Identified Hadron Productions in Heavy Ion Collisions at Large p_T Region

Wei Dai

Tsinghua University

In Collaboration With Xiao-Fang Chen, Han-Zhong Zhang, Ben-Wei Zhang and Enke Wang

Wuhan, Hard Probe 2016

September 25, 2016

Based On

- W. Dai, X. F. Chen, B. W. Zhang and E. Wang,Phys. Lett. B **750**, 390 (2015)
- S. Y. Chen, K. M. Shen, W. Dai, B. W. Zhang, H. Z. Zhang and E. K. Wang, Commun. Theor. Phys. **64**, no. 1, 95 (2015)
- W. Dai, B. W. Zhang, H. Z. Zhang, and E. K. Wang, "ρ^0 and ϕ Meson Production at LO", to be submitted

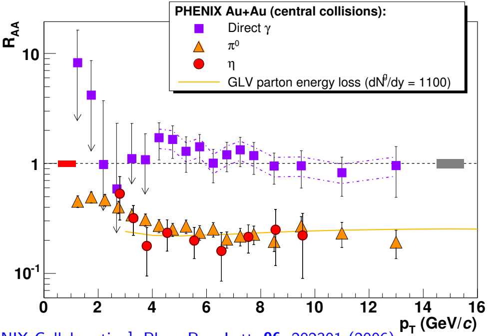
Overview

Motivation

Jet Quenching Observables

- Large Transverse Momentum Hadron Suppression

"conclude that all these observations are in agreement with a scenario where the parent parton first loses energy in the produced dense medium and then fragments into a leading meson in the vacuum according to the same probabilities that govern high-p_T hadroproduction in more elementary systems (p+p, e^+e^-)."



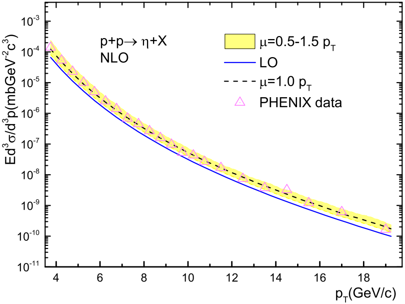
S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **96**, 202301 (2006)

Formalism in p+p Collisions

pQCD Improved Parton Model :

$$\frac{d\sigma_{pp}^h}{dyd^2p_T} = \sum_{abcd}\int dx_a dx_b f_{a/p}(x_a,\mu^2) f_{b/p}(x_b,\mu^2)$$

$$\times \frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd)\frac{D^0_{h/c}(z_c,\mu^2)}{\pi z_c} + \mathcal{O}(\alpha_s^3), (1)$$



W. Dai, X. F. Chen, B. W. Zhang and E. Wang,

PLB(2015)

η as the second well measured meson compared to π^0.

C. A. Aidala, F. Ellinghaus, R. Sassot, J. P. Seele and M. Stratmann,
Phys. Rev. D **83**, 034002 (2011)

In AESSS parametrization because of the absence of enough data on inclusive η productions, the η FFs can not be extracted separately for each quark flavor without additional assumptions, and the assumption is made that all light quark fragmentations are the same.

Formalism in A+A Collisions

X. F. Chen, T. Hirano, E. Wang, X. N. Wang and H. Zhang,
Phys. Rev. C **84**, 034902 (2011)

Cross section of the single hadron in HIC collisions could be expressed as:

$$\frac{1}{N_{\rm bin}^{AB}(b)}\frac{d\sigma_{AB}^h}{dyd^2p_T} = \sum_{abcd}\int dx_a dx_b f_{a/A}(x_a,\mu^2) f_{b/B}(x_b,\mu^2) \times \frac{d\sigma}{d\hat{t}}(ab\to cd)\frac{\langle \tilde{D}_c^h(z_h,Q^2,E,b)\rangle}{\pi z_c} + \mathcal{O}(\alpha_s^3).$$

The effective modifications of parton FFs in hot and dense medium:

$$\tilde{D}_q^h(z_h,Q^2) = D_q^h(z_h,Q^2) + \frac{\alpha_s(Q^2)}{2\pi}\int_0^{Q^2}\frac{d\ell_T^2}{\ell_T^2} \times \int_{z_h}^1 \frac{dz}{z}\left[\Delta\gamma_{q\to qg}(z,x,x_L,\ell_T^2) D_q^h(\frac{z_h}{z},Q^2) + \Delta\gamma_{q\to gq}(z,x,x_L,\ell_T^2) D_g^h(\frac{z_h}{z},Q^2)\right] \quad (3)$$

Assume all the energy loss of a fast parton is that carried away by the radiative gluon in the multiple scattering processes, the corresponding parton energy loss in the QCD medium can be expressed as:

$$\frac{\Delta E}{E}(2) = \frac{N_c\alpha_s}{\pi}\int dy^- dz d\ell_T^2 \frac{(1+z)^3}{\ell_T^4} \times \hat{q}_{\rm R}(E,y)\sin^2[\frac{y^-\ell_T^2}{4Ex(1-z)}] \quad (4)$$

The jet transport parameter $\hat{q}_{\rm R}(E,y)$ is related to the parton density distribution in the medium, therefore can characterizes the evolutionary medium properties.

Hirano full three-dimensional(3+1D)ideal

hydrodynamics has been employed.

Nuclear Modification Factor in A+A Collisions

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)

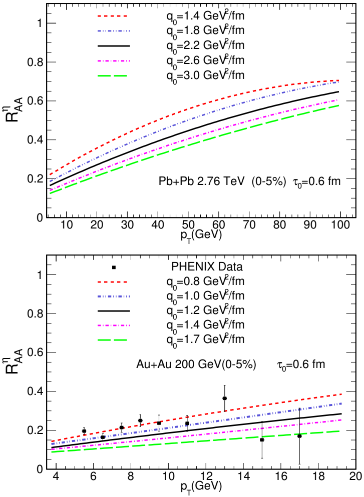
$$R_{AB}(b) = \frac{d\sigma^h_{AB}/dyd^2p_T}{N^{AB}_{bin}(b)d\sigma^h_{pp}/dyd^2p_T} \quad (5)$$

Questions:

- Even η meson is 4 times heavier than π^0, a similar flat production suppression has been observed at RHIC in this p_T range independent of their mass?
- Can it be explained in one simple story that parton jets loss their energies first in the QCD medium and then fragment into hadrons in the vacuum?

Therefore:

hadron production ratio has been measured.



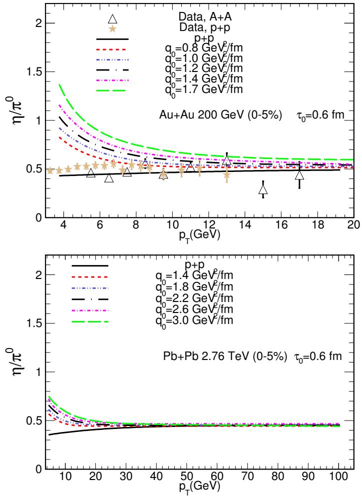
η/π^0 ratio in A+A Collisions

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)

Findings and more questions:

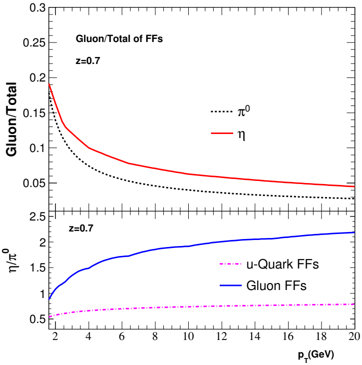
Confront with A. Morreale [ALICE Collaboration] arXiv:1512.05250

- Simple story that parton jets loss their energies first in the QCD medium and then fragment into hadrons in the vacuum can not explain everything.
- Similar trend could be seen at the RHIC and LHC that with the in- creasing of p_T, the η/π^0 ratio in A + A collisions comes closer to the p + p curve, and at very larger p_T two curves coincide with each other.
- In principle, a change of flavor compositions of parton jets may affect the ratio of η/π^0 due to the fact that gluon jet suffers larger energy loss than quark jet in QCD medium.
- Why the increasing of the q_0 gives higher ratio of η/π^0 in $A + A$?



η and π^0 FFs

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)



- At very high p_T region, $D_{q\to\eta}/D_{q\to\pi^0}$ at $z_h = 0.7$ is approximately 0.5. (why same as η/π^0 rario?)
- At high p_T, quark FFs $D_{q\to\eta,\pi^0}(z_h, Q = p_T)$ have a weak dependence on z_h and p_T in the typical z_h region $0.4 - 0.7$ for identified hadron production

Re-write the The Hadron Yield

- The hadron yield in $\mathrm{p}+\mathrm{p}$ will be determined by two factors: the initial (parton-)jet spectrum $f_{q,g}(p_T)$ and the parton fragmentation functions $D_{q,g\to\eta,\pi^0}(z_h, p_T)$.

$$\frac{1}{p_T}\frac{d\sigma_{\pi^0,\eta}}{dp_T} = \int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta,\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2} + \int f_g(\frac{p_T}{z_h}) \cdot D_{g\to\eta,\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2} \quad . \tag{6}$$

- Energy loss effect is to shift z_h of quark FFs in vacuum.

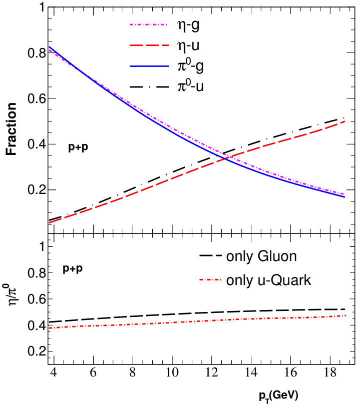
η/π^0 ratio only considering gluon and quark in p+p

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)

- In the asymptotic region with $p_T \to \infty$:

$$R(\eta/\pi^0) = \frac{d\sigma_\eta}{dp_T} / \frac{d\sigma_{\pi^0}}{dp_T} \approx \frac{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta}(z_h, p_T)\frac{dz_h}{z_h^2}}{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2}} \approx \frac{\Sigma_q D_{q\to\eta}(\langle z_h\rangle, p_T)}{\Sigma_q D_{q\to\pi^0}(\langle z_h\rangle, p_T)} . \quad (7)$$

- The yields of both π^0 and η should also predominantly come from quarks.
- At very high p_T region, the ratios of η/π^0 in both $\mathrm{A}+\mathrm{A}$ and $\mathrm{p}+\mathrm{p}$ should overlap with the one in e^+e^- scattering, and reach a universal value ~ 0.5.



η/π^0 ratio only considering gluon and quark in p+p

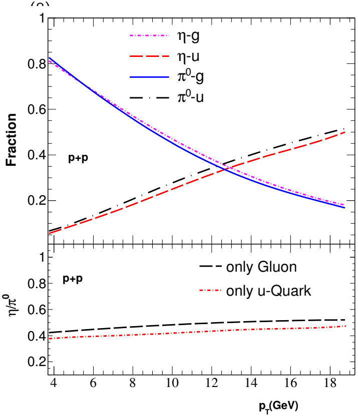
- For the transverse momentum p_T is not very high.

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)

$$G^{\eta,\pi^0}(p_T) = \frac{\int f_g(\frac{p_T}{z_h}) \cdot D_{g\to\eta,\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2}}{\frac{1}{p_T}\frac{d\sigma_{\pi^0,\eta}}{dp_T}},$$

$$G^{\pi^0}(p_T) \approx G^{\eta}(p_T)$$

in the p_T region of 4 − 20 GeV.
Thus, the flavor compositions or mixture of quarks and gluons in $\mathrm{p+p}$ have nearly negligible effect.



$$R(\eta/\pi^0) = \frac{\frac{1}{1-G^{\eta}(p_T)}\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta}(z_h, p_T)\frac{dz_h}{z_h^2}}{\frac{1}{1-G^{\pi^0}(p_T)}\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2}}$$

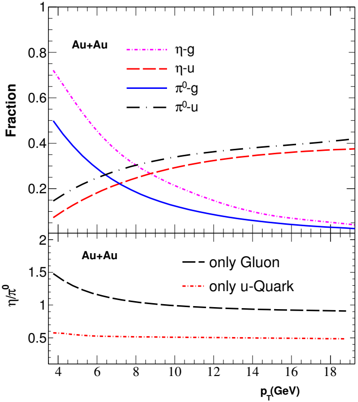
$$\approx \frac{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta}(z_h, p_T)\frac{dz_h}{z_h^2}}{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2}}$$

$$\approx \frac{\int f_g(\frac{p_T}{z_h}) \cdot D_{g\to\eta}(z_h, p_T)\frac{dz_h}{z_h^2}}{\int f_g(\frac{p_T}{z_h}) \cdot D_{g\to\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2}}.$$

η/π^0 ratio only considering gluon and quark in A+A

W. Dai, X. F. Chen, B. W. Zhang and E. Wang, PLB(2015)

- A naive expectation is that because gluon may give larger η/π^0 ratio than quark does, the larger suppression of gluons in the QCD medium will reduce η/π^0, against calculation.
- The suppression of gluon in QCD medium imposes a larger reduction of the yield of π^0 than that of η.
- We emphasize that the identified hadron yield in heavy-ion collisions relies on three factors: the initial hard jet spectrum, the energy loss mechanism, and parton fragmentation functions to the hadron in vacuum.



Initial Fragmentation Functions at initial Scale Q^2=1.5 GeV^2

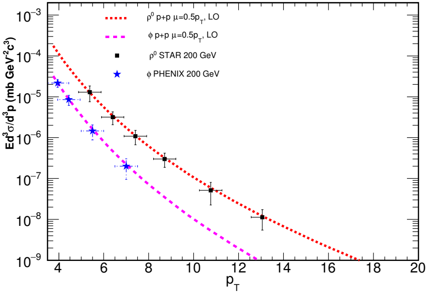
Quark fragmentation functions into members of meson octet in terms of the SU(3) functions, α, β and γ. — H. Saveetha, D. Indumathi and S. Mitra, Int. J. Mod. Phys. A **29**, no. 07, 1450049 (2014)

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/ϕ	**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	:	$2\beta+\gamma$
fragmenting quark		ρ^+	**fragmenting quark**		ρ^-
u	:	$\alpha+\beta+\frac{3}{4}\gamma$	u	:	2γ
d	:	2γ	d	:	$\alpha+\beta+\frac{3}{4}\gamma$
s	:	$2\beta+\gamma$	s	:	$2\beta+\gamma$
fragmenting quark		$\overline{K^{*0}}$	**fragmenting quark**		K^{*-}
u	:	$2\beta+\gamma$	u	:	2γ
d	:	2γ	d	:	$2\beta+\gamma$
s	:	$\alpha+\beta+\frac{3}{4}\gamma$	s	:	$\alpha+\beta+\frac{3}{4}\gamma$

ρ^0 and ϕ Productions in p+p Collisions at LO

pQCD Improved Parton Model :

$$\frac{d\sigma^h_{pp}}{dyd^2p_T} = \sum_{abcd} \int dx_a dx_b f_{a/p}(x_a, \mu^2) f_{b/p}(x_b, \mu^2) \times \frac{d\hat{\sigma}}{d\hat{t}}(ab \to cd) \frac{D^0_{h/c}(z_c, \mu^2)}{\pi z_c} + \mathcal{O}(\alpha_s^3)(10)$$



M. Hirai and S. Kumano, Comput. Phys. Commun. **183**, 1002 (2012)

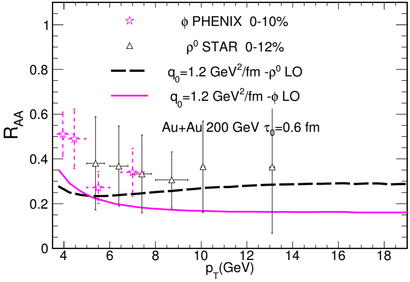
Failed to give the NLO FFs, since the NLO/LO factor can not be held.

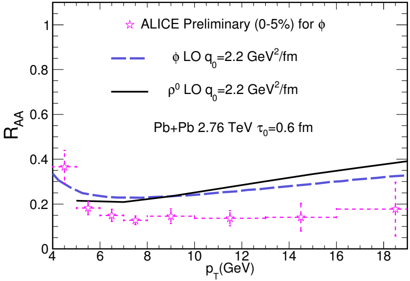
DGLAP evolution is considered to have the initial

FFs evolving with the scale Q^2 at LO

To be submitted (2016)

ρ^0 and ϕ Productions in A+A Collisions at LO





To be submitted (2016)

Outlook

At the asymptotic region when $p_T \to \infty$ the ratios of η/π^0 in both $\mathrm{Au+Au}$ and $\mathrm{p+p}$ are almost determined only by quark jets fragmentation and thus approach to the one in e^+e^- scattering.

The almost identical gluon (quark) contribution fractions to η and to π result in a rather moderate variation of η/π^0 distribution at intermediate and high p_T region in $\mathrm{A+A}$ relative to that in $\mathrm{p+p}$;

A slightly higher η/π^0 at small p_T in $\mathrm{Au+Au}$ can be observed due to larger suppression of gluon contribution fraction to π^0 as compared to the one to η.

Same framework to predict ρ^0 and ϕ meson.

Thank you!