Title: The Holography of de Sitter Space: DSSYK as a concrete example (Vision Talk)

Speakers: Leonard Susskind

Collection/Series: QIQG 2025

Subject: Quantum Gravity, Quantum Information

Date: June 23, 2025 - 10:00 AM

URL: https://pirsa.org/25060002

Abstract:

I will discuss the holographic principle as applied to de Sitter space and the concrete example of double-scaled SYK at infinite temperature.

10:03 AM Mon Jun 23

"Philosophical" Questions

Observers and experiments

Dimensionality of Global $\mathcal{H}$

Meaning of S_{dS}

What we need is a

concrete example

$$DSSYK_\infty \longleftrightarrow \text{JT - de Sitter} \quad \begin{matrix} HV \\ LS \end{matrix}$$

$$= dS_3/S_1$$

10:04 AM Mon Jun 23 96%

"Philosophical" Questions

Observers and experiments

Dimensionality of Global $\mathcal{H}$

Meaning of S_{dS}

What we need is a

10:04 AM Mon Jun 23 96%

Obser… …periment

Dimensionality of Global $\mathcal{H}$

Meaning of S_{dS}

What we need is a

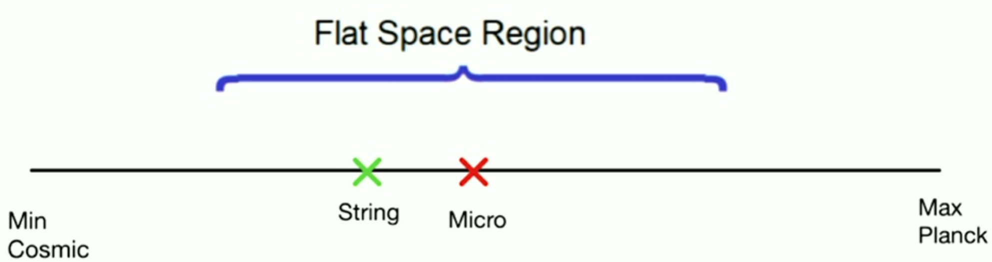
concrete example

$DSSYK_\infty \longleftrightarrow$ JT - de Sitter

HV
LS

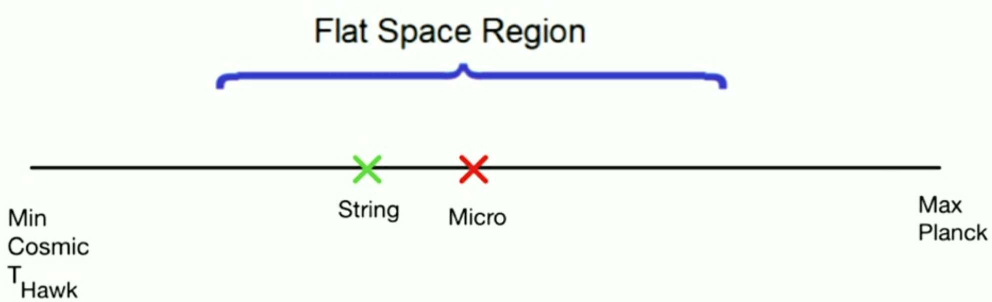
$= dS_3/S_1$

Separation of Scales



10:06 AM Mon Jun 23 95%

Separation of Scales



What is the bulk particle

10:07 AM Mon Jun 23

Min
Cosmic
T_{Hawk}

Max
Planck

What is the bulk particle
Spectrum?

Forces?

Fields

Couplings ?

How is the Standard model

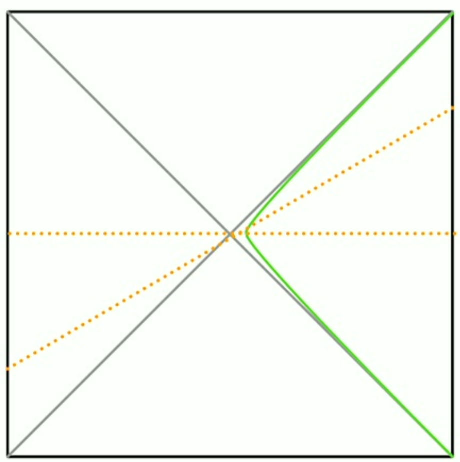
10:08 AM Mon Jun 23 95%

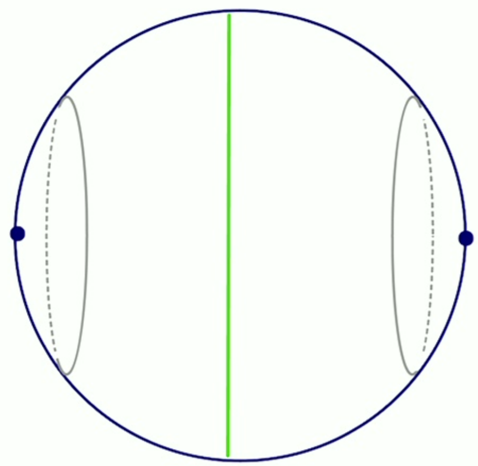
$dS(2+1) \longrightarrow JT\text{-}dS$

H. Verlinde

A. Rahman + L.S.

$dS\,(2+1)$





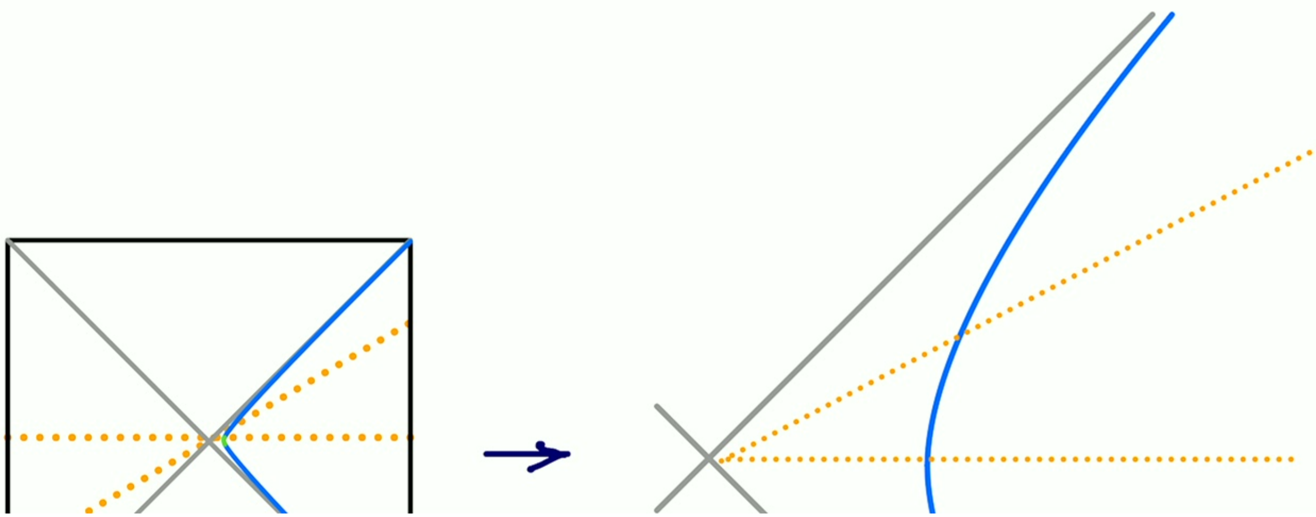
10:08 AM Mon Jun 23

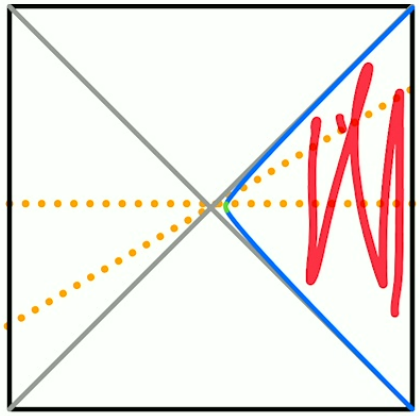
Flat Space Limit

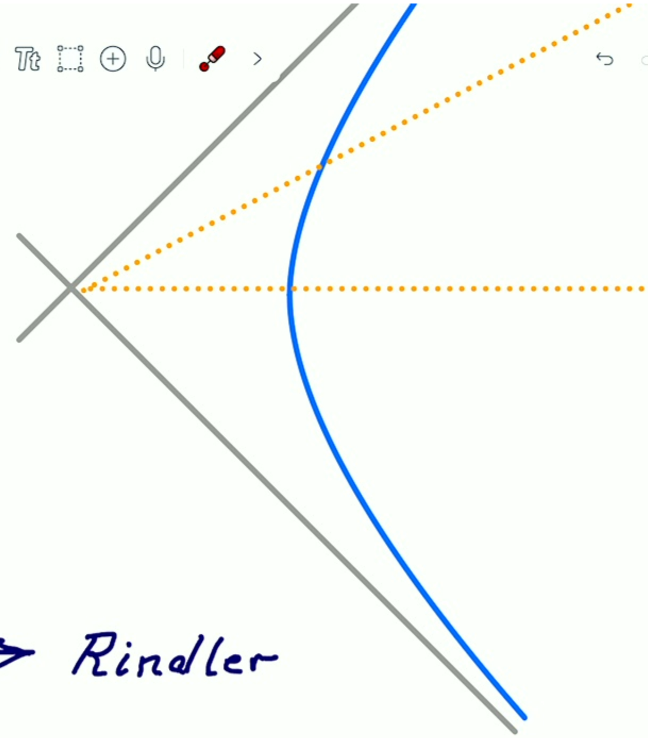
$\ell \to \infty$

or $S \to \infty$

$N \to \infty$







dS Static Patch $\longrightarrow$ Rindler

$$\boxed{\text{Flat-Space Theory in Rindler Coordinates}}$$

10:11 AM Mon Jun 23 94%

Complex DSSYK$_\infty$

$$\bar{\psi}_i \, , \, \psi_i \qquad i = 1, 2, \cdots, N$$

$$\{\psi_i, \psi_j\} = 0$$

$$\{\bar{\psi}^i, \bar{\psi}^j\} = 0$$

Paste Paste Image

$$\{\bar{\psi}^i, \psi_j\} = \delta^i_j$$

$$H = \sum_{\substack{i_1 < i_2 \cdots \\ j_1 < j_2 \cdots}} J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p} \psi_{j_1} \psi_{j_2} \cdots \psi_{j_p} \bar{\psi}^{i_p} \cdots \bar{\psi}^{i_2} \bar{\psi}^{i_1}$$

10:12 AM Mon Jun 23

$$\{ \bar{\psi}^i , \psi_j \} = \delta^i_j$$

$$H = \sum_{\substack{i_1 < i_2 \cdots \\ j_1 < j_2 \cdots}} J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p} \psi_{j_1} \psi_{j_2} \cdots \psi_{j_p} \bar{\psi}^{i_p} \cdots \bar{\psi}^{i_2} \bar{\psi}^{i_1}$$

$$\mu(J) = \exp\left\{ - \sum \frac{J^{j_1, j_2 \cdots}_{i_1, i_2 \cdots} J^{i_1, i_2 \cdots}_{j_1, j_2 \cdots}}{\mathrm{Var}\, J} \right\}$$

$$\mathrm{Var}\, J = \mathcal{J}^2 \frac{N}{P^2} \frac{P!\ P!}{N^P\ N^P}$$

$$\frac{P^2}{N} = \lambda \quad (\text{fixed})$$

$$T = \infty \qquad \rho \sim e^{-\frac{H}{T}} \qquad \text{CLPW}$$

10:13 AM Mon Jun 23

$$\{\bar{\Psi}^i, \Psi_j\} = \delta^i_j$$

$$H = \sum_{\substack{i_1 < i_2 \cdots \\ j_1 < j_2 \cdots}} J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p} \psi_{j_1} \psi_{j_2} \cdots \psi_{j_p} \bar{\Psi}^{i_p} \cdots \bar{\Psi}^{i_2} \bar{\Psi}^{i_1}$$

$$\mu(J) = \exp\left\{ - \sum \frac{J^{j_1, j_2, \cdots}_{i_1, i_2 \cdots} J^{i_1, i_2 \cdots}_{j_1, j_2, \cdots}}{\mathrm{Var}\, J} \right\}$$

$$\mathrm{Var}\, J = \mathcal{J}^2 \frac{N}{P^2} \frac{P!\, P!}{N^P N^P}$$

$$\frac{P^2}{N} = \lambda \quad (\text{fixed})$$

$$T_B = \infty \qquad \rho \sim e^{-\frac{H}{T_B}} \qquad \text{CLPW}$$

10:13 AM Mon Jun 23 93%

$$\{\bar{\psi}^i, \psi_j\} = \delta^i_j$$

$$H = \sum_{\substack{i_1 < i_2 \cdots \\ j_1 < j_2 \cdots}} J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p} \psi_{j_1} \psi_{j_2} \cdots \psi_{j_p} \bar{\psi}^{i_p} \cdots \bar{\psi}^{i_2} \bar{\psi}^{i_1}$$

$$\mu(J) = \exp\left\{- \sum \frac{J^{j_1, j_2, \cdots}_{i_1, i_2 \cdots} J^{i_1, i_2 \cdots}_{j_1, j_2, \cdots}}{\mathrm{Var}\, J}\right\}$$

$$\mathrm{Var}\, J = \mathcal{J}^2 \frac{N}{p^2} \frac{p!\ p!}{N^p\ N^p}$$

$$\frac{p^2}{N} = \lambda \quad (\text{fixed})$$

$$T_B = \infty \qquad \rho \sim e^{-\frac{H}{T_B}} \qquad \text{CLPW}$$

10:13 AM Mon Jun 23 93%

$$\mathrm{Var}\, J = \mathcal{J}^2 \frac{N}{p^2} \frac{p!\; p!}{N^p\, N^p}$$

$$\frac{p^2}{N} = \lambda \quad \text{(fixed)}$$

$$T_B = \infty \qquad \rho \sim e^{-\frac{H}{T_B}} \qquad \text{CLPW}$$

Flat-space limit: $N \to \infty$

Useful graphical notation

10:14 AM Mon Jun 23 92%

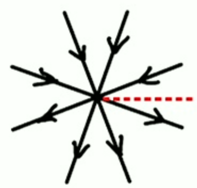
$$\frac{P^2}{N} = \lambda \quad \text{(fixed)}$$

$$T_B = \infty \qquad \rho \sim e^{-\frac{H}{T_B}} \qquad \text{CLPW}$$

Flat-space limit: $N \to \infty$

Paste Paste Image

Useful graphical notation

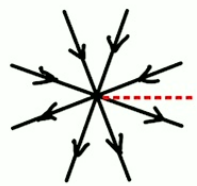
$\mathcal{J}$  $\bar{\psi} \cdot\cdot \bar{\psi} \; \psi \cdot\cdot \psi$

10:16 AM Mon Jun 23

Flat-space limit: $N \to \infty$

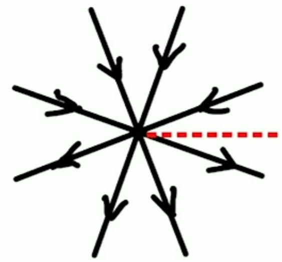
92%

Useful graphical notation

$\mathcal{J}$  $\bar\psi \cdot\cdot \bar\psi \; \psi \cdot\cdot \psi$

$$\text{——} \; = \; \epsilon(t_2 - t_1)$$

$$\text{- - - - -} \; = \; \frac{N}{p^2} \, \frac{p! \; p!}{N^{p} \cdot N^{p}}$$

$\mathcal{J}$  $\bar{\psi}\cdot\cdot\bar{\psi}\ \psi\cdot\cdot\psi$

 $= \epsilon(t_2 - t_1)$

 $= \dfrac{N}{p^2} \dfrac{p!\ p!}{N^{p} \cdot N^{p}}$

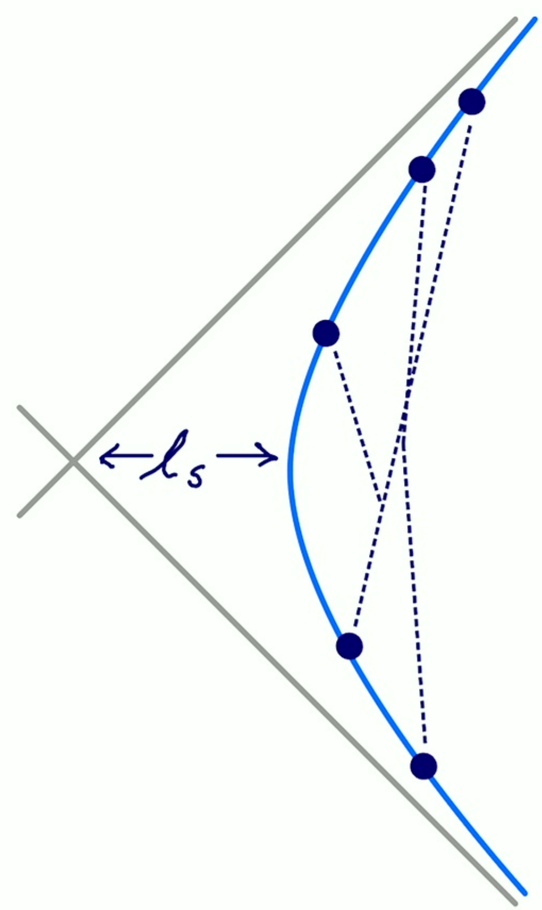
Decoding the Hologram

Particle Spectrum

Fields

Interactions

Correlation functions



10:20 AM Mon Jun 23

90%

Symmetries

10:21 AM Mon Jun 23

Symmetries of DSSYK$_\infty$

Disorder-Averaged Vs unaveraged

	DA	UA
C, T, U(1)	✓	✓
SU(N) $\psi_i \to U_i^j \psi_j$	✓	X

Symmetri … K∞

Disorder-averaged Vs unaveraged

		DA	UA
$C, T, U(1)$		✓	✓
$SU(N)$	$\psi_i \to U_i^j \psi_j$	✓	X

$$H = \sum_{i_1<i_2\cdots} J^{j_1,j_2\cdots j_p}_{i_1,i_2\cdots i_p}\, \psi_{j_1}\psi_{j_2}\cdots\psi_{j_p}\,\bar{\Psi}^{i_p}\cdots\bar{\Psi}^{i_2}\,\bar{\Psi}^{i_1}$$

10:23 AM Mon Jun 23 89%

Disorder-Averaged Vs unaveraged

	DA	UA
$C, T, U(1)$	✓	✓
$SU(N)$ $\quad \psi_i \to U_i^j \psi_j$	✓	X

$$H = \sum_{\substack{i_1 < i_2 \cdots \\ j_1 < j_2 \cdots}} J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p} \psi_{j_1} \psi_{j_2} \cdots \psi_{j_p} \bar{\psi}^{i_p} \cdots \bar{\psi}^{i_2} \bar{\psi}^{i_1}$$

$$\mu(J) = \exp\left\{ - \sum \frac{J^{j_1, j_2 \cdots}_{i_1 i_2 \cdots} J^{i_1 i_2 \cdots}_{j_1, j_2 \cdots}}{\mathrm{Var}\, J} \right\}$$

10:24 AM Mon Jun 23

89%

$\mu(J)$ $\left[\sum J^{j_1, j_2 \cdots} J^{i_1, i_2 \cdots} \right.$ Var $J \Big\}$

Transform $J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p}$

Unaveraged Theory

(Fixed $J^{j_1, j_2 \cdots j_p}_{i_1, i_2 \cdots i_p}$)

dependence on J

No Symmetry

No conservation laws

Averaged Theory

Paste Paste Image

10:26 AM Mon Jun 23 No conservation laws 88%

Averaged Theory

$\int \mu(J)\, dJ \,\bullet$

Yes Symmetry

No conservation laws

Diagnostics

$$\bar{\psi}_i \psi_i = \text{singlet} = S$$

$$\bar{\psi}_i \psi_j = \text{adjoint} = A$$

$$\langle S\ A \rangle = \mathrm{Tr}\ S\ A = 0$$

$$\langle S \; A \rangle = \mathrm{Tr}\; S \; A = 0$$

$$\mathrm{Tr}\; S(0)\, A(t) = \mathrm{Tr}\; \underbrace{S\, e^{-iHt} A\, e^{iHt}}_{W}$$

$$= \langle W(J) \rangle \neq 0$$

Ens Ave $\langle W \rangle = \big(\langle W \rangle\big) \simeq 0$

10:28 AM Mon Jun 23

$$\langle S\ A\rangle = \mathrm{Tr}\ S\ A = 0$$

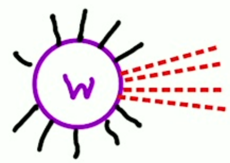
$$\mathrm{Tr}\ S(0)A(t) = \mathrm{Tr}\ S\underbrace{e^{-iHt}A\,e^{iHt}}_{W}$$

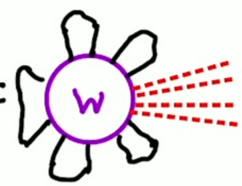
$$= \langle W(J)\rangle \neq 0$$

$$\text{Ens Ave } \langle W\rangle = \left(\langle W\rangle\right) \simeq 0$$

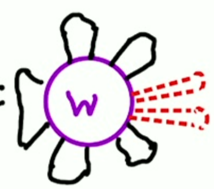
10:30 AM Mon Jun 23 87%

Graphically

$W =$ 

$\langle W \rangle =$ 

$\neq 0$ Depends on J

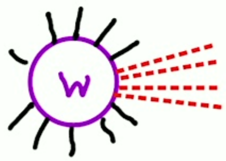
$(\langle W \rangle) =$ 

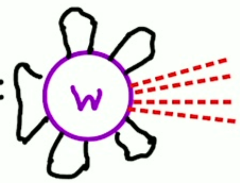
$= 0$

10:31 AM Mon Jun 23

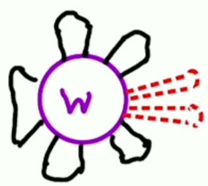
86%

Graphically

$W =$ 

$\langle W \rangle =$ 

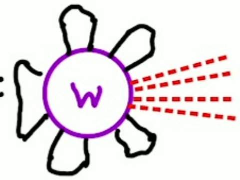
$\neq 0$ Depends on J

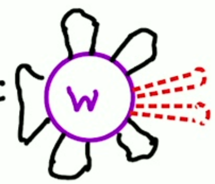
$(\langle W \rangle) =$ 

$= 0$

10:32 AM Mon Jun 23 86%

$W =$ 

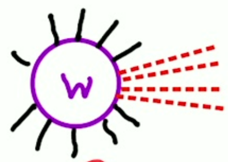
$\langle W \rangle =$  $\neq 0$ Depends on J

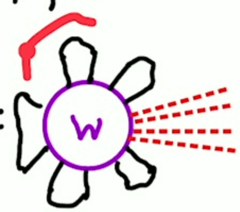
$(\langle W \rangle) =$  $= 0$

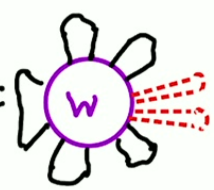
Variance

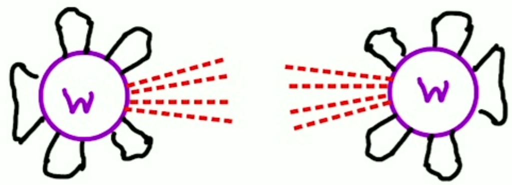
$$(\langle W \rangle \langle W \rangle) - (\langle W \rangle)^2$$

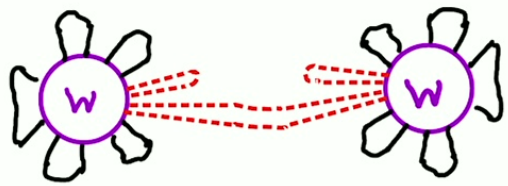
Graphically

W = 

$\langle W \rangle$ =  $\neq 0$ Depends on J

$\big(\langle W \rangle\big)$ =  $= 0$

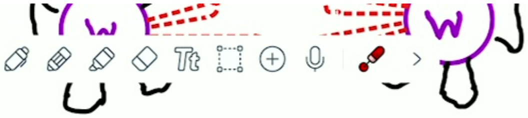
$\langle W \rangle^2 =$ 

$\left(\langle W \rangle^2 \right) =$ 

 $= \frac{N}{p^2} \frac{p!\, p!}{N^{p} \cdot N^{p}} = \frac{1}{\lambda} \left(\frac{p}{N} \right)^{2p}$

10:35 AM Mon Jun 23

85%

$$(\langle W \rangle) =$$ 

$$= \frac{N}{p^2}\,\frac{p!\,p!}{N^{p}\cdot N^{p}} = \frac{1}{\lambda}\left(\frac{p}{N}\right)^{2p}$$

$$= \frac{1}{\lambda}\left(\frac{N}{\lambda}\right)^{-\sqrt{N\lambda}}$$

$$\boxed{(\langle W^2 \rangle) \approx \frac{1}{\lambda^2}\left(\frac{N}{\lambda}\right)^{-2\sqrt{N\lambda}} \longrightarrow 0 \quad < N^{c} \text{ all } c}$$

10:36 AM Mon Jun 23 84%

$$= \frac{1}{\lambda}\left(\frac{N}{\lambda}\right)^{-\sqrt{N\lambda}}$$

$$\boxed{\left(\langle W^2\rangle\right) \approx \frac{1}{\lambda^2}\left(\frac{N}{\lambda}\right)^{-2\sqrt{N\lambda}} \rightarrow 0 \quad < N^c \text{ all } c}$$

In DSSYK SU(N) is a global

10:37 AM Mon Jun 23

84%

Paradox

Hot Plasma: N^2 gluons

$$S \sim N^2$$

But in DSSYK $S \leq N \log 2$

Resolution: In (1+1) dimensions there are no gauge bosons. The gauge fields

10:38 AM Mon Jun 23

84%

But in DSSYK $S \leq N \log 2$

Resolution: In $(1+1)$ dimensions there are no gauge bosons. The gauge fields mediate instantaneous $V \sim g^2 N |r|$.

Gauge fields in $(1+1)$ are Nondynamical and do not contribute

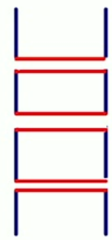
10:39 AM Mon Jun 23 83%

In $DSSYK_\infty$ $S \sim N$ (fermions $\bar{\psi}, \psi$)

$$\bar{q}, q \longleftrightarrow \bar{\psi}, \psi$$

<u>Confinement</u>

10:41 AM Mon Jun 23 83%



$$H_{LC} = \frac{m_q^2}{x(1-x)} + g^2 N \, |r_q - r_{\bar{q}}|$$

$$m_q^2 = \mu^2 N$$

$$H_{LC} = N\mu^2 \left(\frac{1}{x(1-x)} + \frac{g^2}{\mu^2} |r| \right)$$

$$\bar{g}^2 = \frac{g^2}{\mu^2}$$

16
25

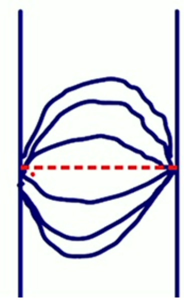
10:41 AM Mon Jun 23 82%

$$\bar{\alpha} = \bar{g}^2 N$$

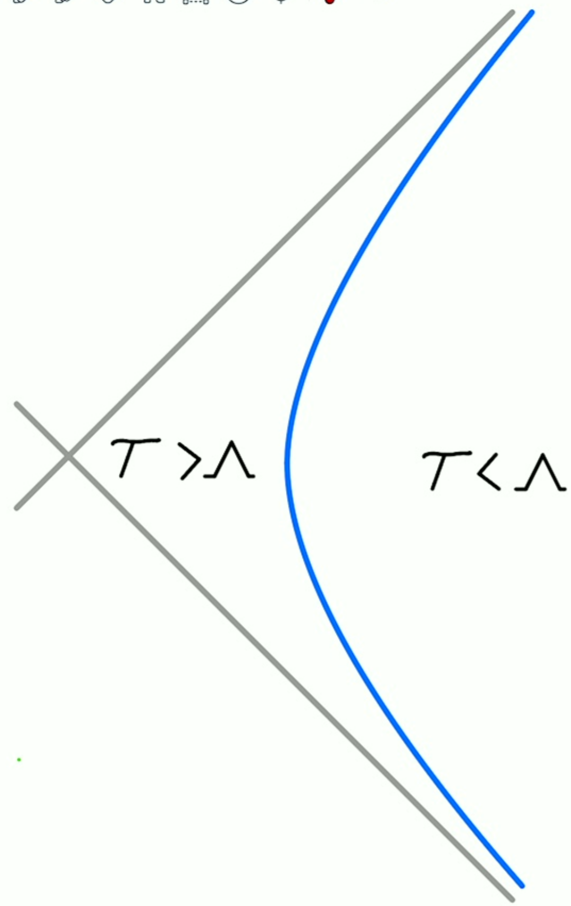
$$A = \sum_n \frac{F_n(\bar{\alpha})}{N^n}$$

DSSYK

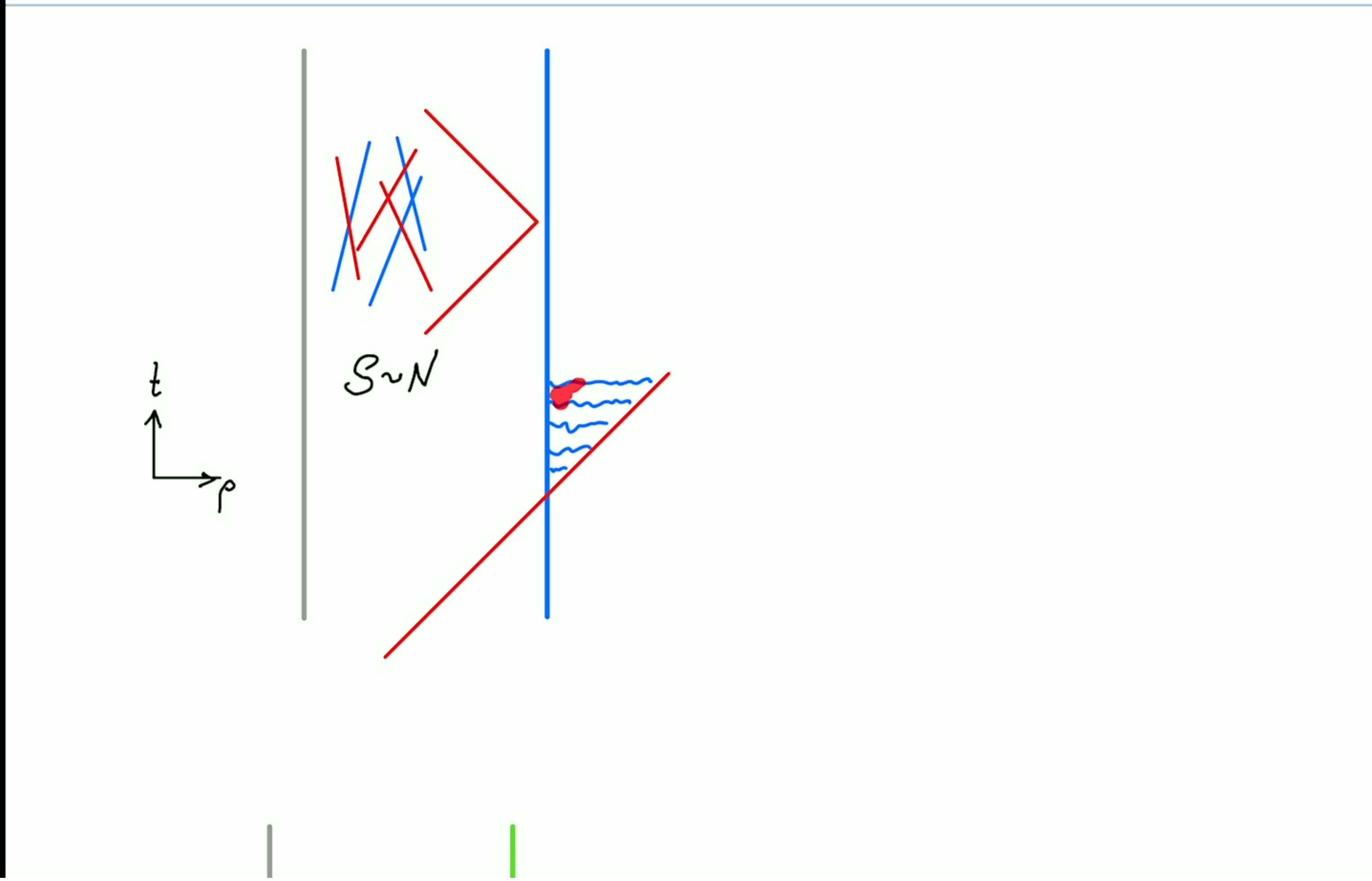
$$A = \sum_n \frac{F_n(p^2)}{N^n}$$

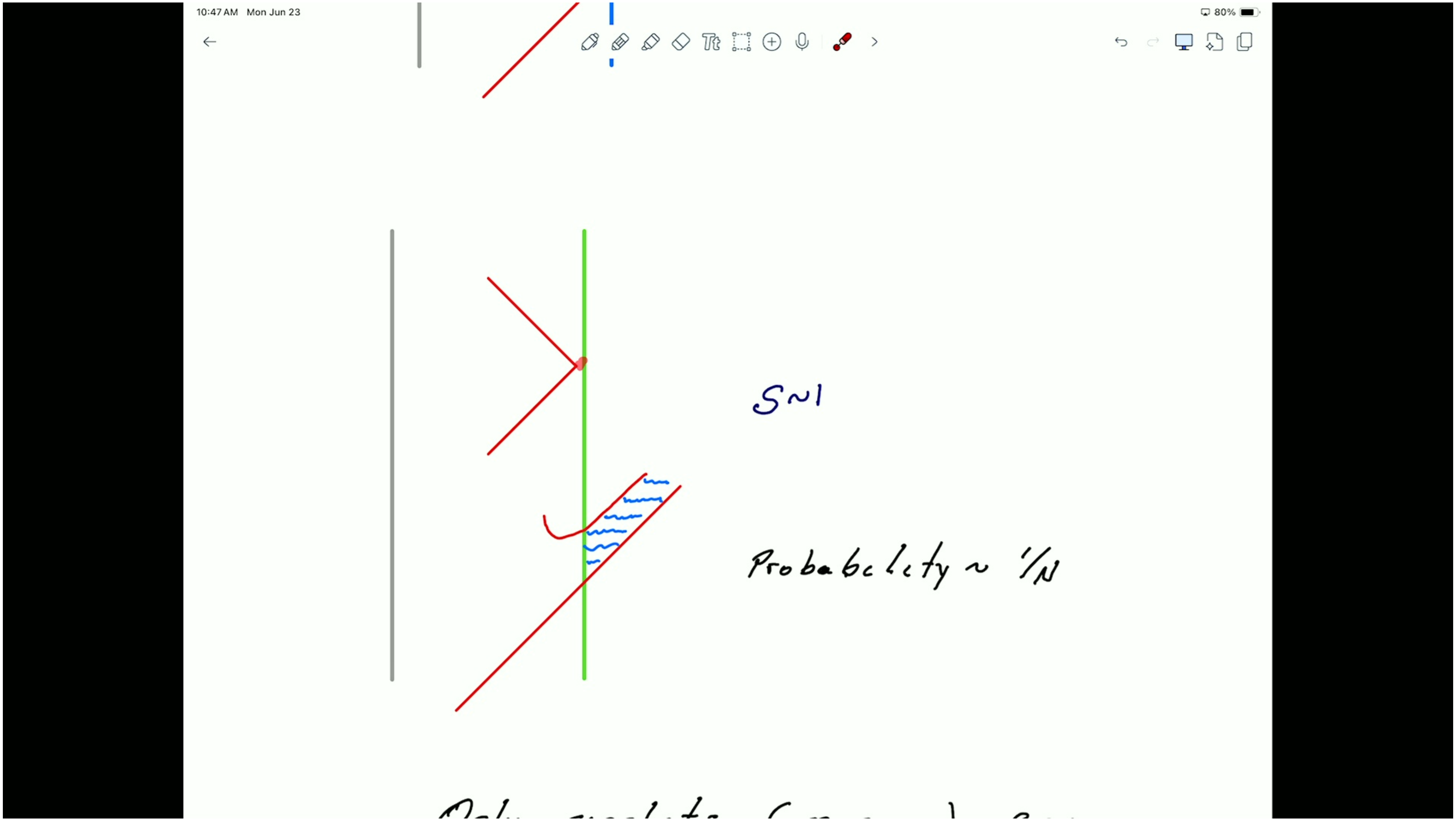


$$T = \frac{1}{2\pi\rho}$$



$$\rho_{SH} = \frac{1}{2\pi\Lambda} = l_s$$


S~N
t
ρ

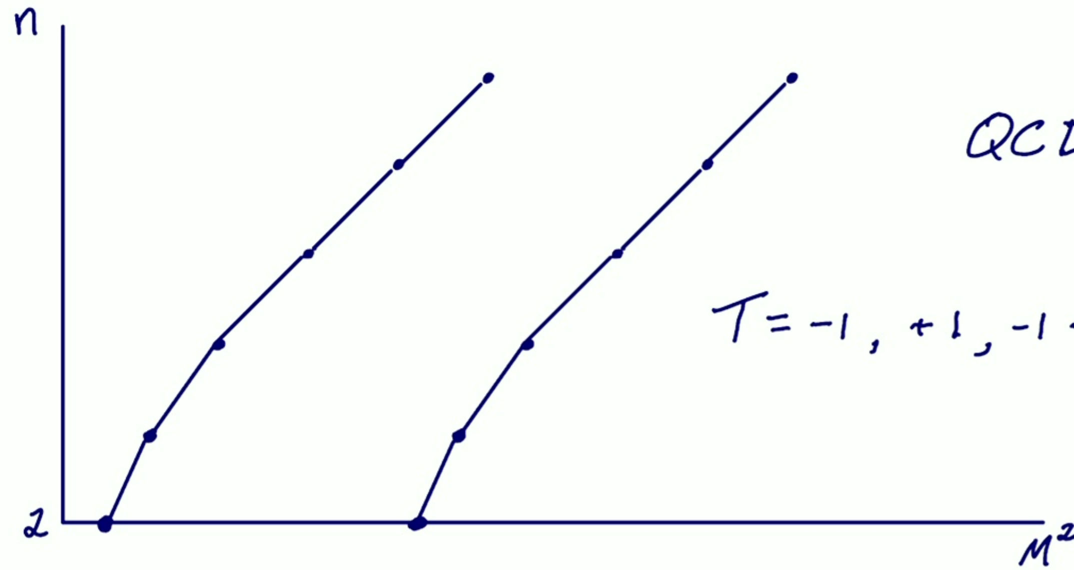

10:47 AM Mon Jun 23
80%
$S \sim 1$
Probability $\sim 1/N$

10:47 AM Mon Jun 23

Only singlets (mesons) can propagate in the bulk.

$$\boxed{\begin{aligned} S_{SH} &\approx N \\ S_{BULK} &\sim 1 \end{aligned}}$$

Compare with scalar FT



QCD_2

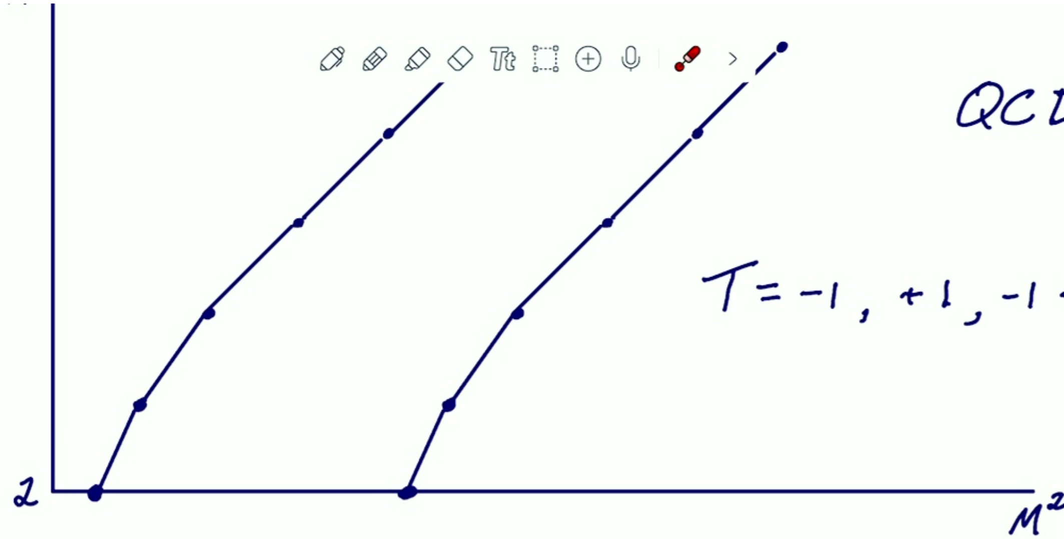
$T = -1,\ +1,\ -1 \cdots$

$\bar{q}_i q_i \qquad \bar{q}_i \dot{q}_i \qquad \bar{q}_i \ddot{q}_i \qquad \bar{q}_i \dddot{q}_i \qquad \bar{q}_i \ddddot{q}_i \cdots$

$\bar{q}_i \dot{q}_i \downarrow \frac{1}{2}\left(\bar{q}_i \dot{q}_i - \dot{\bar{q}}_i q_i\right)$

$\bar{q}_i \ddot{q}_i \downarrow \frac{1}{4}\left(\ddot{\bar{q}} q - 2\dot{\bar{q}}\dot{q} + \bar{q}\ddot{q}\right)$

10:50 AM Mon Jun 23 79%



QCD_2

$T = -1, +1, -1 \cdots$

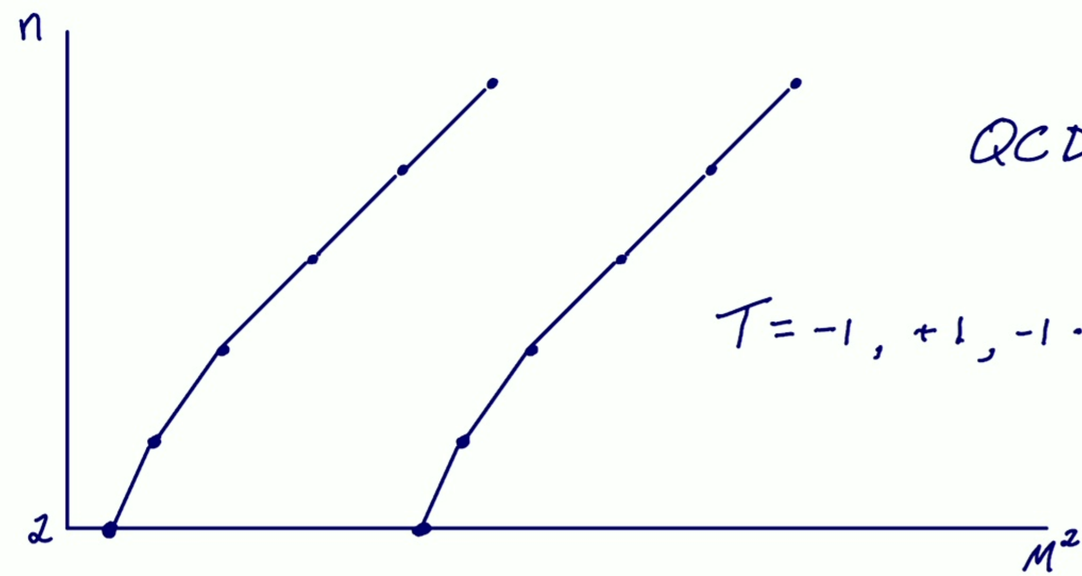
$\bar{q}_i q_i \quad \bar{q}_i \dot{q}_i \quad \bar{q}_i \ddot{q}_i \quad \bar{q}_i \dddot{q}_i \quad \bar{q}_i \ddddot{q}_i \cdots$

$\downarrow \quad \frac{1}{2}(\bar{q}_i \dot{q}_i - \dot{\bar{q}}_i q_i)$

$\downarrow \quad \frac{1}{4}(\ddot{\bar{q}} q - 2\dot{\bar{q}}\dot{q} + \bar{q}\ddot{q})$

$\bar{\Psi}_i \Psi_i \quad \bar{\Psi}_i \dot{\Psi}_i \quad \bar{\Psi}_i \ddot{\Psi}_i \quad \bar{\Psi}_i \dddot{\Psi}_i \quad \cdots$

10:52 AM Mon Jun 23 78%



QCD$_2$

$T = -1, +1, -1 \cdots$

$\bar{q}_i q_i \quad \bar{q}_i \dot{q}_i \quad \bar{q}_i \ddot{q}_i \quad \bar{q}_i \dddot{q}_i \quad \bar{q}_i \ddddot{q}_i \cdots$

$\downarrow$ $\frac{1}{2}(\bar{q}_i \dot{q}_i - \dot{\bar{q}}_i q_i)$

$\downarrow$ $\frac{1}{4}(\ddot{\bar{q}} q - 2 \dot{\bar{q}} \dot{q} + \bar{q} \ddot{q})$