The open string pair production and its detection

Jian-Xin Lu

The Peng Huanwu Center for Fundamental Theory (PCFT)
and
The Interdisciplinary Center for Theoretical Study (ICTS)
University of Science & Technology of China

2020 NCTS Dark Physics Workshop, Hsinchu

January 10, 2020

The talk is based on the following papers:

- J. X. Lu, B. Ning, R. Wei and S. S. Xu, "Interaction between two non-threshold bound states, "Phys. Rev. D **79**, 126002 (2009)
- J. X. Lu and S. S. Xu, "The Open string pair-production rate enhancement by a magnetic flux," JHEP **0909**, 093 (2009)
- J. X. Lu and S. S. Xu, "Remarks on D(p) and D(p-2) with each carrying a flux," Phys. Lett. B **680**, 387 (2009)
- J. X. Lu,"Magnetically-enhanced open string pair production," JHEP **1712**, 076 (2017), [arXiv:1710.02660 [hep-th]]
- J. X. Lu, "Some aspects of interaction amplitudes of D branes carrying worldvolume fluxes," Nucl. Phys. B **934**, 39 (2018)
- J. X. Lu, "A possible signature of extra-dimensions: The enhanced open string pair production," Phys. Lett. B **788**, 480 (2019)
- Q. Jia and J. X. Lu,"Remark on the open string pair production enhancement," Phys. Lett. B **789**, 568 (2019)
- Q. Jia, J. X. Lu, Z. Wu and X. Zhu, "On D-brane interaction & its related properties," arXiv:1904.12480 [hep-th].
- J. X. Lu, "A note on the open string pair production of the D3/D1 system," JHEP **1910**, 238 (2019), [arXiv:1907.12637 [hep-th]]

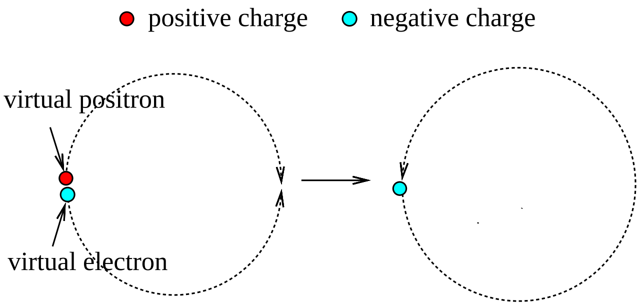
Outline

- A brief introduction/motivation
- The D3/D1 system
- Discussion & Implication

QED Vacuum Fluctuations

VACUUM FLUCTUATION!

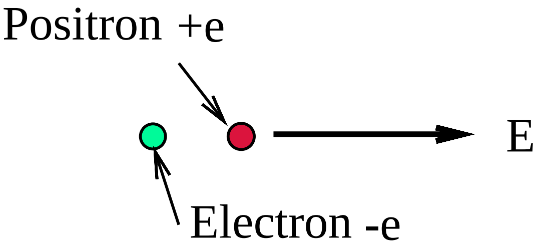
An anti-charge moving forward in time equivalent to a charge moving backward in time



$$(\delta t \sim 10^{-21} s)$$

QED Vacuum Fluctuations

Applying a constant E to QED vacuum, there is certain probability to create real electron and positron pairs from the vacuum fluctuations, called Schwinger pair production (1951).



The pair production rate

$$\mathcal{W}^{(1)} = \frac{(eE)^2}{(2\pi)^2} e^{-\frac{\pi m_e^2}{eE}}. \tag{1.1}$$

The required E can be estimated: $2eE\,\frac{1}{m_e} \approx 2m_e \to E = \frac{m_e^2}{e} \sim 10^{18}\,V/m$

The current lab DC E-field limit: $\sim 10^{10}\,V/m$

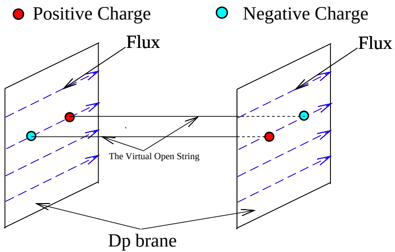
The open string pair production

The natural question to ask is if an analogous process exists in string theory.

The answer is yes and in this talk we will focus on D-branes in Type II string theory.

The open string pair production

The simplest setup for this is to consider two D3 branes, placed parallel at a separation, with each brane carrying collinear electric and magnetic fields.



The open string pair production rate

The open string pair production rate can be computed as (Lu'17)

$$\mathcal{W}^{(1)}_{\rm D3/D3} = \frac{2(eE)(eB)}{(2\pi)^2}\,\frac{\left[\cosh\frac{\pi B}{E}+1\right]^2}{\sinh\frac{\pi B}{E}}\,e^{-\frac{\pi m^2}{eE}}, \qquad (1.2)$$

where E and B are the lab electric and magnetic fields and we have introduced a mass scale

$$m = T_f y = \frac{y}{2\pi\alpha'}. \qquad (1.3)$$

Since $\alpha' eE \sim \alpha' eB \sim 10^{-8} m_e^2/M_s^2 \sim 10^{-21} \ll 1$, so only the lowest open string/anti-open string modes,

$$(8_F + 8_B)_+/(8_F + 8_B)_- \text{ or } (8_F + 8_B)_-/(8_F + 8_B)_+, \qquad (1.4)$$

each having the same mass m, contribute to the above rate.

The open string pair production rate

In other words, the above rate is for the 16 pairs of charge /anti-charge modes.

Since these modes all have the same mass m, due to unbroken SUSY, we expect $m > \mathrm{TeV}$. A detection of the pair production requires either

$$eE \sim m^2 > \mathrm{TeV}^2$$

if $B/E \sim \mathcal{O}(1)$
or $eB \sim m^2$ if $B/E \gg 1$ since now

$$\mathcal{W}^{(1)}_{\mathrm{D3/D3}} \sim \frac{(eE)(eB)}{(2\pi)^2} e^{-\frac{\pi(m^2 - eB)}{eE}}. \quad (1.5)$$

This is impossible since the lab limits

$$eE \sim eB \sim 10^{-8} m_e^2 \sim 10^{-21} \mathrm{TeV}^2 \ll m^2 \sim \mathrm{TeV}^2. \quad (1.6)$$

A possibility of detection

For a potential detection, we need to have

- a non-supersymmetric system of D-branes even in the absence of worldvolume fluxes,
- the corresponding mass scale is comparable to the current lab electric field.

One such system is the D3/D1 (Lu&Xu' 09, Jia et al'19), which has no SUSY and the D1 appears effectively as a stringy scale magnetic such that it can gives a small effective mass scale.

A possibility of detection

To compute the rate, we first need to compute the one-loop open string annulus amplitude between the D3 and D1, placed parallel in the following manner at a separation y,

	0	1	2	3
D1	×	×		
D3	×	×	×	×

with the D3 and D1 carrying their respective dimensionless worldvolume fluxes ($\hat{F} = 2\pi\alpha' F$) as follows

$$\hat{F}_3 = \begin{pmatrix} 0 & \hat{f} & 0 & 0 \\ -\hat{f} & 0 & 0 & 0 \\ 0 & 0 & 0 & \hat{g} \\ 0 & 0 & -\hat{g} & 0 \end{pmatrix}, \qquad \hat{F}'_1 = \begin{pmatrix} 0 & \hat{f}' \\ -\hat{f}' & 0 \end{pmatrix}, \qquad (2.1)$$

where $|\hat{f}|, |\hat{f}'| < 1$ and $|\hat{g}| < \infty$.

A possibility of detection

The amplitude is

$$\Gamma_{3,1} = \frac{2V_2|\hat{f} - \hat{f}'|}{8\pi^2\alpha'} \int_0^\infty \frac{dt}{t}\; e^{-\frac{y^2 t}{2\pi\alpha'}} \frac{[\cosh \pi\nu_1 t - \cos \pi\bar{\nu}_0 t]^2}{\sin \pi\bar{\nu}_0 t \sinh \pi\nu_1 t} \prod_{n=1}^{\infty} Z_n \tag{2.2}$$

where

$$Z_n = \frac{|1 - 2|z|^{2n} e^{-i\pi\bar{\nu}_0 t} \cosh \pi\nu_1 t + |z|^{4n} e^{-2i\pi\bar{\nu}_0 t}|^4}{(1 - |z|^{2n})^4 [1 - 2|z|^{2n} \cosh 2\pi\nu_1 t + |z|^{4n}][1 - 2|z|^{2n} \cos 2\pi\bar{\nu}_0 t + |z|^{4n}]}, \tag{2.3}$$

with $|z| = e^{-\pi t} < 1$. The electric parameter $\bar{\nu}_0$ and the magnetic one ν_1 are related to their respective fluxes as

$$\tanh \pi\bar{\nu}_0 = \frac{|\hat{f} - \hat{f}'|}{1 - \hat{f}\hat{f}'}, \qquad \tan \pi\nu_1 = \frac{1}{|\hat{g}|}, \tag{2.4}$$

where $\bar{\nu}_0 \in [0, \infty)$, $\nu_1 \in [0, 1/2]$.

A possibility of detection

Note that the integrand of the amplitude (2.2) has a factor $\sin \pi \bar{\nu}_0 t$ in its denominator, giving rise to an infinite number of simple poles at $t_k = k/\bar{\nu}_0$ with $k = 1, 2, \cdots$.

This reflects the instability of the system via the open string pair production and the decay rate is given as the residues of the integrand at these simple poles times π per unit D1 worldvolume (Bachas & Porrati'92)

$$\mathcal{W} = \frac{4|\hat{f} - \hat{f}'|}{8\pi^2 \alpha'} \sum_{k=1}^{\infty} \frac{(-)^{k-1}}{k} e^{-\frac{k y^2}{2\pi \alpha' \bar{\nu}_0}} \frac{\left[\cosh \frac{\pi k \nu_1}{\bar{\nu}_0} - (-)^k\right]^2}{\sinh \frac{\pi k \nu_1}{\bar{\nu}_0}} Z_k(\bar{\nu}_0, \nu_1), \tag{2.5}$$

where

$$Z_k(\bar{\nu}_0, \nu_1) = \prod_{n=1}^{\infty} \frac{\left[1 - 2(-)^k |z_k|^{2n} \cosh \frac{\pi k \nu_1}{\bar{\nu}_0} + |z_k|^{4n}\right]^4}{(1 - |z_k|^{2n})^6 \left[1 - 2|z_k|^{2n} \cosh \frac{2\pi k \nu_1}{\bar{\nu}_0} + |z_k|^{4n}\right]}, \tag{2.6}$$

with $|z_k| = e^{-\pi k/\bar{\nu}_0}$.

A possibility of detection

The pair production rate is given by the $k = 1$ term above (Nikishov'70)

$$\mathcal{W}^{(1)}_{D3/D1} = \frac{4|\hat{f} - \hat{f}'|}{8\pi^2\alpha'} e^{-\frac{y^2}{2\pi\alpha'\bar{\nu}_0}} \frac{\left[\cosh\frac{\pi\nu_1}{\bar{\nu}_0} + 1\right]^2}{\sinh\frac{\pi\nu_1}{\bar{\nu}_0}} Z_1(\bar{\nu}_0, \nu_1), \tag{2.7}$$

where

$$Z_1(\bar{\nu}_0, \nu_1) = \prod_{n=1}^{\infty} \frac{\left[1 + 2|z_1|^{2n}\cosh\frac{\pi\nu_1}{\bar{\nu}_0} + |z_1|^{4n}\right]^4}{(1 - |z_1|^{2n})^6 \left[1 - 2|z_1|^{2n}\cosh\frac{2\pi\nu_1}{\bar{\nu}_0} + |z_1|^{4n}\right]}. \tag{2.8}$$

A possibility of detection

We take the D3 as our own world and for simplicity set $\hat{f}' = 0$.

In practice, $\hat{f} = 2\pi\alpha' eE \ll 1$ and $\hat{g} = 2\pi\alpha' eB \ll 1$, from (2.4), we have

$$\bar{\nu}_0 = 2\alpha' eE \ll 1, \quad \nu_1 \sim 1/2 \to \frac{\nu_1}{\bar{\nu}_0} \gg 1. \tag{2.9}$$

So we have from (2.7)

$$\mathcal{W}^{(1)}_{D3/D1} \approx \frac{eE}{2\pi}\, e^{-\frac{\pi m^2_{\rm eff}}{eE}}, \tag{2.10}$$

where we have used $Z_1(\bar{\nu}_0, \nu_1) \approx 1$ and defined an effective mass $m^2_{\rm eff} = m^2 - \nu_1/(2\alpha')$ with $m = y/(2\pi\alpha')$.

A possibility of detection

Make comparisons with the D3/D3 rate (1.2) and the QED rate for massive charged vector (Kruglov'01), assuming all with the same mass m,

$$\begin{aligned}
\mathcal{W}^{(1)}_{D3/D1} &= \frac{eE}{2\pi} e^{-\frac{\pi\left(m^2 - \frac{\nu_1}{2\alpha'}\right)}{eE}}, \\
\mathcal{W}^{(1)}_{D3/D3} &= \frac{2(eE)(eB)}{(2\pi)^2} \frac{\left[\cosh\frac{\pi B}{E} + 1\right]^2}{\sinh\frac{\pi B}{E}} e^{-\frac{\pi m^2}{eE}} \xrightarrow{\frac{B}{E}\gg 1} \frac{(eE)(eB)}{(2\pi)^2} e^{-\frac{\pi(m^2 - eB)}{eE}}, \\
&= 5\mathcal{W}^{(1)}_{\rm scalar} + 4\mathcal{W}^{(1)}_{\rm spinor} + \mathcal{W}^{(1)}_{\rm vector}, \\
\mathcal{W}^{(1)}_{\rm vector} &= \frac{(eE)(eB)}{2(2\pi)^2} \frac{2\cosh\frac{2\pi B}{E} + 1}{\sinh\frac{\pi B}{E}} e^{-\frac{\pi m^2}{eE}} \xrightarrow{\frac{B}{E}\gg 1} \frac{(eE)(eB)}{(2\pi)^2} e^{-\frac{\pi(m^2 - eB)}{eE}} \qquad (2.11)
\end{aligned}$$

The present D3/D1 rate appears to give a unique stringy signature.

A possibility of detection

Most importantly, unlike the rate for D3/D3 or QED rates, the present rate gives a possibility for detection in the following sense:

The lowest string modes define an effective mass $m_{\rm eff}^2 = m^2 - 1/(4\alpha')$ when we take $\hat{g} = 0$. Concretely, if $m \approx 1/(2\sqrt{\alpha'})$, or $y \sim \pi\sqrt{\alpha'}$, giving a small effective $m_{\rm eff}$, we need then only a small $eE \sim m_{\rm eff}^2$ to detect the pair production.

Further, with a small tunable $\hat{g} = 2\pi\alpha' eB \ll 1$, we can check the rate behavior against E and B and this can be used to check the stringy computations.

Implication

Implications: If such a detection, for example as an electric current due to the pair production, is indeed possible,

- it first implies the existence of extra dimensions.
- secondly, it gives a new way to verify the underlying string theory without the need to compactify 10 D to 4D so long the pair production is concerned.

THANK YOU!