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Schwinger-like pair production of baryons in electric field

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In this Letter we evaluate the probability rate for the Schwinger production of baryons in an external electric field in the worldline instanton approach in holographic QCD. The new exponentially suppressed processes in a constant electric field involving the composite worldline instantons are suggested which include the non-perturbative decay of a neutron into proton and charged meson and the spontaneous production of $p\bar{n}\pi^-$ and $n\bar{p}\pi^+$ states.

The worldline instanton method is similar to the one used in [1] to calculate the rate of Schwinger pair production and in [2] to describe monopole pair production in weak magnetic field. The holographic Schwinger effect has been discussed in the $N=4$ SYM in [3] and has been extended for non-conformal backgrounds in [4–6] for the creation of the massive quark-antiquark pair.

We consider the approximation when baryon is the point-like solitonic object and we evaluate the action on the circular worldline instanton trajectory in the leading approximation. We neglect nucleon-antinucleon interaction due to massive mesons exchanges. In the Witten–Sakai–Sugimoto (WSS) model [7, 8] model at $T=0$ the holographic background looks as the cigar-like geometry involving coordinates (u,τ) supplemented with sphere S^4 and four-dimensional Minkowski space-time. Corresponding metric is

$$ds^2=\left(\frac{u}{R}\right)^{3/2}(\eta_{\mu\nu}dx^\mu dx^\nu+f(u)d\tau^2)+ \\ +\left(\frac{R}{u}\right)^{3/2}\left(\frac{du^2}{f(u)}+u^2d\Omega_4^2\right),\quad f(u)=1-\frac{u_k^3}{u^3}. \quad (1)$$

The flavor degrees of freedom are introduced by adding N_f $D8-\bar{D}8$ branes extended along all coordinates but τ. Holographic baryon can be considered as the baryonic vertex with the N_c string attached [9]. In terms of the 5d Yang–Mills (YM) theory with the flavor gauge group the baryon is the instanton solution localized in (z,x_1,x_2,x_3) coordinates.

Since we consider the baryon-antibaryon pair we encounter the new situation when some part of N_c strings can be long and connect instanton and antiinstanton. We shall consider three different situations when all strings from vertex are short, when all strings connect the instanton and antiinstanton and the case when only part of the strings are stretched between the instanton-antiinstanton pair. The production rate in the leading approximation reads as

$$\omega\propto\exp(-\frac{M^2}{eE_{\text{eff}}}), \quad (2)$$

where effective electric field is $E_{\text{eff}}=E-kT_{\text{str}}$, k is the number of long strings. The process is possible only for $E_{\text{eff}}>0$.

Consider the Schwinger effect for baryon involving a heavy quark. In WSS model the quark mass can be described as separation between the flavor D8 branes. The Schwinger process probability in the weak field limit is

$$w\sim e^{-S}=\exp\left(-\frac{\pi M_1^2}{qE}+A\frac{qE}{M_1}\right), \quad (3)$$

where u_q is the brane radial coordinate and $A = \frac{g_{YM}^2N_c}{4\pi M_{kk}}\ln\left(\frac{\alpha u_q}{u_k}\right)$.

We suggest the non-perturbative process in which the neutron decays into a proton and charged meson, π^--meson or ρ^--meson, and then charged meson weakly decays into the final state, see Fig. 1 for corresponding instanton trajectory.

The action evaluated at the saddle point world-line instanton solution reads as

$$S_{\text{inst}}=m_\pi L_\pi+M_pL_p-eE(\text{Area})-M_nH, \quad (4)$$

where L_π, L_p are the lengths of the corresponding segments of proton and meson trajectories and H is the distance between the junction points in Euclidean time

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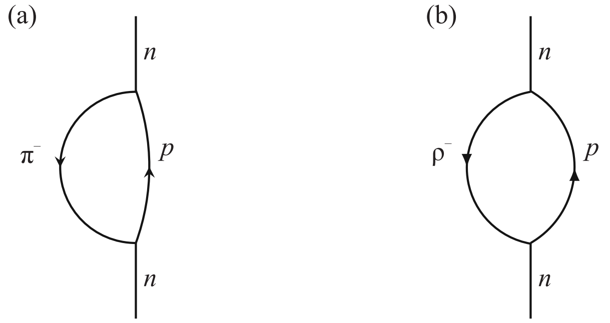

Fig. 1. Bounce for the neutron decay: (a) – via π^- channel; (b) – via ρ^- channel

t_E. In the leading approximation taking into account that $m_\pi << M_p$ the action can be approximated by

$$S^0_{\mathrm{inst}} \propto \frac{m_\pi^2}{2eE}. \tag{5}$$

More accurate saddle-point action for the composite worldline instanton when the ρ-meson propagates in the composite worldline instanton is

$$S_{\mathrm{inst}} = \frac{m_\rho^2}{eE} \arccos \frac{M_n^2 + m_\rho^2 - M_p^2}{2m_\rho M_n} + \\ + \frac{M_p^2}{eE} \arccos \frac{M_n^2 - m_\rho^2 + M_p^2}{2M_p M_n} - \\ - \frac{m_\rho M_n}{eE} \sqrt{1 - \left(\frac{M_n^2 + m_\rho^2 - M_p^2}{2m_\rho M_n}\right)^2}. \tag{6}$$

Consider the following composite worldline instanton: the proton-antiptoton trajectory gets started at some initial point, there is the junction at which proton trajectory gets glued with the neutron and π^+ trajectories. In the case of π^- involved into the composite instanton the deformed segment of the circle is small hence the probability in the leading approximation has the form

$$\omega \propto \exp(-\frac{M_p^2}{eE}). \tag{7}$$

If the ρ^- is involved in the composite instanton the trajectory is modified and the probability reads as

$$\omega \propto \exp\Bigg(- \frac{\pi(M_p^2 + m_\rho^2)}{eE} - \frac{M_p M_n}{eE} \times \\ \times \sqrt{1 - \left(\frac{M_p^2 - m_\rho^2 + M_n^2}{2M_p M_n}\right)^2} + \frac{M_p^2}{eE} \times \\ \times \arccos \frac{M_p^2 - m_\rho^2 + M_n^2}{2M_p M_n} + \frac{m_\rho^2}{eE} \arccos \frac{m_\rho^2 - M_p^2 + M_n^2}{2m_\rho M_n}\Bigg). \tag{8}$$

At $t_E = 0$ the solution gets rotated from the Euclidean to Minkowski space-time. The final state involves the antiproton, neutron and meson with the positive charge.

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