Strangeness and multi-strangeness in pp, dAu and AuAu at RHIC, within HIJING/B$\bar{B}$ v2.0 model.

Workshop Strangeness in Collisions,
BNL-Rieken, February 16-17, 2006

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Outline

- Introduction
- Outline of Theory.
  (i) HIJING/B$\bar{\text{B}}$ v1.10
  (ii) HIJING/B$\bar{\text{B}}$ v2.0 (with SCF).
- Strangeness and Multi-Strangeness at RHIC.
  (i) pp, dAu: p_T distributions.
  (ii) dAu, AuAu: Baryon mesons Anomaly.
  (iii) Nuclear modification factors, R_{AA}, R_{CP}. Rapidity, centrality dependence.
  (iv) Experimental evidence of SCF effects ?
- Summary and Conclusions.

Introduction 01

- It has been shown that a hydrodynamic description of relativistic heavy ion collisions reproduces the main characteristic of soft particle production, $p_T < 2$ GeV/c; (Shuryak01,03; Kolb and Heinz03; Heinz05)
- At high momentum transfer ($p_T > 5$ GeV/c), one expects theoretical pQCD calculations to describe the data arising from hard processes. (Wang04,05; Gyulassy et al.03; Vitev04,05)
- Of particular interest are measurements relating to baryon/mesons anomaly in the intermediate transverse momentum region ($1.5 < p_T < 5$ GeV/c), where baryon and mesons are produced in nearly equal proportion.
- Possible explanations for the enhancement: * Multi-quark or gluon processes during hadron formation - *coalescence-recombination.* (Fries, Muller et al.,03; Voloshin, Molnar03; Greco,Ko,Levai03; Hwa and Yang04)
  * Gluon configuration that carry baryon number - baryon junctions (Kharzeev96; Vance et al.98,99; Vitev, Gyulassy03)

- At RHIC energy the gluon density is expected to be high (x ≈ 0.01-0.001) :
  * particle production can be considered as a gluon production in background classical field (CGC).
  (Iancu et al.01; Kharzeev and McLerran03; Venugopalan05; Kovchegov05; Gelis and Venugopolan06).

Introduction 02

- One of the most interesting open issues at RHIC energies is : the baryon distributions.
  * both quark and gluon carry the baryon charge
  * Net-baryon remains at mid-rapidity
  Affect:
  * stopping process at relative early stage
  * the relatively hadron abundances produced in the collisions
  * the proprieties of the system at chemical and thermal freeze-out

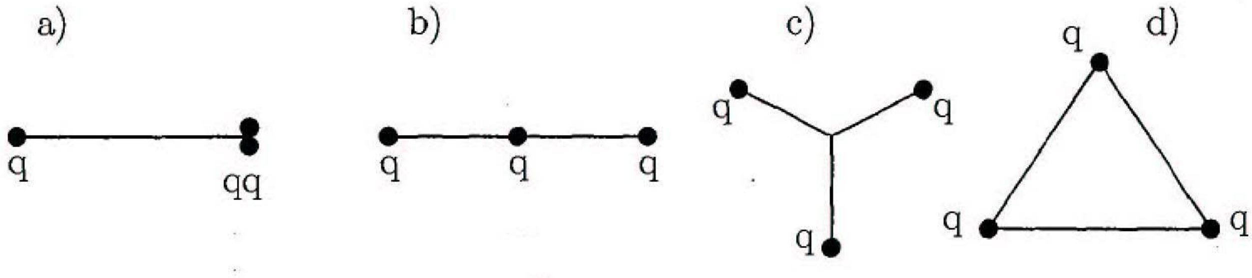
- Strange and especially multistrange particles are also of great interest. Their relative enhancement in central heavy ion collisions with respect to pp collisions, have been suggested as a signature for the transient existence of a QGP phase. (Rafelski and Muller82,86; Koch,Muller,Stocker,W.Greiner88; Huang and Rafelski05)

- As tools for our investigation of heavy-ion reactions:
  * Heavy-Ion Jet Interaction Generator (HIJING v1.37)
  * HIJING/B$\bar{\text{B}}$ v1.10 and HIJING/B$\bar{\text{B}}$ v2.0 (new)
  (modified versions of HIJING)
  models are used in these analysis.

- The goal of this study is to reveal:
  * the interplay between soft and hard physics at RHIC energies
  * the role of baryon junction physics
  * the role of final state interactions
  * the role of initial state interactions
  * the effects of Strong Color Field (SCF).

HIJING /B v1.10 Outline 01

Vance, Gyulassy, Xin-Nian Wang(98,99), PLB443,45(98)



- String models of baryon:
- Baryon junction mechanism:
  * a novel non-equilibrium hadronic mechanism derived from Y-shaped ($SU_c(3)$) gluon structure of the baryon has been introduced by implementing (Rossi, Veneziano (80), Kharzev's P.L. B378(1996)) baryon junction exchange model in a Monte Carlo event generator HIJING/B.
- This baryon junction exchange mechanism is included through a "Y" string configuration for the excited baryon (see Figure). For the reaction without junction exchange the standard 2 qq-q strings are used. The baryon is resolved around the junction via $q\bar{q}$ production and the resulting three beam jets are fragmented as q-$\bar{q}$ strings.
- A value of $\sigma_{BJ} = 18$ mb is taken to reproduce the data from pp collisions at 400 GeV/c ($\sqrt{s}$=27.4 GeV).
- The junction exchange is only allowed if the invariant mass of the excited "Y" configuration $M_c = 6$ GeV.
- The probability for the junction exchange after n collisions
  $P_n = 1 - (1 - P_{NN})^n$.

HIJING/B$\bar{\text{B}}$ v1.10 Outline 02

Vance, Gyulassy(99); PRL83, 1735(99)

- The valence baryon junction exchange mechanism has been extended by including:
  Junction-Antijunction ($J\bar{J}$) loops that naturally arise in Regge phenomenology.

- Fitting $\bar{p}$ and $\bar{\Lambda}$ from pp and pA interactions
  the cross section for $J\bar{J}$ exchange is found to be $\sigma_{B\bar{B}}$= 6 mb.

- The threshold cutoff mass M$_c$ = 6 GeV, provides sufficient kinematical phase space for fragmentation of the strings and for $B\bar{B}$ pair production.

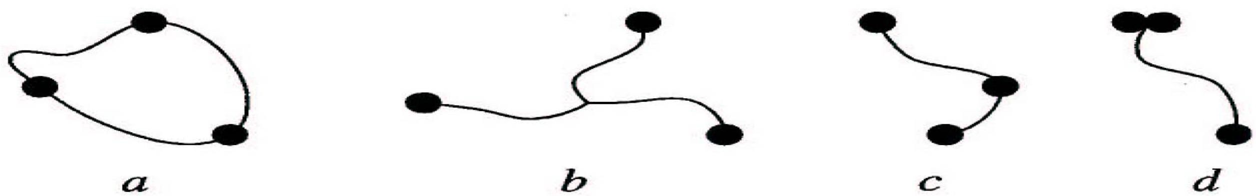
- The p_T for baryons from $J\bar{J}$ loops are obtained adding the p_T of the three sea quarks along with and additional soft p_T kick.
  Gaussian distributtions - width σ=0.6 GeV

- The present version of HIJING/B$\bar{\text{B}}$ v1.10 does not include hadronic final state interactions.

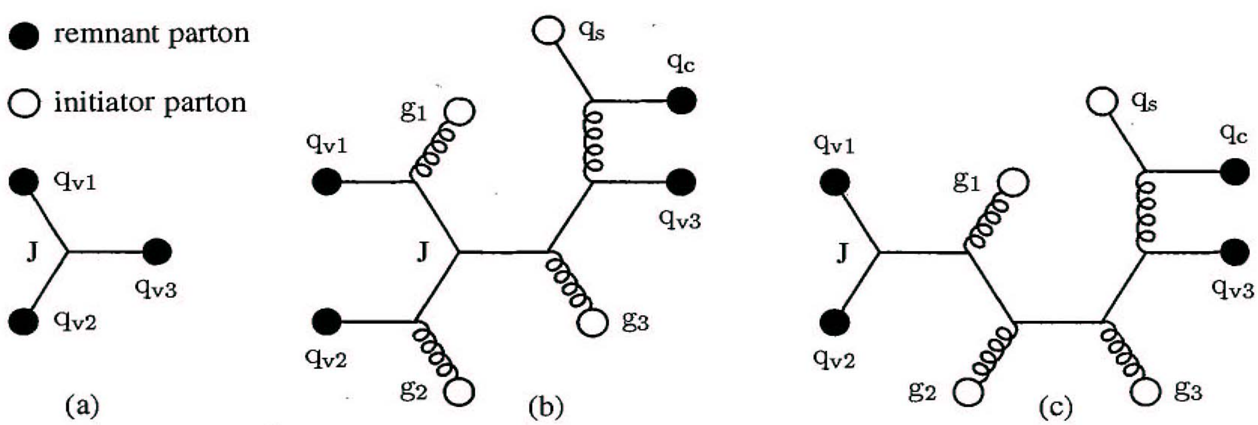
- HIJING/$B\bar{B}$ v1.10 available (OSCAR www)
  S. Vance, Ph. D. thesis, Columbia University,1999
  http://www-cunuke.phys.columbia.edu/people/svance/hijbb.html

Topologies of $J\bar{J}$ loops 01

- Gerard't Hooft, hep-th/0408148;
  If classical string picture is adopted for baryonic states, at least one of the three arms will soon disapear, shedding its energy into the excitation mode of the other arms (q-qq) configuration. *the Y configuration appears to be a better representation of the baryon (in comparison with Δ model)

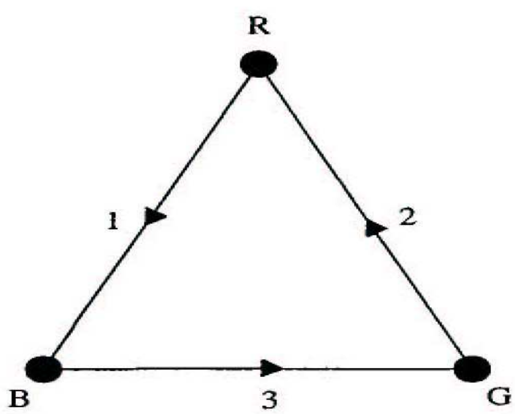


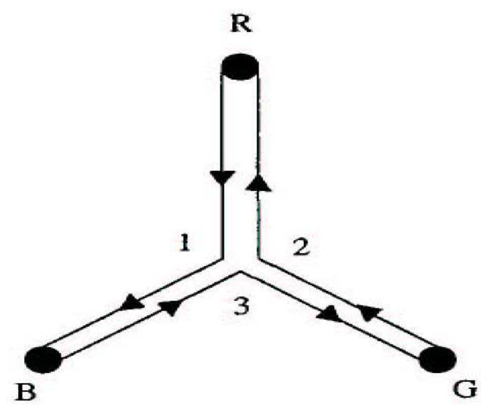
- Sjostrand and Skands NPB659,243(2003) J.HEP 3, 53(2004)hep-ph/0401060
  Novel baryon junction dynamics -topology with the junction in the remnant.



Topologies of $J\bar{J}$ loops 02

- G. Ripka Lect.Note Phys639(04)
  In dual-superconductor models of color confinement for the Y geometry (Mercedes Configuration): * The flux tubes converge first toward the center of triangles and there is also another component that runs in opposite direction. They attract each other, and this lowers the energy of the Y configuration.





- M. Cristoforetti et al.,PRD71,114010(2005)
  Shuryak 04,05
  Study of di-quark correlations inside the nucleon. Instanton forces are sufficiently strong to form a di-quark bound state, with a mass of ≈ 450 MeV.

- Schmidt,Blankenbecler PRD15,3321(1977)
  B. Kopeliovich PLB211,221(1988)
  There are evidence that dominant configuration of valence quarks in the proton contains a small ud di-quark of a size $r_p \approx$ 0.2 -0.4fm.

HIJING /B$\bar{\text{B}}$ v2.0 Outline 01

Topor et al.,PRC70(04); PRC72(05)

- A new version HIJING/B$\bar{\text{B}}$ v2.0 which implement the $J\bar{J}$ loops better than in v1.10 and simulate final state interactions leading to collectivity, is currently under construction.

- String junction represents a localized topological feature of gluon/string field; The initial state of a baryon, consisting of 3 valence quarks connected antisymmetrically in colour via a central string junction, J (Y topology).

- We assume that out of the non single diffractive NN interaction cross section, $\sigma_{in} - \sigma_{sd}$, a fraction $f_{J\bar{J}} = \sigma_{J\bar{J}}/(\sigma_{in} - \sigma_{sd})$ of the events excite a junction loop. The probability after n_{hits} collisions (binary) that the incident baryon has a $J\bar{J}$ loop is:

$$P_{J\bar{J}} = 1 - (1 - f_{J\bar{J}})^{n_{hits}}$$

  We take $\sigma_{J\bar{J}}$=17 mb, $\sigma_{sd} \approx$ 10 mb and the total inelastic nucleon nucleon cross section $\sigma_{in} \approx$ 42 mb at RHIC energies.

- These cross sections imply that a junction loop occurs with increasing probability from $17/32 \approx 0.5$ in pp collisions to 0.80 in $p+S$ and rapidly approaches 1.0 in AA at RHIC energy.

HIJING /B$\bar{\rm B}$ v2.0 Outline 02

- Multiple hard and soft interactions proceed as in HIJING/B$\bar{\rm B}$ v1.0. Before fragmentation, via JETSET7.3 we compute $P_{J\bar{J}}$. A cutoff mass $M_c = 6\ GeV$, provides sufficient kinematical phase space for fragmentation of the strings and for $B\bar{B}$ pair production.

- HIJING/B$\bar{\rm B}$ v2.0 simulate $J\bar{J}$ loops locally via flavor dependent diquark p_T kick, from the enderlying junction mechanism.

- The gaussian width of transverse momentum distributions of the primary hadrons.

$$\sigma'_{qq} = f \cdot \sigma_{qq}$$

$\sigma_{qq} = 0.360$ GeV/c, as in ($q\bar{q}$) string fragmentation.

- f is fitted to best reproduce the observed p_T spectrum of the baryons; appears as a way of parametrising:
  * explosive initial partons configurations
  * partons collectivity (?).

- This factor f may depend on beam energy, atomic mass number (A), centrality (impact parameter). In the present calculations a good description is obtained with $f = 3$.

- This implementation of the $J\bar{J}$ model marks a radical departure from that implemented in HIJING/B$\bar{\rm B}$v1.10.

HIJING/B$\bar{\text{B}}$ v2.0 +(SCF) 03

- Collective effects related to (QGP):
  The magnitude of a typical field strength at RHIC energies might be as large as 5-12 GeV/fm (Csernai PRC01.)

- Consequences of SCF:
  * Strangeness enhancement (Rafelski,Muller,PRL48(82))
  * Strong baryon transport (Csernai PRC01.)
  * Increase of intrinsic k_T (Soff et al., PL B551(03)).
  * The p_T generation by SCF may lead to a substantial hardening of the spectra. Flow (?) (Nu Xu et al.,(04).)

- The string density can be so high that the color flux tubes overlap(Biro et al., NPB245(84)).

- Long range coherent fields could be induced by a rapid deceleration of the colliding nuclei, which induces also a specific chiral symmetry restoration. (Kharzeev,Tuchin, NP A753(05)).

- For a uniform chromoelectric flux tube with field (E) the probability to create a pair of quarks with mass (m), effective charge (e), and transverse momentum (p_T) per unit time per unit volume is given by: (Nussinov, PRD20(79))

$$P(p_T)\, d^2p_T = -\frac{|eE|}{4\pi^3} ln\Big\{1 - exp\left[-\frac{\pi(m^2+p_T^2)}{|eE|}\right]\Big\}\, d^2p_T$$

HIJING/B$\bar{\text{B}}$ v2.0 +(SCF) 04

- In microscopic string models the heavier flavors are suppressed according to Schwinger formula:

$$\gamma_Q = \frac{P(Q\bar{Q})}{P(q\bar{q})} = exp\left(-\frac{\pi(m_Q^2 - m_q^2)}{\kappa}\right)$$

  $\kappa = |eE|$ is the *string tension*;
  m_Q is a quark mass; (Q=s for strange quark; Q=qq for a di-quark), and q=u,d are the light nonstrange quarks.

- Two possible processes leading to
  an increase of (multi) strangeness production.
  i) increasing the field strength by a modified
  string tension κ = (1-3) κ_0; $\kappa_0 \approx$ 1 GeV/fm.
  or ii) dropping the quark masses due to chiral symmetry restoration (Brown, Rho PRL66(91)).

- The *current quark masses* (PDB-PLB592(04)):
  m_u =1.5-5 MeV; m_d=3-9 MeV, m_s=80-190 MeV; di-quark m_{qq}=450 MeV (Ripka, PRD71(05)).
  The Constituent quark masses $M_{u,d}$= 230 MeV, M_s=350 MeV, M_{qq}=550 $\pm$ 50 MeV.

- Schwinger tunneling: could explain the thermal character of spectra; if κ fluctuates we can define an apparent temperature $T = \sqrt{<\kappa>/2\pi}$ (Florkowski, AP Polonica(04).); ($T \approx$ 250 MeV, for $<\kappa> =$ 2 GeV/fm); ($T \approx$ 310 MeV, for $<\kappa> =$ 3 GeV/fm)

HIJING/B$\bar{\text{B}}$ v2.0 +(SCF) 05

We take into account SCF in our model by an *in medium effective string tension* $\kappa > \kappa_0$, which lead to new values for: *the suppression factors,
*effective intrinsic transverse momentum k_T.

i) the ratio of production rates of di-quark to quark pairs (di-quark suppression factor); $\gamma_{qq} = P(qq\overline{qq})/P(q\bar{q})$

ii) the ratio of production rates of strange to nonstrange quark pairs ; $\gamma_s = P(s\bar{s})/P(q\bar{q})$

iii) the extra suppression associated with a diquark containing a strange quark compared to the normal suppression of strange quark (γ_s); $\gamma_{us} = (P(u\bar{u}s\bar{s})/P(u\bar{u}d\bar{d}))/(\gamma_s)$

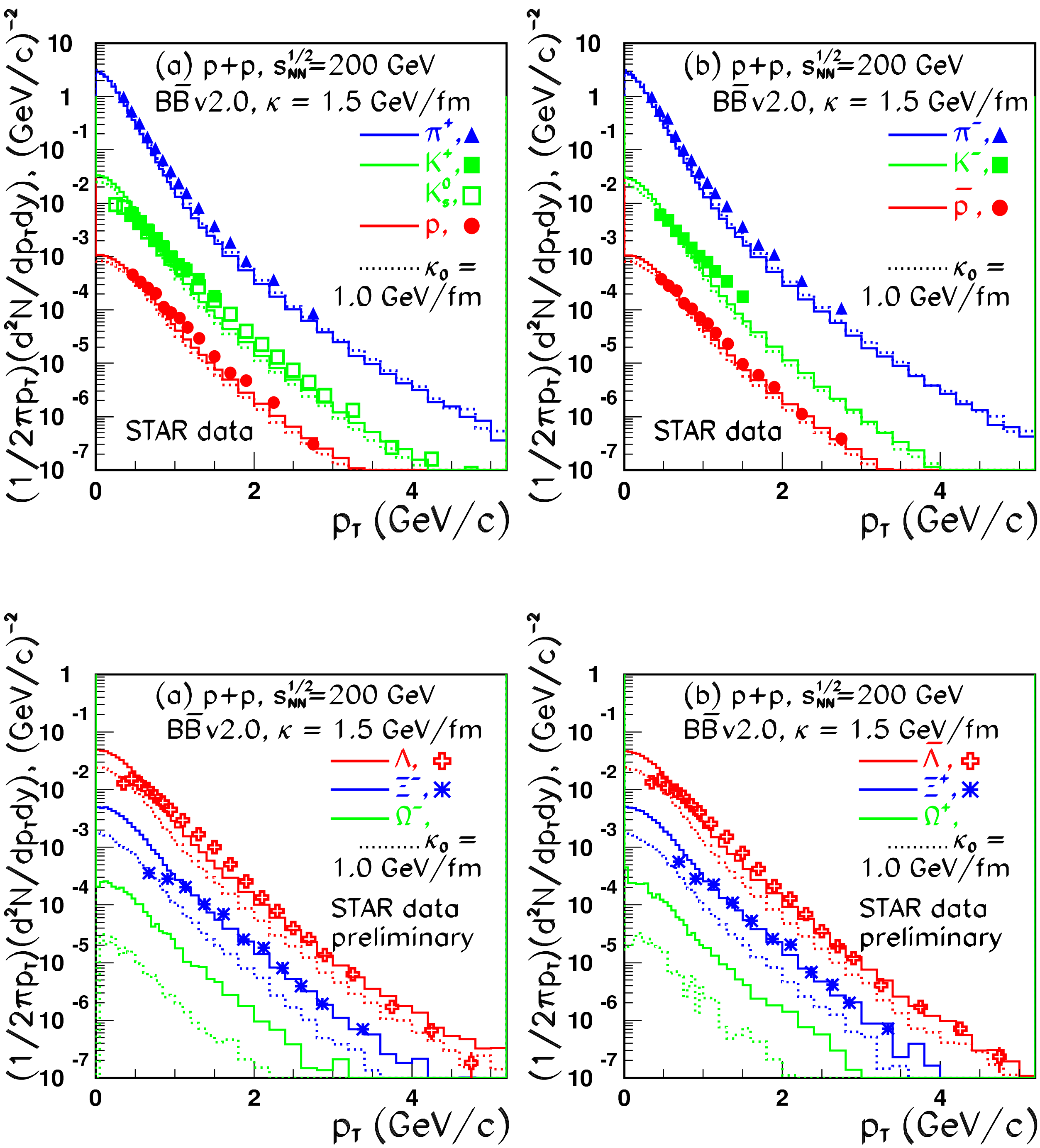
iv) the suppression of spin 1 diquarks relative to spin 0 ones (appart from the factor of 3 enhancement of the former based on counting the number of spin states); γ_{10}

v) Gaussian widths of intrinsic transverse momentum.

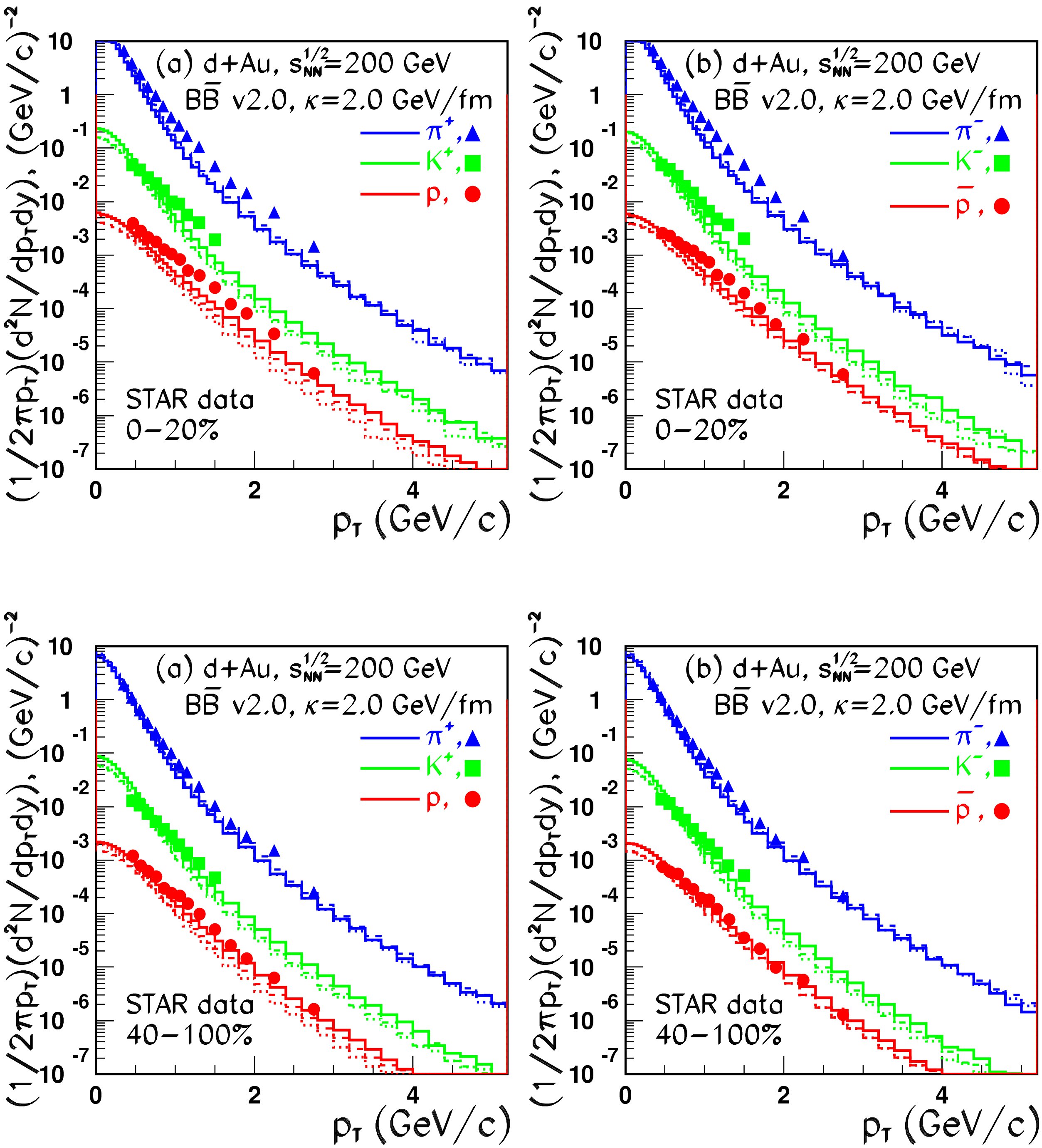
the (anti)quark ($\sigma_q'' = \sqrt{\kappa/\kappa_0} \cdot \sigma_q$)

(anti)di-quark ($\sigma_{qq}'' = \sqrt{\kappa/\kappa_0} \cdot f \cdot \sigma_{qq}$).

Upper: p, π^+, K^+ (left); $\bar{p}$, π^-, K^- (right).
Lower: Λ, Ξ^-, Ω^- (left); $\bar{\Lambda}$, $\bar{\Xi}^-$, $\bar{\Omega}^-$ (right).



p, π^+, K^+ (left); $\bar{p}, \pi^-, K^-$ (right).
Upper: Centrality 0-20%, d+Au.
Lower: Centrality 40-100%, d+Au.



Nuclear modification factor

Heavy Ion nuclear modification factor R_{AA}:

$$R_{AA}(p_\perp) = \frac{d^2N_{AA}/dydp_\perp}{< N_{coll} > d^2N_{pp}/dydp_\perp} \tag{1}$$

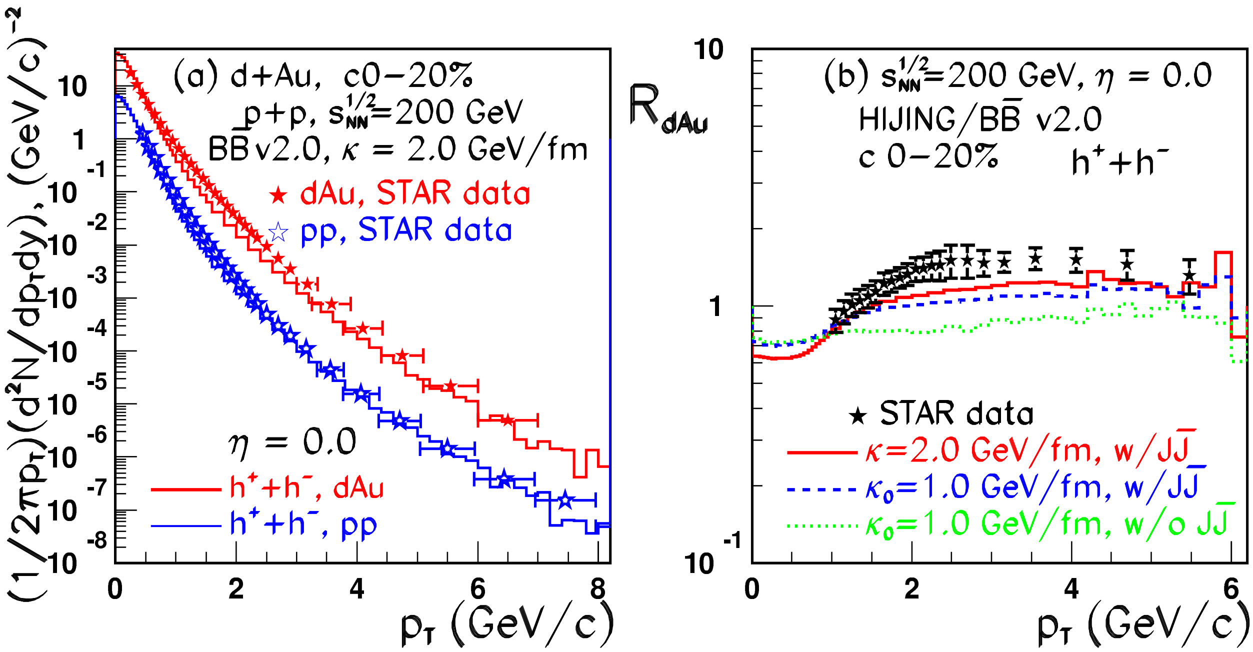
where, $< N_{coll} >$ is the average number of binary collisions of the event sample calculated from the nuclear overlap integral (T_{AA}) and the inelastic nucleon-nucleon cross section $< N_{coll} >= \sigma_{nn}^{inel} < T_{AA} >$.

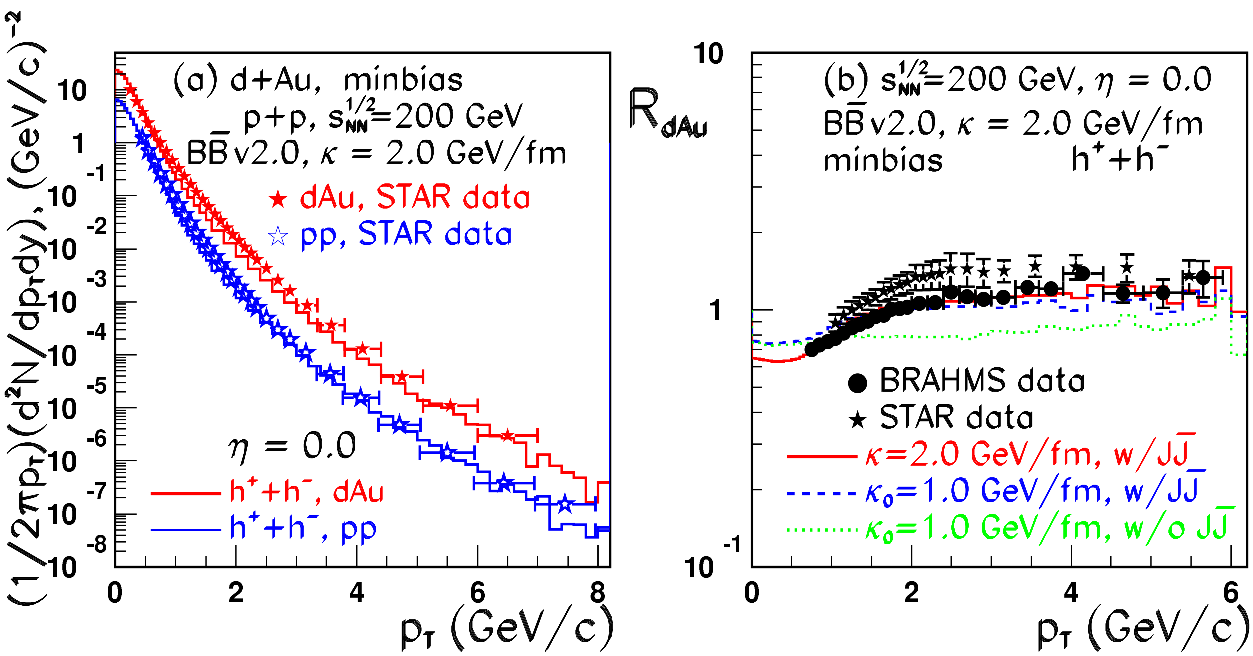
Impact parameter dependent nuclear modification factor R_{cp}:

$$R_{cp}(p_\perp) = \frac{Yield(Central)/ < N_{coll}(Central) >}{Yield(Periph.)/ < N_{coll}(Periph.) >} \tag{2}$$

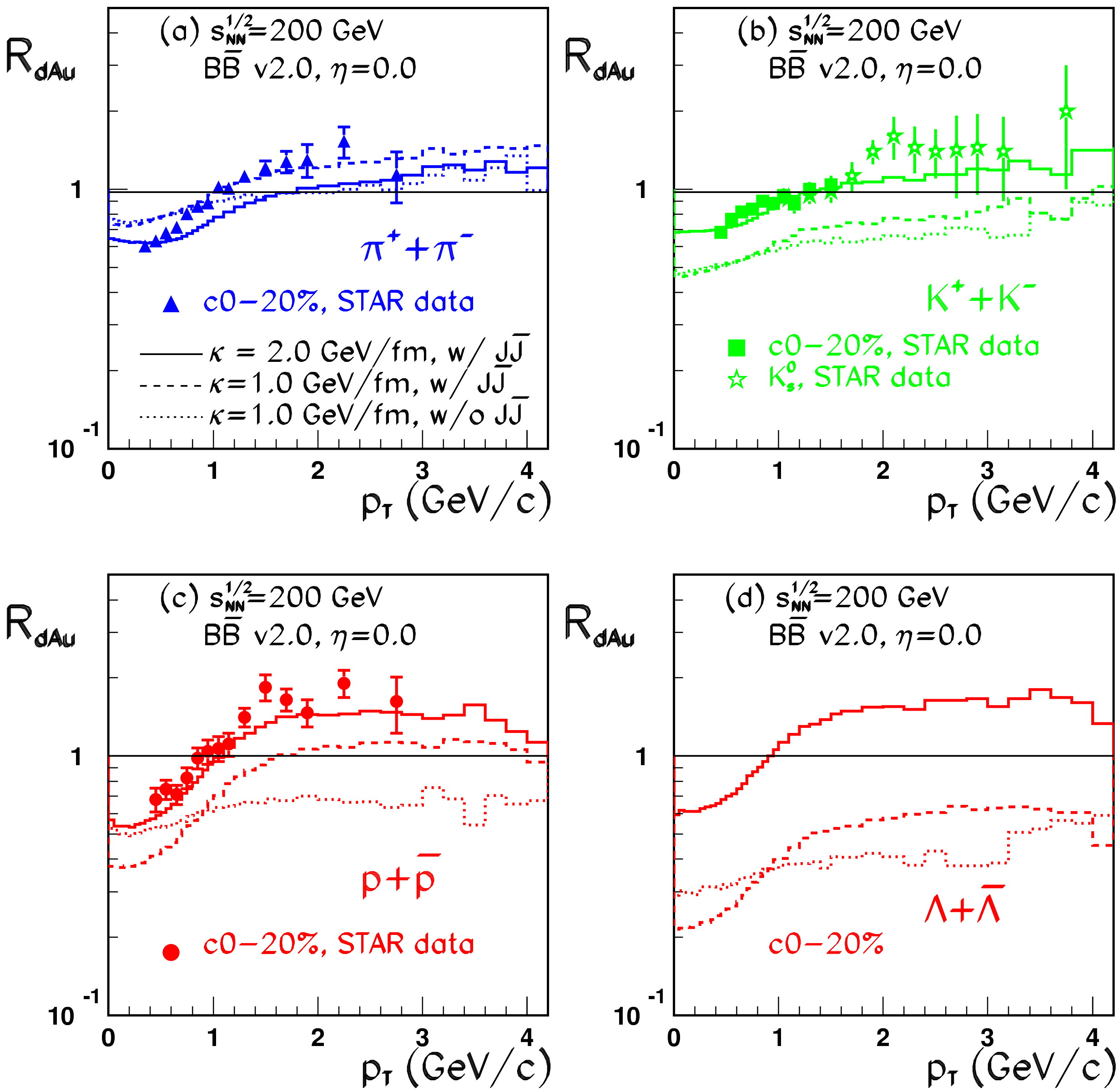
where $Yield = (1/N_{events})(1/2\pi\, p_\perp)(d^2N/dp_\perp dy)$ and $< N_{coll} >$ is defined as above.

$h^{+} + h^{-}$, p_T spectra (left); R_{dAu} (right).
Upper: Centrality 0-20%, d+Au;
Lower: Minbias, d+Au

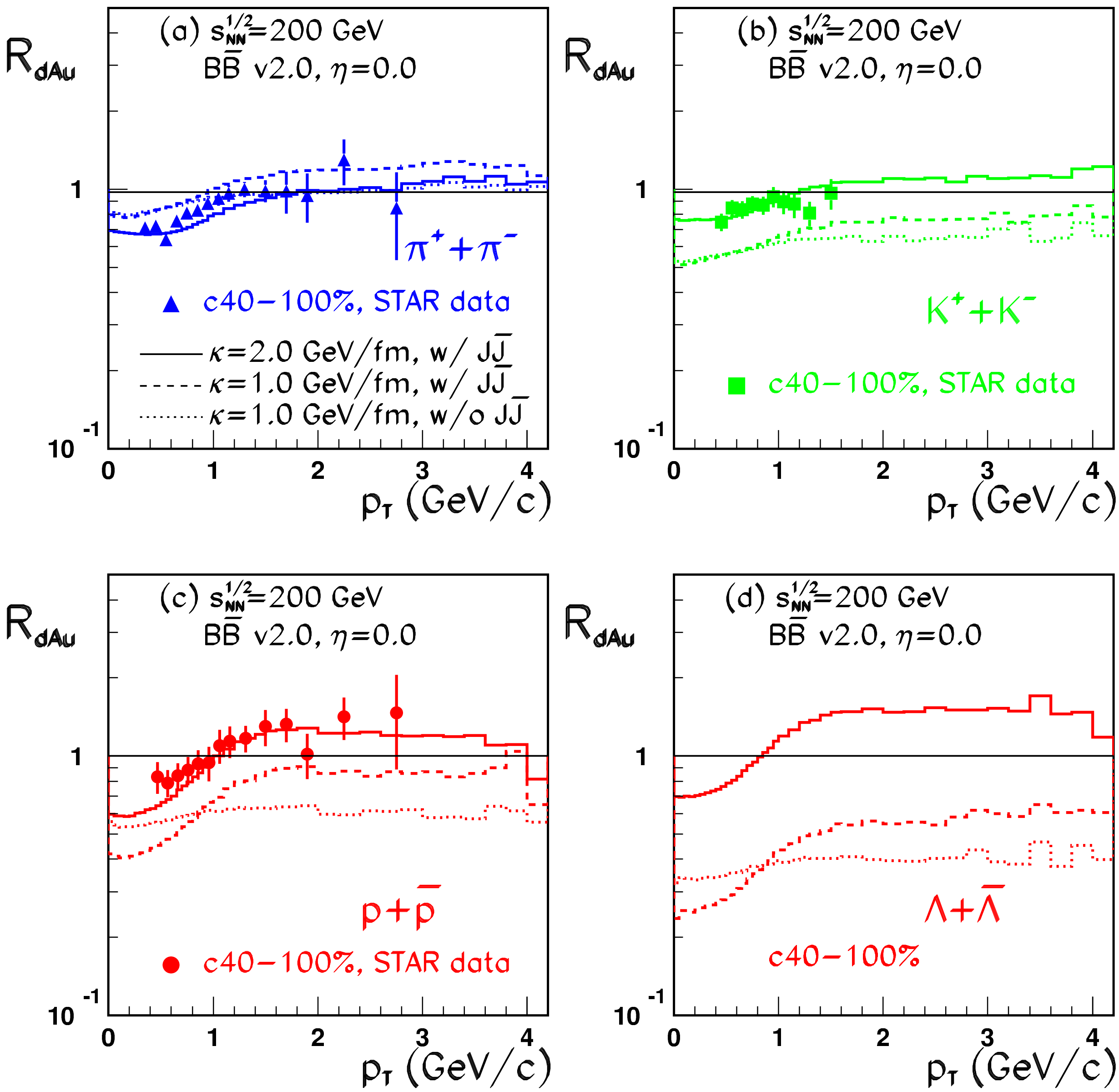




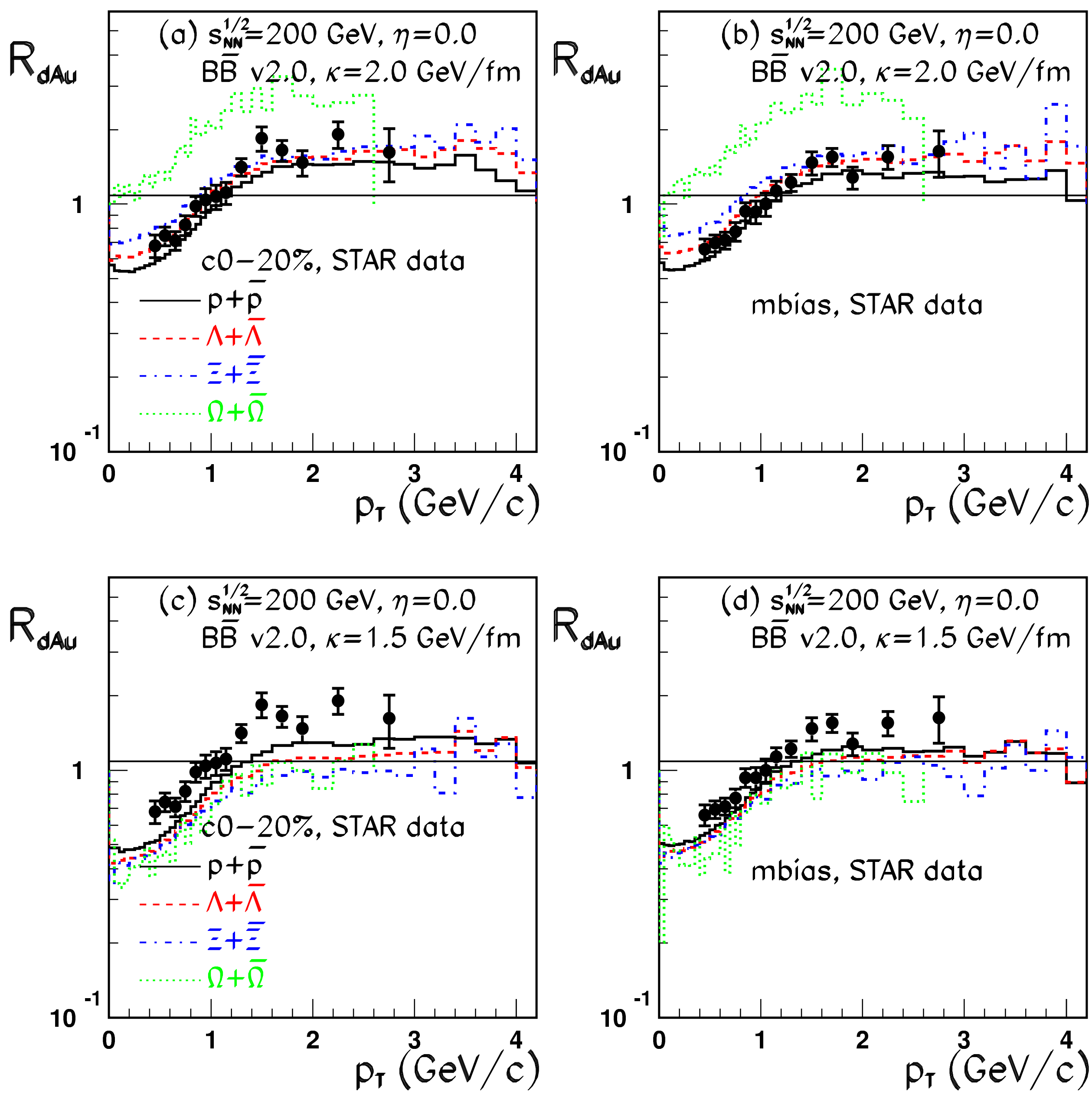
R_{dAu}; ID particles.
Centrality 0-20% (N_{part}=14.7)



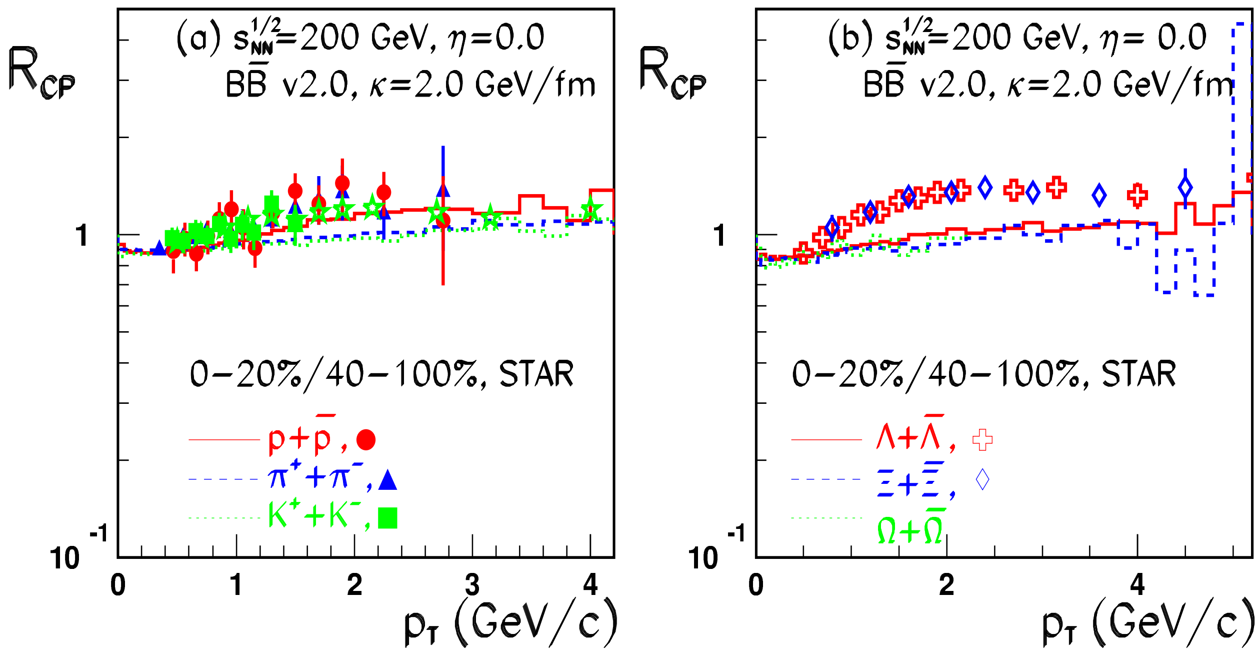
R_{dAu}; ID particles.
Centrality 40-100% (N_{part}=4.6)



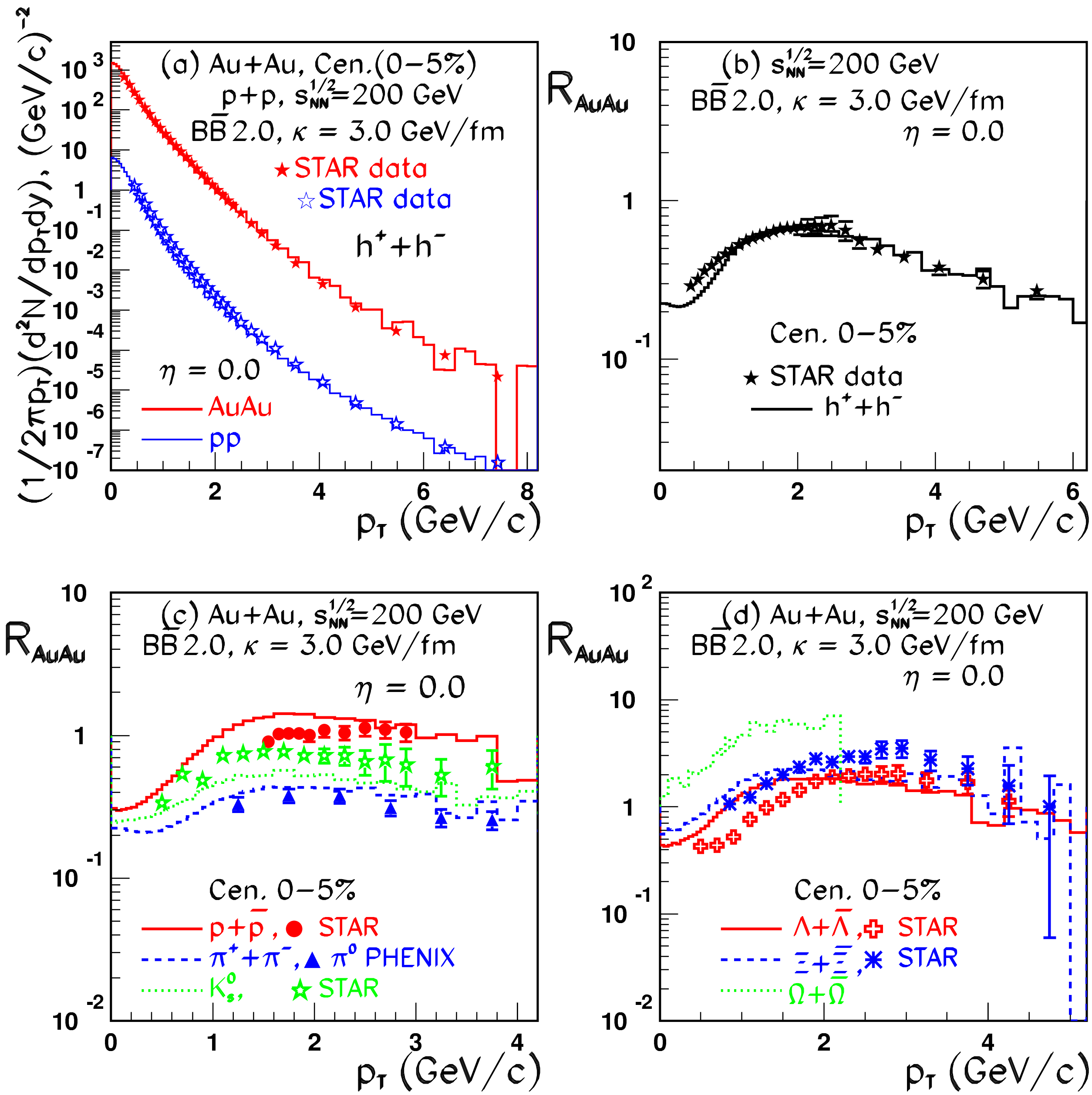
Sensitivity to string tension κ.
R_{dAu}; ID particles.
Centrality 0-20% (left); Minbias (right).



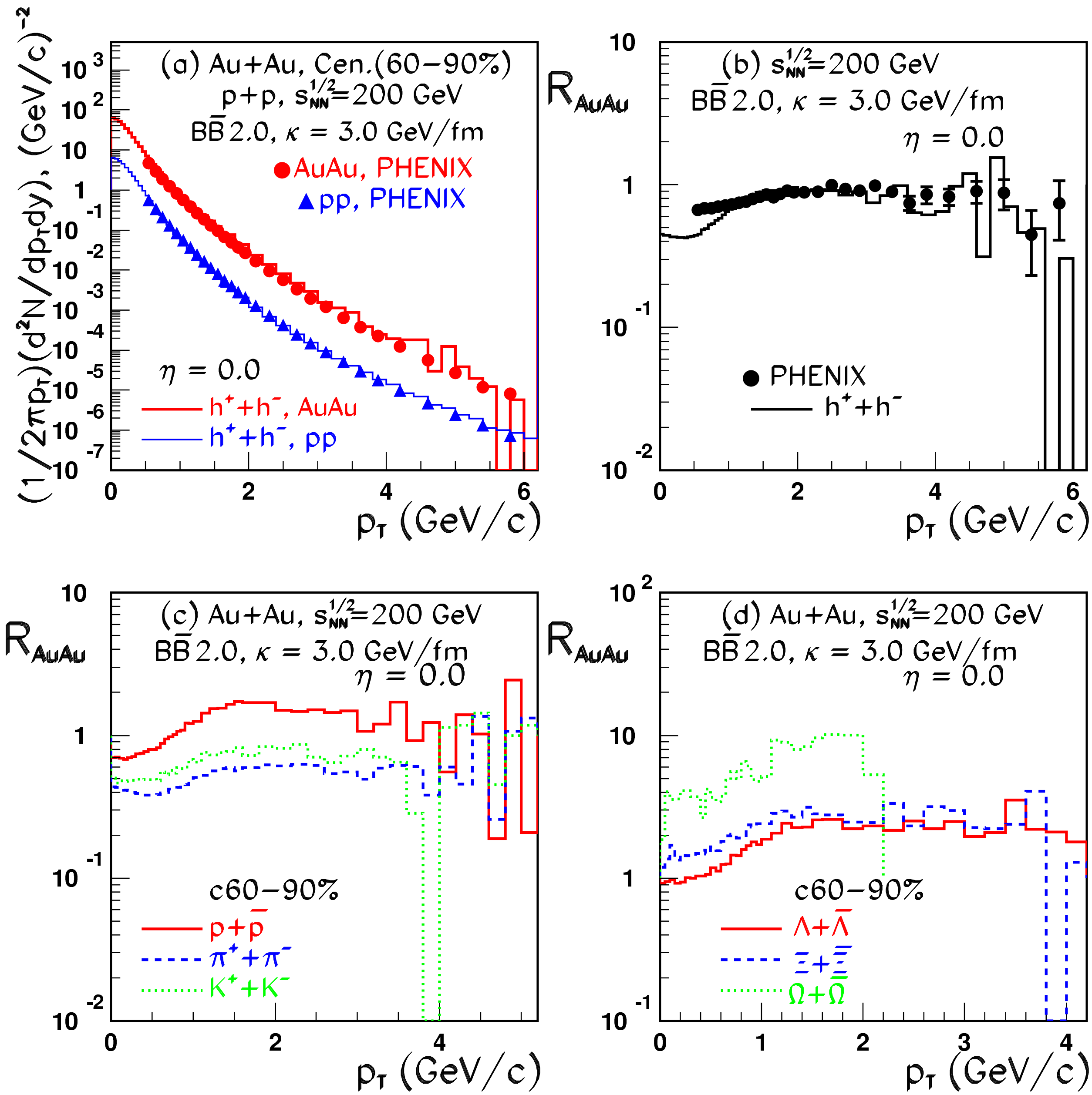
R_{CP} ; d+Au; ID particles. Scaled ratio 0-20%/40-100%



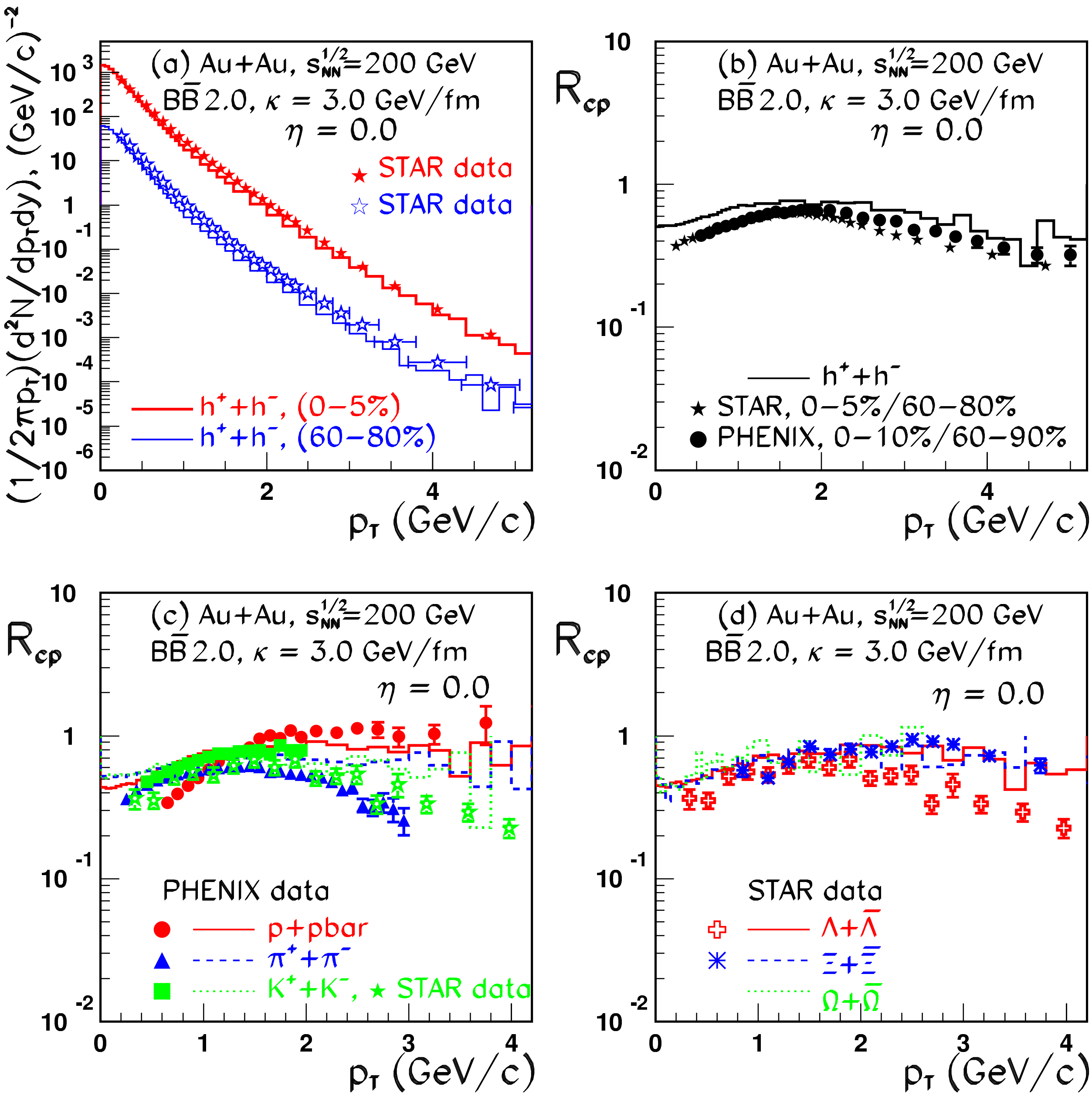
$h^+ + h^-$, p_T spectra. (left); R_{AuAu} (right). Lower: Centrality 0-5%; ID particles.



$h^+ + h^-$, p_T spectra. (left); R_{AuAu} (right). Lower: Periph. 60-90%; ID particles.



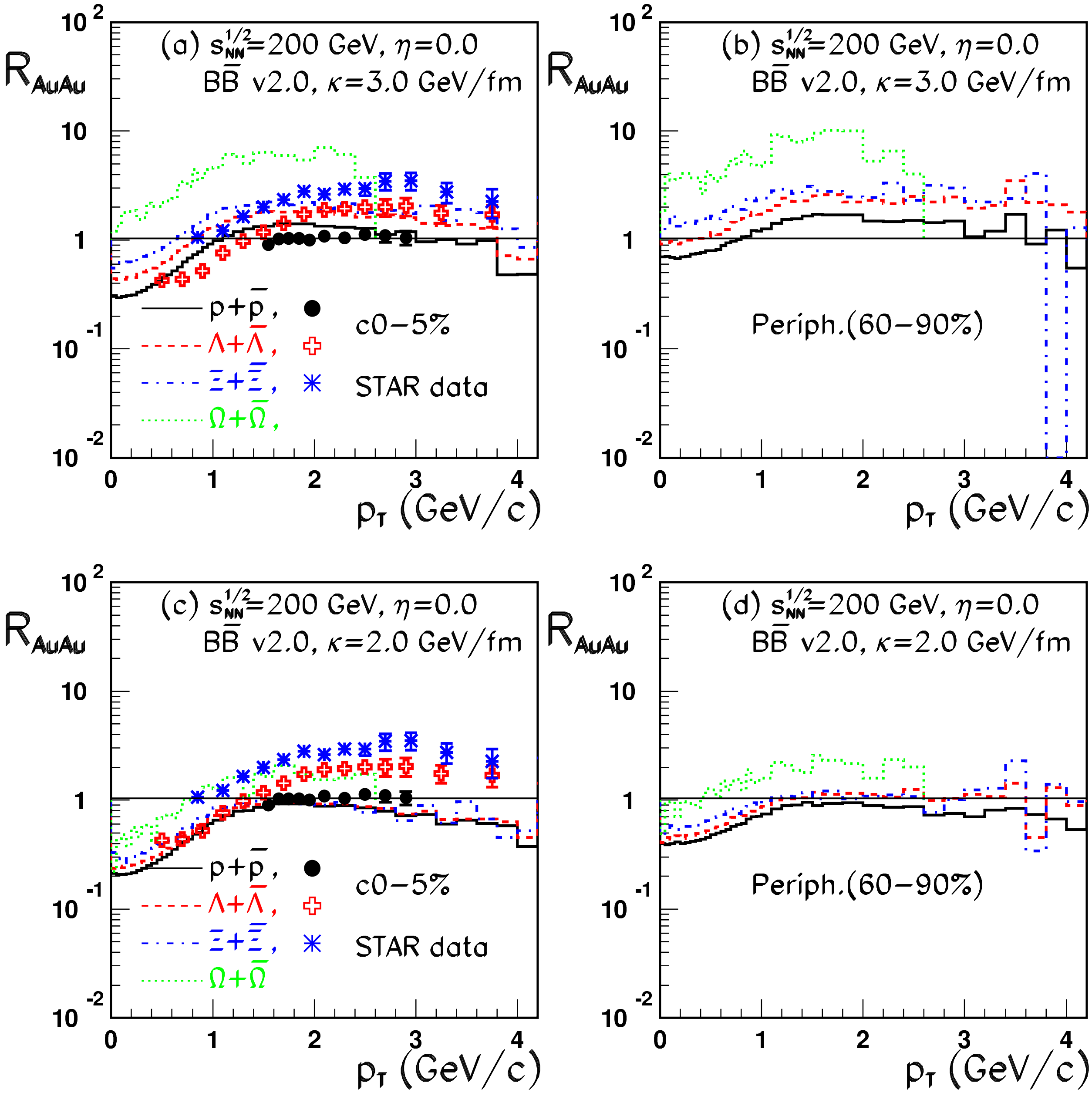
$h^+ + h^-$, p_T spectra. (left); R_{CP} (right). Lower: (0-5%/60-90%); ID particles.



Sensitivity to string tension κ.

R_{AuAu}; ID particles.

Cen.0-5% (left); Periph.60-90% (right).



Summary and Conclusions 01

- Multi-gluon dynamics, “gluon junctions” play an important role in particle production at mid-rapidity at RHIC.
- Introducing a corrected junction loop algorithm leads to a significant improvement in the description of the recent RHIC data.
- The strange and multistrange particles could only be described in the framework of string models, if we consider strong color field effects SCF.
- A greater sensitivity to SCF effects was predicted for the nuclear modification factors of (multi)strange hyperons. The measurement of Ω and $\bar{\Omega}$ yields would provide an important test of the consistency of SCF and baryon junction mechanisms at RHIC.
- The full understanding of the production of (multi)strange particles in relativistic heavy-ion collisions remain an exciting open question.