Two non-BPS Wilson loops: quark-antiquark potential in defect CFT and circular loop beyond the wavy approximation

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Reference setup

Exact results in $\mathcal{N}=4$ SYM are attainable through its high degree of symmetry.

 $\label{eq:linear} \frac{\text{Integrability of planar theory:}}{\text{potential energy of "quark-antiquark" static pair at any }\lambda \\ \text{via QSC method [Gromov, Levkovich-Maslyuk 16].} \\$

$$V = -\frac{\Omega\left(\lambda,\theta\right)}{r}$$



Supersymmetric localization techniques for SUSY-preserving operators QO = 0: 1/2-BPS circular Wilson loop at any g, N [Pestun 07].

$$\langle W \rangle = \frac{1}{N} L_{N-1}^{1} \left(-\frac{g^{2}}{4} \right) \exp \left(\frac{g^{2}}{8} \right) = \frac{2}{\sqrt{\lambda}} I_{1} \left(\sqrt{\lambda} \right) + O\left(N^{-2} \right)$$

Adding the deformations

What can we measure if the symmetries of theory/observables lessen?

Higgsed $\mathcal{N}=4$ SYM with codimension-1 defect

- 1- and 2-point functions perturbatively and with integrability [Buhl-Mortensen, de Leeuw, Ipsen, Kristjansen, Mori, Nagasaki, Vardinghus, Widén, Wilhelm, Yamaguchi, Zarembo, ... 11-17].

- Wilson loop on line [Nagasaki, Tanida, Yamaguchi 11] [de Leeuw, Ipsen, Kristjansen, Wilhelm 16] and circle [Aguilera-Damia, Correa, Giraldo-Rivera 16].

<u>Goal</u>: first results for quark-antiquark potential (= antiparallel Wilson lines) useful for future integrability predictions.

Small path deformation of circular Wilson loop in $\mathcal{N}=4$ SYM

- Deformations = operator insertions into loop, which define a 1d defect superCFT [Cooke, Dekel, Drukker 17] [Giombi, Roiban, Tseytlin 17] [Kim, Kiryu 17] [Kim, Kiryu, Komatsu, Nishimura 17].

- Riemann theta-function formalism for minimal-area surfaces in H_3 [Ishizeki, Kruczenski, Ziama 11].

<u>Goal</u>: symmetry of classical sigma-model (= spectral-parameter independence) survives at $\lambda \ll 1$?

Quark-antiquark potential in defect CFT

[Preti, Trancanelli, EV 17]

D3-D5 defect superCFT



$$\begin{split} \langle \phi_i \rangle_{\mathrm{cl}} &= -\frac{1}{x_3} \begin{bmatrix} t^i_{k \times k} \oplus \mathbf{0}_{(N-k) \times (N-k)} \end{bmatrix}, \qquad x_3 > 0\\ & \begin{bmatrix} t_i, t_j \end{bmatrix} = i\epsilon_{ijl}t_l, \qquad i, j, l = 1, 2, 3 \end{split}$$

Vacuum satisfies e.o.m. and Nahm equations. $SO(2,4) \times SO(6)_R \rightarrow SO(2,3) \times (SO(3) \times SO(3))_R$ Parameters of theory = λ , N, k.

3d defect hypermultiplet

Gauge theory is amenable to standard perturbation theory after

- diagonalization of color structure in quadratic terms,
- propagators with mass $\sim 1/x_3$ are solved in terms of propagators in auxiliary AdS_4 .

[Buhl-Mortensen, de Leeuw, Ipsen, Kristjansen, Wilhelm 16]



Fuzzy-funnel solution of D3-D5 brane system



Antiparallel Wilson lines at 1 loop

$$\mathcal{W} \equiv \operatorname{tr}_{\Box} U(-T,T) , \qquad U(\alpha,\beta) = \mathcal{P} \exp \int_{\alpha}^{\beta} d\tau \underbrace{\left(i\dot{x}^{\mu}A_{\mu} - \theta^{I}\phi_{I} \right)}_{\mathcal{A}}, \qquad T \gg 1$$



WL couples to massive ϕ_3 and massless ϕ_6 .



 $\sim \lambda^{0} \mathrm{tr}_{\Box} U_{\mathrm{cl}} \qquad \sim \lambda \mathrm{tr}_{\Box} \int U_{\mathrm{cl}} \left\langle \tilde{\mathcal{A}} \right\rangle U_{\mathrm{cl}} = 0 \qquad \sim \lambda \mathrm{tr}_{\Box} \int \int \left\langle U_{\mathrm{cl}} \tilde{\mathcal{A}} U_{\mathrm{cl}} \tilde{\mathcal{A}} U_{\mathrm{cl}} \right\rangle$

Single Wilson line was computed in [de Leeuw, Ipsen, Kristjansen, Wilhelm 16].

Antiparallel Wilson lines at 1 loop

Extra diagram $\sim \lambda^1$ (defect) $\times \lambda^0$ (bulk) is zero by 3d conformal symmetry.

Propagator of scalar mass-eigenstate $(x^{\mu} = (\vec{x}, x_3), x_3^{<} = \min(x_3, y_3), x_3^{>} = \max(x_3, y_3))$

$$\kappa^{m^{2}}(x,y) = g^{2} \sqrt{x_{3} y_{3}} \int_{0}^{\infty} \frac{r \, dr}{(2\pi)^{2}} \frac{\sin(|\vec{x}-\vec{y}|r)}{|\vec{x}-\vec{y}|} I_{(m^{2}+1/4)^{1/2}}(rx_{3}^{<}) \kappa_{(m^{2}+1/4)^{1/2}}(rx_{3}^{>})$$

New ladder diagram is suppressed for $\mathcal{T}\gg 1$ \longrightarrow same result of 2 single Wilson lines.

For $N \gg k \gg 1$ on top of the planar limit, V measures the sum of 2 line-defect potentials.

$$V \equiv -\frac{1}{T} \log \langle W \rangle = -\frac{k-1}{2} \sum_{\pm} \frac{\sin \chi_{\pm}}{L \pm d \sin \phi} - \lambda d \frac{k-1}{2} \sum_{\pm} \frac{\sin^3 \chi_{\pm}}{(L \pm d \sin \phi)^2} \int_0^\infty \frac{dr}{(2\pi)^2} \frac{1}{r^2 + \left(\frac{k-1}{2} d \frac{\sin \chi_{\pm}}{L \pm d \sin \phi}\right)^2} \times \left[r I'_{\frac{k}{2}} \left(\frac{r}{d} (L \pm d \sin \phi)\right) K_{\frac{k}{2}} \left(\frac{r}{d} (L \pm d \sin \phi)\right) + I_{\frac{k}{2}} \left(\frac{r}{d} (L \pm d \sin \phi)\right) K_{\frac{k}{2}} \left(\frac{r}{d} (L \pm d \sin \phi)\right) - \frac{1}{2} \right] + O(\lambda^2)$$

Classical AdS calculation

Near-horizon limit of D3's produces $AdS_5 \times S^5$.

Probe D5 = (hyperplane $x_3 = \kappa y$) × S² with "slope" $\kappa \equiv \frac{\pi k}{\sqrt{\lambda}}$ [Nagasaki, Tanida, Yamaguchi 11]

WL in fundamental representation \longleftrightarrow fundamental string



$$\langle \mathcal{W} \rangle = Z_{\mathrm{string}} \stackrel{\lambda \gg 1}{\approx} e^{-TV_{\mathrm{c}}} + e^{-TV_{d}}$$



Connected sol. = tunnel

line-line binding energy

$$V_c = rac{\sqrt{\lambda}}{2d} C_c \left(|\chi_+ - \chi_-|
ight) \leq 0$$

[Maldacena 98]

Disconnected sol. = 2 sheets on probe D5

sum of 2 defect-line potentials

$$V_d = \sum_{\pm} \frac{\sqrt{\lambda}}{L \pm d \sin \phi} C_d (\chi_{\pm}, \kappa) \le 0$$

[Nagasaki, Tanida, Yamaguchi 11]

Phase transitions at $\lambda = \infty$

Gross-Ooguri transition = existence of 2, competing saddle-points in (dimensionless) string free energy $Vd \equiv -\frac{d}{T} \log Z_{\text{string}}$. The dominant saddle-point has the lowest potential at given L/d.



Large L/d: Connected solution dominates.

Critical L/d: $V_c d$ starts exceeding $V_d d$. Lower L/d: connected solution exists as unstable saddle-point. Critical L/d: Connected solution hits D5. Lower L/d: eventually first-order transition if it crosses the D5; more work to do if it breaks apart into 2 sheets.

Two studies of non-BPS Wilson loops 9

Circular loop beyond the wavy approximation

[Cooke, Dekel, Drukker, Trancanelli, EV in progress]

Small deformations of circular Wilson loop

$$\begin{split} X\left(\theta\right) &= \exp\left(i\theta + G\left(\theta\right)\right)\,, \qquad G\left(\theta\right) = \sum_{i=1}^{\infty} \epsilon^{i} c_{i}\left(\theta\right) = \sum_{i=1}^{\infty} \sum_{n \in \mathbb{Z}} \epsilon^{i} c_{i,n} e^{in\theta} \in \mathbb{R} \\ \langle \mathcal{W} \rangle &\equiv \left\langle \frac{1}{N} \mathcal{P} \exp \oint \left(iA_{\mu} \dot{x}^{\mu} + \phi_{\mathbf{3}}\right) \right\rangle \equiv \langle \mathcal{W} \rangle_{\epsilon^{\mathbf{0}}} + \epsilon^{\mathbf{2}} \langle \mathcal{W} \rangle_{\epsilon^{\mathbf{2}}} + \epsilon^{\mathbf{4}} \langle \mathcal{W} \rangle_{\epsilon^{\mathbf{4}}} + \dots \end{split}$$

Localization computes undeformed loop [Pestun 07] and its wavy deformation [Correa, Henn, Maldacena, Sever 12].

$$\begin{split} \left\langle \mathcal{W} \right\rangle_{\epsilon^{\mathbf{0}}} &= \frac{1}{N} L_{N-1}^{\mathbf{1}} \left(-\frac{\lambda}{4N} \right) \exp \left(\frac{\lambda}{8N} \right) = \frac{2}{\sqrt{\lambda}} I_{\mathbf{1}}(\sqrt{\lambda}) + O(N^{-2}) \\ \left\langle \mathcal{W} \right\rangle_{\epsilon^{\mathbf{0}}} &= B \oint \frac{c_{\mathbf{1}}\left(\theta_{\mathbf{1}} \right) c_{\mathbf{1}}\left(\theta_{\mathbf{2}} \right)}{\left(2\sin \frac{\theta_{\mathbf{1}} - \theta_{\mathbf{2}}}{2} \right)^{4}} = 2\pi^{2} B \sum_{n \in \mathbb{Z}} |n| \left(n^{2} - 1 \right) |c_{\mathbf{1},n}|^{2} \end{split}$$

 $\langle W \rangle_{e^2}$ displays the universal structure (function of λ) × (functional of $X(\theta)$) [Semenoff, Young 04].

$$B = \frac{\lambda}{2\pi^2} \partial_\lambda \log \langle \mathcal{W} \rangle_{\epsilon^0} = \text{Bremsstrahlung function}$$

This is the full answer up to ϵ^2 . I will focus on $\langle W \rangle_{\epsilon^4}$.

Minimal surfaces in H_3 and exact symmetry

Consider Wilson loops on closed contours in $\mathbb{R}^2 \subset \mathbb{R}^{1,3}$ and coupled to fixed ϕ^3 , which are dual to minimal-area surfaces with disk topology in $H_3 \subset AdS_5$.

Pohlmeyer reduction of bosonic string sigma-model to subspace $H_3 = \frac{SO(1,3)}{SO(3)}$.



The holomorphic function f(z) and the real function $\alpha(z, \bar{z})$ determine the surface $(X(z, \bar{z}), \bar{X}(z, \bar{z}), Z(z, \bar{z}))$, its regularized area $A_{\text{reg}} = -2\pi - 4 \int_{\tau, \sigma} |f|^2 e^{-2\alpha}$ and WL shape $X(\theta)$.

Given f and α , there exists a family of surfaces and WLs generated by $f(z) \rightarrow e^{i\varphi}f(z)$ with $e^{i\varphi}$ = spectral parameter. All surfaces have the same area, so all WLs have the same vev at $\lambda = \infty$ [Ishizeki, Kruczenski, Ziama 11] [Klose, Loebbert, Münkler 16].

Approximate symmetry at $\lambda \ll 1$

This symmetry does not survive beyond $\lambda = \infty$, but the breaking is mild at $\lambda \ll 1$ [Dekel 15], e.g. for an asymmetric circle-like contour.

$$\varphi = n \frac{\pi}{4}$$
 $n = 0, 1, 2, 3, 4$
 $\epsilon = 0.07$

$$\begin{split} \log \langle \mathcal{W} \rangle &= \sqrt{\lambda} \left[-1 - \frac{3}{2} \epsilon^2 - \frac{1\,917}{40} \epsilon^4 - \frac{350\,823}{400} \epsilon^6 - \frac{2\,475\,105\,369}{156\,800} \epsilon^8 + O(\epsilon^{10}) \right] + \ldots = \frac{\sqrt{\lambda}}{2\pi} A_{\rm reg} \qquad \lambda \gg 1 \\ \langle \mathcal{W} \rangle &= 1 + \lambda \left[\frac{1}{8} + \frac{3}{8} \epsilon^2 + \frac{773}{64} \epsilon^4 + \frac{57\,359}{1256} \epsilon^6 + \frac{1\,182\,155\,647 + 62\,208\cos(2\varphi)}{286\,720} \epsilon^8 + O(\epsilon^{10}) \right] + \ldots \quad \lambda \ll 1 \end{split}$$

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| lent unknown reason | |
| nt new example found by us | |
| nt many examples in [Dekel 15] as above | e |
| ł ł r | ent circular loop is invariant under φ -def ent universal structure of wavy deformati ent <u>unknown reason</u> new example found by us nt many examples in [Dekel 15] as above |

What is the symmetry that protects terms $\sim \lambda \epsilon^4$ from acquiring dependence on $e^{i\varphi}$? How is it related to the exact symmetry of the classical sigma-model? Check independence in terms $\sim \lambda \epsilon^4$ (next slides) and $\sim \lambda^2 \epsilon^4$ (in progress).

Perturbation around circle

Start with general form $f(z) = e^{i\varphi} \left(0 + \epsilon \sum_{p=0}^{\infty} a_p z^p\right)$ and derive contour $X(\theta)$ and vev $\langle W \rangle$.

Ansatz for α , β_2

$$\alpha(z,\bar{z}) = -\log\left(1-|z|^{2}\right) + \epsilon^{2}\alpha_{2}(z,\bar{z}) + O(\epsilon^{4})$$

$$\begin{aligned} \alpha(z,\bar{z}) &\equiv -\log\xi + \beta_2(\theta) \left(1+\xi\right)\xi^2 + O(\xi^4) \,, \qquad \xi \equiv 1 - |z|^2 \to 0 \,, \qquad z = r \, e^{i\theta} \\ \beta_2(\theta) &= 0 + \epsilon^2 \beta_{2,2}(\theta) + O(\epsilon^4) \end{aligned}$$

Generalized cosh-Gordon equation and small- ξ behavior of α

$$\partial \bar{\partial} \alpha(z,\bar{z}) = e^{2\alpha(z,\bar{z})} + |f(z)|^2 e^{-2\alpha(z,\bar{z})}$$

order ϵ^2 : $\left[\partial \bar{\partial} - 2\left(1 - |z|^2\right)^{-2} \right] \alpha_2(z,\bar{z}) = \left(1 - |z|^2\right)^2 \left| \sum_{p=0}^{\infty} a_p z^p \right|^2$

$$\alpha_2(z,\bar{z}) = \text{function of } a_n, \ p_n \qquad \qquad \alpha_2(z,\bar{z}) = \beta_{2,2}(\theta)\xi^2 + O(\xi^3)$$

Perturbation around circle

Ansatz for WL contour $X(\theta)$

$$X(\theta) = e^{i\theta} + e^{i\theta} \sum_{n=1}^{3} \epsilon^{n} x_{n}(\theta) + O(\epsilon^{4})$$

Schwarzian derivative equation

$$\{X(\theta), \theta\} \equiv \frac{X'''}{X'} - \frac{3}{2} \left(\frac{X''}{X'}\right)^2 = \frac{1}{2} - 12\beta_2(\theta) - 4i \operatorname{Im}\left(e^{2i\theta}f(\theta)\right)$$

order ϵ : $L_2\left[x_1(\theta)\right] = 4\operatorname{Im}\left(e^{2i\theta+i\varphi}\sum_{p=0}^{\infty}a_pz^p\right)$
order ϵ^2 : $L_2\left[x_2(\theta)\right] = x'_1\left(\theta\right)\left(-ix''_1{}''(\theta) + 3x''_1\left(\theta\right) + \frac{i}{2}x'_1\left(\theta\right)\right)$
 $-\frac{3i}{2}x''_1{}^2\left(\theta\right) + x_1\left(\theta\right)L_2\left[x'_1(\theta)\right] - 12\beta_{2,2}(\theta)$
order ϵ^3 : $L_2\left[x_3(\theta)\right] = \log \exp expression$

Apply the inverse of $L_2[g(\theta)] = g^{\prime\prime\prime}(\theta) + g^{\prime}(\theta)$ on both sides.

1- and 2-loop vev

$$\begin{split} f(z) &= \epsilon e^{i\varphi} \sum_{p=0}^{\infty} a_p z^p , \qquad X(\theta) = e^{i\theta} + e^{i\theta} \sum_{n=1}^{3} \epsilon^n x_n(\theta) + O(\epsilon^4) \\ x_1(\theta) &= \sum_{p=0}^{\infty} \left(\frac{2a_p e^{i(p+2)\theta + i\varphi}}{(p+1)(p+2)(p+3)} + \frac{2\bar{a}_p e^{-i(p+2)\theta - i\varphi}}{(p+1)(p+2)(p+3)} \right) \\ x_2(\theta) &= \sum_{p=0}^{\infty} \left(\frac{(5p+8)a_p^2 e^{i(2p+4)\theta + 2i\varphi}}{(p+1)^2(p+2)^2(2p+3)(2p+5)} - \frac{(5p+12)\bar{a}_p^2 e^{-i(2p+4)\theta - 2i\varphi}}{(p+2)^2(p+3)^2(2p+3)(2p+5)} \right) \\ &+ \sum_{p>q} \left(\frac{4\bar{a}_p a_q e^{-i(p-q)\theta}}{(p+1)(p+2)(p+3)(q+1)(q+2)} - \frac{4a_p \bar{a}_q e^{i(p-q)\theta}}{(p+1)(p+2)(p+3)(q+2)(q+3)} \right) \\ &+ \frac{4a_p a_q (p^2 + 3pq + q^2 + 9p + 9q + 16) e^{i(p+q+4)\theta + 2i\varphi}}{(p+1)(p+2)(q+1)(q+2)(p+q+3)(p+q+4)(p+q+5)} \\ &- \frac{4\bar{a}_p \bar{a}_q (p^2 + 3pq + q^2 + 11p + 11q + 24) e^{-i(p+q+4)\theta - 2i\varphi}}{(p+2)(p+3)(q+2)(q+3)(p+q+3)(p+q+4)(p+q+5)} \right) \\ x_3(\theta) &= \text{long expression} \end{split}$$

Generic smooth contour in \mathbb{R}^2 , fixed scalar, planar limit [Bassetto, Griguolo, Pucci, Seminara 08]

$$\begin{split} \langle \mathcal{W} \rangle_{\lambda} &= -\frac{\lambda}{16\pi^2} \oint I(\theta_1, \theta_2) \equiv -\frac{\lambda}{16\pi^2} \oint \frac{(\dot{X}(\theta_1)\dot{\bar{X}}(\theta_2) + \dot{X}(\theta_2)\dot{\bar{X}}(\theta_1)) - 2|\dot{X}(\theta_1)\dot{X}(\theta_2)|}{2|X(\theta_1) - X(\theta_2)|^2} \\ \langle \mathcal{W} \rangle_{\lambda^2} &= -\frac{\lambda^2}{128\pi^4} \oint \epsilon(\theta_1, \theta_2, \theta_3) I(\theta_1, \theta_3) \log \left| \frac{X(\theta_1) - X(\theta_2)}{X(\theta_3) - X(\theta_1)} \right|^2 \frac{(X(\theta_3) - X(\theta_2))\dot{\bar{X}}(\theta_2) + \text{h.c.}}{2|X(\theta_3) - X(\theta_2)|^2} \\ &+ \frac{\lambda^2}{2} \left(\frac{1}{16\pi^2} \oint d\theta_1 \, d\theta_2 \, I(\theta_1, \theta_2) \right)^2 - \frac{\lambda^2}{64\pi^4} \int_{\theta_1 > \theta_2 > \theta_3 > \theta_4} I(\theta_1, \theta_3) I(\theta_2, \theta_4) \end{split}$$

1- and 2-loop results so far

We verified no dependence on $e^{i\varphi}$ at order $\lambda\epsilon^4.$

$$\begin{split} \langle \mathcal{W} \rangle_{\lambda} &= \frac{\lambda}{8} + \lambda \epsilon^{2} \sum_{p=0}^{\infty} \frac{|a_{p}|^{2}}{(p+1)(p+2)(p+3)} + \lambda \epsilon^{4} \sum_{p=0}^{\infty} \frac{2|a_{p}|^{4} \left(17\rho^{4} + 136p^{3} + 412p^{2} + 560p + 291\right)}{3(p+1)^{3}(p+2)^{3}(p+3)^{3}(2p+3)(2p+5)} \\ &+ \lambda \epsilon^{4} \sum_{p>q} \left(\frac{8|a_{p}|^{2}|a_{q}|^{2}}{3(p+1)^{2}(p+2)^{2}(p+3)^{2}(q+1)(q+2)(q+3)(p+q+3)(p+q+4)(p+q+5)} \right) \\ &\times (p^{5} + 9p^{4}q + 25p^{3}q^{2} + 7p^{2}q^{3} - 6pq^{4} - 2q^{5} + 28p^{4} + 172p^{3}q + 192p^{2}q^{2} - 20pq^{3} - 32q^{4} \\ &+ 280p^{3} + 908p^{2}q + 329pq^{2} - 149q^{3} + 1160p^{2} + 1684pq - 76q^{2} + 2023p + 799q + 1164) \\ &+ \frac{4(\tilde{a}_{2p-q}\tilde{a}_{q}a_{p}^{2} + a_{2p-q}a_{q}a_{p}^{2})}{3(p+1)^{2}(p+2)^{2}(p+3)^{2}(2p+3)(2p+5)(2p-q+1)(2p-q+2)(2p-q+3)} \\ &\times (72p^{4} - 71p^{3}q + 16p^{2}q^{2} + 434p^{3} - 362p^{2}q + 64pq^{2} + 937p^{2} - 585pq + 60q^{2} \\ &+ 866p - 306q + 291) \bigg) \end{split}$$

+ next slide

1- and 2-loop results so far

 $\langle \mathcal{W} \rangle_{\lambda} = \text{previous slide}$

$$\begin{split} &+\lambda\epsilon^4\sum_{q>p>r}\frac{8(a_{p+q-r}a_r\tilde{a}_p\tilde{a}_p+q_-r\tilde{a}_r)}{3(p+1)(p+2)(p+3)(q+1)(q+2)(q+3)(p+q+3)(p+q+4)(p+q+5)} \\ &\times\frac{1}{(p+q-r+1)(p+q-r+2)(p+q-r+3)} \\ &\times(p^5+16p^4q-7p^4r+55p^3q^2-34p^3qr+4p^3r^2+55p^2q^3-60p^2q^2r+12p^2qr^2+16pq^4 \\ &-34pq^3r+12pq^2r^2+q^5+4q^3r^2-7q^4r+28p^4+280p^3q-108p^3r+540p^2q^2-396p^2qr \\ &+48p^2r^2+280pq^3-396pq^2r+96pqr^2+28q^4+48q^2r^2-108q^3r+280p^3+1525p^2q \\ &-617p^2r+1525pq^2-1384pqr+188pr^2+280q^3-617q^2r+188qr^2+1160p^2+3160pq \\ &-1476pr+1160q^2-1476qr+240r^2+2023p+2023q-1224r+1164) \end{split}$$

We don't have $\langle W \rangle_{\lambda^2}$ in closed form, but a very efficient algorithm to calculate it for arbitrary frequencies p, q, ... in the input function $f(z) = \epsilon e^{i\varphi} \sum_{p=0}^{\infty} a_p z^p$. We will see if also $\langle W \rangle_{\lambda^2}$ does not depend on $e^{i\varphi}$ too.

Conclusion

Conclusion

Quark-antiquark potential in D3-D5 dCFT

We initiated the study at $\lambda \ll 1$ and quantified Gross-Ooguri transitions at $\lambda \gg 1$.

- Essential to derive the form of defect Lagrangian beyond k = 0 [DeWolfe, Freedman, Ooguri 02] for higher-loop corrections, localization, ...

- 1-loop corrections at $\lambda \gg 1$ are accessible, e.g. via heat kernel [Forini, Tseytlin, EV 17].

- Fate of transitions beyond D5-probe limit, when D5 "puffs into" a backreacted space, which is type IIB SUGRA solution in warped $AdS_4 \times S^2 \times S^2 \times \Sigma_2$ [d'Hoker, Estes, Gutperle 07]. Parameters of new theory = g, N, k, N_f . I fixed $N \gg k$ and $N_f = 1$ in the talk.

Circular loop beyond the wavy approximation

We are addressing the puzzle of $e^{i\varphi}$ -independence of Wilson loop vev at $\lambda \epsilon^4, \lambda^2 \epsilon^4$.

- Physical interpretation of (whole/part of) ϵ^4 -coefficient in language of classical EM.
- Holographic computation of entanglement entropy in 2+1 dimensions.