ω and k_s Meson Productions in Pb+Pb Collisions and Global Extraction of $\hat{q}$ with Six Types of Identified Hadrons Suppression at the NLO

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In Collaboration with G. Y. Ma, B. W. Zhang and E. Wang

June 22, 2018

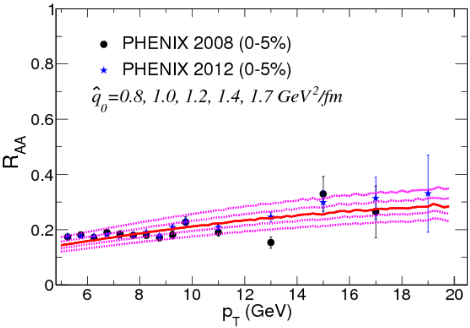
Overview

- Motivation
- η, ϕ and ρ^0 Meson Productions
- ω and K_s Meson Productions at larger momentum
  - NLO DGLAP evolved Fragmentation Functions
  - ω and K_s Productions in p+p Collisions at NLO
  - Formalism in A+A Collisions
  - Flavor Dependent Production Fraction of ω Productions in p+p and A+A Collisions at NLO
  - Particle Ratio in p+p and A+A Collisions
- Extraction of $\hat{q}$ with Six Types of Identified Hadrons Suppression
  - Nuclear Modification Factor in A+A Collisions
  - χ^2 Fit to Extract $\hat{q}$
- Summary and Outlook

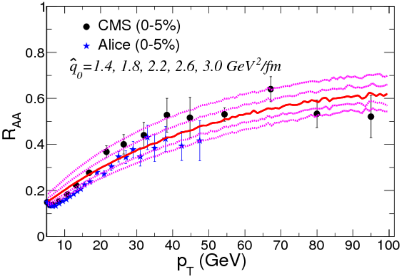
Motivation

R_{AA} measurement(larger p_T): E-LOSS model controlled by $\hat{q}_0$

$\pi^0(Au + Au\ 200 GeV)$



$\pi^0(Pb + Pb\ 2.76 TeV)$

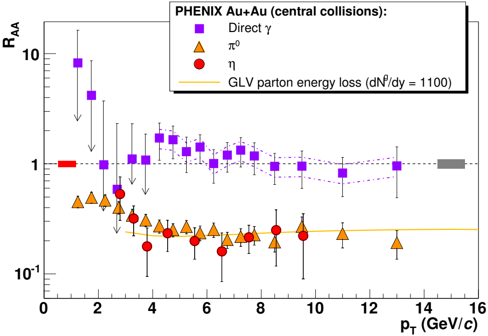


JET Collaboration, Phys.Rev. C90 (2014) no.1, 014909

Motivation

To explore the nature of hadron $R_{\rm AA}$ at large p_T

"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)

Motivation

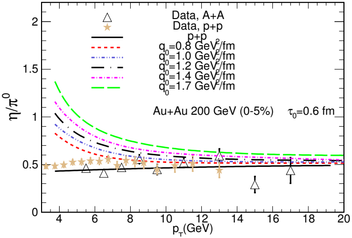
To explore the nature of hadron R_{AA} at large p_T

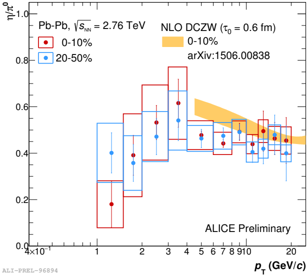
- Are similar R_{AA} trend shared among different species of final state hadrons? What is the nature?
- Can the scenario of E-lost parton jet fragment outside the QGP medium tell a full story of R_{AA} ? independent of MASS or SPECIES.
- Is the changing of jet chemistry playing a part in it? HOW?
- Hadron production ratio is therefore needed as a second pair of eyes to disclose the jet chemistry changing along the theoretical study.

η/π^0 ratio in A+A Collisions

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

ALICE.J.Phys.Conf.Ser. 832 (2017) no.1, 012011





Findings:

Confronted 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.
- 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.

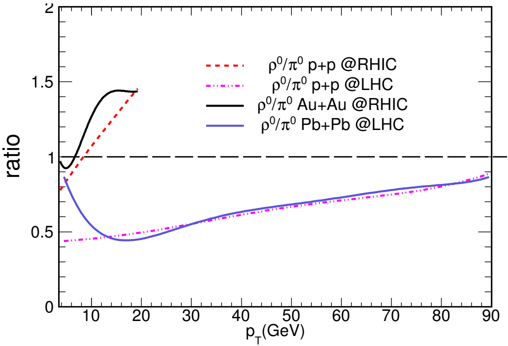
ρ^0/π^0 ratio in A+A Collisions

W. Dai, B. W. Zhang and E. Wang,

arXiv:1701.04147

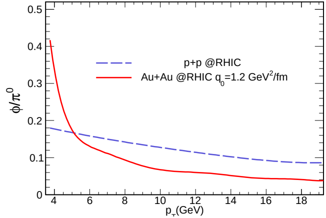
Findings:

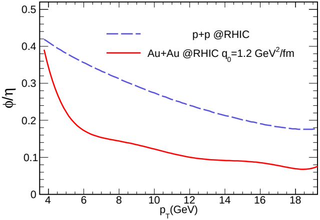
- Nature of same suppression of some light quark hadron productions is due to the light quark dominated production, such as π^0, η and ρ^0, thus gives similar behavior of ρ^0/π^0, η/π^0 at very high p_{T} in A+A collisions from the ones in p+p at both the RHIC and the LHC energies.



ϕ/π^0 ratio in A+A Collisions

W. Dai, B. W. Zhang H. Z. Zhang, X. F. Chen and E. Wang, EPJC (2017)





Findings:

- The ϕ meson (ssbar) production is however non quark dominated, hint a non-light meson will have nonnegligible gluon contribution.

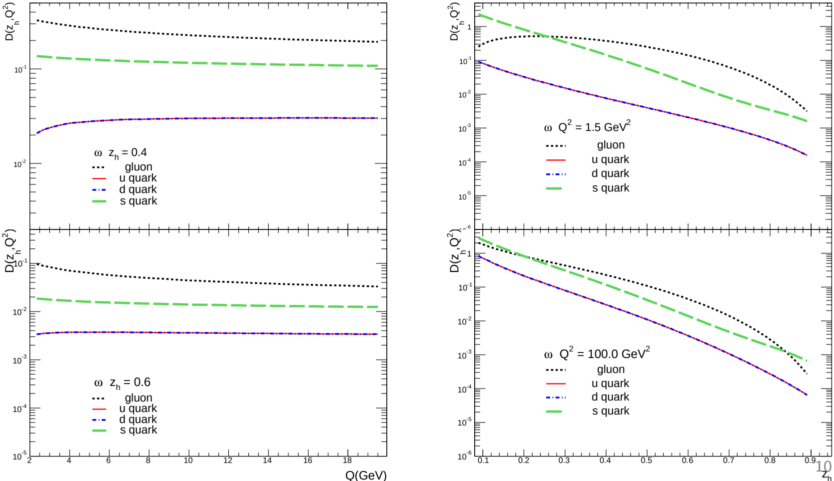
Initial Fragmentation Functions at initial Scale Q^2=1.5 GeV^2

Quark fragmentation functions into members of meson octet in terms of the SU(3) functions, α, β, γ and λ. — 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	:	$\alpha+\beta+\frac{3}{4}\gamma$

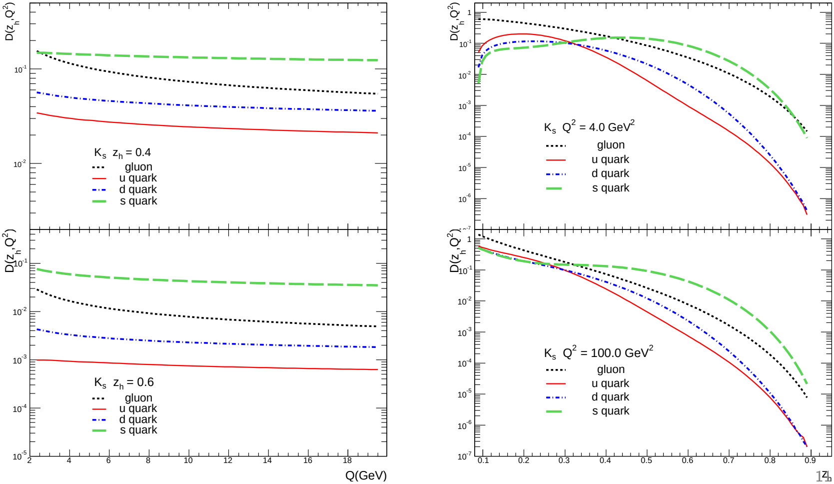
ω FFs evolution at NLO

DGLAP evolution is considered to have the initial FFs evolving with the scale Q^2 at NLO



K_s FFs evolution at NLO

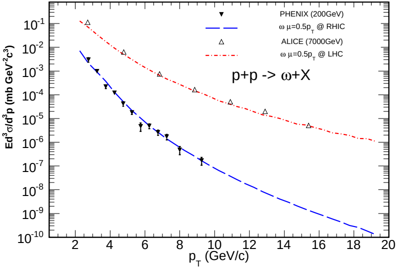
S. Albino, B. A. Kniehl and G. Kramer, Nucl. Phys. B **803**, 42 (2008) AKK08



Formalism in p+p Collisions

pQCD Improved Parton Model :

$$
\begin{aligned}
\frac{d\sigma_{pp}^{h}}{dyd^2p_T} &= \sum_{abcd}\int dx_a dx_b f_{a/p}(x_a,\mu^2) f_{b/p}(x_b,\mu^2) \\
&\times \frac{d\hat{\sigma}}{d\hat{t}}(ab\to cd)\frac{D^0_{h/c}(z_c,\mu^2)}{\pi z_c} + \mathcal{O}(\alpha_s^3), (1)
\end{aligned}
$$



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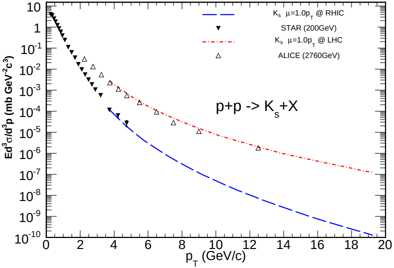
(2018)



G, Y, Ma, W. Dai, B. W. Zhang and E. Wang

(2018)

Formalism in A+A Collisions

X. F. Chen, T. Hirano, E. Wang, X. N. Wang and H. Zhang, Phys. Rev. C **84**, 034902 (2011)
Huichao Song , Ulrich W. Heinz,Phys.Rev. C77 (2008) 064901

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

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

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

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

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:

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

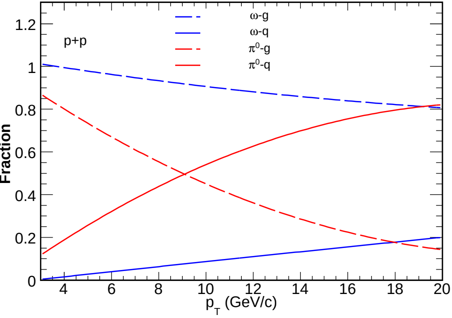
The jet transport parameter $\hat{q}_{\rm R}(E,y)$ is related to the parton density distribution in the medium, therefore can characterizes the evolutionary medium properties.

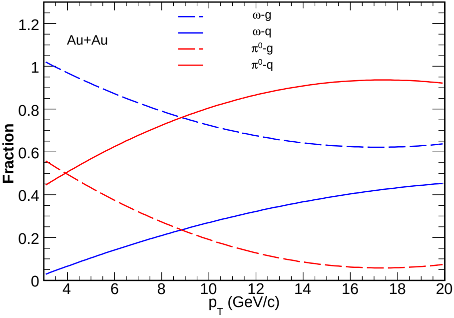
Hirano full three-dimensional(3+1D)ideal

hydrodynamics has been replaced by Ohio State

University (2+1) viscous hydrodynamics.

Production Fraction of ω Productions in p+p and A+A Collisions





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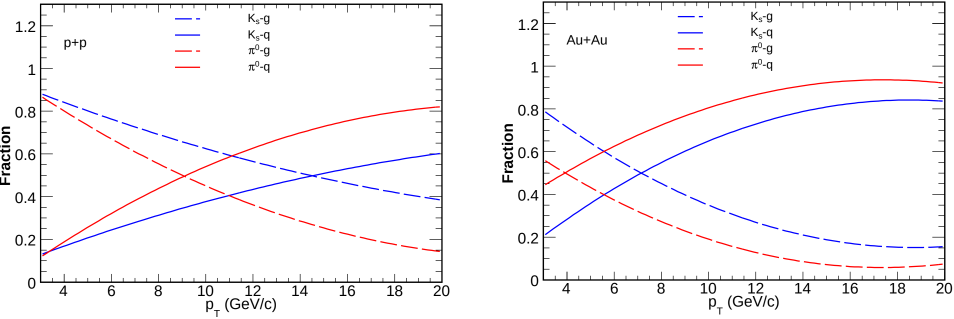
Production Fraction of K_s Productions in p+p and A+A Collisions



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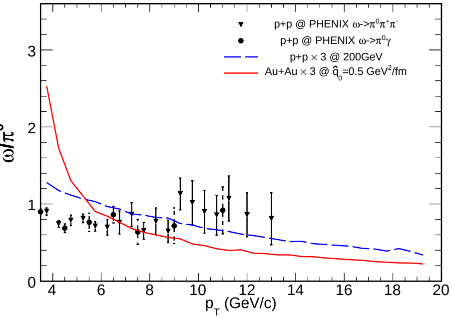
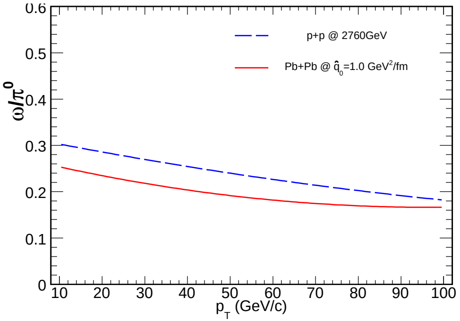
ω/π^0 ratio in P+P and A+A Collisions

RHIC



LHC



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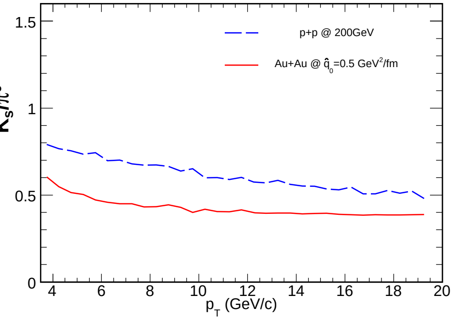
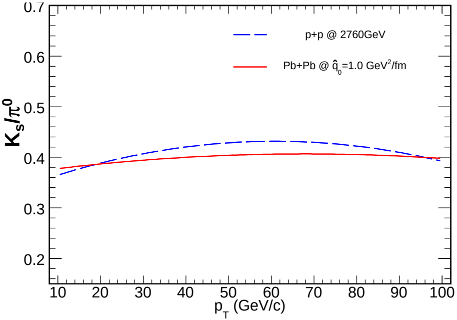
K_s/π^0 ratio in P+P and A+A Collisions

RHIC



LHC



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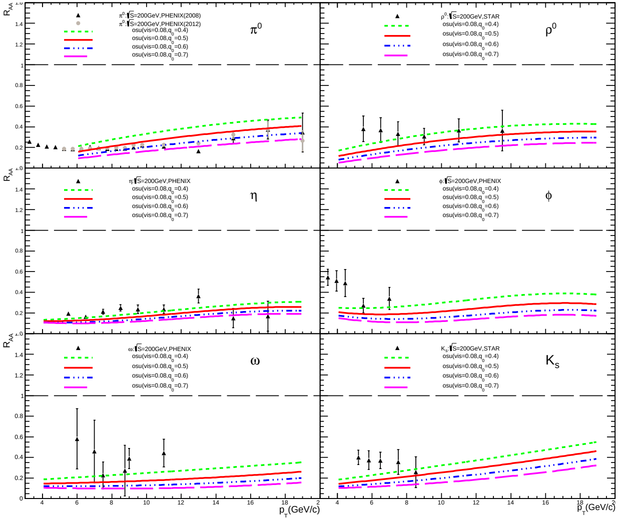
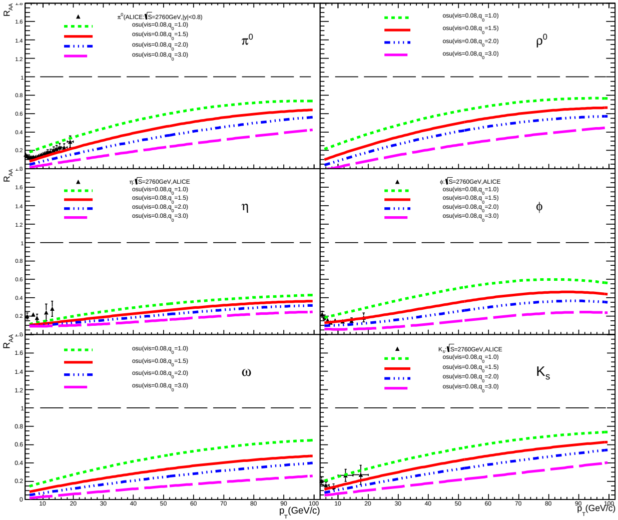
Nuclear Modification Factor in Au+Au Collisions



Nuclear Modification Factor in Pb+Pb Collisions



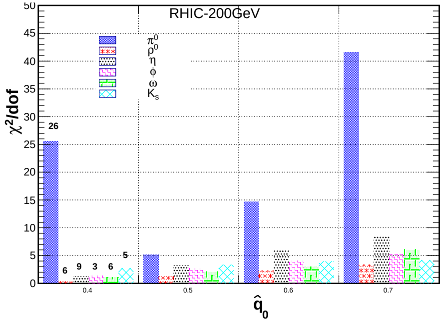
χ^2 Fit to Extract $\hat{q}$

RHIC

$$\chi^2(a_j) = \sum_i \frac{[D_i - T_i(a_j)]^2}{\sigma_i^2} \quad (5)$$

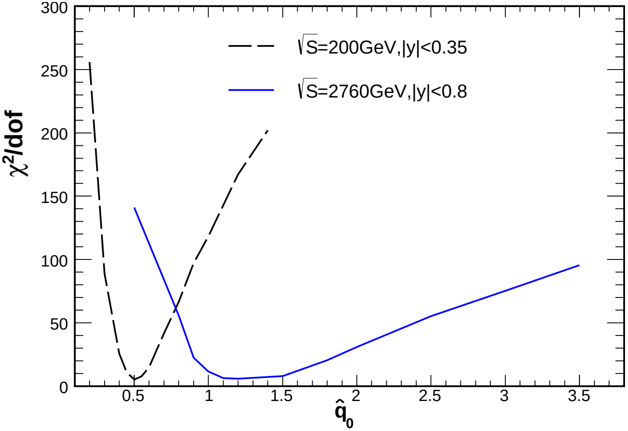
$$\sigma_i^2 = e_y^2 + [\frac{1}{2}(e_x)f'(x)]^2 \quad (6)$$

In the above equations, D_j represents the experimental grids and T_i is our theoretical prediction. σ_i^2 means the systematic and statistical experimental errors.



G, Y, Ma, W. Dai, B. W. Zhang and E. Wang (2018)

χ^2 Fit to Extract $\hat{q}$ at the RHIC and at the LHC



Summary

With the same higher-twist approach to take into account the jet quenching effect by medium modified FFs, the nuclear modification factors and particle ratio has been calculated for ω meson and K^0_{short} meson at the RHIC as it is the first theoretical calculation has been presented.

We re-extract the $\hat{q}$ by fitting the theoretical results of all 6 identified mesons' $R_{\rm AA}$ at hand with the available experimental data both in the RHIC and the LHC. Therefore the constraint to the $\hat{q}$ by different final state hadrons has been performed.

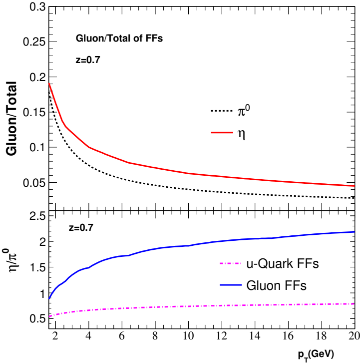
Thank you!

BAK UP

η and π^0 FFs

- 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

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



Re-write the The Hadron Yield

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

$$\frac{1}{p_T}\frac{d\sigma_{\pi^0,\eta}}{dp_T} = \int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta,\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2} + \int f_g(\frac{p_T}{z_h}) \cdot D_{g\to\eta,\pi^0}(z_h, p_T)\frac{dz_h}{z_h^2} \quad . \tag{7}$$

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

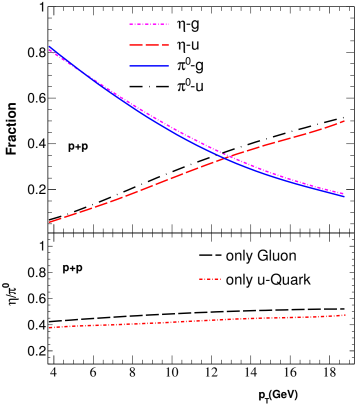
η/π^0 ratio only considering gluon and quark in p+p

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

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

$$
\begin{aligned}
R(\eta/\pi^0) &= \frac{d\sigma_\eta}{dp_T} \Big/ \frac{d\sigma_{\pi^0}}{dp_T} \\
&\approx \frac{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\eta}(z_h, p_T) \frac{dz_h}{z_h^2}}{\int f_q(\frac{p_T}{z_h}) \cdot D_{q\to\pi^0}(z_h, p_T) \frac{dz_h}{z_h^2}} \\
&\approx \frac{\Sigma_q D_{q\to\eta}(\langle z_h\rangle\,, p_T)}{\Sigma_q D_{q\to\pi^0}(\langle z_h\rangle\,, p_T)}\,. \qquad (8)
\end{aligned}
$$

- 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 $\mathrm{A+A}$ and $\mathrm{p+p}$ should overlap with the one in e^+e^- scattering, and reach a universal value $\sim$ 0.5.



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

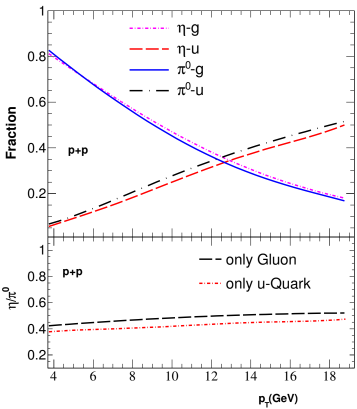
- For the transverse momentum p_T is not very high.

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.



$$\begin{aligned}R(\eta/\pi^0) &= \frac{\frac{1}{1-G^{\eta}(p_T)}\int f_q(\frac{p_T}{z_h})\cdot D_{q\to\eta}(z_h,p_T)\frac{dz_h}{z_h^2}}{\frac{1}{1-G^{\pi^0}(p_T)}\int f_q(\frac{p_T}{z_h})\cdot D_{q\to\pi^0}(z_h,p_T)\frac{dz}{z}}\\ &\approx \frac{\int f_q(\frac{p_T}{z_h})\cdot D_{q\to\eta}(z_h,p_T)\frac{dz_h}{z_h^2}}{\int f_q(\frac{p_T}{z_h})\cdot D_{q\to\pi^0}(z_h,p_T)\frac{dz_h}{z_h^2}}\\ &\approx \frac{\int f_g(\frac{p_T}{z_h})\cdot D_{g\to\eta}(z_h,p_T)\frac{dz_h}{z_h^2}}{\int f_g(\frac{p_T}{z_h})\cdot D_{g\to\pi^0}(z_h,p_T)\frac{dz_h}{z^2}}. \qquad (1\end{aligned}$$

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.