Spatial Wilson loops in high-energy heavy-ion collisions

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Collisions of heavy ions at high energies provide opportunity to study non-linear dynamics of strong QCD color fields[1)]. The field of a very dense system of color charges at rapidities far from the source is determined by the classical Yang-Mills equations with a recoilless current along the light cone[2)]. It consists of gluons characterized by a transverse momentum p_T on the order of the density of valence charges per unit transverse area Q_s^2; this saturation momentum scale separates the regime of non-linear color field interactions at $p_T \lesssim Q_s$ or distances $r \gtrsim 1/Q_s$ from the perturbative regime at $p_T \gg Q_s$.

Right after the impact strong longitudinal chromomagnetic fields $B_z \sim 1/g$ develop due to the fact that the individual projectile and target fields do not commute[3)]. They fluctuate according to the random local color charge densities of the valence sources. Here we show that magnetic loops

$$W_M(R) = \frac{1}{N_c}\left\langle \mathrm{tr}\,\mathcal{P}\exp\left(ig\oint dx^i A^i\right)\right\rangle \qquad (1)$$

effectively exhibit area law scaling, $W_M(R) \sim e^{-\sigma\,\pi R^2}$, and we compute the magnetic string tension σ. Furthermore, we argue that at length scales $\sim 1/Q_s$ the field configurations might be viewed as uncorrelated Z(N) vortices. We also compare to the expectation value of the Z(N_c) part of the loop; thus, for two colors we compute

$$W_M^{Z(2)}(R) = \left\langle \mathrm{sgn}\,\mathrm{tr}\,\mathcal{P}\exp\left(ig\oint dx^i A^i\right)\right\rangle \qquad (2)$$

where sgn() denotes the sign function.

The field in the forward light cone immediately after a collision[4)], at proper time $\tau \equiv \sqrt{t^2 - z^2} \to +0$, is given by $A^i = \alpha_1^i + \alpha_2^i$. In turn, before the collision the individual fields of projectile and target are 2d pure gauges,

$$\alpha_m^i = \frac{i}{g} U_m\, \partial^i U_m^\dagger \quad , \quad \partial^i \alpha_m^i = g\rho_m \ , \qquad (3)$$

where $m = 1, 2$ labels projectile and target, respectively, and U_m are SU(N) matrices. Note that for a non-Abelian gauge group, the sum A^i of two pure gauges is not a pure gauge, so $W_M \neq 1$.

The large-x valence charge density ρ is a random variable. For a large nucleus, the effective action describing color charge fluctuations is quadratic[2)], $S_{\rm eff} = \rho^a(\mathbf{x})\rho^a(\mathbf{x})/2\mu^2$. The variance of color charge fluctuations determines the saturation scale $Q_s^2 \sim g^4\mu^2$. The brackets in eq. (1) denote an average over the fluctuating color charges $\rho_1(\mathbf{x})$, $\rho_2(\mathbf{x})$ of the two charge sheets corresponding to projectile and target, respectively.

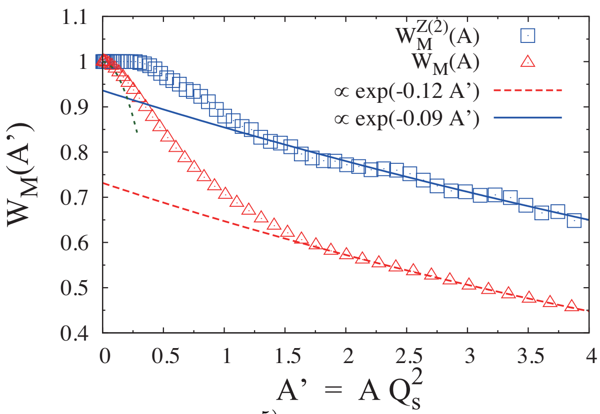

Fig. 1. Expectation value[5)] of the magnetic flux loop right after a collision of two nuclei (time $\tau = +0$) as a function of its area $A' \equiv A\,Q_s^2$. Symbols show numerical results for $SU(2)$ Yang-Mills on a 4096^2 lattice; the lattice spacing is set by $g^2\mu_L = 0.0661$. The lines represent fits over the range $4 \geq A' \geq 2$.

In fig. 1 we show numerical results for W_M immediately after a collision. It exhibits area law behavior for loops larger than $A \gtrsim 2/Q_s^2$. The corresponding "magnetic string tension" is $\sigma_M/Q_s^2 = 0.12(1)$. The area law indicates uncorrelated magnetic flux fluctuations through the Wilson loop and that the area of magnetic vortices is rather small, their radius being on the order of $R_{\rm vtx} \sim 0.8/Q_s$. We do not observe a breakdown of the area law up to $A \sim 4/Q_s^2$, implying that vortex correlations are small at such distance scales. Also, restricting to the Z(2) part reduces the magnetic flux through small loops but σ_M is comparable to the full SU(2) result.

References

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