Rho zero and Eta production in heavy ion collisions at NLO

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Outline

1. Motivation
2. ρ^0 and η fragmentation functions
3. Modified FFs with bulk evolutions
4. Numerical results
5. Conclusion and Outlook

Motivation

Suppression of high pT hadron

Jet queching

STAR
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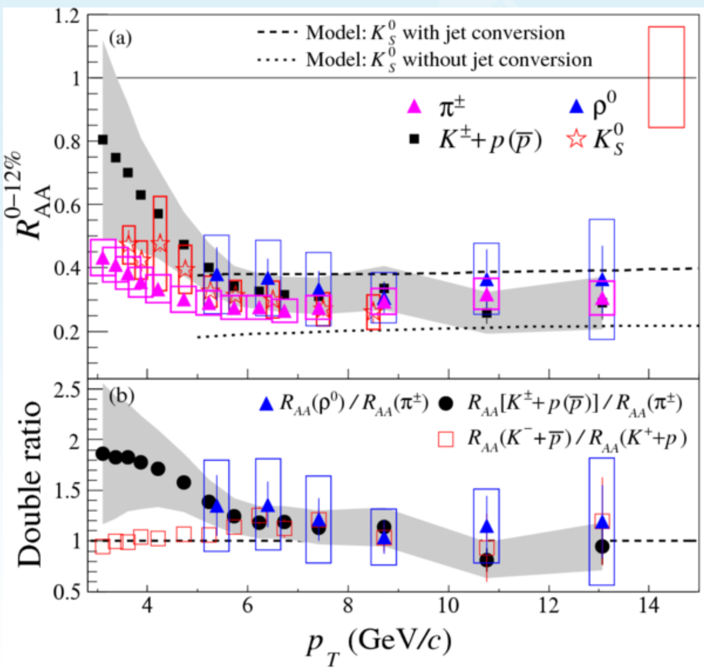

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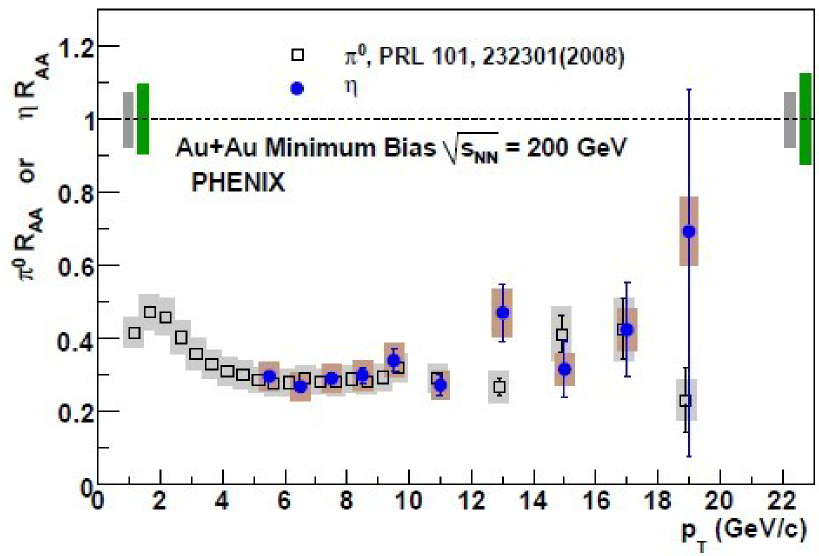
Phys.Rev.C.82 (2010) 011902



η fragmentation functions

$$|\eta\rangle \simeq |u\bar{u} + d\bar{d} - 2s\bar{s}\rangle$$

AESSS PRD 83, 034002

Parametrize the flavor singlet combination at an input scale of $\mu_0 = 1GeV$

Assume:

$$D_u^\eta = D_{\bar{u}}^\eta = D_d^\eta = D_{\bar{d}}^\eta = D_s^\eta = D_{\bar{s}}^\eta$$

$$D_i^\eta(z,\mu_0) = N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}] \times \frac{1}{B[2+\alpha_i,\beta_i+1]+\gamma_i B[2+\alpha_i,\beta_i+\delta_i+1]}$$

ρ^0 fragmentation functions

The octet fragmentation functions

H.Saveetha,
D.Indumathi
Arxiv:1102.5594

All fragmentation functions are described in terms of three SU(3) symmetric functions:

$\alpha(x, Q^2)$ $\beta(x, Q^2)$ $\gamma(x, Q^2)$

fragmenting quark		K^{*+}	fragmenting quark		K^{*0}
u	:	$\alpha+\beta+\frac{3}{4}\gamma$	u	:	$2\beta+\gamma$
d	:	$2\beta+\gamma$	d	:	$\alpha+\beta+\frac{3}{4}\gamma$
s	:	2γ	s	:	2γ
fragmenting quark		ω	**fragmenting quark**		ρ^0
u	:	$\frac{1}{6}\alpha+\frac{9}{6}\beta+\frac{9}{8}\gamma$	u	:	$\frac{1}{2}\alpha+\frac{1}{2}\beta+\frac{11}{8}\gamma$
d	:	$\frac{1}{6}\alpha+\frac{9}{6}\beta+\frac{9}{8}\gamma$	d	:	$\frac{1}{2}\alpha+\frac{1}{2}\beta+\frac{11}{8}\gamma$
s	:	$\frac{4}{6}\alpha+\frac{9}{6}\gamma$	s	:	$2\beta+\gamma$

Input scale

$Q^2 = 1.5 GeV$

Application of SU(3) invariance leads to $\beta = \gamma/2$. Hence there are two independent combinations: $V(x,Q^2) \equiv \alpha+\beta-5/4\gamma$ and $\gamma(x,Q^2)$, apart from the gluon fragmentation function.

Single hadron production

$$\frac{d\sigma^h_{pp}}{dy\,d^2P_T} = \sum_{abcd}\int dx_a dx_b\, f_{a/p}(x_a,\mu^2)\, f_{b/p}(x_b,\mu^2)\times\frac{d\sigma}{d\hat{t}}(ab\to cd)\,\frac{D^0_{h/c}(z_c,\mu^2)}{\pi z_c}+o(\alpha_s^3)$$

$f_{a/p}(x_a,\mu^2)$ Given by the CTEQ6M

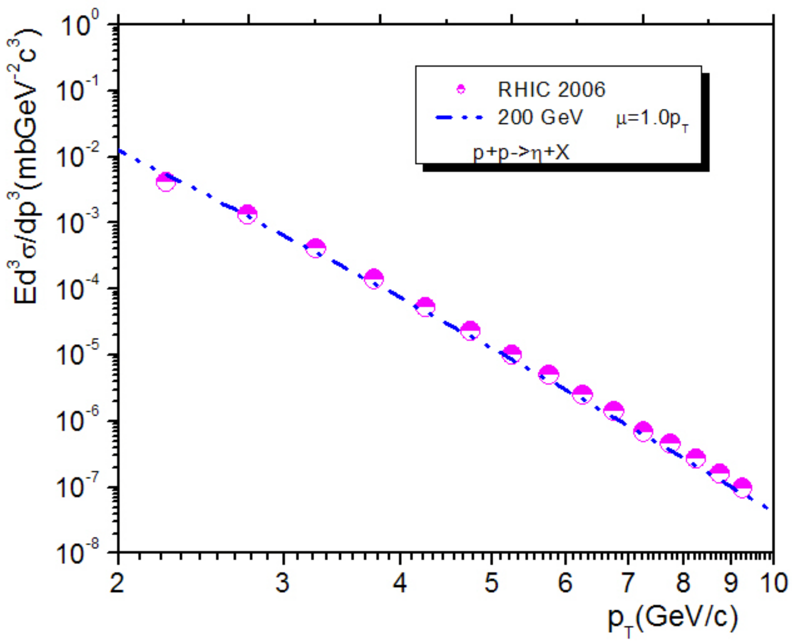
p+p ⟶ h + X

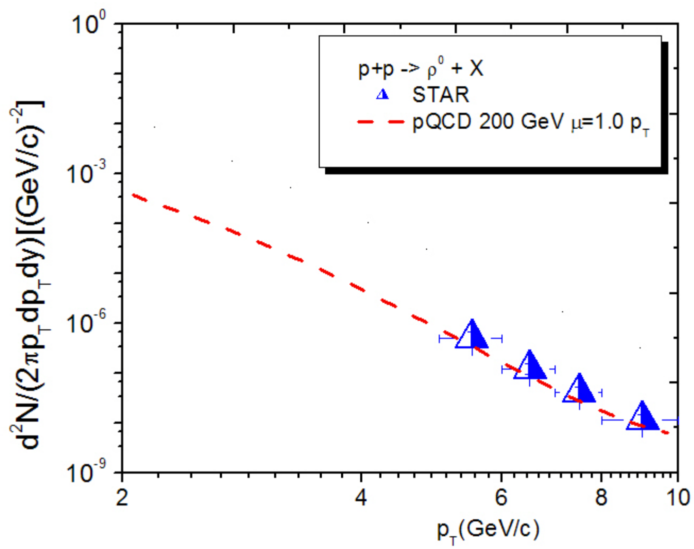
$D^0_{h/c}(z_c,\mu^2)$ DGLAP Evolution

NLO

Numerical solution:
QCDNUM：arXiv:1005.1481
HKN : arXiv:1106.1553 (2011)

PHENIX PRD 83, 032001(2011)





STAR PRL 108, 72302(2012)

Single hadron production

Au+Au → h + X

$$\frac{1}{N_{bin}^{AB}(b)}\frac{d\sigma_{AB}^{h}}{dyd^2P_T} = \sum_{abcd}\int dx_a dx_b f_{a/A}(x_a,\mu^2) f_{b/B}(x_b,\mu^2)$$

$$\times \frac{d\sigma}{d\hat{t}}(ab \to cd)\frac{<\tilde{D}_c^h(z_c,Q^2,E,b)>}{\pi z_c} + o(\alpha_s^3)$$

Medium-modified parton FF averaged over the initial production position and jet propagation direction.

$$<\tilde{D}_c^h(z_c,Q^2,E,b)> = \frac{1}{\int d^2 r t_A(|\vec{r}|) t_B(|\vec{b}-\vec{r}|)}$$

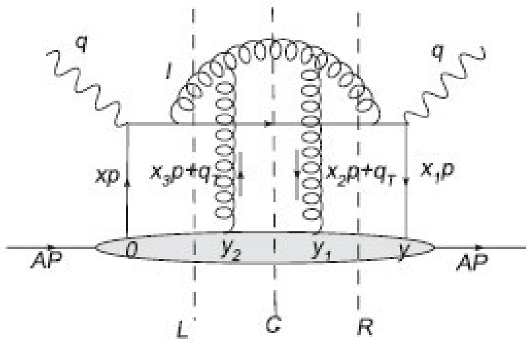
$$\times \int \frac{d\phi}{2\pi} d^2 r t_A(|\vec{r}|) t_B(|\vec{b}-\vec{r}|) \tilde{D}_c^h(z_c,Q^2,E,r,\phi,b)$$

→ Medium

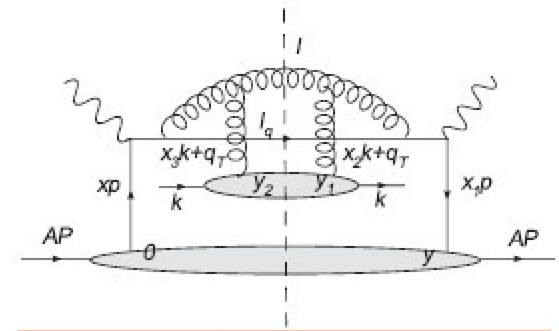
Modular--- generate data table

$$R_{AB}(b) \frac{d\sigma_{AB}^h / dyd^2P_T}{N_{bin}^{AB}(b) d\sigma_{pp}^h / dyd^2P_T}$$

Modified FF with bulk evolutions



X.F.Guo
Xin-Nian Wang



$$|A\rangle \to \int \frac{d^3k}{(2\pi)^3 2k^+}\psi_k(y)e^{ik\cdot y}|k\rangle \otimes |A\rangle$$

DIS

$$\tilde{D}_q^h(z_h, Q^2) = D_q^h(z_h, Q^2) + \frac{\alpha_s(Q^2)}{2\pi}\int_0^{Q^2}\frac{d\ell_T^2}{\ell_T^2} \times \int_{z_h}^1 \frac{dz}{z}\left[\Delta\gamma_{q\to qg}(z, x, x_L, \ell_T^2) D_q^h\left(\frac{z_h}{z}\right) + \Delta\gamma_{q\to gq}(z, x, x_L, \ell_T^2) D_g^h\left(\frac{z_h}{z}\right)\right],$$

$$\Delta\gamma_{q\to qg}(z, x, x_L, \ell_T^2) = \left[\frac{1+z^2}{(1-z)_+} T_{qg}^A(x, x_L) + \delta(1-z)\Delta T_{qg}^A(x, x_L)\right]\frac{2\pi\alpha_s C_A}{\ell_T^2 N_c f_q^A(x)}$$

$$\Delta\gamma_{q\to gq}(z, x, x_L, \ell_T^2) = \Delta\gamma_{q\to qg}(1-z, x, x_L, \ell_T^2)$$

The total quark jet energy loss in DIS

$$\frac{\Delta E}{E} = \frac{C_A \alpha_s^2}{N_c}\int_0^{Q^2}\frac{d\ell_T^2}{\ell_T^4}\int_0^1 dz(1+z)^2 \frac{T_{qg}^A(x, x_L)}{f_q^A(x)}$$

$$\Delta T_{qg}^A(x, x_L) = \int_0^1 dz \frac{1}{1-z}\left[2T_{qg}^A(x, x_L)|_{z=1} - (1+z^2) T_{qg}^A(x, x_L)\right],$$

$$f_q^A(x) = \int \frac{dy^-}{2\pi} e^{ixp^+y^-}\langle A|\bar{\psi}_q(0)\frac{\gamma^+}{2}\psi_q(y^-)|A\rangle$$

Modified FF with bulk evolutions

After the **assumption and** Neglect multiple particle correlations inside the hot medium

$$\frac{T^A_{qg}(x,x_L)}{f^A_q(x)} = \frac{N_c^2-1}{4\pi\alpha_s C_R}\frac{1+z}{2}\int dy^- 2\sin^2\left[\frac{y^-\ell_T^2}{4Ez(1-z)}\right] \times [\hat{q}_R(E,x_L,y) + c(x,x_L)\hat{q}_R(E,0,y)],$$

$$c(x,x_L) = f^A_q(x+x_L)/f^A_q(x)$$

pure elastic energy loss

pure radiative processes

Generalized jet transport parameter

$$\hat{q}_R(E,x_L,y) = \frac{4\pi^2\alpha_s C_R}{N_c^2-1}\int\frac{d^3k}{(2\pi)^3}f(k,y) \times \int\frac{d^2q_T}{(2\pi)^2}\phi_k(x_T+x_L,q_T)$$

The transverse-momentum-dependent-gluon distribution function from the quasiparticle in the medium

$$\phi_k(x,q_T) = \int\frac{d\xi^-}{2\pi k^+}d^2\xi_T\, e^{ixk^+\xi^- - i\mathbf{q}_T\cdot\xi_T} \times \langle k|F^+_\sigma(0)F^{+\sigma}(\xi^-,\xi_T)|k\rangle$$

Focus on radiative energy loss

Assume $x \gg x_L, x_T$

Modified FF with bulk evolutions

Therefore: $c(x, x_L) \approx 1,\ \hat{q}_R(E, x_L, y) \approx \hat{q}_R(E, 0, y) \equiv \hat{q}_R(E, y)$

Quark energy loss

$$\frac{\Delta E}{E} = \frac{N_c \alpha_s}{\pi} \int dy^- dz d\ell_\perp^2 \frac{(1+z)^3}{\ell_T^4} \times \hat{q}_R(E, y) \sin^2\left[\frac{y^- l_T^2}{4Ez(1-z)}\right]$$

Same formalism,
But differ by a factor of 9/*4*
for quark and gluon jets.

Phenomenological treat

$$\hat{q}_R(E, \vec{b}, \vec{r}, r) = C\rho(\tau, b, \vec{r} + \vec{n}\tau)$$

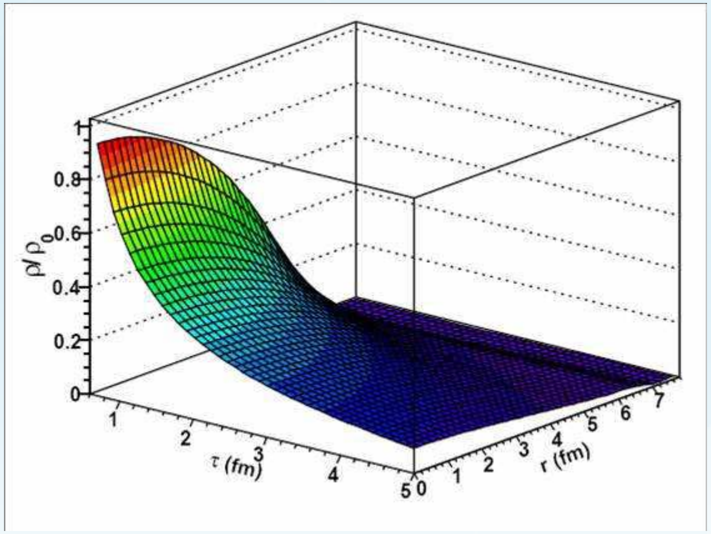
$$C = \hat{q}_0(b, r_0, \tau_0) / \rho_0(b, r_0, \tau_0)$$

$\hat{q}_0$ is the initial value of jet transport parameter at initial time τ_0.

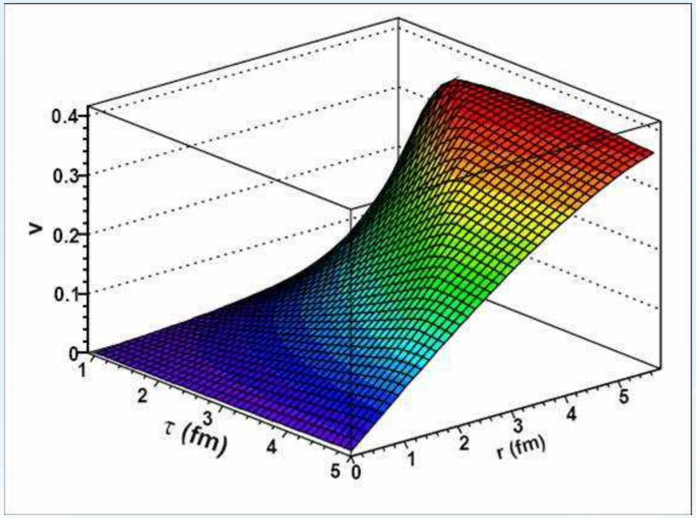
Modified FF with bulk evolutions

(1 + 3)d ideal hydrodynamical expansion

Parton Density



flow

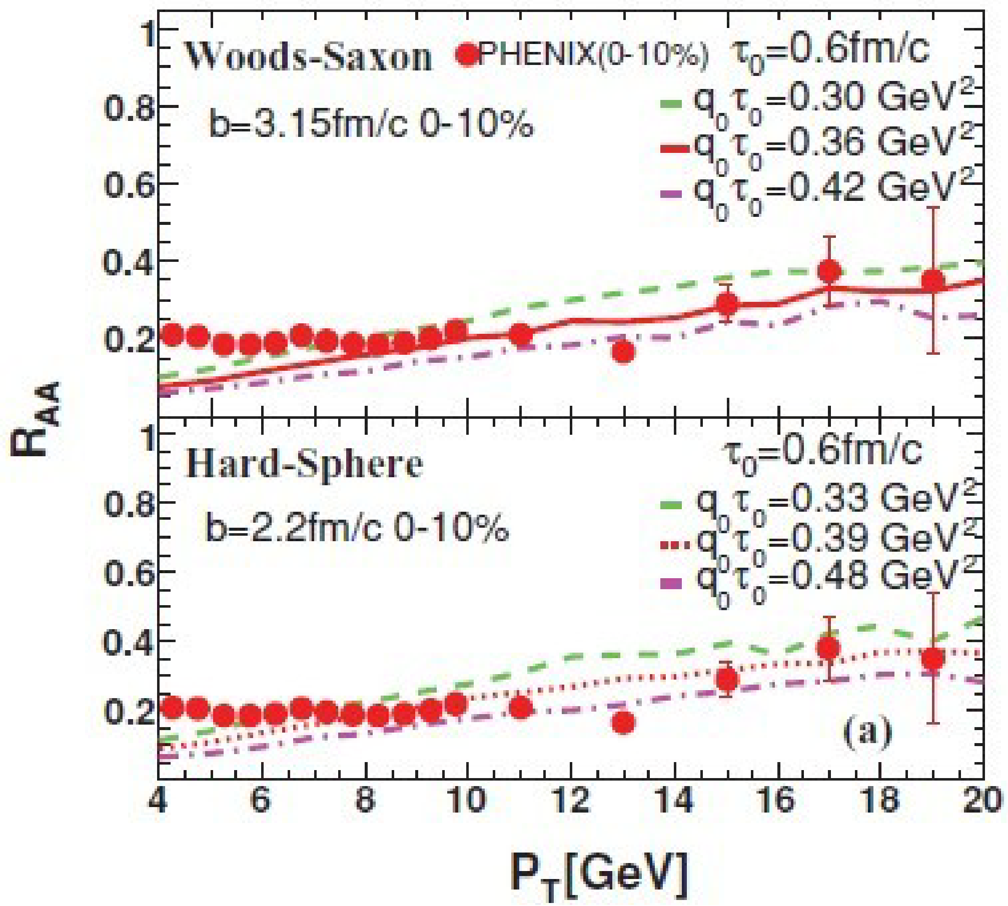


By Xiao-Fang Chen

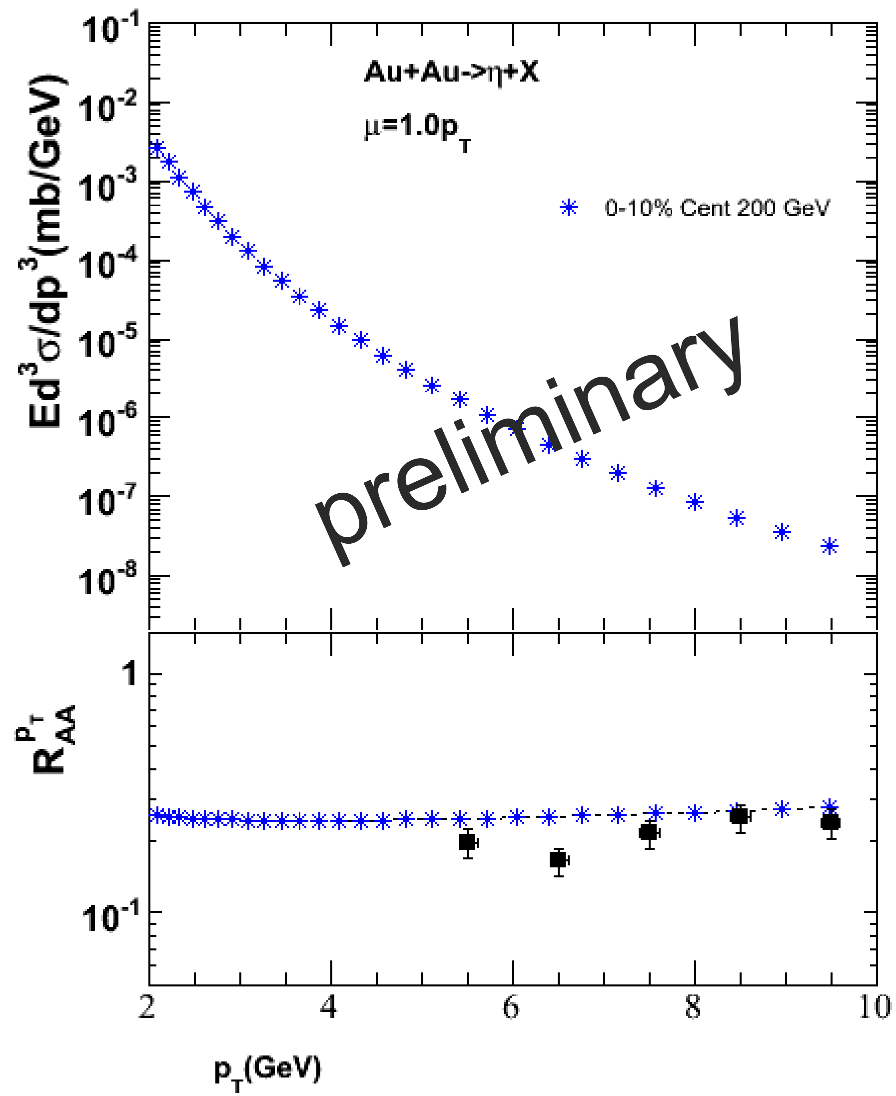
Outputs from the following references:

T. Hirano, U. Heinz, D. Kharzeev, R. Lacey and Y. Nara,
Phys. Lett. B636, 299 (2006)
Phys. Rev. C77, 044909 (2008)

Xiao-Fang Chen，Carsten Greiner ，etc
PRC 81，164908（2010）



Numerical results



$$q_0\tau_0 = 0.36GeV^2$$

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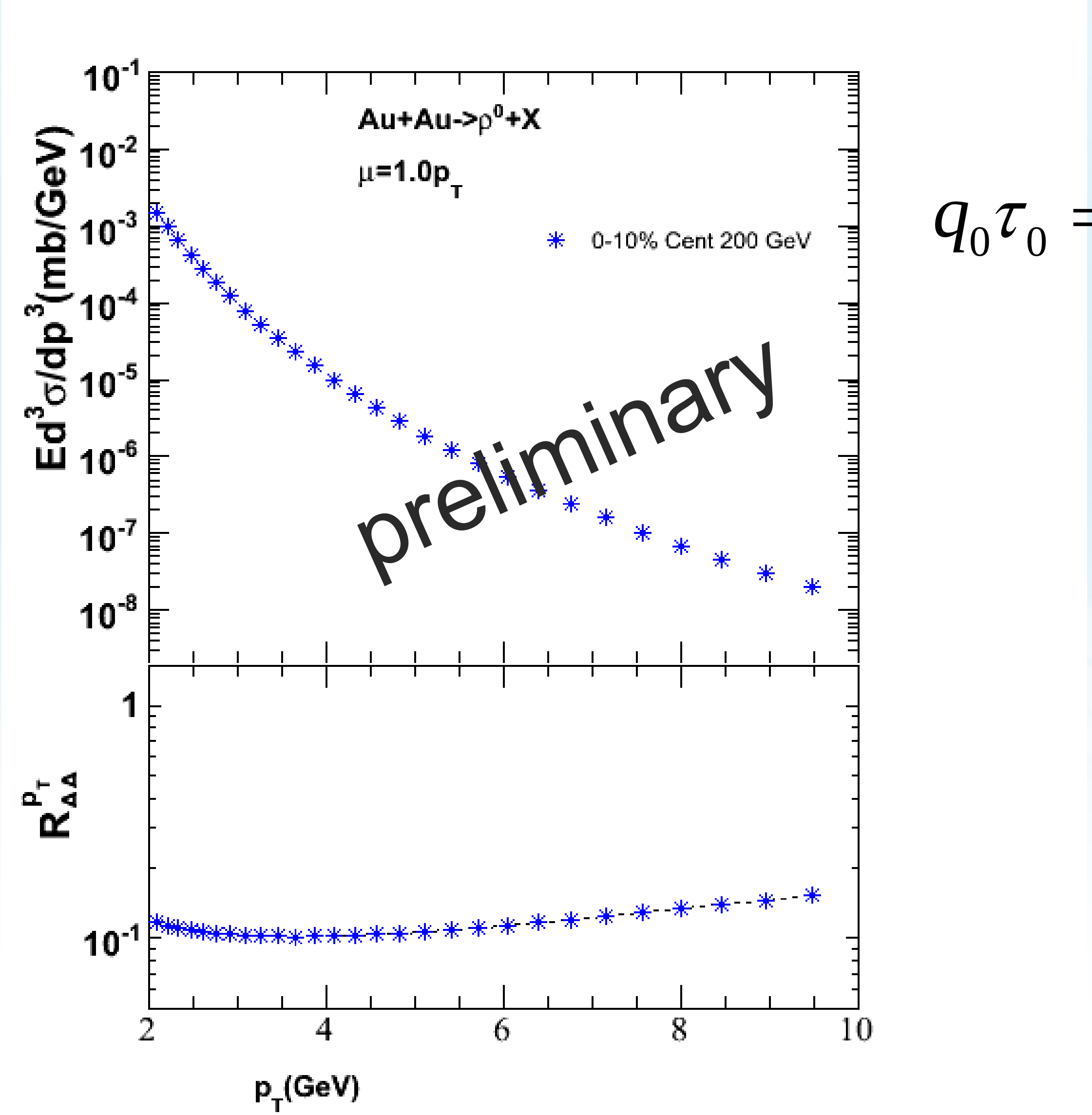
Numerical results



$$q_0\tau_0 = 0.36GeV^2$$

Conclusion and Outlook

Same Framework of the calculation for π^0 has been applied to ρ^0 and η
It provided the potential to understand the other identified hadrons productions and suppression in heavy ion collisions.

The theoretical prediction of the η productions and nuclear modification are in fairly agreement with the experimental Data, using the high twist formalism for medium modification of the parton fragmentation functions and the NLO order pQCD parton model for initial jet production.

We improve ρ^0 fragmentation function to NLO using SU(3) Model, and firstly confront the NLO prediction of the p+p spectra with experimental Data. Still, More experimental Data are needed to further constraint the fragmentation functions.

The study in the LHC case is proceeding

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Thank You !

Modified FF with bulk evolutions

bag model, hydrodynamic solution:

$$\rho^{QGP} = \left(16\frac{\zeta(3)}{\pi^2} + 36\frac{3\zeta(3)}{4\pi^2}\right) T^3 \equiv a_1 T^3,$$

$$\epsilon^{QGP} = \left(16\frac{\pi^2}{30} + 36\frac{7\pi^2}{240}\right) T^4 + B \equiv b_1 T^4 + B$$

$$B = (247 \text{ Mev})^4$$

first-order phase transition Tc =170 MeV

QGP Phase

$$\hat{q} = \hat{q}_0 \frac{\rho^{QGP}}{\rho_0} \equiv \hat{q}_0 \frac{(\epsilon - B)^{3/4}}{(\epsilon_0 - B)^{3/4}}$$

Hadronic Phase — Hadron resonance gas

$$\hat{q}_h = \frac{\hat{q}_N}{\rho_N}\left[\frac{2}{3}\sum_M \rho_M(T) + \sum_B \rho_B(T)\right]$$

$$\rho_N = n_0 \approx 0.17 \text{ fm}^{-3}$$

nucleon density in the center of a large nucleus

Include all hadron resonances with mass below 1 GeV

Modified FF with bulk evolutions

Therefore: $c(x, x_L) \approx 1,\ \hat{q}_R(E, x_L, y) \approx \hat{q}_R(E, 0, y) \equiv \hat{q}_R(E, y)$

Quark energy loss

$$\frac{\Delta E}{E} = \frac{N_c \alpha_s}{\pi} \int dy^- dz d\ell_\perp^2 \frac{(1+z)^3}{\ell_T^4} \times \hat{q}_R(E, y) \sin^2\left[\frac{y^- l_T^2}{4Ez(1-z)}\right]$$

Same formalism,
But differ by a factor of 9/*4*
for quark and gluon jets.

Phenomenological treat

$$\hat{q}_R(E, \vec{b}, \vec{r}, r) = C\rho(\tau, b, \vec{r} + \vec{n}\tau)$$
$$C = \hat{q}_0(b, r_0, \tau_0) / \rho_0(b, r_0, \tau_0)$$

$\hat{q}_0$ is the initial value of jet transport parameter at initial time τ_0.

Modified FF with bulk evolutions

From High Twist approach

Medium modified parton fragmentation function:

$$\tilde{D}_q^h(z_h, Q^2, E, r, \phi) = D_q^h(z_h, Q^2) + \Delta D_q^h(z_h, Q^2, E, r, \phi)$$

$$\Delta D_q^h \propto \int_{\tau_0}^{\tau_0+\Delta L} d\tau \int dz \frac{(1+z^2)(1+z)}{z(1-z)} D_q^h(z_h/z) \times \int_{\mu_0^2}^{Q^2} \frac{dl_T^2}{l_T^4} sin^2\left[\frac{(\tau-\tau_0)l_T^2}{4Ez(1-z)}\right] \times \hat{q}_0 \frac{\rho(b,\vec{r},\tau)}{\rho_0(b,\vec{r}_0,\tau_0)}$$

→ $\hat{q}$

$\hat{q}_0$ is the initial value of jet transport parameter at initial time τ_0.

$\hat{q}$ is an important jet-quenching parameter.

It's very significant to study the dependence of the medium-modified FF on the space-time evolution of the bulk medium.

Q^2 evolution for FFs

$$\frac{\partial}{\partial \ln Q^2} D^h_{q_i^+}(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\left[\sum_j P_{q_j q_i}(x,\alpha_s)\otimes D^h_{q_j^+}(x,Q^2) + 2P_{gq}(x,\alpha_s)\otimes D^h_g(x,Q^2)\right],$$

$$\frac{\partial}{\partial \ln Q^2} D^h_g(x,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\left[P_{qg}(x,\alpha_s)\otimes \sum_j D^h_{q_j^+}(x,Q^2) + P_{gg}(x,\alpha_s)\otimes D^h_g(x,Q^2)\right],$$