Potential Analysis in Holographic Schwinger Effect

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Abstract : We consider the Schwinger effect from the viewpoint of quark-anti quark potential.
The potential analysis gives a strong support for Semenoff-Zarembo's proposal from another perspective.

★What is the Schwinger effect ? [Schwinger, PR 82(1951) 664]

- Pair creations of electron and positron in an external electric field.

  Pair creations of particle and anti-particles in an external field are said ubiquitously.

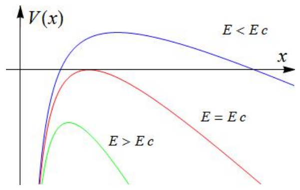
- Non-perturbative phenomenon

  The Schwinger effect is a tunneling process with the potential barrier $V(x) = 2m - eEx - \dfrac{\alpha_s}{x}$.

- Critical electric field

  The potential barrier decreases gradually as E becomes large. When $E = E_c$, the potential barrier vanishes.

  ➡ E_c is a critical electric field. However, this is not confirmed in QED.



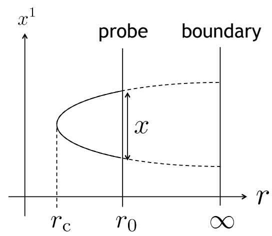
★Pair creation in N=4 SYM and Potential Analysis [YS, K. Yoshida, JHEP 08 (2013) 002 [arXiv:1304.7917]]

- To argue the Schwinger effect, a U(1) gauge field should be introduced. It is necessary to spontaneously break SU(N+1) to SU(N) x U(1).
- Quark : SU(N) fundamental rep., U(1) charge: $g_{\rm YM}$

The potential barrier vanishes when $E \simeq 0.70 \dfrac{2\pi m^2}{\sqrt{\lambda}}$ with $\alpha_s = 4\pi^2\sqrt{\lambda}/\Gamma(1/4)^4$.

The critical electric field is not the same as the one of DBI result. $\left(E_{\rm DBI} = \dfrac{2\pi m^2}{\sqrt{\lambda}},\ S_{\rm DBI} = -T_{\rm D3}\dfrac{r_0^4}{L^4}\int {\rm d}^4x\sqrt{1 - \dfrac{(2\pi\alpha')^2 L^4}{r_0^4}E^2} \right)$

We revisit this issue. The probe is put near the horizon! cf. [Semenoff-Zarembo, PRL 107 (2011) 171601]



The metric of $AdS_5 \times S^5$:

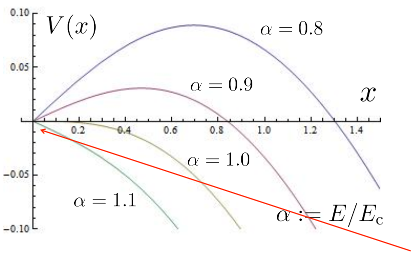
$$ {\rm d}s^2 = \frac{r^2}{L^2}\eta_{\mu\nu}{\rm d}x^\mu {\rm d}x^\nu + \frac{L^2}{r^2}{\rm d}r^2 + L^2 {\rm d}\Omega_5^2 $$

The distance between quark and anti quark:

$$ x = \frac{2L^2}{r_0 a}\int_1^{1/a} \frac{{\rm d}y}{y^2\sqrt{y^4-1}} \qquad \left(a := \frac{r_c}{r_0} \right) $$

The Coulomb potential + the static energy:

$$ V_{\rm CP+SE} = 2T_{\rm F} r_0 \int_1^{1/a} {\rm d}y \frac{ay^2}{\sqrt{y^4-1}} $$



The potential barrier vanishes when $\alpha = 1.0$ **!!** Also analytically shown.

Finite!! ➡ The theory is not an usual gauge theory but a non-linear QED.

★Potential Analysis in confining background [YS, K. Yoshida, arXiv:1306.5512]

The metric (AdS-Soliton): [G. T. Horowitz, R. C. Myers, PRD 59 (1998) 026005]

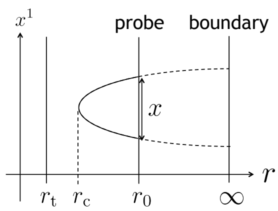
$$ {\rm d}s^2 = \frac{r^2}{L^2}\left(\eta_{\mu\nu}{\rm d}x^\mu{\rm d}x^\nu + f(r)({\rm d}x^3)^2\right) + \frac{L^2}{r^2}f(r)^{-1}{\rm d}r^2 + L^2{\rm d}\Omega_5^2\,, \quad f(r) = 1 - \frac{r_t^4}{r^4} $$

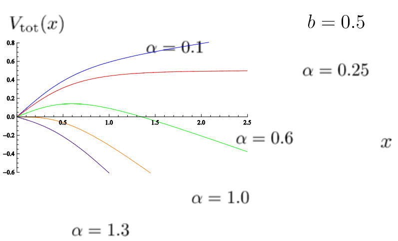
The distance between quark and anti quark:

$$ x = \frac{2L^2}{r_0 a}\int_1^{1/a} \frac{{\rm d}y}{\sqrt{(y^4-1)(y^4-(b/a)^4)}} \qquad \left(a := \frac{r_c}{r_0}\,,\quad b := \frac{r_t}{r_0} \right) $$

The potential energy + the static energy:

$$ V_{\rm PE+SE} = 2T_{\rm F} r_0 \int_1^{1/a} {\rm d}y \frac{ay^4}{\sqrt{(y^4-1)(y^4-(b/a)^4)}} $$





Two critical electric fields.

(1) The orange line($\alpha = 1.0$):

The potential barrier vanishes. This behaviour is the same as the previous case.

(2) The red line($\alpha = b^2$):

The potential barrier becomes flat around $x \to \infty$.
The electric field is balanced with the confining string tension $T_{\rm F}\left(\dfrac{r_0}{L}\right)^2 b^2$.