OSp 不変な超弦の場の理論

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Plan

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collaboration with
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1. Introduction

✳ Motivation

We would like to construct closed superstring field theory.

✳ Closed Bosonic String Field Theory (SFT)

- Light-cone gauge SFT — Kaku-Kikkawa
- Non-polynomial SFT — Saadi-Zwiebach, Kugo-Kunitomo-Suehiro
- HIKKO — Hata-Itoh-Kugo-Kunitomo-Ogawa
- *OSp* invariant SFT — W. Siegel
- …

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Why *OSp* invariant SFT?

In *OSp* invariant closed bosonic SFT,
we can construct D-brane states.

Y.B.-Ishibashi-Murakami

2. OSp Invariant String Field Theory

W. Siegel

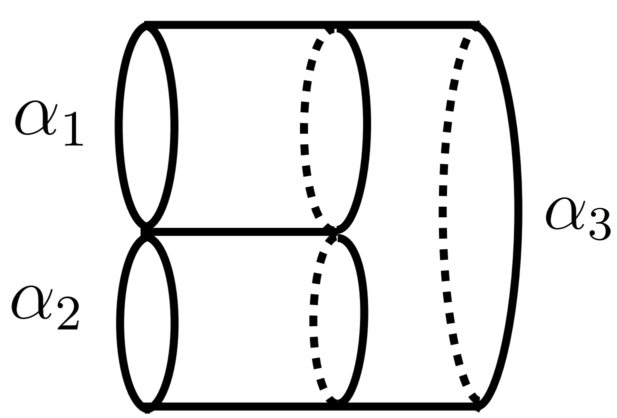
✳ Light-cone gauge String Field Theory

$$\boxed{X^+, X^-}, X^i, \quad (i = 2, \ldots, 25)$$

$$t = x^+, \alpha = 2p^+$$

- action

$$S = \int dt \left[-\frac{1}{2} \Phi K \Phi + \frac{2g}{3} (\Phi)^3 \right]$$



Φ :string field

g :string coupling

$$K = \frac{1}{\alpha} \left(-i\alpha \frac{\partial}{\partial t} + L_0 + \tilde{L}_0 - 2 \right) = \frac{1}{\alpha} \left(-i\alpha \frac{\partial}{\partial t} + \sum_{i=1}^{24} p^i p^i + M^2 \right)$$

Light-cone gauge SFT

$X^+, X^-, X^i, \quad (i = 2, \ldots, 25)$

t, α

Light-cone gauge SFT

$X^+, X^-, X^i, \quad (i = 2, \ldots, 25)$

$X^+, X^- \longrightarrow t, \alpha$

OSp extension
(Adding topological sector)

$$\delta_{ij} \longrightarrow \begin{array}{c|cc|cc} & & & C & \bar{C} \\ & & & & \\ & \eta_{\mu\nu} & & & \\ C & & & 0 & -i \\ \bar{C} & & & i & 0 \end{array} \qquad \mu = +'', -'', 2, \ldots, 25$$

$$O(24) \longrightarrow OSp(25, 1|2)$$

$$O(25,1) \longrightarrow OSp(26, 2|2)$$

$X^+, X^-, X^i, X^{+''}, X^{-''}, X^C, X^{\bar{C}}$

topological

BRST $\sim \mathcal{M}^{C-''} \in OSp(25, 1|2)$

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"Lorentz transformation" $(+, -) \leftrightarrow (+'', -'')$

OSp invariant SFT

$X^+, X^-, X^\mu, X^C, X^{\bar{C}}$

cancel

spacetime

BRST $\delta_{\mathrm{B}} = \dfrac{1}{2}\mathcal{M}^{C-}$

✶ $X^{+''}, X^{-''}, X^{C}, X^{\bar{C}}$ sector

general states in this sector

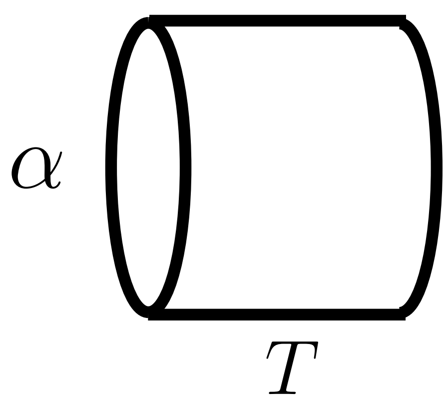
$$| \ \rangle \otimes f(p^{+''}, p^{-''}, p^{C}, p^{\bar{C}})$$

$\mathcal{M}^{C-''}$ **cohomology class**

$$|0\rangle \otimes 1$$

- two point function

$$= \int \frac{dp^{+''}dp^{-''}dp^{C}dp^{\bar{C}}}{2\pi} \langle 0|0\rangle \, e^{-i\frac{T}{\alpha}\left(-2p^{+''}p^{-''}-2ip^{C}p^{\bar{C}}\right)} \underline{=1}$$



$$p^{+''}p^{-''} + ip^{C}p^{\bar{C}} = \{\mathcal{M}^{C-''}, p^{+''}p^{\bar{C}}\}$$ **:exact**

Parisi-Sourlas formula

Parisi-Sourlas, Kugo

$$\int \frac{dp^{+''}dp^{-''}dp^{C}dp^{\bar{C}}}{2\pi} F(p^{+''}p^{-''} + ip^{C}p^{\bar{C}}) = F(0)$$

Light-cone gauge SFT $X^+, X^-, X^i, \quad (i = 2, \ldots, 25)$

$X^+, X^- \longrightarrow t, \alpha$

OSp extension

(Adding topological sector)

$$\delta_{ij} \longrightarrow \begin{array}{c|cc|cc} & & & C & \bar{C} \\ \hline & \multicolumn{2}{c|}{\eta_{\mu\nu}} & & \\ C & & & 0 & -i \\ \bar{C} & & & i & 0 \end{array} \qquad \mu = +'', -'', 2, \ldots, 25$$

$X^+, X^-, X^i, X^{+''}, X^{-''}, X^C, X^{\bar{C}}$

topological

$$O(24) \longrightarrow OSp(25,1|2)$$
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OSp invariant SFT

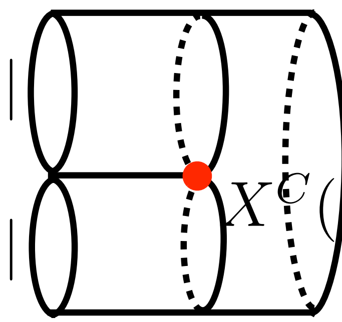
$X^+, X^-, X^\mu, X^C, X^{\bar{C}}$

cancel

spacetime

BRST $\delta_{\mathrm{B}} = \dfrac{1}{2}\mathcal{M}^{C-}$

- BRST symmetry



$$\delta_{\rm B}|\Phi\rangle = \frac{1}{2}\mathcal{M}^{C-}|\Phi\rangle = Q_{\rm B}|\Phi\rangle + g|\Phi \overset{X^C}{*} \Phi\rangle$$

$$Q_{\rm B} = Q_{\rm B}^{\rm KO} + \frac{ip^C}{\alpha}\left(\alpha \left.\frac{\partial}{\partial\alpha}\right|_{b,c} + 1\right)$$

$$\alpha_n^C = -in\alpha c_n\ , \quad \tilde\alpha_n^C = -in\alpha\tilde c_n\ ; \quad \alpha_n^{\bar C} = \frac{1}{\alpha}b_n\ , \quad \tilde\alpha_n^{\bar C} = \frac{1}{\alpha}\tilde b_n\ ,$$

$$x^C = 2\alpha c_0^+\ , \quad p^{\bar C} = \frac{1}{2\alpha}b_0^+\ ,$$

- BRST invariant observable

$$\mathcal{O}(t,p) = \int_{-\infty}^{\infty}\frac{d\alpha}{2}\int dp^C dp^{\bar C}\ {}_{\rm gh}\langle 0| \otimes {}_{\rm m}\langle\overline{\rm DDF}|\Phi(t,\alpha,p^\mu,p^C,p^{\bar C})\rangle$$

gh: $X^C, X^{\bar C}$

m: X^μ

$${}_{\rm m}\langle\overline{\rm DDF}|\overline{\rm DDF}\rangle_{\rm m} = 1$$

- Free propagator

$$\langle\!\langle \mathcal{O}_1(t_1,p_1)\mathcal{O}_2(t_2,p_2)\rangle\!\rangle_{\rm free}$$

$$= \int_0^\infty \frac{d\alpha_1}{2\alpha_1}\int dp_1^C dp_1^{\bar C}\ e^{-i\frac{t_1-t_2}{\alpha_1}\left(p_1^\mu p_{1,\mu} - 2ip_1^C p_1^{\bar C} + M^2\right)}(2\pi)^{26}\delta^{26}(p_1+p_2)$$

$$= \frac{-i}{p_1^2+M^2}(2\pi)^{26}\delta^{26}(p_1+p_2)$$

3. OSp Invariant Superstring Field Theory

✳ Light-cone gauge (NSR formalism)

$$\boxed{\begin{matrix} X^+, X^- \\ \psi^+, \psi^- \\ \tilde{\psi}^+, \tilde{\psi}^- \end{matrix}} \begin{matrix} , X^i \\ , \psi^i \\ , \tilde{\psi}^i \end{matrix} \qquad (i = 2, \ldots 9)$$

gauge fixing

$$\boxed{X^+(\tau,\sigma) = t - i\alpha\tau \qquad \psi^+(\tau,\sigma) = 0\ , \qquad \tilde{\psi}^+(\tau,\sigma) = 0}$$

Virasoro constraint

$$\rightarrow \boxed{\alpha_n^- = \frac{2}{\alpha}\left(L_n - \frac{1}{2}\delta_{n,0}\right) \qquad \psi_k^- = \frac{2}{\alpha}G_k}$$

L_n, G_k:superconformal generator

k R-sector : integer
NS-sector : half integer

✳ NS-NS sector

Light-cone gauge SFT

X^+, X^-, X^i

$\psi^+, \psi^-, \psi^i \qquad (i = 2, \ldots 9)$

$\tilde{\psi}^+, \tilde{\psi}^-, \tilde{\psi}^i$

OSp extension

$O(8) \longrightarrow OSp(9,1|2)$

$O(9,1) \longrightarrow OSp(10,2|2)$

$X^+, X^-, X^i \; X^{+''}, X^{-''}, X^C, X^{\bar{C}}$

$\psi^+, \psi^-, \psi^i \; \psi^{+''}, \psi^{-''}, \psi^C, \psi^{\bar{C}},$

$\tilde{\psi}^+, \tilde{\psi}^-, \tilde{\psi}^i \; \tilde{\psi}^{+''}, \tilde{\psi}^{-''}, \tilde{\psi}^C, \tilde{\psi}^{\bar{C}}$

cancel

BRST $\mathcal{M}^{C-''}$

"Lorentz transformation" $(+,-) \leftrightarrow (+'',-'')$

OSp invariant SFT

$X^+, X^- \; X^i \; X^{+''}, X^{-''}, X^C, X^{\bar{C}}$

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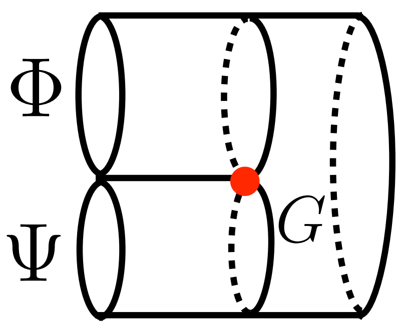
cancel

$$\delta_{\mathrm{B}} = \frac{1}{2}\mathcal{M}^{C-}$$

- BRST transformation

$$\delta_{\mathrm{B}}|\Phi\rangle = \frac{1}{2}\mathcal{M}^{C-}|\Phi\rangle = Q_{\mathrm{B}}|\Phi\rangle + g|\Phi \overset{G}{*} \Phi\rangle$$



$$Q_{\mathrm{B}} = Q_{\mathrm{B}}^{\mathrm{super}} + \frac{ip^C}{\alpha}\left(\alpha \frac{\partial}{\partial\alpha}\Big|_{b,c,\beta,\gamma} + A\right)$$

A : constant

$A = 1$ for NS-NS sector

$$\alpha_n^C = -in\alpha c_n\ ,\quad \tilde{\alpha}_n^C = -in\alpha\tilde{c}_n\ ,\quad \alpha_n^{\bar{C}} = \frac{1}{\alpha}b_n\ ,\quad \tilde{\alpha}_n^{\bar{C}} = \frac{1}{\alpha}\tilde{b}_n\ ,\quad x^C = 2\alpha c_0^+\ ,$$

$$p^{\bar{C}} = \frac{1}{2\alpha}b_0^+\ ,\quad \psi_k^C = i\alpha\gamma_k\ ,\quad \tilde{\psi}_k^C = i\alpha\tilde{\gamma}_k\ ,\quad \psi_k^{\bar{C}} = \frac{1}{\alpha}\beta_k\ ,\quad \tilde{\psi}_k^{\bar{C}} = \frac{1}{\alpha}\tilde{\beta}_k\ ,$$

cf. HIKKO

- Observable

$$\mathcal{O}(t,p) = \int_{-\infty}^{\infty}\frac{d\alpha}{2}\int dp^C dp^{\bar{C}}\ {}_{\mathrm{gh}}\langle 0| \otimes {}_{\mathrm{m}}\langle\overline{\mathrm{DDF}}|\Phi(t,\alpha,p^\mu,p^C,p^{\bar{C}})\rangle$$

- Free propagator

$$\langle\langle\mathcal{O}_1(t_1,p_1)\mathcal{O}_2(t_2,p_2)\rangle\rangle_{\mathrm{free}} = \frac{-i}{p_1^2+M^2}(2\pi)^{26}\delta^{26}(p_1+p_2)$$

✴ R-NS sector (NS-R sector)

Light-cone gauge SFT

X^+, X^-, X^i

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BRST $\mathcal{M}^{C-''}$?

"Lorentz transformation" $(+,-) \leftrightarrow (+'', -'')$

OSp invariant SFT ?

$\boxed{X^+, X^-}\; X^i \; X^{+''}, X^{-''}, \boxed{X^C, X^{\bar{C}}}$

$\boxed{\psi^+, \psi^-}\; \psi^i \; \psi^{+''}, \psi^{-''} \boxed{\psi^C, \psi^{\bar{C}},}$

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$$\delta_{\mathrm{B}} = \frac{1}{2}\mathcal{M}^{C-}$$

cancel

- $(+'', -'', C, \bar{C})$ sector

  zero mode

$$p^{+''}, p^{-''}, p^{C}, p^{\bar{C}}, \psi_0^{-''}, \psi_0^{\bar{C}} \left(\psi_0^{+''} = -\frac{\partial}{\partial \psi_0^{-''}},\ \psi_0^{C} = i\frac{\partial}{\partial \psi_0^{\bar{C}}} \right)$$

- $(+'', -'', C, \bar{C})$ sector

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Parisi-Sourlas mechanism

- $(+'', -'', C, \bar{C})$ sector

  zero mode

  ?

  $$\boxed{p^{+''}, p^{-''}, p^{C}, p^{\bar{C}}}\ \psi_0^{-''}, \psi_0^{\bar{C}} \left(\psi_0^{+''} = -\frac{\partial}{\partial \psi_0^{-''}},\ \psi_0^{C} = i\frac{\partial}{\partial \psi_0^{\bar{C}}} \right)$$

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?

Parisi-Sourlas mechanism

- Adding 4+4 directions $(+'', -'', C, \bar{C}, \underline{+', -', C', \bar{C}'})$

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$$\boxed{p^{+'}, p^{-'}, p^{C'}, p^{\bar{C}'}}\ \boxed{\psi_0^{+'}, \psi_0^{C'}} \left(\psi_0^{-'} = -\frac{\partial}{\partial \psi_0^{+'}},\ \psi_0^{\bar{C}'} = -i\frac{\partial}{\partial \psi_0^{C'}}\right)$$

BRST transformation $\delta_{\mathrm{B}} = \frac{1}{2}\left(\mathcal{M}^{C-''} + \mathcal{M}^{C'-'}\right)$

cohomology $|0\rangle \otimes 1$

- Adding 4+4 directions $(+'', -'', C, \bar{C}, \underline{+', -', C', \bar{C}'})$

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BRST transformation $\delta_{\mathrm{B}} = \frac{1}{2}\left(\mathcal{M}^{C-''} + \mathcal{M}^{C'-'}\right)$

cohomology $|0\rangle \otimes 1$

- two point function

$$\int \frac{dp^{+''}dp^{-''}dp^{C}dp^{\bar{C}}}{2\pi} \int \frac{dp^{+'}dp^{-'}dp^{C'}dp^{\bar{C}'}}{2\pi}\ e^{-i\frac{T}{\alpha}\left(-2p^{+''}p^{-''}-2ip^{C}p^{\bar{C}}-2p^{+'}p^{-'}-2ip^{C'}p^{\bar{C}'}\right)}$$

$$\times \int \frac{d\psi_0^{C'}d\psi_0^{\bar{C}}d\psi_0^{+'}d\psi_0^{-''}}{2\pi}$$

- Adding 4+4 directions $(+'', -'', C, \bar{C}, \underline{+', -', C', \bar{C}'})$

$$\boxed{p^{+''}, p^{-''}, p^{C}, p^{\bar{C}}}, \boxed{\psi_0^{-''}, \psi_0^{\bar{C}}} \left(\psi_0^{+''} = -\frac{\partial}{\partial \psi_0^{-''}},\ \psi_0^{C} = i\frac{\partial}{\partial \psi_0^{\bar{C}}}\right)$$

$$\boxed{p^{+'}, p^{-'}, p^{C'}, p^{\bar{C}'}}, \boxed{\psi_0^{+'}, \psi_0^{C'}} \left(\psi_0^{-'} = -\frac{\partial}{\partial \psi_0^{+'}},\ \psi_0^{\bar{C}'} = -i\frac{\partial}{\partial \psi_0^{C'}}\right)$$

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$$\boxed{\textbf{cohomology} \qquad |0\rangle \otimes 1}$$

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$$\int \frac{dp^{+''} dp^{-''} dp^{C} dp^{\bar{C}}}{2\pi} \int \frac{dp^{+'} dp^{-'} dp^{C'} dp^{\bar{C}'}}{2\pi}\ e^{-i\frac{T}{\alpha}\left(-2p^{+''}p^{-''} - 2ip^{C}p^{\bar{C}} - 2p^{+'}p^{-'} - 2ip^{C'}p^{\bar{C}'}\right)}$$

$$\times \int \frac{d\psi_0^{C'} d\psi_0^{\bar{C}} d\psi_0^{+'} d\psi_0^{-''}}{2\pi} \boxed{e^{iT'\left(\psi_0^{C'}\psi_0^{\bar{C}} + i\psi_0^{+'}\psi_0^{-''}\right)}} = 1$$

Light-cone gauge SFT

$$X^+, X^-, X^i$$
$$\psi^+, \psi^-, \psi^i \qquad (i = 2, \ldots 9)$$
$$\tilde{\psi}^+, \tilde{\psi}^-, \tilde{\psi}^i$$

OSp extension

$$X^+, X^-, X^i \; X^{+''}, X^{-''}, X^C, X^{\bar{C}} X^{+'}, X^{-'}, X^{C'}, X^{\bar{C}'}$$
$$\psi^+, \psi^-, \psi^i \; \psi^{+''}, \psi^{-''}, \psi^C, \psi^{\bar{C}}, \psi^{+'}, \psi^{-'}, \psi^{C'}, \psi^{\bar{C}'}$$
$$\tilde{\psi}^+, \tilde{\psi}^-, \tilde{\psi}^i \; \tilde{\psi}^{+''}, \tilde{\psi}^{-''}, \tilde{\psi}^C, \tilde{\psi}^{\bar{C}} \; \tilde{\psi}^{+'}, \tilde{\psi}^{-'}, \tilde{\psi}^{C'}, \tilde{\psi}^{\bar{C}'}$$

BRST

$$\frac{1}{2}(\mathcal{M}^{C-''} + \mathcal{M}^{C'-'})$$

cancel

"Lorentz transformation" $(+, -) \leftrightarrow (+'', -'')$

OSp invariant SFT

$$X^+, X^- \; X^i \; X^{+''}, X^{-''} \; X^C, X^{\bar{C}}, X^{+'}, X^{-'}, X^{C'}, X^{\bar{C}'}$$
$$\psi^+, \psi^- \; \psi^i \; \psi^{+''}, \psi^{-''} \; \psi^C, \psi^{\bar{C}}, \psi^{+'}, \psi^{-'}, \psi^{C'}, \psi^{\bar{C}'}$$
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cancel

$$\delta_{\mathrm{B}} = \frac{1}{2}(\mathcal{M}^{C-} + \mathcal{M}^{C'-'})$$

- Observable

$$\boxed{\mathcal{O}(t,p)=\int_{-\infty}^{\infty}d\alpha\frac{\alpha^{\frac{1}{2}}}{2}\int dp_{\mathrm{gh}}\;{}_{\mathrm{gh}}\langle 0|\otimes{}_{\mathrm{m}}\langle\overline{\mathrm{DDF}}|\Phi(t,\alpha,p)\rangle}$$

gh: $(C,\bar{C},C',\bar{C}',+',-')$

m: μ

$$dp_{\mathrm{gh}}=\frac{dp^{+'}dp^{-'}dp^{C}dp^{\bar{C}}dp^{C'}dp^{\bar{C}'}d\psi_0^{C'}d\psi_0^{\bar{C}}d\psi_0^{+'}}{2^{\frac{5}{2}}\pi^2}$$

- Free propagator

$$\langle\langle\mathcal{O}_1(t_1,p_1)\mathcal{O}_2(t_2,p_2)\rangle\rangle_{\mathrm{free}}=\underline{\frac{-i\sqrt{2}G_0^{\mathrm{m}}}{p_1^2+M^2}(2\pi)^{26}\delta^{26}(p_1+p_2)}$$

$\sqrt{2}G_0^{\mathrm{m}}$:Dirac operator

$$\int\frac{d\psi_0^{C'}d\psi_0^{\bar{C}}d\psi_0^{+'}}{2^{\frac{3}{2}}\pi}e^{iT'\left(\psi_0^{C'}\psi_0^{\bar{C}}+\frac{2i}{\alpha}\psi_0^{+'}G_0^{\mathrm{m}}+\dots\right)}=\frac{\sqrt{2}G_0^{\mathrm{m}}}{\alpha}$$

- **Observable**

$$\boxed{\mathcal{O}(t,p) = \int_{-\infty}^{\infty} d\alpha \frac{\alpha^{\frac{1}{2}}}{2} \int dp_{\rm gh}\ {}_{\rm gh}\langle 0| \otimes {}_{\rm m}\langle \overline{\rm DDF}|\Phi(t,\alpha,p)\rangle}$$

gh: $(C, \bar{C}, C', \bar{C}', +', -')$

m: μ

$$dp_{\rm gh} = \frac{dp^{+'}dp^{-'}dp^{C}dp^{\bar{C}}dp^{C'}dp^{\bar{C}'}d\psi_0^{C'}d\psi_0^{\bar{C}}d\psi_0^{+'}}{2^{\frac{5}{2}}\pi^2}$$

- **Free propagator**

$$\langle\langle \mathcal{O}_1(t_1,p_1)\mathcal{O}_2(t_2,p_2)\rangle\rangle_{\rm free} = \underline{\frac{-i\sqrt{2}G_0^{\rm m}}{p_1^2+M^2}(2\pi)^{26}\delta^{26}(p_1+p_2)}$$

$\sqrt{2}G_0^{\rm m}$:Dirac operator

$$\int \frac{d\psi_0^{C'}d\psi_0^{\bar{C}}d\psi_0^{+'}}{2^{\frac{3}{2}}\pi} \underline{e^{iT'\left(\psi_0^{C'}\psi_0^{\bar{C}}+\frac{2i}{\alpha}\psi_0^{+'}G_0^{\rm m}+\dots\right)}} = \frac{\sqrt{2}G_0^{\rm m}}{\alpha}$$

$T' \to 0$: 1

$T' \to \infty$: $\sim \frac{4\pi}{\alpha}\delta(\psi_0^{C'})\delta(\psi_0^{\bar{C}})G_0^{\rm m}\psi_0^{+'}$

picture changing operator

$\sim \delta(\beta_0)G_0^{\rm m}$

4. Conclusions

✳ $\boxed{\text{OSp invariant Superstring Field Theory}}$

$\sim$ Light-cone + (4+4)-directions

- correct two-point functions
- "picture changing operator" $\sim$ 1

- R-R sector ?
- N-point amplitude ?
- regularization ?
- D-brane states ?