Search for the Effects of the QCD Color Factor in High-Energy Collisions at RHIC

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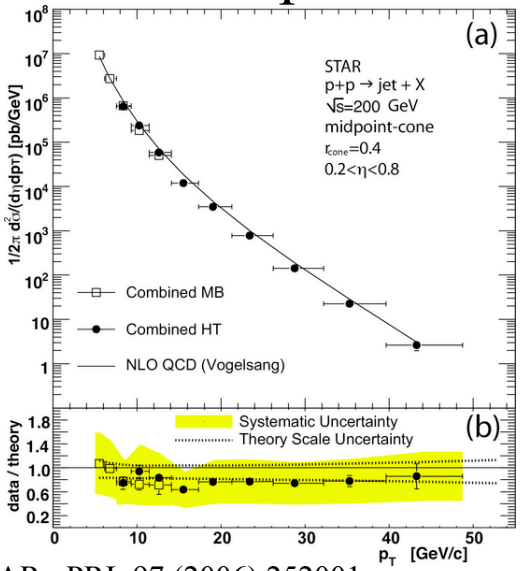
LBNL

Outline

- Motivation
- Color Factors
- Search for Color Factor Effects at RHIC
- Summary and Outlook

Theory of Strong Interactions : QCD

Very successful Examples -



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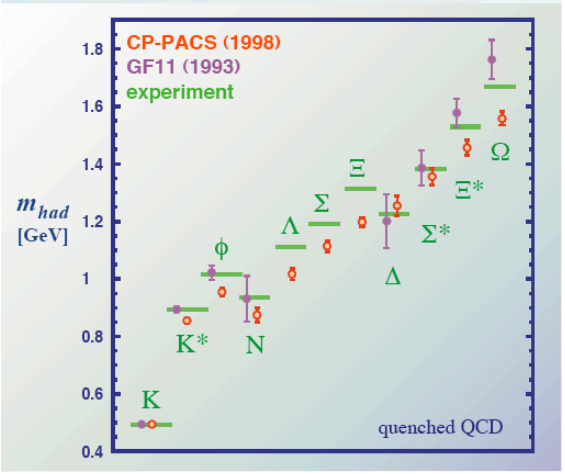
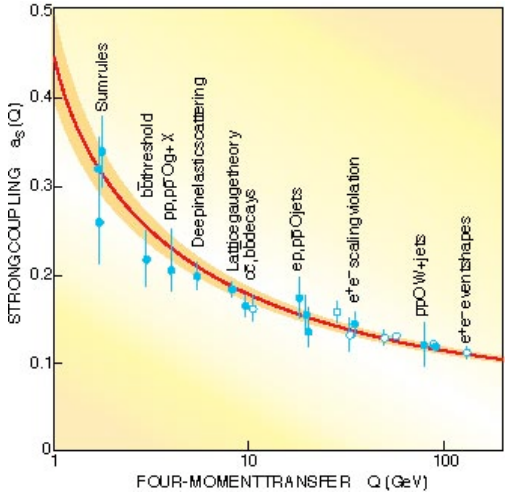


CP-PACS : PRL 84 (2000) 238

Some key ingredients

Strong coupling constant

Gauge Group - SU(3)



QCD potential at short distance

$$V_{QCD} = -\frac{4}{3}\frac{\alpha_s}{r}$$

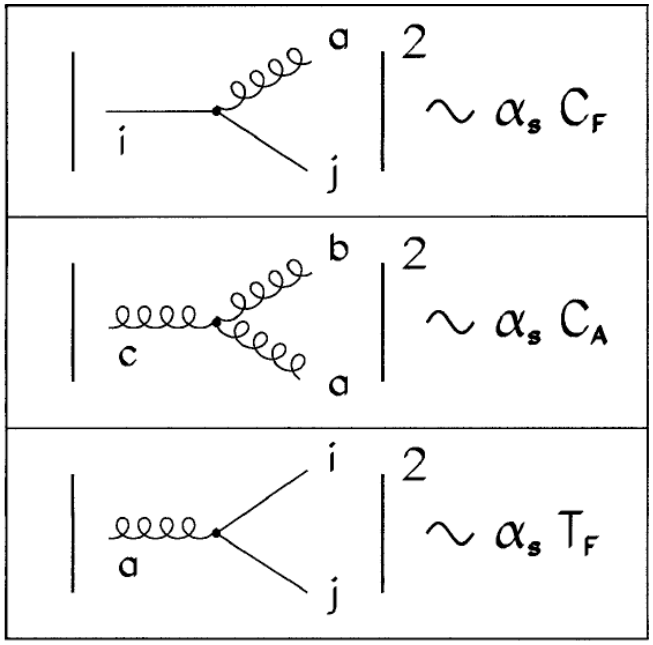
Color factor

The focus of this talk

Color Factors

If N_c is the dimension of the group (Lie) -
$C_A = N_c$, $C_F = (N_c^2-1)/2N_c$ and $T_F = 1/2$
A and F represent adjoint and fundamental representations.

QCD : For SU(3) :
$N_c = 3$
$C_A = 3$, $C_F = 4/3$



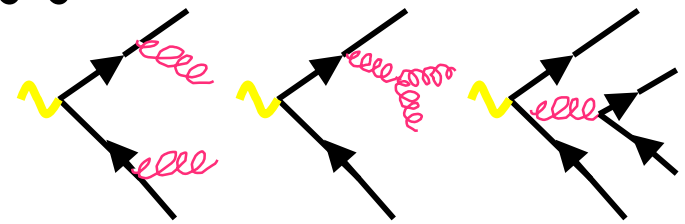
$C_F \sim$ strength of a gluon coupling to a quark
$C_A \sim$ strength of the gluon self coupling
$T_F \sim$ strength of gluon splitting into a quark pair

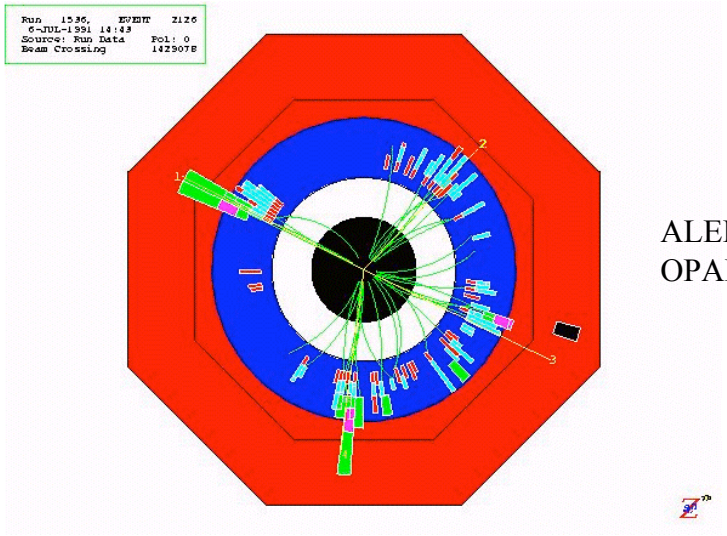
i,j represent fermion field indices and a,b gauge field indices

Color factors reflect basic properties of QCD. They are therefore measured to prove SU(3) is the gauge group of QCD

Measurement of Color Factors

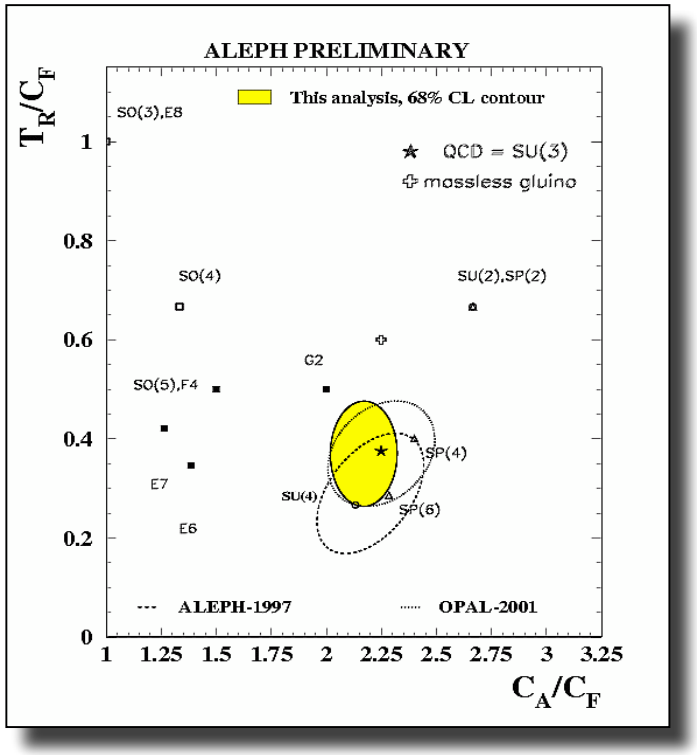
- ✓Three basic vertices in four jet production in e^+e^-
- ✓ Spin-1 or spin-1/2 particles in different configurations. Leads to different angular distributions in the final states.
- ✓Observed jet angular distributions are fitted to theoretical predictions with C_A, C_F, T_F as free parameters.





ALEPH : ZPC 76 (1997) 1
OPAL :EJPC 20 (2001) 601

$\alpha_S = 0.119$



SU(3) is the gauge group for QCD

What are the expectations of effect of color factor on observables in HI collisions ?

Color Factor Effect in QCD Matter at RHIC ?

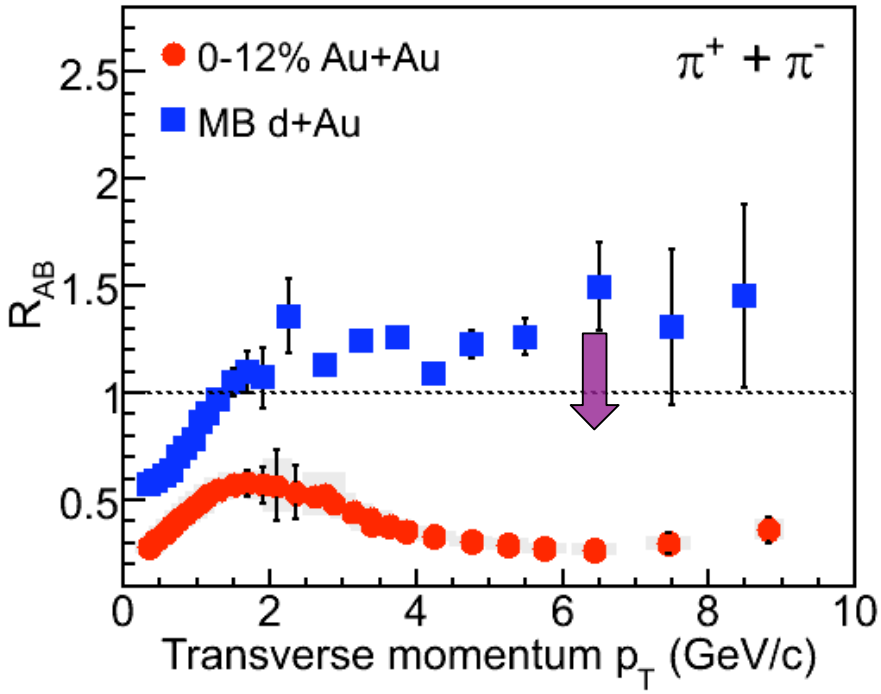
- ✓ Relate fundamental aspect of QCD to some observables
- ✓ A tool to study the properties of the hot/dense medium at RHIC
- ✓ Application of pQCD basics to high- energy nuclear collisions

Look for effects of difference in color factor of quarks and gluons.

Where to look for :

- ✓ High p_T
- ✓ Observable that reflects parton interaction

$$R_{AB} = \frac{1}{N_{bin}} \frac{d^2 N^{AB} / dp_T d\eta}{d^2 \sigma^{pp} / dp_T d\eta}$$



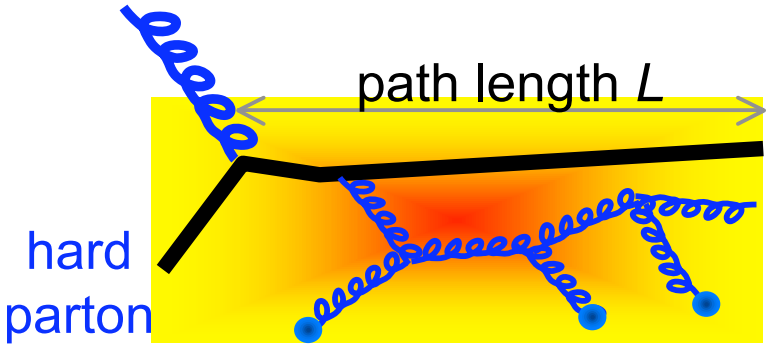
Interpretation : Energy loss (interaction) of partons (quarks and gluons) in a dense medium

STAR : PLB 637 (2006) 161
STAR : PRL 97 (2006) 152301

Energy Loss and QCD

Suppression in high p_T particle production is due to energy loss of partons in medium formed in nucleus-nucleus collisions

One mechanism of energy loss :
Medium induced gluon radiation



$$\langle \Delta E \rangle \sim \alpha_s \; C \; <\hat{q}> L^2$$

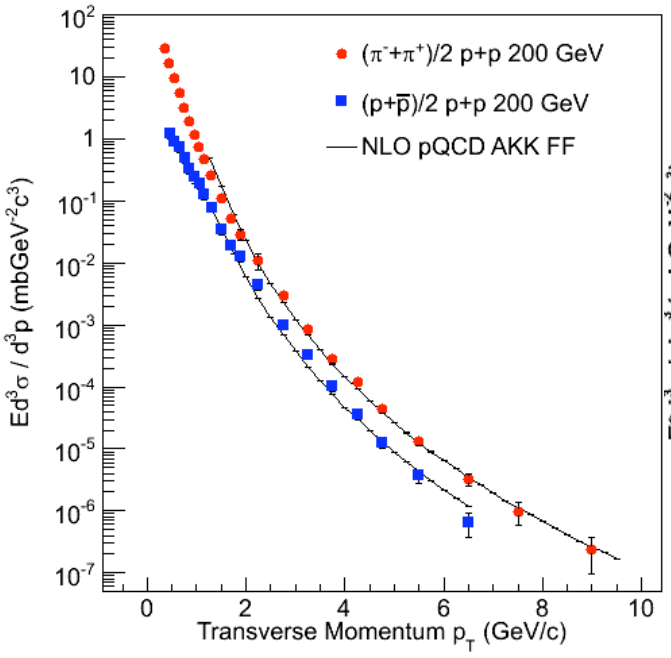
$$\frac{\Delta E_g}{\Delta E_q} \sim 9/4$$

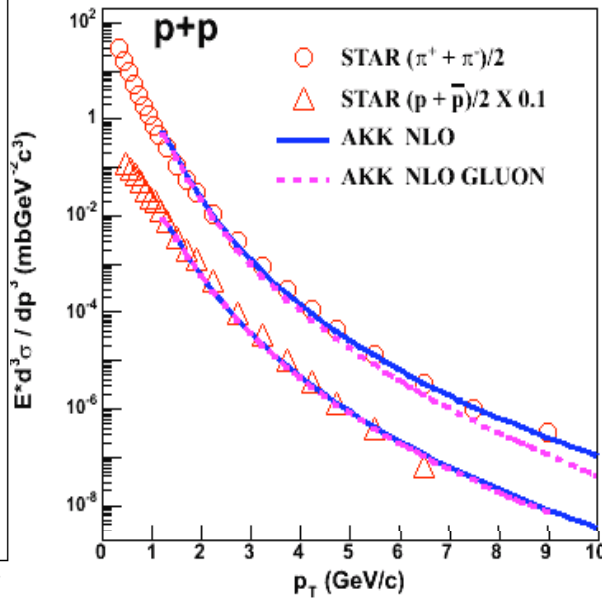
Color factor:
4/3 for quarks
3 for gluons

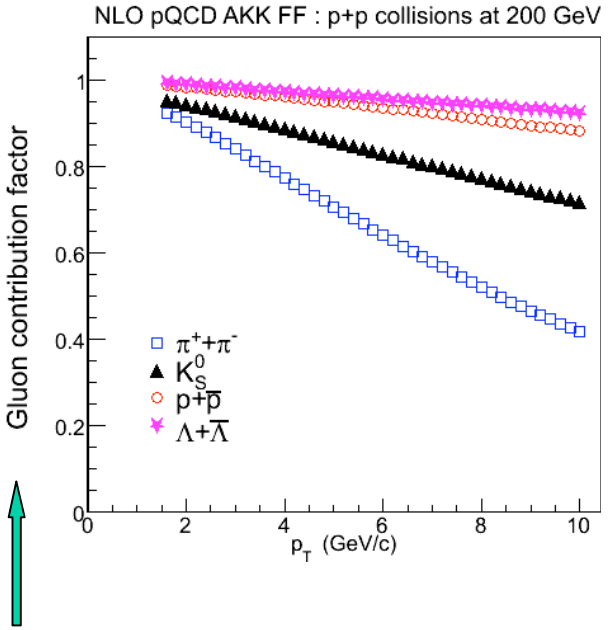
An opportunity to relate experimental observable (of E_{loss}) to basic ingredient of QCD - Gauge Group through Color Factors

Dominat Source of high p_T hadrons : quarks or gluons

High p_T particle production well explained by NLO pQCD calculations







$N_g(i)/ (N_g(i) + N_q(i))$; i = π, K, p…

At high p_T range measured :
Large gluon contribution (~ 90%) to produced baryons
Substantial quark contribution (~ 40%) to produced mesons

STAR : PLB 637 (2006) 161 S. Albino at al, NPB 725 (2005) 181 B. Mohanty (for STAR) nucl-ex/0705.9053

Expectations

Recall : Nucleus-Nucleus collisions produces a dense medium where gluons loose more energy than quarks.
No such dense medium expected in p+p and d+Au collisions

$$\frac{\Delta E_g}{\Delta E_q} \sim 9/4$$

Then naïve expectation at high p_T :

pbar/p (pp or dAu) > pbar/p (central Au+Au)

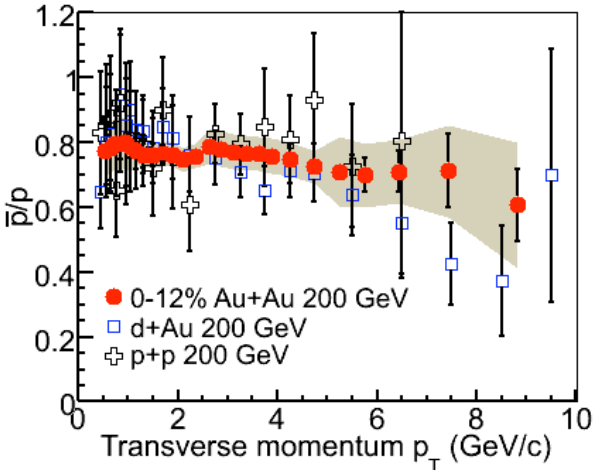
pbar/π (pp or dAu) > pbar/π (central Au+Au)

$R_{cp}(\pi)$ > R_{cp} (pbar+p)

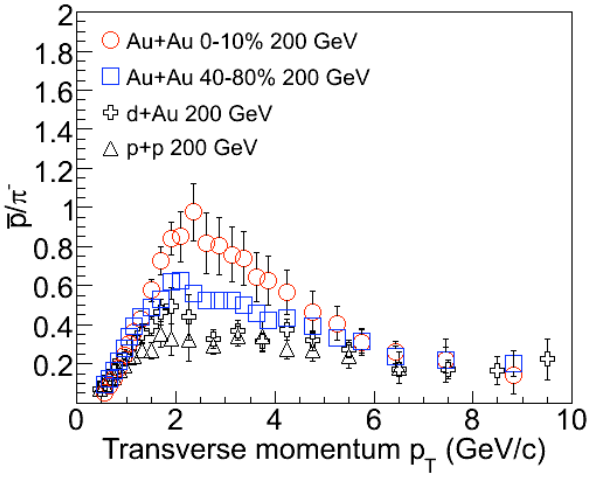
Do we see the color factor effect in experimental observables ?

Observations In High p_T Particle Production

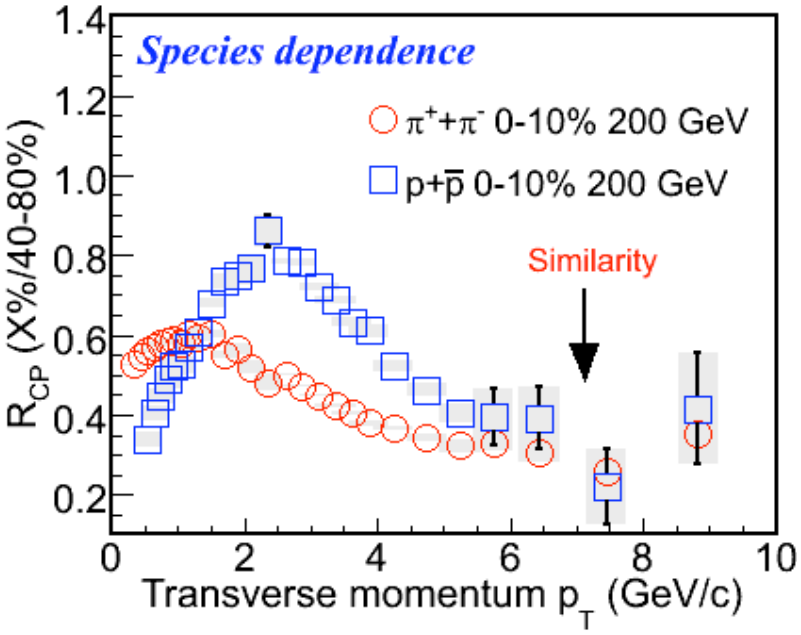
Anti-particle to particle ratio



Anti-Baryon to meson ratio



Baryon & meson NMF

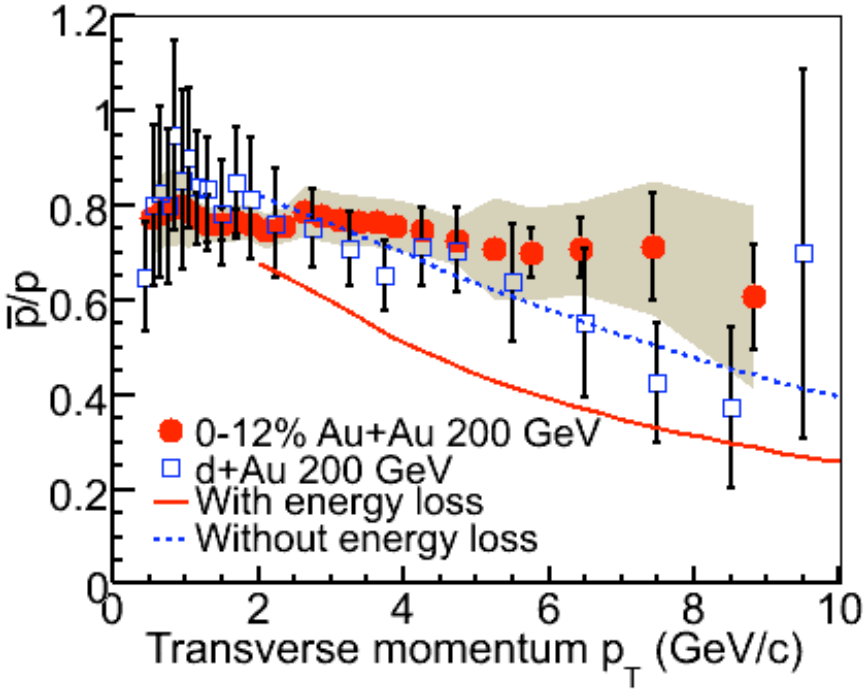


Observations different from expectation -
Why particle ratios at high p_T in Au+Au similar to d+Au and p+p ?
Why π have similar R_{CP} as p+pbar ?
Where is the color factor effect ?

STAR : PLB 637 (2006) 161 STAR : PRL 97 (2006) 152301 STAR : nucl-ex/0703040

Model Comparison To Data

Model calculation with partonic energy loss in heavy ion collisions
+ Color factor effect not consistent with measurements



STAR : nucl-ex/0703040

STAR : PLB 637 (2006) 161
STAR : PRL 97 (2006) 152301
Wang et al, PRC 70 (2004) 031901

Absence of color factor effect in data ?
What could be the possible reasons ?
What are the new probes to explore in future ?

Possible Reasons

- ✓ Gluon dominated initial conditions in heavy ion collisions at RHIC ?
- ✓ Possibility of conversions between quark and gluon jets in the medium ?

- ✓ $\Delta E^g/\Delta E^q \sim 9/4$ only apparent for the limit $\Delta E/E_{jet}$ tending to zero ?
- ✓ High α_S and a low Q^2 regime at RHIC ?
- ✓ Sensitive to different energy loss scenarios ?

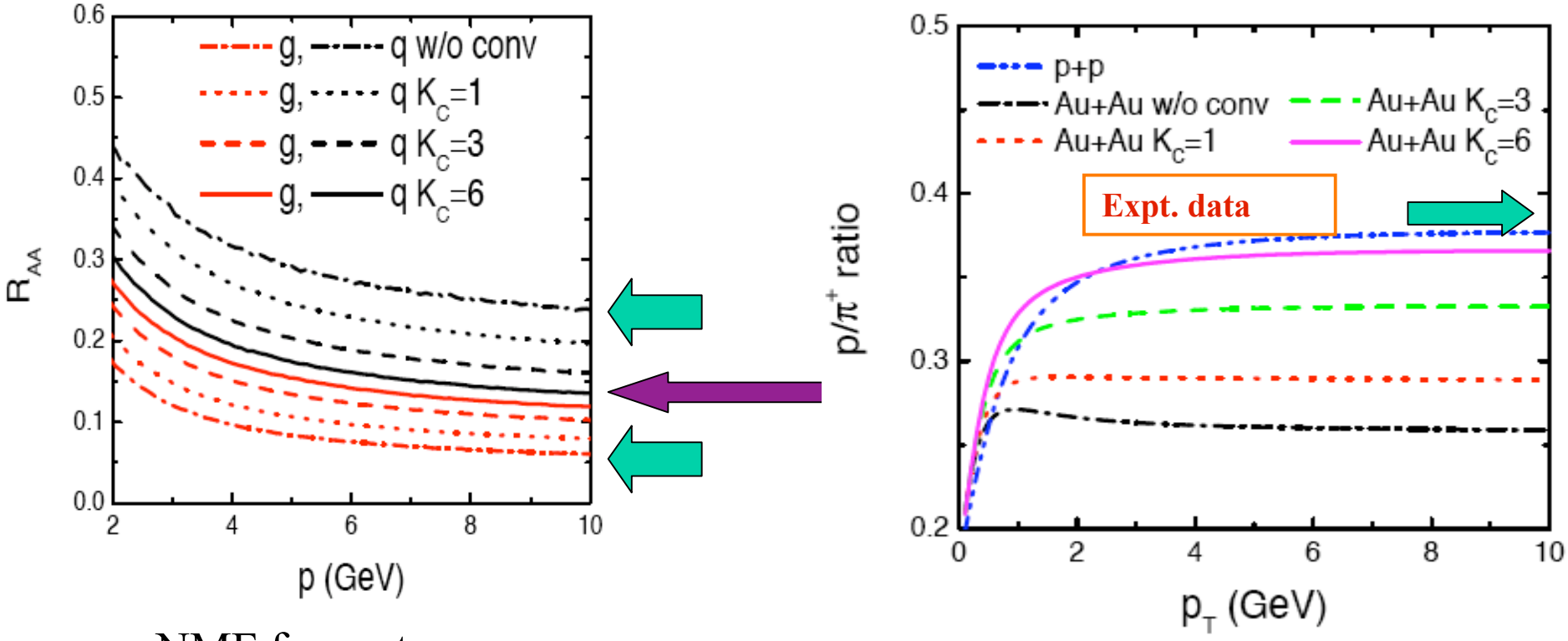
W. Liu et al., nucl-th/0607047
I.Vitev PLB 639 (2006) 38

T. Renk and K.J. Eskola hep-ph/0702096

B. Mohanty (for STAR) nucl-ex/0705.9053

Physics Possibilities : Quark and Gluon Jet Conversions

Conversions between q- and g- jets via both inelastic (qqbar -- gg) and elastic (gq(qbar) -- q(qbar)g) scatterings with thermal partons in the QGP



NMF for partons

W. Liu et al., nucl-th/0607047

Summary of Search of Color Factor Effect

Observations at high p_T

- ✓ Anti-particle to particle, anti-baryon-to-meson ratios are similar in central, peripheral Au+Au, d+Au and p+p
- ✓ R_{cp} of π is similar to R_{cp} of p+pbar
- ✓ Observation different from that expected due to color factor difference between quarks and gluons

Possibilities

- ✓ May be jet conversions in medium is the reason
- ✓ May be we need to go higher p_T or jet energy to see the effect
- ✓ May be giving us more information on energy loss mechanism

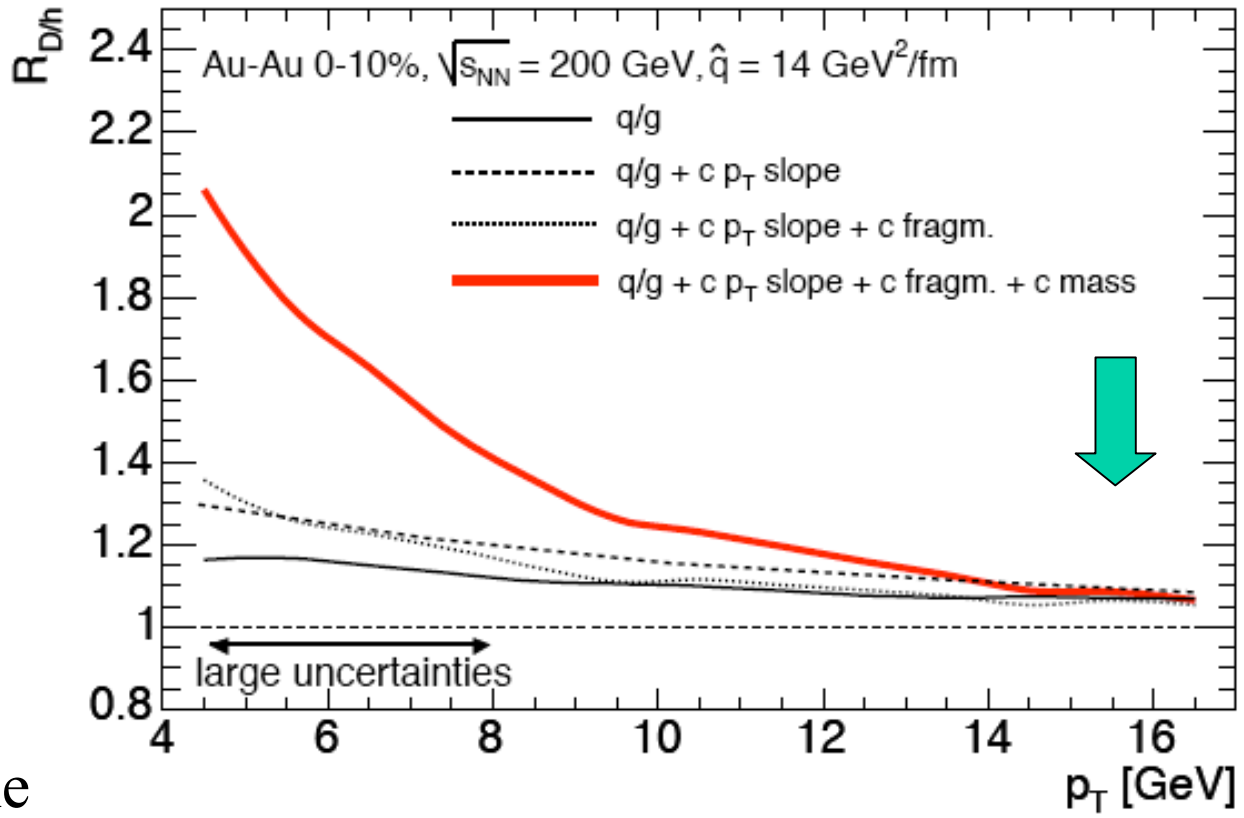
Outlook …..

Outlook - Heavy Flavor Sector

High p_T ratio of heavy to light NMF ratio is sensitive to color factor effect

$$R_{D(B)/h}(p_t) = R_{AA}^{D(B)}(p_t) \Big/ R_{AA}^{h}(p_t)$$

Similar idea can also applied for R (ϕ/h)



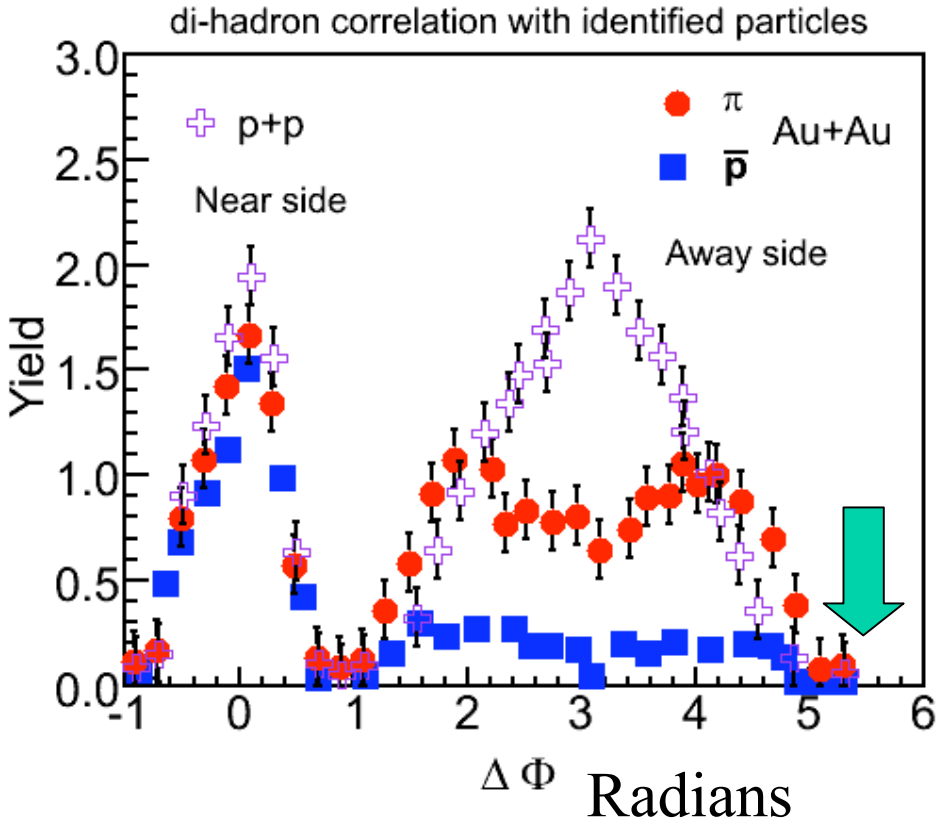
Both the observable are very promising to see the color factor effects

N. Armesto et al., PRD 71 (2005) 05427

Outlook - PID di-Hadron Correlations

Suppression pattern in the away side of identified di-hadron correlations.

Expectation is something like ..
(This is not data)

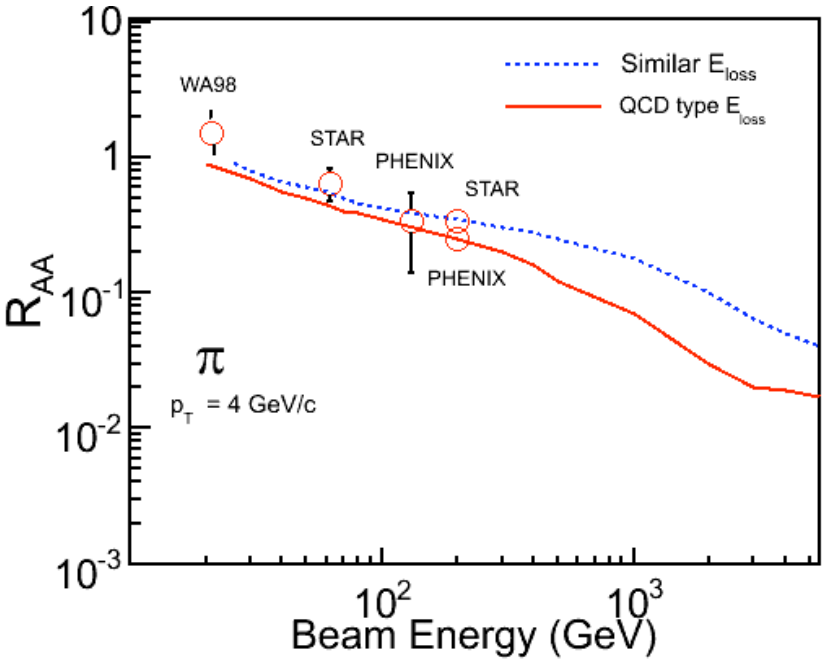


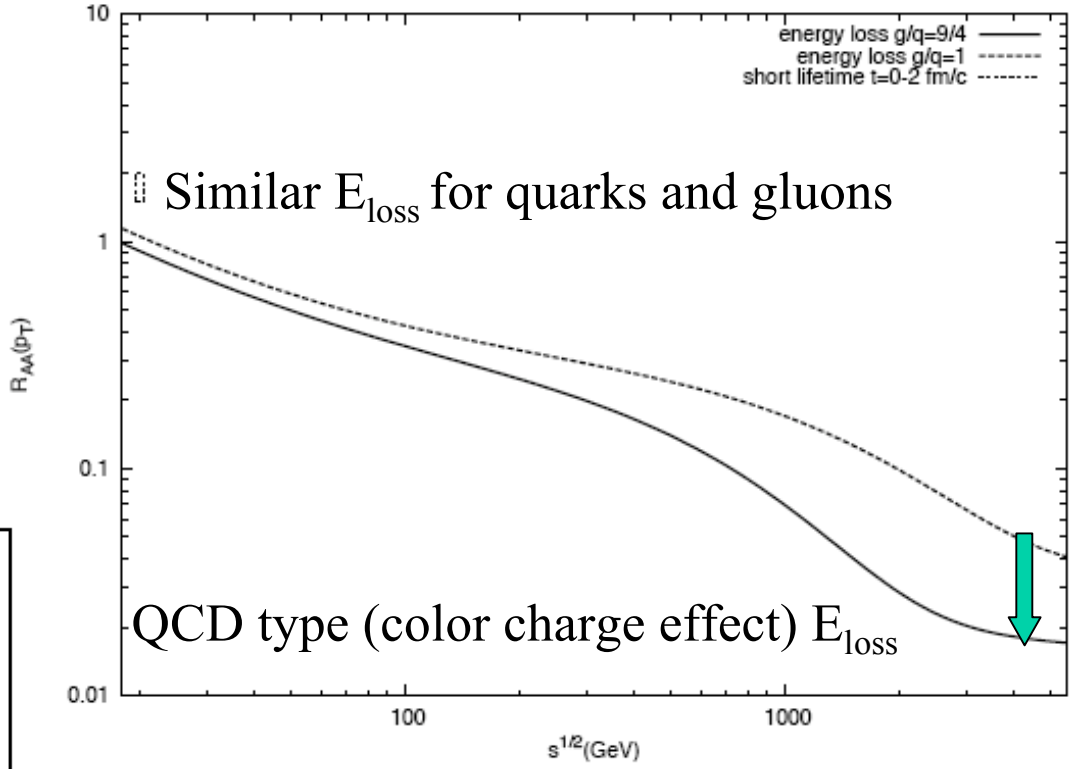
Choosing different particles may reflect varying contribution of quark and gluon at high $p_{T.}$

Will be interesting to see heavy-flavor correlations - probing quark energy loss.

Outlook - Energy Dependence

Probing quark dominated jet production at lower energy to gluon dominated jet production at higher energy





Wang et al., PRC 58 (1998) 2321
Wang et al., PRC 71 (2005) 014903

Thanks

Thanks to Organizers

Thanks to STAR Collaboration

Back up slides

Physics Possibilities : E_{loss} Scenarios

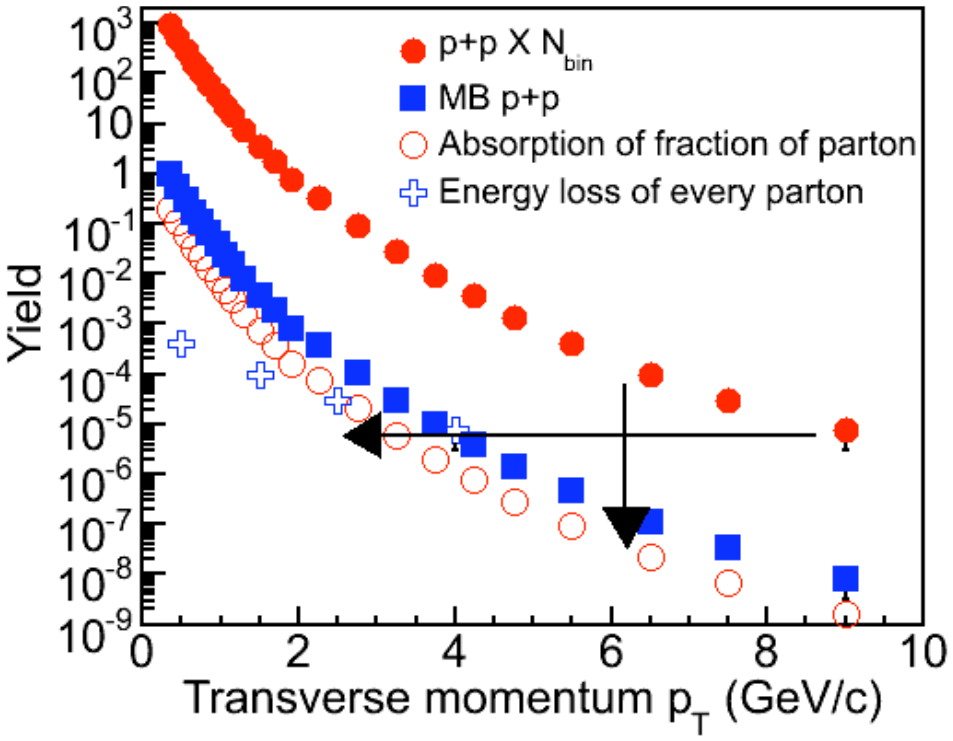
Energy loss : absorption of fraction of partons (Dense core + pp like corona)

or

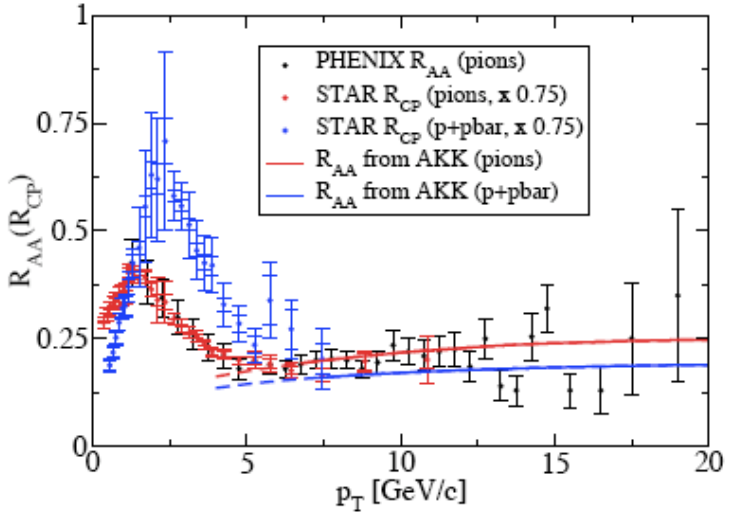
energy loss of every parton

or

some combination of the two



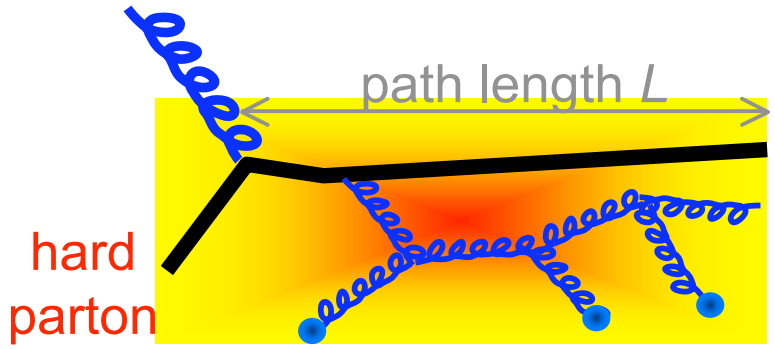
T. Renk and K.J. Eskola
hep-ph/0702096



What is the relative contribution of different energy loss scenario ?

E_{loss} Formalism : BDMPS & GLV

One mechanism of energy loss :
Medium induced gluon radiation



$$\langle \Delta E \rangle \sim \alpha_s \; C \; <\hat{q}> L^2$$

$$\langle \Delta E \rangle \sim \alpha_s^3 \; C \; dN^g/dy \; \; L \; /A_T$$

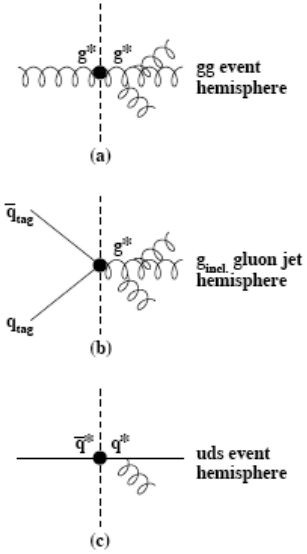
$$\frac{\Delta E_g}{\Delta E_q} \sim 9/4$$

Color factor:
4/3 for quarks
3 for gluons

Definition Jets

- Theoretical definition: creation of a $g-$jet pair (gg) from a colour singlet point source.

- Theoretical: creation of a $q\bar{q}$ pair from a colour singlet point source



1. $g-$jets are broader than $q-$jets (Jade 1982)

2. $g-$jets have larger multiplicities (Opal 1991)

$$\frac{N_{had}^{g-jet}}{N_{had}^{q-jet}} \approx \frac{C_A}{C_F} = \frac{9}{4}$$

3. particles in $g-$jets are less energetic