TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Three- and Four-point correlators of excited bosonic twist fields

Pascal Anastasopoulos

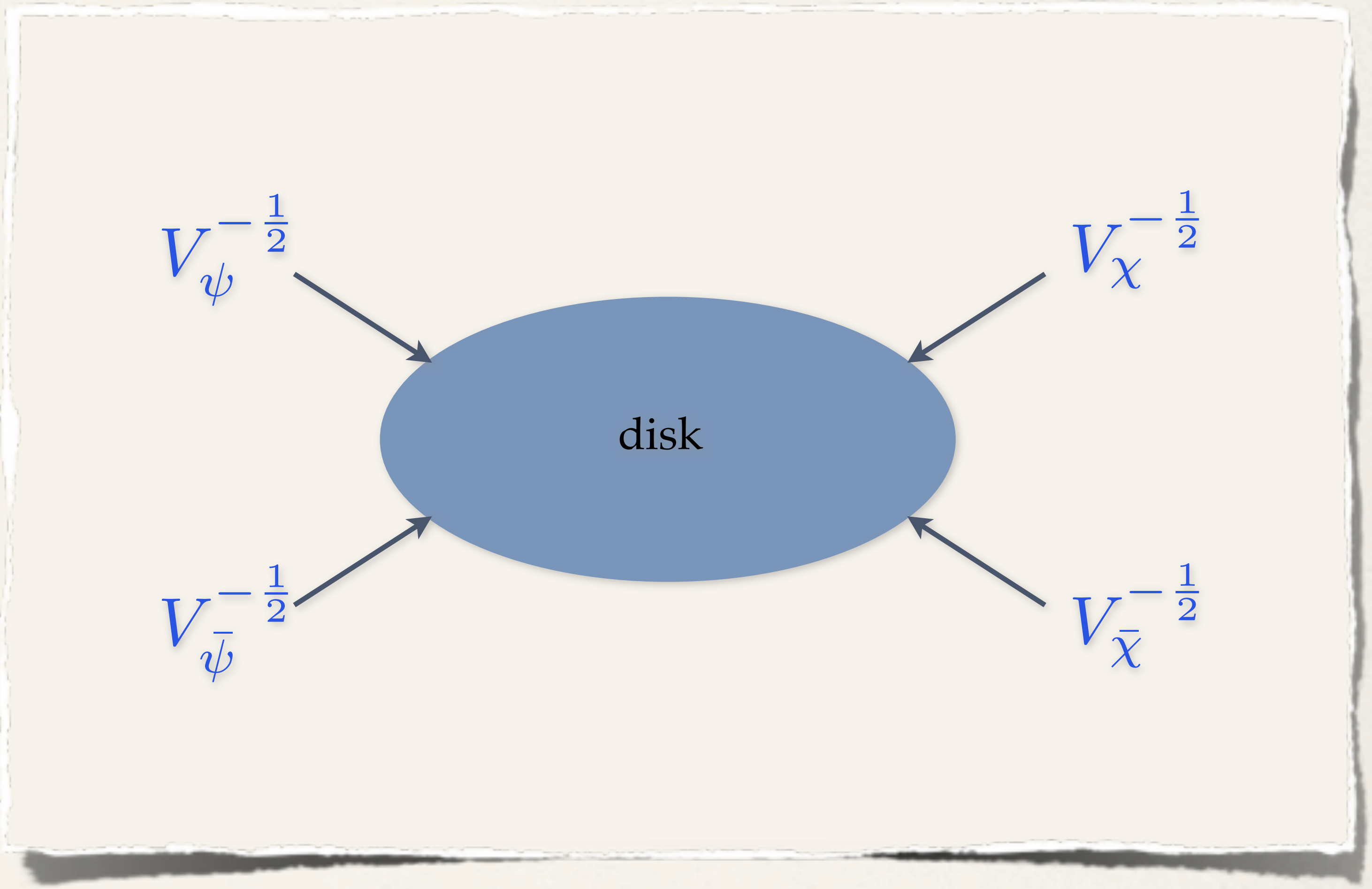
arxiv: 1305.7166

with M. D. Goodsell and R. Richter.

Corfu - 08/09/2013

Plan of the talk

- Motivation
- D-brane model building
- Three-point correlators
- Four-point correlators
- Conclusions


$V_\psi^{-\frac{1}{2}}$
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- Particular interest have the intersecting D-brane scenarios.

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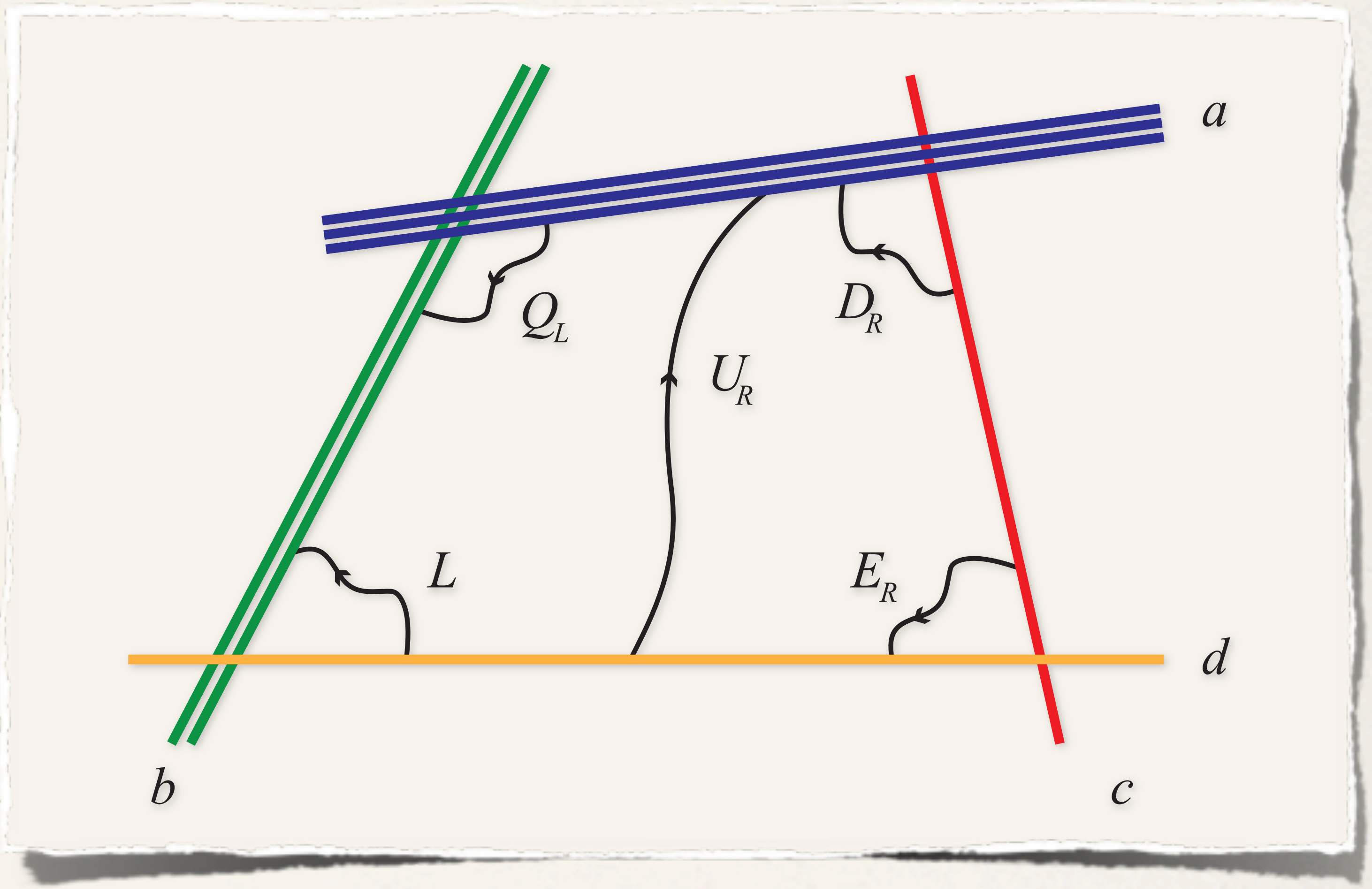
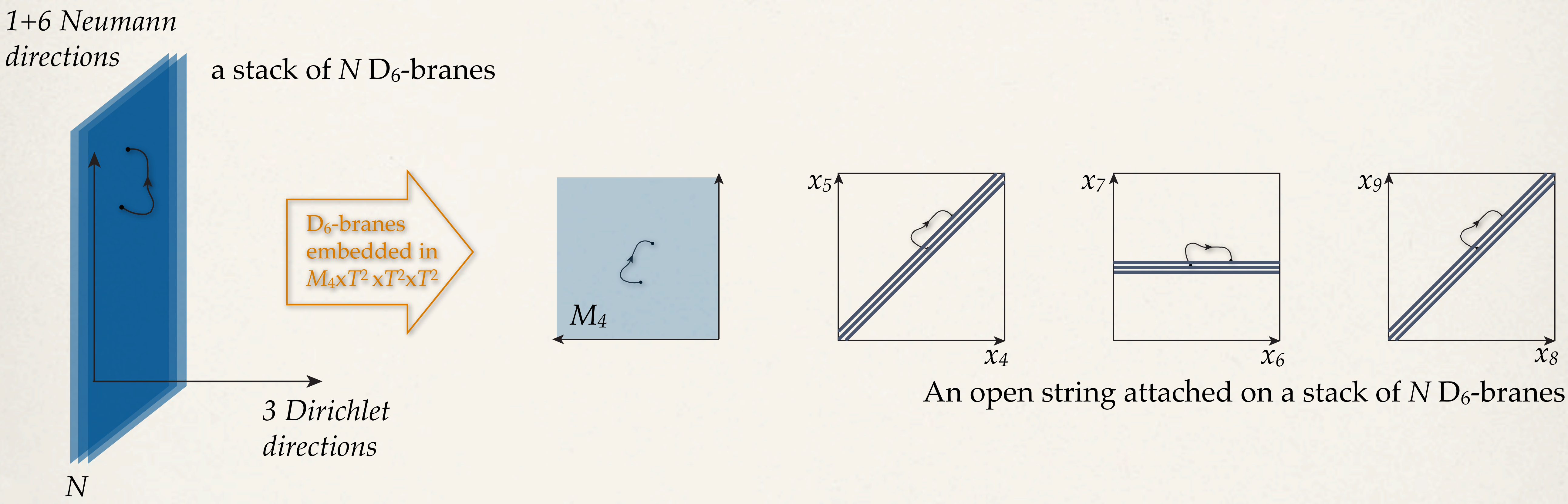
- It is very interesting to study their decay channels and their lifetimes.
- In order to do so, we have to extend our tools by evaluating the correlation functions of three and four twisted states.



D-brane compactifications

Our tools

- We focus on type IIA constructions in a $T^2 \times T^2 \times T^2$ space with intersecting D6 branes:



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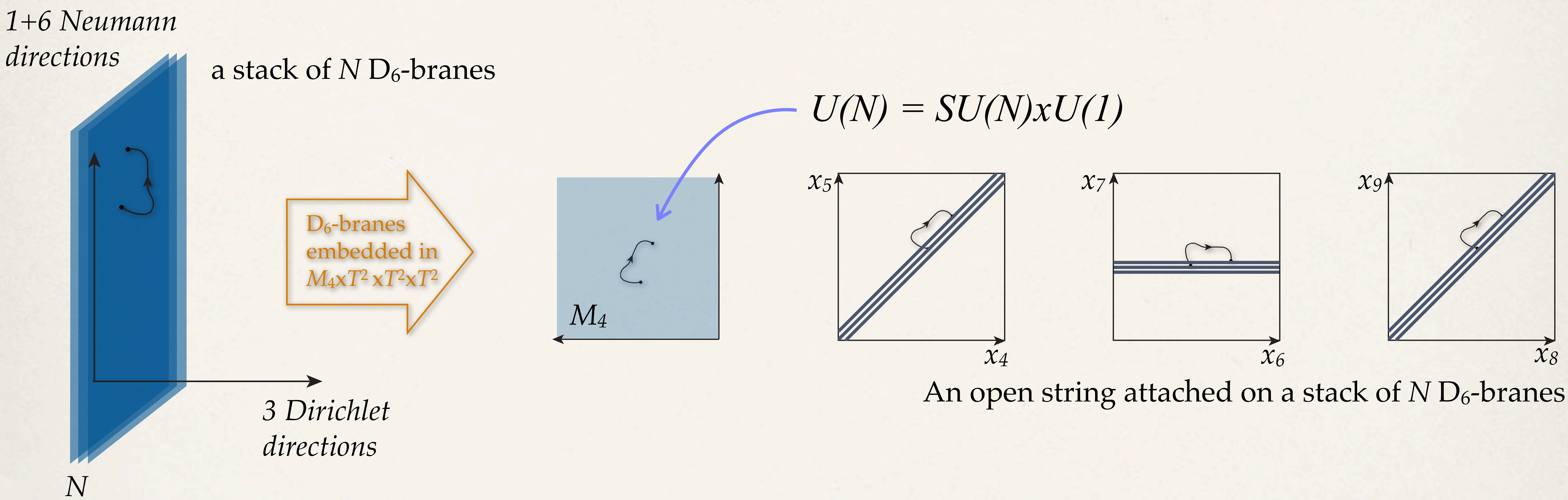

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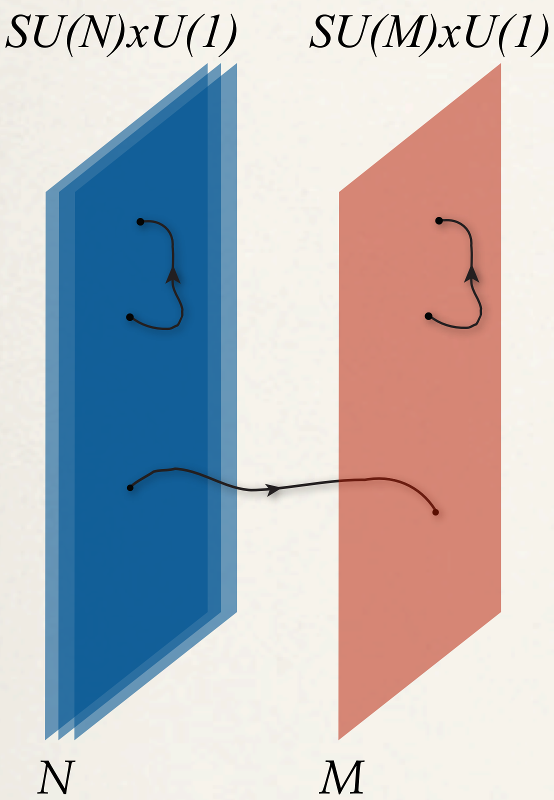

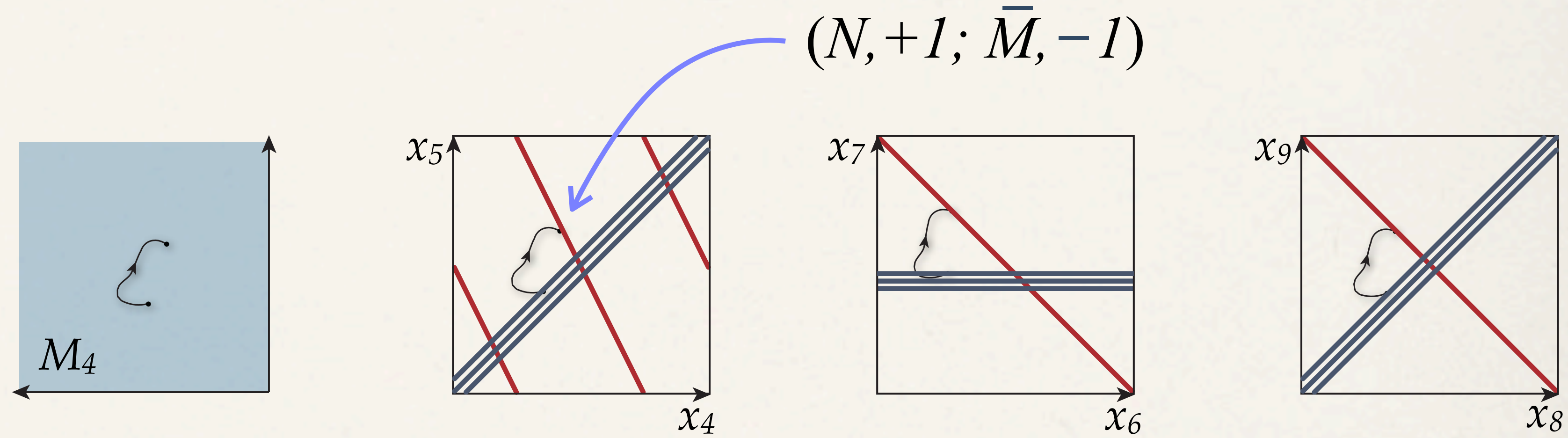

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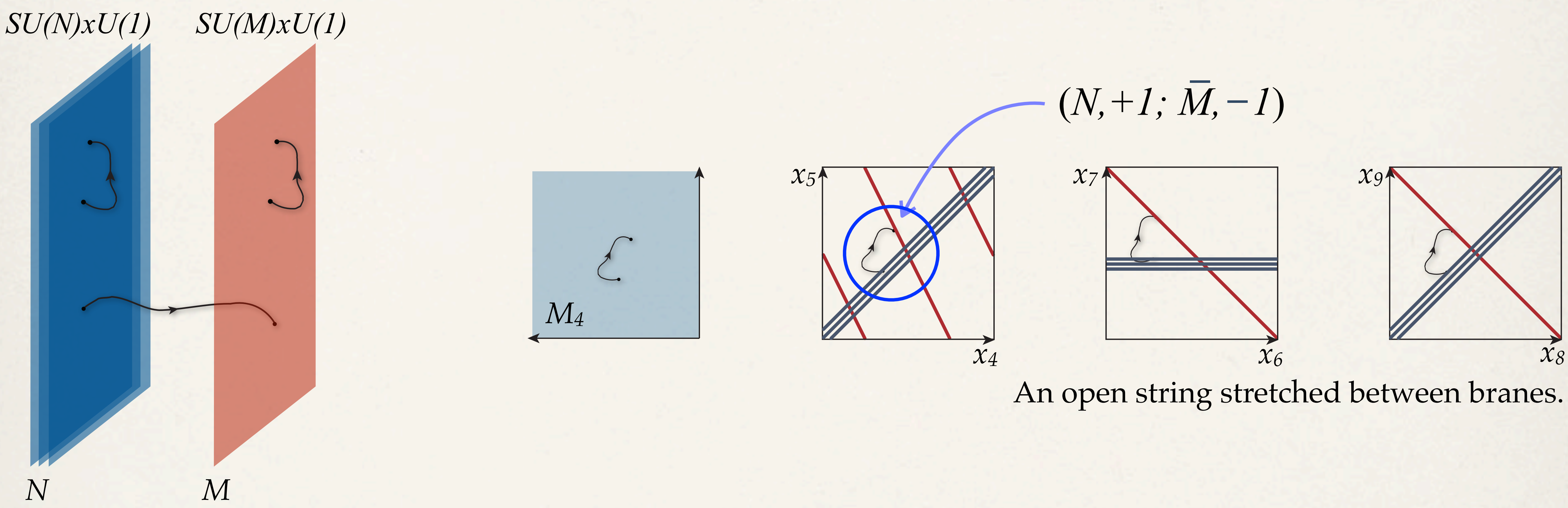

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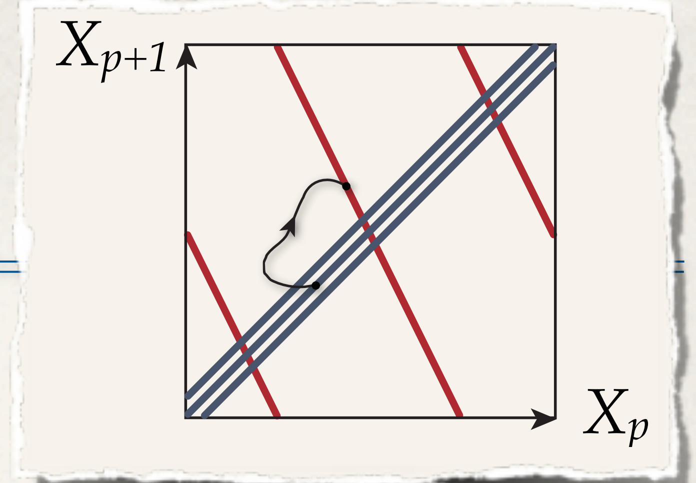
- Strings with both ends on a stack of branes give rise to $U(N) = SU(N) x U(1)$ group.
- Strings stretched between different stacks transform as bifundamentals.
- Lets focus more on these states at the intersections.

Quantization at angles



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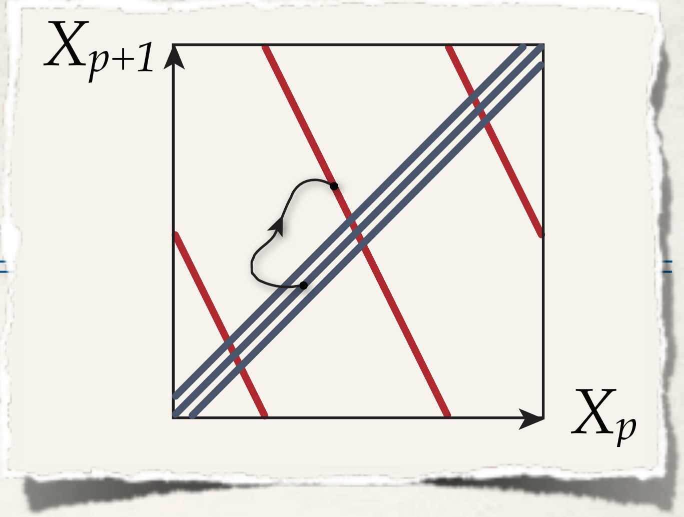

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- Mode expansion ($Z^p = X^p + iX^{p+1}$):

$$\partial Z^I(z) = \sum_n \alpha^I_{n-\theta_I}\ z^{-n+\theta_I-1} \qquad \partial \bar{Z}^I(z) = \sum_n \alpha^I_{n+\theta_I}\ z^{-n-\theta_I-1}$$

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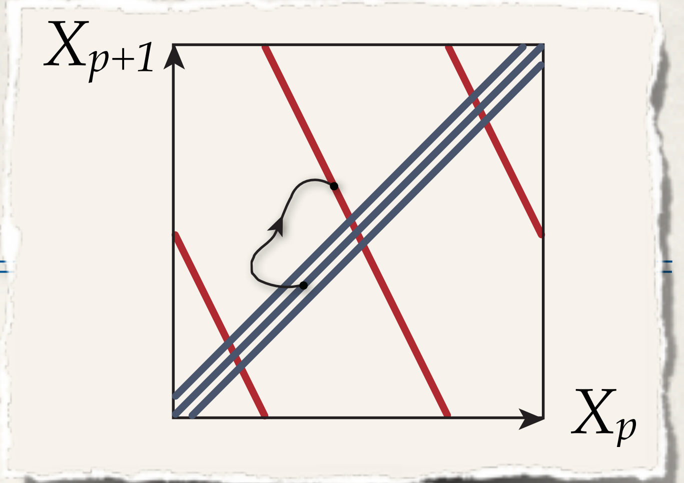

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- For the quantization we define the commutator/anticommutators:

$$[\alpha^I_{n\pm\theta}, \alpha^{I'}_{m\mp\theta}] = (m \pm \theta)\, \delta_{n+m}\, \delta^{II'} \qquad \{\psi^I_{m-\theta_I}, \psi^{I'}_{n+\theta_I}\} = \delta_{m,n}\delta^{II'}$$

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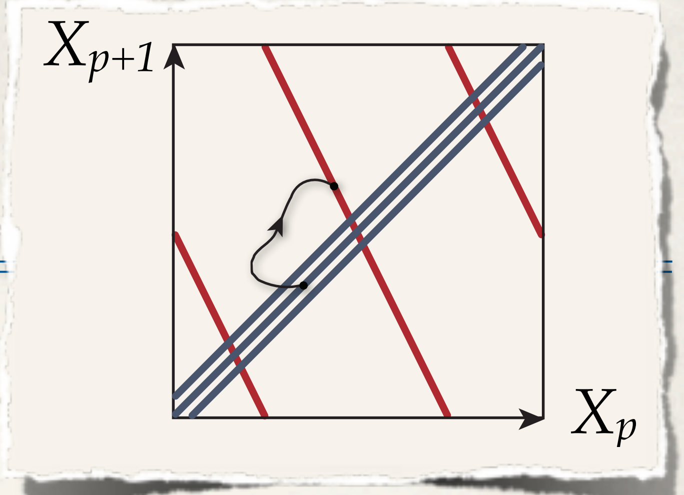

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- And the three vacua that these states act on:

WS bosonic: $|\,\theta^{ab}_{1,2,3}\,\rangle_B$

WS fermionic (NS): $|\,\theta^{ab}_{1,2,3}\,\rangle_{NS}$

WS fermionic (R): $|\,\theta^{ab}_{1,2,3}\,\rangle_R$

NS sector at the intersections

- Lets consider the NS sector for simplicity.

- The first states (which are also massless by SUSY) are:

$$\Phi \quad : \qquad \prod_I \psi_{-\frac{1}{2}+\theta_I} | \, \theta^{ab}_{1,2,3} \, \rangle_{B \otimes NS} \qquad M^2 = (1 - \frac{1}{2}(\theta_1 + \theta_2 + \theta_3))M_s^2 = 0$$

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$$\tilde{\Phi} \quad : \quad \alpha_{-\theta_1} \prod_I \psi_{-\frac{1}{2}+\theta_I} |\, \theta^{ab}_{1,2,3} \,\rangle_{B\otimes NS} \qquad\qquad M^2 = (1 - \frac{1}{2}\sum_I \theta_I + \theta_1)M_s^2 = \theta_1 M_s^2$$

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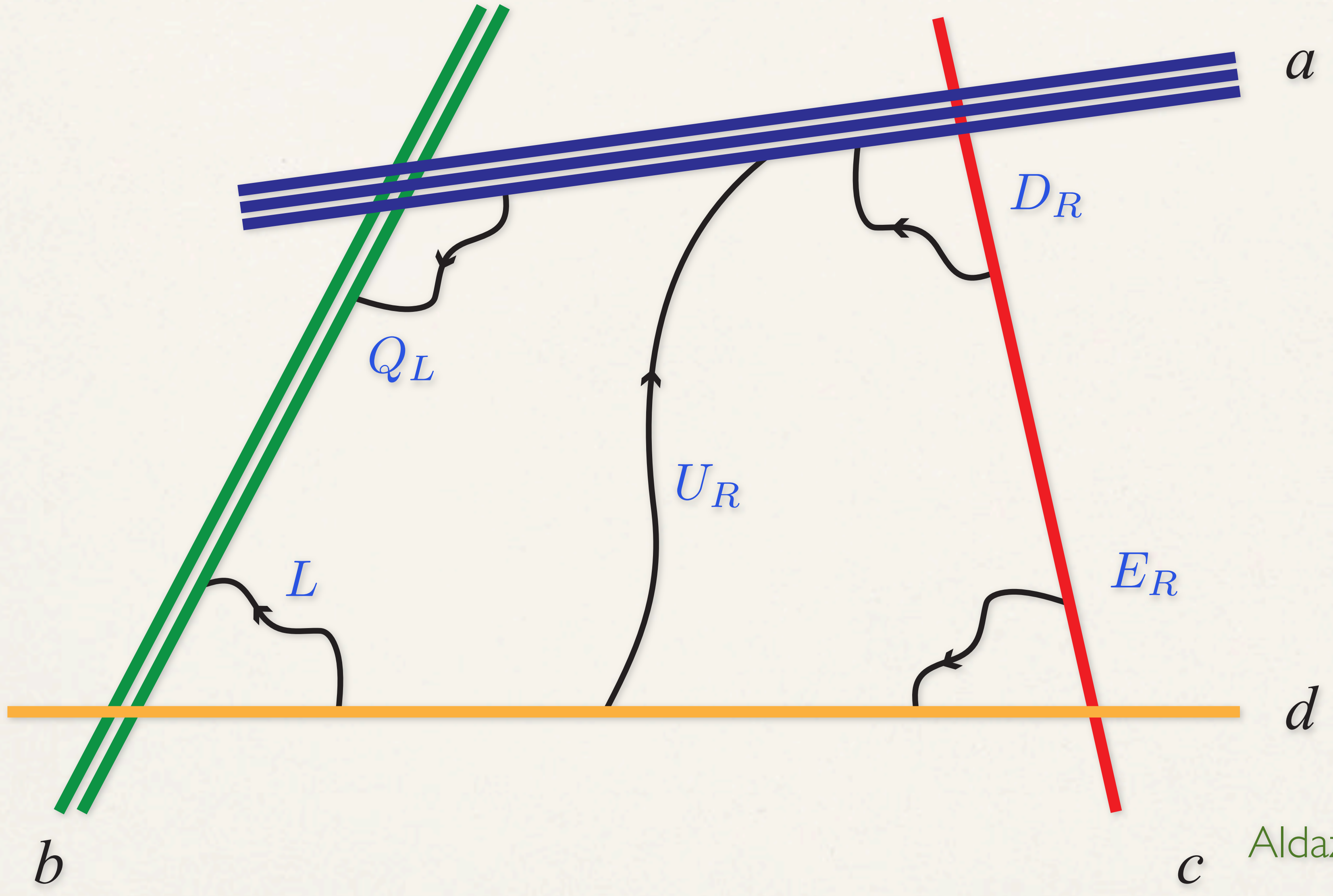
- If the string scale is low, and the angles are small, such states have very low masses.

D-brane worlds

- In semi-realistic D-brane compactifications, the SM matter fields are massless states, living at the intersections:



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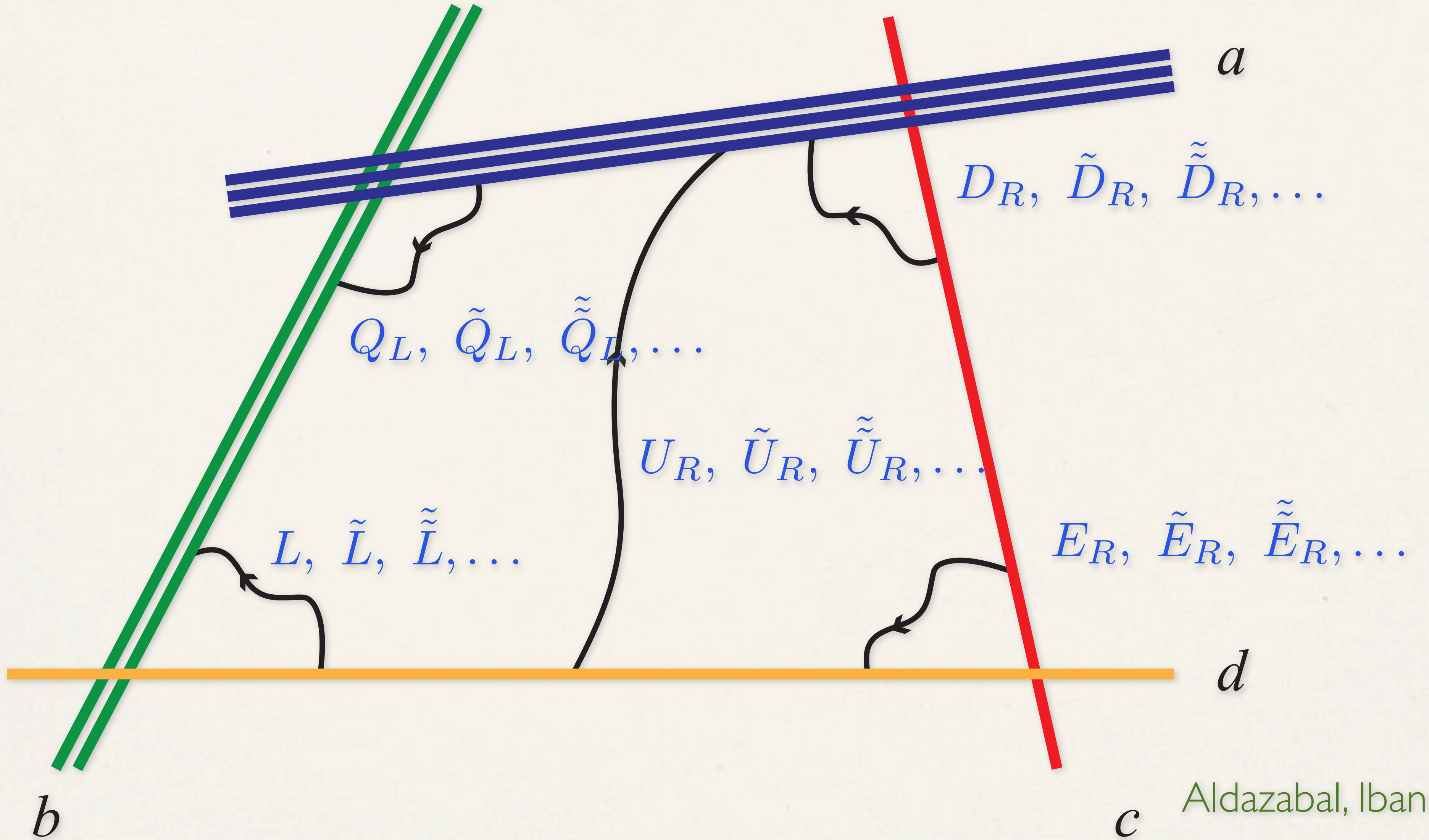

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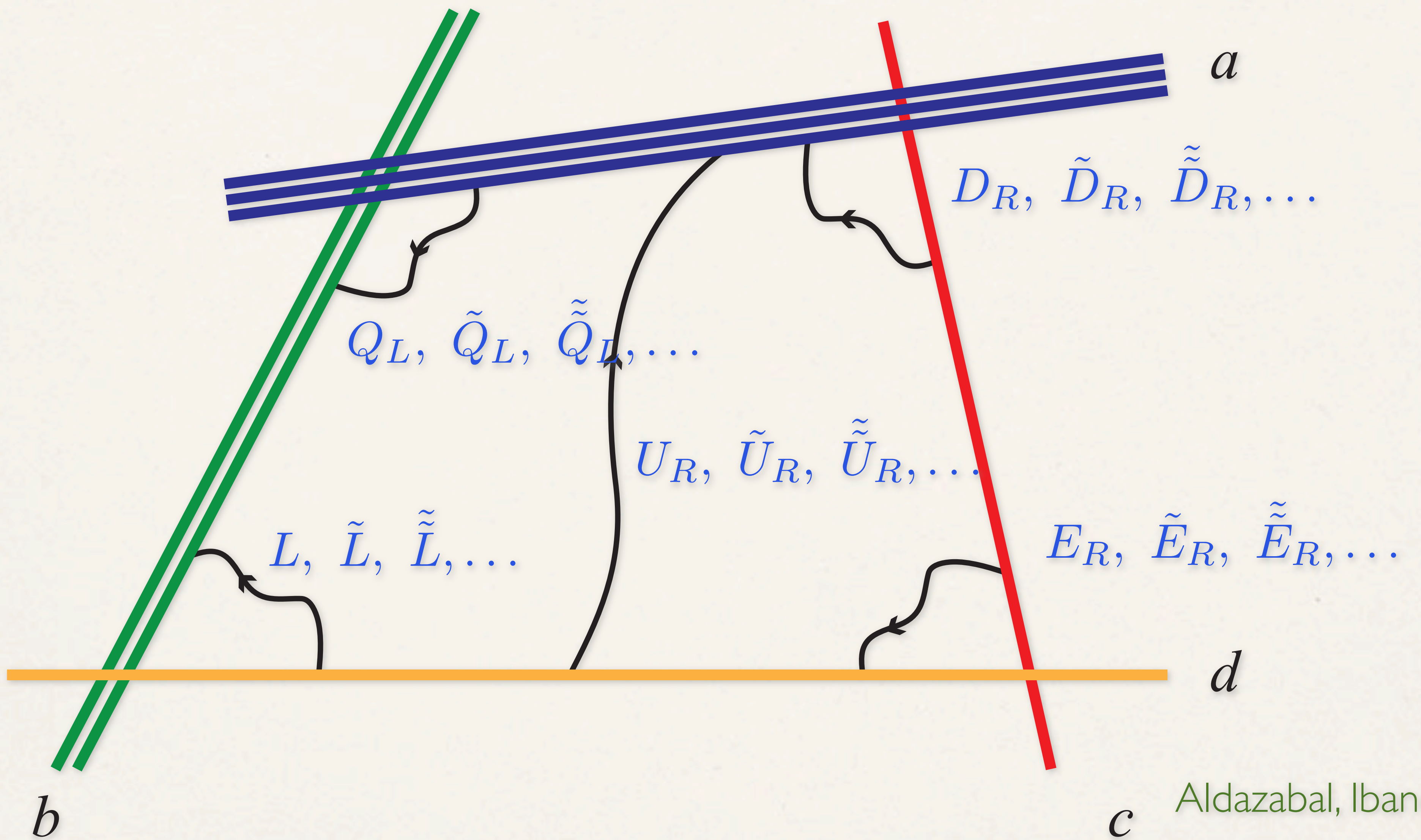

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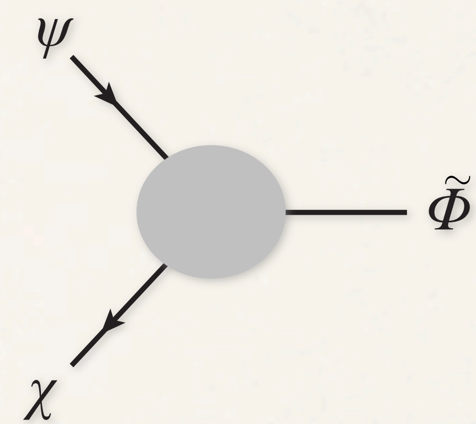
- However, there is a whole tower of stringy excitations with same quantum numbers.

- The study of the decay channels and the lifetimes of such states is very interesting.

Amplitudes with outgoing excited states

- We wand to compute: the decay amplitudes of two chiral fermions and a scalar:

$\langle \tilde{\Phi}\ \psi\ \chi \rangle =$



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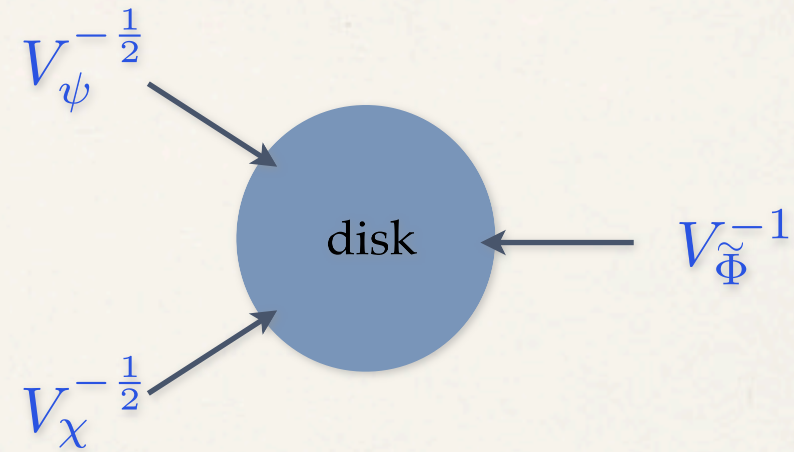

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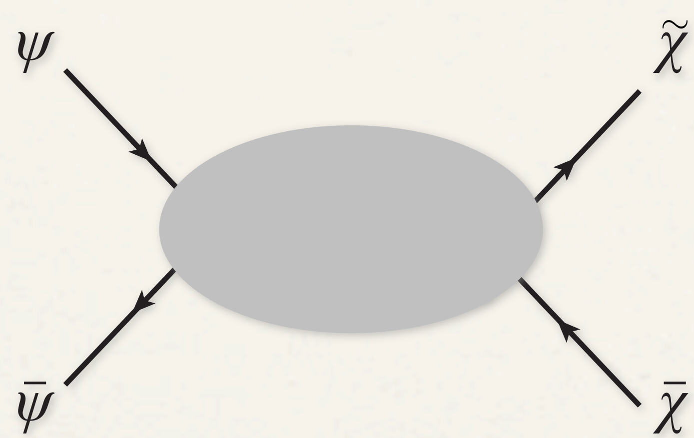

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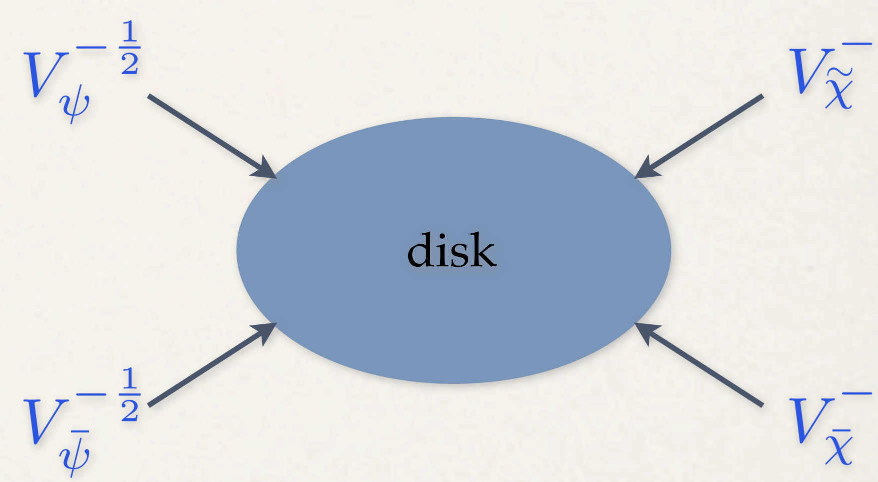

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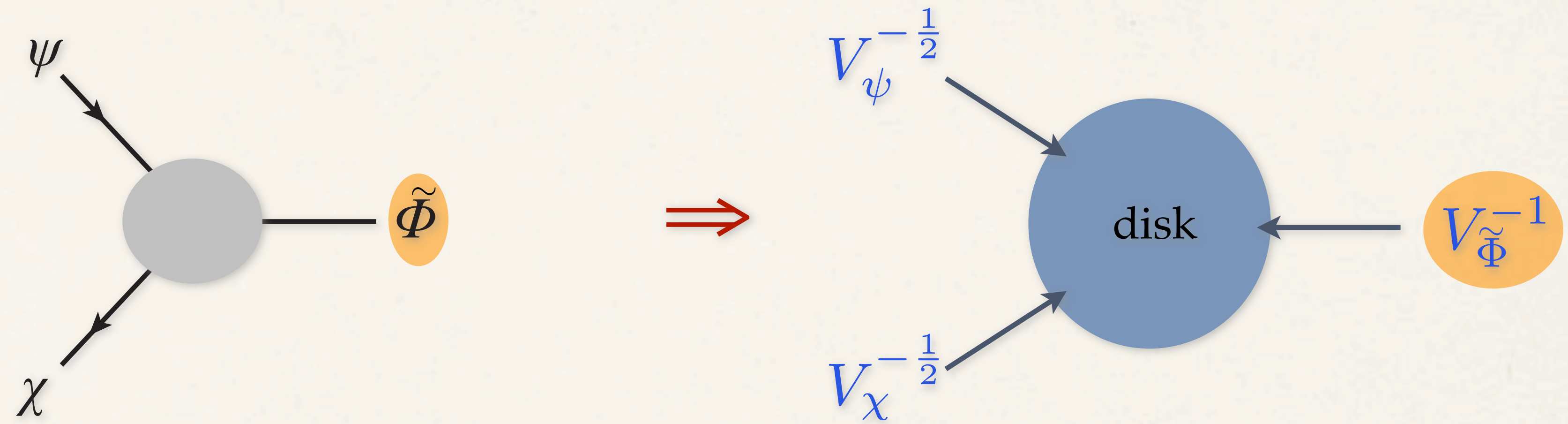

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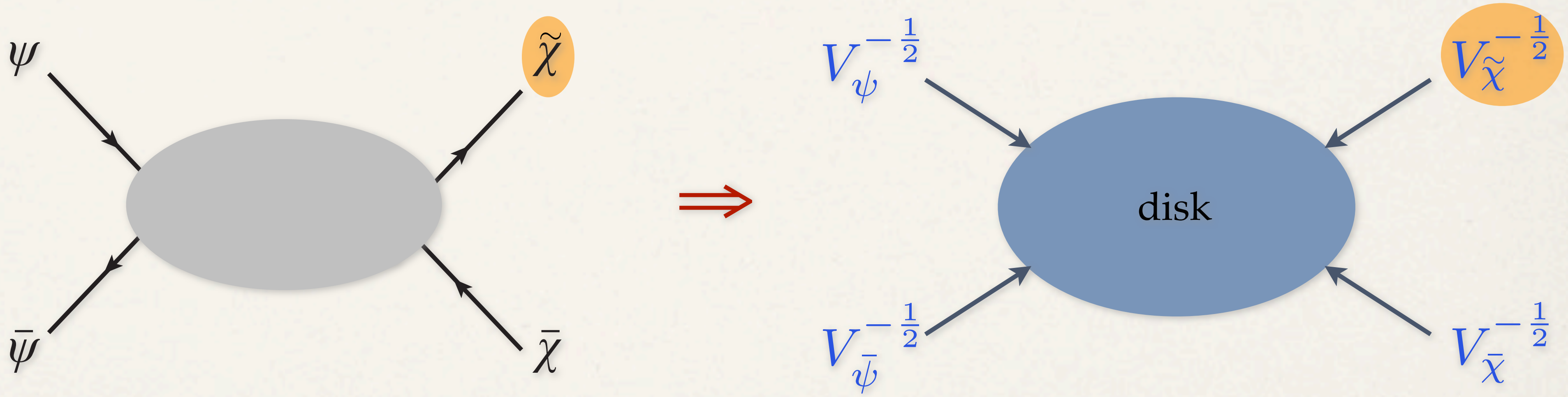

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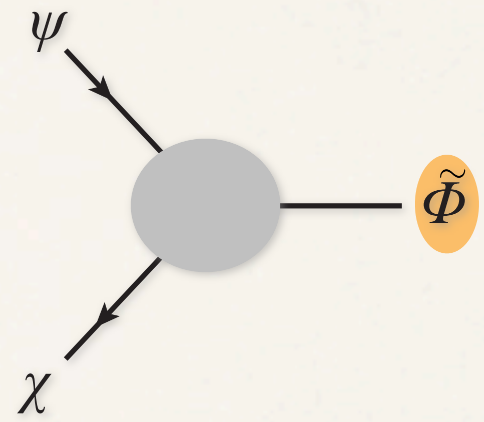

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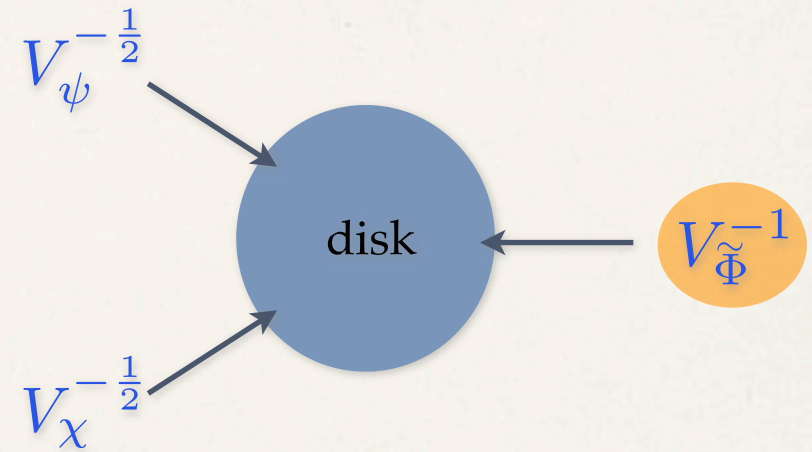

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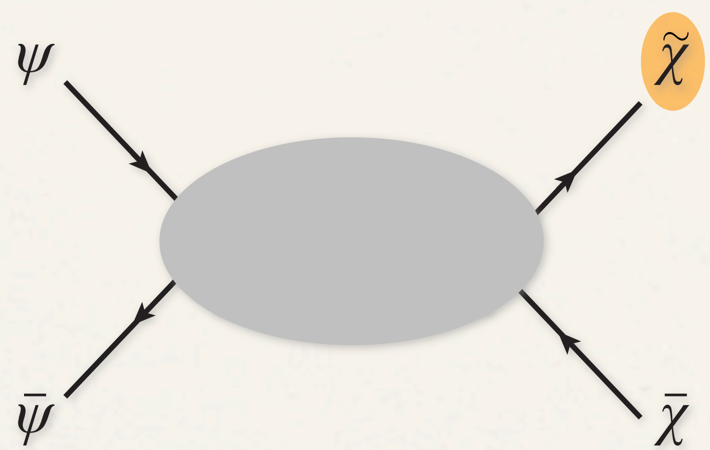

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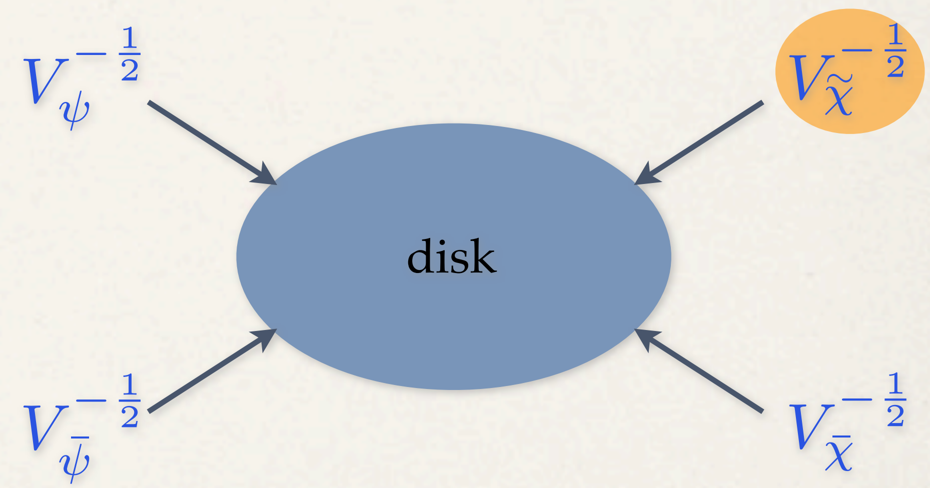

- Two difficulties: 1. Vertex operators

  2. Bosonic twist field correlator

1. Vertex Operators

- For the NS-sector we have the following dictionary

positive angle θ

$$
\begin{array}{lcl}
|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \sigma_\theta^+ \\
\alpha_{-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \tau_\theta^+ \\
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\alpha_{\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \tau^-_{-\theta} \\
(\alpha_{\theta})^2\,|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \omega^-_{-\theta} \\
\psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \sigma^-_{-\theta} \\
\alpha_{\theta}\,\psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \tau^-_{-\theta} \\
(\alpha_{\theta})^2\ \psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \omega^-_{-\theta}
\end{array}$$

- For the R-sector apply the following dictionary

positive angle θ

$$|\,\theta\,\rangle_{B\otimes R} \quad : \quad e^{i(\theta-1/2)H}\ \sigma^+_\theta$$

negative angle θ

$$|\,\theta\,\rangle_{B\otimes R} \quad : \quad e^{i(\theta+1/2)H}\ \sigma^-_{-\theta}$$

1. Vertex Operators

- For the NS-sector we have the following dictionary

positive angle θ

$$
\begin{array}{lcl}
|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \sigma_\theta^+ \\
\alpha_{-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \tau_\theta^+ \\
(\alpha_{-\theta})^2\,|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \omega_\theta^+ \\
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\alpha_{-\theta}\,\psi_{-\frac{1}{2}+\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta-1)H}\ \tau_\theta^+ \\
(\alpha_{-\theta})^2\ \psi_{-\frac{1}{2}+\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta-1)H}\ \omega_\theta^+
\end{array}
$$

negative angle θ

$$
\begin{array}{lcl}
|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \sigma_{-\theta}^- \\
\alpha_{\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \tau_{-\theta}^- \\
(\alpha_{\theta})^2\,|\,\theta\,\rangle_{B\otimes NS} & : & e^{i\theta H}\ \omega_{-\theta}^- \\
\psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \sigma_{-\theta}^- \\
\alpha_{\theta}\,\psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \tau_{-\theta}^- \\
(\alpha_{\theta})^2\ \psi_{-\frac{1}{2}-\theta}|\,\theta\,\rangle_{B\otimes NS} & : & e^{i(\theta+1)H}\ \omega_{-\theta}^-
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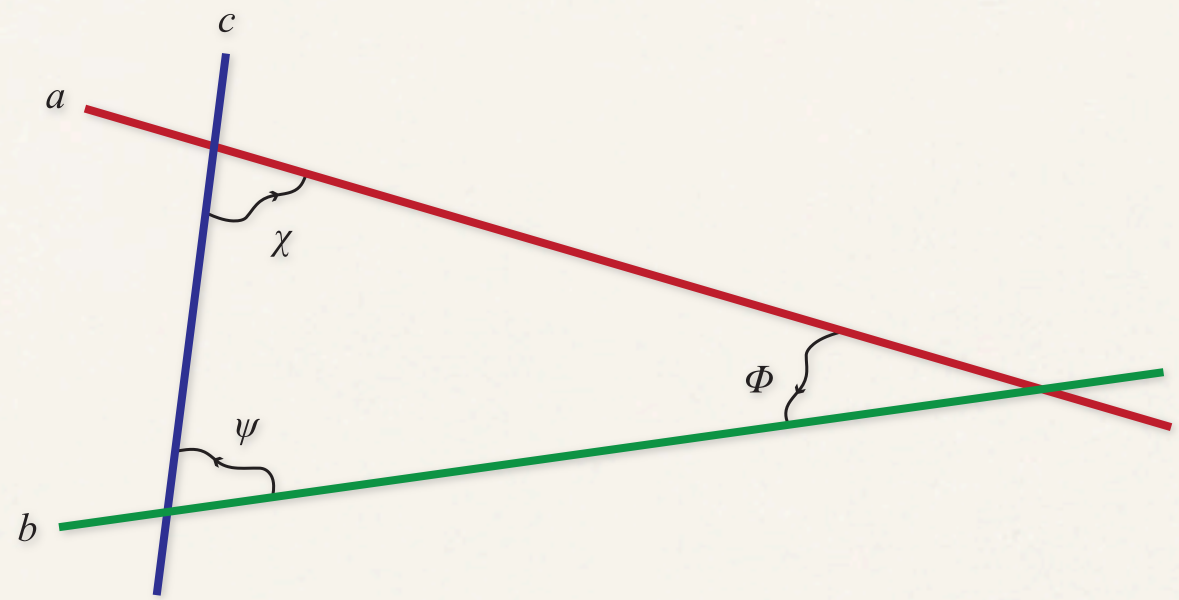
- The σ, τ, ω are twisted bosonic conformal fields.

Anastasopoulos Bianchi Richter

Our setup

- In order to proceed we need to specify our setup.
- Consider three stacks of D-branes within a semi-realistic brane configuration:



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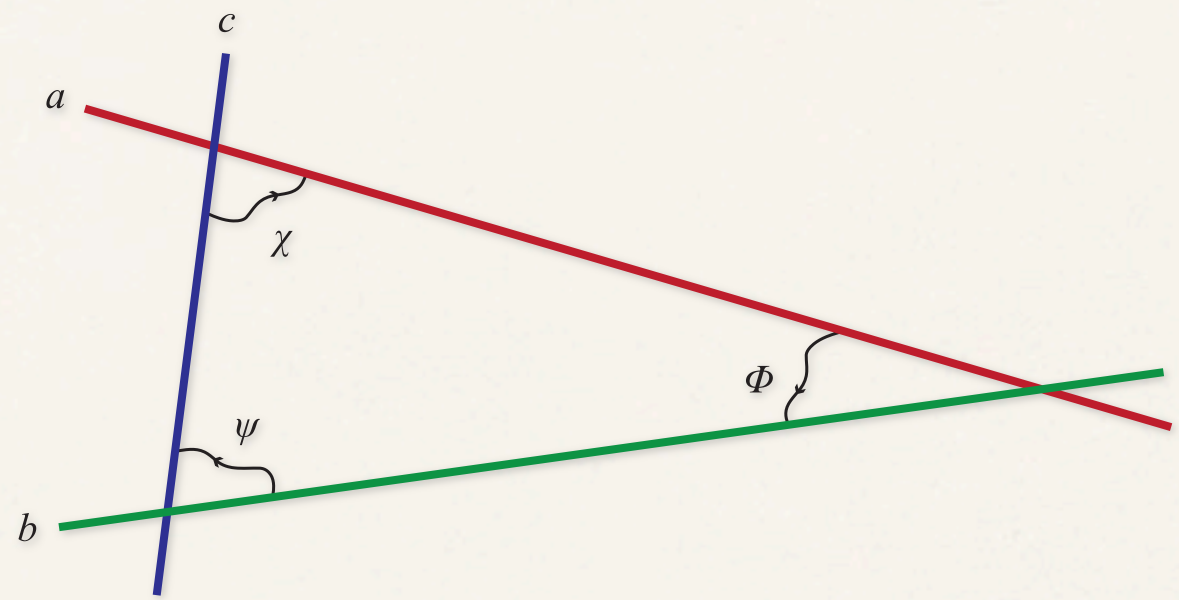

- For the sake of concreteness we choose a supersymmetric setup with:

$$
\begin{array}{lll}
\theta^1_{ab} > 0\ , & \theta^2_{ab} > 0\ , & \theta^3_{ab} < 0 \\
\theta^1_{bc} > 0\ , & \theta^2_{bc} > 0\ , & \theta^3_{bc} < 0 \\
\theta^1_{ca} < 0\ , & \theta^2_{ca} < 0\ , & \theta^3_{ca} < 0
\end{array}
\quad \Rightarrow \quad
\begin{array}{l}
\theta^1_{ab} + \theta^2_{ab} + \theta^3_{ab} = 0 \\
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\theta^1_{ca} + \theta^2_{ca} + \theta^3_{ca} = -2
\end{array}
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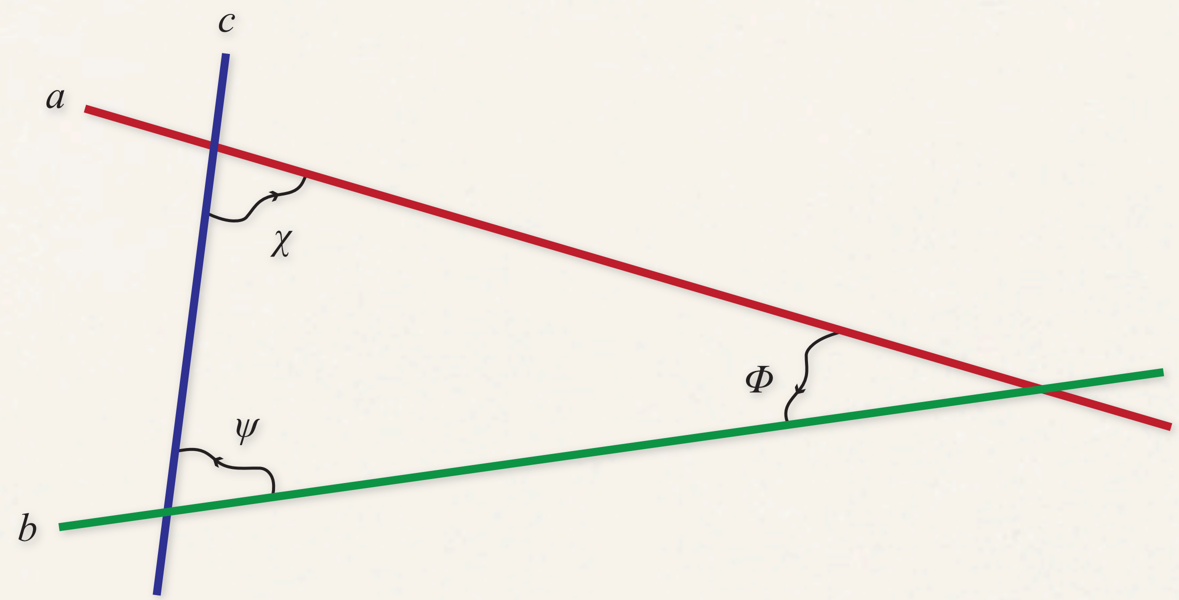

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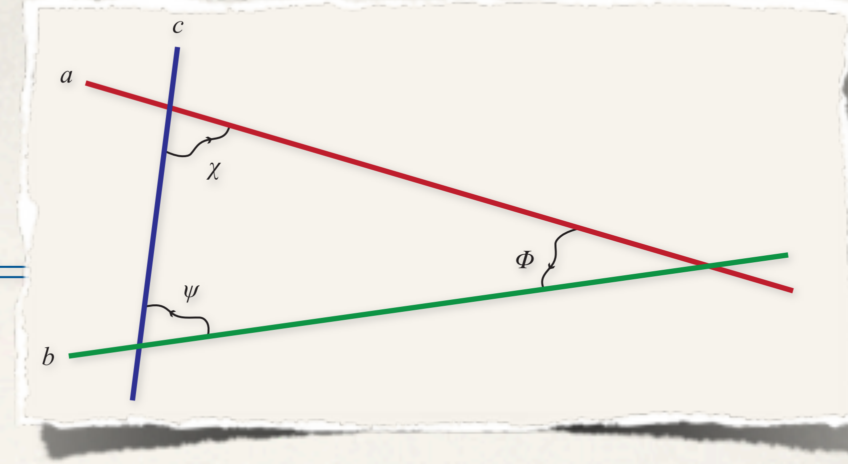
- At the intersections live chiral fermions ψ, $\bar{\psi}$, χ ,$\bar{\chi}$, ϕ, $\bar{\phi}$ and their superparteners Ψ, X, Φ.

The vertex operators



- Using our dictionary, we have for example

$$V_{\psi}^{(-1/2)} = \Lambda_{bc}\psi^{\alpha}\, e^{-\varphi/2} S_{\alpha}\left(\sigma^{+}_{\theta^1_{bc}}\, e^{i\left(\theta^1_{bc}-\frac{1}{2}\right)H_1}\right)\left(\sigma^{+}_{\theta^2_{bc}}\, e^{i\left(\theta^2_{bc}-\frac{1}{2}\right)H_2}\right)\left(\sigma^{-}_{-\theta^3_{bc}}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H_3}\right)e^{ikX}$$

$$V_{\tilde{\psi}}^{(-1/2)} = \Lambda_{bc}\tilde{\psi}^{\alpha}\, e^{-\varphi/2} S_{\alpha}\left(\tau^{+}_{\theta^1_{bc}}\, e^{i\left(\theta^1_{bc}-\frac{1}{2}\right)H_1}\right)\left(\sigma^{+}_{\theta^2_{bc}}\, e^{i\left(\theta^2_{bc}-\frac{1}{2}\right)H_2}\right)\left(\sigma^{-}_{-\theta^3_{bc}}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H_3}\right)e^{ikX}$$

$$V_{\tilde{\tilde{\psi}}}^{(-1/2)} = \Lambda_{bc}\tilde{\tilde{\psi}}^{\alpha}\, e^{-\varphi/2} S_{\alpha}\left(\omega^{+}_{\theta^1_{bc}}\, e^{i\left(\theta^1_{bc}-\frac{1}{2}\right)H_1}\right)\left(\sigma^{+}_{\theta^2_{bc}}\, e^{i\left(\theta^2_{bc}-\frac{1}{2}\right)H_2}\right)\left(\sigma^{-}_{-\theta^3_{bc}}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H_3}\right)e^{ikX}$$

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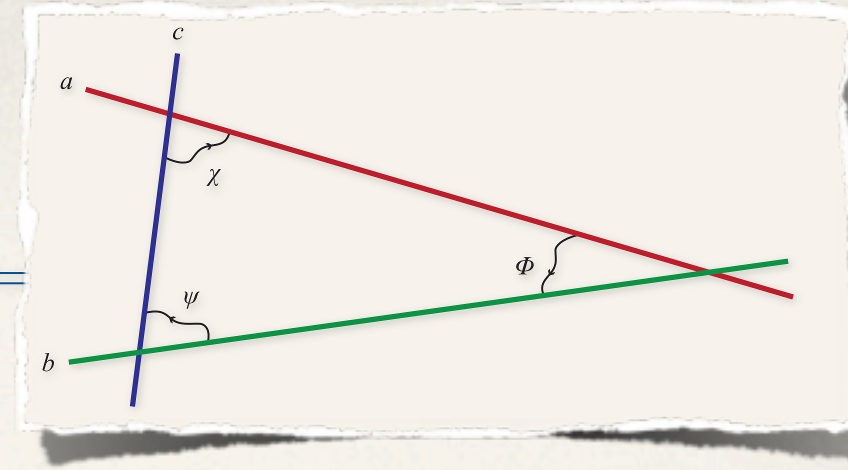

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- We will need various correlation functions:

$$\langle \tilde{\Phi}\ \psi\ \chi\rangle,\ \langle \tilde{\tilde{\Phi}}\ \psi\ \chi\rangle \ldots \quad \Rightarrow \quad \begin{array}{l} \left\langle \tau^{+}_{\alpha}(x_1)\sigma^{+}_{\beta}(x_2)\sigma^{+}_{\gamma}(x_3)\right\rangle \\ \left\langle \tau^{+}_{\alpha}(x_1)\tau^{+}_{\beta}(x_2)\sigma^{+}_{\gamma}(x_3)\right\rangle \\ \left\langle \omega^{+}_{\alpha}(x_1)\sigma^{+}_{\beta}(x_2)\sigma^{+}_{\gamma}(x_3)\right\rangle \ \ldots \end{array}$$

$$\begin{array}{c} \langle \bar{\psi}\ \psi\ \tilde{\chi}\ \bar{\chi}\rangle,\ \langle \bar{\psi}\ \psi\ \tilde{\chi}\ \bar{\tilde{\chi}}\rangle, \\ \langle \bar{\psi}\ \psi\ \tilde{\tilde{\chi}}\ \bar{\chi}\rangle, \ldots \end{array} \quad \Rightarrow \quad \begin{array}{l} \left\langle \tau^{+}_{\alpha}(x_1)\sigma^{-}_{\alpha}(x_2)\sigma^{+}_{\beta}(x_3)\sigma^{-}_{\beta}(x_4)\right\rangle \\ \left\langle \tau^{+}_{\alpha}(x_1)\tau^{-}_{\alpha}(x_2)\sigma^{+}_{\beta}(x_3)\sigma^{-}_{\beta}(x_4)\right\rangle \\ \left\langle \omega^{+}_{\alpha}(x_1)\sigma^{-}_{\alpha}(x_2)\sigma^{+}_{\beta}(x_3)\sigma^{-}_{\beta}(x_4)\right\rangle \ \ldots \end{array}$$

2. Correlation functions

$$\langle \tau_\alpha^+(x_1)\sigma_\beta^+(x_2)\sigma_\gamma^+(x_3)\rangle$$
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- The excited twist fields, τ and ω are not primaries.

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- Thus, we will take a detour: we will evaluating higher correlators with only primaries:

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$$\begin{aligned}
&\partial Z(z)\,\sigma^+_\alpha(w)\sim(z-w)^{\alpha-1}\tau^+_\alpha(w) && \partial\bar Z(z)\,\sigma^+_\alpha(w)\sim(z-w)^{-\alpha}\tilde\tau^+_\alpha(w)\\
&\partial Z(z)\,\tau^+_\alpha(w)\sim(z-w)^{\alpha-1}\omega^+_\alpha(w) && \partial\bar Z(z)\,\tau^+_\alpha(w)\sim(z-w)^{-\alpha-1}\sigma^+_\alpha(w)\\
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&\partial Z(z)\,\sigma^-_\alpha(w)\sim(z-w)^{-\alpha}\tau^-_\alpha(w) && \partial\bar Z(z)\,\sigma^-_\alpha(w)\sim(z-w)^{\alpha-1}\tilde\tau^-_\alpha(w)\\
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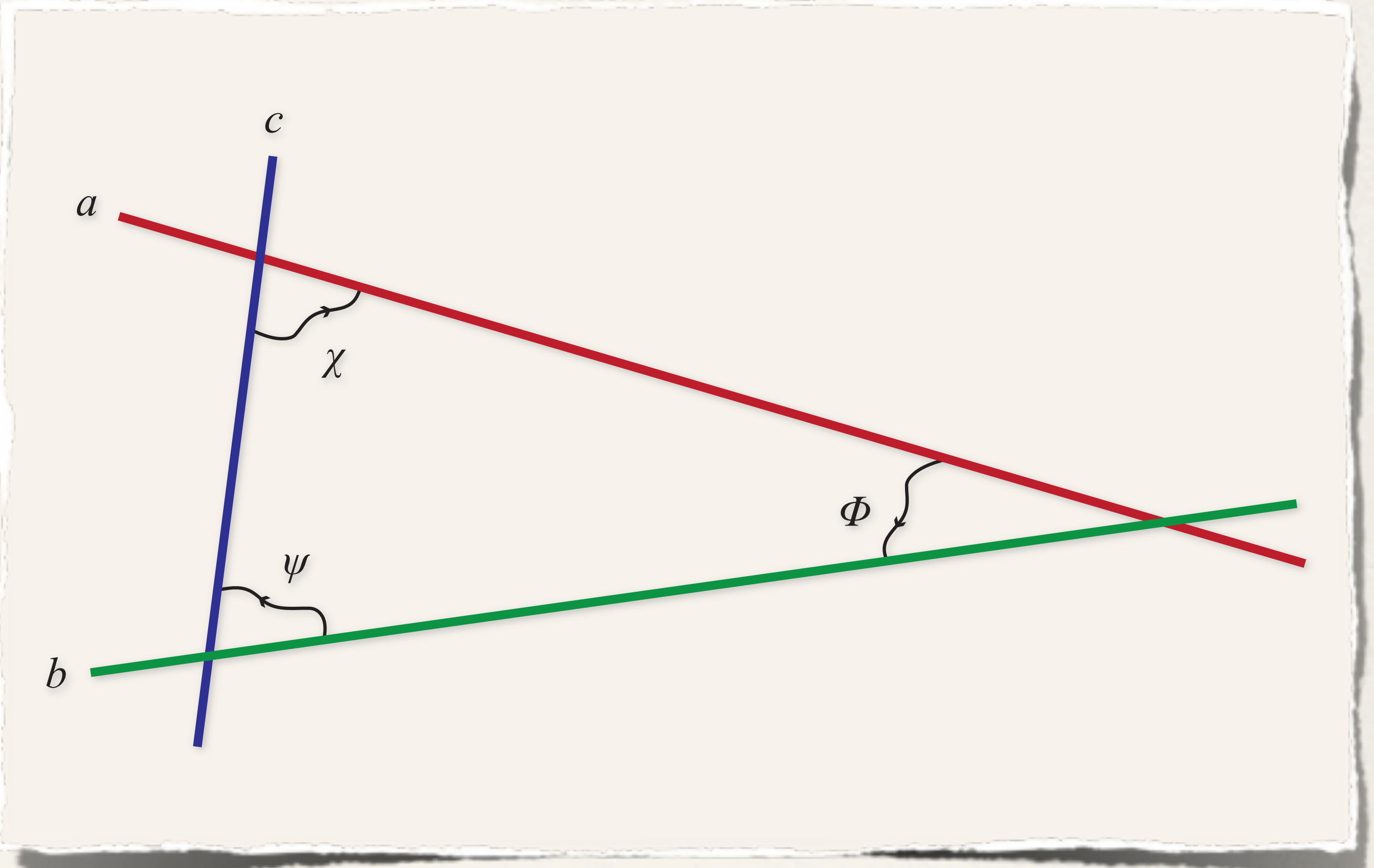
\end{aligned}$$

we get our desired correlators:

$$\big\langle \tau_\alpha(x_1)\sigma_\beta(x_2)\sigma_\gamma(x_3)...\big\rangle \qquad \big\langle \tau_\alpha(x_1)\tilde\tau_\beta(x_2)\sigma_\gamma(x_3)...\big\rangle$$



Three-point correlators

The three-point correlators

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- Out starting point are the five-point correlators:

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- The ∂Z, $\partial \bar{Z}$ split on a classical and a quantum part:

$$\partial Z = \partial Z_{cl} + \partial Z_{qu} \qquad\qquad \partial \bar{Z} = \partial \bar{Z}_{cl} + \partial \bar{Z}_{qu}\ .$$

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- Since correlators with odd number of ∂Z_{qu}, $\partial \bar{Z}_{qu}$ are zero, we have to evaluate:

$$\partial Z_{cl}(z) \partial \bar{Z}_{cl}(w) \langle \sigma^+_\alpha(x_1) \sigma^+_\beta(x_2) \sigma^+_\gamma(x_3) \rangle \ + \ \langle \partial Z_{qu}(z) \partial \bar{Z}_{qu}(w) \sigma^+_\alpha(x_1) \sigma^+_\beta(x_2) \sigma^+_\gamma(x_3) \rangle$$
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- The two parts can be evaluated separately.

The "classical" part

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$$\partial Z_{cl}(z)\partial \bar{Z}_{cl}(w)\langle\sigma^+_\alpha(x_1)\sigma^+_\beta(x_2)\sigma^+_\gamma(x_3)\rangle$$
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$$\partial \bar{Z}_{cl}(z)\partial \bar{Z}_{cl}(w)\langle\sigma^+_\alpha(x_1)\sigma^+_\beta(x_2)\sigma^+_\gamma(x_3)\rangle$$

can be computed using the three-point function:

$$\langle\sigma^+_\alpha(x_1)\sigma^+_\beta(x_2)\sigma^+_\gamma(x_3)\rangle = \left(2\pi\frac{\Gamma(\alpha)\Gamma(\beta)\Gamma(\gamma)}{\Gamma(1-\alpha)\Gamma(1-\beta)\Gamma(1-\gamma)}\right)^{\frac{1}{4}} x_{12}^{-(1-\alpha)\,(1-\beta)}\, x_{13}^{-(1-\alpha)\,(1-\gamma)}\, x_{23}^{-(1-\beta)\,(1-\gamma)}\ .$$

and the classical solutions:

$$\partial Z_{cl}(z) = e^{i\pi(\gamma-1)} z^{\alpha-1}(z-1)^{\beta-1} v_c \frac{\Gamma(1-\gamma)}{\Gamma(\alpha)\,\Gamma(\beta)}$$
$$\partial \bar{Z}_{cl}(z) = 0\ ,$$

Lust Meyr Richter Stieberger
Abel Owen
Cvetic Richter Weigand

The "quantum" part

- The "quantum" part:

$$
\begin{aligned}
g(z,w) &\sim \left\langle \partial Z_{qu}(z)\partial \bar{Z}_{qu}(w)\sigma_\alpha^+(x_1)\sigma_\beta^+(x_2)\sigma_\gamma^+(x_3)\right\rangle \\
k(z,w) &\sim \left\langle \partial Z_{qu}(z)\partial Z_{qu}(w)\sigma_\alpha^+(x_1)\sigma_\beta^+(x_2)\sigma_\gamma^+(x_3)\right\rangle \\
m(z,w) &\sim \left\langle \partial \bar{Z}_{qu}(z)\partial \bar{Z}_{qu}(w)\sigma_\alpha^+(x_1)\sigma_\beta^+(x_2)\sigma_\gamma^+(x_3)\right\rangle
\end{aligned}
$$

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\end{aligned}
$$

can be evaluated by using:

  - the local behavior

$$\partial Z_{qu}(z)\partial \bar{Z}_{qu}(w) \sim \frac{1}{(z-w)^2} \qquad \partial Z_{qu}(z)\partial Z_{qu}(w) \sim \text{regular} \qquad \partial \bar{Z}_{qu}(z)\partial \bar{Z}_{qu}(w) \sim \text{regular}$$

  - the monodromy conditions:

$$e^{i\pi\alpha}\int_{x_1}^{x_2} m(z,w)\,dw - e^{-i\pi\alpha}\int_{x_1}^{x_2} g(z,w)\,dw = 0$$

Cvetic Papadimitriou
Abel Owen

The results

- Adding the classical and quantum parts we get the total five-point correlators:

$$\langle \partial Z(z) \partial \bar{Z}(w) \sigma^+_\alpha(x_1) \sigma^+_\beta(x_2) \sigma^+_\gamma(x_3) \rangle$$

$$\langle \partial Z(z) \partial Z(w) \sigma^+_\alpha(x_1) \sigma^+_\beta(x_2) \sigma^+_\gamma(x_3) \rangle$$

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- Taking various limits, like $z \to x_1, w \to x_2$ or $w \to x_1$ and using the OPE's we get:

$$\langle \tau_\alpha^+(x_1)\tilde{\tau}_\beta^+(x_2)\sigma_\gamma^+(x_3)\rangle = \alpha \frac{\left(2\pi \frac{\Gamma(1-\alpha)\Gamma(1-\beta)\Gamma(1-\gamma)}{\Gamma(\alpha)\Gamma(\beta)\Gamma(\gamma)}\right)^{\frac{1}{4}}}{x_{12}^{1+\alpha-(1-\alpha)\beta}\, x_{13}^{-(1-\alpha)\gamma}\, x_{23}^{(1+\beta)\gamma}} \sum_n e^{-S_{cl}}$$

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$$\times \sum_n \left\{1 - \frac{\sin(\pi\alpha)\sin(\pi\beta)}{\pi \sin(\pi\gamma)}|v_c|^2\right\} x_{12}^{-\alpha\beta-\alpha-\beta}\, x_{13}^{-\alpha(2+\gamma)-\gamma+1}\, x_{23}^{-\beta(2+\gamma)-\gamma+1}\, e^{-S_{cl}}$$

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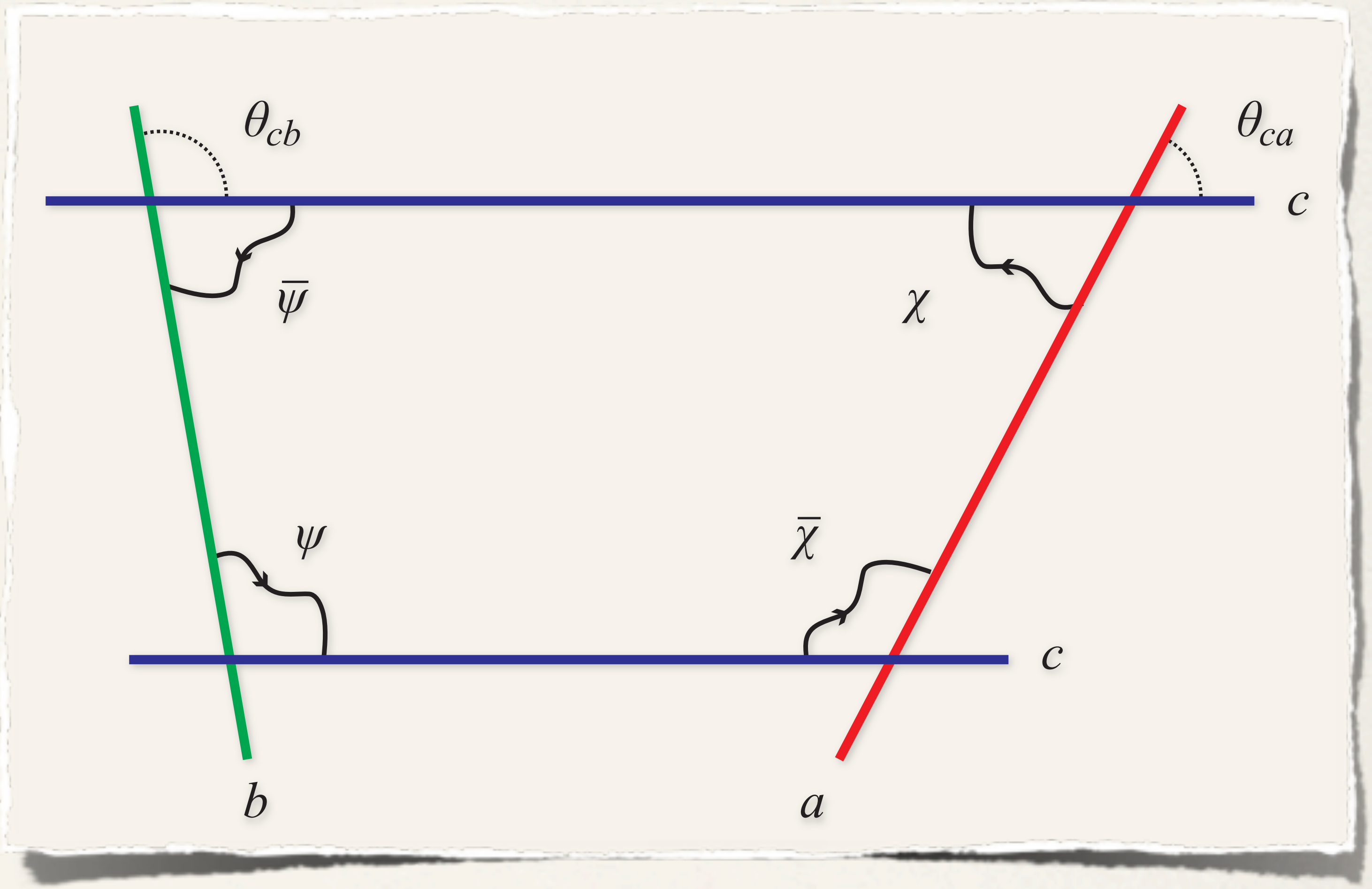
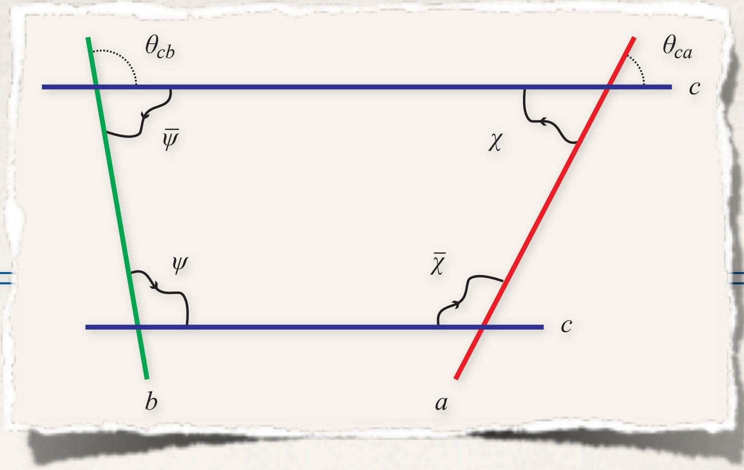
- This is a work in progress.



Four-point correlators

Four-point procedure



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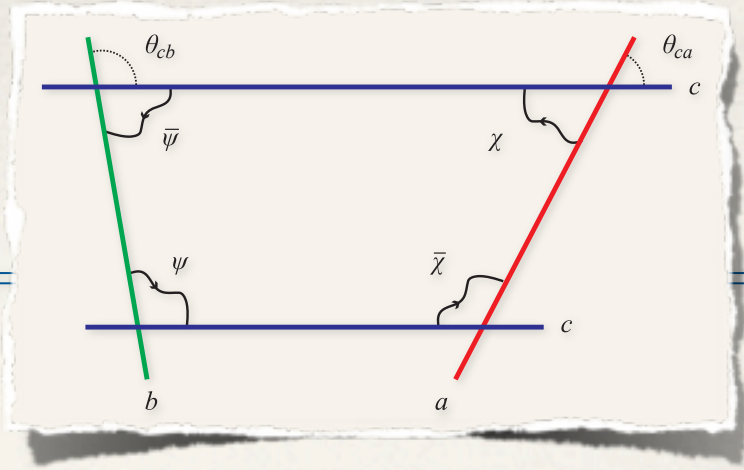

- Similarly for the four-point correlators:

  1. we start with the six-point correlators of primary fields:

$$\langle \partial Z(z) \partial \bar{Z}(w) \sigma^+_\alpha(x_1) \sigma^+_{1-\alpha}(x_2) \sigma^+_\beta(x_3) \sigma^+_{1-\beta}(x_4) \rangle$$
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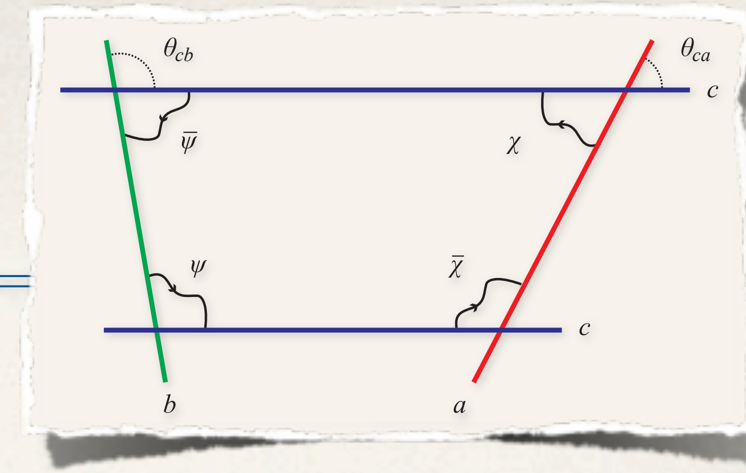

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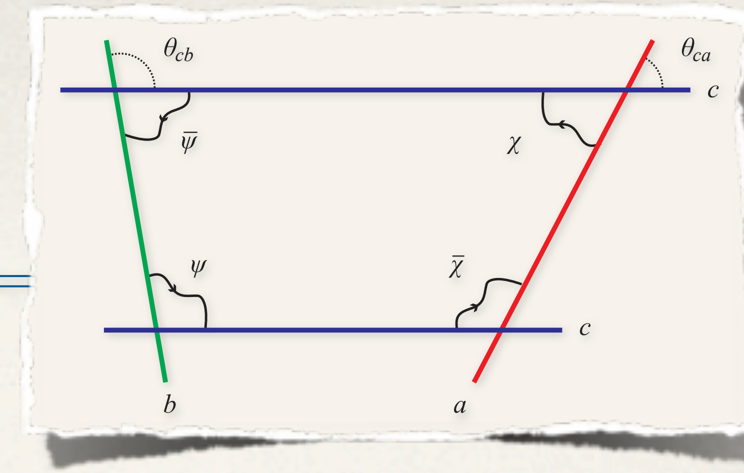

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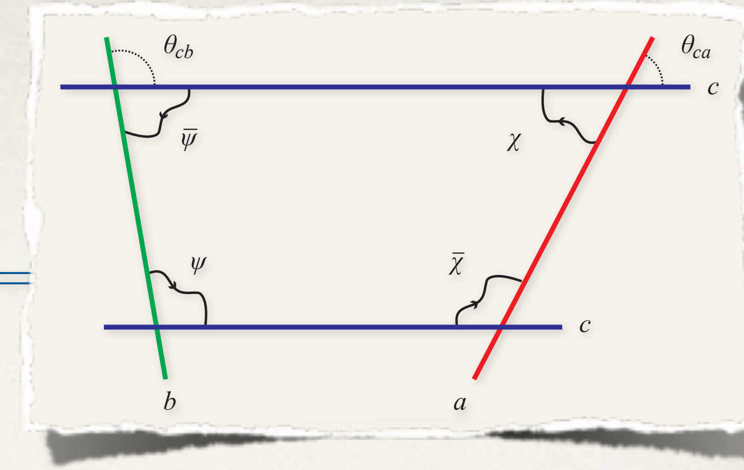

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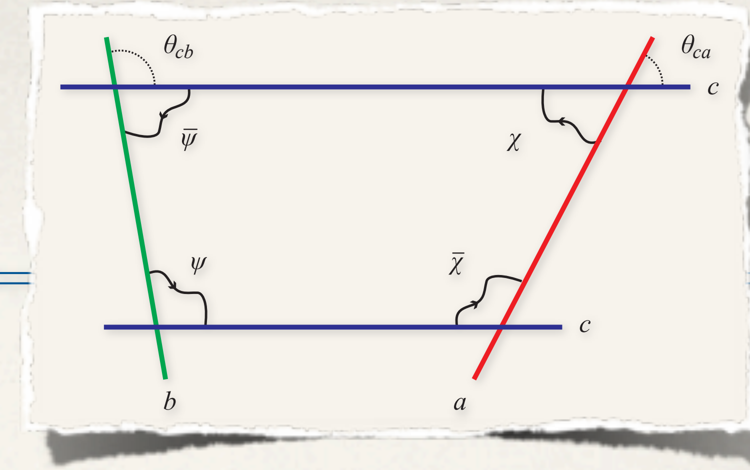

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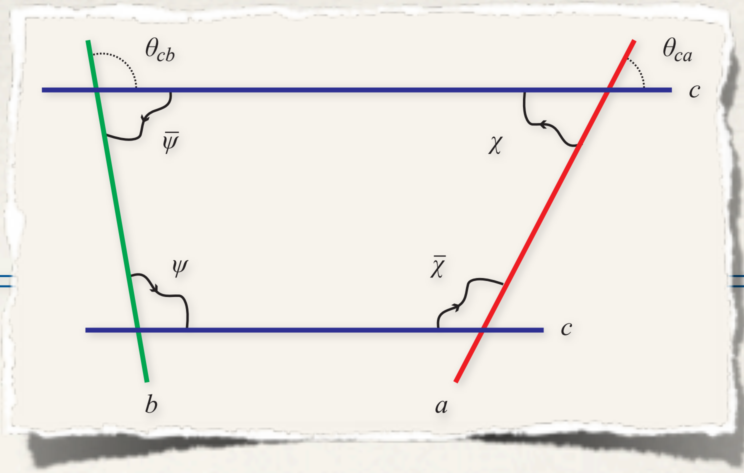
5. we take various limits and we use the known OPE's.

Four-point results



- Some four-point correlators with:

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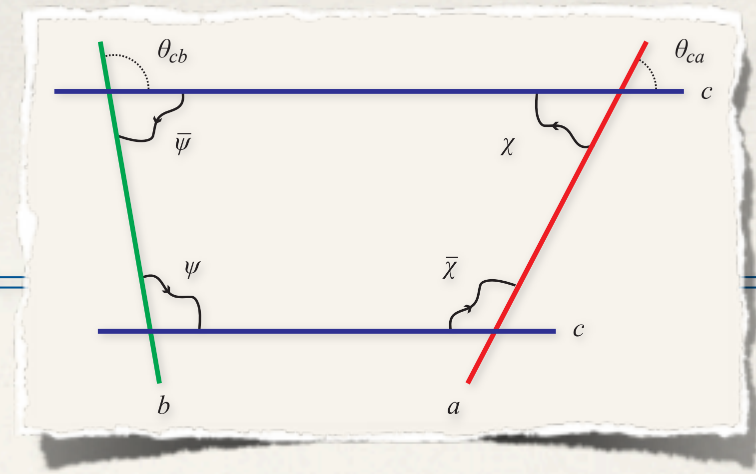

- Some four-point correlators with:
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$$\left\langle \tau_{\alpha}^{+}(x_1)\sigma_{\alpha}^{-}(x_2)\sigma_{\beta}^{+}(x_3)\sigma_{\beta}^{-}(x_4)\right\rangle = -x_{12}^{-\alpha(2-\alpha)}\, x_{34}^{-\beta(1-\beta)} \left(\frac{x_{23}}{x_{13}}\right)^{\alpha\beta-\frac{\alpha}{2}-\frac{\beta}{2}} \left(\frac{x_{14}}{x_{24}}\right)^{\alpha\beta-\frac{3\alpha}{2}-\frac{\beta}{2}}$$

$$\times \sqrt{2\pi}\, e^{-i\pi\alpha} \sum_{p,q} \frac{\left(G_2[x]v_b + \frac{\sin(\pi\alpha)}{\pi}(1-x)^{\alpha-\beta} B_1 H_1[1-x] e^{i\pi\alpha} v_a\right)}{I^{\frac{3}{2}}(x)}\, e^{-S_{cl}}$$

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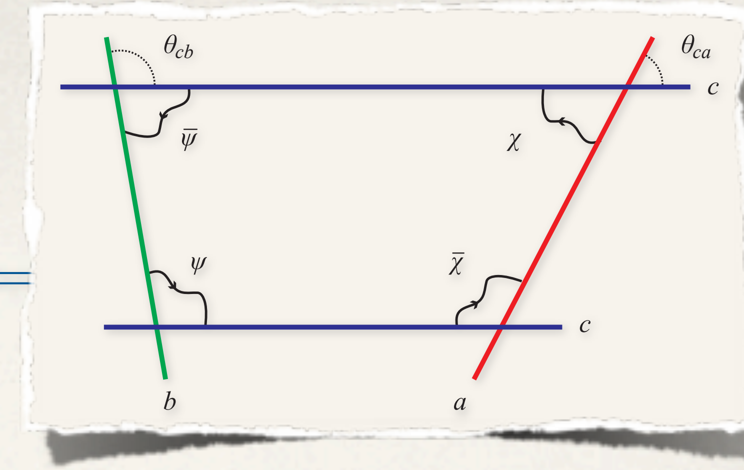

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$$\langle \tau_\alpha^+(x_1)\widetilde{\tau}_\alpha^-(x_2)\,\sigma_\beta^+(x_3)\sigma_\beta^-(x_4)\rangle$$

$$= \sqrt{\frac{2\pi}{I(x)}}x_{12}^{\alpha(\alpha-3)}x_{34}^{-\beta(1-\beta)}\left(\frac{x_{14}x_{23}}{x_{13}x_{24}}\right)^{\alpha\beta-\frac{\alpha}{2}-\frac{3\beta}{2}}\sum_{p,q}\Bigg\{-\alpha(1-x)^{\beta-\alpha}\frac{B_2H_2[1-x]}{I(x)}\,{}_2F_1[-\alpha,\beta,1,x]$$

$$+\frac{B_2G_1[x]}{I(x)}\Big(\alpha H_2[1-x]-\beta\,{}_2F_1[-\alpha,\beta,1-\alpha+\beta,1-x]\Big)+\alpha(1-x)^{\beta-\alpha}\,\frac{{}_2F_1[-\alpha,\beta,1,x]}{G_1[x]}$$

$$-\frac{\left(G_1[x]v_b+\frac{\sin(\pi\alpha)}{\pi}B_1H_1[1-x]e^{i\pi\alpha}v_a\right)\left(G_2[x]v_b-\frac{\sin(\pi\alpha)}{\pi}B_2H_2[1-x]e^{i\pi\alpha}v_a\right)}{I^2(x)}\Bigg\}e^{-S_{cl}}\;,$$

etc etc...

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- Indeed, from dijet searches for related resonances, since the cross-section is so suppressed we can infer that the bounds on such states will be much less than a TeV.
- This raises the intriguing prospect that the string scale could be just out of reach of the LHC, but the light stringy states could be hiding in plain sight.

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- Four-point functions will help in the study of the decay channels of these light stringy states which could be observed at LHC.