Holographic Yang-Mills-Chern-Simons Defects

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arXiv.org > hep-th > arXiv:1601.00525

Why (YM)-CS Holography with/without Defects?

$$S_A = -\frac{1}{4g_{3\mathrm{d}}^2}\int d^3x\,\mathrm{Tr}(F^{\mu\nu}F_{\mu\nu}) + \frac{k}{4\pi}\int Tr\,(A\wedge F)$$

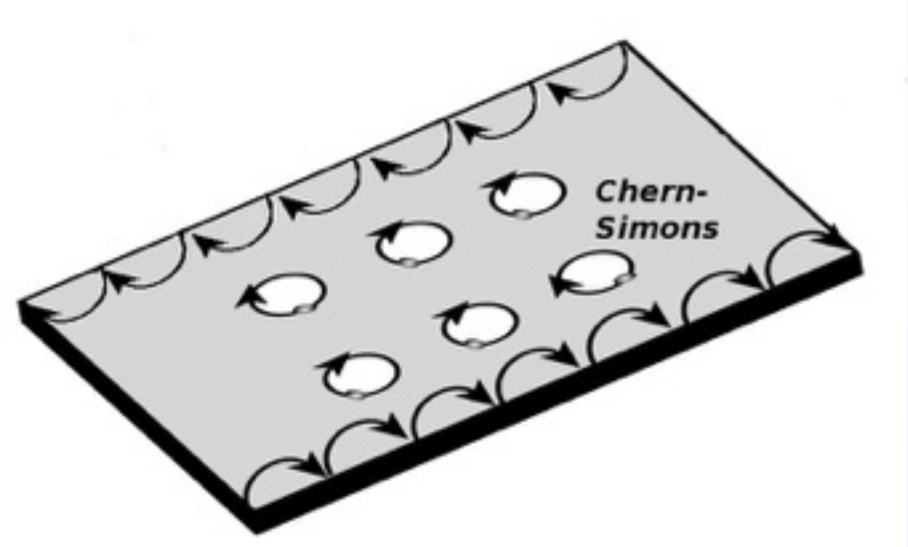
Confinement/ Topological

Level-Rank Duality

$$SU(N)_k \leftrightarrow U(k)_{-N,-N}$$

[Aharony 1512.00161]

FQHE / Edge States



$$\sigma_{xy} = \nu\frac{e^2}{h}$$

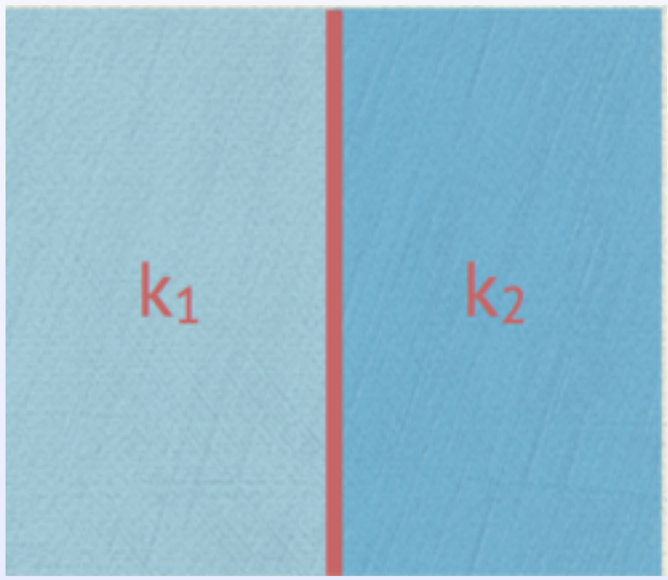
$$\nu = \frac{1}{2k+1} \qquad U(1)_{2k+1}$$

$$\nu = \frac{1}{2} \qquad SU(2)_2$$

[Fradkin-Nayak-Tsvelik-Wilczek '98]

Chern-Simons Level-Changing Defects

Two regions w/different level:



level-changing defect

$$S_{CS} = \frac{k_1}{4\pi}\int_{y<0} \omega_3(A) + \frac{k_2}{4\pi}\int_{y>0} \omega_3(A)$$

$$Tr(A \wedge dA + \frac{2}{3} A \wedge A \wedge A)$$

Gauge transformation:

$$\delta S_{CS} = \frac{k_1 - k_2}{4\pi}\int_{y=0} Tr(\lambda F)$$

not gauge invariant

For k fundamental chiral fermions trapped on defect:

$$S_F = \int d^2x \psi_i^\dagger (i\partial_+ + A_+)\psi^i$$

Gauge Anomaly

Fermion effective action:

$$\delta S_F = \frac{k}{4\pi}\int d^2x Tr(\lambda F)$$

For $k = k_2 - k_1$: [Laughlin ’81, Callan-Harvey ‘85]

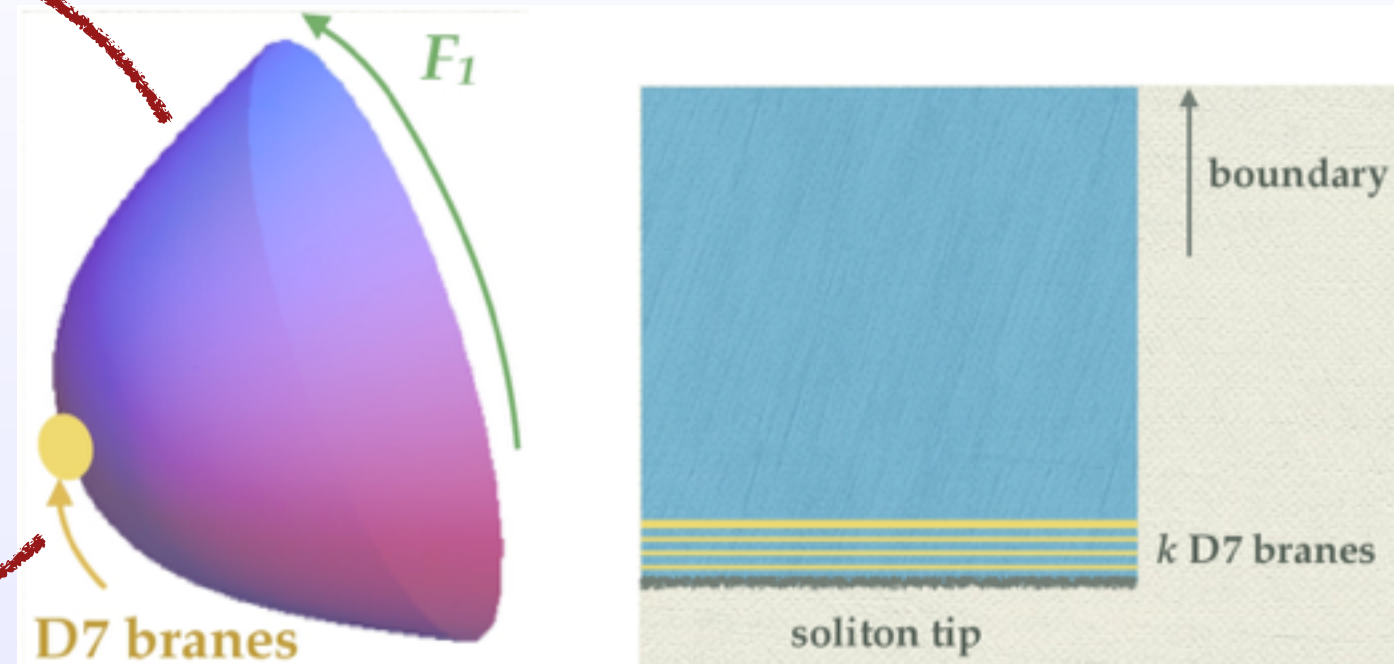
total action is gauge invariant

Holographic YMCS & Defect D7 Branes

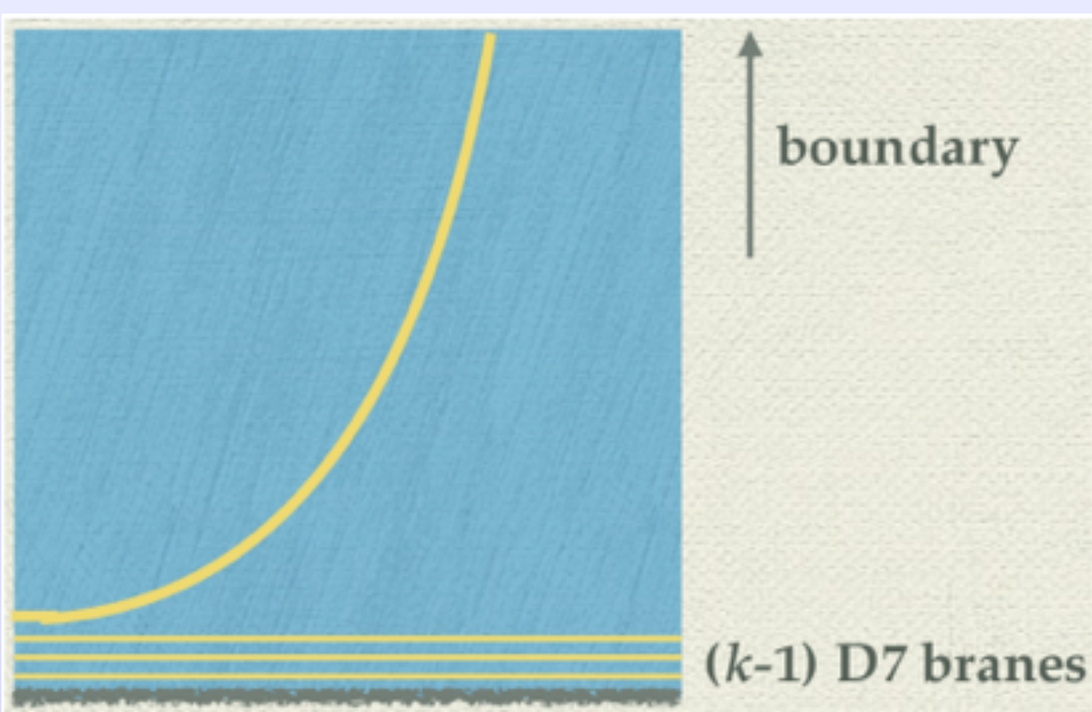
$$-\frac{1}{4g_{3d}^2}\int d^3x Tr_{SU(N)}F^2$$

$$\frac{k}{4\pi}\int d^3x Tr_{SU(N)} A\wedge F$$

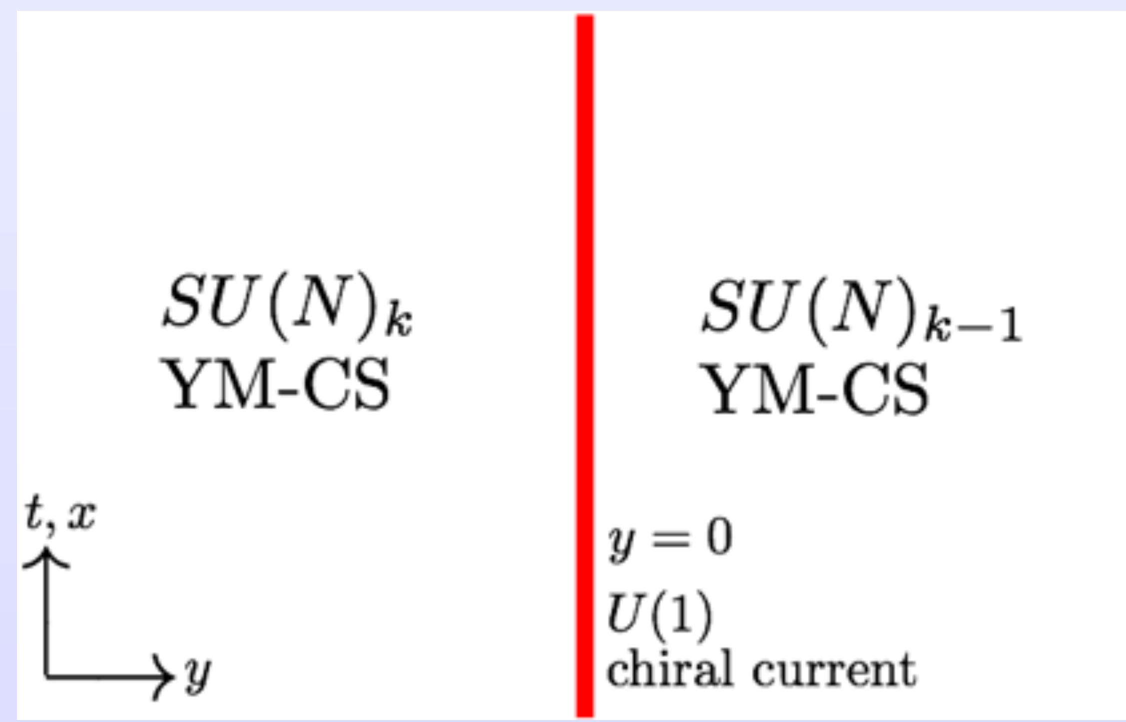
$g_{3\mathrm{d}}^2 = g_s M_{\mathrm{KK}}$



Fujita+Li+Ryu+Takayanagi 0901.0924

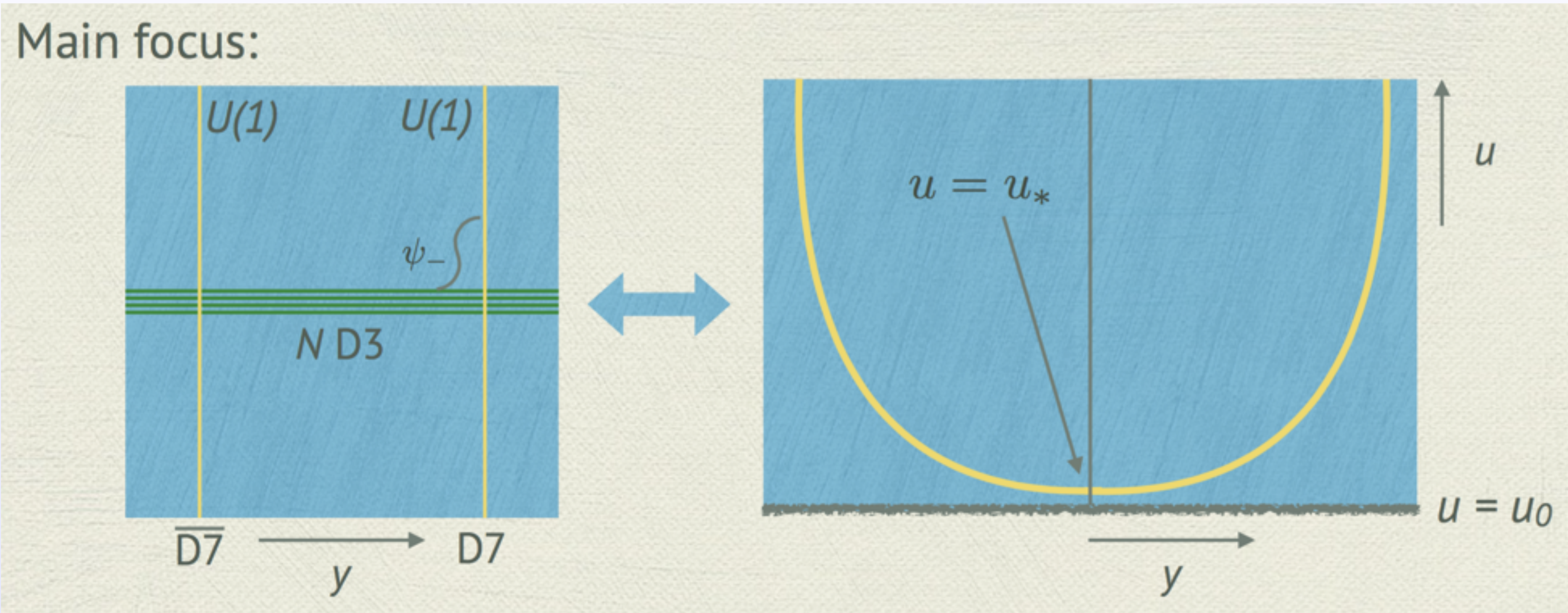


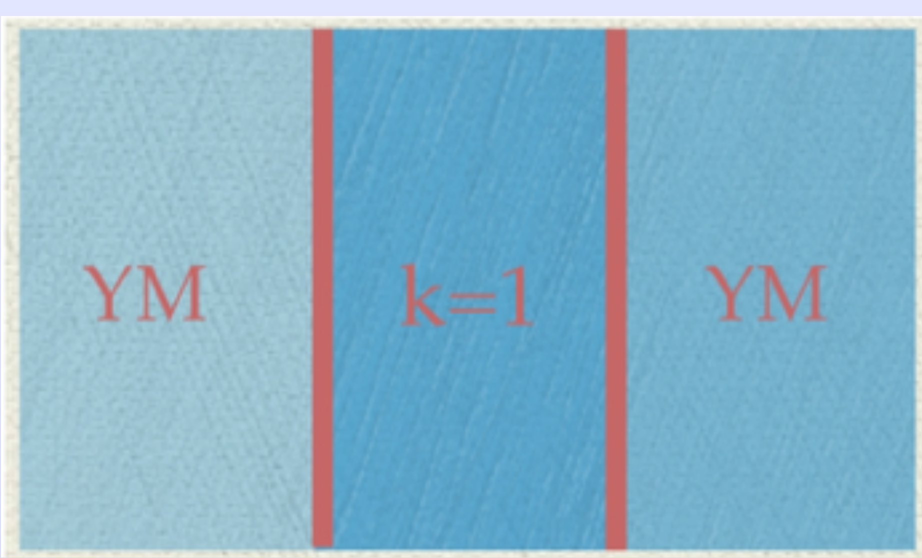
Fujita, Melby-Thompson, Meyer, Sugimoto 1601.00525



$$S_\psi = \int_{y=0} d^2x\, \psi_-^\dagger (i\partial_+ + A_+)\psi_-$$

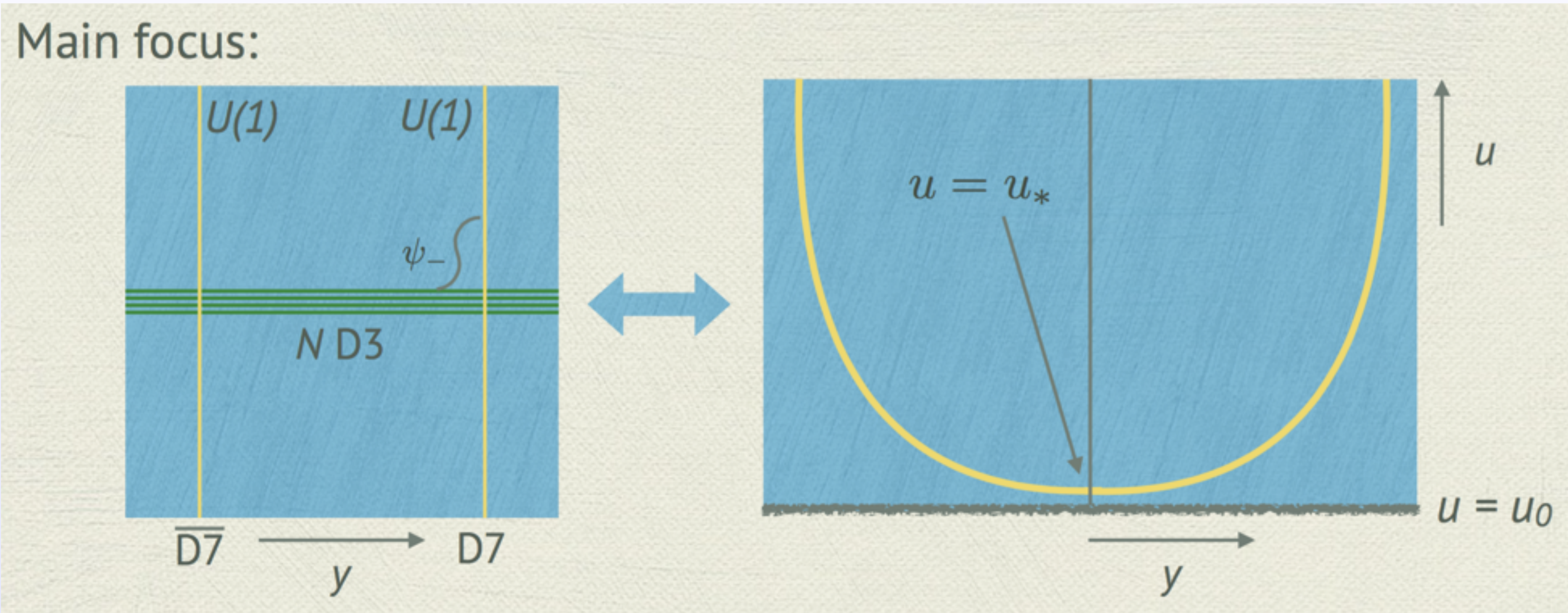
Holography of Defect D7 Branes

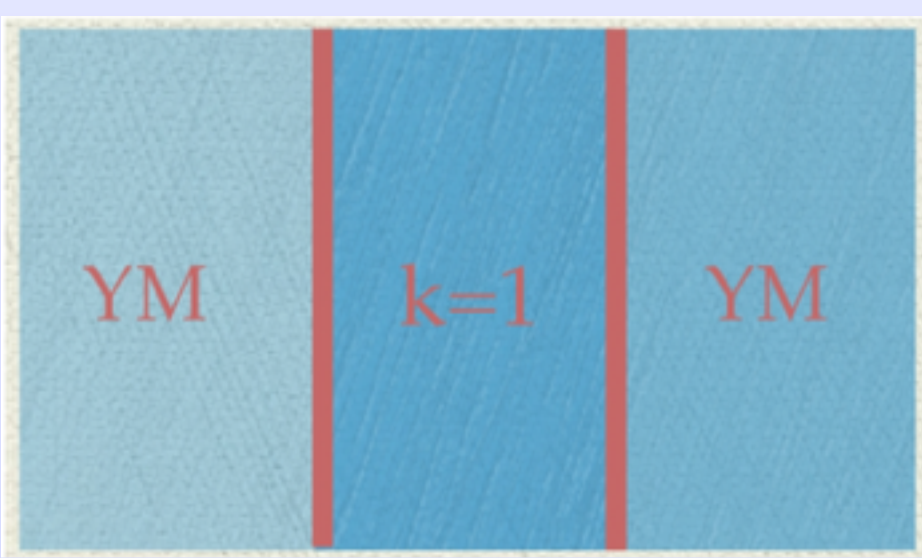




	0	1	2	3	4	5	6	7	8	9
D3	x	x	x	x						
D7	x	x			x	x	x	x	x	x
$\bar{D}7$	x	x			x	x	x	x	x	x

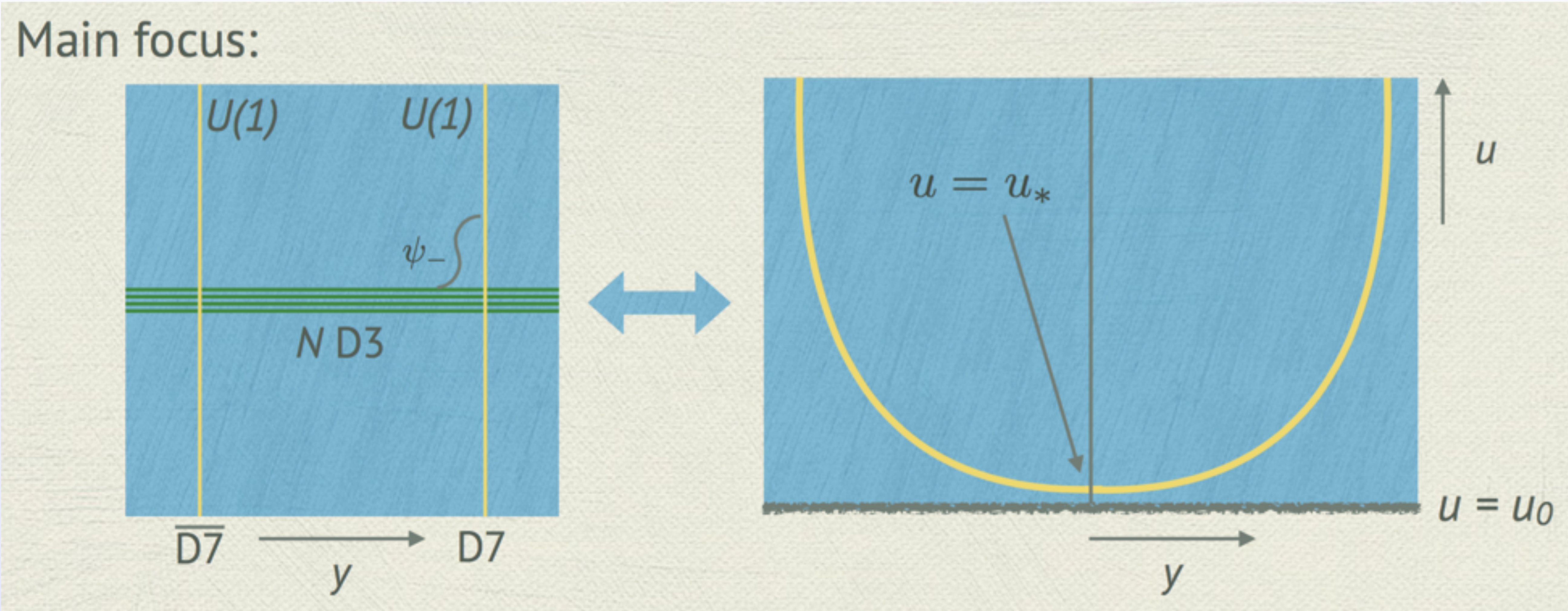
Holography of Defect D7 Branes

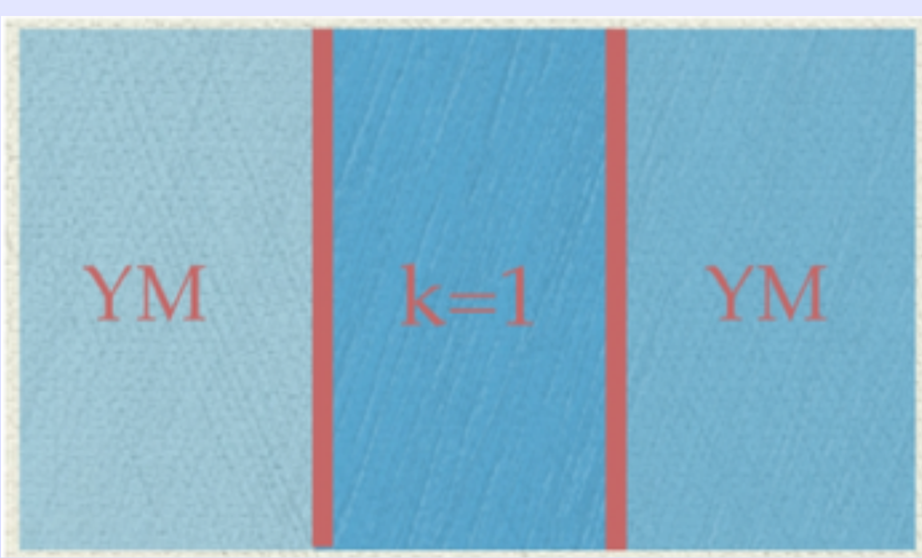




	t	x	y	τ	r	S_5	S_5	S_5	S_5	S_5
D3	x	x	x	x						
D7	x	x	$y(r)$	$\tau(r)$	x	x	x	x	x	x
$\bar{D}7$	x	x	$y(r)$	$\tau(r)$	x	x	x	x	x	x

Holography of Defect D7 Branes



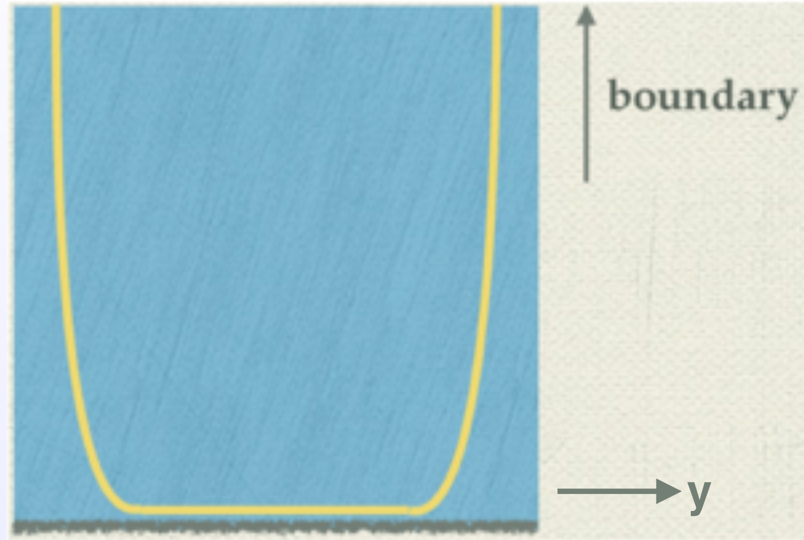


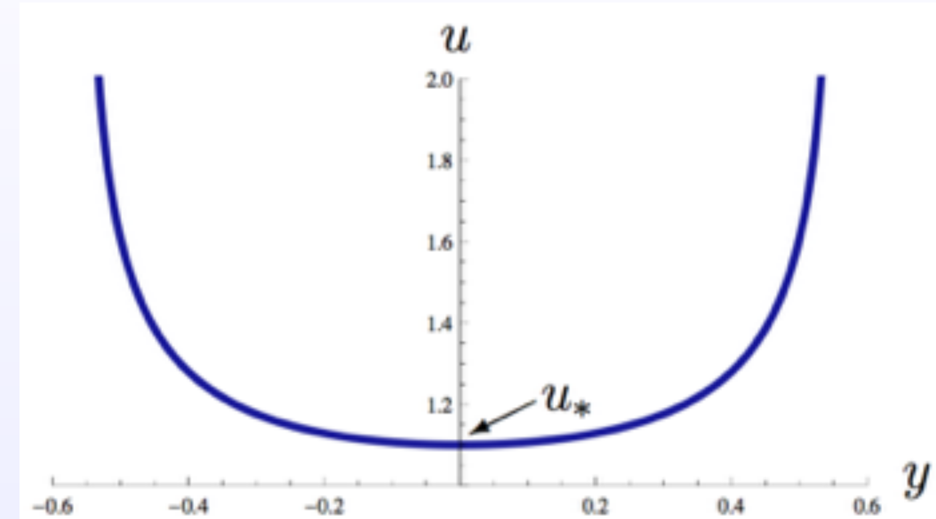
Fractional (?) QH Sample

$$\sigma_{xy}^{U(1)\subset U(N)} = \frac{N}{k}\frac{e^2}{h}$$

[Fujita+Li+Ryu+Takayanagi 0901.0924]

Holography of Defect D7 Branes





Single D7 wrapped on S^5, extended in $x^M = (t, x^1, u)$, S^5 singlet states only

Bosonic fields: $y(x^M)$, $\tau(x^M)$, $a_M(x^M)$

Fields at right-hand defect (left-hand defect has opposite chirality):

operator	Δ	source	vev
$J_- \sim \psi_-^\dagger \psi_-$	1	a_+	a_-
$\mathcal{O}_y \sim \psi_-^\dagger F_{+y} \psi_-$	3	y	y
$\mathcal{O}_+ \sim \psi_-^\dagger F_{+y}^2 \psi_-$	5	a_-	a_+

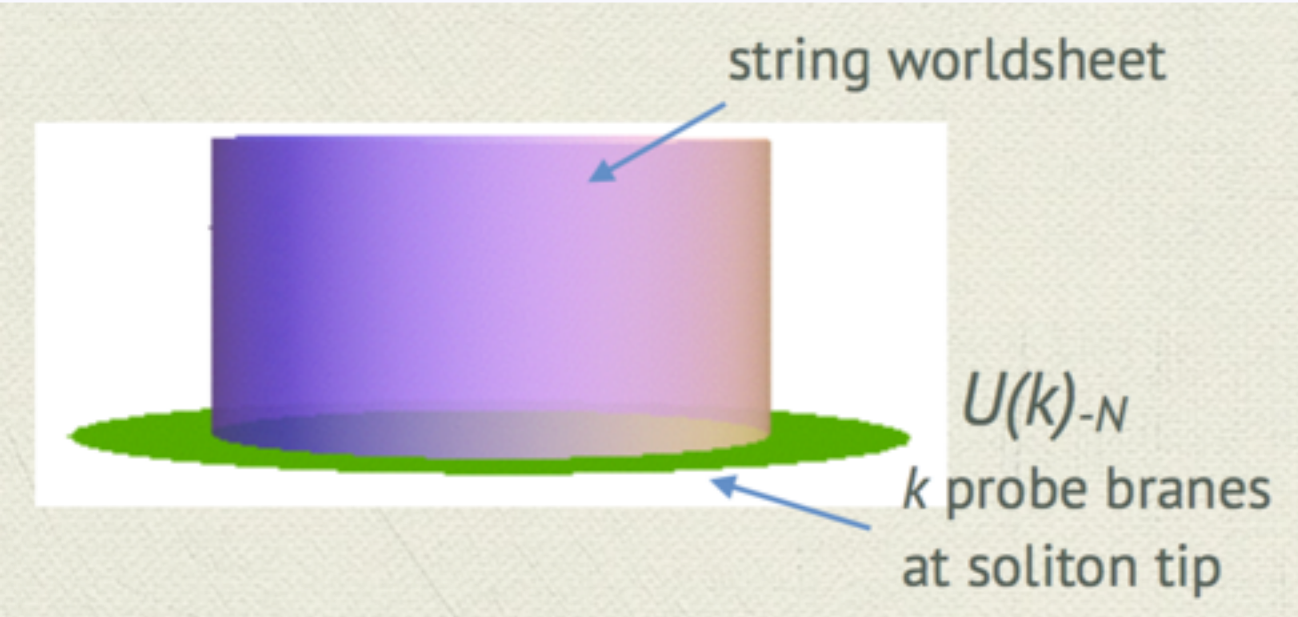
[Harvey+Royston 0804.2854]

Field	Asymptotic form $(w = u/u_0)$
y	$y_0 - \frac{R w_*^3}{4 w^4} + \ldots$
a_-	$a_-^{(4)} w^4 + (\ldots) + a_-^{(0)} + \ldots$
a_+	$a_+^{(0)} + a_+^{(-4)} w^{-4} + \ldots$

[Fujita, Melby-Thompson, Meyer, Sugimoto]

(F statistical SU(N) gauge field strength)

Topology vs. Confinement

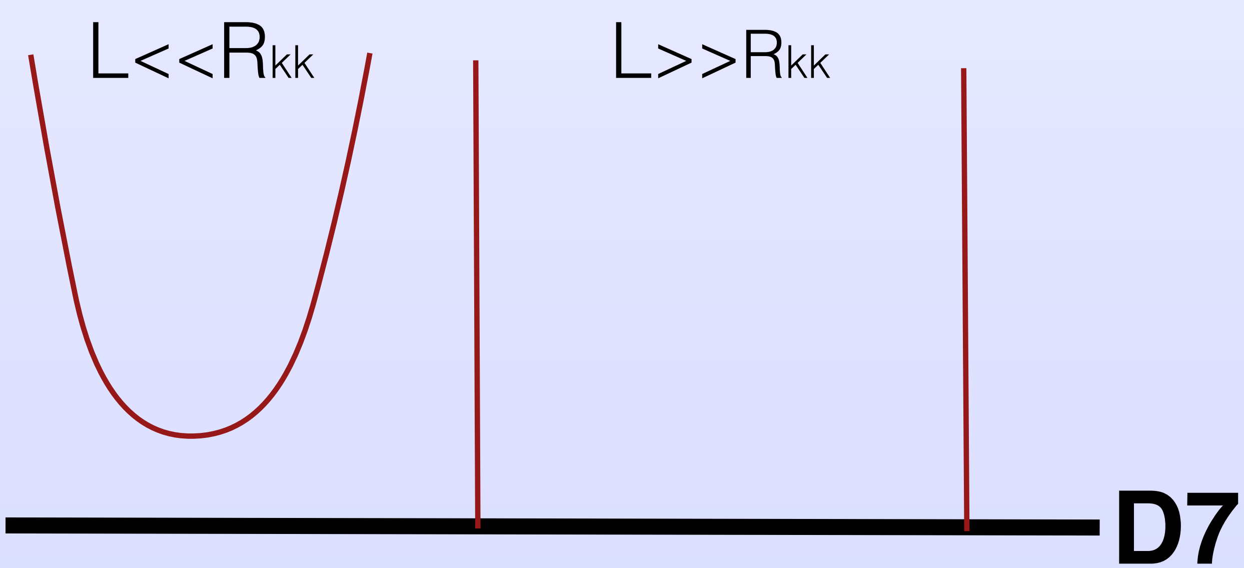


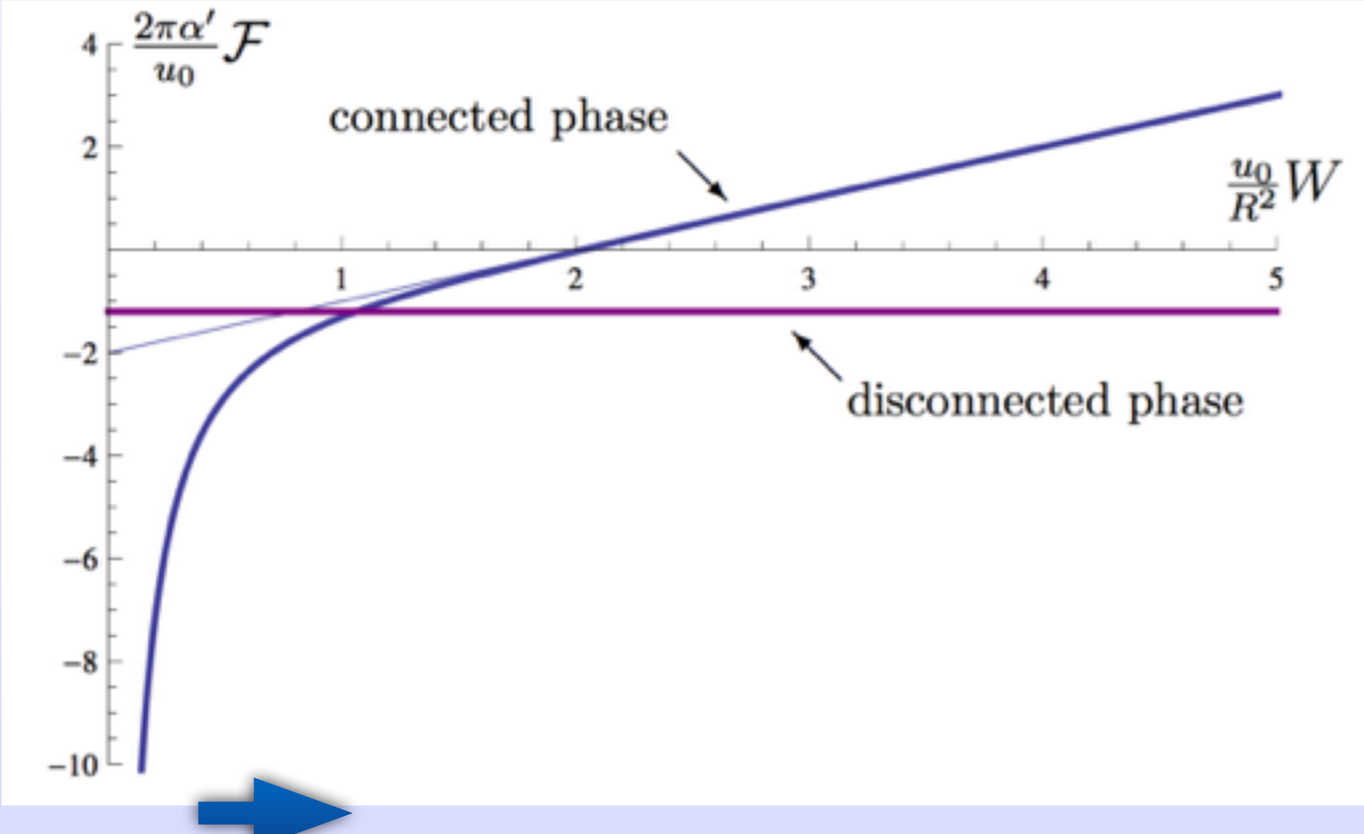
Topological Wilson Loop

Level-Rank Duality

$$SU(N)_k \leftrightarrow U(k)_{-N,-N}$$

[Fujita+Li+Ryu+Takayanagi 0901.0924]



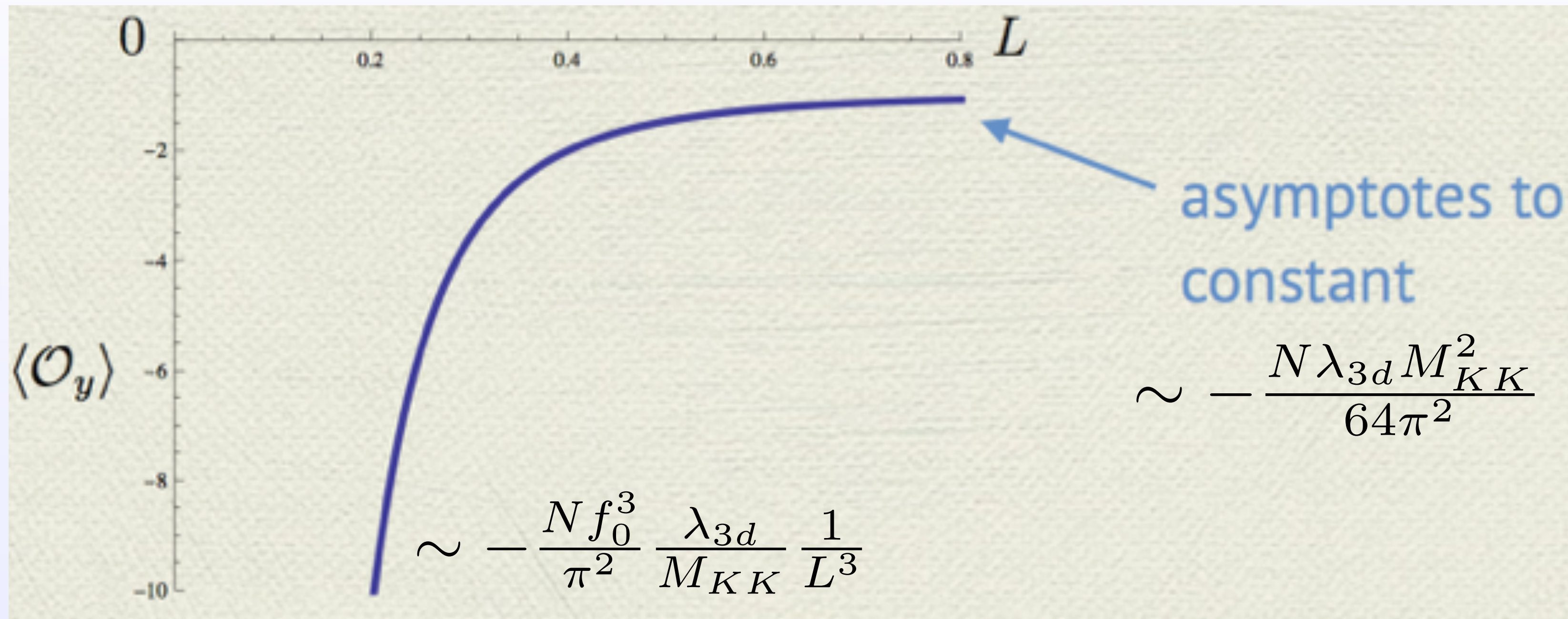


One Point Functions & Anomaly

(1) Scalar condensate:

$$\langle O_y \rangle \sim \frac{\partial S}{\partial L} \sim \langle \psi_-^\dagger F_{+y} \psi_- \rangle$$

Known?



(2) Current:

$$\langle J^+ \rangle = -\frac{N}{4\pi} a_-^{(0)}$$

$$\partial_+ \langle J_- \rangle = \frac{N}{2\pi} \partial_- \mathcal{A}_+$$

Chiral anomaly

(3) Chiral edge bosons: $a_\pm^{(0)} \sim \partial_\pm \phi$

$\mathcal{A}_+ = 0 \Rightarrow \partial_+ \phi = 0$

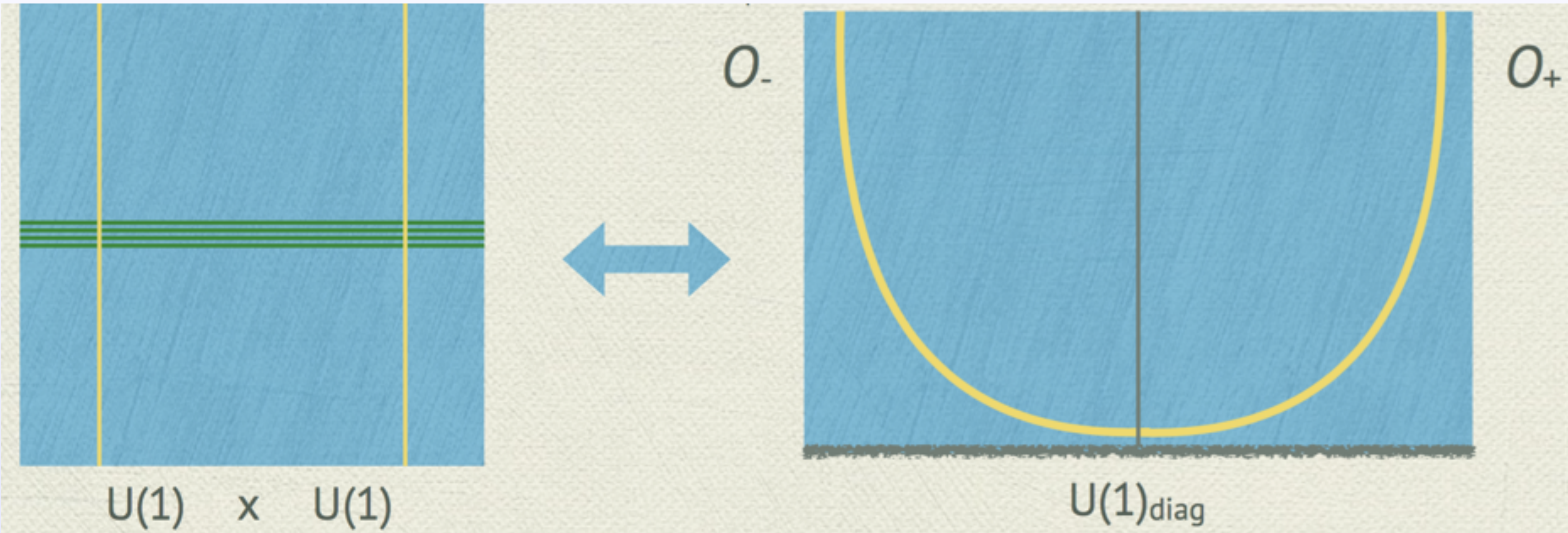
(4) Dim. 5 operator:

$$\langle \mathcal{O}_+ \rangle = \frac{\delta S_{total}^{o.s.}}{\delta \mathcal{C}_-} = -\frac{N}{4\pi} \frac{c_+}{8\pi\alpha'} \frac{u_*^4}{R^8} e^{-\xi} \quad \Rightarrow \quad \langle \mathcal{O}_- \mathcal{O}_+ \rangle \simeq -\frac{N}{4\pi} \frac{u_0^8 e^{2c_0}}{R^{16}} e^{-(2M_{KK})2L}$$

Known?

Edge Chiral Symmetry Breaking

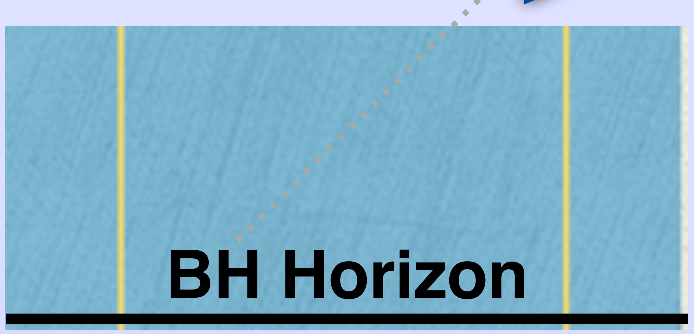
$\langle J_+ \rangle \sim \partial_+ \phi'$ $\langle J_- \rangle \sim \partial_- \phi$



Chiral currents: Flat part of the connection $a^{(0)} = d\phi$

Shift in $\phi + \phi'$ doesn't change $\int_L^R a^{(0)} = \int_L^R d\phi = \phi - \phi'$ → U(1)$_{\text{diag}}$

Shift in $\phi - \phi'$ does → NG boson ("Pion", as in **[Sakai-Sugimoto]**)



(lifted by quantum effects)

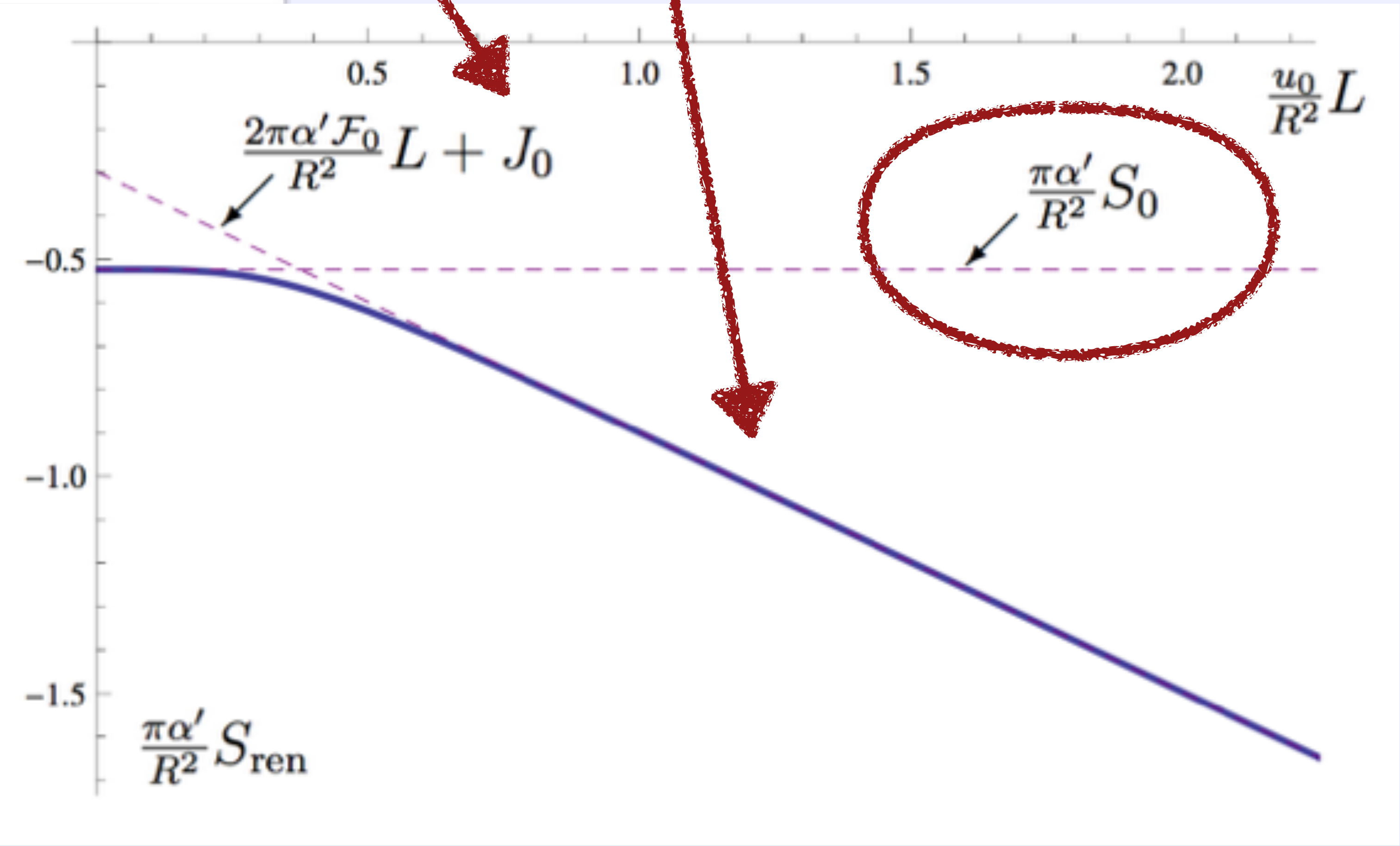
(restored at T>>M$_{\text{KK}}$)

Edge Chiral Symmetry Breaking

$$\langle \psi_L^\dagger \mathcal{P} e^{i\int_R^L A} \psi_R \rangle = e^{-S_{\rm ren}^{F1}}$$

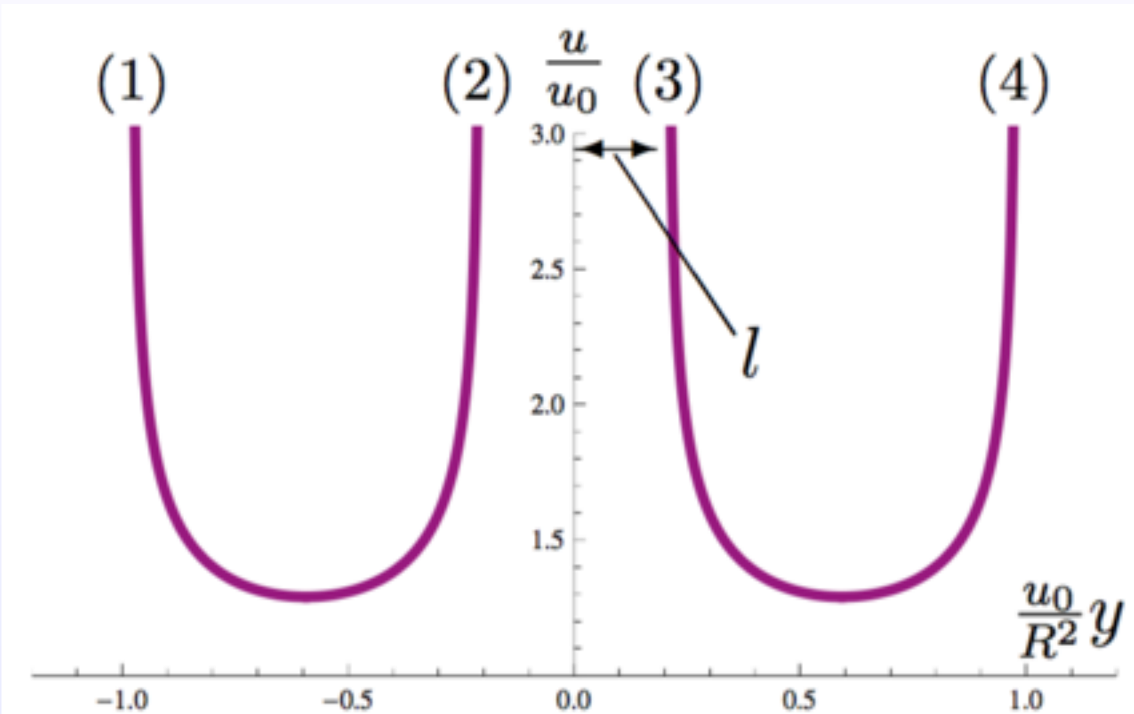
[Aharony+Kutasov 0803.3547]

Edge mode
=
Nambu-Goldstone boson of broken chiral symmetry

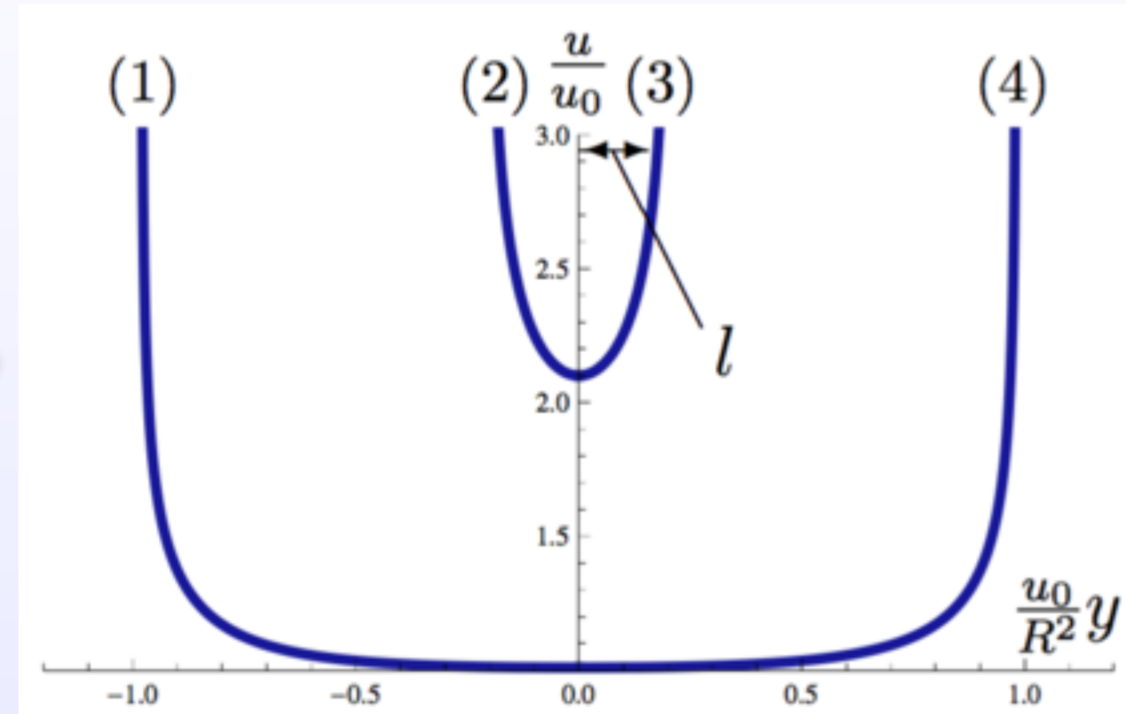


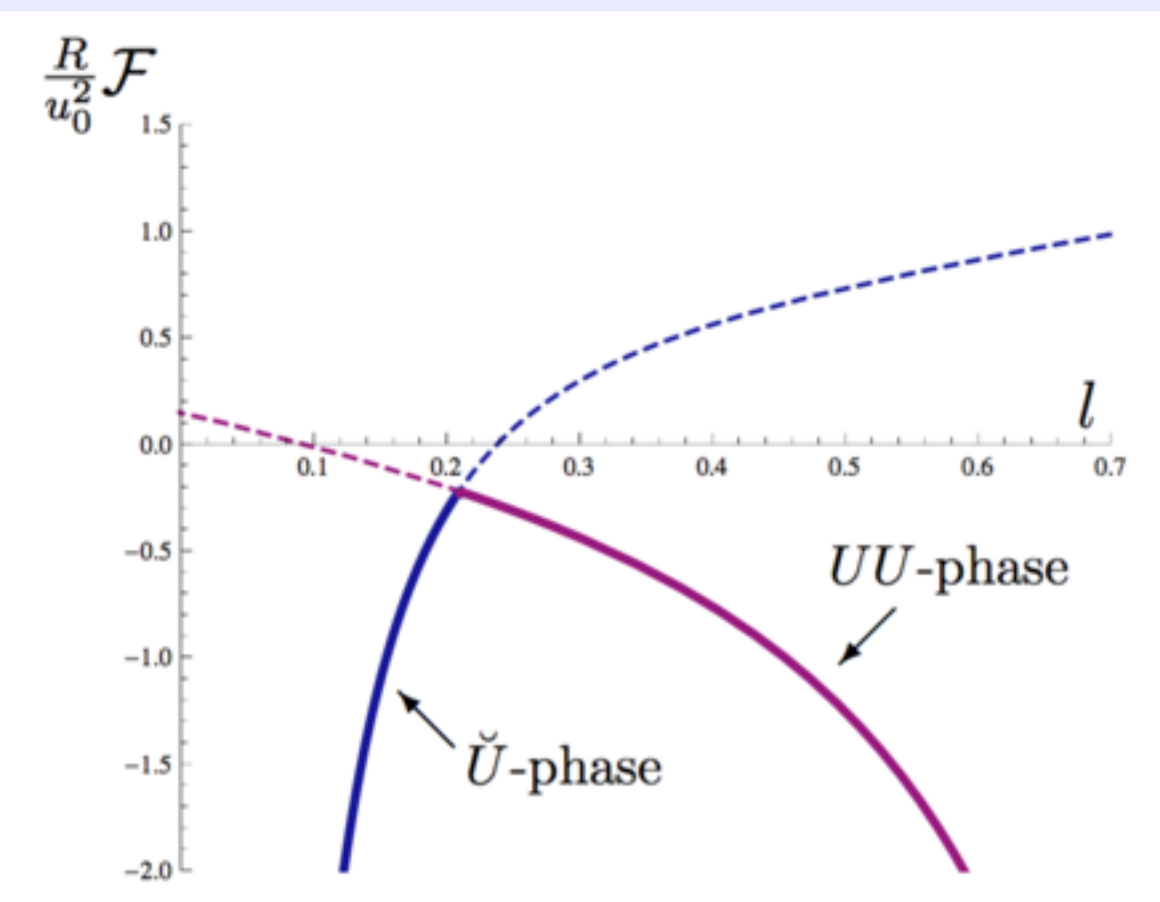
Known?

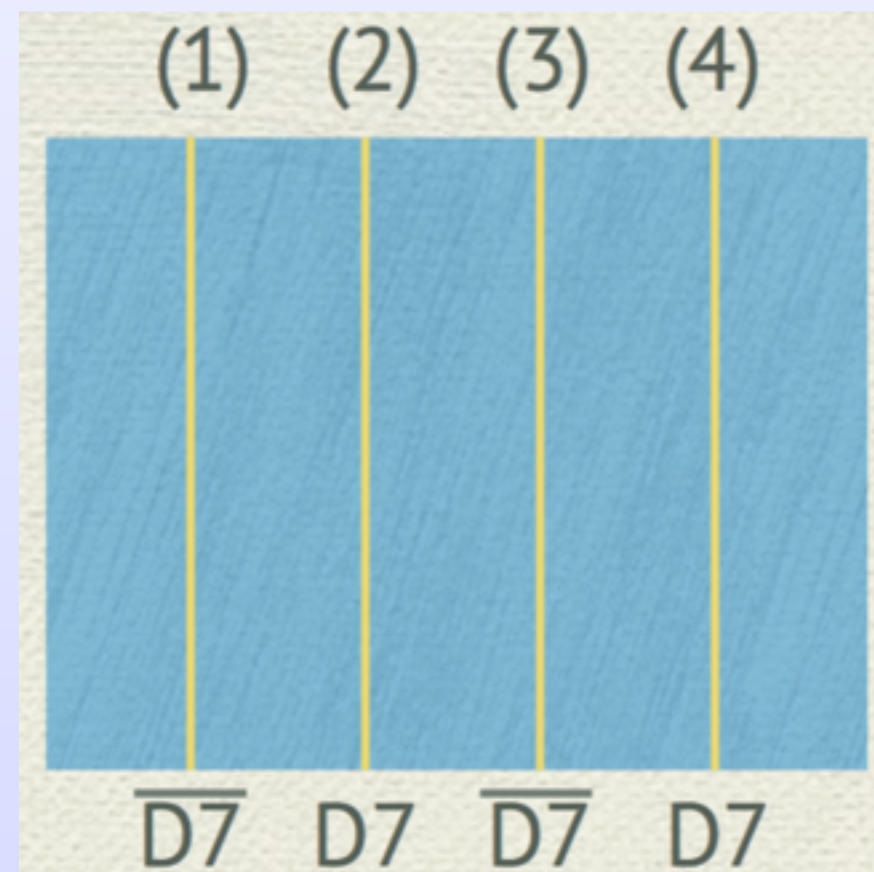
Correlations and Phase Transitions



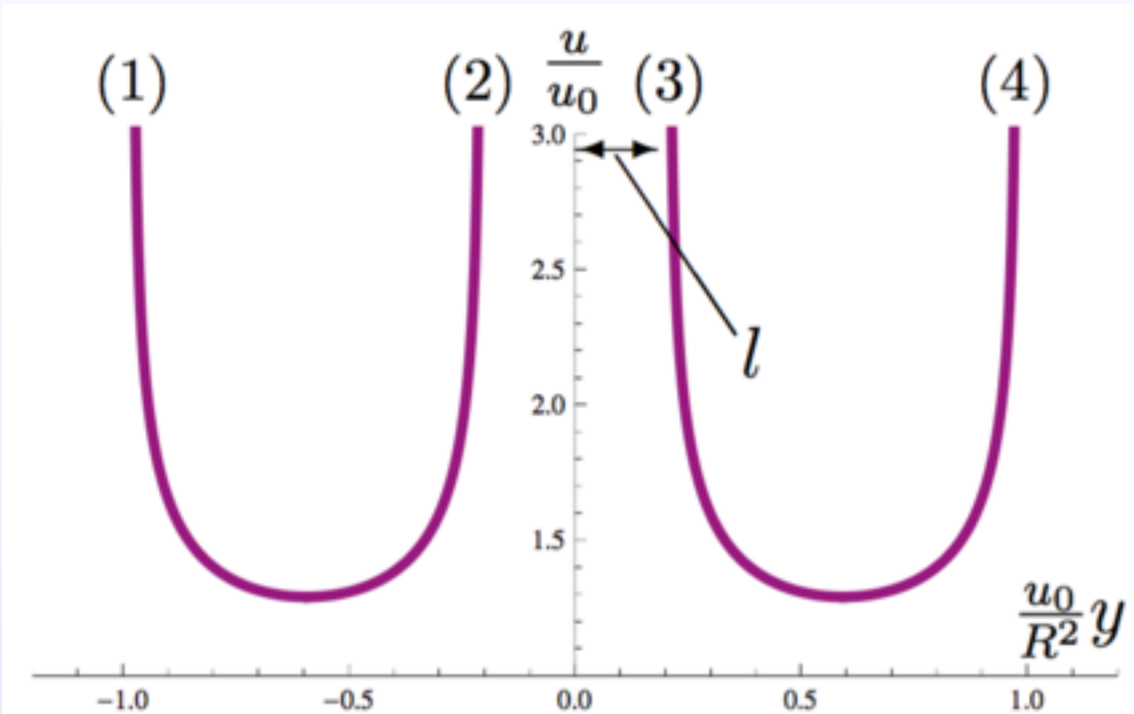
$l_c \sim L_{KK}$

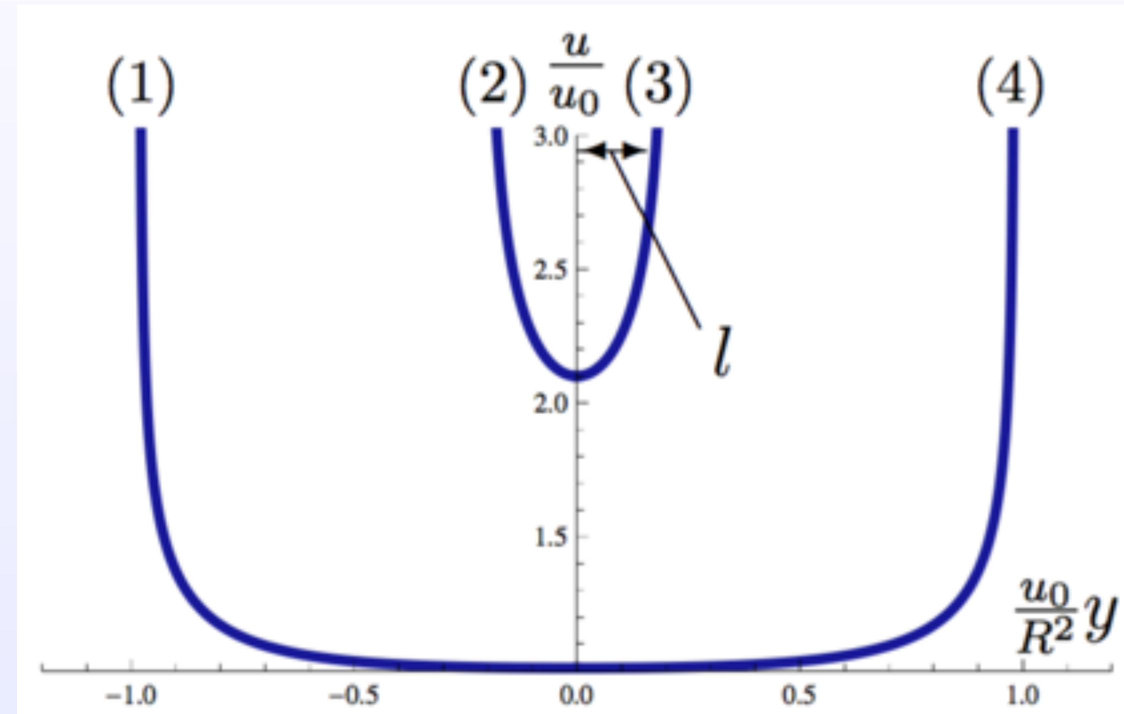






Correlations and Phase Transitions





Dimension 5 Correlations

$\mathcal{O}_\pm \sim \psi^\dagger_\mp F^2_{\pm y} \psi_\mp$

Large l > 1/Gap: adjacent correlations $\langle \mathcal{O}_-^{(1)} \mathcal{O}_+^{(2)} \rangle \neq 0 \quad \langle \mathcal{O}_-^{(3)} \mathcal{O}_+^{(4)} \rangle \neq 0$

Small l < 1/Gap: distant correlations $\langle \mathcal{O}_+^{(2)} \mathcal{O}_-^{(3)} \rangle \neq 0 \quad \langle \mathcal{O}_-^{(1)} \mathcal{O}_+^{(4)} \rangle \neq 0$

Known?

(F statistical gauge field)

(vanish at T > gap)

Correspondence between FQHE and 2D QCD

(1) Basically 2+1 dimensional holographic domain wall fermions = 2D holographic QCD with all its features (chiral symmetry breaking, Goldstone modes, anomaly)

(2) By compactifying and T-dualizing perpendicular to the defect, the system becomes the holographic dual to 2D QCD of **[Yee-Zahed 1103.6286]**

(3) LEEA of (abelian) FQH States: U(1) CS theory

LEEA of single flavored 2D QCD:
U(1) DBI-CS Theory on a D7 brane **[Yee-Zahed 1103.6286]**

- Anyonic quasiparticle (couples with unit charge to the statistical gauge field) ~ Fundamental quark (baryon number charge 1/N) ~ Fundamental string ending on D7 brane

- Electron ~ Baryon vertex (bound state of N quarks has baryon number charge (electric charge) 1)

Conclusions/Outlook

- YM-CS theory with level-changing defects in Holography
- Similarities to FQH samples

$$\sigma_{xy}^{U(1)\subset U(N)} = \frac{N}{k}\frac{e^2}{h}$$

[Fujita+Li+Ryu+Takayanagi 0901.0924]

- Chiral Symmetry Breaking between Edges

- VEVs involving edge fermions & statistical gauge field, Transitions between samples, Dim. 5 correlations

- Edge transport, Impurity scattering, Relation to 2D QCD, Backreaction, Tunneling of anyons/electrons, …
- Non-abelian (YM)CS in strongly coupled systems