Experimental Evidences of Strong Color Field Effects in High-Energy pp Collisions*

J. Barrette, V. Topor Pop, A. Warburton
McGill University

M. Gyulassy
Columbia University

* Work supported by NSERC and the US Department of Energy
Introduction

- The LHC is designed to discover what lies beyond the TeV scale probed at the Tevatron.
- The precision of the physics description provided by simulation calculations is critical for the understanding of LHC data and identification of new physics.
- It is thus important that one has in p+p collisions a complete understanding of the reaction mechanism including the interplay of non-perturbative and to perturbative QCD phenomena.
- This is also important to provide a good baseline in the study of heavy-ion collisions.
Introduction

- In string fragmentation phenomenology implemented in HIGING/BB v2.0, it has been shown that Strong Color Field is a possible source of novel baryon/meson physics in the region of RHIC energy (both in H-I and p+p collisions)
  - Topor Pop, J.B., Gyulassy, Phys. Rev. Lett. 102, 232302 (2009)

- Is strong color field an important soft mechanism of particle production at higher energy i.e. LHC energy
  - What would be its energy dependence?
  - What would be the experimental observables sensitive to SCF effects?
In the Schwinger mechanism for static field the probability of pair creation is given by

$$\frac{dN}{dt d^3x} = \frac{\kappa^2}{4\pi^3} \exp\left(-\pi m^2 / \kappa\right)$$

$$\kappa = eE \approx 1\text{ GeV} / \text{fm}$$

Gives a ratio of production rate (e.g. heavy quark to light quark)

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

Reaction dynamics induced a strong time dependence of the strong color field that can be described by an effective string tension ($\kappa_{\text{eff}}$)

$$\gamma^Q_{\infty}(\kappa_{\text{eff}}) = \gamma^Q(\tau)$$

Nuclear Modification Factor in Au+Au at RHIC

\[ R_{AA}(p_T) = \frac{d^2N_{AA}/dydp_T}{<N_{\text{coll}}>/d^2N_{pp}/dydp_T} \]

Particle $p_t$ distribution in $p+p$ at RHIC energy (200 GeV)

Nuclear Modification Factor in Au+Au at RHIC

Charged-Particle Central Pseudorapidity Density

\[ \kappa(s) = \kappa_0 \left( \frac{s}{s_0} \right)^{0.06} \quad \text{with} \quad s_0 = 1 \text{GeV}^2 \quad \text{and} \quad \kappa_0 = 1 \text{GeV} / \text{fm} \]

\[ \sigma_{\text{tot}}(s) = \sigma_{\text{elas}}(s) + \sigma_{sd}(s) + \sigma_{dd}(s) + \sigma_{nd}(s) \]

\[ \begin{array}{cc}
\text{INEL} & 100 \quad 1.74 \\
1000 \quad 2.3 \\
1000 \quad 3.0 \\
\end{array} \]

NSD
Charged-Particle Pseudorapidity Density

(a) $p + \bar{p}$, $s_{NN}^{1/2} = 1.8$ TeV, NSD
- $\kappa = \kappa(s)$ GeV/fm, 1.8 TeV
- $\kappa = 1.0$ GeV/fm, 1.8 TeV
- CDF 1.8 TeV
- CDF 0.63 TeV
- $0.63$ TeV, $pp$

(b) $p + p$, $s_{NN}^{1/2} = 0.9$ TeV, NSD
- $\kappa = \kappa(s)$ GeV/fm
- $\kappa = 1.0$ GeV/fm
- ALICE 0.9 TeV
- CMS 0.9 TeV

(c) $p + p$, $s_{NN}^{1/2} = 2.36$ TeV, NSD
- $\kappa = \kappa(s)$ GeV/fm
- $\kappa = 1.0$ GeV/fm
- ALICE 2.36 TeV
- CMS 2.36 TeV

(d) $p + p$, $s_{NN}^{1/2} = 7$ TeV, NSD
- $\kappa = \kappa(s)$ GeV/fm
- $\kappa = 1.0$ GeV/fm
- CMS 7 TeV
Baryon to Meson Ratios in p+p

(a) $p + \bar{p}$, $s_{NN}^{1/2} = 0.54$ TeV

- $\kappa = \kappa(s)$ GeV/fm
- $\kappa_0 = 1.0$ GeV/fm

(b) $p + \bar{p}$, $s_{NN}^{1/2} = 1.8$ TeV

- $\kappa = \kappa(s)$ GeV/fm
- $\kappa_0 = 1.0$ GeV/fm

- UA2 data
- E735 data

- E735 data ($-1.0 < \eta < 1.0$)
Strange Baryon to Meson Ratios

(a) $p + \bar{p}$, $s_{NN}^{1/2} = 1.80$ TeV

(b) $p + \bar{p}$, $s_{NN}^{1/2} = 1.80$ TeV

- $\kappa = \kappa(s)$ GeV/fm
- $\kappa_0 = 1.0$ GeV/fm

CDF data

$\frac{(\Lambda^0 + \bar{\Lambda}^0)/K_S^0}{\Lambda^0 + \bar{\Lambda}^0}$

$\frac{d^2N/dp_Tdy}{[GeV/c]^2}$

- $K_S^0 \times 20$ (upper)
- $\Lambda^0 + \bar{\Lambda}^0$ (lower)

Mid-rapidity transverse momentum ratios

Ratio extracted from published min. bias spectra fit parameterizations (1-sigma parameter variations)

- (UA1) $p + \bar{p}$ @ 630 GeV
- (CDF) $p + \bar{p}$ @ 1800 GeV
- PYTHIA: (1M) $p + p$ @ 14 TeV


CAP Congress 2010
Predicted Baryon to Meson Ratios at the LHC

\[ \kappa = \kappa(s) \text{ GeV/fm} \]

- 7 TeV (X 100)
- 2.36 TeV (X 10)
- 0.9 TeV
- 0.63 TeV (X 0.01)

\[ \left( \frac{1}{2\pi p_T} \right)^2 \frac{d^2 N_{ch}}{dp_T d\eta} = \text{[GeV/c]}^2 \]

- CMS, 7 TeV
- CMS, 2.36 TeV
- CMS, 0.9 TeV
- UA1, 0.9 TeV
- ATLAS, 0.9 TeV
- CDF, 0.63 TeV

\[ p_T \text{ [GeV/c]} \]
Multiplicity distributions

(a) $p + p$, $s_{NN}^{1/2} = 0.9$ TeV

- $\kappa = \kappa(s)$ GeV/fm
- $\kappa_0 = 1.0$ GeV/fm

(b) $p + \bar{p}$, $s_{NN}^{1/2} = 1.96$ TeV

- $\kappa = \kappa(s)$ GeV/fm
- $\kappa = 3.0$ GeV/fm

- ATLAS $|\eta| < 2.5$
- $p_T > 0.5$ GeV/c

- CDF data $|\eta| \leq 1.0$
- $p_T > 0.4$ GeV/c
(Mini)Jet Decomposition of Multiplicity Distributions

(a) $p + \bar{p}, s_{NN}^{1/2} = 0.9$ TeV

$\bar{B}B v2.0, \kappa = \kappa(s)$ GeV/fm

\(\nabla\) UA5 data

Probability $P(N_{ch})$

$r$ $p_T > 0$

Multiplicity $N_{ch}$

(b) $p + \bar{p}, s_{NN}^{1/2} = 0.9$ TeV

$|\eta| < 1.5$

$p_T > 0$

Probability $P(N_{ch})^*$

$N_{jet} = 0$, $N_{jet} = 1$

$N_{jet} > 1$

Sum

$\nabla$ UA5 data

Multiplicity $N_{ch}^*$
Summary

- HIJING/BB with SCF modeled here by an increased effective string tension, describe well the energy dependence of charged particle production in p+p reactions up to LHC energies.
- SCF explains the high baryon to meson ratios observed not only in H-I collisions but in p+p at CDF energies.
- It is predicted this high ratio will persist at LHC energies.
Outlook

- This effect should be flavor dependent and thus study of heavy quark production could provide a more definitive signature and a better test of such an effect.

Outlook

- Our analysis suggests that one should look at high multiplicity events and high $p_t$ distributions for new physics.
  - High $p_t$ distributions may be interpreted as possible “jet quenching” as seen in H-I
  - High multiplicity events may reveal new collective phenomena.