
Anomalous baryon production in $p + p$ and Pb+Pb collisions at the LHC.

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Abstract

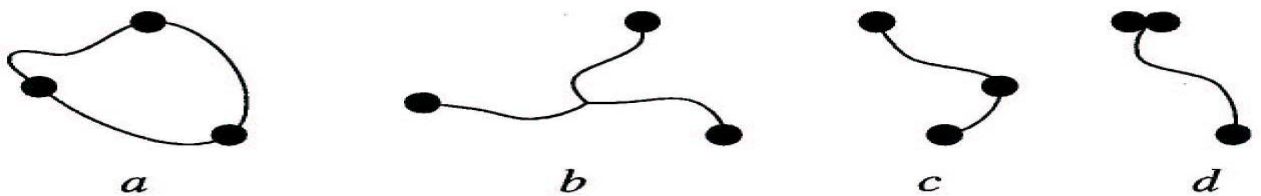
With the **HIJING/B \bar{B} v2.0** event generator, we explore the phenomenological consequences of the enhanced "in medium" **strong longitudinal color field (SCF)** and of (gluonic) baryon-anti-baryon junctions, **J \bar{J} loops**. This analysis focuses on $p+p$ collisions at $\sqrt{s_{NN}} = 0.900, 2.36$ and 7 TeV and on central Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ 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 pseudorapidity densities $(2dN_{ch}/d\eta)/N_{part}$ and especially the hadron **flavor dependence (mesons and baryons)** of the $R_{AA}(p_T)$ 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{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

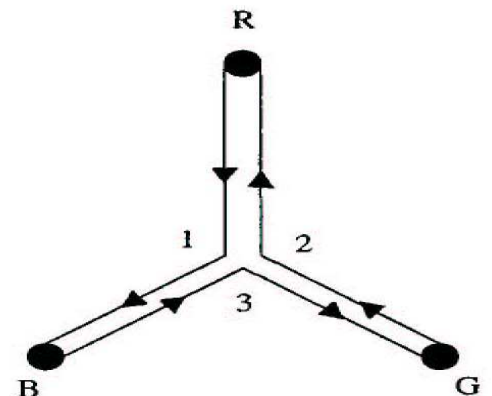
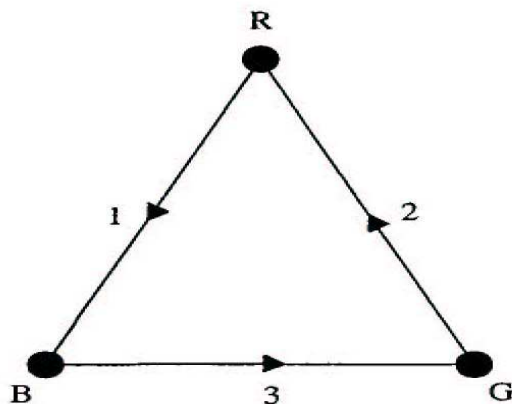
- Interesting open issues at RHIC and LHC energies include:
 - baryon charge can be carry by quark and(or) gluon?.
 - net-baryon rapidity distributions (?)
 - jet quenching (parton energy loss in a medium)
- (Multi)strange particles are of great interest. Their relative enhancement in central heavy ion 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{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{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{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

$$\sigma_{\text{jet}} = \int_{p_0^2}^{s/4} dp_T^2 dy_1 dy_2 \frac{1}{2} \frac{d\sigma_{\text{jet}}}{dp_T^2 dy_1 dy_2},$$
$$\frac{d\sigma_{\text{jet}}}{dp_T^2 dy_1 dy_2} = K \sum_{a,b} x_1 f_a(x_1, p_T^2) x_2 f_b(x_2, p_T^2) \frac{d\sigma^{ab}(\hat{s}, \hat{t}, \hat{u})}{d\hat{t}}$$

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 $p_0 = 2 \text{ GeV}/c = \text{constant}$ 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 $p_0(s) = 0.832 \sqrt{s_{\text{NN}}}^{0.191} \text{ GeV}/c$ 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{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

$$(dE_q/dx) = 1 \text{ GeV/fm and } \lambda_q = 2 \text{ fm};$$

(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); $n_{\text{LHC}}^{\text{ch}} = 2.2n_{\text{RHIC}}^{\text{ch}}$ at mid- η .

Therefore, the energy loss increase by a factor of ≈ 2.0 at the LHC.

For a quark jet at the LHC:

$$(dE_q/dx) \approx 2 \text{ GeV/fm and mfp } \lambda_q \approx 1 \text{ fm}.$$

For a gluon jet $(dE_g/dx) = 2(dE_q/dx)$ and mfp $\lambda_g = 0.5\lambda_q$.

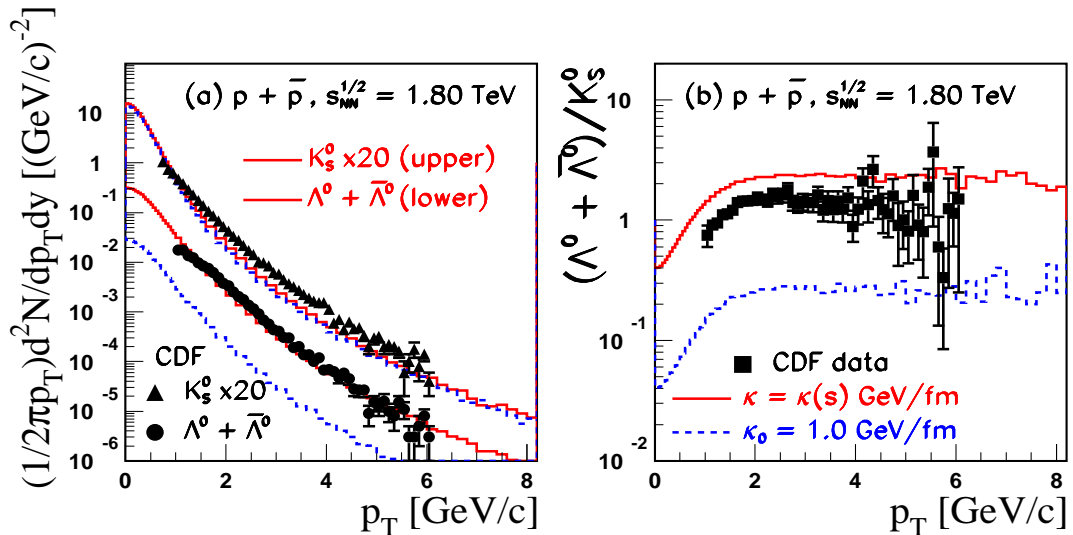
Throughout this analysis we will consider the results with two sets of parameters for hard interactions:

$$(dE/dx)_1, \text{ i.e., } K = 1.5; (dE_q/dx) = 1 \text{ GeV/fm; } \lambda_q = 2 \text{ fm}$$

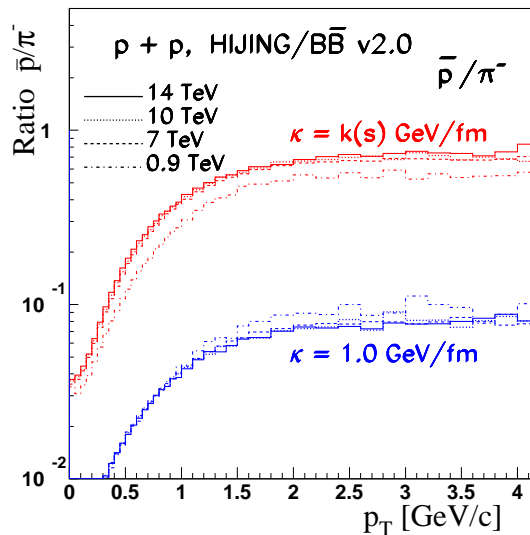
$$(dE/dx)_2, \text{ i.e., } K = 1.5; (dE_q/dx) = 2 \text{ GeV/fm; } \lambda_q = 1 \text{ fm}.$$

p+p Minimum bias.

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



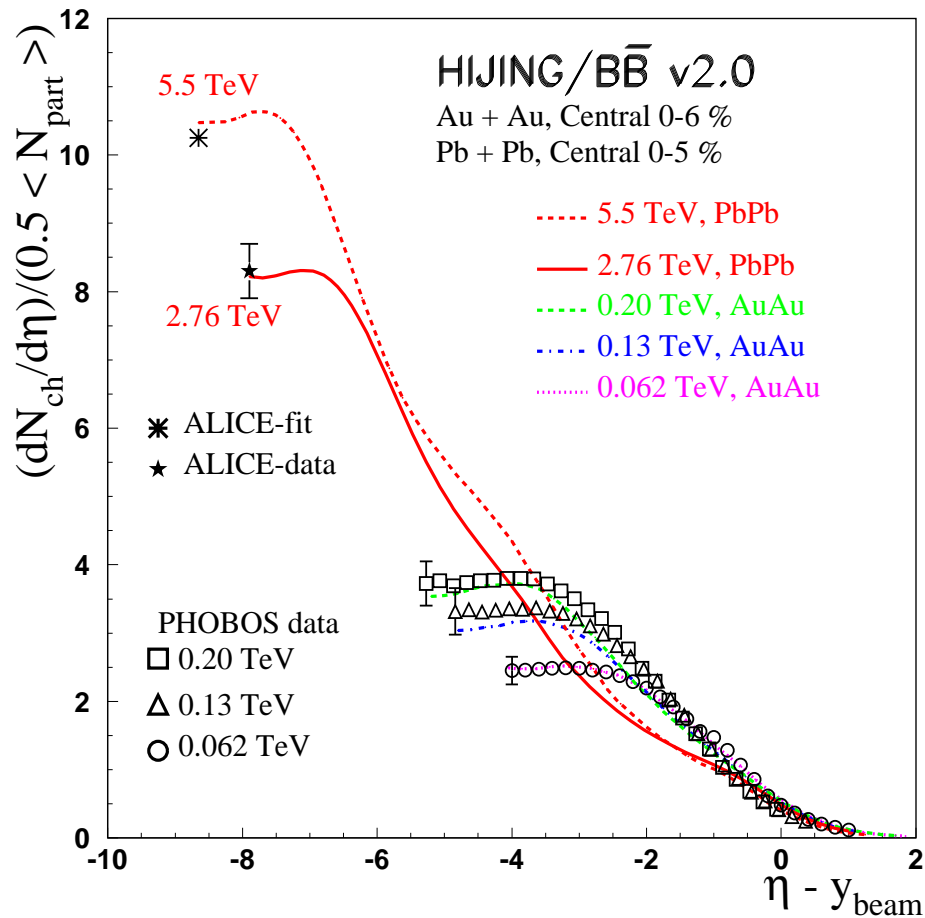
The ratio $(\Lambda + \bar{\Lambda})/K_s^0$ from $p + p$ collisions at $\sqrt{s_{NN}} = 1.8$ TeV is better described by including **JJ loops** and **SCF** with $\kappa(s) = 2.45$ GeV/fm.



The ratio \bar{p}/π^- : 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

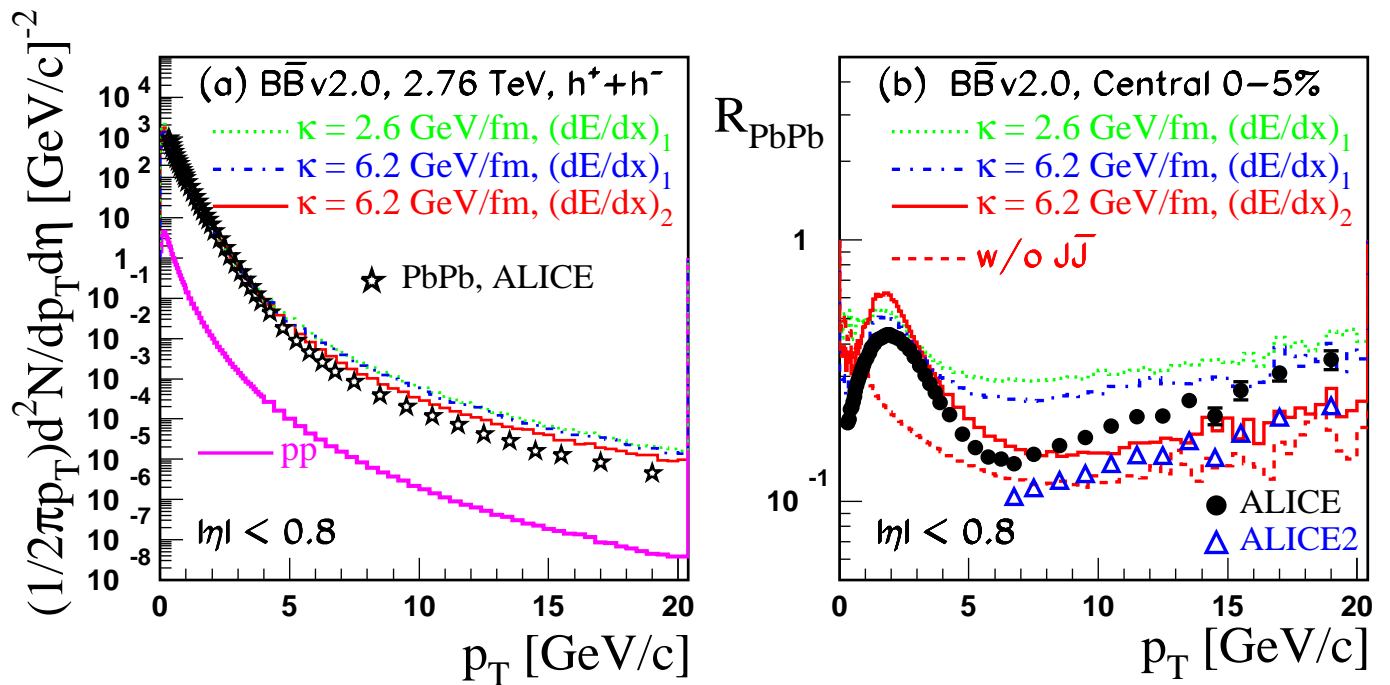


Our model predicts ≈ 8.4 produced charged hadrons per participant pair in central (0-5%) Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-pseudorapidity. This value is higher than those obtained by requiring **limiting fragmentation**. Our calculations show that at RHIC energies the model predict 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} .

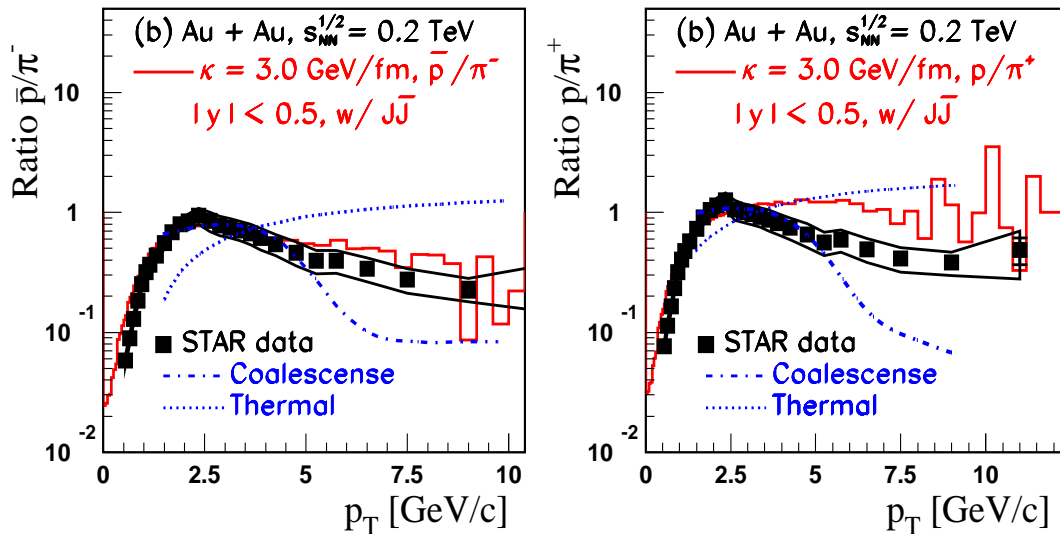


In medium modification of NMF R_{PbPb} , is mainly caused by the (mini)jet quenching suffered by partons while transverse the plasma due to collisions and the radiation of gluons, before they fragment, and the nuclear shadowing.

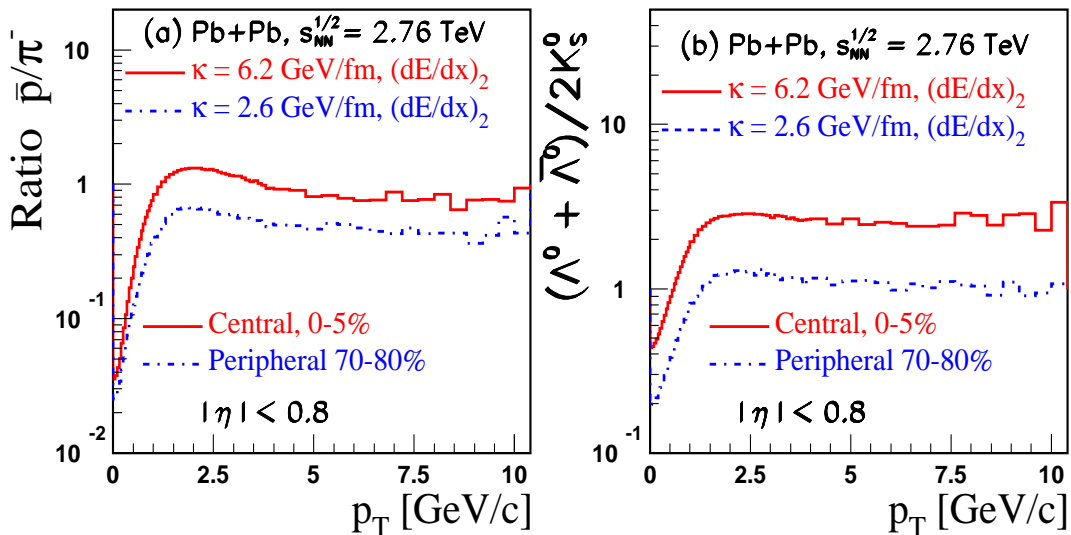
The observed shape with a maximum at approximately $p_T = 2$ GeV/c in the region of low $p_T < 6$ GeV/c can be explained as a specific interplay between non-perturbative (SCF effects) and perturbative ($J\bar{J}$ dynamical loops) mechanisms contribution. The scenario without $J\bar{J}$ loops strongly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



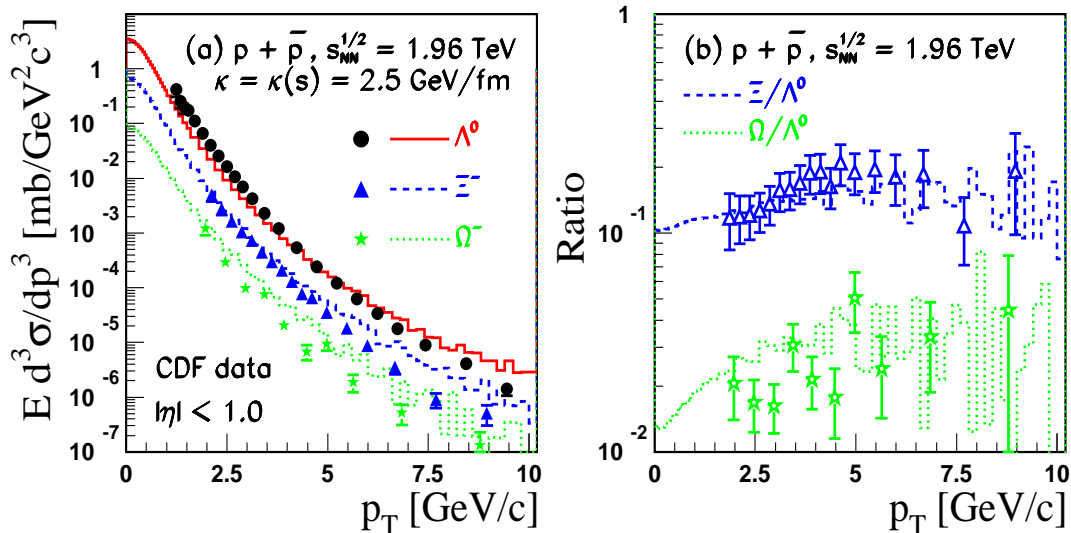
At RHIC energies the model provide an **alternative description** to models based on **constituent quark coalescence** (R. J. Fries, PRC(2003), Ann.Rev.Nucl.Sci(2008)).



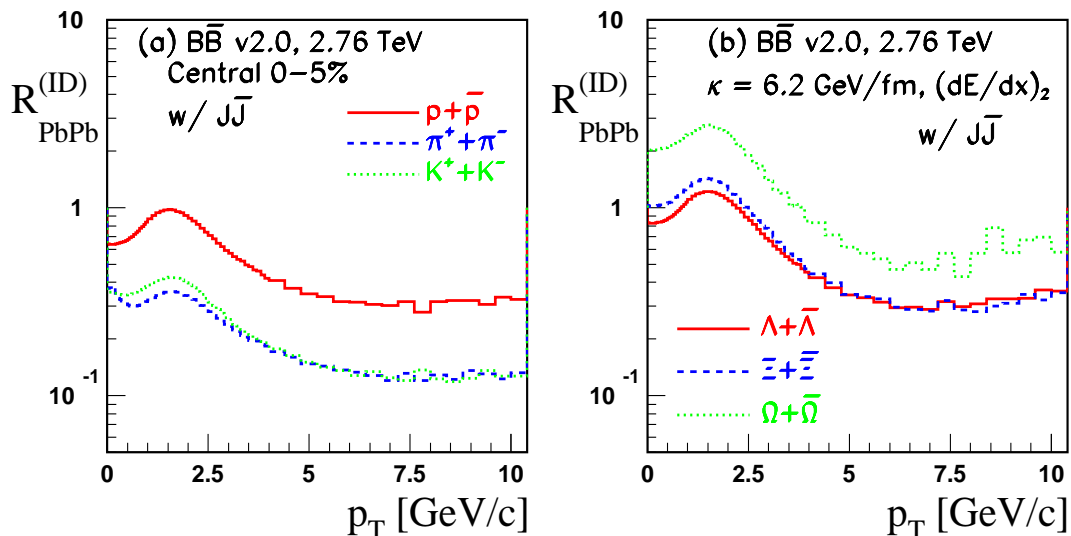
The model predict that these ratios does not depend strongly on energy and **centrality** at the LHC. The baryon/meson anomaly will persist up to high $p_T = 10$ GeV/c.

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 $\Omega(sss)$.



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

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 $qq\bar{q}\bar{q}$ 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 $R_{PbPb}^{ID}(p_T)$ 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**.