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Light stringy states

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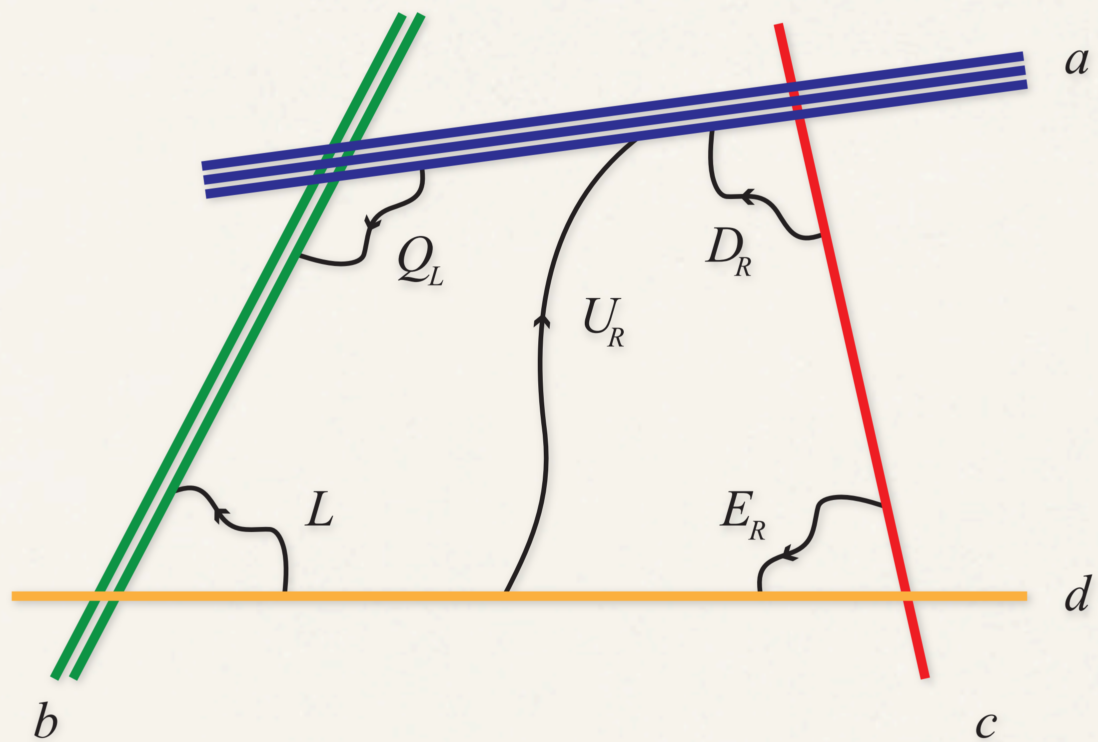
Based on: 1110.5359 [hep-th], 1110.5424 [hep-th]
with P. Anastasopoulos & M. Bianchi

Nordic String Meeting - 20/02/2012



Introduction and Motivation

Motivation

- D-brane compactifications provide a promising framework for model building
- They allow for large extra dimensions which imply a significantly lower string scale, even of just a few TeV.
- Scenarios of these kinds may explain the hierarchy problem, but also allow for stringy signatures that can be observed at LHC.

  Antoniadis, Arkani-Hamed, Dimopoulos, Dvali
- There exists a class of amplitudes containing arbitrary number of gauge bosons and maximal two chiral fermions that exhibit a universal behaviour independently of the specifics of the compactification

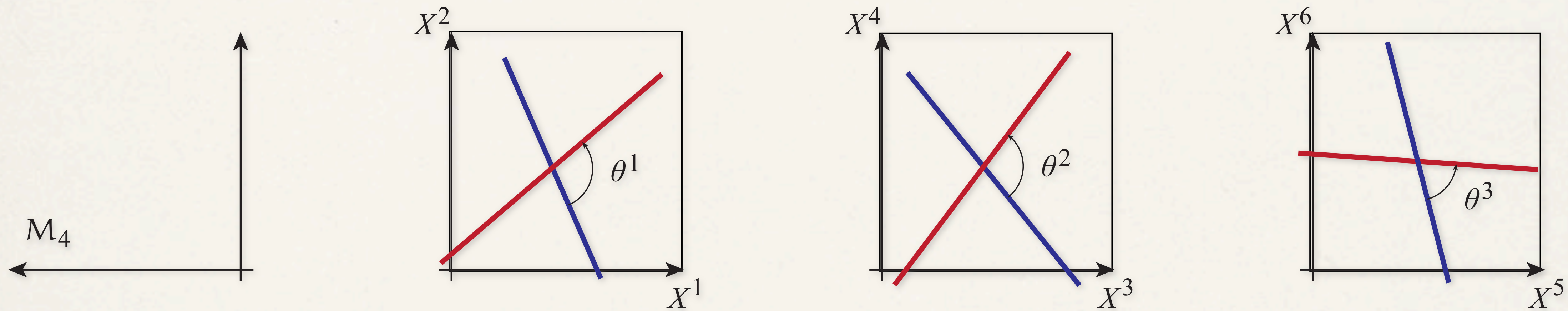
  Lust, Stieberger, Taylor, et. al.
- Due to their universal behaviour they have predictive power.
- The observed poles correspond to the exchanges of Regge excitations of the standard model gauge bosons, whose masses scale with the string mass M_s.
- Such poles might be observable at LHC if one has low string scale

Motivation

- On the other hand there exist a tower of stringy excitations localized at the intersections of two stacks of D-branes.
- Their masses depend on the string mass M_s and the intersection angle θ and thus can be significantly lighter than the Regge excitations of the gauge bosons.
- As we will see those light stringy states show up as poles in the scattering amplitudes containing four fermions.
- Such amplitudes are very model dependent, thus do not have the predictive power of the universal amplitudes.
- However the poles corresponding to light stringy states should be observed primary to Regge excitations for the universal amplitudes and thus may provide a first step towards evidence for string theory.

Intersecting D6-branes

For the sake of calculability we assume two intersectng D6-branes on $T^2 \times T^2 \times T^2$, where the D6-branes wrap in each torus a one-cycle

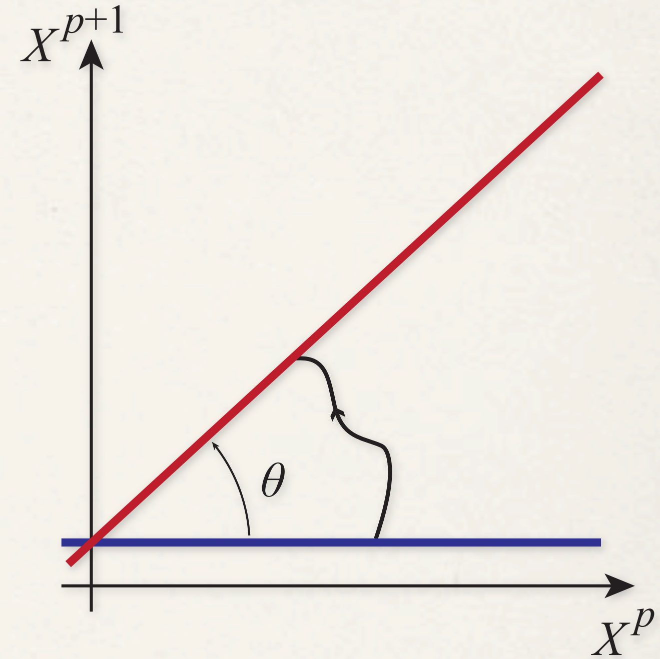


- Supersymmetry translates into: $\theta_1 + \theta_2 + \theta_3 = 0 \mod 2$

- We will take a closer look at the (massless and massive) states appearing at such an intersection.

Quantization at angles

- Boundary conditions for strings between branes at angles:



$$\partial_\sigma X^p(\tau, 0) = X^{p+1}(\tau, 0) = 0$$
$$\partial_\sigma X^p(\tau, \pi) + \tan(\pi\theta)\ \partial_\sigma X^{p+1}(\tau, \pi) = 0$$
$$X^{p+1}(\tau, \pi) - \tan(\pi\theta)\ X^p(\tau, \pi) = 0$$

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

$$\partial Z^I(z) = \sum_n \alpha^I_{n-\theta_I}\ z^{-n+\theta_I-1} \qquad \partial \bar{Z}^I(z) = \sum_n \alpha^I_{n+\theta_I}\ z^{-n-\theta_I-1}$$
$$\Psi^I(z) = \sum_{r\in\mathbb{Z}+\nu} \psi^I_{r-\theta_I}\ z^{-r-\frac{1}{2}+\theta_I} \qquad \bar{\Psi}^I(z) = \sum_{r\in\mathbb{Z}+\nu} \psi^I_{r+\theta_I}\ \bar{z}^{-r-\frac{1}{2}-\theta_I}$$

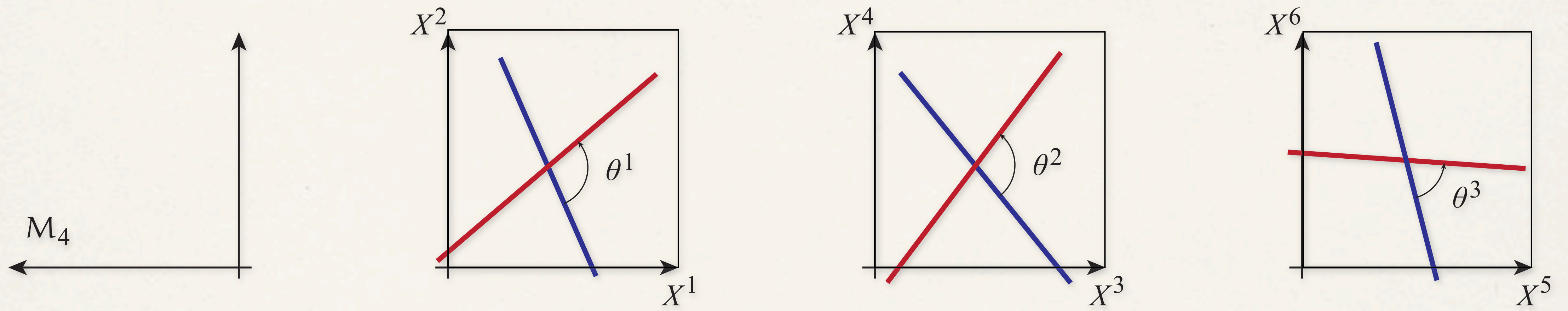
for $\nu = 0, 1/2$ for R and NS respectively.

- The commutator / anticommutators:

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

The vacuum

- Intersecting branes in 10D:



- NS sector (4D bosons):

  - Positive angle

$$\alpha_{m-\theta_I}|\theta_I\rangle_{NS}=0 \qquad m\geq 1 \qquad \psi_{r-\theta_I}|\theta_I\rangle_{NS}=0 \qquad r\geq 1/2$$
$$\alpha_{m+\theta_I}|\theta_I\rangle_{NS}=0 \qquad m\geq 0 \qquad \psi_{r+\theta_I}|\theta_I\rangle_{NS}=0 \qquad r\geq 1/2$$

  - Negative angle

$$\alpha_{m-\theta_I}|\theta_I\rangle_{NS}=0 \qquad m\geq 0 \qquad \psi_{r-\theta_I}|\theta_I\rangle_{NS}=0 \qquad r\geq 1/2$$
$$\alpha_{m+\theta_I}|\theta_I\rangle_{NS}=0 \qquad m\geq 1 \qquad \psi_{r+\theta_I}|\theta_I\rangle_{NS}=0 \qquad r\geq 1/2$$

- Recall: GSO-projection requires odd number of fermionic excitations.

Lightest string states

- Recall the mass formula:

$$-\frac{1}{8} \pm \frac{1}{2}\theta_I$$

$$M^2 = M_s^2 \sum_I \left(\sum_{m \epsilon Z} : \alpha^I_{-m+\theta_I} \alpha^I_{m-\theta_I} : + \sum_{m \epsilon Z} (m - \theta_I) : \psi^I_{-m+\theta_I} \psi^I_{m-\theta_I} : + \epsilon^I_0 \right)$$

- Concrete setup: $\theta_1^{ab} < 0\,,\ \theta_2^{ab} < 0\,,\ \theta_3^{ab} < 0$ with $\theta_1^{ab} + \theta_2^{ab} + \theta_3^{ab} = -2$ (SUSY).

- The lowest fermionic excitations of this configuration:

$$\psi_{-\frac{1}{2}-\theta_I^{ab}} |\, \theta_{1,2,3}^{ab} \,\rangle_{NS} \qquad M^2 = \frac{1}{2}(\theta_I^{ab} - \sum_{J \neq I} \theta_J^{ab}) M_s^2 = \left(1 + \theta_I^{ab}\right) M_s^2$$

$$\prod_I \psi_{-\frac{1}{2}-\theta_I^{ab}} |\, \theta_{1,2,3}^{ab} \,\rangle_{NS} \qquad M^2 = (1 + \frac{1}{2}(\theta_1^{ab} + \theta_2^{ab} + \theta_3^{ab})) M_s^2 = 0$$

Lightest string states

- Some additional light states (for small θ_1):

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

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

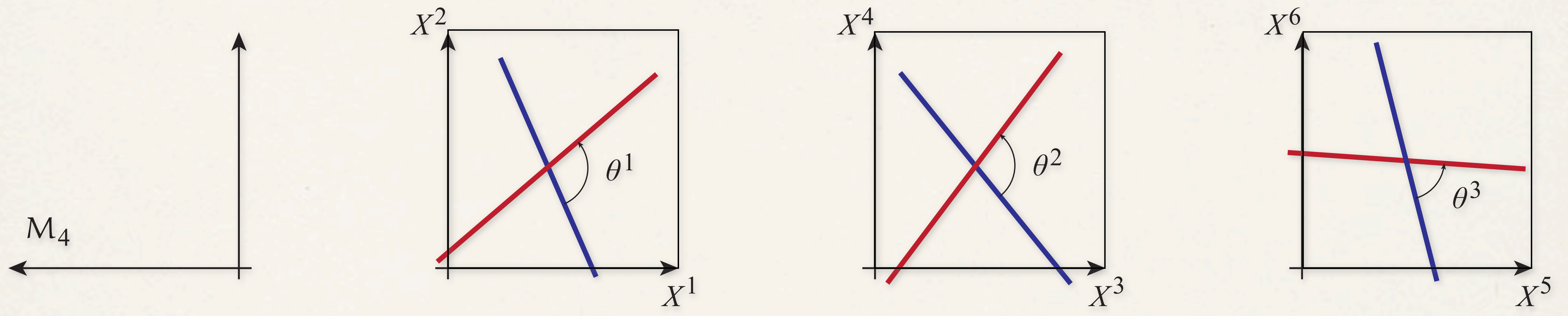
- These scalars are potentially very light, depending on the intersection angles.

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

- Additional states, such as Higher Spin states, but even $\theta_I \to 0$ massive.

The vacuum

- Intersecting branes in 10D:



- R sector (4D fermions):

  - Positive angle

$$\alpha_{m-\theta_I}|\theta_I\rangle_R = 0 \qquad m \geq 1 \qquad\qquad \psi_{r-\theta_I}|\theta_I\rangle_R = 0 \qquad r \geq 1$$

$$\alpha_{m+\theta_I}|\theta_I\rangle_R = 0 \qquad m \geq 0 \qquad\qquad \psi_{r+\theta_I}|\theta_I\rangle_R = 0 \qquad r \geq 0$$

  - Negative angle

$$\alpha_{m-\theta_I}|\theta_I\rangle_R = 0 \qquad m \geq 0 \qquad\qquad \psi_{r-\theta_I}|\theta_I\rangle_R = 0 \qquad r \geq 0$$

$$\alpha_{m+\theta_I}|\theta_I\rangle_R = 0 \qquad m \geq 1 \qquad\qquad \psi_{r+\theta_I}|\theta_I\rangle_R = 0 \qquad r \geq 1$$

Lightest string states

- Recall the mass formula:

$$M^2 = M_s^2 \left(\sum_I \left(\sum_{m \epsilon Z} : \alpha^I_{-m+\theta_I} \alpha^I_{m-\theta_I} : + \sum_{m \epsilon Z} (m - \theta_I) : \psi^I_{-m+\theta_I} \psi^I_{m-\theta_I} : \right) + \epsilon_0 \right)$$

0

- Concrete setup: $\theta_1^{ab} < 0\,,\ \theta_2^{ab} < 0\,,\ \theta_3^{ab} < 0$ with $\theta_1^{ab} + \theta_2^{ab} + \theta_3^{ab} = -2$

- Massless state: the vaccum: $|\,\theta^{ab}_{1,2,3}\,\rangle_R$

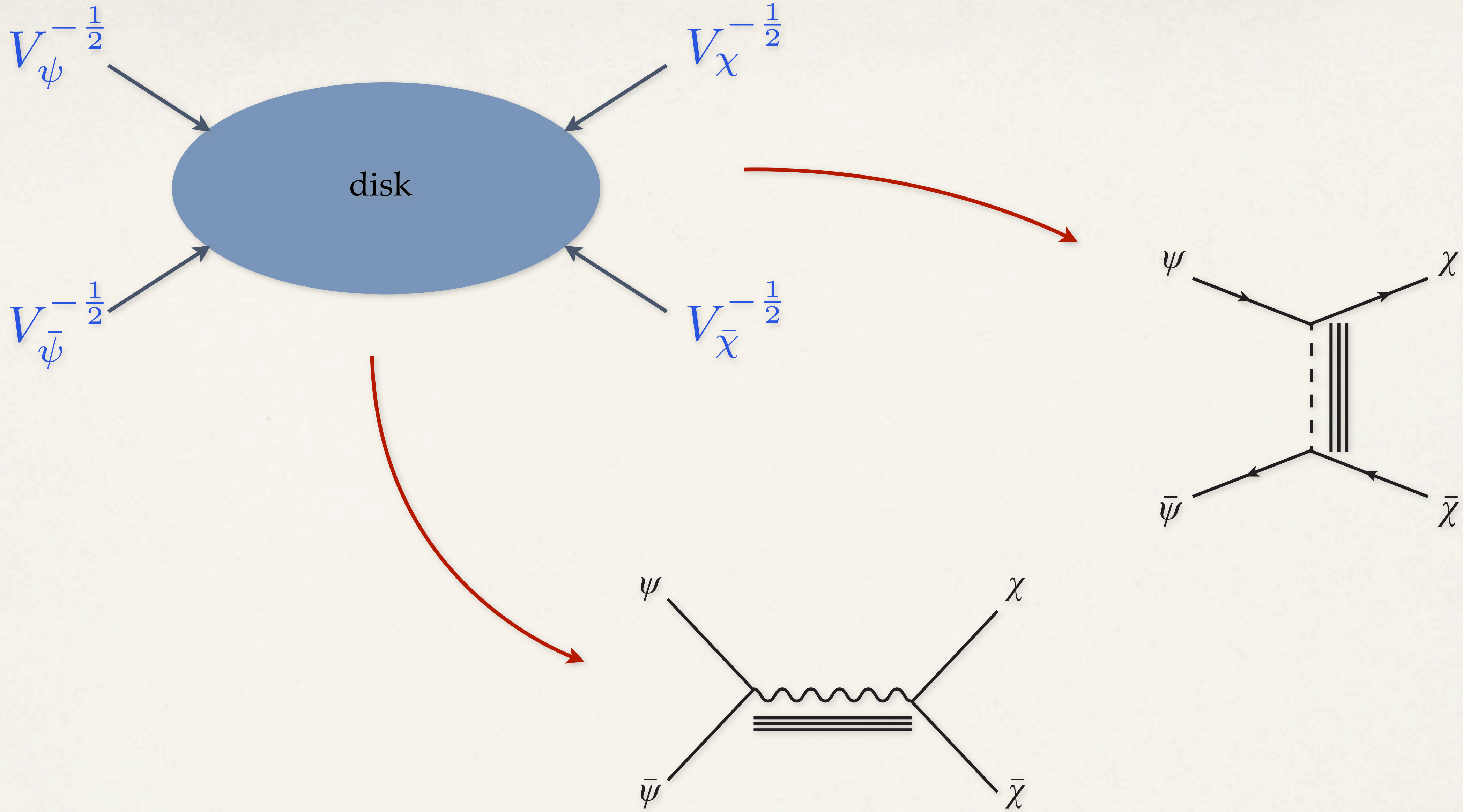
- Light states: (θ_1 is small):

$$\alpha_{\theta_1} |\,\theta^{ab}_{1,2,3}\,\rangle_R \qquad M^2 = -\theta_1 M_s^2$$

$$(\alpha_{\theta_1})^2 |\,\theta^{ab}_{1,2,3}\,\rangle_R \qquad M^2 = -2\theta_1 M_s^2$$

- These states are the corresponding superpartners to the NS-scalars.

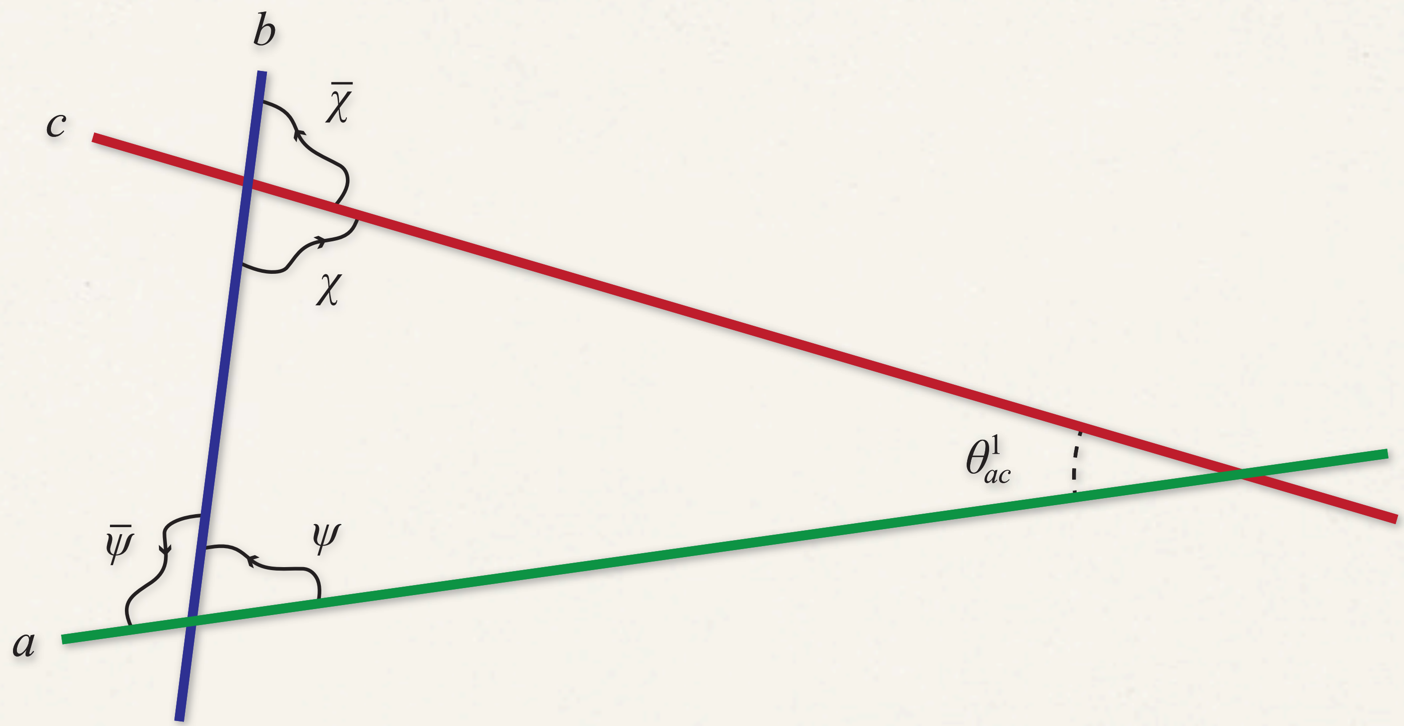
- Question: Can they be observed?



The Amplitude

Amplitude

- Consider three stacks of D-branes within a semi-realistic brane configuration:



- For the sake of concreteness we choose the setup

$$\theta^1_{ab} > 0\,, \quad \theta^2_{ab} > 0\,, \quad \theta^3_{ab} < 0$$
$$\theta^1_{bc} > 0\,, \quad \theta^2_{bc} > 0\,, \quad \theta^3_{bc} < 0$$
$$\theta^1_{ca} < 0\,, \quad \theta^2_{ca} < 0\,, \quad \theta^3_{ca} < 0$$

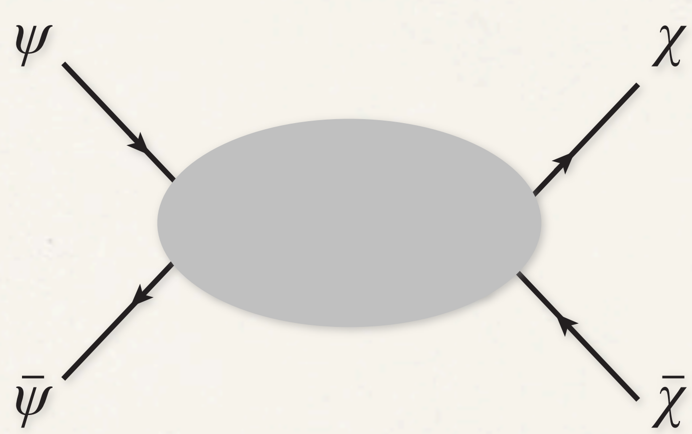
$$\Rightarrow \quad \begin{aligned} \theta^1_{ab} + \theta^2_{ab} + \theta^3_{ab} &= 0 \\ \theta^1_{bc} + \theta^2_{bc} + \theta^3_{bc} &= 0 \\ \theta^1_{ca} + \theta^2_{ca} + \theta^3_{ca} &= -2 \end{aligned}$$

- At the intersections live chiral fermions: ψ, $\bar{\psi}$, χ, $\bar{\chi}$.

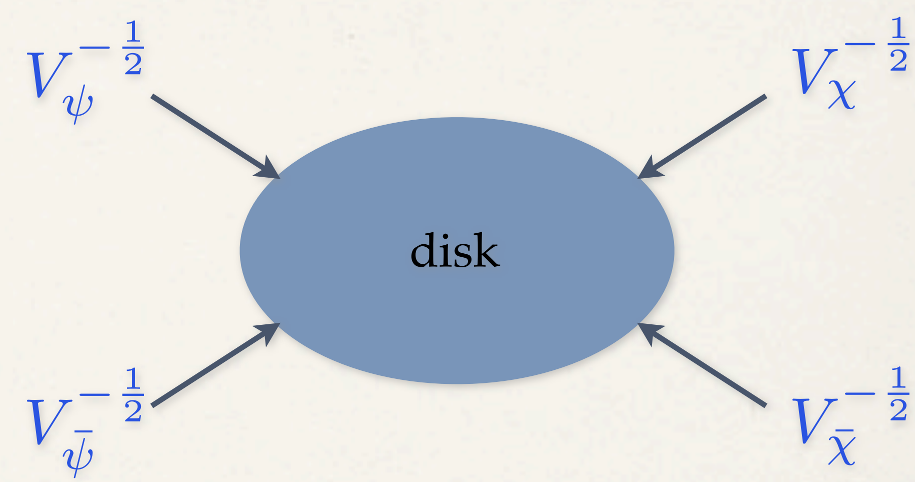
Amplitude

- We want to compute the scattering amplitudes of four chiral fermions:

$\langle \bar{\psi}\, \psi\, \chi\, \bar{\chi} \rangle =$

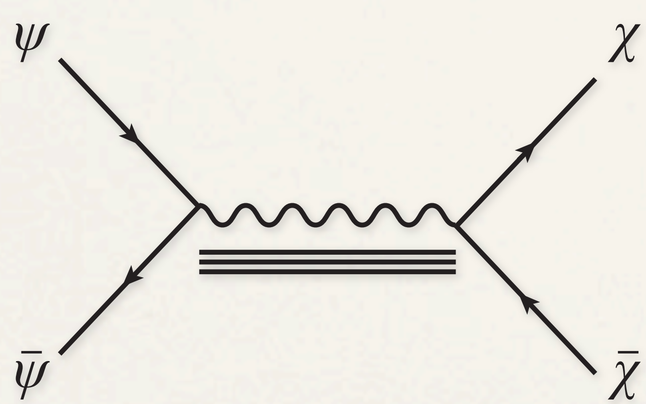


$\Rightarrow$



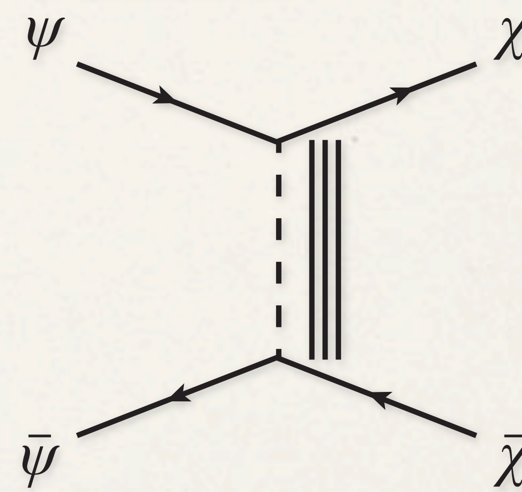
- The corresponding diagram contains different channels:

s-channel



gauge boson + ...

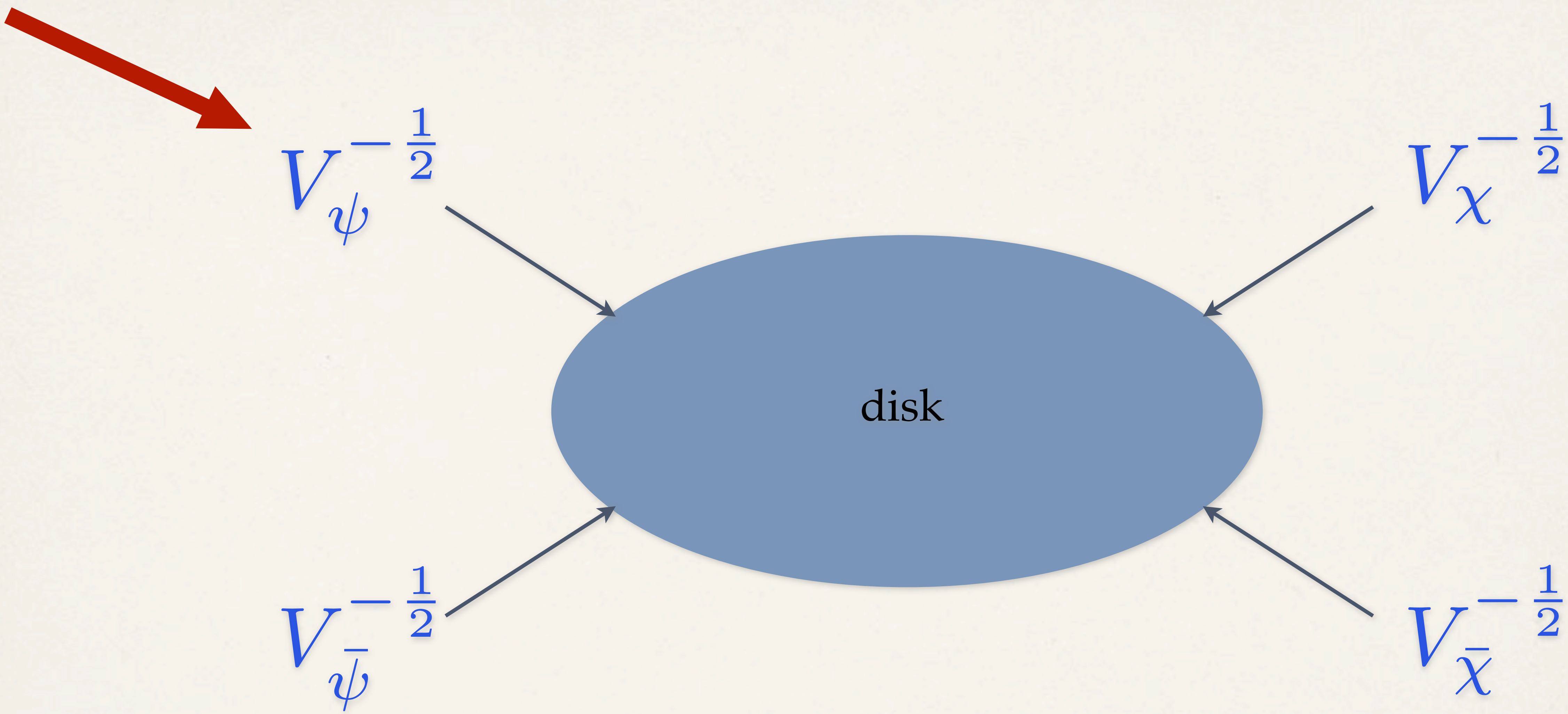
t-channel



scalar + ...

- Two difficulties: 1. Vertex operators

  2. Bosonic Twist field correlator



Vertex Operators

Vertex Operators

- To each state there is a corresponding vertex operator, whose form crucially depends on the intersection angle

- challenging part is the internal part $\rightsquigarrow$ bosonic and fermionic twist fields

- Method: We determine the OPE's of $\partial Z, \partial \overline{Z}, \Psi$ and $\overline{\Psi}$ with vacuum and excitations of it

- Example: $|\theta_I\rangle_{NS} \sim s_{\theta_I} \sigma_{\theta_I}$

$$\partial Z^I(z) |\, \theta_I \,\rangle_{NS} = \sum_{n=-\infty}^{\infty} \alpha^I_{n-\theta_I}\; z^{-n+\theta_I-1} |\, \theta_I \,\rangle_{NS} = \sum_{n=-\infty}^{0} \alpha^I_{n-\theta_I}\; z^{-n+\theta_I-1} |\, \theta_I \,\rangle_{NS}$$

$$\rightarrow\; z^{\theta_I-1}\, \alpha^I_{-\theta_I} |\, \theta_I \,\rangle_{NS} = z^{\theta_I-1}\; \tau^+_{\theta_I}(0)$$

$$\partial \overline{Z}^I(z) |\, \theta_I \,\rangle_{NS} = \sum_{n=-\infty}^{\infty} \alpha^I_{n+\theta_I}\; z^{-n-\theta_I-1} |\, \theta_I \,\rangle_{NS} = \sum_{n=-\infty}^{-1} \alpha^I_{n+\theta_I}\; z^{-n-\theta_I-1} |\, 0 \,\rangle_{NS}$$

$$\rightarrow\; z^{-\theta_I}\, \alpha^I_{-1+\theta_I} |\, \theta_I \,\rangle_{NS} = z^{-\theta_I}\; \tilde{\tau}^+_{\theta_I}(0)$$

- analogous for fermionic degrees of freedom and higher excitations

- OPE's give us detailed knowledge of the conformal twist fields.

Vertex Operators

- For the NS-sector apply the following dictionary

positive angle θ

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

negative angle θ

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

- For the R-sector apply the following dictionary

positive angle θ

$$|\,\theta\,\rangle_R \quad : \quad e^{i(\theta-1/2)H}\ \sigma_\theta^+$$

negative angle θ

$$|\,\theta\,\rangle_R \quad : \quad e^{i(\theta+1/2)H}\ \sigma_{-\theta}^-$$

An example

- Consider $\theta_1^{ab} < 0\,,\ \theta_2^{ab} < 0\,,\ \theta_3^{ab} < 0$ with $\theta_1^{ab} + \theta_2^{ab} + \theta_3^{ab} = -2$
- A massless state in the NS-sector and the corresponding VO:

$$\prod_{I=1}^{3} \psi_{-1/2-\theta_I^{ab}} |\theta_{1,2,3}^{ab}\rangle_{NS} \quad : \qquad V^{(-1)} = \Lambda_{ab}\ \Phi\ e^{-\varphi} \prod_{I=1}^{3} e^{i(\theta_I^{ab}+1)H_I} \sigma^{-}_{-\theta_I^{ab}} e^{ikX}$$

Conformal dimension — World-sheet charge

$$h = 2 - \frac{1}{2}\sum_I \theta_I^{ab} + \frac{k^2}{2} = 1 + \frac{k^2}{2} \qquad U(1)_{WS} = \sum_{I=1}^{3} (\theta_I^{ab} + 1) = 1$$

- A massless state in the R-sector and the corresponding VO:

$$|\theta_{1,2,3}^{ab}\rangle_R \quad : \qquad V^{-\frac{1}{2}} = \Lambda_{ab}\psi_\alpha S^\alpha e^{-\varphi/2} \prod_{I=1}^{3} e^{i\left(\theta_I^{ab}+\frac{1}{2}\right)H_I} \sigma^{-}_{-\theta_I^{ab}} e^{ikX}$$

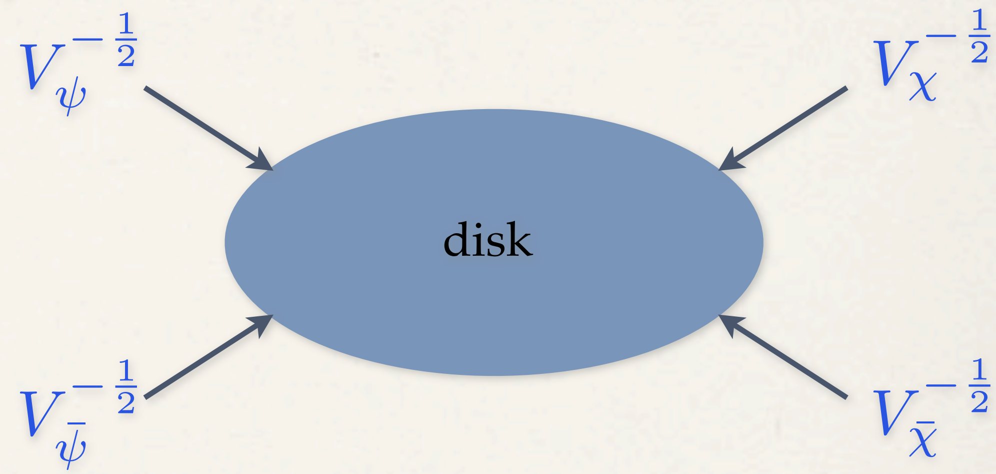
Conformal dimension — World-sheet charge

$$h = \frac{3}{8} + \frac{1}{4} + \frac{3}{8} + \frac{k^2}{2} = 1 + \frac{k^2}{2} \qquad U(1)_{WS} = \sum_{I=1}^{3}\left(\theta_I^{ab} + \frac{1}{2}\right) = -\frac{1}{2}$$

Amplitude

- For this configuration, the amplitude is $\left\langle \bar{\psi}\ \psi\ \chi\ \bar{\chi} \right\rangle$

$$\begin{array}{lll} \theta^1_{ab} > 0\ , & \theta^2_{ab} > 0\ , & \theta^3_{ab} < 0 \\ \theta^1_{bc} > 0\ , & \theta^2_{bc} > 0\ , & \theta^3_{bc} < 0 \\ \theta^1_{ca} < 0\ , & \theta^2_{ca} < 0\ , & \theta^3_{ca} < 0 \end{array}$$



with the corresponding vertex operators:

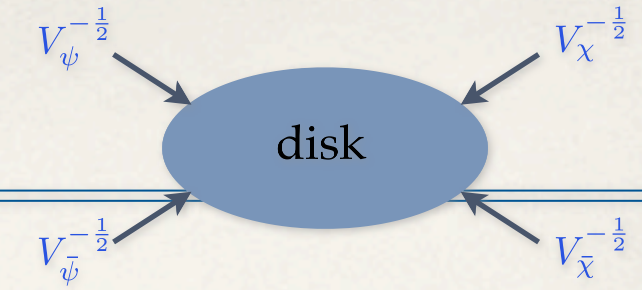
$$ab: \qquad V_\psi^{-\frac{1}{2}} = \Lambda_{ab}\psi^\alpha\, e^{-\varphi/2} S_\alpha \prod_{I=1}^{2} \sigma^+_{\theta^I_{ab}}\, e^{i\left(\theta^I_{ab}-\frac{1}{2}\right)H_I}\, \sigma^-_{-\theta^3_{ab}}\, e^{i\left(\theta^3_{ab}+\frac{1}{2}\right)H_3}\ e^{ikX}$$

$$ba: \qquad V_{\bar{\psi}}^{-\frac{1}{2}} = \Lambda_{ba}\bar{\psi}_{\dot{\alpha}}\, e^{-\varphi/2} S^{\dot{\alpha}} \prod_{I=1}^{2} \sigma^-_{\theta^I_{ab}}\, e^{i\left(-\theta^I_{ab}+\frac{1}{2}\right)H_I}\, \sigma^+_{-\theta^3_{ab}}\, e^{i\left(-\theta^3_{ab}-\frac{1}{2}\right)H_3}\ e^{ikX}$$

$$bc: \qquad V_\chi^{-\frac{1}{2}} = \Lambda_{bc}\chi^\alpha\, e^{-\varphi/2} S_\alpha \prod_{I=1}^{2} \sigma^+_{\theta^I_{bc}}\, e^{i\left(\theta^I_{bc}-\frac{1}{2}\right)H_I}\, \sigma^-_{-\theta^3_{bc}}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H_3}\ e^{ikX}$$

$$cb: \qquad V_{\bar{\chi}}^{-\frac{1}{2}} = \Lambda_{cb}\bar{\chi}_{\dot{\alpha}}\, e^{-\varphi/2} S^{\dot{\alpha}} \prod_{I=1}^{2} \sigma^-_{\theta^I_{bc}}\, e^{i\left(-\theta^I_{bc}+\frac{1}{2}\right)H_I}\, \sigma^+_{-\theta^3_{bc}}\, e^{i\left(-\theta^3_{bc}-\frac{1}{2}\right)H_3}\ e^{ikX}$$

Amplitude

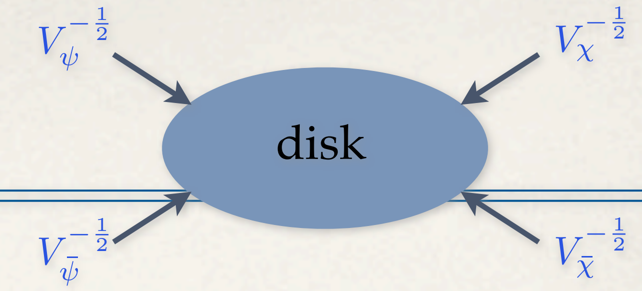


- Computing: $\mathcal{A} = \Big\langle \bar\psi(0)\ \psi(x)\ \chi(1)\ \bar\chi(\infty) \Big\rangle$

 which takes the form:

$$
\begin{aligned}
\mathcal{A} \ &= \ Tr\,(\Lambda_{ba}\,\Lambda_{ab}\,\Lambda_{bc}\,\Lambda_{cb})\,\bar\psi_{\dot\alpha}\,\psi^{\alpha}\,\chi^{\beta}\,\bar\chi_{\dot\beta} \\
& \int_0^1 dx \Big\langle e^{-\varphi/2(0)} e^{-\varphi/2(x)} e^{-\varphi/2(1)} e^{-\varphi/2(\infty)} \Big\rangle \\
& \quad \times \Big\langle S^{\dot\alpha}(0)\, S_{\alpha}(x)\, S_{\beta}(1) S^{\dot\beta}(\infty) \Big\rangle \Big\langle e^{ik_1 X(0)}\, e^{ik_2 X(x)}\, e^{ik_3 X(1)}\, e^{ik_4 X(\infty)} \Big\rangle \\
& \quad \times \Big\langle \sigma^{+}_{-\theta^3_{ab}}(0)\, \sigma^{-}_{-\theta^3_{ab}}(x)\, \sigma^{-}_{-\theta^3_{bc}}(1)\, \sigma^{+}_{-\theta^3_{bc}}(\infty) \Big\rangle \\
& \quad \times \prod_{I=1}^{2} \Big\langle \sigma^{-}_{\theta^I_{ab}}(0)\, \sigma^{+}_{\theta^I_{ab}}(x)\, \sigma^{+}_{\theta^I_{bc}}(0)\, \sigma^{-}_{\theta^I_{bc}}(\infty) \Big\rangle \\
& \quad \times \Big\langle e^{i\left(-\theta^3_{ab}-\frac{1}{2}\right)H^3(0)} e^{i\left(\theta^3_{ab}+\frac{1}{2}\right)H^3(x)}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H^3(1)}\, e^{i\left(-\theta^3_{bc}-\frac{1}{2}\right)H^3(\infty)} \Big\rangle \\
& \quad \times \prod_{I=1}^{2} \Big\langle e^{i\left(-\theta^I_{ab}+\frac{1}{2}\right)H^I(0)} e^{i\left(\theta^I_{ab}-\frac{1}{2}\right)H^I(x)}\, e^{i\left(\theta^I_{bc}-\frac{1}{2}\right)H^I(1)}\, e^{i\left(-\theta^I_{bc}+\frac{1}{2}\right)H^I(\infty)} \Big\rangle
\end{aligned}
$$

Amplitude



- Computing: $\mathcal{A} = \left\langle \bar{\psi}(0)\ \psi(x)\ \chi(1)\ \bar{\chi}(\infty) \right\rangle$

  which takes the form:

$$[x(1-x)]^{-\frac{1}{4}}\ x_\infty^{-\frac{3}{4}}$$

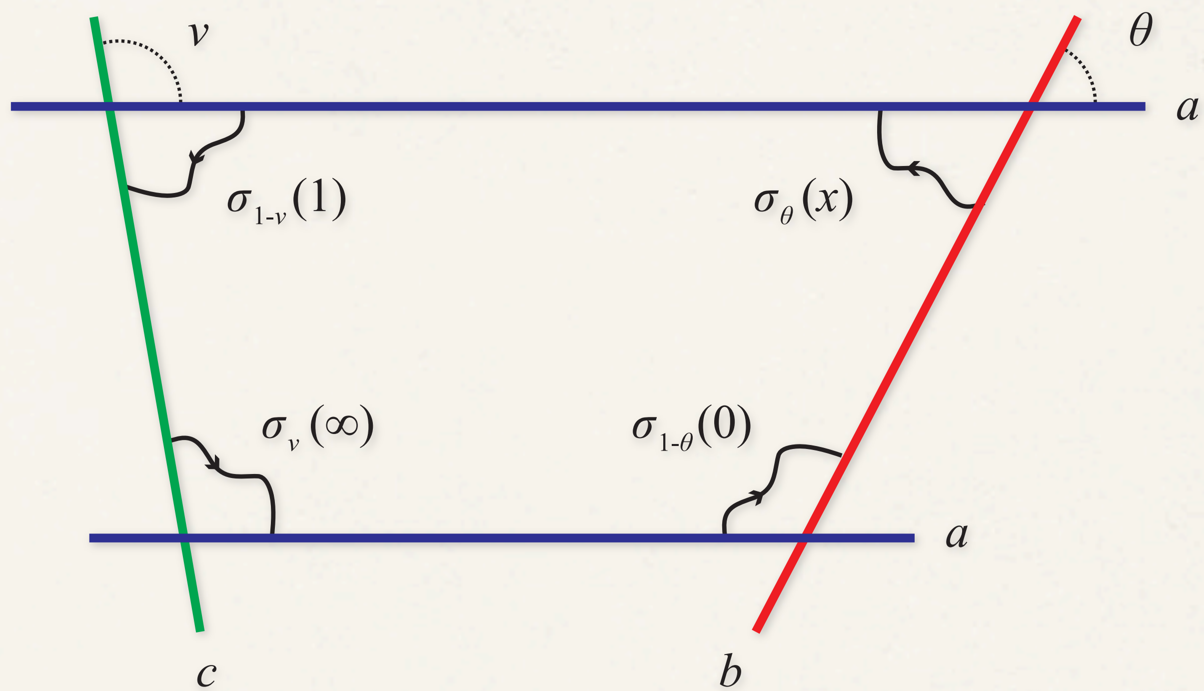
$$\begin{aligned}
\mathcal{A} \;=\; & Tr\left(\Lambda_{ba}\,\Lambda_{ab}\,\Lambda_{bc}\,\Lambda_{cb}\right)\bar{\psi}_{\dot\alpha}\,\psi^{\alpha}\,\chi^{\beta}\,\bar{\chi}_{\dot\beta} \\
& \int_0^1 dx \left\langle e^{-\varphi/2(0)} e^{-\varphi/2(x)} e^{-\varphi/2(1)} e^{-\varphi/2(\infty)} \right\rangle \\
& \times \left\langle S^{\dot\alpha}(0)\, S_{\alpha}(x)\, S_{\beta}(1) S^{\dot\beta}(\infty) \right\rangle \left\langle e^{ik_1 X(0)}\ e^{ik_2 X(x)}\ e^{ik_3 X(1)}\ e^{ik_4 X(\infty)} \right\rangle \\
& \times \left\langle \sigma^{+}_{-\theta^3_{ab}}(0)\, \sigma^{-}_{-\theta^3_{ab}}(x)\, \sigma^{-}_{-\theta^3_{bc}}(1)\, \sigma^{+}_{-\theta^3_{bc}}(\infty) \right\rangle \\
& \times \prod_{I=1}^{2} \left\langle \sigma^{-}_{\theta^I_{ab}}(0)\, \sigma^{+}_{\theta^I_{ab}}(x)\, \sigma^{+}_{\theta^I_{bc}}(0)\, \sigma^{-}_{\theta^I_{bc}}(\infty) \right\rangle \\
& \times \left\langle e^{i\left(-\theta^3_{ab}-\frac{1}{2}\right)H^3(0)} e^{i\left(\theta^3_{ab}+\frac{1}{2}\right)H^3(x)}\ e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H^3(1)}\ e^{i\left(-\theta^3_{bc}-\frac{1}{2}\right)H^3(\infty)} \right\rangle \\
& \times \prod_{I=1}^{2} \left\langle e^{i\left(-\theta^I_{ab}+\frac{1}{2}\right)H^I(0)} e^{i\left(\theta^I_{ab}-\frac{1}{2}\right)H^I(x)}\ e^{i\left(\theta^I_{bc}-\frac{1}{2}\right)H^I(1)}\ e^{i\left(-\theta^I_{bc}+\frac{1}{2}\right)H^I(\infty)} \right\rangle
\end{aligned}$$

$$\epsilon_{\alpha\beta}\,\epsilon_{\dot\alpha\dot\beta}\ (1-x)^{-\frac{1}{2}}\ x_\infty^{-\frac{1}{2}}$$

$$x^{k_1\cdot k_2}\ (1-x)^{k_2\cdot k_3}\ x_\infty^{k_4(k_1+k_2+k_3)}$$

?

$$x^{\left(-\theta^3_{ab}-\frac{1}{2}\right)\left(\theta^3_{ab}+\frac{1}{2}\right)}(1-x)^{\left(\theta^3_{ab}+\frac{1}{2}\right)\left(\theta^3_{bc}+\frac{1}{2}\right)} x_\infty^{\left(-\theta^3_{bc}-\frac{1}{2}\right)\left(\left(-\theta^3_{ab}-\frac{1}{2}\right)+\left(\theta^3_{ab}+\frac{1}{2}\right)+\left(\theta^3_{bc}+\frac{1}{2}\right)\right)}$$



The correlator: $\langle \sigma^+_{1-\theta}(0)\, \sigma^+_{\theta}(x)\, \sigma^+_{1-\nu}(1)\, \sigma^+_{\nu}(\infty) \rangle$

Recipe A

- Extend via the "doubling trick" the upper half plane to the whole complex plane.
- Quantum part is then computed by employing conformal field theory techniques (energy momentum tensor method) $\rightsquigarrow$ analogous to the closed string derivation:

$$T(z)\Phi(w) \sim \frac{h_\Phi \Phi(w)}{(z-w)^2} + \frac{\partial_w \Phi(w)}{z-w} + \ldots$$

$$\lim_{z\to z_2}\left(\frac{\langle T(z)\sigma_\alpha(z_1)\,\sigma_\beta(z_2)\,\sigma_\gamma(z_3)\,\sigma_\delta(z_4)\rangle}{\langle\sigma_\alpha(z_1)\,\sigma_\beta(z_2)\,\sigma_\gamma(z_3)\,\sigma_\delta(z_4)\rangle} - \frac{h_{\sigma_\beta}}{(z-z_2)^2}\right)$$

$$= \partial_{z_2} \ln\langle\sigma_\alpha(z_1)\,\sigma_\beta(z_2)\,\sigma_\gamma(z_3)\,\sigma_\delta(z_4)\rangle$$

- The classical part is given by the sum over all quadrangles connecting the four chiral fields $e^{-\sum \frac{Area}{2\pi\alpha'}}$.
- The final result is then given in the so-called Lagrangian Form.

Cvetic, Papadimitriou, Abel, Owen

Recipe A

- One independent angle:

$$x_\infty^{\theta(1-\theta)}\langle\sigma_{1-\theta}(0)\,\sigma_\theta(x)\,\sigma_{1-\theta}(1)\,\sigma_\theta(\infty)\rangle = \sqrt{\sin(\pi\theta)}\,\frac{[x(1-x)]^{-\theta(1-\theta)}}{\sqrt{F(x)F(1-x)}}$$

$$\times \sum_{\tilde{p}\in\Lambda_p,\tilde{q}\in\Lambda_q^*} \exp\left[-\frac{\pi}{\alpha'}\sin(\pi\theta)F(x)F(1-x)\left(\left(\frac{\tilde{p}L_a}{F(1-x)}\right)^2+\left(\frac{qL_b}{F(x)}\right)^2\right)\right]$$

- Two independent angles:

$$x_\infty^{\nu(1-\nu)}\,\langle\sigma_{1-\theta}(0)\,\sigma_\theta(x)\,\sigma_{1-\nu}(1)\,\sigma_\nu(\infty)\rangle = \frac{x^{-\theta(1-\theta)}(1-x)^{-\theta(1-\nu)}}{{}_2F_1[\theta,1-\nu,1,x]}\sqrt{\frac{\sin(\pi\theta)}{t(x)}}$$

$$\times\sum_{\widetilde{p},q}\exp\left[-\pi\frac{\sin(\pi\theta)}{t(x)}\,\frac{L_a^2}{\alpha'}\,\widetilde{p}^2-\pi\frac{t(x)}{\sin(\pi\theta)}\,\frac{R_1^2\,R_2^2}{\alpha'\,L_a^2}\,q^2\right]\,.$$

with: $$t(x) = \frac{\sin(\pi\theta)}{2\pi}\left(\frac{\Gamma(\theta)\,\Gamma(1-\nu)}{\Gamma(1+\theta-\nu)}\,\frac{{}_2F_1[\theta,1-\nu,1+\theta-\nu;1-x]}{{}_2F_1[\theta,1-\nu,1;x]} + \frac{\Gamma(\nu)\,\Gamma(1-\theta)}{\Gamma(1+\nu-\theta)}\,\frac{{}_2F_1[1-\theta,\nu,1-\theta+\nu;1-x]}{{}_2F_1[1-\theta,\nu,1;x]}\right)$$

Recipe B

- A generic closed twisted-field correlator takes the form:

$$\mathcal{A}_{closed} = |K(z)|^2 \sum_{\vec{k},\vec{v}} c_{\vec{k}\vec{v}} w(z)^{\frac{\alpha' p_L^2}{4}} \; \bar{w}(\bar{z})^{\frac{\alpha' p_R^2}{4}}$$

where $w(z)$ is holomorphic, $\vec{k},\ \vec{v} \in \Lambda^*$ and

$$p_L^2 = \left(\vec{k} + \frac{\vec{v}}{\alpha'}\right)^2 \qquad\qquad p_R^2 = \left(\vec{k} - \frac{\vec{v}}{\alpha'}\right)^2$$

- The open twisted-field correlator will look like (Hamiltonian Form):

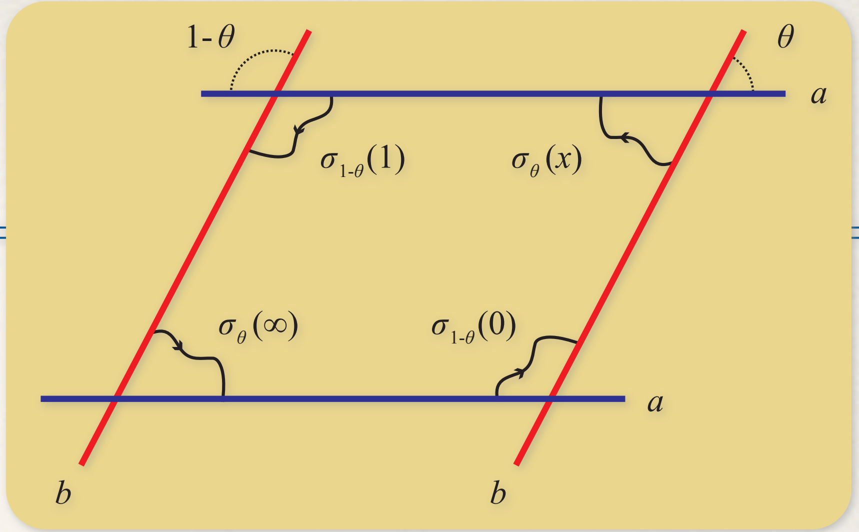
$$\mathcal{A}_{open} = K(x) \sum_{p,q} c_{p,q} w(x)^{\alpha' p_{open}^2}$$

where for the simple case of a D_1-brane we have:

$$p_{open}^2 = \frac{1}{L^2} p^2 + \frac{1}{\alpha'^2} \frac{R_1^2 R_2^2}{L^2} q^2$$

- Our task is to bring the *closed* correlator to the above form and get the *open* one.

Correlator: One angle



- The closed string result has the form:

$$|z_\infty|^{2\theta(1-\theta)} \left\langle \sigma_{1-\theta}(0)\, \sigma_\theta(z,\bar{z})\, \sigma_{1-\theta}(1)\, \sigma_\theta(\infty) \right\rangle$$

$$= \frac{\mathcal{C}}{V_\Lambda} \frac{|z(1-z)|^{-2\theta(1-\theta)}}{|{}_2F_1[\theta, 1-\theta; z]|^2} \times \sum_{k\in\Lambda^*, v_1\in\Lambda_c} \exp\left[-2\pi i f_{23}\cdot k\right]\; w(z)^{\frac{1}{2}(k+\frac{v}{2})^2}\; \bar{w}(\bar{z})^{\frac{1}{2}(k-\frac{v}{2})^2}$$

where $w(z) = \exp\left[\frac{i\pi\tau(z)}{\sin(\pi\theta)}\right]$ and $\tau(z) = \tau_1 + i\tau_2 = i\frac{{}_2F_1[\theta, 1-\theta; 1-z]}{{}_2F_1[\theta, 1-\theta; z]}$.

Dixon, Friedan, Martinec, Shenker

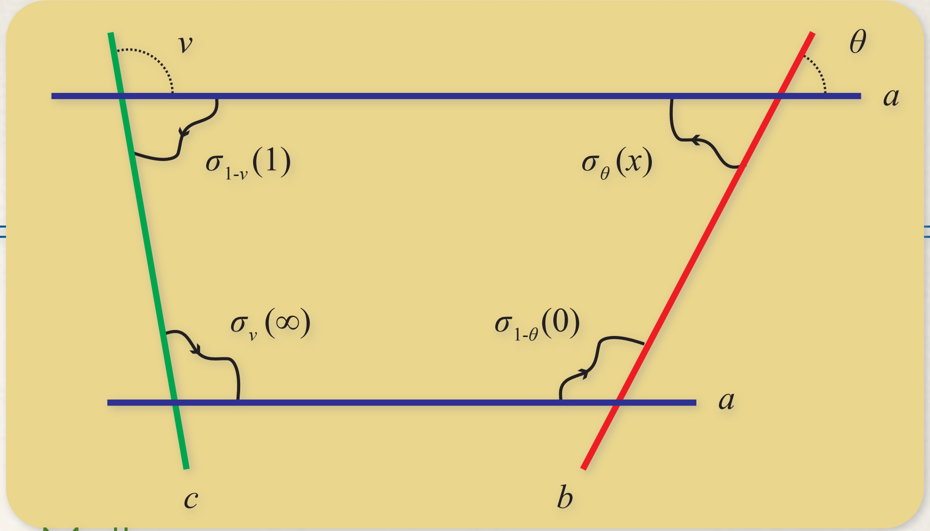
- The open string result has the form:

$$x_\infty^{\theta(1-\theta)} \left\langle \sigma_{1-\theta}(0)\, \sigma_\theta(x)\, \sigma_{1-\theta}(1)\, \sigma_\theta(\infty) \right\rangle = \frac{L_a}{\alpha'} \frac{[x(1-x)]^{-\theta(1-\theta)}}{{}_2F_1[\theta, 1-\theta; x]} \sum_{p,q} w(x)^{\left(\frac{\alpha'}{L_a^2} p^2 + \frac{1}{\alpha'} \frac{R_1^2 R_2^2}{L_a^2} q^2\right)}$$

where $w(x) = \exp\left[-\frac{\pi t(x)}{\sin(\pi\theta)}\right]$ and $t(x) = \frac{1}{2i}\left(\tau(x) - \bar{\tau}(x)\right) = \frac{{}_2F_1[\theta, 1-\theta; 1-x]}{{}_2F_1[\theta, 1-\theta; x]}$.

after Poisson resummation the same result as via recipe A.

Correlator: Two angles



- Following the same recipe, we get (original closed result is far too complicated to display here):

Burwick, Kaiser, Muller

$$x_\infty^{\nu(1-\nu)} \left\langle \sigma_{1-\theta}(0)\, \sigma_\theta(x)\, \sigma_{1-\nu}(1)\, \sigma_\nu(\infty) \right\rangle =$$

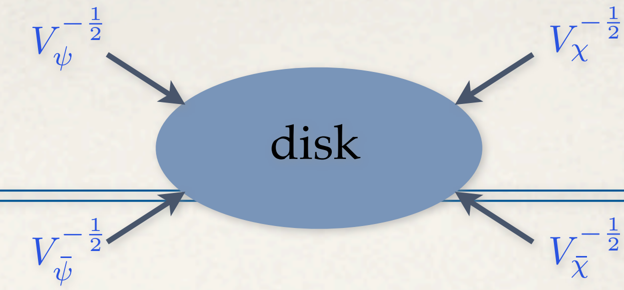
$$\frac{\sqrt{\alpha'}}{L_a} \frac{x^{-\theta(1-\theta)}(1-x)^{-\theta(1-\nu)}}{{}_2F_1[\theta, 1-\nu, 1; x]} \sum_{p,q} w(x)^{\left(\frac{\alpha'}{L_a^2} p^2 + \frac{1}{\alpha'} \frac{R_1^2 R_2^2}{L_a^2} q^2\right)}$$

with the $w(x) = \exp\left[-\frac{\pi t(x)}{\sin(\pi\theta)}\right]$ and

$$t(x) = \frac{\sin(\pi\theta)}{2\pi} \left(\frac{\Gamma(\theta)\,\Gamma(1-\nu)}{\Gamma(1+\theta-\nu)} \frac{{}_2F_1[\theta, 1-\nu, 1+\theta-\nu; 1-x]}{{}_2F_1[\theta, 1-\nu, 1; x]} + \frac{\Gamma(\nu)\,\Gamma(1-\theta)}{\Gamma(1+\nu-\theta)} \frac{{}_2F_1[1-\theta, \nu, 1-\theta+\nu; 1-x]}{{}_2F_1[1-\theta, \nu, 1; x]} \right)$$

- Again after Poisson resummation the same result as obtained via recipe A.

Amplitude (Back)



- Computing: $\mathcal{A} = \left\langle \bar\psi(0)\ \psi(x)\ \chi(1)\ \bar\chi(\infty) \right\rangle$

which takes the form:

$$\mathcal{A} \;=\; Tr\left(\Lambda_{ba}\,\Lambda_{ab}\,\Lambda_{bc}\,\Lambda_{cb}\right)\bar\psi_{\dot\alpha}\,\psi^{\alpha}\,\chi^{\beta}\,\bar\chi_{\dot\beta}$$

$$\int_0^1 dx \left\langle e^{-\varphi/2(0)} e^{-\varphi/2(x)} e^{-\varphi/2(1)} e^{-\varphi/2(\infty)} \right\rangle$$

$$\times \left\langle S^{\dot\alpha}(0)\,S_{\alpha}(x)\,S_{\beta}(1)S^{\dot\beta}(\infty)\right\rangle \left\langle e^{ik_1 X(0)}\,e^{ik_2 X(x)}\,e^{ik_3 X(1)}\,e^{ik_4 X(\infty)}\right\rangle$$

$$\times \left\langle \sigma^{+}_{-\theta^3_{ab}}(0)\,\sigma^{-}_{-\theta^3_{ab}}(x)\,\sigma^{-}_{-\theta^3_{bc}}(1)\,\sigma^{+}_{-\theta^3_{bc}}(\infty)\right\rangle$$

$$\times \prod_{I=1}^{2}\left\langle \sigma^{-}_{\theta^I_{ab}}(0)\,\sigma^{+}_{\theta^I_{ab}}(x)\,\sigma^{+}_{\theta^I_{bc}}(0)\,\sigma^{-}_{\theta^I_{bc}}(\infty)\right\rangle$$

$$\times \left\langle e^{i\left(-\theta^3_{ab}-\frac{1}{2}\right)H^3(0)} e^{i\left(\theta^3_{ab}+\frac{1}{2}\right)H^3(x)}\,e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H^3(1)}\,e^{i\left(-\theta^3_{bc}-\frac{1}{2}\right)H^3(\infty)}\right\rangle$$

$$\times \prod_{I=1}^{2}\left\langle e^{i\left(-\theta^I_{ab}+\frac{1}{2}\right)H^I(0)} e^{i\left(\theta^I_{ab}-\frac{1}{2}\right)H^I(x)}\,e^{i\left(\theta^I_{bc}-\frac{1}{2}\right)H^I(1)}\,e^{i\left(-\theta^I_{bc}+\frac{1}{2}\right)H^I(\infty)}\right\rangle$$

$[x(1-x)]^{-\frac{1}{4}}\ x_\infty^{-\frac{3}{4}}$

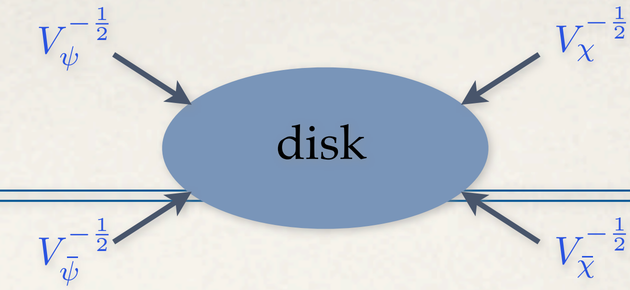
$\epsilon_{\alpha\beta}\,\epsilon_{\dot\alpha\dot\beta}\ (1-x)^{-\frac{1}{2}}\ x_\infty^{-\frac{1}{2}}$

$x^{k_1\cdot k_2}\ (1-x)^{k_2\cdot k_3}\ x_\infty^{k_4(k_1+k_2+k_3)}$

?

$x^{(-\theta^3_{ab}-\frac{1}{2})\,(\theta^3_{ab}+\frac{1}{2})}(1-x)^{(\theta^3_{ab}+\frac{1}{2})\,(\theta^3_{bc}+\frac{1}{2})}x_\infty^{(-\theta^3_{bc}-\frac{1}{2})((-\theta^3_{ab}-\frac{1}{2})+(\theta^3_{ab}+\frac{1}{2})+(\theta^3_{bc}+\frac{1}{2}))}$

Amplitude (Back)



- Computing: $\mathcal{A} = \left\langle \bar\psi(0)\ \psi(x)\ \chi(1)\ \bar\chi(\infty) \right\rangle$

  which takes the form:

$$\mathcal{A} \;=\; Tr\left(\Lambda_{ba}\,\Lambda_{ab}\,\Lambda_{bc}\,\Lambda_{cb}\right)\bar\psi_{\dot\alpha}\,\psi^{\alpha}\,\chi^{\beta}\,\bar\chi_{\dot\beta}$$

$$\int_0^1 dx \left\langle e^{-\varphi/2(0)} e^{-\varphi/2(x)} e^{-\varphi/2(1)} e^{-\varphi/2(\infty)} \right\rangle$$

$$\times \left\langle S^{\dot\alpha}(0)\, S_{\alpha}(x)\, S_{\beta}(1) S^{\dot\beta}(\infty) \right\rangle \left\langle e^{ik_1X(0)}\, e^{ik_2X(x)}\, e^{ik_3X(1)}\, e^{ik_4X(\infty)} \right\rangle$$

$$\times \left\langle \sigma^{+}_{-\theta^3_{ab}}(0)\, \sigma^{-}_{-\theta^3_{ab}}(x)\, \sigma^{-}_{-\theta^3_{bc}}(1)\, \sigma^{+}_{-\theta^3_{bc}}(\infty) \right\rangle$$

$$\times \prod_{I=1}^{2} \left\langle \sigma^{-}_{\theta^I_{ab}}(0)\, \sigma^{+}_{\theta^I_{ab}}(x)\, \sigma^{+}_{\theta^I_{bc}}(0)\, \sigma^{-}_{\theta^I_{bc}}(\infty) \right\rangle$$

$$\times \left\langle e^{i\left(-\theta^3_{ab}-\frac{1}{2}\right)H^3(0)} e^{i\left(\theta^3_{ab}+\frac{1}{2}\right)H^3(x)}\, e^{i\left(\theta^3_{bc}+\frac{1}{2}\right)H^3(1)}\, e^{i\left(-\theta^3_{bc}-\frac{1}{2}\right)H^3(\infty)} \right\rangle$$

$$\times \prod_{I=1}^{2} \left\langle e^{i\left(-\theta^I_{ab}+\frac{1}{2}\right)H^I(0)} e^{i\left(\theta^I_{ab}-\frac{1}{2}\right)H^I(x)}\, e^{i\left(\theta^I_{bc}-\frac{1}{2}\right)H^I(1)}\, e^{i\left(-\theta^I_{bc}+\frac{1}{2}\right)H^I(\infty)} \right\rangle$$

$$[x(1-x)]^{-\frac{1}{4}}\ x_{\infty}^{-\frac{3}{4}}$$

$$\epsilon_{\alpha\beta}\,\epsilon_{\dot\alpha\dot\beta}\ (1-x)^{-\frac{1}{2}}\ x_{\infty}^{-\frac{1}{2}}$$

$$x^{k_1\cdot k_2}\ (1-x)^{k_2\cdot k_3}\ x_{\infty}^{k_4(k_1+k_2+k_3)}$$

✓

$$x^{\left(-\theta^3_{ab}-\frac{1}{2}\right)\left(\theta^3_{ab}+\frac{1}{2}\right)}(1-x)^{\left(\theta^3_{ab}+\frac{1}{2}\right)\left(\theta^3_{bc}+\frac{1}{2}\right)} x_{\infty}^{\left(-\theta^3_{bc}-\frac{1}{2}\right)\left(\left(-\theta^3_{ab}-\frac{1}{2}\right)+\left(\theta^3_{ab}+\frac{1}{2}\right)+\left(\theta^3_{bc}+\frac{1}{2}\right)\right)}$$

Amplitude

- Combining all together we get:

$$\mathcal{A} = i g_s \mathcal{C} \, Tr\left(\Lambda_{ba}\,\Lambda_{ab}\,\Lambda_{bc}\,\Lambda_{cb}\right) \bar{\psi}\cdot\bar{\chi}\,\psi\cdot\chi(2\pi)^4\delta^{(4)}\left(\sum_i^4 k_i\right)$$

$$\times \int_0^1 dx \frac{x^{-1+k_1\cdot k_2}\,(1-x)^{-\frac{3}{2}+k_2\cdot k_3}\, e^{-S_{cl}(\theta^1_{ab},1-\theta^1_{bc})}\, e^{-S_{cl}(\theta^2_{ab},1-\theta^2_{bc})}\, e^{-S_{cl}(1+\theta^3_{ab},-\theta^3_{bc})}}{\left[I(\theta^1_{ab},1-\theta^1_{bc},x)\,I(\theta^2_{ab},1-\theta^2_{bc},x)\,I(1+\theta^3_{ab},-\theta^3_{bc},x)\right]^{\frac{1}{2}}}$$

where

$$I(\theta,\nu,x) = \frac{1}{2\pi}\left\{\frac{\Gamma(\theta)\,\Gamma(1-\nu)}{\Gamma(1+\theta-\nu)}\,{}_2F_1[1-\theta,\nu,1;x]{}_2F_1[\theta,1-\nu,1+\theta-\nu;1-x]\right.$$
$$\left. + \frac{\Gamma(\nu)\,\Gamma(1-\theta)}{\Gamma(1+\nu-\theta)}\,{}_2F_1[\theta,1-\nu,1;x]{}_2F_1[1-\theta,\nu,1-\theta+\nu;1-x]\right\}$$

$$e^{-S_{cl}(\theta,\nu)} = \sum_{\widetilde{p}_i,q_i} \exp\left[-\pi\frac{\sin(\pi\theta)}{t(\theta,\nu,x)}\,\frac{L^2_{b^i}}{\alpha'}\,\widetilde{p}^2_i - \pi\frac{t(\theta,\nu,x)}{\sin(\pi\theta)}\,\frac{R^2_{x_i}\,R^2_{y_i}}{\alpha' L^2_{b^i}}\,q^2_i\right]$$

- Finally, we need to normalize the amplitude.

Amplitude at the s-channel $(x \to 0)$

- At the limit $x \to 0$ the amplitude factorizes on the exchange of a gauge boson:

- that allows to normalize the amplitude ($p_i = q_i = 0$)

$$A_4(k_1,k_2,k_3,k_4) = \mathrm{i} \int \frac{\mathrm{d}^4k\, \mathrm{d}^4k'}{(2\pi)^4} \frac{\sum_g A^g_\mu(k_1,k_2,k)A^{g,\mu}(k_3,k_4,k')\delta^{(4)}(k-k')}{k^2 - \mathrm{i}\epsilon}$$

with

g_{D6_b}

$$A^g_\mu(k_1,k_2,k_3) = \mathrm{i}\sqrt{(2\pi)^4 \frac{\alpha'^{3/2} g_s}{\prod_{i=1}^3 2\pi L_{b_i}}}\,(2\pi)^4\delta^{(4)}\left(\sum_{i=1}^{3} k_i\right) \bar{\psi}\sigma^\mu\psi\; Tr(\Lambda_{ba}\,\Lambda_{ab}\Lambda_{bb})$$

- Comparing the two results we normalize the amplitude to: $\mathcal{C} = 2\pi$.

Amplitude at the s-channel $(x \to 0)$

- At the limit $x \to 0$ there are other (higher order) poles corresponding to other massive exchanges:

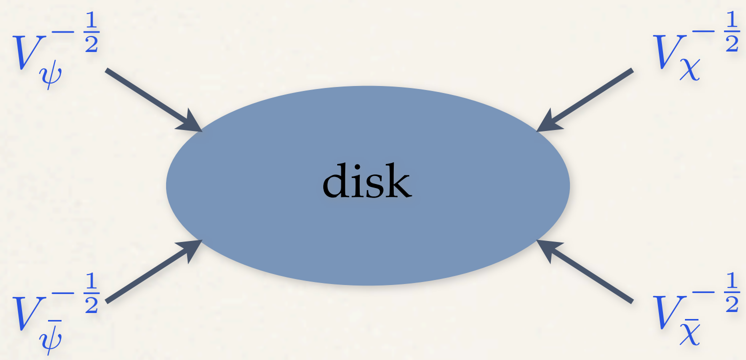
- Other poles that arise from $p_i \neq 0 \neq q_i$, they correspond to KK and winding states exchanges.

- Additional poles from higher order poles of the "quantum part" corresponding to Regge excitations.

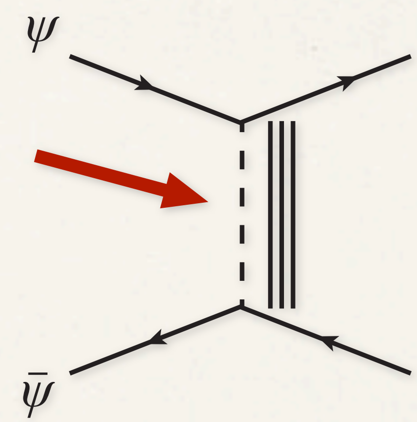
- Similar pole structure than the behavior of amplitudes containing at most two chiral fermions. Thus "universal behavior" dressed with poles arising from KK and winding states.

Amplitude at the t-channel $(x \to 1)$

- In the limit $x \to 1$ the amplitude factorizes on the exchange of scalar particles



$\Longrightarrow$



- In this limit the amplitude takes the form (SUSY preserved, ignore WS-instantons):

$$\Gamma_{\alpha,\beta,\gamma} = \frac{\Gamma(\alpha)\,\Gamma(\beta)\,\Gamma(\gamma)}{\Gamma(1-\alpha)\,\Gamma(1-\beta)\,\Gamma(1-\gamma)}$$

etc...

$$\begin{aligned}\mathcal{A} \;=\; & \bar{\psi}\cdot\bar{\chi}\,\psi\cdot\chi \int_{1-\epsilon}^{1} dx\,(1-x)^{-1+k_2\cdot k_3}\;\Gamma^{-\frac{1}{2}}_{1-\theta^1_{ab},1-\theta^1_{bc},\theta^1_{ab}+\theta^1_{bc}}\;\Gamma^{-\frac{1}{2}}_{1-\theta^2_{ab},1-\theta^2_{bc},\theta^2_{ab}+\theta^2_{bc}}\;\Gamma^{-\frac{1}{2}}_{-\theta^3_{ab},-\theta^3_{bc},2+\theta^3_{ab}+\theta^3_{bc}} \\ & \times\Bigg[\left(1+\frac{\Gamma_{1-\theta^1_{ab},1-\theta^1_{bc},\theta^1_{ab}+\theta^1_{bc}}}{\Gamma_{\theta^1_{ab},\theta^1_{bc},2-\theta^1_{ab}-\theta^1_{bc}}}(1-x)^{2(1-\theta^1_{ab}-\theta^1_{bc})}\right) \\ & \times\left(1+\frac{\Gamma_{1-\theta^2_{ab},1-\theta^2_{bc},\theta^2_{ab}+\theta^2_{bc}}}{\Gamma_{\theta^2_{ab},\theta^2_{bc},2-\theta^2_{ab}-\theta^2_{bc}}}(1-x)^{2(1-\theta^2_{ab}-\theta^2_{bc})}\right) \\ & \times\left(1+\frac{\Gamma_{-\theta^3_{ab},-\theta^3_{bc},2+\theta^3_{ab}+\theta^3_{bc}}}{\Gamma_{1+\theta^3_{ab},1+\theta^3_{bc},-\theta^3_{ab}-\theta^3_{bc}}}(1-x)^{2(-\theta^3_{ab}-\theta^3_{bc}-1)}\right)\Bigg]^{-\frac{1}{2}}\end{aligned}$$

massless scalar exchange

Subdominant poles

- Assuming that $1-\theta^1_{ab}-\theta^1_{bc}=-\theta^1_{ca}$ is small, the amplitude becomes:

$$\mathcal{A} \;=\; \bar{\psi}\cdot\bar{\chi}\,\psi\cdot\chi\int_{1-\epsilon}^{1} dx\,(1-x)^{-1+k_2\cdot k_3}\;Y^2_{\psi\chi\phi}\Big(1+c_1(1-x)^{2(1-\theta^1_{ab}-\theta^1_{bc})}+\ldots\Big)$$

- Thus we have the exchange of:
  - a massless scalar Φ: $\prod_I \psi_{-1/2-\theta^I_{ca}}\,|\,\theta^{ca}_{1,2,3}\rangle_{NS}$
  - a massive scalar $\tilde{\tilde{\Phi}}$: $(\alpha_{\theta^1_{ca}})^2\prod_I \psi_{-1/2-\theta^I_{ca}}\,|\,\theta^{ca}_{1,2,3}\rangle_{NS}$ with $M^2=-2\theta^1_{ca}M_s^2$.
- Note that there is no coupling to the lightest massive field with mass $M^2=-\theta^1_{ca}M_s^2$.
- This is can be traced back to the fact that the two bosonic twist fields σ_α and σ_β do not couple to the excited twist field $\tau_{\alpha+\beta}$, but only to an even excited twist field.

$$\sigma_\alpha(w)\,\sigma_\beta(z)\sim C_\sigma(z-w)^{-\alpha\beta}\sigma_{\alpha+\beta}+C_\rho(z-w)^{-\alpha\beta+2-2\alpha-2\beta}\rho_{\alpha+\beta}$$

Further poles

- The exchange particle is a scalar field, thus the signatures induced by the tower $(\alpha_{\theta^1_{ca}})^m \prod_I \psi_{-1/2-\theta^I_{ca}} |0\rangle$ resembles signatures of KK states in extra-dimensional theories.
- Above just the first sub-dominant poles, but there are many more poles.
- In case the fermions are too much separated in the internal manifold WS-instantons cannot be ignored; poles arising from them correspond to exchanges of KK and winding excitations.
- There are also integer poles, that correspond to exchange of Higher Spin states.
- Other poles that correspond to exchanges of massive scalar fields whose mass is non-vanishing even for vanishing intersection angles.
- Rich spectrum of signatures, but the first once to be observed correspond to lightest string states.

Conclusions

- We have studied the spectrum of open strings localized at the intersections of D6-branes.
- The masses of such states scale as $M^2 \approx \theta M_s^2$ and can thus be parametrically smaller than the string scale if the relevant angle is small.
- We have considered scattering amplitudes that expose such light stringy states.

Along the computation

Give a description to formulate the vertex operators for states localized at intersections.

Rederived the four bosonic twist field correlator with one and two independent angles.

- Investigated s- and t-channel and found poles corresponding to light stringy states.
- Assuming a scenario with a low string scale, these states may be observable at LHC.
- However further poles corresponding to KK and winding states, as well as Higher Spin states

$\rightsquigarrow$ Rich spectrum of signatures