Strong color fields effects and baryon/meson anomaly in p+p and central Pb+Pb collisions at the LHC.

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Abstract

With the HIJING/B$\bar{\text{B}}$ v2.0 event generator, we explore the phenomenological consequences of the enhanced "in medium" strong longitudinal color field (SCF) and of (gluonic) baryon-anti-baryon junctions, J$\bar{\text{J}}$ loops. This analysis focuses on p+p collisions at $\sqrt{s_{\text{NN}}}$ = 0.9-7 TeV and on central Pb+Pb collisions at $\sqrt{s_{\text{NN}}}$ = 2.76 TeV, where recent data have been reported by LHC Collaborations.

The large (strange)baryon-to-meson ratios measured at the Tevatron in p+p collisions are well described and a significant enhancement of these ratios is predicted up to the highest LHC energy.

We present predictions for the energy dependence of pseudo-rapidity densities $(2dN_{\text{ch}}/d\,\eta)/N_{\text{part}}$ and the hadron hadron flavor dependence (mesons and baryons) of $R_{\text{AA}}(p_T)$ for Pb+Pb central collisions.

We show that the jet quenching suppresses the hard pQCD component of the particle spectra, thereby exposing novel components of baryon dynamics that we attribute to J$\bar{\text{J}}$ loops and SCF effects. We predict that baryon/mesons anomaly for $p_T < 10$ GeV/c will persist at the LHC energies with a moderate centrality dependence.

Introduction

- Open issues at RHIC and LHC energies include:
  - are baryon charge carried by quark and(or) gluon?.
  - net-baryon rapidity distributions (?)
  - the effect of jet quenching (parton energy loss in a medium)
  - the relative enhancement of (multi)strange particles in central heavy-ion with respect to pp collisions. Have been suggested as a signature for the transient existence of a QGP phase (Rafelski and Muller,PRL82,86).

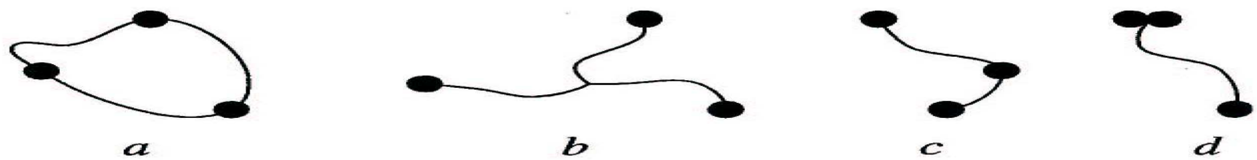
- The goals of this work is to study:
  -the interplay between soft and hard physics at RHIC, Tevatron and LHC energies
  -the role of baryon junction physics ($J\bar{J}$ loops)
  -the effects of the Strong Color Field (SCF)
  -the effects of the jet quenching.

- As a tool for our investigation of heavy-ion collisions Monte Carlo HIJING/$B\bar{B}$ v2.0, (V. Topor Pop et al., PRC (2007), JPG(2008), PRL(2009)) a modified version of regular HIJING (Heavy Ion Jet Interacting Generator) model is used.

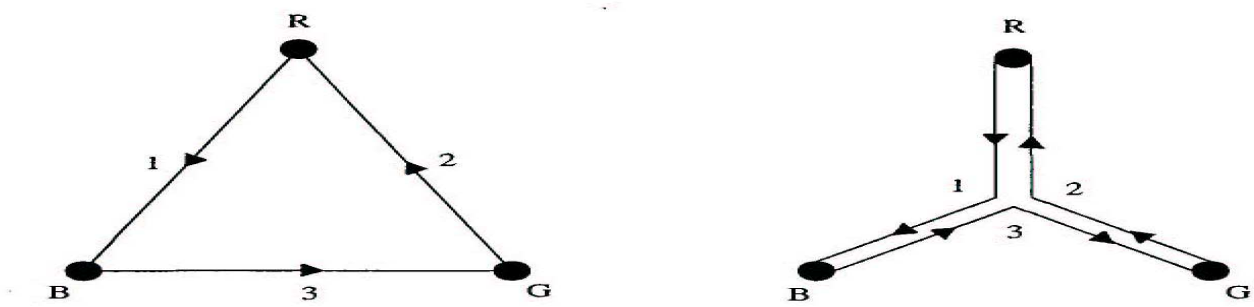
- In the present work we introduce an energy and system size dependence of the SCF and the characteristic parameters of the hard interaction.

HIJING/B$\bar{\text{B}}$ v2.0
Topologies of $J\bar{J}$ loops

- If classical string picture is adopted for baryonic states, at least one of the three arms will soon disappear, 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) (Gerard't Hooft, hep-th/0408148).



- In dual-superconductor models of color confinement for the Y geometry (Mercedes Configuration) the flux tubes converge first toward the center of triangles. There is another component that runs in opposite direction. They attract each other, and this lowers the energy of the Y configuration (G. Ripka, Lect.Note Phys., 639(04)).



- The dynamical mechanism of J$\bar{\text{J}}$ loops have been implemented in HIJING/B$\bar{\text{B}}$ v2.0 (V. Topor Pop et al., PRC (2005)) and could explain partly the observed anomalous increase of baryons at RHIC.

HIJING/B$\bar{\text{B}}$ v2.0; SCF

- In a strong longitudinal color field (SCF), the heavier flavor suppression factor $\gamma_{Q\bar{Q}}$ varies with the effective string tension, $\kappa = eE_{\text{eff}}$, via the Schwinger formula (E_{eff}- the strength of SCF)

$$\gamma_{Q\bar{Q}} = \frac{\Gamma_{Q\bar{Q}}}{\Gamma_{q\bar{q}}} = exp\left(-\frac{\pi(M_Q^2 - m_q^2)}{\kappa}\right) < 1$$

  for $Q =$ qq, s, c or b and $q = u$, d. The above formula implies a suppression of heavier quark (Q) production for usual value of the vacuum string tension $\kappa_0 \approx 1$ GeV/fm.

- The combined effects of hard and soft sources of multiparticle production can reproduce the available LHC data on p+p collisions in the range $0.02 < \sqrt{s} < 7$ TeV assuming an energy dependence of κ.

$$\kappa(s) = \kappa_0\ (s/s_0)^{0.06}\ \text{GeV/fm}$$

  where $\kappa_0 \approx 1$ GeV/fm

- For a color rope , on the other hand, the *average string tension* value κ could increases due to *in-medium* effect.

- For $A + A$ collisions we introduce a system size dependence given by:

$$\kappa(s, A)_{\text{RHIC}} = \kappa(s) A^{0.087}\ ,\ \kappa(s, A)_{\text{LHC}} = \kappa(s) A^{0.167}$$

- Both the energy and system size dependences of SCF efects play an important role in the successful description of the experimental data.

HIJING/B$\bar{\text{B}}$ v2.0; hard interactions

The nucleon-nucleon (NN) collisions at high energy can be divided into *soft* and *hard* processes. The separation between these two processes is characterized by a cut-off parameter p_0. Bellow p_0 the interaction is considered non-perturbative, and characterized by a cross section σ_{soft}.

The inclusive jet cross section σ_{jet} at leading order (LO) is

$$\sigma_{jet} = \int_{p_0^2}^{s/4} \mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2 \frac{1}{2} \frac{\mathrm{d}\sigma_{jet}}{\mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2}, \text{where,}$$

$$\frac{\mathrm{d}\sigma_{jet}}{\mathrm{d}p_T^2 \mathrm{d}y_1 \mathrm{d}y_2} = K \sum_{a,b} x_1 f_a(x_1, p_T^2) x_2 f_b(x_2, p_T^2) \frac{\mathrm{d}\sigma^{ab}(\hat{s}, \hat{t}, \hat{u})}{\mathrm{d}\hat{t}}$$

σ^{ab} is the parton-parton cross section and $f_a(x, p_T^2)$ is the parton distribution functions (PDF).

$K \approx 1.5 - 2$ accounts for the next-to-leading order (NLO) corrections.

For $p + p(\bar{p})$ collisions $p_0 = 2$ GeV/c has been used (V. Topor Pop et al., PRC (2011)).

For A+A collisions: the *coherent interaction* becomes important and an energy dependent cut-off value $p_0(s) = 0.832 \sqrt{s_{\text{NN}}}^{\,0.191}$ GeV/c is introduced.

The calculations take also into consideration shadowing effects as in HIJING (Wang, PhysRep (1997)), introducing a shadowing factor $S_{a/A}(x, r)$ for the PDF $f_{a/A}(x, Q^2, r) = S_{a/A}(x, r) f_{N/A}$.

HIJING/B$\bar{\text{B}}$ v2.0; jet quenching

The ratio $R_{AA}(p_T)$ can be used to quantify the effect of jet quenching:

$$R_{AA} = \frac{(1/N_{\text{evt}}^{AA}) d^2 N_{AA}/d^2 p_T dy}{N_{\text{coll}}(1/N_{\text{evt}}^{pp}) d^2 N_{pp}/d^2 p_T dy}$$

For a parton a, the energy loss per unit distance is $dE_a/dx = \epsilon_a/\lambda_a$.

where ϵ_a-the radiative energy loss per scattering and $\lambda_a$represent the mean free path (mfp) for the inelastic scattering.

At RHIC energies the data can be described assuming for a quark jet $(dE_q/dx) = 1$ GeV/fm and $\lambda_q = 2$ fm; (V. Topor Pop et al., PRC (2007), PRL(2009)).

It has been observed (ALICE Collab.(PLB696, 2011)) that at the LHC the charged particle densities $(2dN_{\text{ch}}/d\eta)/N_{\text{part}}$ at mid-pseudorapidity is roughly 2.2 times larger than at RHIC top energy (0.2 TeV).

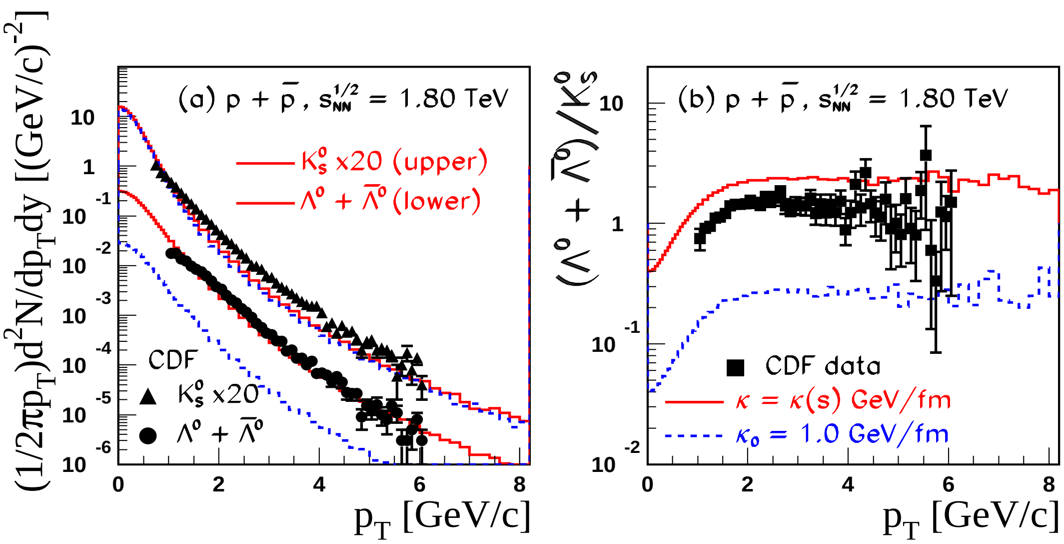
Since the initial parton density is proportional to the final hadron multiplicity we can conclude that the energy loss increase by a factor of ≈ 2.0 at the LHC.

In our calculation at the LHC energies we assume for a quark jet $(dE_q/dx) = 2$ GeV/fm and mfp $\lambda_q = 1$ fm. Gluon jets are assumed to have twice the energy loss of quark jet.

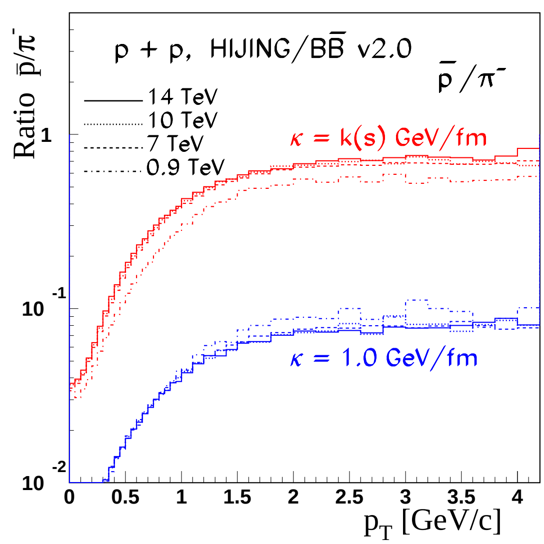
To study the sensitivity of the model on the jet quenching parameters we present the results corresponding to two sets of parameters:
$(dE/dx)_1$, $K = 1.5$; $(dE_q/dx) = 1$ GeV/fm; $\lambda_q = 2$ fm
$(dE/dx)_2$, $K = 1.5$; $(dE_q/dx) = 2$ GeV/fm; $\lambda_q = 1$ fm.

p+p Minimum bias.

Tevatron; $(\Lambda+\bar{\Lambda})/K_s^0$ ratio (upper). LHC; $\bar{p}/\pi^-$ ratio (lower)



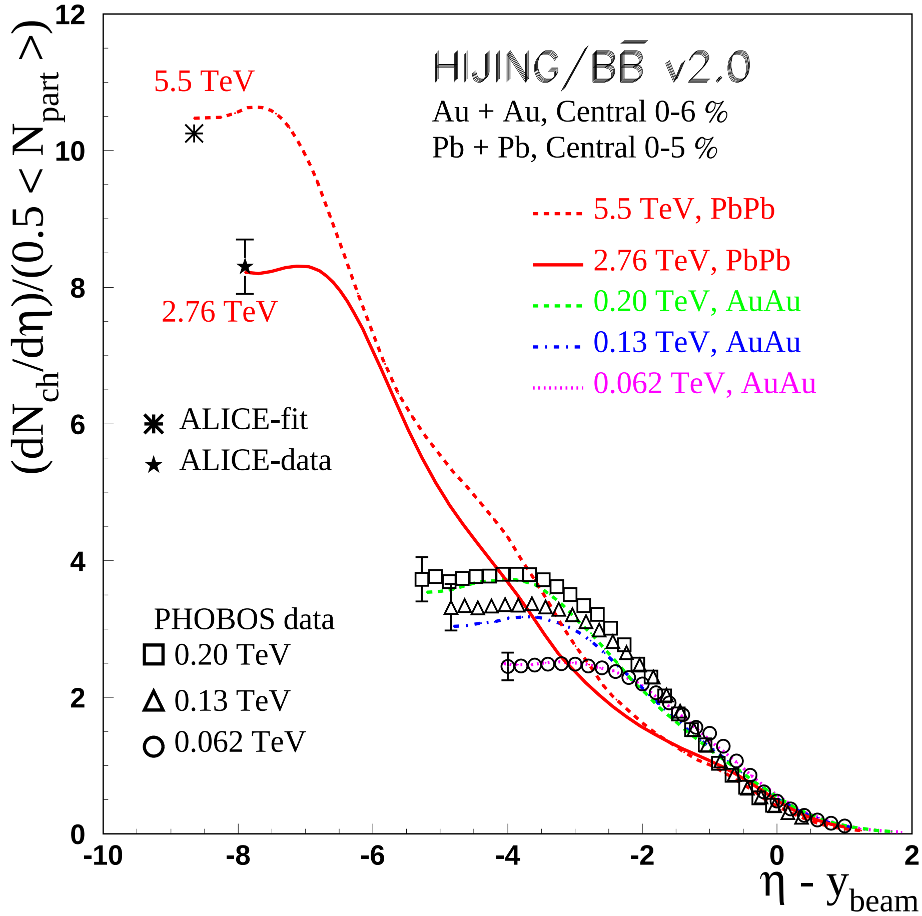
The measured ratio $(\Lambda+\bar{\Lambda})/K_s^0$ in $p+p$ collisons at $\sqrt{s_{NN}} =$ 1.8 TeV is better described (red histograms) by considering an energy dependent string tension, $\kappa(s)$ = 2.45 GeV/fm, indicative of SCF effects.



An enhancement of the $\bar{p}/\pi^-$ ratio up to 14 TeV and a weak energy dependence, with a saturation that sets in for $\sqrt{s} >$ 2.36 TeV is predicted.

Charged particle production (1)

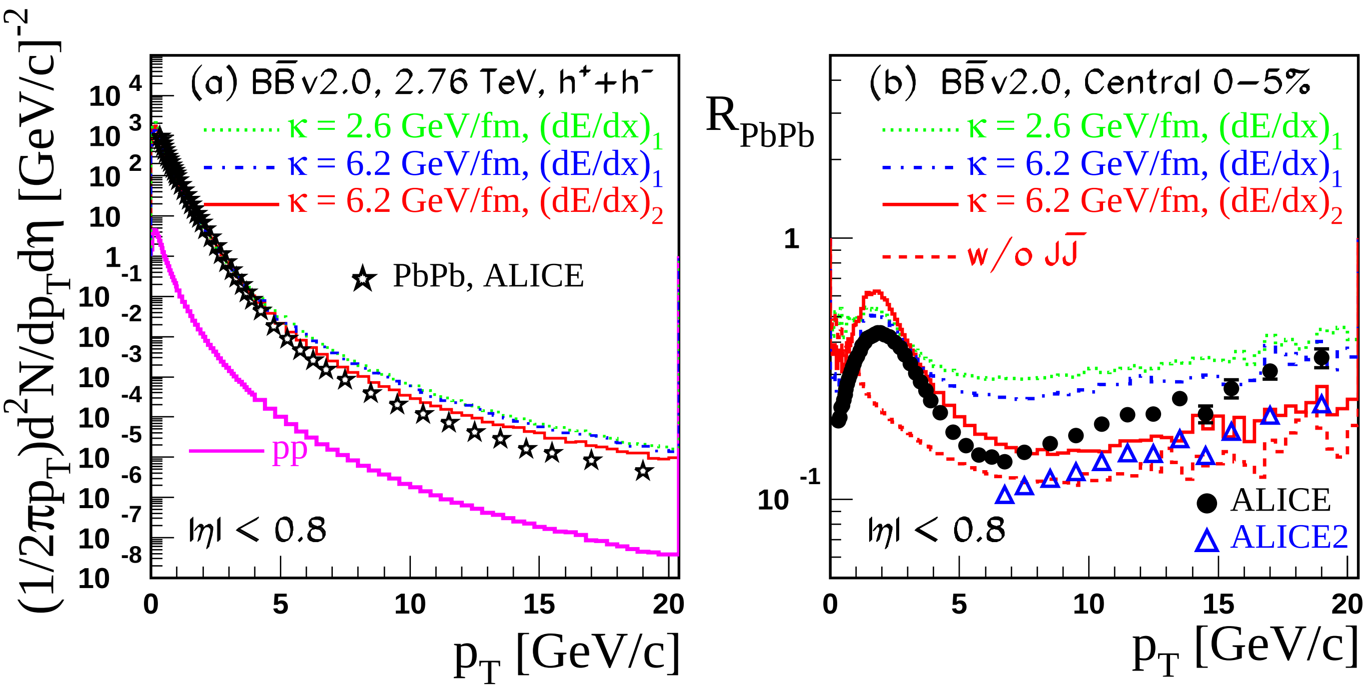
Pseudorapidity distributions; RHIC and LHC



Our model well reproduced the measured charged hadrons density in central (0-5%) Pb+Pb collisions at mid-pseudorapidity (ALICE results). Our calculations show that at RHIC energies the model predict approximately a scaling seen also in data (PHOBOS results). However, a degree of violation of the phenomenon of *limiting fragmentation* and of the *extended longitudinal scaling* is predicted at both LHC energies. This violation is due to the partons hard scattering included in our model and missing in CGC models.

Charged particle production (2)

Left: LHC; p_T spectra.
Right: LHC; $R_{\rm PbPb}$.

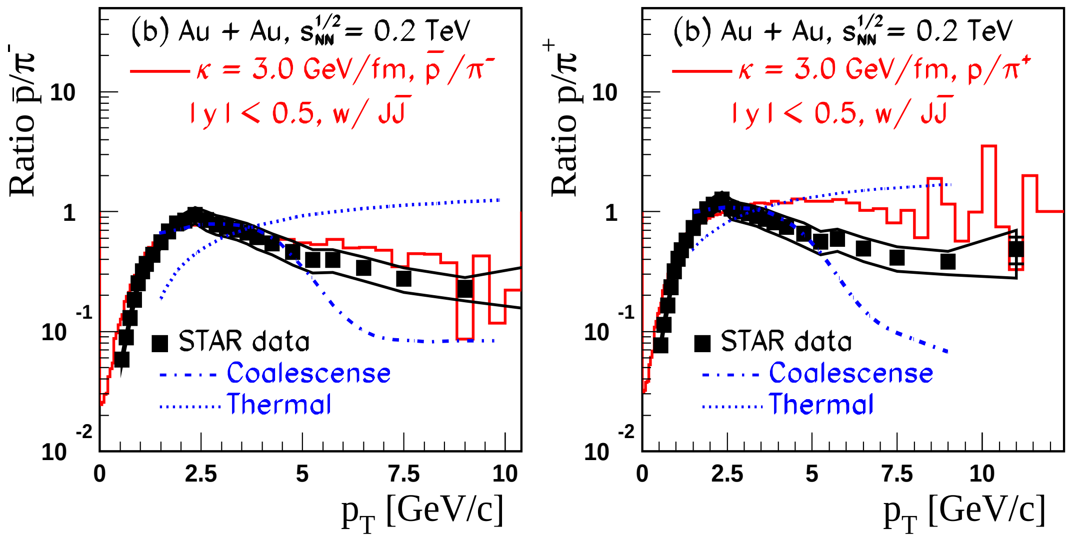


The p_T spectra in central Pb+Pb collisions is fairly well described (left figure). In medium modification of $R_{\rm PbPb}(p_T)$ (right figure), is mainly caused by the energy loss suffered by partons transversing the plasma due to collisions and the radiation of gluons, before they fragment, The best description of $R_{\rm PbPb}(p_T)$ is obtained using $k(s,A) = 6.2$ GeV/fm and $(dE/dx)_2$ (continue red histogram).

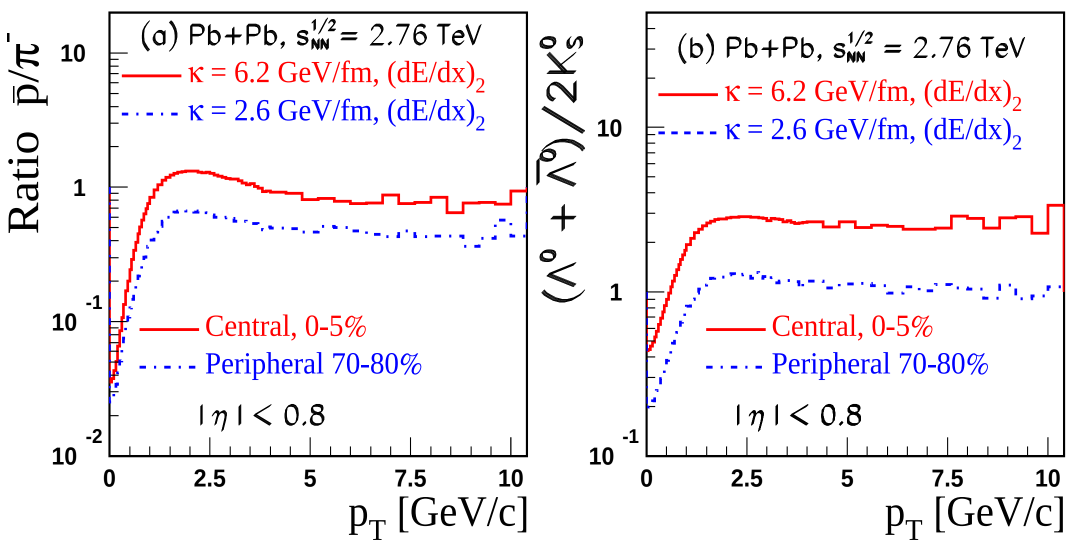
The observed shape with a maximum at approximately $p_T = 2$ GeV/c can be explained as a specific interplay between non-perturbative (SCF effects) and perturbative ($J\bar{J}$ dynamical loops) mechanisms contribution. The scenario without $J\bar{J}$ loops strongly underestimate the data in the region $0.5 < p_T < 6$ GeV/c.

Baryon anomalous production (1)

RHIC; baryon-to-meson ratio (upper)
LHC; (Strange)baryon-to-meson (lower)



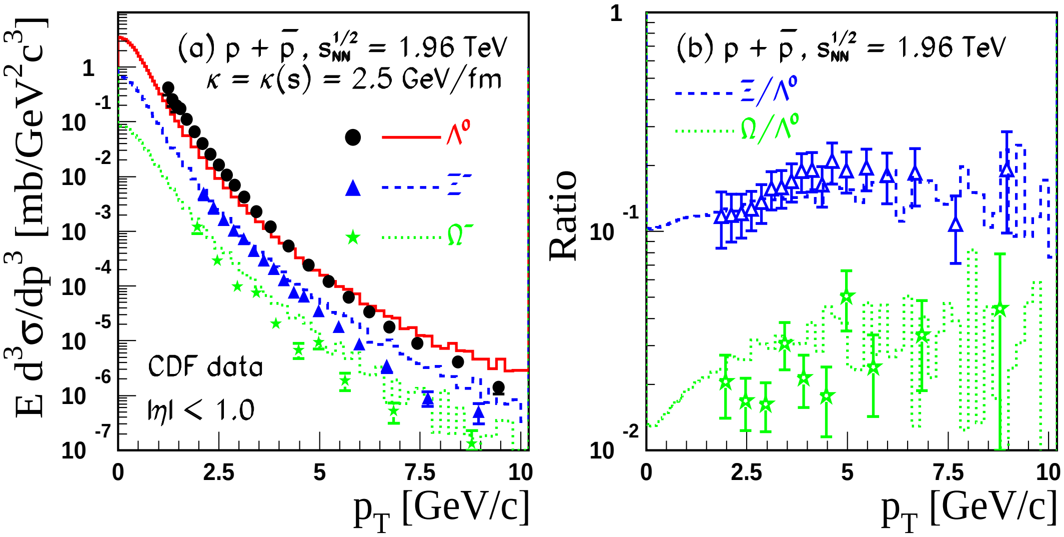
At RHIC energies our model provides alternative description to models based on constituent quark coalescence (R. J. Fries, PRC(2003), Ann.Rev.Nucl.Sci(2008)).



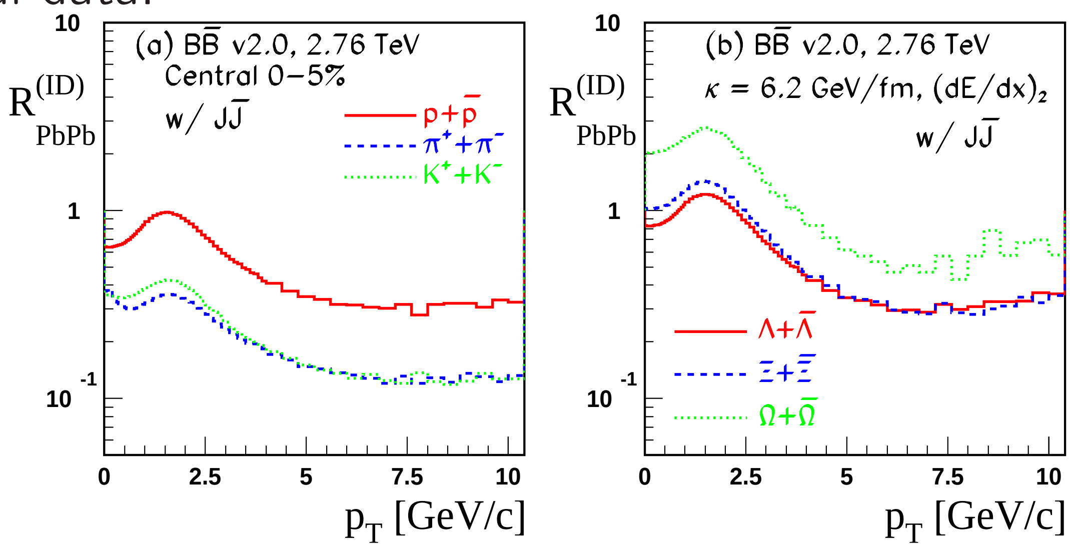
Our model predicts that (strange)baryon-to-meson ratios does not depend strongly on energy and centrality at the LHC. The baryon/meson anomaly is predicted to persist up to high p_T = 10 GeV/c.

Baryon anomalous production (2)

Tevatron; (Multi)strange hyperons (upper)
LHC; R^{ID}_{AA} ID particles (lower)



For $p+p$ collisions at the Tevatron our model including SCF efects predicts an enhancement of the hyperons yields with increasing strangeness content in agreement with the experimental data.



The predicted $R^{\mathrm{ID}}_{\mathrm{PbPb}}(p_T)$ exhibit an ordering with strangeness content, the increase of the yield being higher for multi-strange hyperons than that for (non)strange baryons, $R_{\mathrm{PbPb}}(\Omega) > R_{\mathrm{PbPb}}(\Xi) > R_{\mathrm{PbPb}}(\Lambda) > R_{\mathrm{PbPb}}(p)$.

Summary and Conclusions

- We have studied the influence of strong longitudinal color fields and of possible multi-gluon J$\bar{\text{J}}$ loops dynamics in particle production in $p+p$ and Pb+Pb collisions at LHC energies.

- Strong Color Field effects are modeled by varying the effective string tension that controls the $q\bar{q}$ and qq$\overline{\text{qq}}$ pair creation rates and strangeness suppression factors. SCF modifies the fragmentation processes which results in an increase of (strange)baryons production.

- By introducing an energy and mass dependent string tension we could described measured charged particle densities and nuclear modification factor in Pb+Pb at the LHC as well as the observed baryon/meson anomaly in $p+p$ and heavy-ion collisions.

- The baryon/meson anomaly is predicted to persist up to high $p_T = 10$ GeV/c. We also predict that the $R^{\text{ID}}_{\text{PbPb}}(p_T)$ exhibit an ordering with strangeness content at low and intermediate p_T, the increase of the yield being higher for multi-strange hyperons than that for (non)strange baryons.

- The validity of our model wil be tested by the future LHC measurements. This will help us to understand better initial conditions, parton distributions at low Bjorken-x, scaling factors, energy loss for gluon and quark jets in medium.