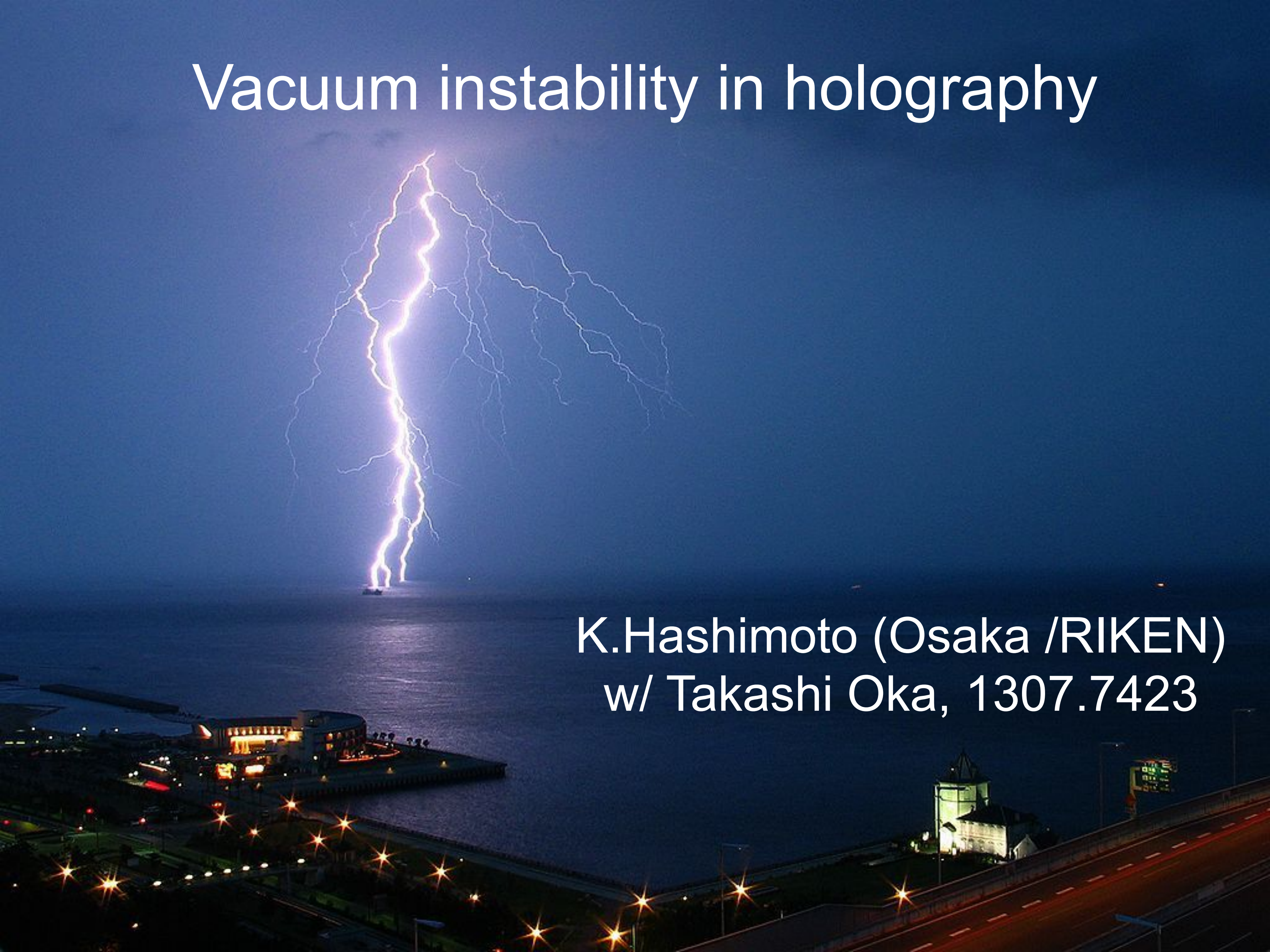
Vacuum instability in holography



K.Hashimoto (Osaka /RIKEN)
w/ Takashi Oka, 1307.7423

Problem

1

4 pages

How can electric field break confinement?

Cause

2

3 pages

Non-linear elemag and strong coupling

Our solution

3

7 pages

N=2 Super QCD

↓

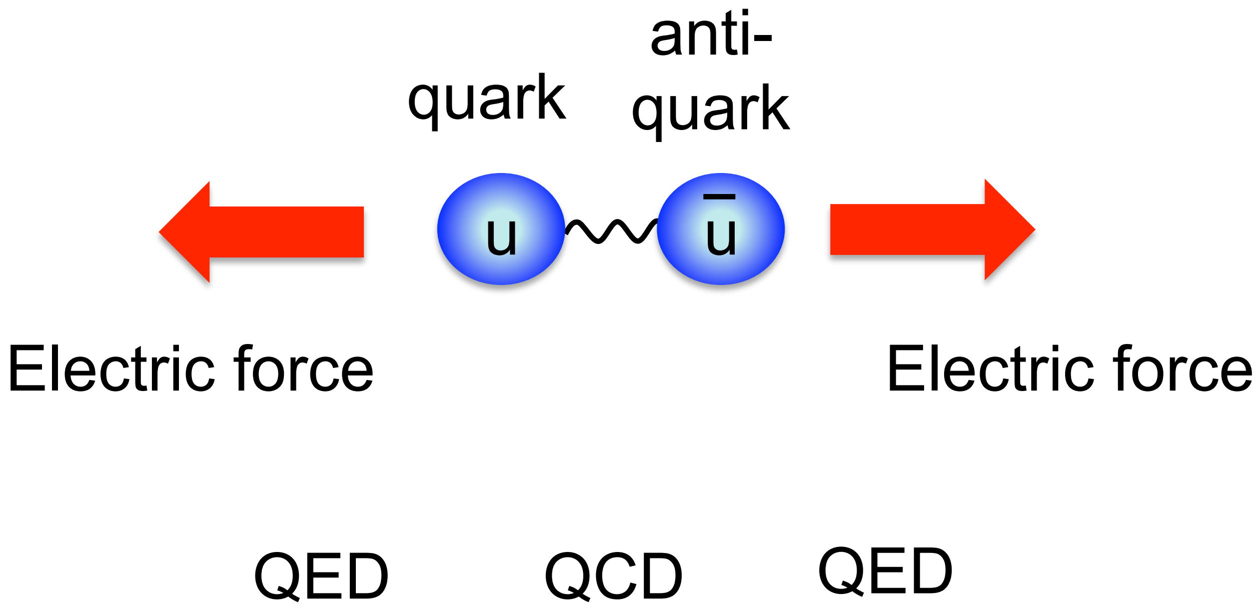
AdS/CFT + imaginary D-brane action

↓

Schwinger effect, Rapid thermalization

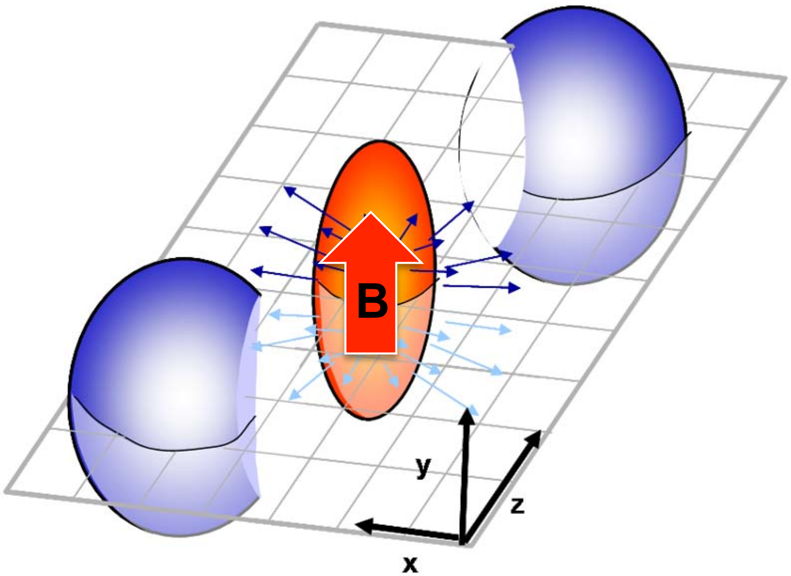
1-1 How can electric field break confinement?

Strong electric field can make confined quarks separate?

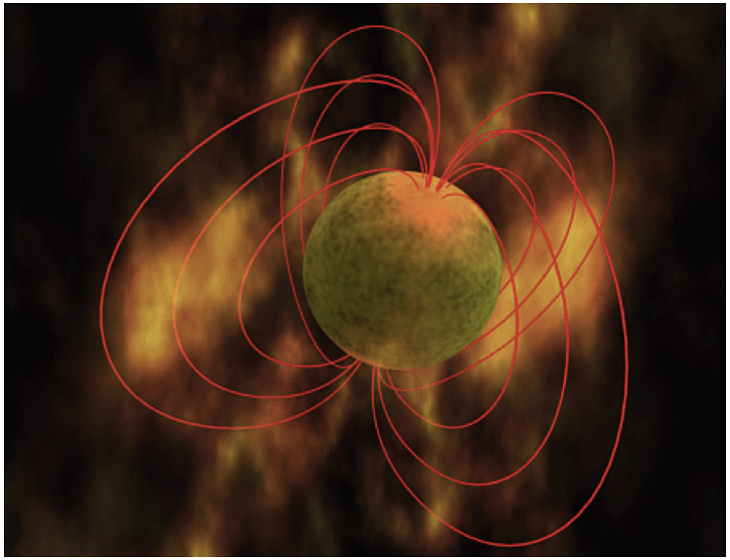


1-2 How can electric field break confinement?

Strong elemag fields appearing in QCD in reality



Heavy ion collisions



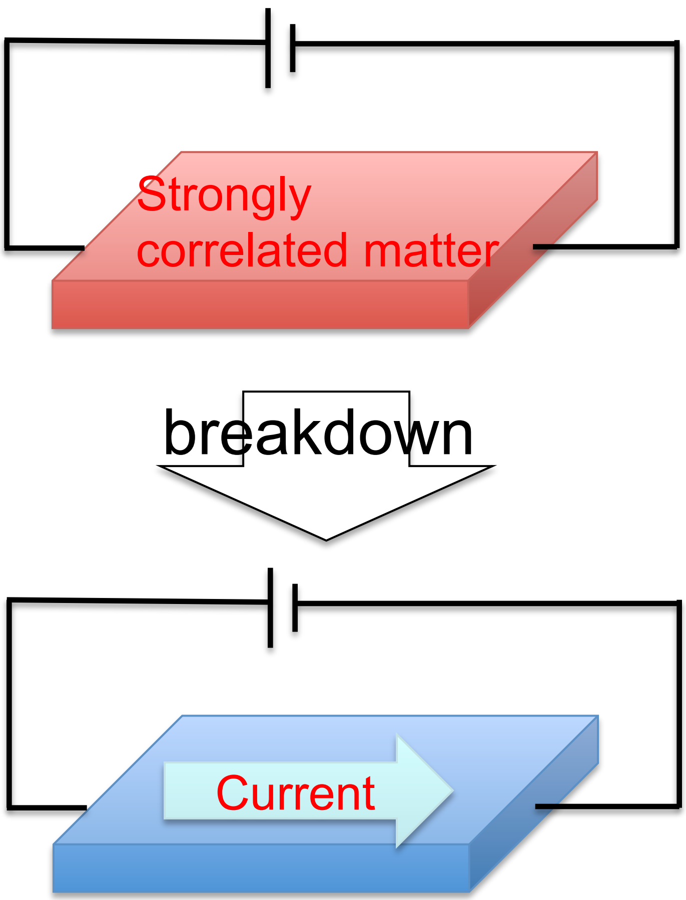
Neutron stars

[Kharzeev,McLerran,Warringa, 0711.0950]
[Voronyuk et.al 1103.4239]

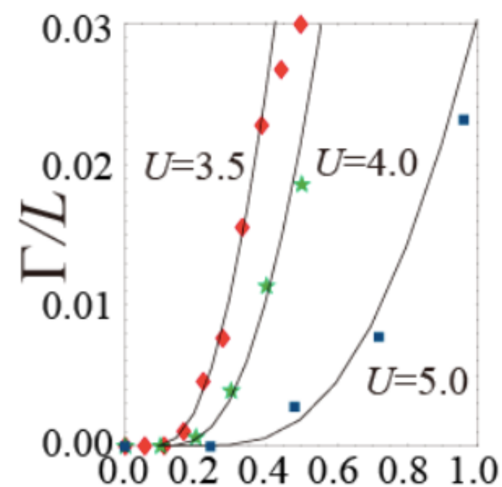
e.g. [Merechetti, 1304.4825] for a review

1-3 How can electric field break confinement?

Dielectric breakdown in material



Numerically:
Decay probability in
1-d Mott insulator



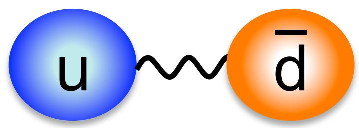
[Oka, Aoki, PRL 95 (2005) 137601]

1-4 How can electric field break confinement?

Confining phase of 1-flavor Large N_c QCD = Insulator

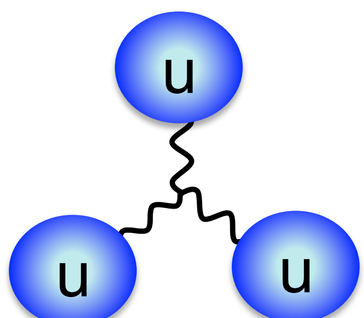
Electrically charged objects in QCD, confining phase :

- Charged mesons



--- not present in 1-flavor case

- Baryons



--- too heavy in the large N_C limit

1 — Problem (4 pages)

How can electric field break confinement?

2 — Cause (3 pages)

Non-linear elemag and strong coupling

3 — Our solution (7 pages)

N=2 Super QCD

↓

AdS/CFT + imaginary D-brane action

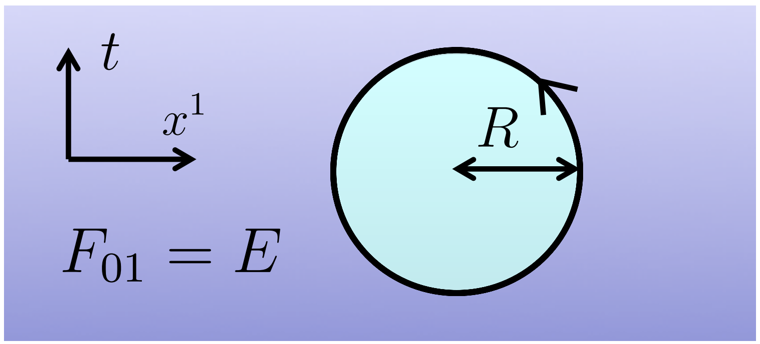
↓

Schwinger effect, Rapid thermalization

2-1 Non-linear elemag and strong coupling?

Schwinger effect in <u>QED</u>

= Quantum instability of constant electric field



Spontaneous pair-creation of electron + positoron

$$S_{\rm inst} = 2\pi R m_e - \pi R^2 e E$$

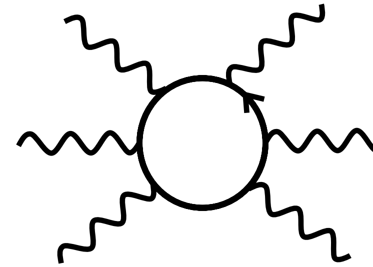
$$\frac{dS_{\rm inst}}{dR} = 0 \quad \Rightarrow \quad S_{\rm inst} = \frac{\pi m_e^2}{eE}$$

- Creation probability, exponentially suppressed

$$\text{Im}\,\mathcal{L} \;\propto\; \exp\left[-S_{\rm inst}\right] \;=\; \exp\left[-\frac{\pi m_e^2}{eE}\right]$$

- Created pairs move apart (= currents), cancel *E*

2-2 Non-linear elemag and strong coupling?



Long history behind.

"Nonlinear elemag" (Euler-Heisenberg action)

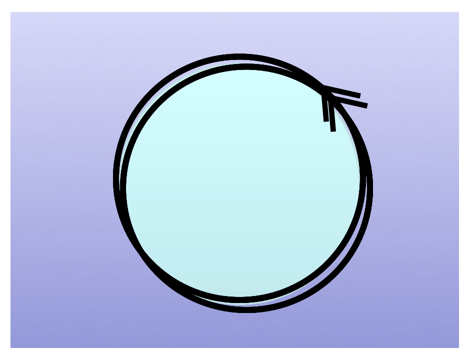
$$\mathcal{L} = \frac{1}{2}E^2 - \frac{1}{8\pi^2}\int_0^\infty \frac{ds}{s^3}\left[eEs\cot(eEs) - 1 + \frac{1}{3}(eEs)^2\right]$$

[Heisenberg, Euler 1936]

From poles…
[Schwinger 1951]

$$\mathrm{Im}\,\mathcal{L} = \sum_{n=1}^{\infty}\frac{e^2E^2}{4\pi^3}\frac{1}{n^2}\exp\left[-\frac{n\pi m_e^2}{eE}\right]$$

n instantons
||
n -windings

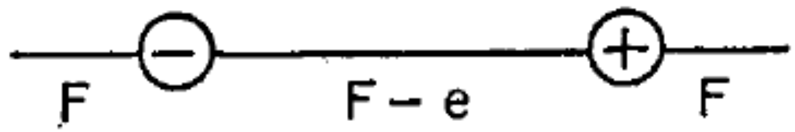


2-3 Non-linear elemag and strong coupling?

At strong coupling? Expect :

Decay possible only with *E* stronger than confining force.

Analogy in QED = 1 spatial dimension, flux confinement



Massive Schwinger model (1+1 dim. QED)

[Coleman, Jackiw, Susskind 1975] [Coleman 1976]

E can make sense only at $0 < E < e$

($E > e$ giving vacuum instability due to pair-creation)

Problem

1

How can electric field break confinement?

4 pages

Cause

2

Non-linear elemag and strong coupling

3 pages

Our solution

3

$\mathcal{N}$=2 Super QCD

7 pages

↓

AdS/CFT + imaginary D-brane action

↓

Schwinger effect, Rapid thermalization

3-1 Holography and D-brane action

Euler-Heisenberg action = D7-brane in $AdS_5 \times S^5$

$$\mathcal{L} = \mathcal{T}_{\rm D7} 2\pi^2 R^2 \int_0^\infty dr\ r^3 \sqrt{1 - (2\pi\alpha' E)^2 \frac{R^4}{((2\pi\alpha' m)^2 + r^2)^2}}$$

Result 1. Critical *E* field
= confinement force

$$E_{\rm cr} = \frac{2\pi\alpha' m^2}{R^2} = \frac{\sqrt{2}\pi m^2}{\sqrt{\lambda}}$$

Result 2. "Automatic Schwinger"

$$\mathrm{Im}\ \mathcal{L} = \frac{N_c}{2^5\pi} e^2 E^2 \left(1 + 2^{5/2} \frac{m^2}{\sqrt{\lambda} eE} \log \frac{m^2}{\sqrt{\lambda} eE} + \text{higher}\right)$$

Result 3. Temperature independence for *m=0*

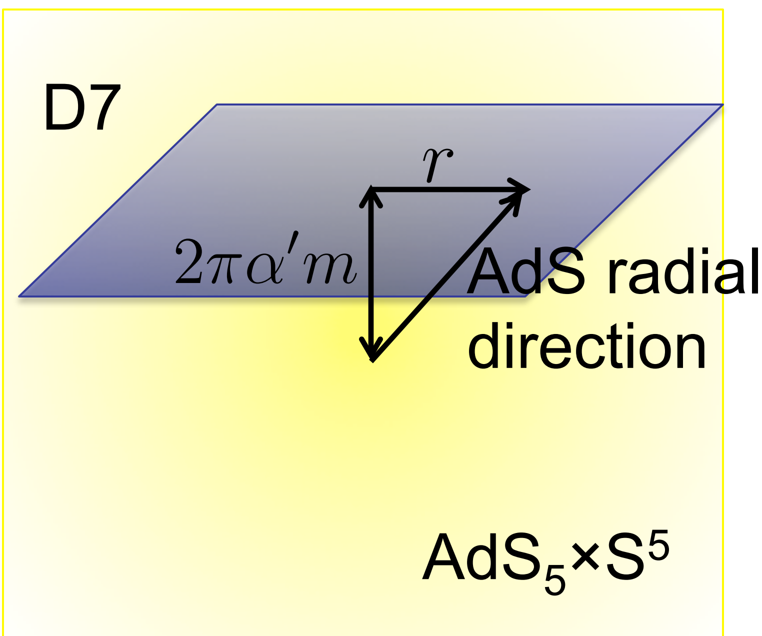
Result 4. Rapid thermalization

3-2 Holography and D-brane action

Euler-Heisenberg action = D7-brane in $AdS_5 \times S^5$

$$\mathcal{L} = \mathcal{T}_{\rm D7} 2\pi^2 R^2 \int_0^\infty dr\ r^3 \sqrt{1 - (2\pi\alpha' E)^2 \frac{R^4}{((2\pi\alpha' m)^2 + r^2)^2}}$$

Full nonlinear elemag is obtained, easy



Put D7 along 01234567.
In AdS, solution = a flat D7

[Karch, Katz (02)]

The DBI action = effective action

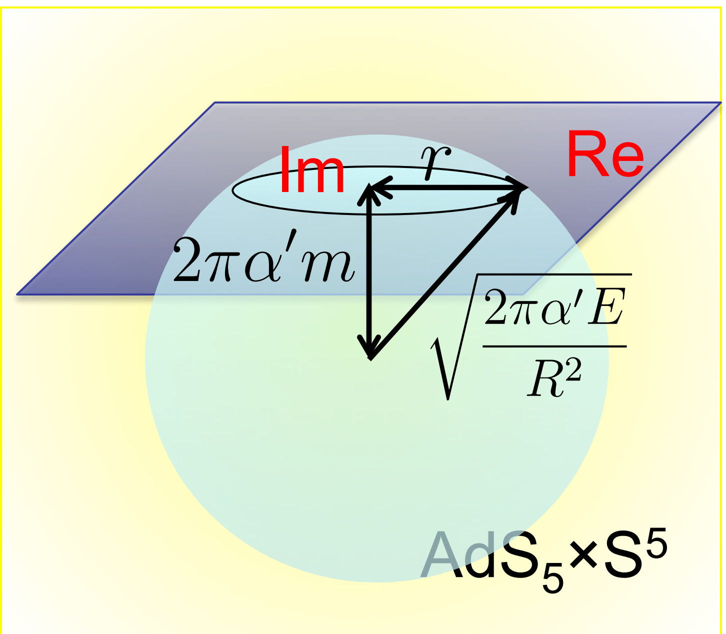
$$\mathcal{T}_{\rm D7} \int dt d^3x dr d\Omega_3 \sqrt{-\det[P[g]_{ab} + 2\pi\alpha' F_{ab}]}$$

3-3 Holography and D-brane action

Result 1. Critical *E* field = confinement force

The DBI action can be imaginary for large *E*

$$\mathcal{L} = \mathcal{T}_{\rm D7} 2\pi^2 R^2 \int_0^\infty dr\ r^3 \sqrt{1 - (2\pi\alpha' E)^2 \frac{R^4}{((2\pi\alpha' m)^2 + r^2)^2}}$$



Positivity inside the sq root

$$\Leftrightarrow \quad (2\pi\alpha' m)^2 + r^2 > 2\pi\alpha' E R^2$$

Imaginary action

above critical electric field

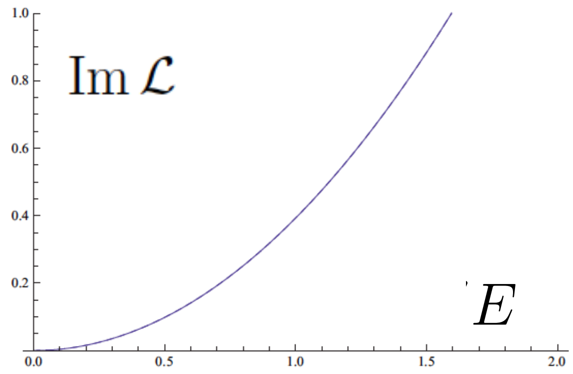
$$E_{\rm cr} = \frac{2\pi\alpha' m^2}{R^2} = \frac{\sqrt{2}\pi m^2}{\sqrt{\lambda}}$$

[Erdmenger, Meyer, Shock (07)]

Holography and D-brane action

Result 2. "Automatic Schwinger"

Massless quark case



Imaginary part of DBI

$$\mathrm{Im}\,\mathcal{L} = \frac{N_c}{32\pi}E^2$$

Agrees with the Schwinger effect formula with m_e=0

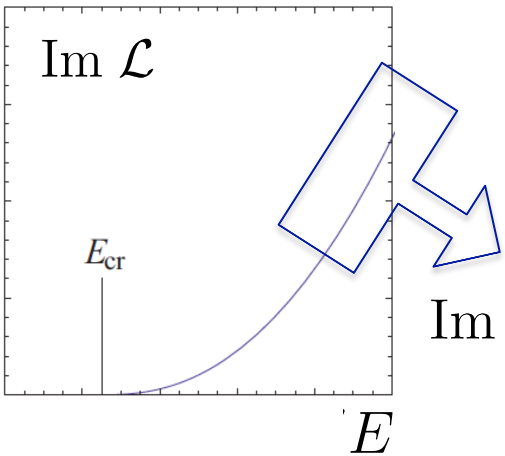
$$N_c\left(\mathrm{Im}\,\mathcal{L}^{1-\mathrm{loop}}_{\mathrm{spinor}}\Big|_{m_e=0} + 2\,\mathrm{Im}\,\mathcal{L}^{1-\mathrm{loop}}_{\mathrm{scalar}}\Big|_{m_e=0}\right) = \frac{N_c}{32\pi}E^2$$

$$\left(\mathrm{Im}\,\mathcal{L}_{\mathrm{spinor}} = \frac{e^2E^2}{8\pi^3}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left[-\frac{m_e^2\pi}{eE}n\right],\quad \mathrm{Im}\,\mathcal{L}_{\mathrm{scalar}} = \frac{e^2E^2}{16\pi^3}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{n^2}\exp\left[-\frac{m_e^2\pi}{eE}n\right]\right)$$

3-5 Holography and D-brane action

Result 2. "Automatic Schwinger"

Massive quark case



Expand the imaginary part of DBI for large E

$$\mathrm{Im}\,\mathcal{L} = \frac{N_c}{2^5\pi} e^2 E^2 \left(1 + 2^{5/2} \frac{m^2}{\sqrt{\lambda} eE} \log \frac{m^2}{\sqrt{\lambda} eE} + \text{higher}\right)$$

Agrees with the Schwinger effect, once replaced $E_{\rm cr} \leftrightarrow m_e^2$

$$\mathrm{Im}\,\mathcal{L} = \frac{N_c}{2^5\pi} e^2 E^2 \left(1 + \frac{4}{\pi} \frac{m_e^2}{eE} \log \frac{m_e^2}{2eE} + \text{higher}\right)$$

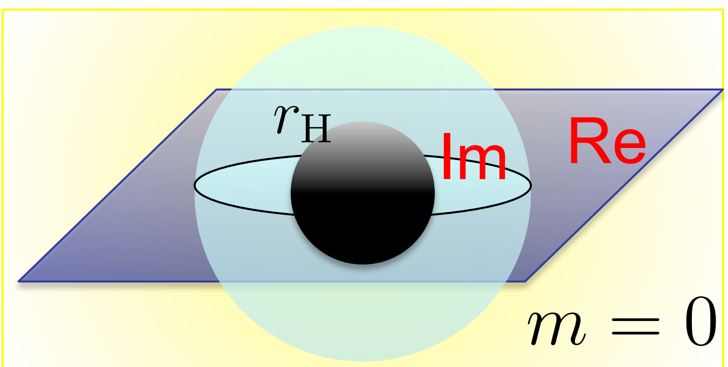
$$\left(\mathrm{Im}\,\mathcal{L}_{\rm spinor} = \frac{e^2E^2}{8\pi^3} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left[-\frac{m_e^2\pi}{eE} n\right], \quad \mathrm{Im}\,\mathcal{L}_{\rm scalar} = \frac{e^2E^2}{16\pi^3} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{n^2} \exp\left[-\frac{m_e^2\pi}{eE} n\right] \right)$$

3-6 Holography and D-brane action

Result 3. Temperature independence for *m=0*

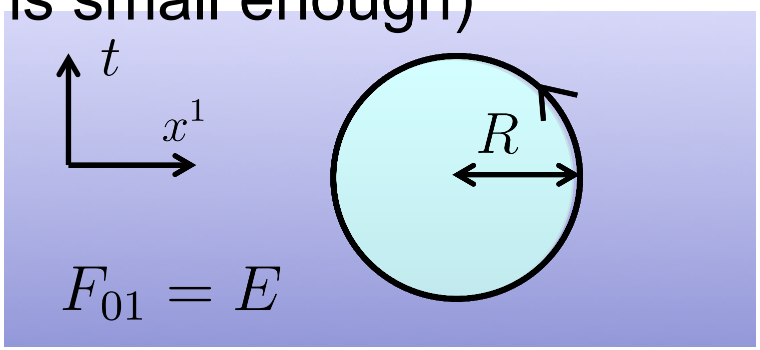
Finite temperature (= Putting a black hole in AdS)

$$\mathcal{L} = \mathcal{T}_{D7} 2\pi^2 R^2 \int_{r_H}^{\infty} dr\, r^3 \sqrt{1 - (2\pi\alpha' E)^2 \frac{R^4}{r^4} \left(1 - \frac{r_H^4}{r^4}\right)^{-1}}$$



$\text{Im}\,\mathcal{L}$ does not depend on r_H
→ temperature independence

Consistent with instantons
(Independent of temperature
if Matsubara period *m²/eE*
is small enough)

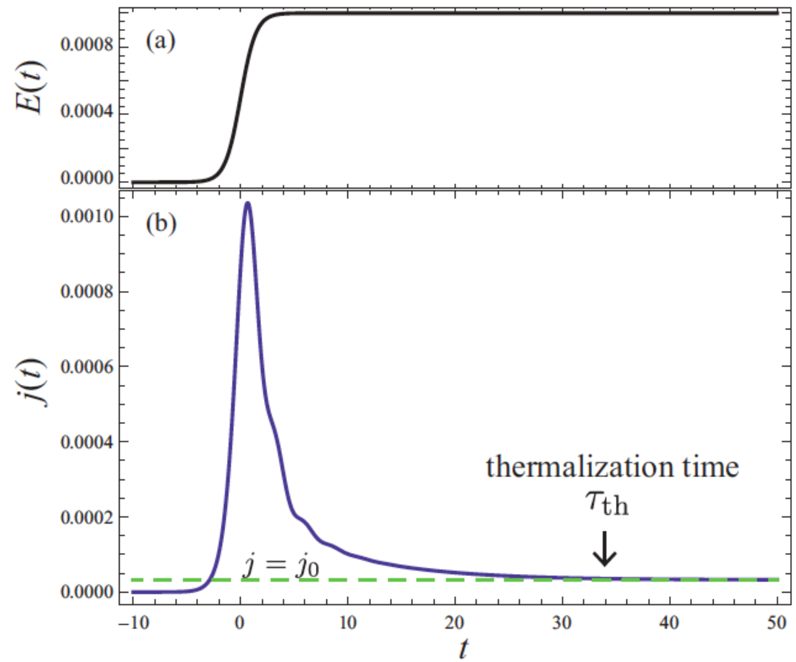


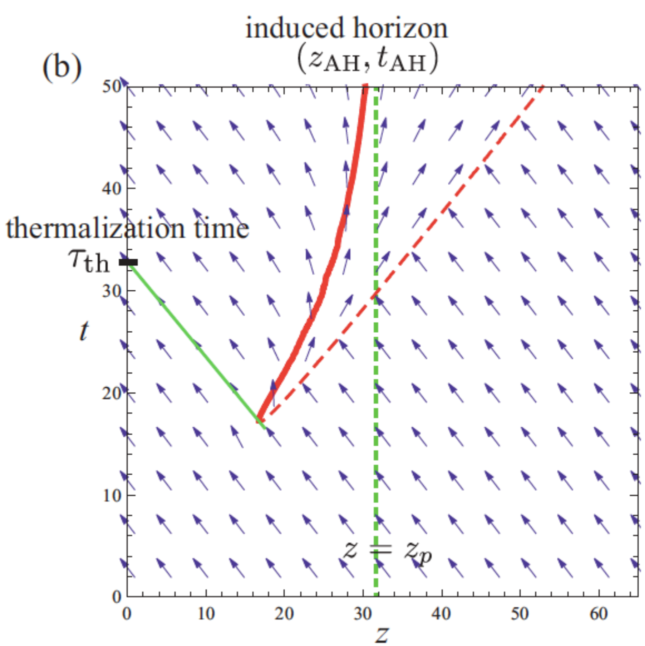
3-7 Holography and D-brane action

Result 4. Time-dependence solved, thermalization.

$$E(t) = \frac{E}{2}(1 + \tanh(\omega t))$$

It relaxes and approaches the stationary current.





Thermalization?

Apparent horizon for the induced metric on the D7-brane, formed at a Planckian time.

$$\tau_{\mathrm{th}} \sim a\pi \left(\frac{\lambda}{2\pi^2}\right)^{1/4} \frac{\hbar}{k_B} E^{-1/2} \sim 1\ [\mathrm{fm/c}]$$

3-1 Holography and D-brane action

Euler-Heisenberg action = D7-brane in $AdS_5 \times S^5$

$$\mathcal{L} = \mathcal{T}_{\mathrm{D7}} 2\pi^2 R^2 \int_0^\infty dr\ r^3 \sqrt{1 - (2\pi\alpha' E)^2 \frac{R^4}{((2\pi\alpha' m)^2 + r^2)^2}}$$

Result 1. Critical *E* field
= confinement force

$$E_{\mathrm{cr}} = \frac{2\pi\alpha' m^2}{R^2} = \frac{\sqrt{2}\pi m^2}{\sqrt{\lambda}}$$

Result 2. “Automatic Schwinger”

$$\mathrm{Im}\ \mathcal{L} = \frac{N_c}{2^5\pi} e^2 E^2 \left(1 + 2^{5/2} \frac{m^2}{\sqrt{\lambda} eE} \log \frac{m^2}{\sqrt{\lambda} eE} + \mathrm{higher}\right)$$

Result 3. Temperature independence for *m=0*

Result 4. Rapid thermalization

1

Problem

How can electric field break confinement?

4 pages

2

Cause

Non-linear elemag and strong coupling

3 pages

3

Our solution

N=2 Super QCD

7 pages

AdS/CFT + imaginary D-brane action

Schwinger effect, Rapid thermalization