Title: Quantum Fields and Strings Lecture - 230331

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Collection: Quantum Fields and Strings (2022/2023)

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## Minimal QET model (Masahiro Hotta)

two qubits. Alice can measure qubit A and send information to Bob, who can

$$\hat{H} = \hat{H}_A + \hat{H}_B + \hat{V}$$

$$\hat{H}_A = h\hat{\sigma}_z^A + f(h,k)\mathbb{1}, \quad \hat{H}_B = h\hat{\sigma}_z^B + f(h,k)\mathbb{1}, \quad \hat{V} = 2\left[k\hat{\sigma}_x^A\hat{\sigma}_x^B + \frac{k^2}{h^2}f(h,k)\right.$$

$$h,k > 0, \quad f(h,k) = \frac{h^2}{\sqrt{h^2+k^2}}$$

$$\langle g|\hat{H}_A|g\rangle = \langle g|\hat{H}_B|g\rangle = \langle g|\hat{V}|g$$

$$|g\rangle = \frac{1}{\sqrt{2}}\left(\sqrt{1-\frac{f(h,k)}{h}}\,|1_A\rangle|1_B\rangle + \right.$$

$$\sum_{\alpha} \hat{P}(\alpha) = \mathbb{1}$$

$$\ldots | W_B^{\dagger} H_A W_B | g \rangle = \langle g | H_A | g \rangle = 0$$

times of energy propagation

is $\sim \frac{1}{k}$

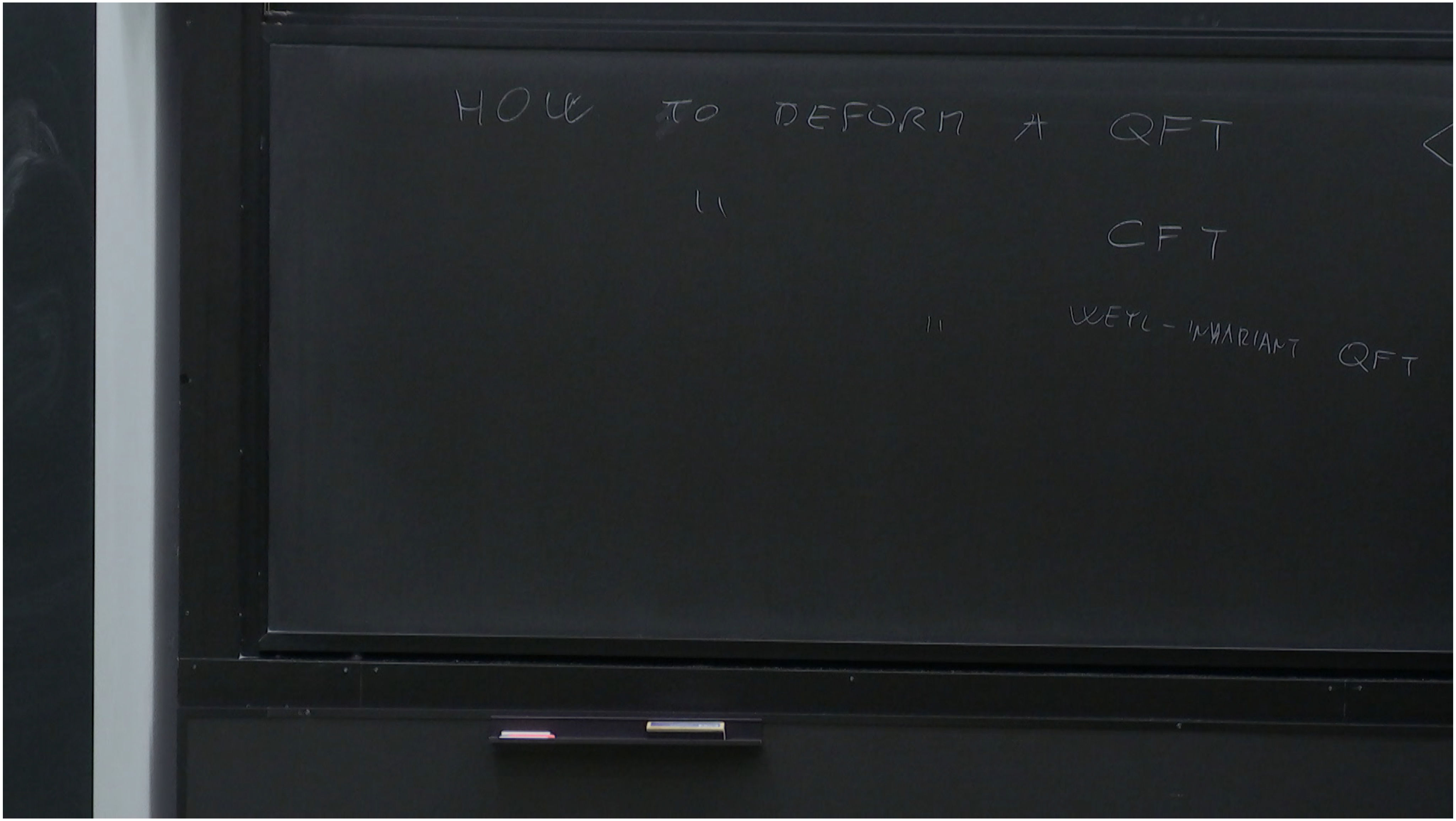
...m A to B:

$$\ldots \hat{H}_B e^{-iHt} P_A | g \rangle = \frac{1}{2} f(h,k) \left(1 - \cos(4kt)\right)$$

$$\ldots e^{-iHt} P_A | g \rangle = 0$$

$$\mathcal{O}_2 \rangle_{T+\delta T} = \langle \mathcal{O}_1 \cdots \mathcal{O}_2 \rangle_T + \int_{\mathbb{R}^D - \cup_i B^\epsilon(x_i)} d^D x \, \langle \mathcal{O}_1(x_1) \cdots \mathcal{O}_2(x_2) \, I(x) \rangle$$

$$+ \langle \delta_\epsilon \mathcal{O}_1 \cdots \mathcal{O}_2 \rangle + \cdots$$


HOW TO DEFORM A QFT
" CFT
" WEYL-INVARIANT QFT

$$\cdots O_2 \rangle_{T+\delta T} = \langle O_1 \cdots O_2 \rangle_T + \int_{\mathbb{R}^D - \bigcup_i B^\epsilon(x_i)} d^D x \, \langle O_1(x_1) \cdots O_2(x_2) \, I(x) \rangle$$

$$+ \langle \delta_\epsilon O_1 \cdots O_2 \rangle + \cdots$$

$$\langle O_1 \cdots O_2 \rangle_{T+\delta T} = \langle O_1 \cdots O_2 \rangle_T + \int_{\mathbb{R}^D - \cup_i B^\epsilon(x_i)} d^D x \, \langle O_1(x_1) \cdots O_2(x_2)\, I(x) \rangle + \langle \delta_\epsilon O_1 \cdots O_2 \rangle + \cdots$$

QFT

2d CFT

$$\int d^2 z \, I(z, \bar{z})$$

$$I(z,\bar{z})\, d^2 z = I'(z', \bar{z}')\, d^2 z'$$

$$I(z,\bar{z}) = I'(z', \bar{z}') \left| \frac{dz'}{dz} \right|^2$$

PRIMARY OPERATOR $\Delta = 1, \bar{\Delta} = 1$

$|I\rangle$ $\quad L_n|I\rangle = 0 \quad n \geq 0 \quad \bar{L}_n|I\rangle = 0$

$L_0|I\rangle = |I\rangle \quad \bar{L}_0|I\rangle = |I\rangle$

$|I\rangle \otimes |gh\rangle$ IS STRING STATE (ASSUMING $c = 2$

MODULO $L_{-n}|J\rangle \otimes gl \rightarrow \quad I = \partial(z^n J)$

$$= \langle O_1 \cdots O_n \rangle_T + \int_{\mathbb{R}^D - \cup_i B^\epsilon(x_i)} d^D x \, \langle O_1(x_1) \cdots O_n(x_n) \, I(x) \rangle$$

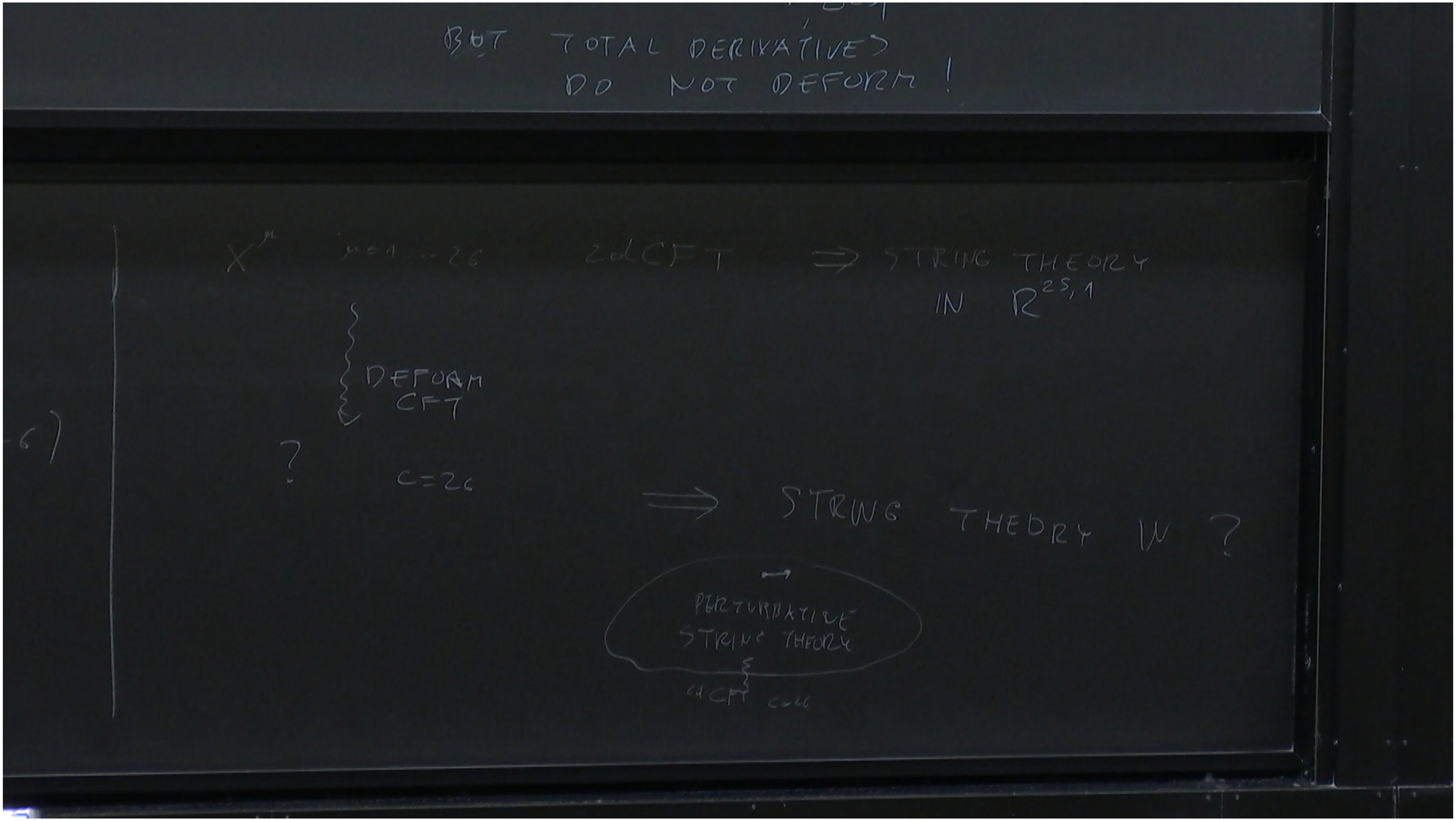
$$+ \langle \delta_\epsilon O_1 \cdots O_n \rangle + \dots$$

$$I(z,\bar z)\, d^2 z = I'(z',\bar z')\, d^2 z'$$

$$I(z,\bar z) = I'(z',\bar z') \left| \frac{dz'}{dz} \right|^2$$

PRIMARY OPERATOR $\Delta = 1$, $\bar\Delta = 1$

BUT TOTAL DERIVATIVES DO NOT DEFORM!

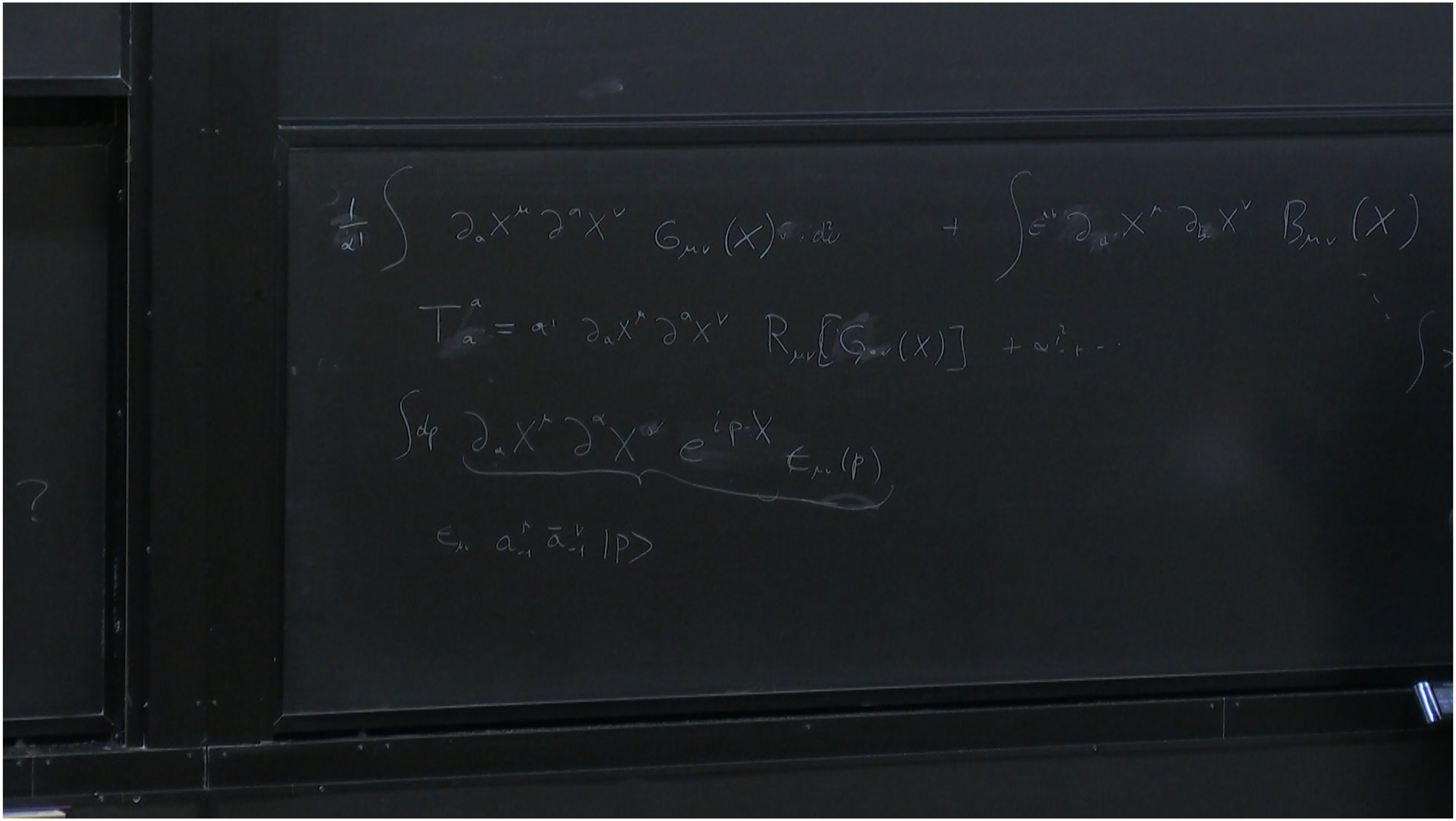

BUT TOTAL DERIVATIVES
DO NOT DEFORM !
X^μ μ=1...26
2dCFT ⇒ STRING THEORY
IN R^25,1
DEFORM CFT
?
c=26
⇒ STRING THEORY IN ?
PERTURBATIVE
STRING THEORY
2dCFT c=26

$$\frac{1}{\alpha'}\int \partial_a X^\mu \partial^a X^\nu \, G_{\mu\nu}(X) \, d^2\sigma$$

$$T^a_a = \alpha' \, \partial_a X^\mu \partial^a X^\nu \, R_{\mu\nu}[G_{\mu\nu}(X)] + \alpha'^2 + \cdots$$

$$\int dp \, \underbrace{\partial_a X^\mu \partial^a X^\nu e^{ip\cdot X} \epsilon_{\mu\nu}(p)}$$

$$\epsilon_{\mu\nu} \, a^\mu_{-1} \bar{a}^\nu_{-1} |p\rangle$$


$\frac{1}{\alpha'}\int \partial_a X^\mu \partial^a X^\nu G_{\mu\nu}(X) + \int \epsilon^{ab} \partial_a X^\mu \partial_b X^\nu B_{\mu\nu}(X)$
$T^a_a = \alpha' \partial_a X^\mu \partial^a X^\nu R_{\mu\nu}[G(X)] + \alpha'^2 + \cdots$
$\int dp \, \partial_a X^\mu \partial^a X^\nu e^{ip\cdot X} \epsilon_{\mu\nu}(p)$
$\epsilon_{\mu\nu} a^\mu_{-1} \bar{a}^\nu_{-1} |p\rangle$
?

$$\frac{1}{\alpha'}\int \partial_a X^\mu \partial^a X^\nu \, G_{\mu\nu}(X)\, d^2\sigma \quad + \int \epsilon^{ab}\partial_a X^\mu \partial_b X^\nu \, B_{\mu\nu}(X)$$

$$T^a_a = \alpha' \, \partial_a X^\mu \partial^a X^\nu \, R_{\mu\nu}[G_{\mu\nu}(X)] + \alpha'^2 + \cdots$$

$$\delta G_{\mu\nu}(X)$$

$$\int dp \, \underbrace{\partial_a X^\mu \partial^a X^\nu \, e^{ip\cdot X} \, \epsilon_{\mu\nu}(p)}$$

$$|p\rangle \to e^{ipX}$$

$$\epsilon_{\mu\nu} \, a^\mu_{-1} \bar{a}^\nu_{-1} |p\rangle$$

$$\partial_a X^\mu \partial^a X^\nu \, G_{\mu\nu}(X) \, d\bar{z} \quad + \int \epsilon^{ab} \partial_a X^\mu \partial_b X^\nu \, B_{\mu\nu}(X) \quad + \quad \text{DILATON} \quad + \int$$

$$\frac{\delta S}{\delta G_{\mu\nu}}(G, B, \text{DIL}, T \ldots)$$

$$= \alpha' \, \partial_a X^\mu \partial^a X^\nu \, R_{\mu\nu}\left[\cancel{G_{\mu\nu}(X)}\right] + \alpha'^2 + \cdots$$

$$\delta G_{\mu\nu}(X)$$

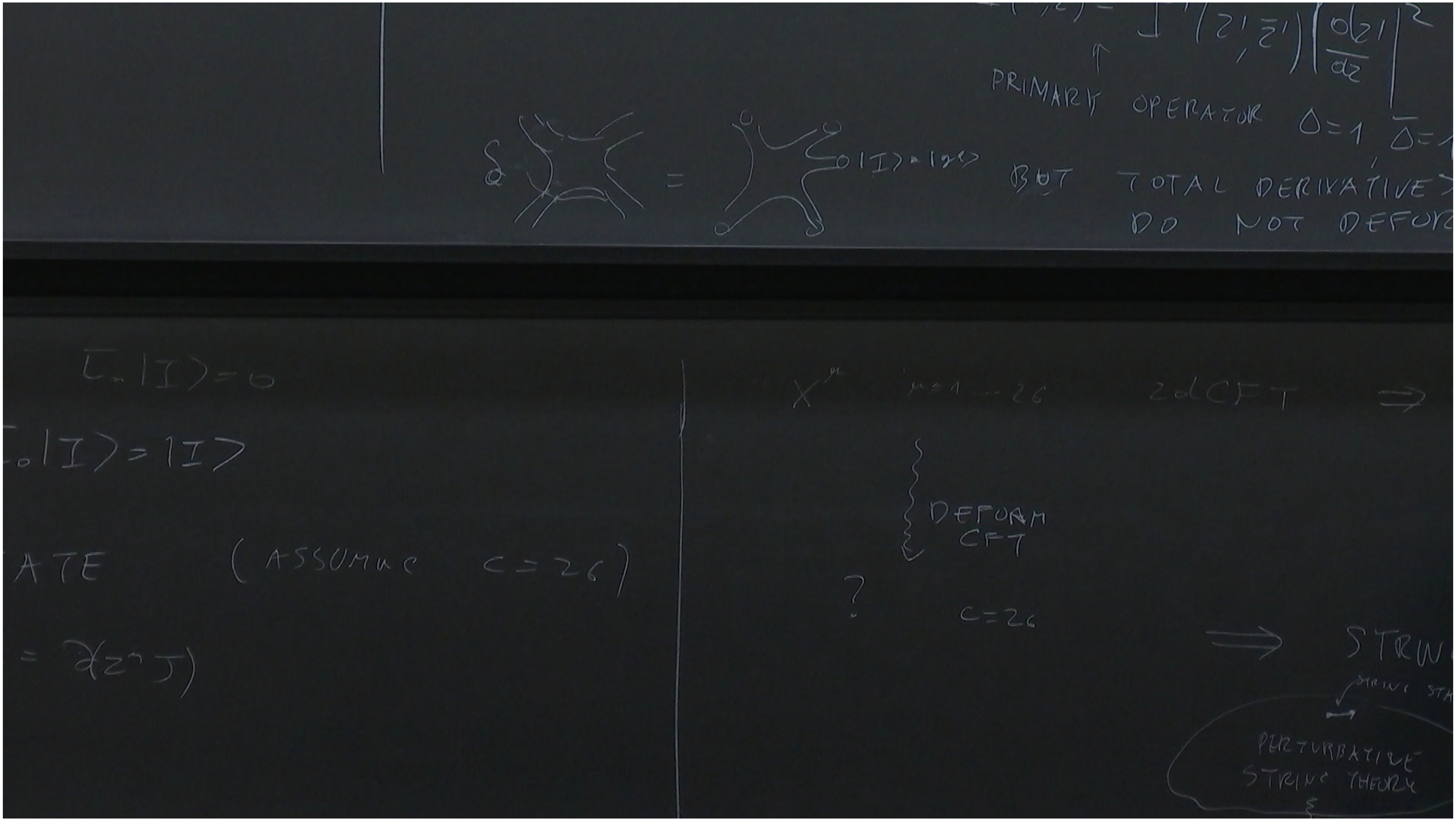
$$\epsilon^A_{\mu\nu} \, \partial X^\mu \partial X^\nu e^{ipX}$$

$$\int \partial X^\mu A_\mu$$

$$\underbrace{\partial_a X^\mu \partial^a X^\nu e^{ip\cdot X} \, \epsilon_{\mu\nu}(p)}$$

$$|p\rangle \to e^{ipX}$$

$$a^\mu_{-1} \bar{a}^\nu_{-1} |p\rangle$$


PRIMARY OPERATOR Δ=1
BUT TOTAL DERIVATIVES
DO NOT DEFOR
L_n|I>=0
L_0|I>=|I>
ATE (ASSUMING c=26)
X^μ μ=1...26 2d CFT
DEFORM CFT
?
c=26
STRIN
PERTURBATIVE STRING THEORY

$$\frac{1}{\alpha'}\int \partial_a X^\mu \partial^a X^\nu \left(G_{\mu\nu}(X) + \frac{\delta G_{\mu\nu}}{\delta \lambda}\right) + \int \epsilon^{ab}\partial_a X^\mu \partial_b X^\nu B_{\mu\nu}(X)$$

$$\frac{\delta S}{\delta G_{\mu\nu}}(G, B, D_{IK}, T \dots)$$

$$T^a_a = \alpha' \partial_a X^\mu \partial^a X^\nu \cancel{R_{\mu\nu}[G_{\mu\nu}(X)]} + \alpha'^2 + \dots$$

$$\delta G_{\mu\nu}(X)$$

$$\downarrow$$

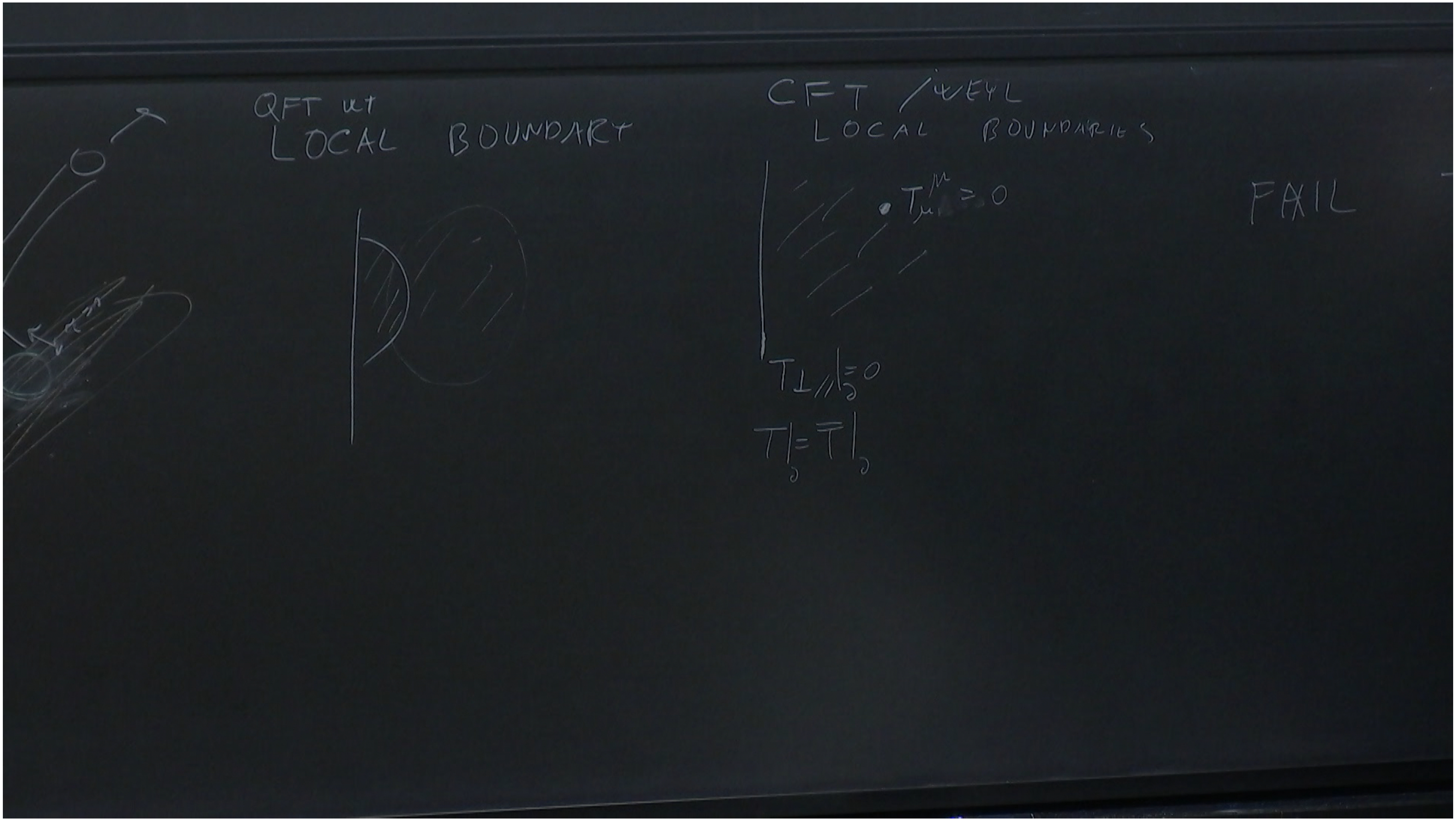
$$\epsilon^A_{\mu\nu}\partial X^\mu \partial X^\nu e^{ipX}$$

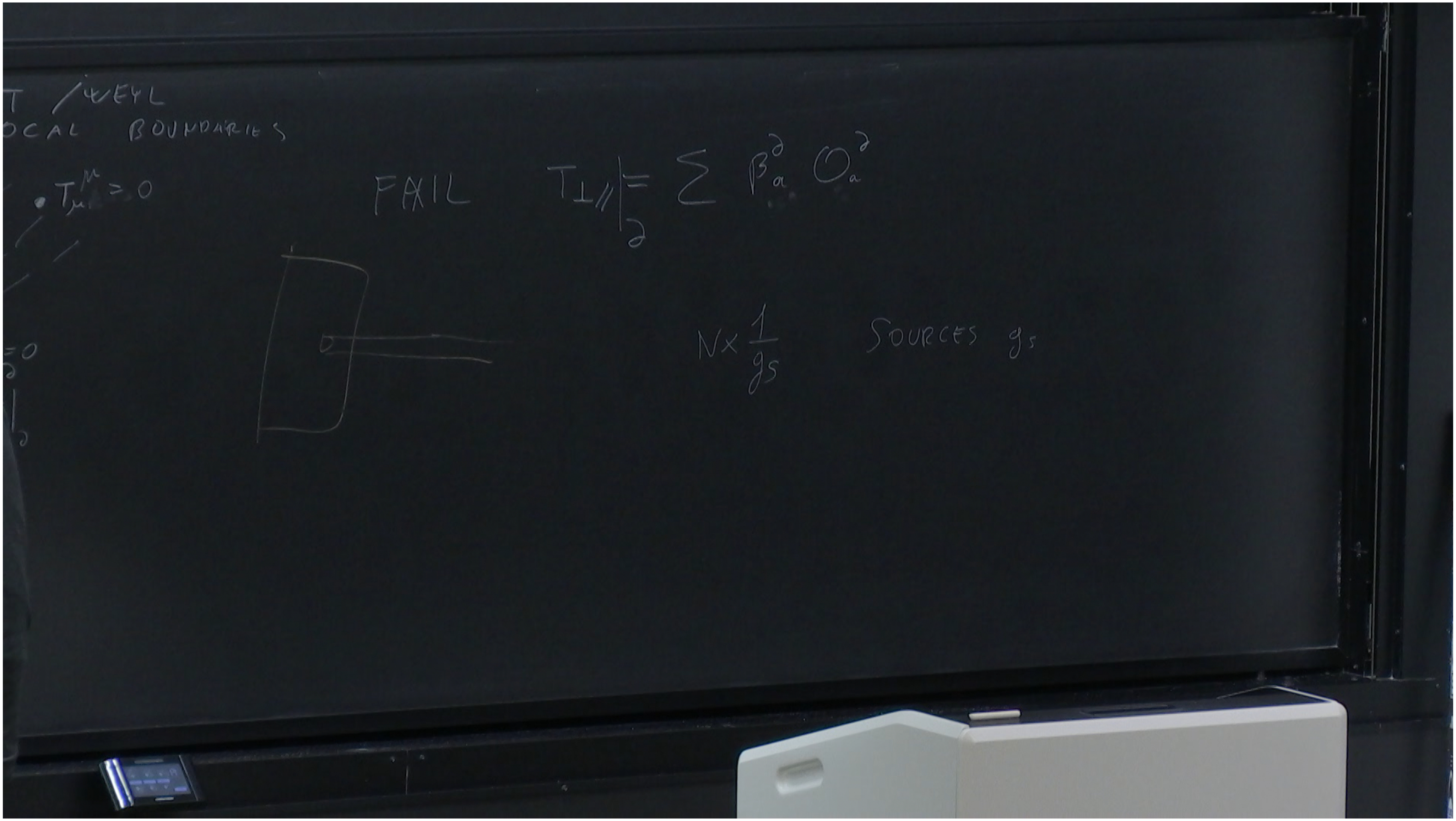
$$\int \partial_t X^\mu A_\mu$$

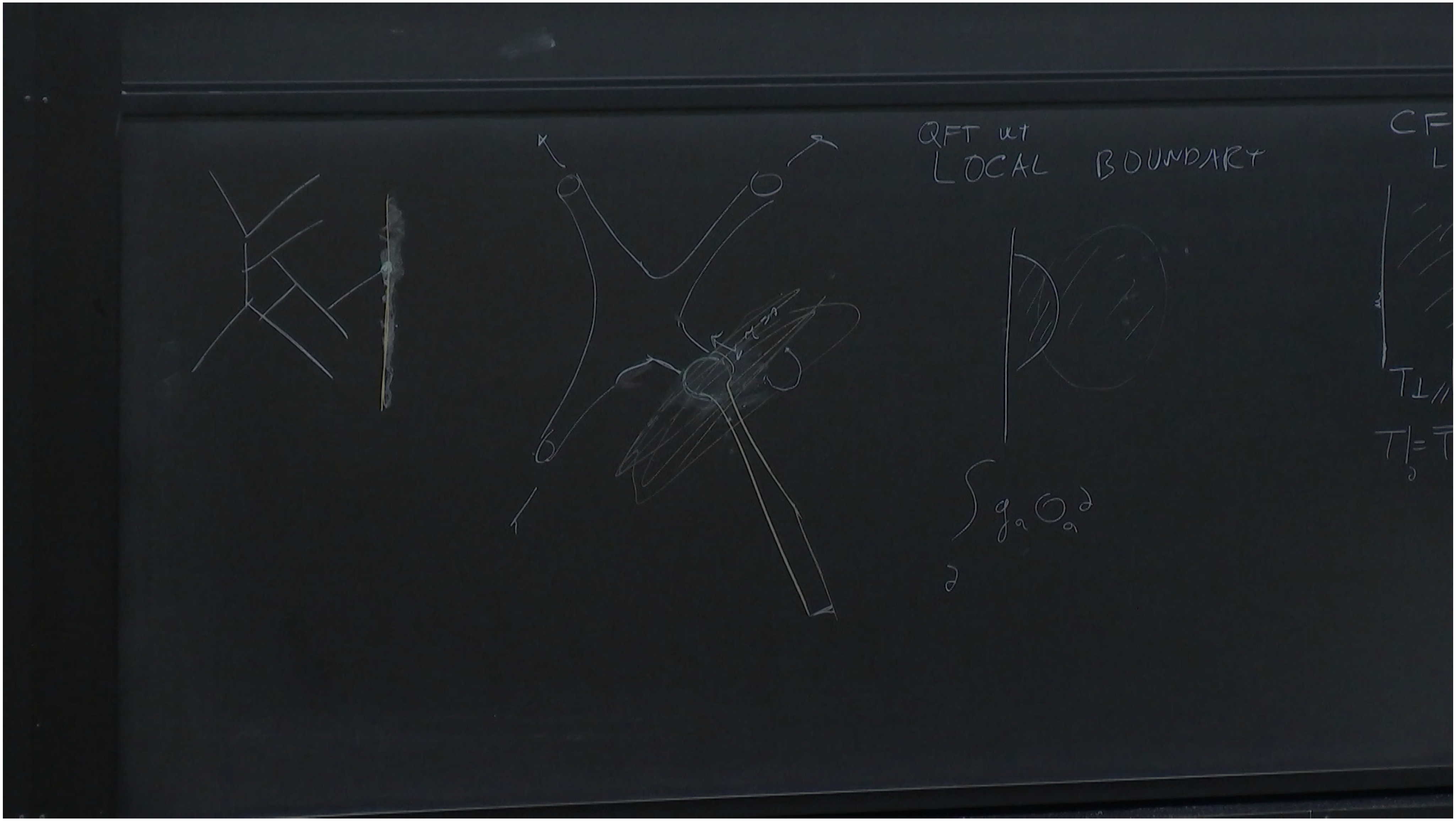
$$\int dp\, \underbrace{\partial_a X^\mu \partial^a X^\nu e^{ip\cdot X}\epsilon_{\mu\nu}(p)}$$

$$|p\rangle \to e^{ipX}$$

$$\epsilon^S_{\mu\nu}\, a^\mu_{-1}\bar a^\nu_{-1}|p\rangle$$


QFT w/
LOCAL BOUNDARY
CFT / WEYL
LOCAL BOUNDARIES
$T_\mu^\mu = 0$
FAIL
$T_{\perp //}|_\partial = 0$
$T|_\partial = \bar{T}|_\partial$


WEYL
BOUNDARIES
FAIL
$T_{\perp\parallel}|_\partial = \sum \beta^\partial_a \mathcal{O}^\partial_a$
$N \times \frac{1}{g_s}$
SOURCES $g_s$


QFT w/
LOCAL BOUNDARY
$\int_\partial g_a \mathcal{O}_a^\partial$
CF
L
$T_{\perp\parallel}$
$T|_\partial = T$