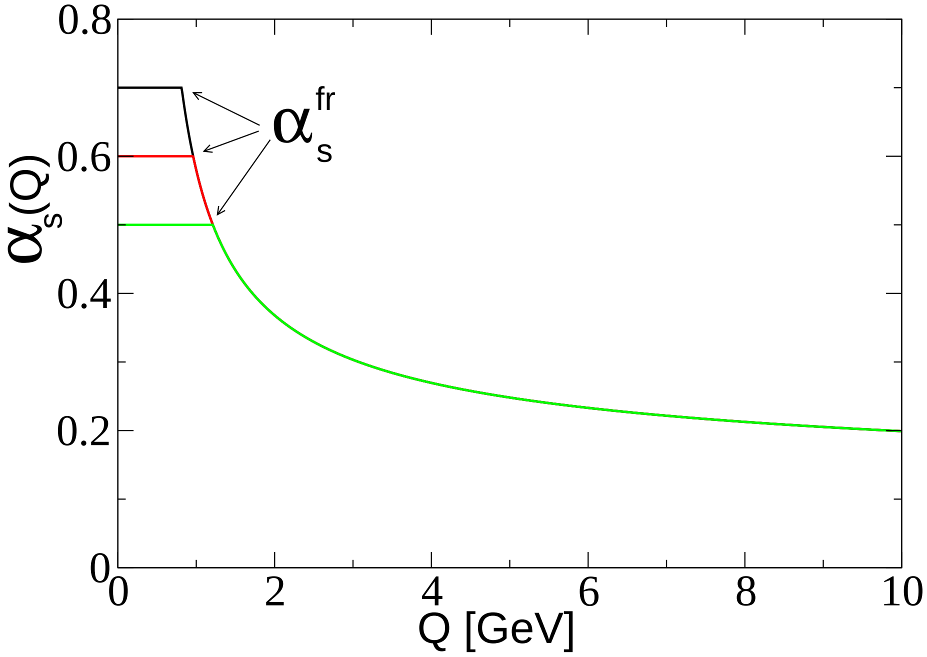
$\omega = E - E'$ is the energy transfer, $v \approx 1$ is the quark velocity, $P = (E, \vec{p})$ and $K = (k, \vec{k})$ 4-momenta for incoming partons, $P' = (E', \vec{p}')$ and $K' = (k', \vec{k}')$ 4-momenta for outgoing partons, $M(s,t)$ is matrix element for $Qp \to Qp$ scattering, $n_q(k) = (e^{k/T}+1)^{-1}$ and $n_g(k) = (e^{k/T}-1)^{-1}$, $\epsilon_q = -1$, $\epsilon_g = 1$, $g_q = 4N_c N_f$, $g_g = 2(N_c^2-1)$. Similarly to the radiative energy loss we take $\omega_{max} = E/2$.

$$\omega = \frac{-t - tk_z/E + 2\vec{k}_\perp \vec{q}_\perp}{2(k-k_z)} .$$

Bjorken neglected the red terms. In this case neglecting the statistical Pauli-blocking and Bose enhancement factors one can obtain

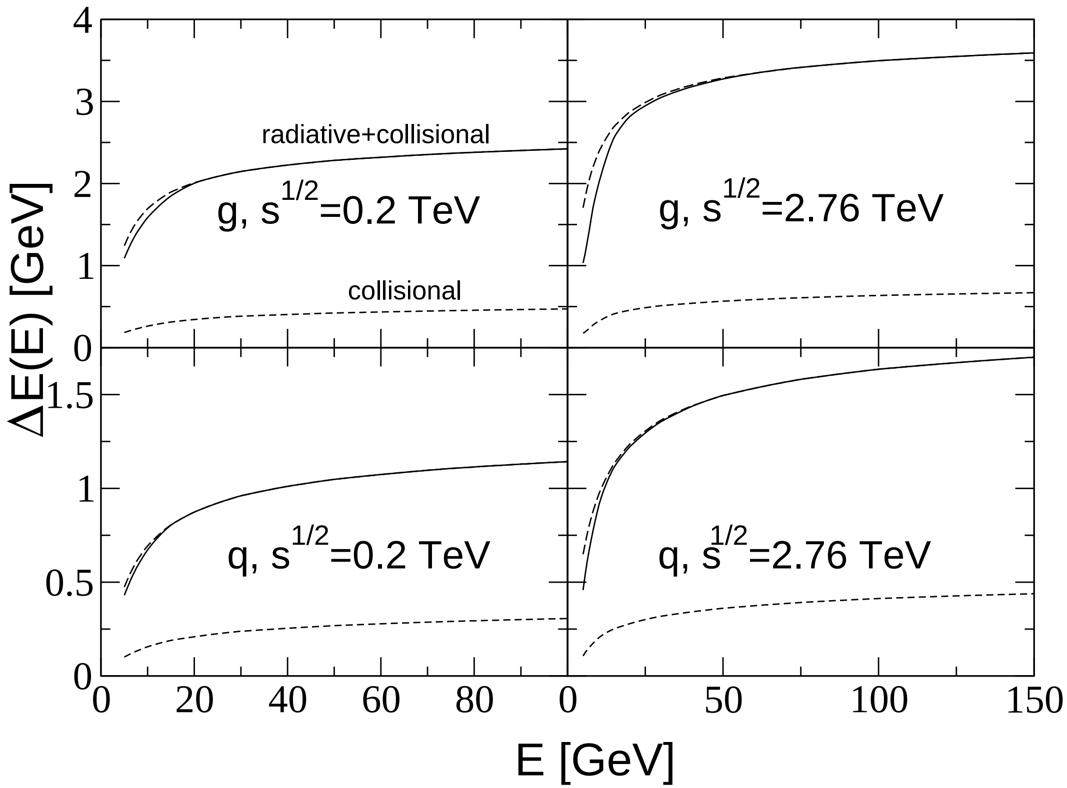
$$\frac{dE_{col}}{dz} \approx \frac{1}{2(2\pi)^3} \sum_{p=q,g} g_p \int d\vec{k} \frac{n_p(k)}{k} \int_0^{|t|_{max}} dt|t|\frac{d\sigma}{dt} , \quad |t|_{max} \approx 2(k-k_z)\omega_{max} .$$

Parametrization of $\alpha_s(Q)$



We use running α_s frozen at $\alpha_s^{fr} = 0.4, 0.5, 0.6, 0.7.$ In vacuum $\alpha_s^{fr} \approx 0.7$ (obtained from the data on F_2^p at low x) [Nikolaev, BGZ (1991,1994)], it agrees with $\int_0^{2\,GeV} dQ \frac{\alpha_s(Q^2)}{\pi} \approx 0.36$ GeV obtained from the analysis of the heavy quark energy loss in vacuum [Dokshitzer, Khoze, Troyan (1996)].

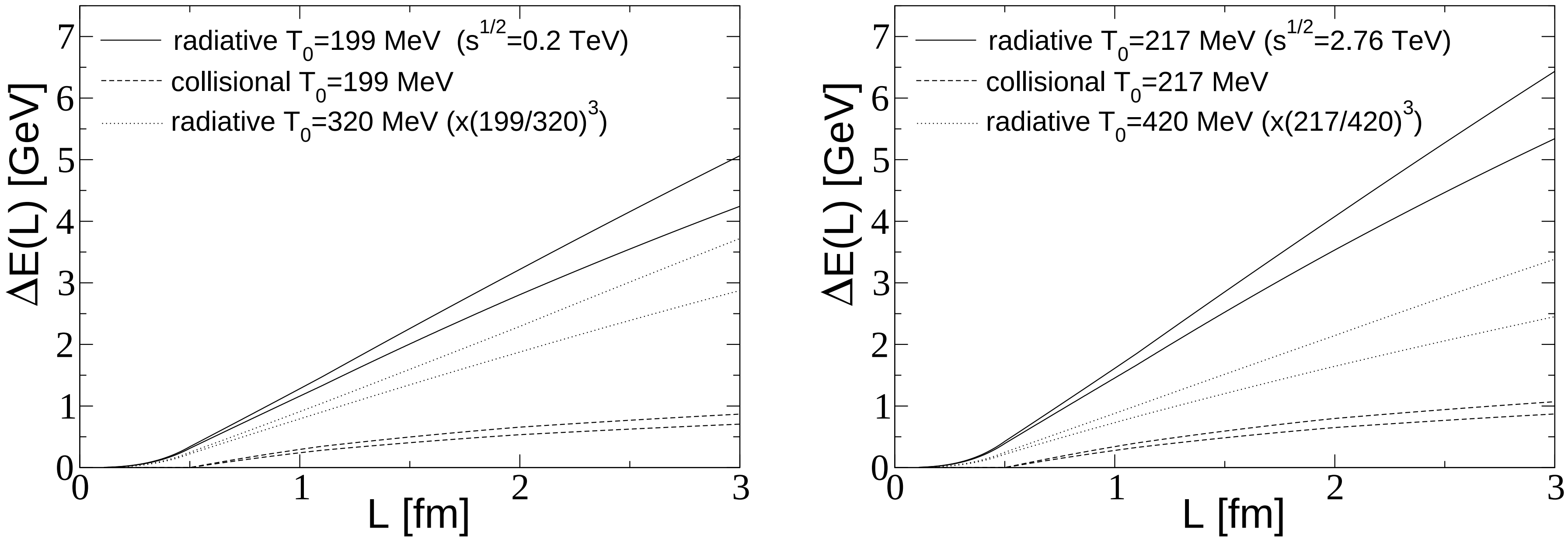
Energy dependence of energy loss in mini-QGP



Energy dependence of the energy loss for partons produced in the center of the mini-QGP fireball at $\sqrt{s} = 0.2$ TeV (left) and $\sqrt{s} = 2.76$ TeV (right). Solid line: total (radiative plus collisional) energy loss calculated with the fireball radius R_f and the initial temperature T_0 obtained with the UE $dN_{ch}/d\eta$ dependent on the initial parton energy E; dashed line: same as solid line but for collisional energy loss; long-dashed line: same as solid line but for R_f and T_0 obtained with the UE $dN_{ch}/d\eta$ in the plateau region.

$\alpha_s^{fr} = 0.6$ and $s_0 \propto \tau$ at $\tau < \tau_0 = 0.5$ fm.

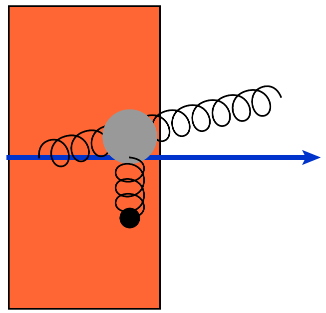
L- and T_0-dependence of energy loss



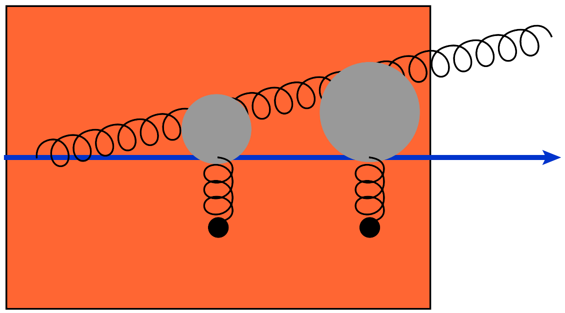
Radiative (solid) and collisional (dashed) gluon energy loss vs the path length L in the QGP with $T_0 = 199$ and 217 MeV for (bottom to top) $E = 20$ and 50 GeV. The dotted lines show radiative energy loss for $T_0 = 320$ and 420 MeV rescaled by the factors $(199/320)^3$ and $(217/420)^3$. $\alpha_s^{fr} = 0.6$ and $s_0 \propto \tau$ at $\tau < \tau_0 = 0.5$ fm.

The deviation from the T^3 scaling comes mostly from the increase of the LPM suppression (and partly from the increase of the Debye mass) for the QGP produced in AA collisions.

Difference between small and large QGP



small-size QGP



large-size QGP

From the Schrödinger diffusion relation one can obtain for the typical transverse size of the two parton system $\rho^2 \sim 2\xi/\omega$, ξ is the path length after gluon emission. $\sigma(\rho)$ is dominated by the t-channel gluon exchanges with virtualities up to $Q^2 \sim 10/\rho^2$ [N.N. Nikolaev, BGZ (1993)] we obtain $Q^2 \sim 5\omega/\xi$. For $\omega \sim 2$ GeV and $\xi \sim 0.5 - 1$ fm $Q^2 \sim 2 - 4$ GeV^2. The virtuality scale for α_s in the gluon emission vertex has a similar form but smaller by a factor of ~ 2.5. The $1/\xi$ dependence of Q^2 persists up to $\xi \sim L_f$. For the large-size QGP one should replace ξ by the real in-medium $L_f \sim 2S_{LPM}\omega/m_g^2$ which is by a factor of ~ 2 larger than the typical values of ξ for the mini-QGP. $\Rightarrow$ $Q^2(pp)/Q^2(AA) \sim 2$. $\Rightarrow$The calculations for pp are more robust than for AA.

It is important to work with running α_s and account for accurately the LPM, finite-size and Coulomb effects (which are very important for the mini-QGP) effect. Otherwise one cannot extrapolate accurately the predictions from AA to pp collisions. The LCPI approach is the only approach which satisfies all these requirements.

Nuclear modification factor for pp- and AA-collisions

$$R_{AA} = \frac{d\sigma(AA \to hX)/d\vec{p}_T dy}{N_{bin}\, d\sigma(pp \to hX)/d\vec{p}_T dy} \,.$$

If the QGP is produced in pp collisions the real pp cross section differs from that in pQCD by its own medium modification factor R_{pp}

$$d\sigma(pp \to hX)/d\vec{p}_T dy = R_{pp} d\sigma_{pert}(pp \to hX)/d\vec{p}_T dy \,.$$

In this scenario the theoretical quantity which should be compared with the experimental R_{AA} reads

$$R_{AA} = R^{st}_{AA}/R_{pp} \,,$$

where R^{st}_{AA} is the standard nuclear modification factor calculated using the pQCD predictions for the particle spectrum in pp collisions.

$$\frac{d\sigma_{pert}(pp \to hX)}{d\vec{p}_T dy} = \sum_i \int_0^1 \frac{dz}{z^2} D_{h/i}(z,Q) \frac{d\sigma(pp \to iX)}{d\vec{p}^{\,i}_T dy} \,, \quad \vec{p}^{\,i}_T = \vec{p}_T/z \,,$$

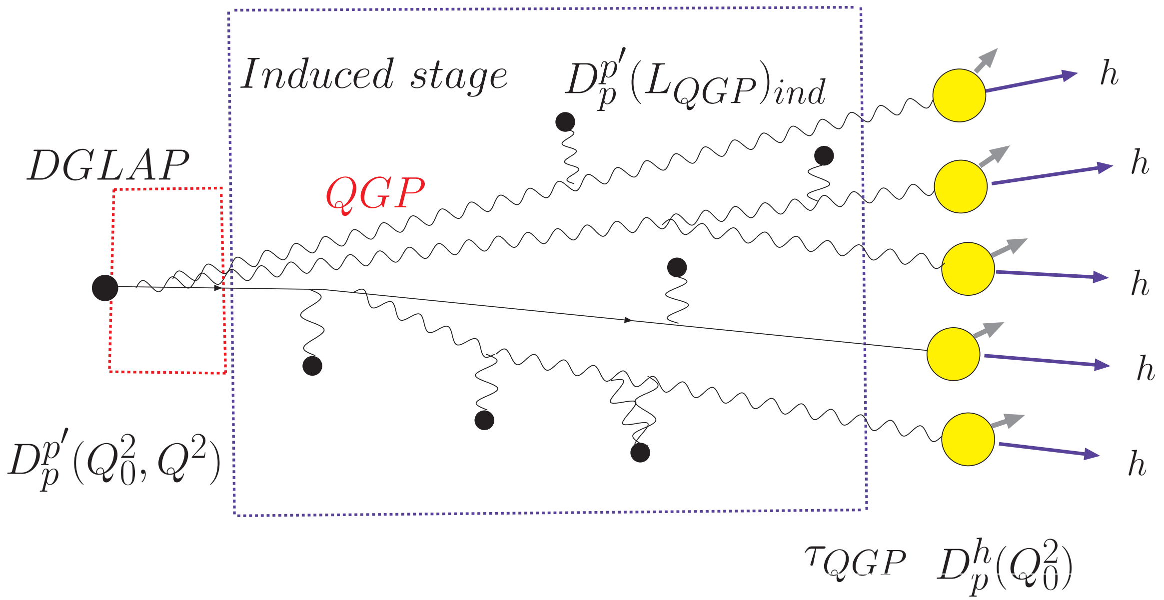
$$\frac{d\sigma(pp \to hX)}{d\vec{p}_T dy} = \sum_i \int_0^1 \frac{dz}{z^2} D^m_{h/i}(z,Q) \frac{d\sigma(pp \to iX)}{d\vec{p}^{\,i}_T dy} \,, \quad \vec{p}^{\,i}_T = \vec{p}_T/z \,.$$

The space-time pattern of jet distortion

The formation length for the DGLAP $\bar{l}_F \sim 0.3 - 1$ fm for $E \lesssim 100$ GeV (if $m_q \sim 0.3$ GeV and $m_g \sim 0.75$ GeV). $\Rightarrow$The DGLAP stage gives initial condition for the induced emission stage at $\tau_{DGLAP} \sim \tau_0$.

$$\Rightarrow \quad D^m_{h/i}(Q) \approx D_{h/j}(Q_0) \otimes D^{ind}_{j/l}(E_l) \otimes D^{DGLAP}_{l/i}(Q_0, Q)\,,$$

$D^{ind}_{j/l}$ is the induced radiation FF (it depends only on the parton energy E), $D^{DGLAP}_{l/i}$ is calculated with the PYTHIA event generator. Our scheme of jet evolution



The FF for the induced stage

To calculate the $D^{ind}_{j/l}$ one needs to take into account the multiple gluon emission. There is no an accurate method of incorporating the multiple gluon emission.
We use Landau method developed for photon emission [BDMS (2001)]

$$P(\Delta E) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[\prod_{i=1}^{n} \int d\omega_i \frac{dP(\omega_i)}{d\omega} \right] \delta \left(\Delta E - \sum_{i=1}^{n} \omega_i \right) \exp \left[- \int d\omega \frac{dP}{d\omega} \right],$$

$dP/d\omega$ is the distribution for one gluon emission.

$$D^{ind}_{q/q}(z) = K_{qq} P_{Landau}(\Delta E = E(1-z)), \quad K_{qq} = \int_0^{\infty} d\Delta E P(\Delta E) / \int_0^{E} d\Delta E P(\Delta E)$$

K_{qq} accounts for the leakage of the probability to $\Delta E > E$ (gluons are not soft enough!).
We take $D^{ind}_{g/q}(z) = K_{gq} dP(z)/dz$ with K_{gq} fixed from momentum conservation
$\int dz z [D^{ind}_{g/q}(z) + D^{ind}_{q/q}(z)] = 1$.

For $g \to g$ we first define $\bar{D}^{ind}_{g/g}(z) = P_{Landau}(\Delta E(1-z)) \quad z > 0.5$. At $z < 0.5$

$\bar{D}^{ind}_{g/g}(z) = dP/dz$. $D^{ind}_{g/g}(z) = K_{gg} \bar{D}^{ind}_{g/g}(z)$. K_{gg} is fixed from $\int dz z D^{ind}_{g/g}(z) = 1$.

We treat the collisional loss as a perturbation and incorporate it by a small renormalization of T_{QGP} according to the change in the ΔE due to the collisional energy loss

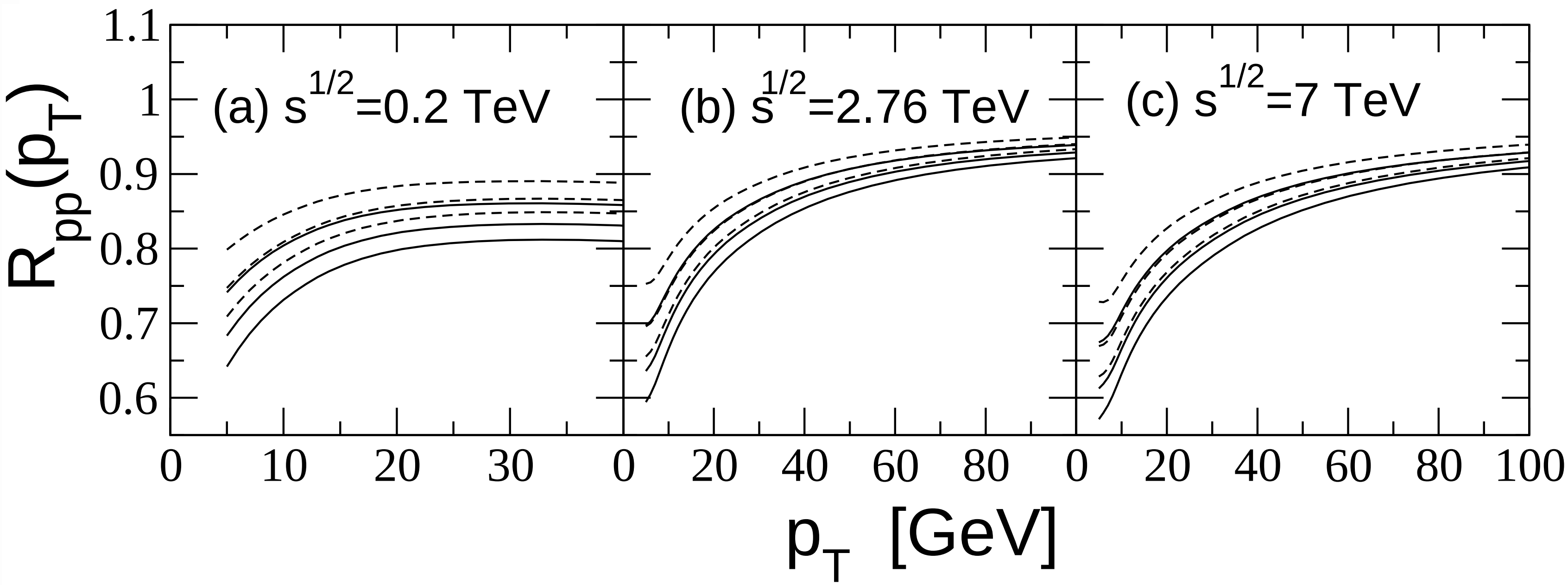
$$\Delta E_{rad}(T') = \Delta E_{rad}(T) + \Delta E_{col}(T)\,.$$

The collisional loss suppresses $R_{AA} \lesssim 15 - 25$ %.

For $d\sigma(N+N \to i+X)/d\vec{p}_T^{\,i}dy$ we use the LO pQCD formula with the CTEQ6 PDFs. We account for the nuclear modification of the PDFs with the EKS98 correction [K.J. Eskola *et al.* Eur. Phys. J. C9, 61 (1999)].
To simulate the higher order K-factor in the hard cross sections we use $\alpha_s(cQ)$ with $c = 0.265$ (like that in PYTHIA).
For $D_{h/q(g)}(z, Q_0)$ we use the KKP parametrization [B. A. Kniehl, G. Kramer, and B. Potter, Nucl. Phys. B582, 514 (2000)]. For $c \to D$ and $b \to B$ we use Peterson FF with $\epsilon_c = 0.06$, $\epsilon_b = 0.0006$. The FF $B/D \to e$ obtained from the CLEO data [A.H. Mahmood *et al.*, Phys. Rev. D**70**, 032003 (2004); R. Poling, arXiv:hep-ex/0606016].

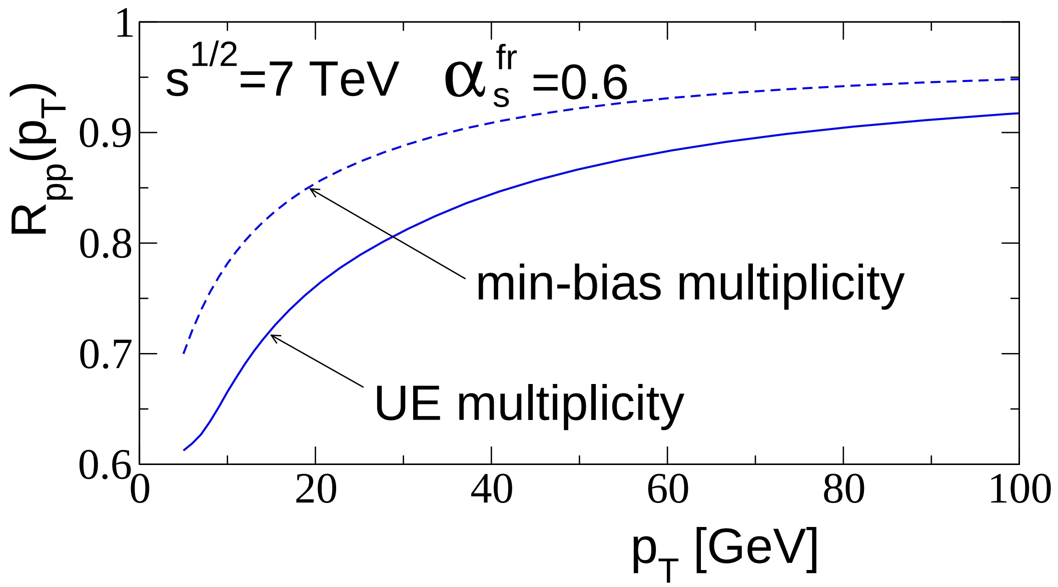
We use the Bjorken $1+1$ QGP expansion $T^3\tau = T_0^3\tau_0$. For each value of the impact parameter b we neglect the variation of T_0 in the transverse directions. We take $\tau_0 = 0.5$ fm and $s \propto \tau$ at $\tau < \tau_0$, for AA-collisions $\tau_{max} = L_{max} = 8$ fm. We fix T_0 using $S/N \approx 7.25$ [B. Mueller and K. Rajagopal (2005)]. $\Rightarrow$ $\langle T_0 \rangle \approx 320$ MeV (central Au+Au, $\sqrt{s} = 200$ GeV), $\langle T_0 \rangle \approx 420$ MeV (central Pb+Pb, $\sqrt{s} = 2.76$ TeV). We take $m_q = 300$, $m_g = 400$ Mev, $m_c = 1.2$ GeV, $m_b = 4.75$ GeV.

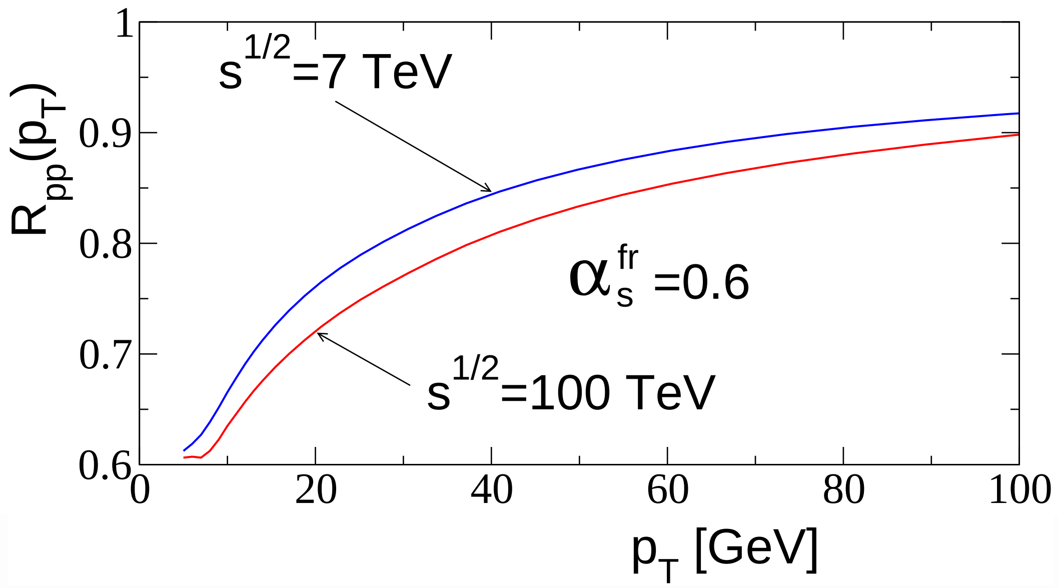
Results for R_{pp}



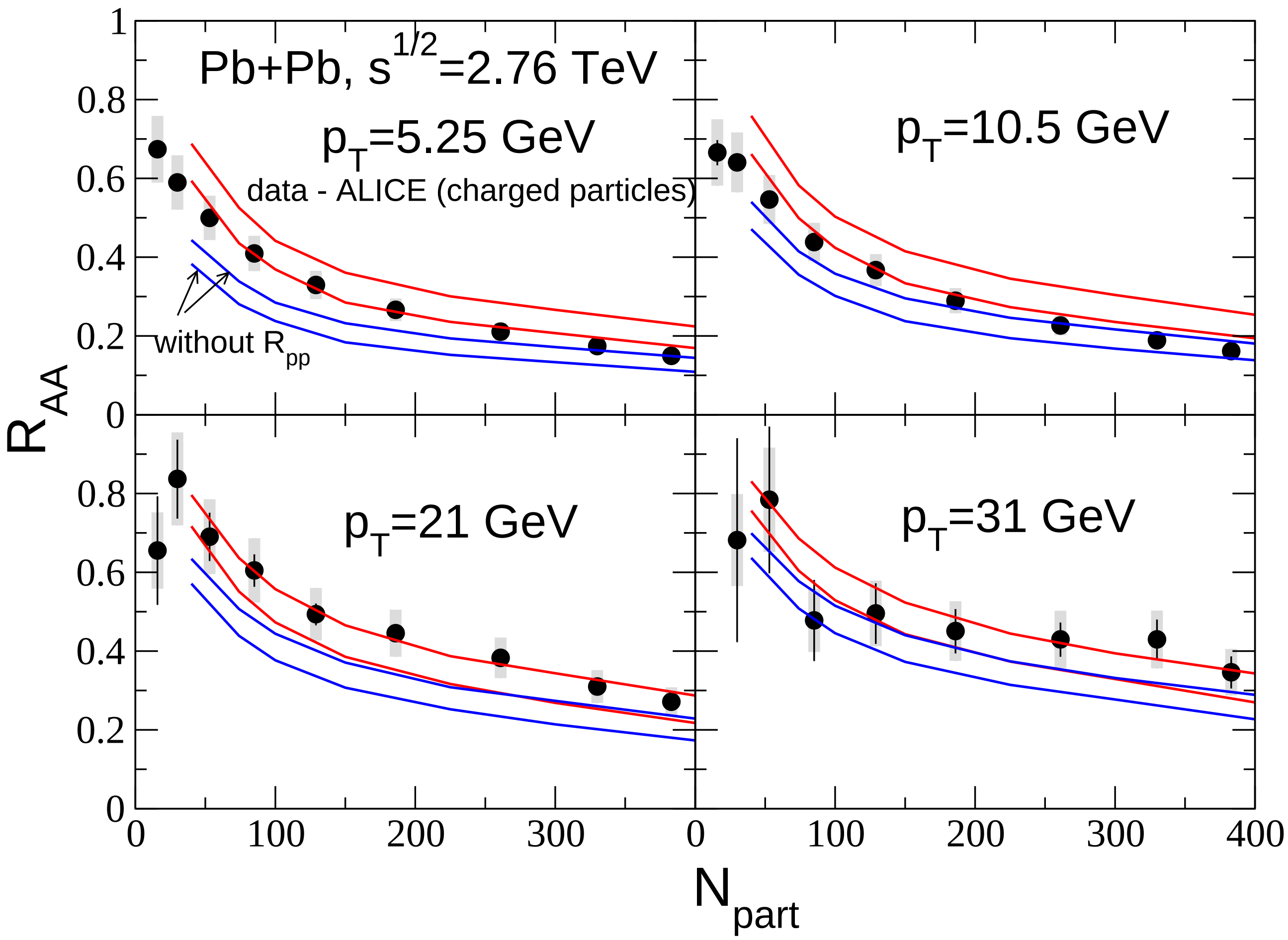
R_{pp} of charged hadrons at $\sqrt{s} = 0.2$ (a), 2.76 (b), 7 (c) TeV for (top to bottom) $\alpha_s^{fr} = 0.5$, 0.6 and 0.7 for $\tau_0 = 0.5$ (solid) and 0.8 (dashed) fm.

To understand the sensitivity to R_f we performed calculations for $R_f \to 0.7R_f$ and $R_f \to 1.3R_f$. It reduces the medium suppression by $\sim 3\%$ and 10%, respectively. The weak dependence on R_f is due to a compensation between the enhancement of the energy loss caused by increase of the fireball size and its suppression caused by reduction of the fireball density. The variation of the plasma density in our test is very large (by a factor of ~ 3.5). This stability indicates indirectly that the effect of the neglected hydrodynamical variation of the plasma density should be small. In pp-collisions the matter spends much time in the mixed phase, where c_s is small and the transverse expansion should be less intensive than in AA collisions.


1
0.9
0.8
0.7
0.6
0
20
40
60
80
100
$R_{pp}(p_T)$
p_T [GeV]
$s^{1/2}$=7 TeV α_s^{fr}=0.6
min-bias multiplicity
UE multiplicity

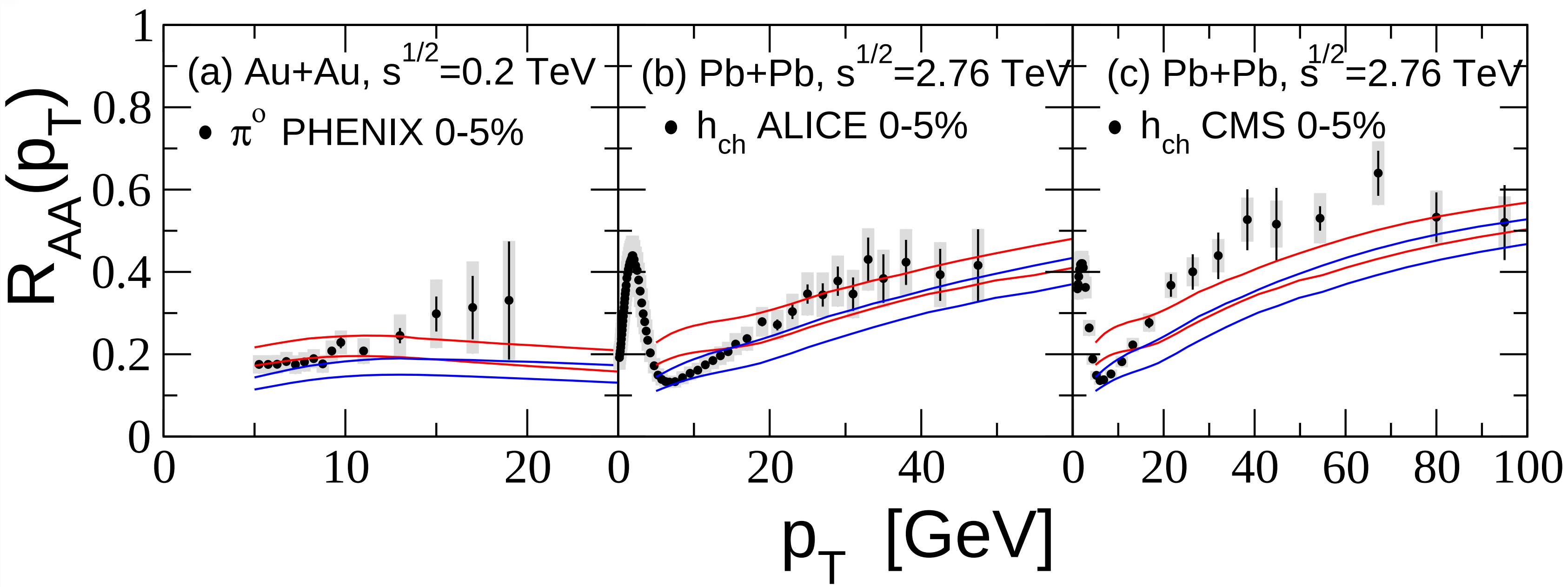

1
0.9
0.8
0.7
0.6
0
20
40
60
80
100
$R_{pp}(p_T)$
p_T [GeV]
$s^{1/2}$=7 TeV
α_s^{fr} =0.6
$s^{1/2}$=100 TeV

Effect of R_{pp} on $R_{AA}(N_{part})$



R_{AA} of charged particles vs N_{part} for Pb+Pb at $\sqrt{s} = 2.76$ TeV with (red) and without (blue) R_{pp}, for (top to bottom) $\alpha_s^{fr} = 0.4$ and 0.5 for $\sqrt{s} = 2.76$ TeV, R_{pp} is calculated at $\alpha_s^{fr} = 0.6$. Data: ALICE Phys. Lett. B720 (2013) 52.

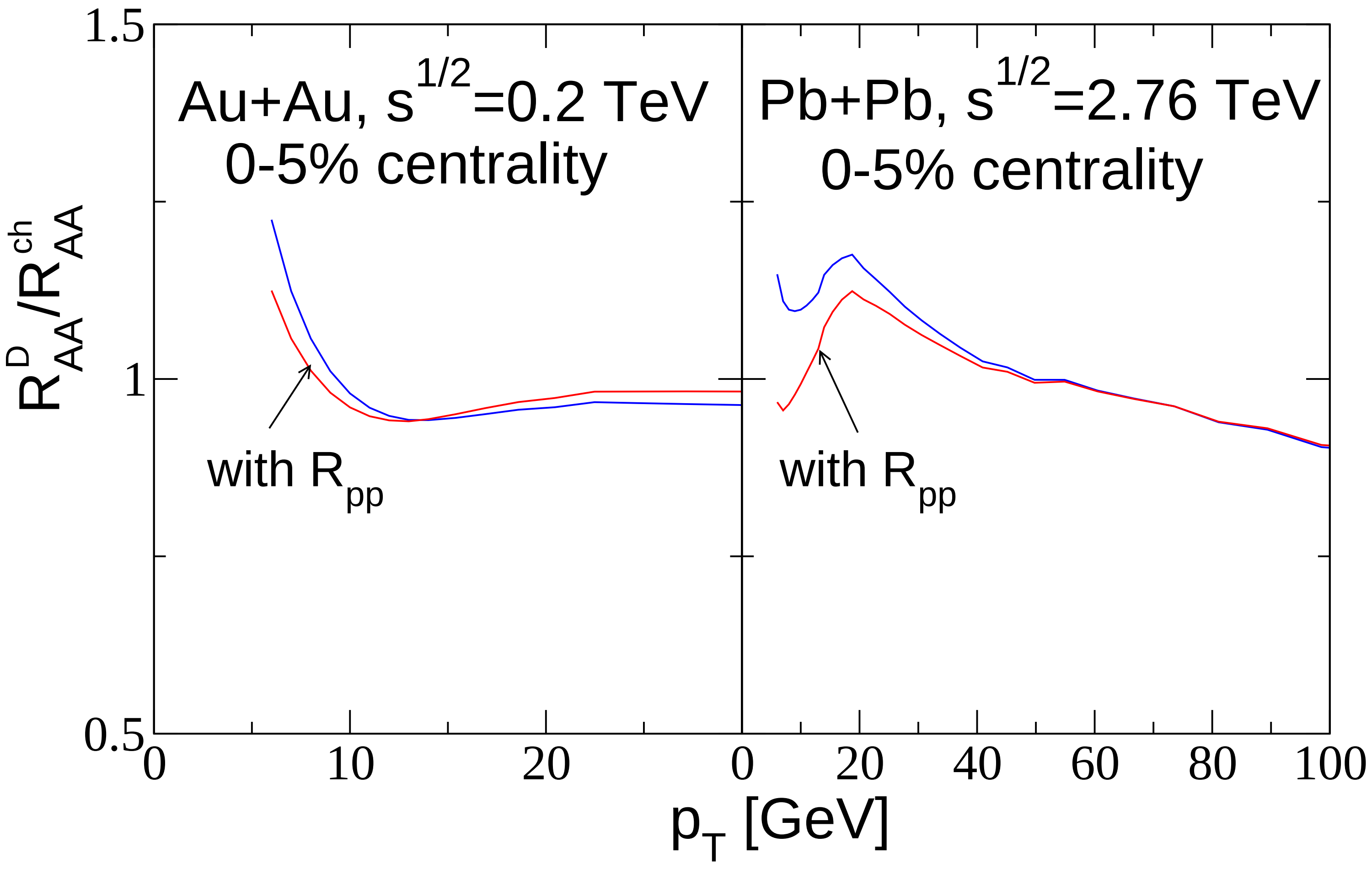
Effect of R_{pp} on $R_{AA}(p_T)$



(a) R_{AA} of π^0 for 0-5% central $Au + Au$ collisions at $\sqrt{s} = 0.2$ TeV from our calculations for (top to bottom) $\alpha_s^{fr} = 0.5$ and 0.6 with (red) and without (blue) $1/R_{pp}$ factor in R_{AA}. (b,c) R_{AA} for charged hadrons for 0-5% central $Pb + Pb$ collisions at $\sqrt{s} = 2.76$ TeV from our calculations for (top to bottom) $\alpha_s^{fr} = 0.4$ and 0.5 with (red) and without (blue) $1/R_{pp}$ factor in R_{AA}. The solid curves are obtained with R_{pp} for $\alpha_s^{fr} = 0.6$. Data points are from PHENIX (a), ALICE (b) and CMS (c).

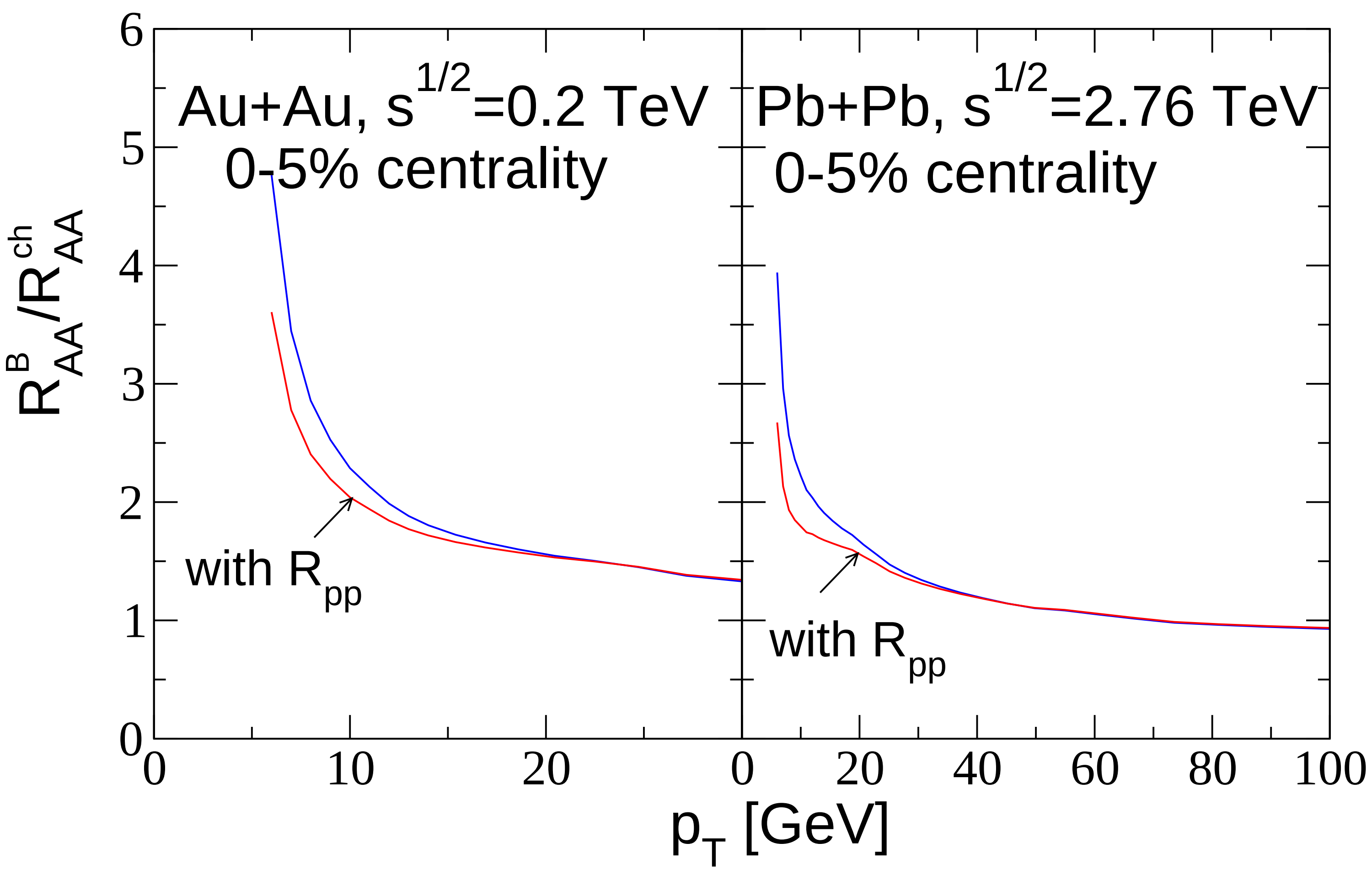
The effect of mini-QGP on R_{AA} should differ for light and heavy flavors, and may be important for description of R_{AA} for heavy flavors.

Effect of R_{pp} on R_{AA} for heavy flavors (c-quark)



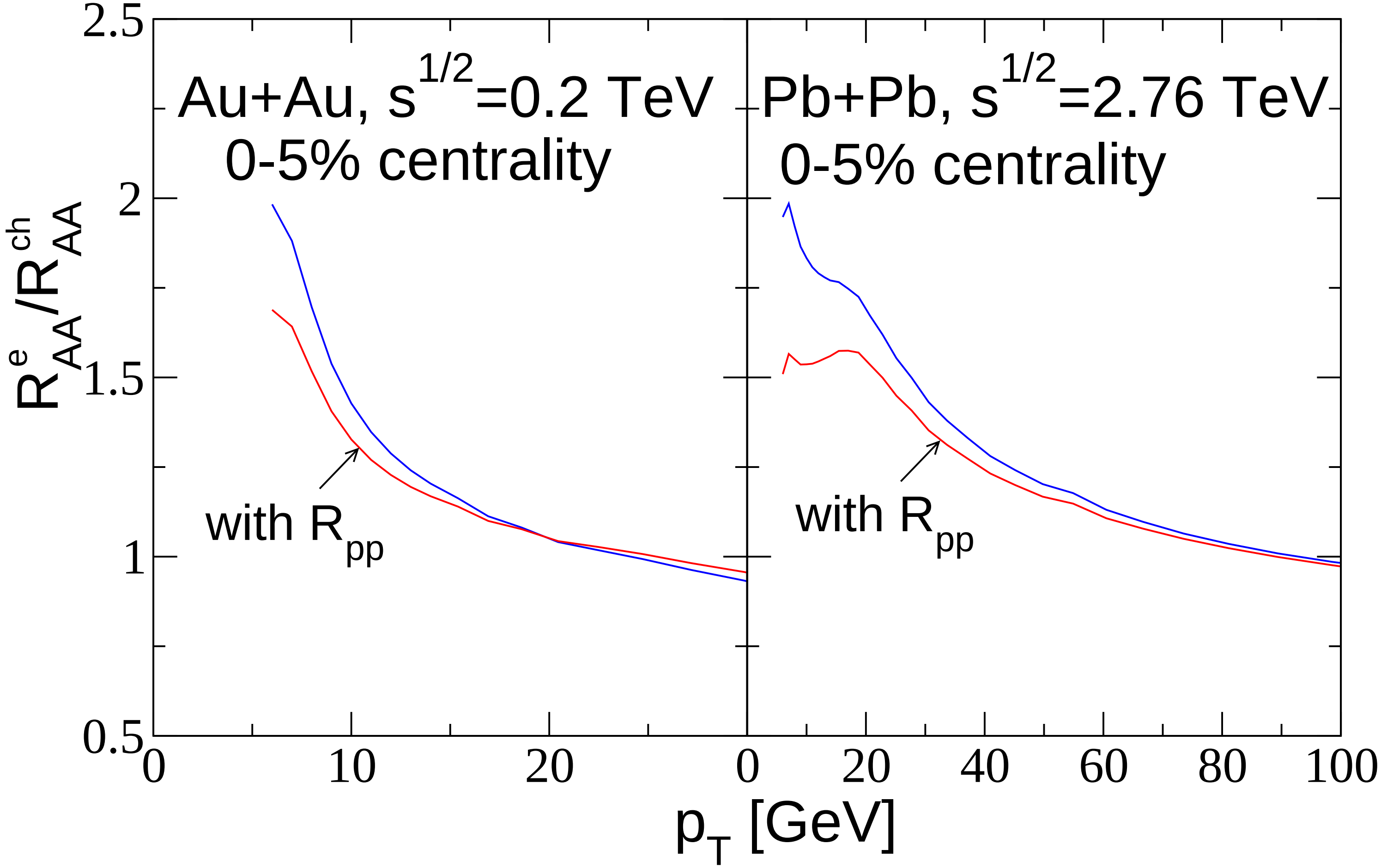
Effect of R_{pp} due to mini-QGP on ratio R_{AA} for D-mesons to R_{AA} for light charged hadrons. $\alpha_s^{fr} = 0.6$ for $\sqrt{s} = 0.2$ TeV and $\alpha_s^{fr} = 0.5$ for $\sqrt{s} = 2.76$ TeV, R_{pp} for light and heavy flavors is calculated at $\alpha_s^{fr} = 0.6$.

Effect of R_{pp} on R_{AA} for heavy flavors (b-quark)



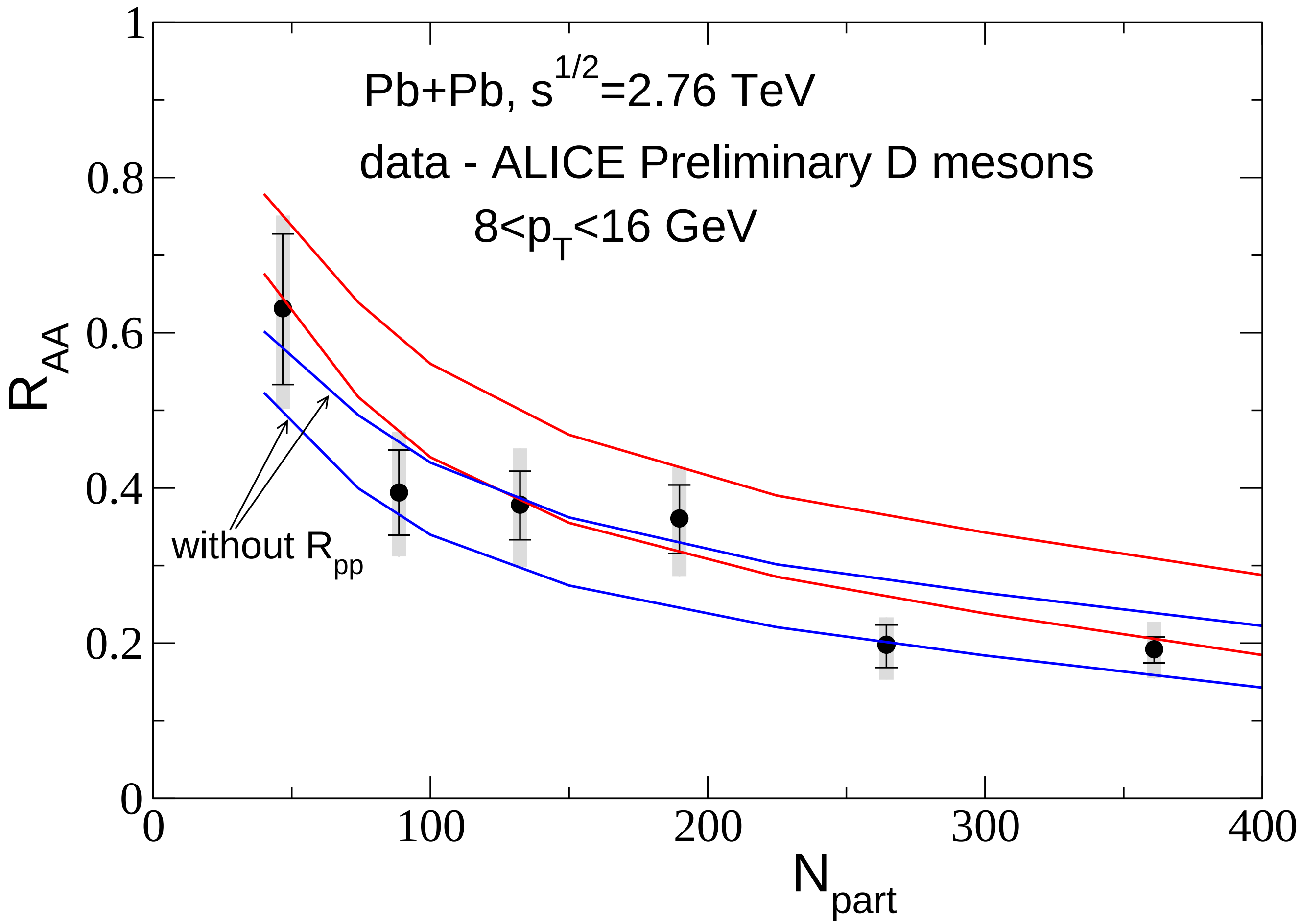
Effect of R_{pp} due to mini-QGP on ratio R_{AA} for B-mesons to R_{AA} for light charged hadrons. $\alpha_s^{fr} = 0.6$ for $\sqrt{s} = 0.2$ TeV and $\alpha_s^{fr} = 0.5$ for $\sqrt{s} = 2.76$ TeV, R_{pp} for light and heavy flavors is calculated at $\alpha_s^{fr} = 0.6$.

Effect of R_{pp} on R_{AA} for non-photonic electrons



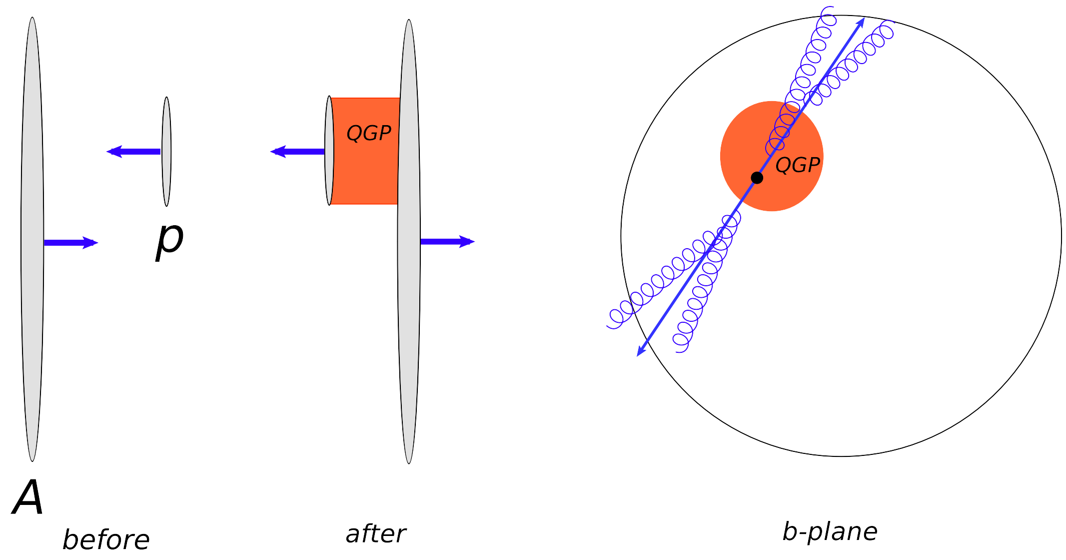
Effect of R_{pp} due to mini-QGP on ratio R_{AA} for non-photonic electrons to R_{AA} for light charged hadrons. $\alpha_s^{fr} = 0.6$ for $\sqrt{s} = 0.2$ TeV and $\alpha_s^{fr} = 0.5$ for $\sqrt{s} = 2.76$ TeV, R_{pp} for light and heavy flavors is calculated at $\alpha_s^{fr} = 0.6$.

$R_{AA}(N_{part})$ of D-mesons with and without R_{pp}



R_{AA} of D-mesons vs N_{part} for Pb+Pb at $\sqrt{s} = 2.76$ TeV with (red) and without (blue) R_{pp}, for (top to bottom) $\alpha_s^{fr} = 0.4$ and $\alpha_s^{fr} = 0.5$, R_{pp} is calculated at $\alpha_s^{fr} = 0.6$.

Mini-QGP in pA-collisions

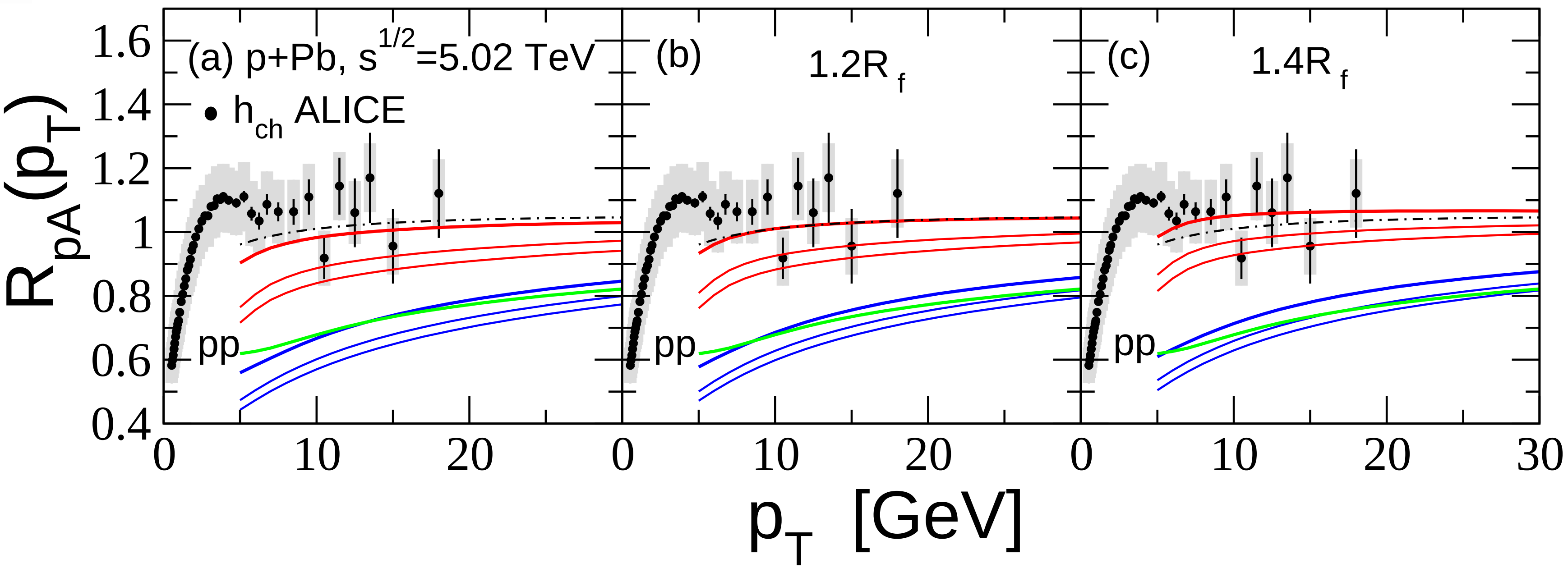


In pA collisions the proton can interact with many nucleons in the nucleus. Naively one can expect that the fireball should be more or less azimuthally symmetric (?). The UE pA multiplicity in jet production is not measured yet. One can expect that the enhancement factor $K_{ue} = dN_{ch}^{UE}/d\eta / dN_{ch}^{mb}/d\eta$ should be smaller than in pp-collisions.
For R_f from A. Bzdak, B. Schenke, P. Tribedy, and R. Venugopalan, Phys. Rev. C87,064906 (2013) we obtain at $\sqrt{s} = 5.02$ TeV

$$R_f^{pPb}[K_{ue} = 1, 1.25, 1.5] \approx [1.63, 1.88, 1.98] \text{ fm},$$

$$T_0^{pPb}[K_{ue} = 1, 1.25, 1.5] \approx [222, 229, 235] \text{ MeV}.$$

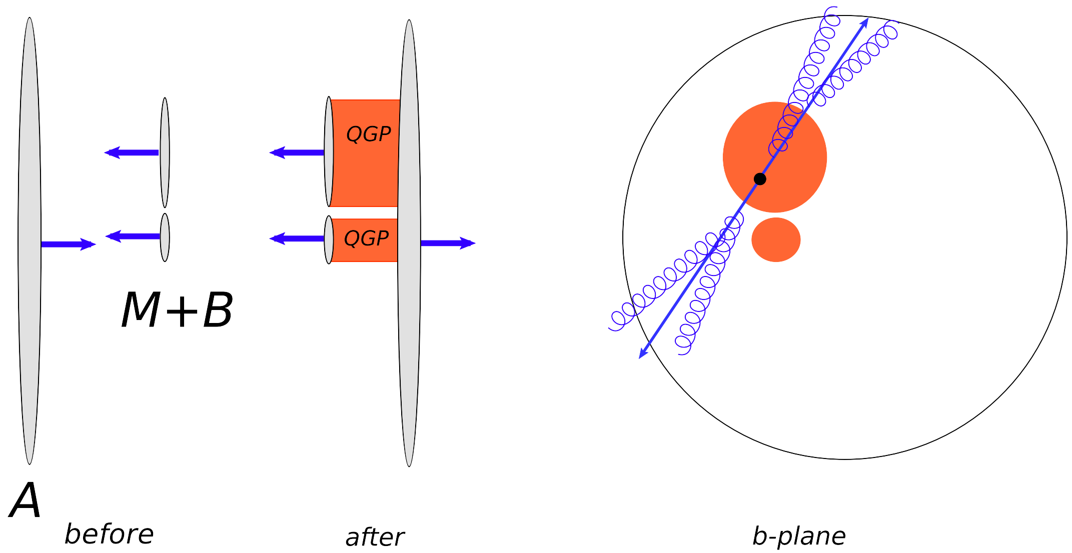
Results for R_{pPb}



(a) R_{pPb} for charged hadrons at $\sqrt{s} = 5.02$ TeV for $\alpha_s^{fr} = 0.6$ with (red) and without (blue) the $1/R_{pp}$ factor for (top to bottom) $K_{ue} = 1$, 1.25 and 1.5, (b,c) same as (a) but for $R_f(pPb)$ times 1.2 and 1.4. The green line shows R_{pp}. The dot-dashed line shows R_{pPb} due to the EKS98 correction to the nucleus PDFs. Data points are from ALICE [B. Abelev *et al.*, Phys. Rev. Lett. 110, 082302 (2013)].

The comparison with the data shows that $K_{ue} \sim 1$. But the situation may change if we take into account the meson-baryon Fock component in the proton.

Mini-QGP in pA-collisions for MB component

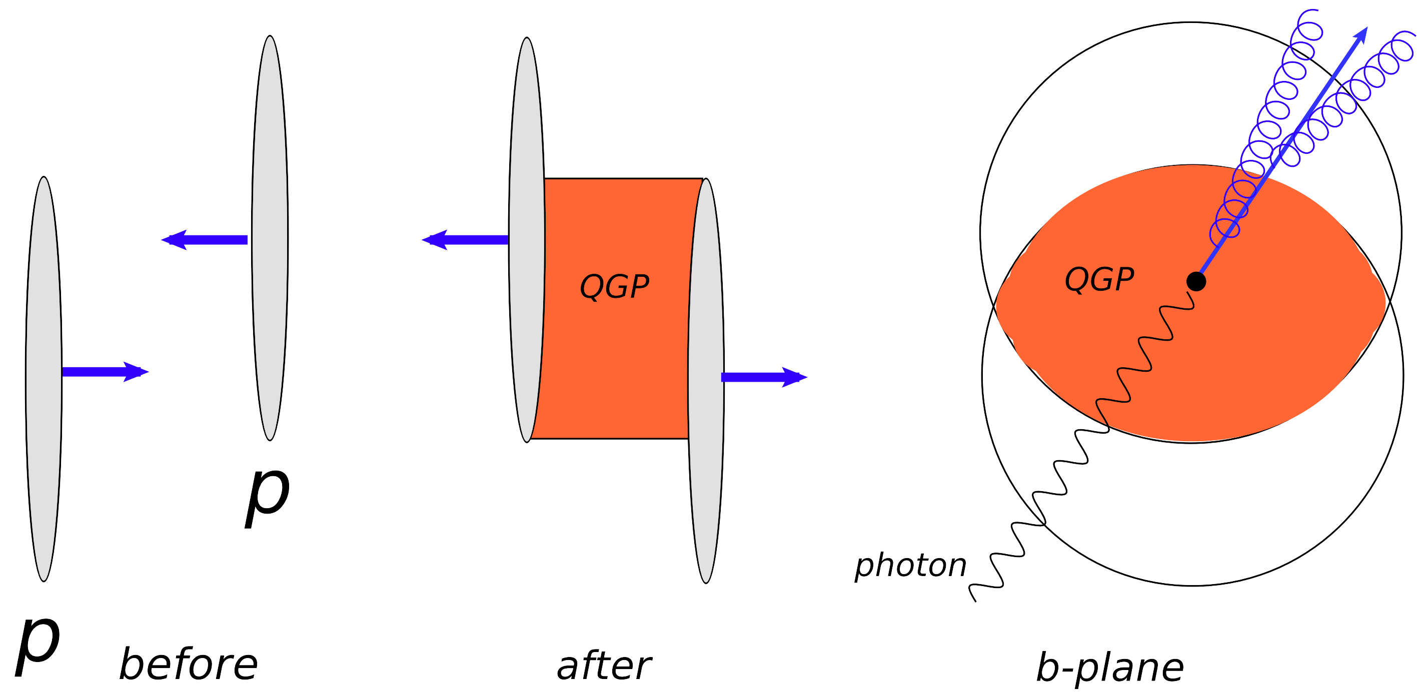


In pA collisions the final-state interaction may be smaller due to meson-baryon Fock component in the the proton

$$|p\rangle = c_b|B\rangle + c_{mb}|MB\rangle\ .$$

The weight of the MB-component is large: $c_{mb}^2 \sim 0.4$ [J. Speth, A W. Thomas, Adv.Nucl.Phys. 24 (1997) 83]. Contrary to pp case in pA-collisions practically in all events meson should produce its own fireball. $\Rightarrow$ In $\sim$40% events we have an essentially asymmetric two-fireball configuration. Since jet may go without interaction with one of the fireball (typically it is meson fireball), the FSI is weaker than for a symmetric fireball (for same $dN_{ch}/d\eta$). The two-fireball state generates v_2 and v_3.

Photon-tagged jets in pp collisions



In 2-jet events we do not know the initial parton energy. In γ+jet events the parton p_T is approximately equal to the photon p_T. The medium effects differ for underlying events with different $dN_{ch}/d\eta$. $\Rightarrow$ It can be used to observe directly the medium modification of the fragmentation function $q \to h$ (similarly to AA-collisions [X.-N. Wang, Z. Huang, and I. Sarcevic, Phys. Rev. Lett. 77, 231 (1996)]).

Calculation of the γ-tagged FF

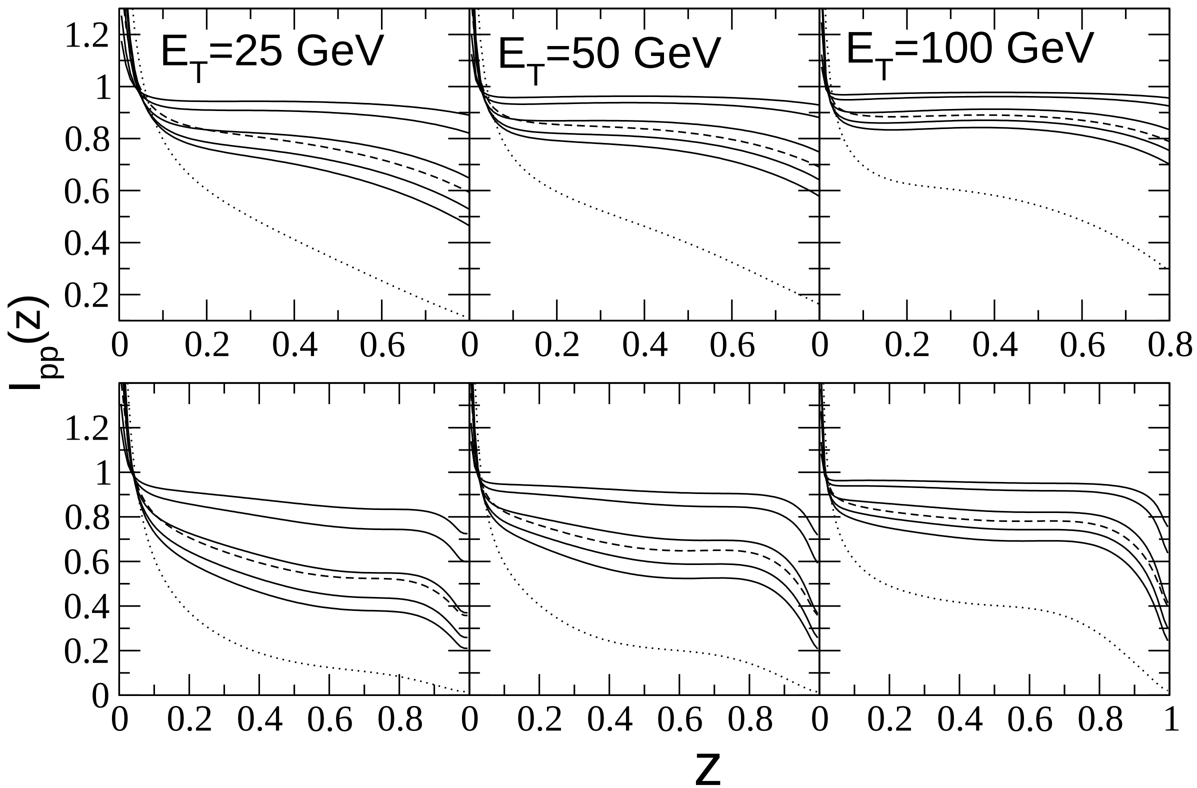
In γ+jet events parton E_T is smeared around E_T^{γ}. The NLO calculations (H. Zhang, J.F. Owens, E. Wang, and X.-N. Wang, Phys. Rev. Lett. 103, 032302 (2009)) show that for AA collisions at $E_T^{\gamma} \sim 8$ the smearing correction, Δ_{sm}, to the medium modification factor $I_{AA}(z)$ of the photon tagged FF blows up at $z \gtrsim 0.8-0.9$ ($z = p_T^h/E_T^{\gamma}$). One can show that $\Delta_{sm} \approx F(z, E_T^{\gamma}) dI_{AA}/dz/{E_T^{\gamma}}^2$, where $F(z, E_T^{\gamma})$ is a smooth function of E_T^{γ}. Using this formula one can show that for $E_T^{\gamma} \gtrsim 25$ GeV smearing should be very small at $z \lesssim 0.9$, and one can take $E_T = E_T^{\gamma}$. Then

$$D_h(z, E_T^{\gamma}, dN_{ch}/d\eta) = \langle\langle \sum_i r_i(E_T^{\gamma}) D_{h/i}(z, E_T^{\gamma}, dN_{ch}/d\eta)\rangle\rangle, \quad (1)$$

where r_i is the fraction of the $\gamma + i$ parton state in the γ+jet events. $\langle\langle ... \rangle\rangle$ means averaging over the transverse geometrical variables of pp collision. We use the LO pQCD r_i, it gives $r_g \ll r_q$ at LHC energies. In principle, r_g/r_q may depend on $dN_{ch}/d\eta$. However, there are no serious physical reasons for the strong multiplicity dependence of this ratio, because the UE activity is driven by fluctuations of soft gluons which should not strongly modify the hard cross sections.

$dN_{ch}/d\eta$	3	6	20	40	60
R_f (fm)	1.046	1.27	1.538	1.538	1.538
T_0 (MeV)	177	196	258	325	372

I_{pp} for γ-tagged and inclusive jets



$$I_{pp}(z, E_T, dN_{ch}/d\eta) = D_h(z, E_T, dN_{ch}/d\eta)/D_h^{vac}(z, E_T)$$

for γ-tagged (upper panels) and inclusive (lower panels) jet FFs at $\sqrt{s} = 7$ TeV for $dN_{ch}/d\eta = [3, 6, 20, 40, 60]$ (solid line). The order (top to bottom) of the curves at large z corresponds to increasing values of $dN_{ch}/d\eta$. The dashed line shows ratio of the FFs for $dN_{ch}/d\eta = 40$ and 3. The dotted line shows the medium modification factor at $\sqrt{s} = 2.76$ TeV for the QGP with $T_0 = 420$ MeV and $L = 5$ fm for $\alpha_s^{fr} = 0.4$. ALICE data on NT90 at $\sqrt{s} = 7$ TeV [1208.0940] support jet quenching for inclusive jets.

Conclusions:

- Assuming that a mini-QGP may be created in pp collisions, we have evaluated the medium modification factor R_{pp} for light and heavy flavors at RHIC ($\sqrt{s} = 0.2$ TeV) and LHC ($\sqrt{s} = 2.76$ and 7 TeV) energies. We have found an unexpectedly large suppression effect. For charged hadrons at $p_T \sim 10$ GeV we obtained
$R_{pp} \sim [0.7 - 0.8,\ 0.65 - 0.75,\ 0.6 - 0.7]$ at $\sqrt{s} = [0.2, 2.76, 7]$ TeV.
- The presence of R_{pp} does not change dramatically the description of R_{AA} for light hadrons in central AA collisions, and its effect may be imitated by some renormalization of α_s. Nevertheless, the effect of the QGP formation in pp collisions may be important in calculating other observables in AA collisions. It affects v_2 and the centrality dependence of R_{AA}, and, due to the flavor dependence of R_{pp} it changes the flavor dependence of R_{AA}.
- We show that the scenario with the QGP in pp and pPb collisions may be consistent with the data on R_{pPb} only if the UE multiplicity density in pPb collisions (which is unknown yet) is close to the minimum bias one. The meson-baryon Fock component in the proton may be important for description of R_{pA}. It may lead to two-fireball state which naturally generates v_2, v_3 in pA-collisions.
- We have evaluated the medium modification factors for the γ-tagged and inclusive jet FFs for $\sqrt{s} = 7$ TeV. We show that in pp collisions with UE $dN_{ch}/d\eta \sim 20 - 40$ the mini-QGP can suppress the γ-tagged FF at $E_T \sim 25 - 100$ GeV and $z \sim 0.5 - 0.8$ by $\sim 10 - 40\%$, and for inclusive jets the effect is even stronger.

Thank you for your attention!