Remarks on the open string pair production enhancement

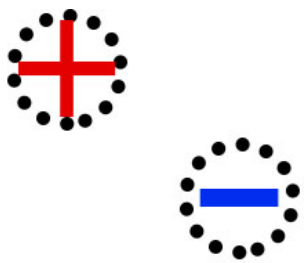
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J.X Lu and Qiang Jia. hep-th/1809.03806

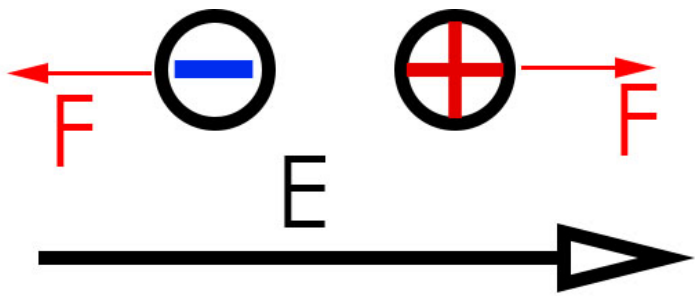
November 5, 2018

Introduction

Schwinger Pair Production[1]



Virtual Pairs

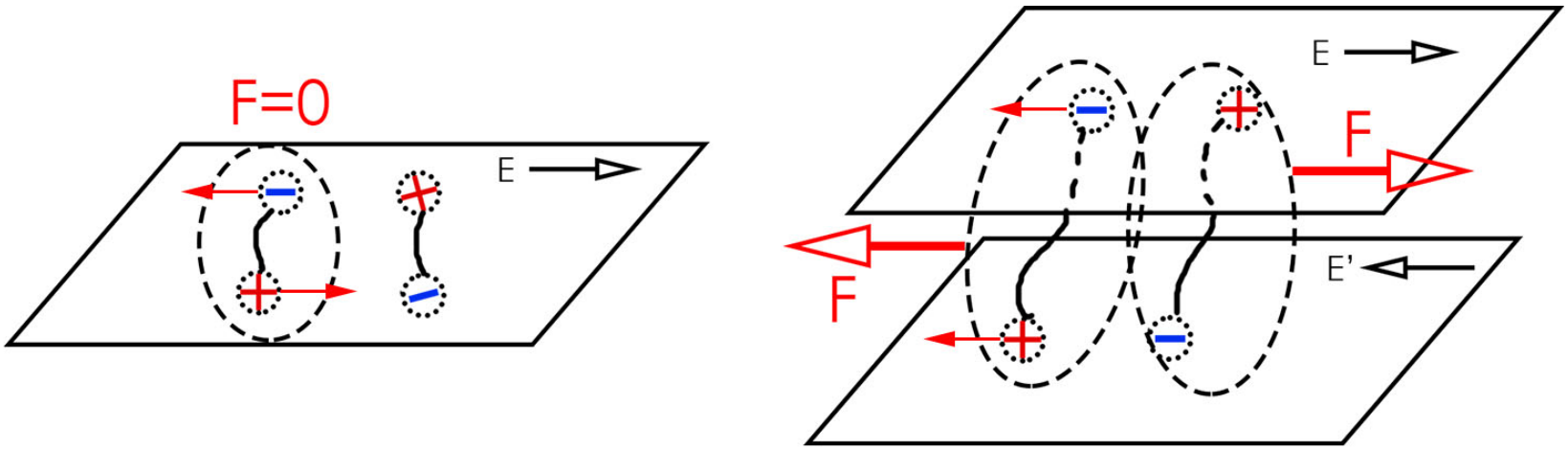


Real Pairs

- $\mathcal{W} \approx \frac{2q^2E^2}{(2\pi)^3} \exp\left(-\frac{\pi m^2}{|q|E}\right)$.
- Similar effect in string theory?

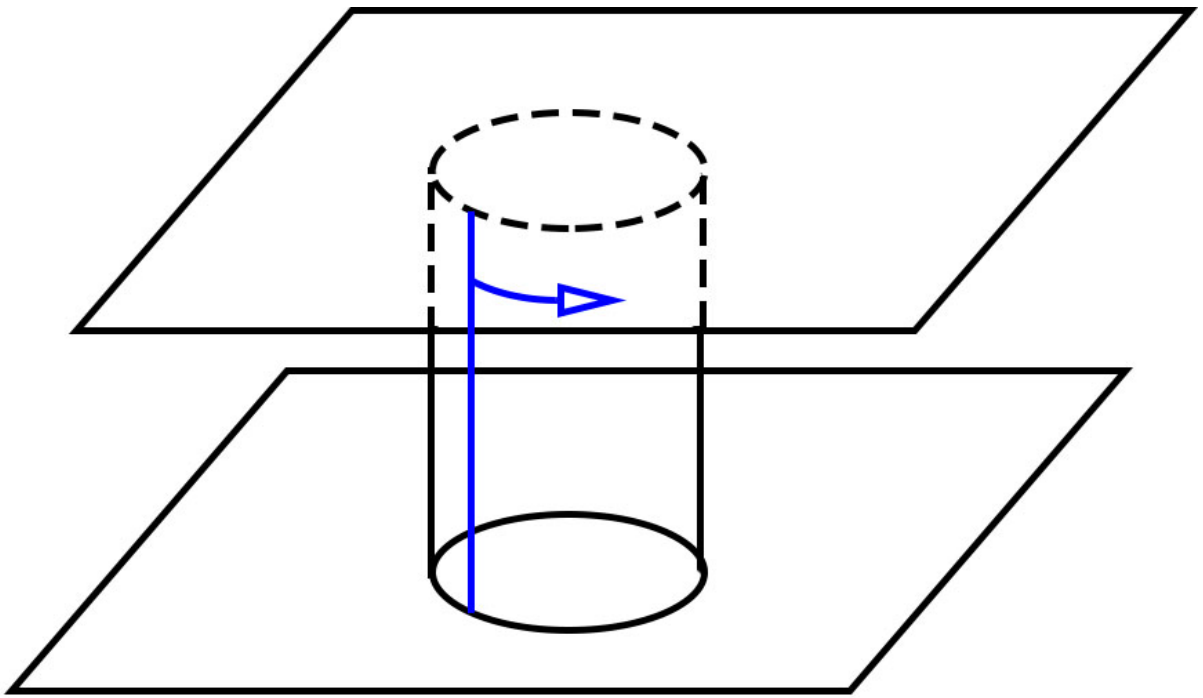
[1] On Gauge Invariance and Vacuum Polarization, Schwinger.J, 1951

String Pair Production



String Pair production is possible on multiple D-branes

String amplitudes



Open String 'One loop' Diagram

Pair production enhancement[2]

- Two parallel Dp-branes ($3 \leq p \leq 6$) with a separation y.
- Flux configurations:

$$\hat{F} = \begin{bmatrix} 0 & f & 0 & 0 & \cdots \\ -f & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & g & \cdots \\ 0 & 0 & -g & 0 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix} \tag{1}$$

  and $\hat{F}'$ is similar with f', g'.
- $\hat{F} \equiv 2\pi\alpha' F$ and $|f|, |f|', |g|, |g|' \ll 1$.

[2] Lu, J. X. and Xu, Shan-Shan. 2009; Lu, J.X. 2017

Enhancement

- Magnetic + electric:

$$\mathcal{W}_{g,g'\neq 0} \approx 8\frac{|f-f'||g-g'|}{(8\pi^2\alpha')^{\frac{1+p}{2}}}(\nu_0)^{\frac{p-3}{2}}\frac{\left[\cosh\frac{\pi\nu_0'}{\nu_0}+1\right]^2}{\sinh\frac{\pi\nu_0'}{\nu_0}}e^{-\frac{y^2}{2\pi\alpha'\nu_0}}$$

- Pure electric

$$\mathcal{W}_{g,g'=0} \approx \frac{32\pi|f-f'|^2}{(8\pi^2\alpha')^{\frac{1+p}{2}}}(\nu_0)^{\frac{p-3}{2}}e^{-\frac{y^2}{2\pi\alpha'\nu_0}}.$$

  where $\nu_0 \approx \frac{|f-f'|}{\pi} \ll 1, \nu_0' \approx \frac{|g-g'|}{\pi} \ll 1.$

- One may adjust $\frac{\nu_0'}{\nu_0} \approx \frac{|g-g'|}{|f-f'|} \gg 1$ s.t.

$$\frac{\mathcal{W}_{g\neq 0}}{\mathcal{W}_{g=0}} = \frac{\nu_0'}{4\nu_0}\frac{\left[\cosh\frac{\pi\nu_0'}{\nu_0}+1\right]^2}{\sinh\frac{\pi\nu_0'}{\nu_0}} \sim e^{\frac{\pi\nu_0'}{\nu_0}} \gg 1. \qquad (2)$$

Compared with Schwinger effect

- In the presence of magnetic flux:

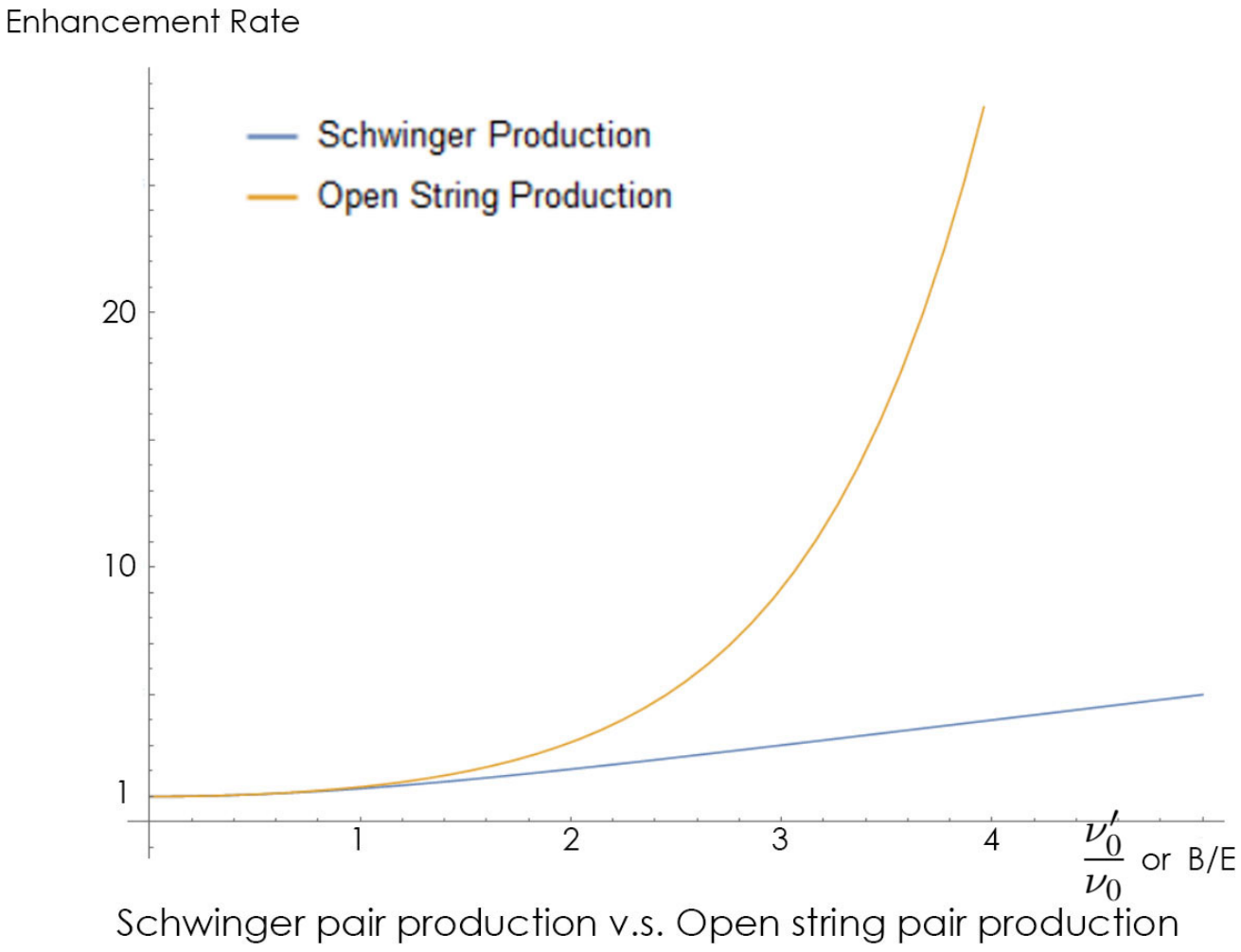
$$\tilde{\mathcal{W}} = \frac{EB}{(2\pi)^2} \coth\left(\frac{\pi B}{E}\right) e^{-\frac{\pi m^2}{E}} \tag{3}$$

- Without the magnetic flux:

$$\tilde{\mathcal{W}}_{B=0} = \frac{2E^2}{(2\pi)^3} e^{-\frac{\pi m^2}{E}} \tag{4}$$

- The ratio is

$$\frac{\tilde{\mathcal{W}}}{\tilde{\mathcal{W}}_{B=0}} = \frac{\pi B}{E} \frac{1}{\tanh\left(\frac{\pi B}{E}\right)} \tag{5}$$



Schwinger pair production v.s. Open string pair production

Is further enhancement possible?

Maximization of the production rate [3]

- Fix flux configurations: production rate decrease as the dimension of Dp-branes grow.

$$r = \frac{(2\pi\alpha')^3 \mathcal{W}_{p=5}}{(2\pi\alpha')^2 \mathcal{W}_{p=3}} \sim \frac{\nu_0}{4\pi} = \frac{|f - f'|}{4\pi^2} = \frac{\alpha' |E - E'|}{2\pi} \tag{6}$$

- Estimation:
  - $M_s > 10^3 \text{GeV} \rightarrow \alpha' = \frac{1}{M_s^2} < 10^{-6} \text{GeV}^{-2}$
  - We choose $E' = 0, E \sim m_e^2 \sim 10^{-7} \text{GeV}^2$.
  - $r < 10^{-14}$.

[3] het-th/1809.03806. Qiang Jia, JX Lu. 2018

- Further enhancement on higher Dp-branes?
- Adding another magnetic flux? ($p \geq 5$)

$$F = \begin{bmatrix} 0 & f_1 & 0 & 0 & 0 & 0 & \cdots \\ -f_1 & 0 & 0 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & g_2 & 0 & 0 & \cdots \\ 0 & 0 & -g_2 & 0 & 0 & 0 & \cdots \\ 0 & 0 & 0 & 0 & 0 & g_3 & \cdots \\ 0 & 0 & 0 & 0 & -g_3 & 0 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix} \tag{7}$$

- The production rate

$$\mathcal{W} \approx \frac{8|f_1 - f_1'||g_2 - g_2'||g_3 - g_3'|}{(8\pi^2\alpha')^{\frac{p+1}{2}}} (\nu_0)^{\frac{p-5}{2}} e^{-\frac{y^2}{2\pi\alpha'\nu_0}} \times \frac{\left[\cosh\frac{\pi(\nu_0'+\nu_0'')}{\nu_0} + 1\right]\left[\cosh\frac{\pi(\nu_0'-\nu_0'')}{\nu_0} + 1\right]}{\sinh\frac{\pi\nu_0'}{\nu_0}\sinh\frac{\pi\nu_0''}{\nu_0}}. \quad (8)$$

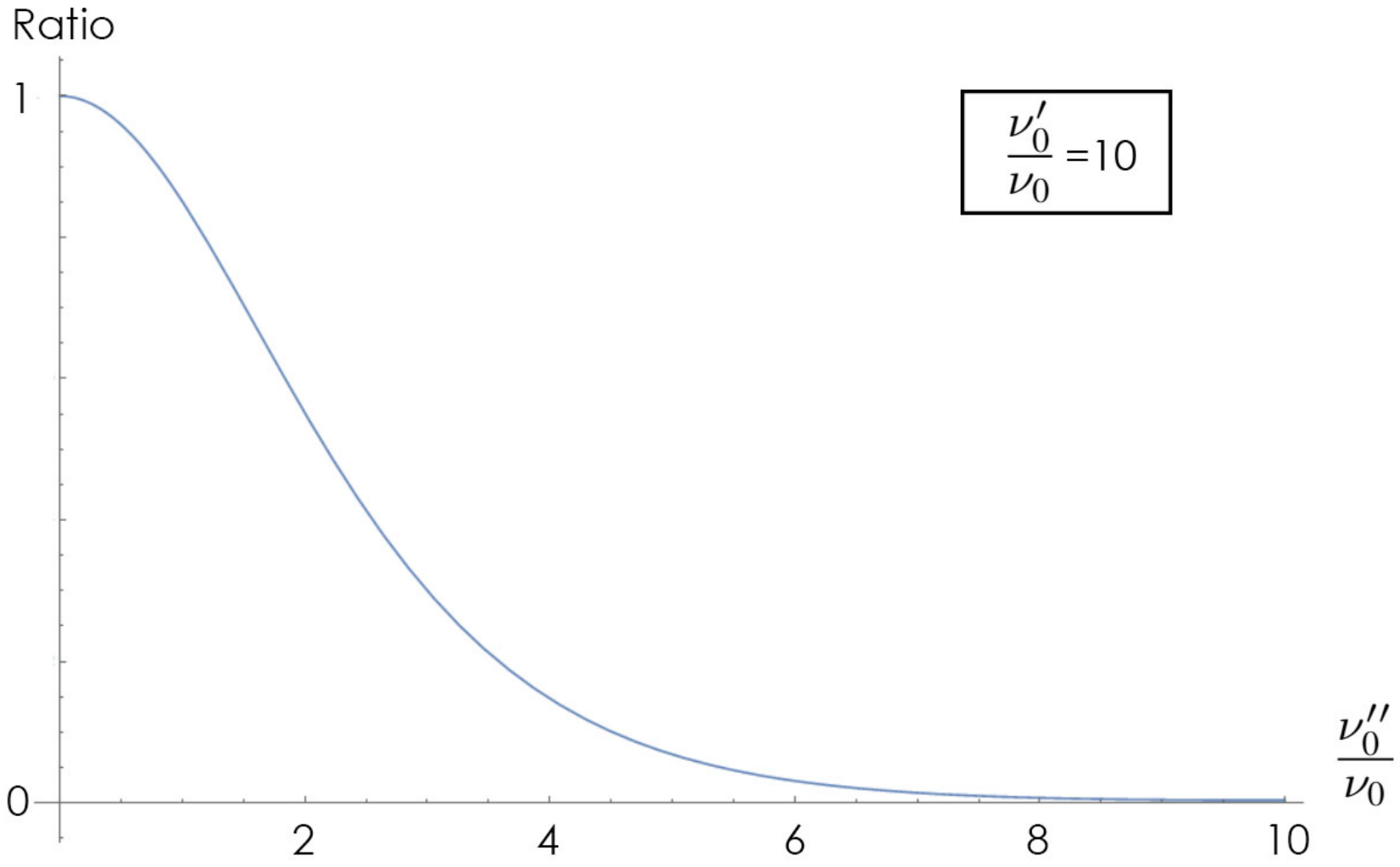
- $\nu_0'' \approx \frac{|g_3 - g_3'|}{\pi} \ll 1$.
- Whether g_3, g_3' will further enhance the rate on the basis of the enhancement of g_2, g_2'. $(\frac{\nu_0'}{\nu_0} \gg 1)$?

Ratio

$$r = \frac{\mathcal{W}_{g_3, g_3' \neq 0}}{\mathcal{W}_{g_3 = g_3' = 0}} = \frac{\pi \nu_0''}{\nu_0} \frac{\left[\cosh \frac{\pi(\nu_0' + \nu_0'')}{\nu_0} + 1\right] \left[\cosh \frac{\pi(\nu_0' - \nu_0'')}{\nu_0} + 1\right]}{\left[\cosh \frac{\pi \nu_0'}{\nu_0} + 1\right]^2 \sinh \pi \frac{\nu_0''}{\nu_0}} \tag{9}$$

- $\nu_0'' \to 0 : r \to 1.$
- $\frac{\nu_0'}{\nu_0} \gg 1, \frac{\nu_0''}{\nu_0} \sim \mathcal{O}(1) : r \sim \frac{\frac{\pi \nu_0''}{\nu_0}}{\sinh \pi \frac{\nu_0''}{\nu_0}} < 1.$
- $\frac{\nu_0'}{\nu_0} > \frac{\nu_0''}{\nu_0} \gg 1 : r \sim e^{-\frac{\pi \nu_0''}{\nu_0}} \ll 1.$

One magnetic flux is enough.



The additional magnetic flux will generally diminish the production rate

More general cases

- It is sufficient to focus on these three representatives.
  - Pure electric.
  - 1 electric + 1 magnetic.
  - 1 electric + 2 magnetic.
- Behaviours of other cases are the same to these three.

Conclusion

- In the absence of g_3, g_3':

$$\frac{(2\pi\alpha')^3\mathcal{W}_{p=5}}{(2\pi\alpha')^2\mathcal{W}_{p=3}} \sim \frac{\nu_0}{4\pi} \ll 1 \tag{10}$$

- The production rate is even smaller with g_3, g_3' turned on.
- The maximal enhancement is reached with one electric and one magnetic flux (sharing no common index) for D3-branes.
- Experiments are possible if we live on such as D3-branes.