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

Quark Matter, Annecy, France
May 22-28th, 2011

V. Topor Pop, M. Gyulassy, J. Barrette, C. Gale
McGill University, Montreal, Canada
Columbia University, New York, USA

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 $\sqrt{s_{\rm NN}} = 0.900$, 2.36 and 7 TeV and on central Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. For p+p collisions the large (strange)baryon-to-meson ratios measured at the Tevatron are well described. A significant enhancement of these ratios is predicted up to the highest LHC energy (14 TeV). We present predictions for the energy dependence of pseudo-rapidity densities $(2dN_{\rm ch}/d\eta)/N_{\rm part}$ and especially the hadron flavor dependence (mesons and baryons) of the $R_{\rm AA}(p_T)$ 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 the J$\bar{\text{J}}$ loops and to 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

- Interesting open issues at RHIC and LHC energies include:
  -baryon charge can be carry by quark and(or) gluon?.
  -net-baryon rapidity distributions (?)
  -jet quenching (parton energy loss in a medium)

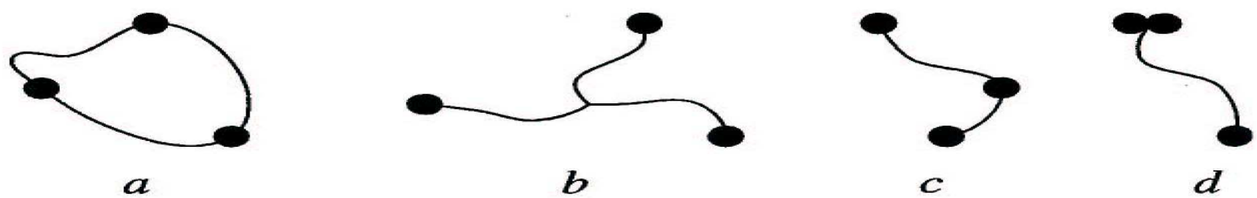
- (Multi)strange particles are of great interest. Their relative enhancement in central heavy ion collisions with respect to pp collisions, have been suggested as a signature for the transient existence of a QGP phase. (Rafelski and Muller,PRL82,86).

- The goals of this study is to reveal:
  -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.

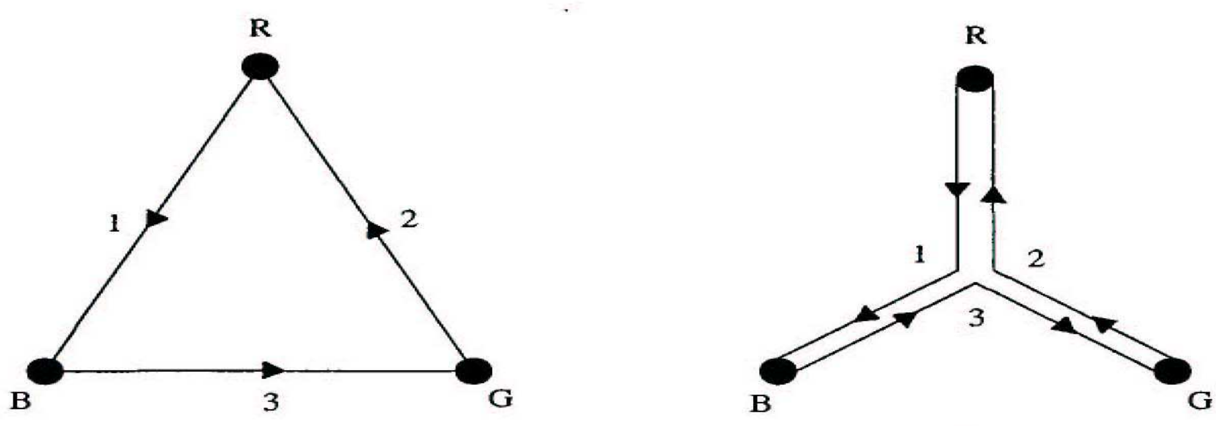
- As a tool for our investigation of heavy-ion collisions Monte Carlo HIJING/$B\bar{B}$ v2.0, modified version of regular HIJING (Heavy Ion Jet Interacting Generator) model is used.

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 and there is also 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).



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 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, vacuum value.

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

- For $A + A$ collisions:

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

- These dynamical mechanisms play an important role on the 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 with at least one pair of jet production with transverse momentum, $p_T > p_0$.

The cut-off scale p_0 has to be introduced below which the interaction is considered non-perturbative, and characterized by σ_{soft}.

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

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

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

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

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

For $p + p(\bar{p})$ collisions $p_0 = 2$ GeV/c = constant in the entire energy region (V. Topor Pop et al., PRC (2011)).

For A+A collisions: The *coherent interaction* becomes important. A new cut-off value $p_0(s) = 0.832 \sqrt{s_{\text{NN}}}^{\,0.191}$ GeV/c is introduced to describe better the experimental data.

The PDF per nucleon inside a nucleus, A:
$f_{a/A}(x, Q^2, r) = S_{a/A}(x, r) f_{N/A}$
$S_{a/A}(x, r)$ shadowing factor , from regular HIJING.

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

To quantify the jet quenching the ratio $R_{AA}(p_T)$:

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

N_{evt} is the number of events.
N_{coll} is number of binary NN collisions.

For a parton a, the energy loss per unit distance is
$dE_a/dx = \epsilon_a/\lambda_a$.
ϵ_a-the radiative energy loss per scattering;
λ_a-the mean free path (mfp) of the inelastic scattering.

For RHIC energies for a quark jet
$(dE_q/dx) = 1$ GeV/fm and $\lambda_q = 2$ fm;
(V. Topor Pop et al., PRC (2007), JPG(2008), PRL(2009)).

The initial parton density -proportional to the final hadron multiplicity density.

The charged particle densities : $(2dN_{\text{ch}}/d\eta)/N_{\text{part}} = n^{\text{ch}}$.
ALICE Collab.(PLB696, 2011); $n_{\text{LHC}}^{ch} = 2.2 n_{\text{RHIC}}^{ch}$ at mid-η.
Therefore, the energy loss increase by a factor of ≈ 2.0 at the LHC.

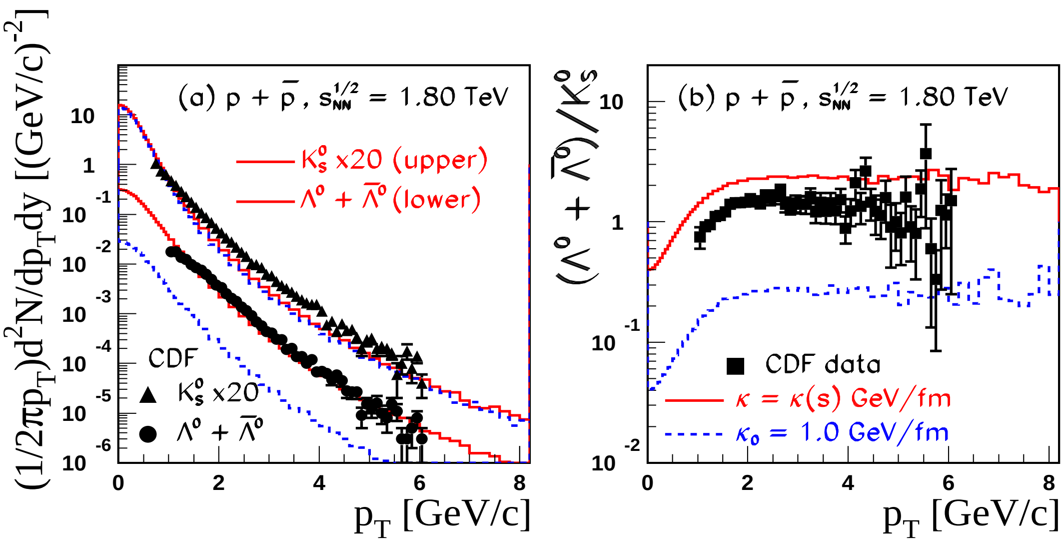
For a quark jet at the LHC:
$(dE_q/dx) \approx 2$ GeV/fm and mfp $\lambda_q \approx 1$ fm.

For a gluon jet $(dE_{\text{g}}/dx) = 2(dE_q/dx)$ and mfp $\lambda_{\text{g}} = 0.5\lambda_q$.

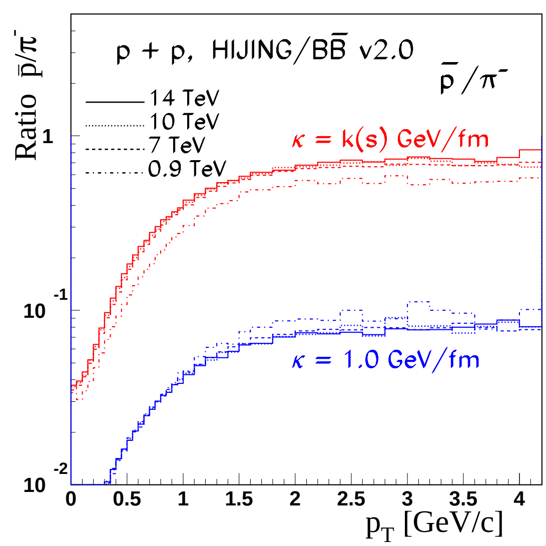
Throughout this analysis we will consider the results with two sets of parameters for hard interactions:
$(dE/dx)_1$, i.e., $K = 1.5$; $(dE_q/dx) = 1$ GeV/fm; $\lambda_q = 2$ fm
$(dE/dx)_2$, i.e., $K = 1.5$; $(dE_q/dx) = 2$ GeV/fm; $\lambda_q = 1$ fm.

p+p Minimum bias.

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

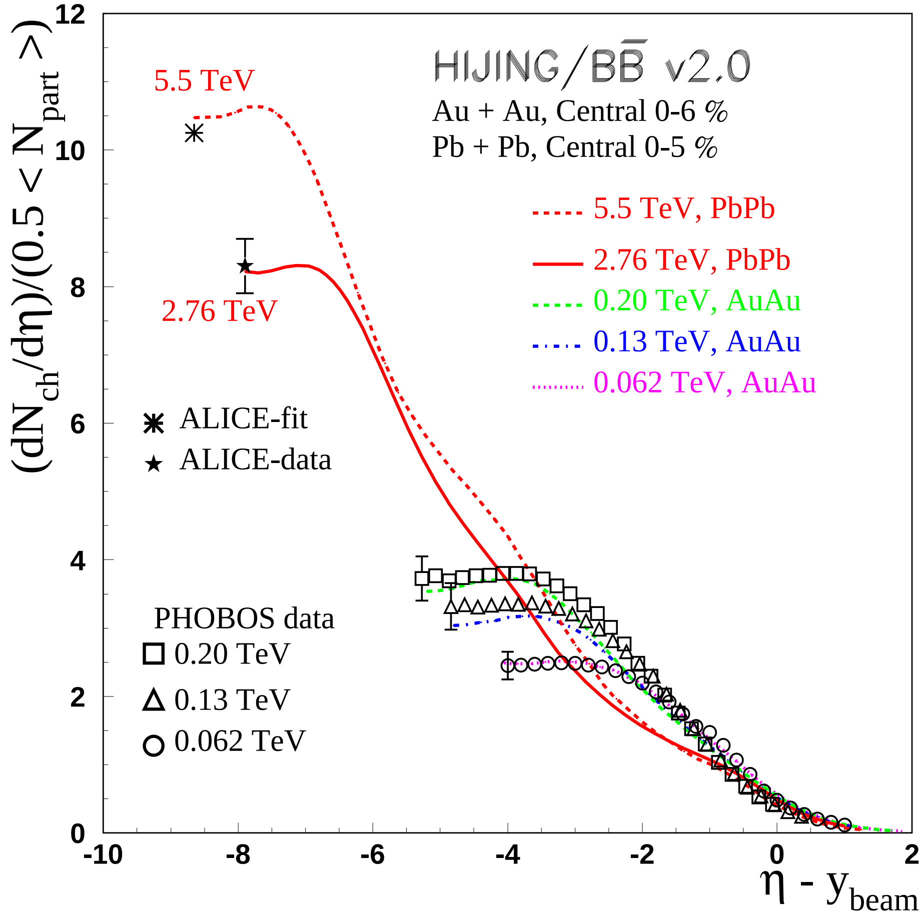


The ratio $(\Lambda+\bar{\Lambda})/K_s^0$ from $p+p$ collisons at $\sqrt{s_{NN}} = 1.8$ TeV is better described by including $J\bar{J}$ loops and SCF with $\kappa(s) = 2.45$ GeV/fm.



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

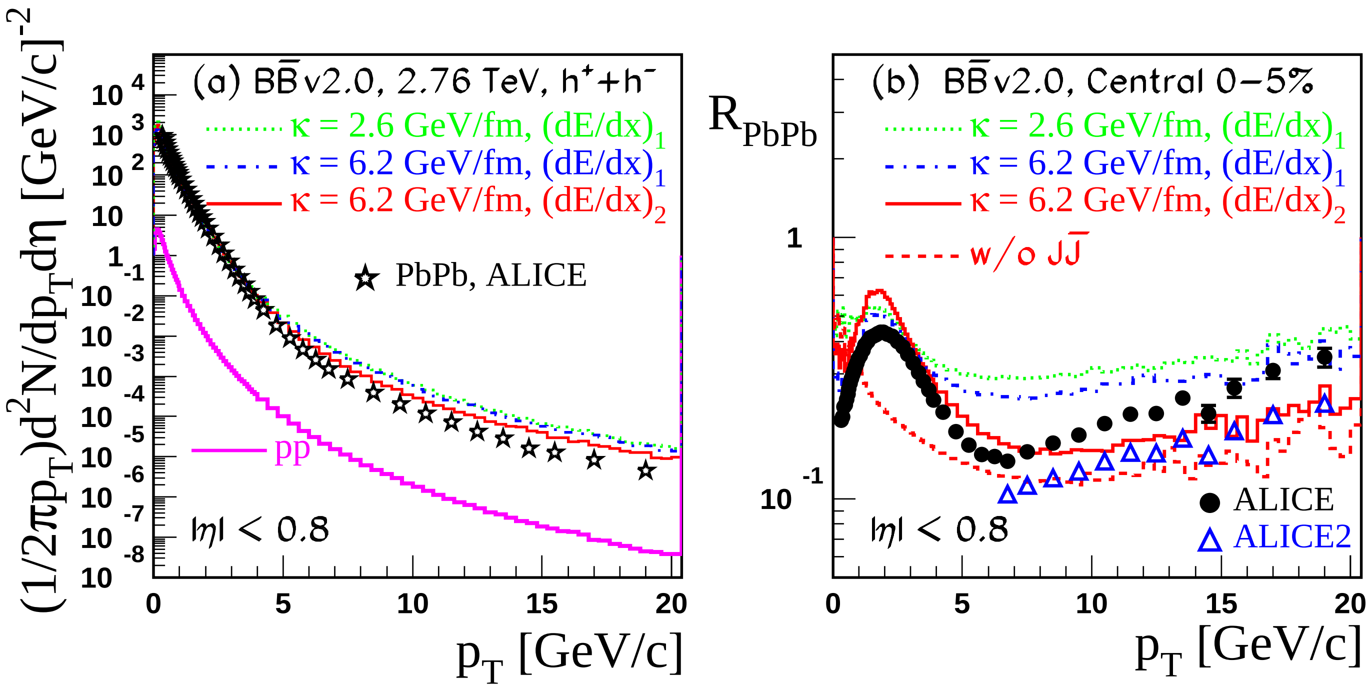
Charged particle production (1)
Pseudorapidity distributions; RHIC and LHC



Our model predicts ≈ 8.4 produced charged hadrons per participant pair in central (0-5%) Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-pseudorapidity. This value is higher than those obtained by requiring limiting fragmentation. Our calculations show that at RHIC energies the model predict approximately a scaling seen also in data. However, a degree of violation of the phenomenon of *limiting fragmentation* and of the *extended longitudinal scaling* is obtained 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_{PbPb}.

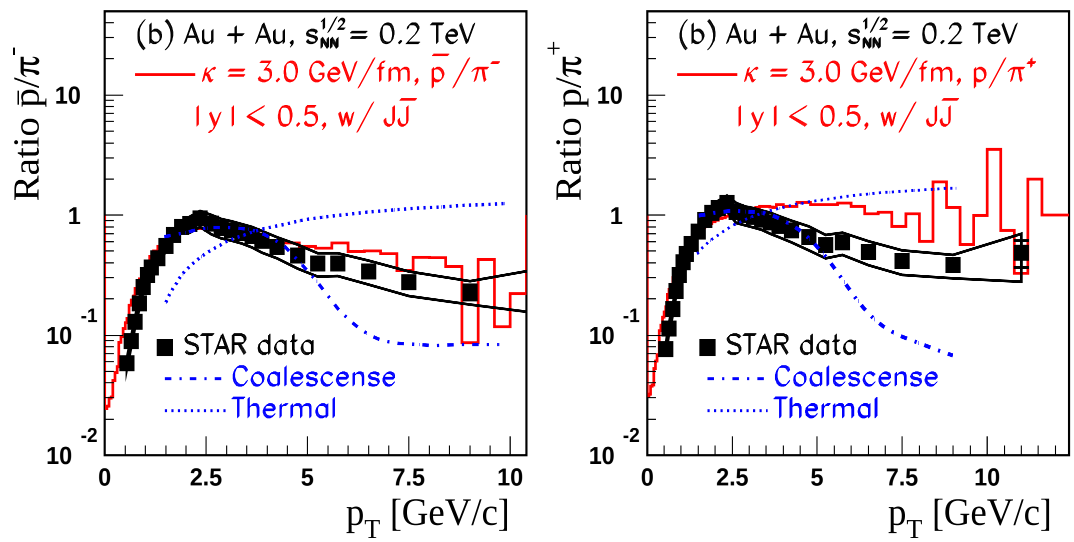


In medium modification of NMF R_{PbPb}, is mainly caused by the (mini)jet quenching suffered by partons while transverse the plasma due to collisions and the radiation of gluons, before they fragment, and the nuclear shadowing.

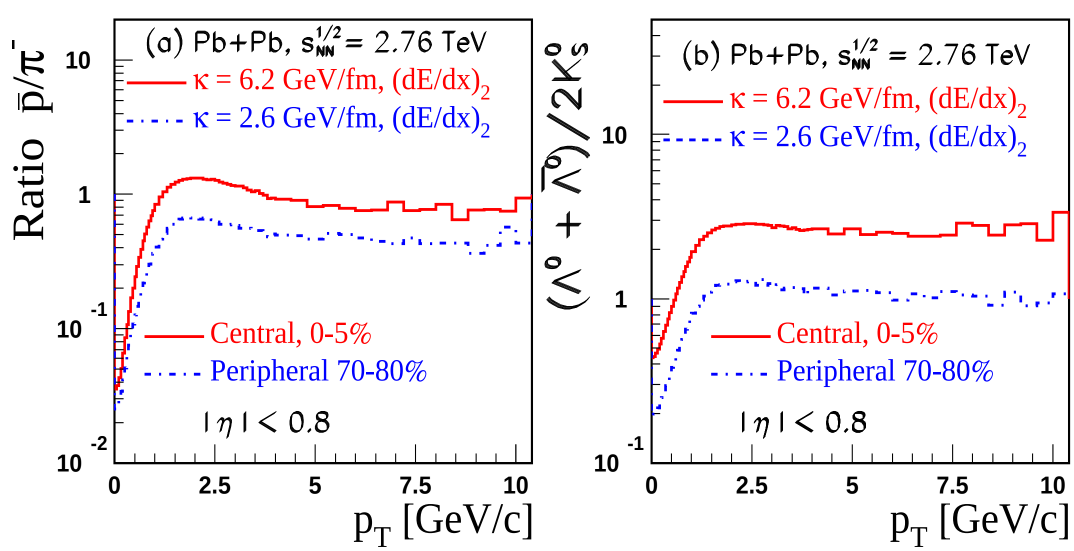
The observed shape with a maximum at approximately $p_T = 2$ GeV/c in the region of low $p_T < 6$ GeV/c can be explained as a specific interplay between non-perturbative (SCF effects) and perturbative ($J\bar{J}$ dynamical loops) mechanisms contribution. The scenario without $J\bar{J}$ loops strongly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



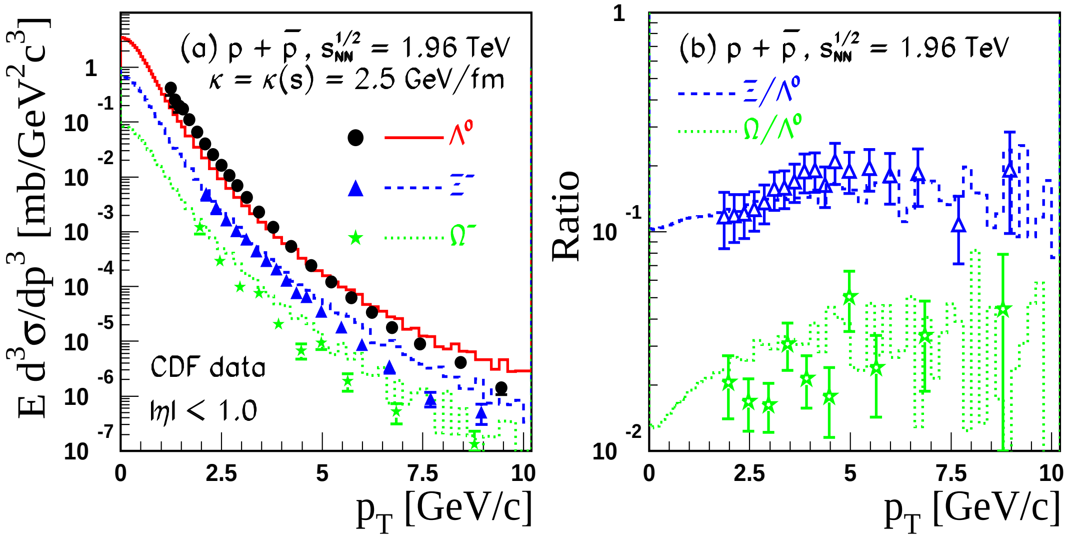
At RHIC energies the model provide an alternative description to models based on constituent quark coalescence (R. J. Fries, PRC(2003), Ann.Rev.Nucl.Sci(2008)).



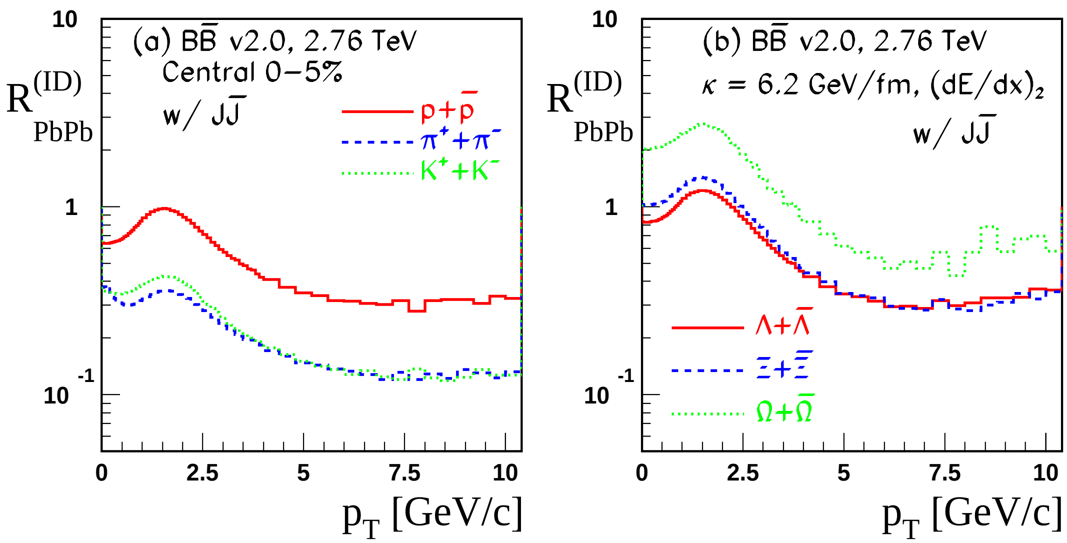
The model predict that these ratios does not depend strongly on energy and centrality at the LHC. The baryon/meson anomaly will persist up to high p_T = 10 GeV/c.

Baryon anomalous production (2)

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



For $p + p$ collisions at the Tevatron the model predict an increase of the hyperons yields with increasing strangeness content, Λ^0 (*uds*), Ξ^- (*dss*), and Ω(*sss*).



The $R_{\mathrm{PbPb}}^{\mathrm{ID}}(p_T)$ 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 $J\bar{J}$ 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 $qq\overline{qq}$ pair creation rates and strangeness suppression factors. SCF, therefore, may modify the fragmentation processes with a result in an increase of (strange)baryons.
- We show that baryon/meson anomaly manifest in baryon-to-meson ratios as well as in distinct patterns of meson and baryon suppression and persist up to high p_T ($p_T < 10$ GeV/c).
- We show also that the $R^{\rm ID}_{\rm PbPb}(p_T)$ 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 LHC measurements 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.