Title: AdS/CFT Correspondence

Date: Jun 28, 2005 02:30 AM

URL: http://pirsa.org/05060098

Abstract:

Holography & Quantum Foam

AdS/CFT : Basics

Holography & Quantum Foam

AdS/CFT : Basics

$\Lambda < 0$



$ds^2 = -\sec^2 \xi \, dt^2 + \ell^2 \, d\xi^2 + \ell^2$

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AdS/CFT: Basics



$\Lambda < 0$

$$ds^2 = -\sec^2\xi\, dt^2 + \ell^2\, d\xi^2 + \ell^2 \tan^2\xi\, d\Omega^2$$

Holography & Quantum Foam

AdS/CFT : Basics

$\Lambda < 0$

$$ds^2 = -\sec^2\xi\, dt^2 + \ell^2\, d\xi^2 + \ell^2 \tan^2\xi\, d\Omega$$





Holography & Quantum Foam

S/CFT : Basics

$\Lambda < 0$



$$ds^2 = -\sec^2\xi\, dt^2 + \ell^2 \left(d\xi^2 + \sin^2\xi\, d\Omega_{n-1}^2 \right)$$

$\xi \to \frac{\pi}{2}$



Holography & Quantum Foam

AdS/CFT : Basics

$\Lambda < 0$

$\rho \to \frac{\pi}{2}$

$$ds^2 = -\sec^2\rho\, dt^2 + l^2\, d\rho^2 + l^2 \tan^2\rho\, d\Omega^2$$



$AdS^{d+1} \to S^d \times R$



$$ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2}$$

$z \to 0$ boundary..

Holography & Quantum Foam

AdS/CFT : Basics

$\Lambda < 0$



$AdS^{d+1} \to S^d \times R$

$\rho \to \frac{r}{L}$

$$ds^2 = -\sec^2\rho\, dt^2 + L^2 d\rho^2 + L^2 \tan^2\rho\, d\Omega^2$$



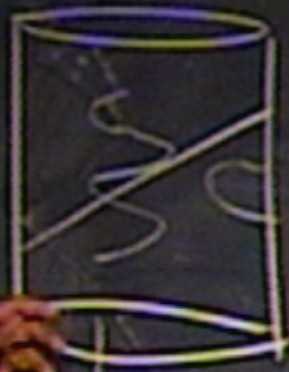
$$ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2}$$

$z \to 0$ boundary..

Holography & Quantum Foam

AdS/CFT : Basics

$\Lambda < 0$



$AdS^{d+1} \to S^d \times R$

$\rho \to \frac{\pi}{2}$

$$ds^2 = -\sec^2\rho\, dt^2 + l^2\, d\rho^2 + l^2 \tan^2\rho\, d\Omega^2$$



$$ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2} \qquad R^{d-1,1}$$

$z \to 0$ boundary.

In String Theory

IIB: $AdS_5 \times S^5$

In String Theory

IIB: $AdS_5 \times S^5$

$\downarrow$

$SO(4,2)$

$(-u^2 - v^2 + \vec{x}^2 + \dots x_4^2 = -l^2$

In String Theory

IIB: $AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$(-u^2 - v^2 + \vec{x}_1^2 \cdots x_4^2 = -l^2$

In String Theory

IIB: $AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$(-u^2 - v^2 + \vec{x}_1^2 \ldots x_4^2 = -l^2$

IIB: $AdS_3 \times S^3 \times T^4$

In String Theory

IIB: $AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$(-u^2 - v^2 + \vec{x}_1^2 \cdots x_4^2 = -l^2$

IIB: $AdS_3 \times S^3 \times T^4$



String theory

$S^5 \times S^5$

$2) \times SO(6)$

$-\vec{x}_1^2 + \ldots x_4^2 = -l^2$

$\times S^3 \times T^4$

String theory

$S^5 \times S^5_1$

$2) \times SO(6)$

$-\vec{x}_1^2 \cdots x_4^2 = -l^2$

$\times S^3 \times T^4$

· Difficult to state in string theory

String theory

$5 \times S^5$

$2) \times SO(6)$

$-\vec{x}_1^2 + \dots x_4^2 = -\ell^2$

$\times S^3 \times T^4$

- Difficult to state in string theory

- Field theory

String theory

$S^5 \times S^5$

$S^2) \times SO(6)$

$-\vec{x}_1^2 + \dots + x_4^2 = -l^2$

$\times S^3 \times T^4$

- Difficult to state in string theory

- Field theory limit

theory

- Difficult to state in string theory

- Field theory limit

$$\int_{\phi \to J} \mathcal{D}\phi \; e^{iS(\phi)}$$

theory

· Difficult to state in string theory

- Field theory limit

$$Z[J] = \int_{\phi \to J} \mathcal{D}\phi \; e^{iS(\phi)} = \left\langle e^{i \int_{\partial M} J\Theta} \right\rangle_{\text{Conformal}}$$

In String theory

IIB: $AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$(-U^2 - V^2 + X_1^2 + \cdots + X_4^2 = -L^2$

IIB: $AdS_3 \times S^3 \times T^4$

$SO(2,2)^3$



- Difficult to state in string theory

- Field theory limit

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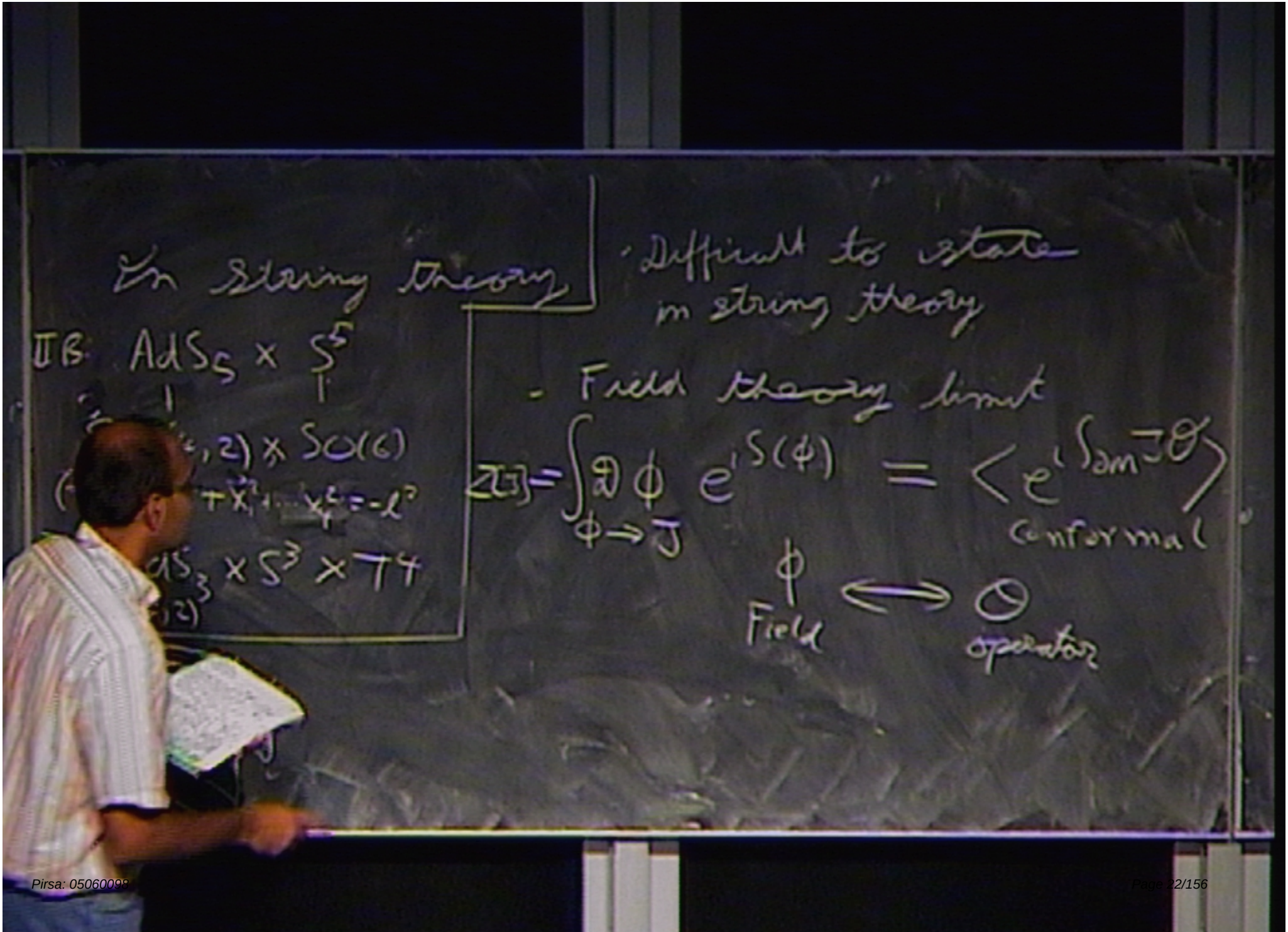
In String theory
IIB $AdS_5 \times S^5$
$\times S^3 \times T^4$
Difficult to state in string theory
- Field theory limit
$Z[J] = \int_{\phi \to J} \mathcal{D}\phi \, e^{iS(\phi)} = \langle e^{i \int_{\partial M} J\mathcal{O}} \rangle$
Conformal
ϕ Field $\longleftrightarrow$ $\mathcal{O}$ operator

In String theory

$AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$x^2 - t^2 + \vec{x}^2 + \ldots + x_4^2 = -l^2$

$AdS_3 \times S^3 \times T^4$

$SO(2,2)^3$

- Difficult to state in string theory

- Field theory limit

$$Z[J] = \int_{\phi \to J} \mathcal{D}\phi \; e^{iS(\phi)} = \langle e^{i \int_{\partial M} J \mathcal{O}} \rangle$$

Conformal

ϕ Field $\Longleftrightarrow$ $\mathcal{O}$ operator



9902131
9905111
0309246

9802150

In String theory

IIB: $AdS_5 \times S^5$

$SO(4,2) \times SO(6)$

$(-u^2 - v^2 + \vec{x}_1^2 + \dots x_4^2 = -l^2$

IIB: $AdS_3 \times S^3 \times T^4$

$SO(2,2)$



· Difficult to state in string theory

- Field theory limit

$$Z[J] = \int_{\phi \to J} \mathcal{D}\phi \, e^{iS(\phi)} = \langle 0 | e^{i \int_{\partial M} J \mathcal{O}} | 0 \rangle$$

conformal

ϕ Field $\Longleftrightarrow$ $\mathcal{O}$ operator

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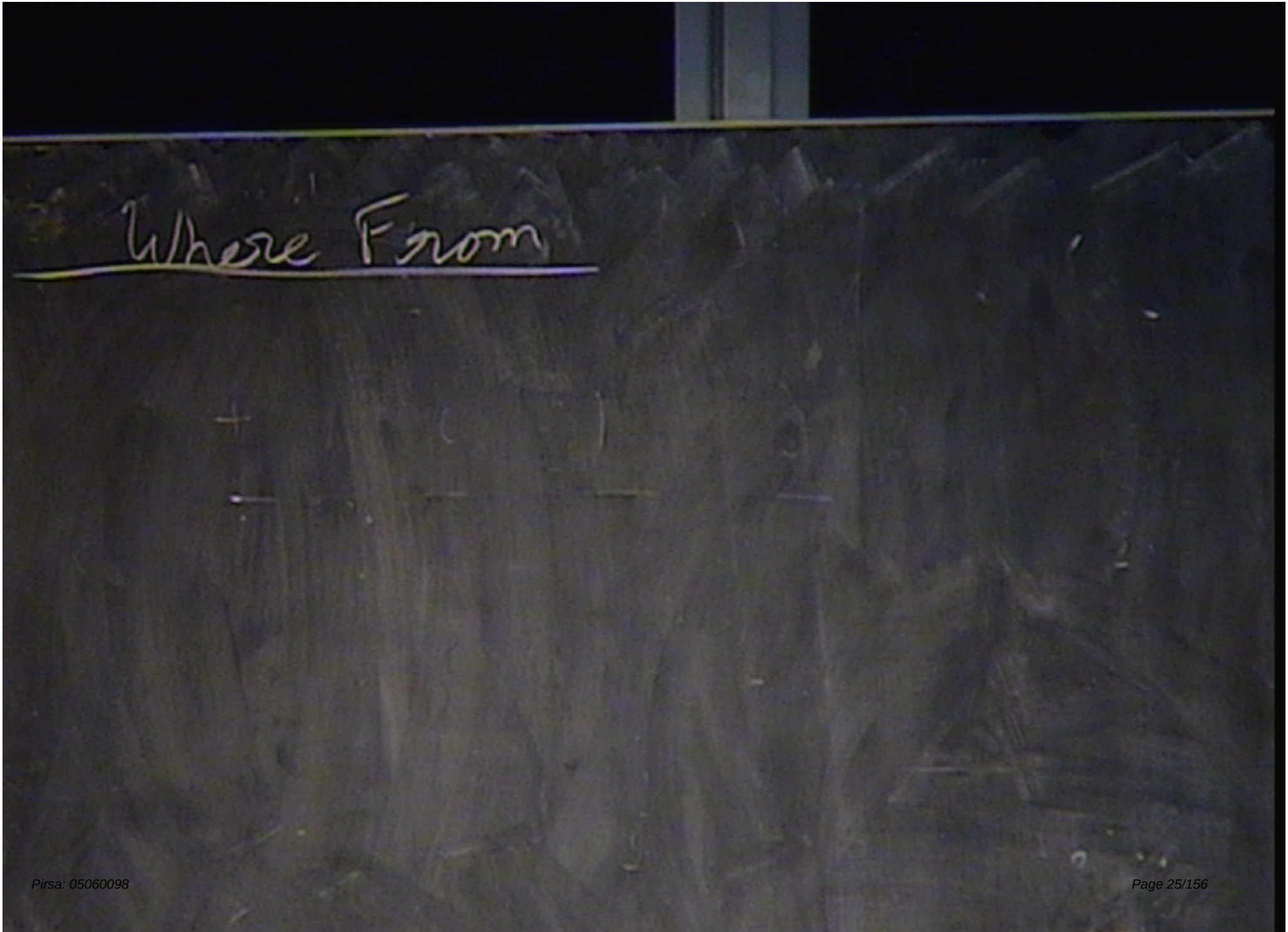

Where From

Where From

D3-branes.



open strings

Where From

D3-branes.



open strings

+

low energy.

Where From

D3-branes

3+1



open strings

low energy

$$\int d^{3+1}x \; \mathrm{Tr}(F^2)$$

Where From

D3-branes.

3+1



open strings

low energy

$$\int d^{3+1}x \; \mathrm{Tr}(F^2) + \psi$$

$$+$$

$\mathcal{N}=4$ SYM $\quad \mathfrak{gl}(N)$

$$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$$

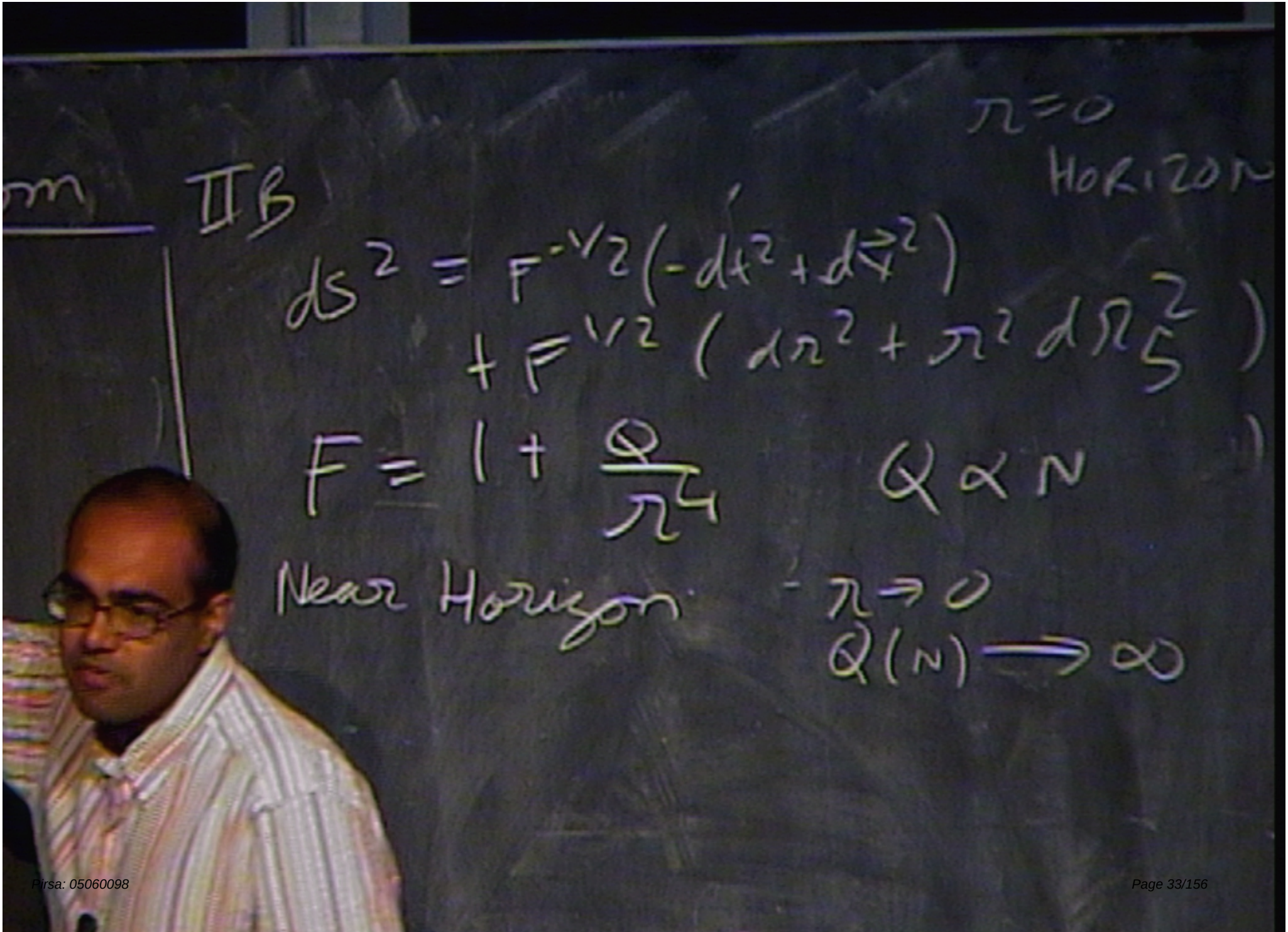
m IIB

$$ds^2 = F^{-1/2}(-dt^2 + d\vec{y}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$$

m IIB

$$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$$

$$F = 1 + \frac{Q}{r^4} \qquad Q \propto N$$


r=0
HORIZON
IIB
$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2)$
$+ F^{1/2}(dr^2 + r^2 d\Omega_5^2)$
$F = 1 + \frac{Q}{r^4}$
$Q \propto N$
Near Horizon
$r \to 0$
$Q(N) \Longrightarrow \infty$

HORIZON

IIB

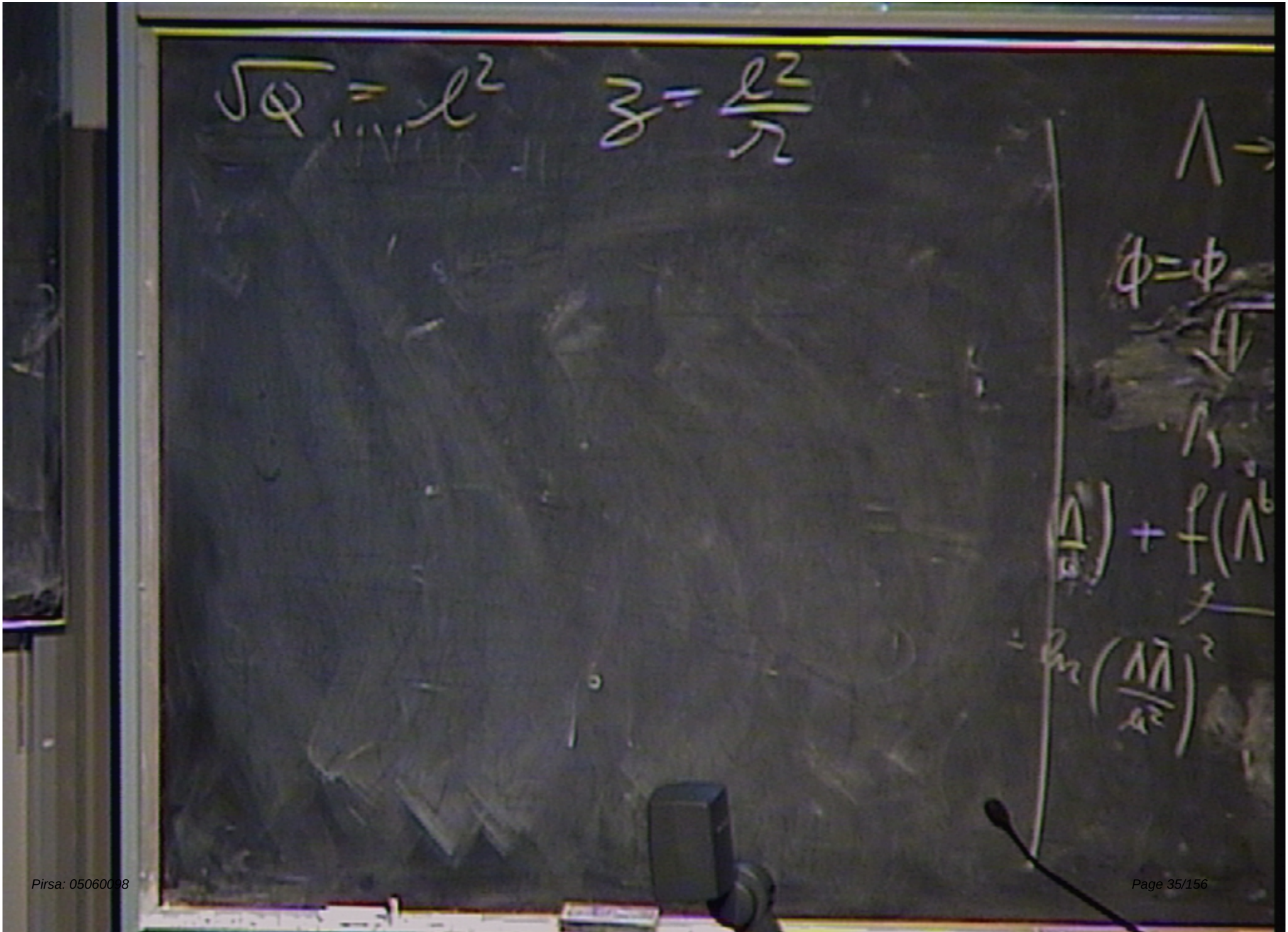
$$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$$

$$F = 1 + \frac{Q}{r^4} \qquad Q \propto N$$

Near Horizon $r \to 0$

$Q(N) \Longrightarrow \infty$

$$ds^2 = \frac{r^2}{\sqrt{Q}}(-dt^2 + d\vec{x}^2) + \sqrt{\frac{Q}{r^2}}(dr^2 + r^2 d\Omega_5^2)$$


$\sqrt{Q} = \ell^2$
$z = \frac{\ell^2}{r}$
$\Lambda \to$
$\phi = \phi$
Λ
$\ln\left(\frac{\Lambda\bar{\Lambda}}{\mu^2}\right)^2$

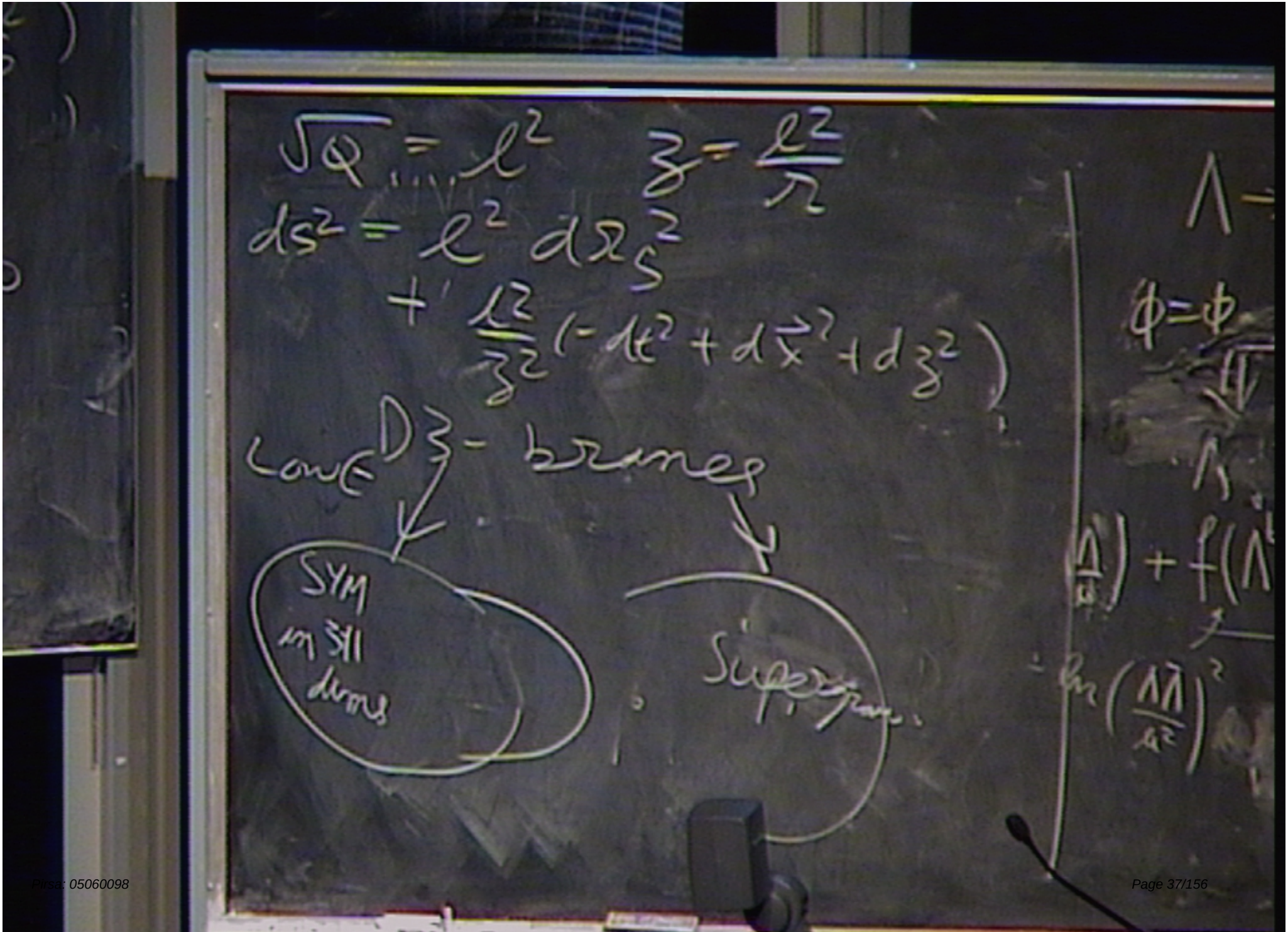
$$\sqrt{Q} = \ell^2 \qquad z = \frac{\ell^2}{r}$$

$$ds^2 = \ell^2 \, d\Omega_S^2 + \frac{\ell^2}{z^2}\left(-dt^2 + d\vec{x}^2 + dz^2\right)$$

$\phi =$

$\left(\frac{\Lambda}{\mu}\right) +$

$\ln\left(\frac{\Lambda}{\mu^2}\right.$

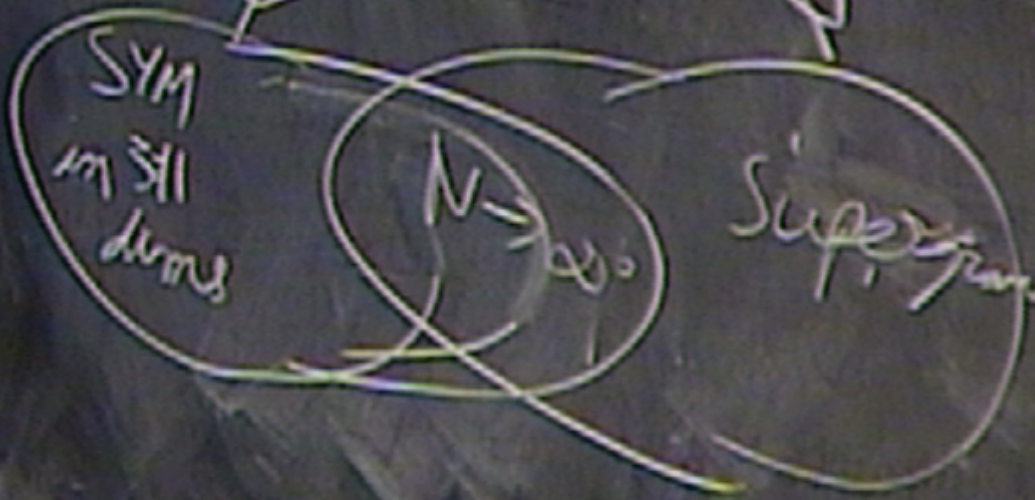

$\sqrt{Q} = \ell^2$
$z = \frac{\ell^2}{r}$
$ds^2 = \ell^2 \, dr_5^2 + \frac{\ell^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$
Low E D3 - branes
SYM in 3+1 dims
Supergrav.
$\Lambda -$
$\phi = \phi$
Λ
$\frac{\Lambda}{a}) + f(\Lambda$
$= \ln\left(\frac{\Lambda\bar{\Lambda}}{a^2}\right)^2$

$\sqrt{Q} = \ell^2 \qquad \frac{R^2}{r^2} = \frac{\ell^2}{z^2}$

$ds^2 = \ell^2 \, d\Omega_5^2$

$+ \frac{r^2}{z^2}\left(-dt^2 + d\vec{x}^2 + dz^2\right)$

Low ϵ D3 - branes



$\Lambda =$

$\Phi = \phi$

Λ

$\frac{\Lambda}{\mu}) + f(\Lambda$

$\left(\frac{\Lambda\bar{\Lambda}}{\mu^2}\right)^2$

In String theory

IIB: $AdS_5 \times S^5$

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$(-u^2 - v^2 + \vec{x}_1^2 + \dots + x_4^2 = -l^2$

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- Difficult to
in string the

- Field theory

$$Z[J] = \int_{\phi \to J} \mathcal{D}\phi \; e^{iS(\phi)} =$$

$N \to \infty$

ϕ

Field

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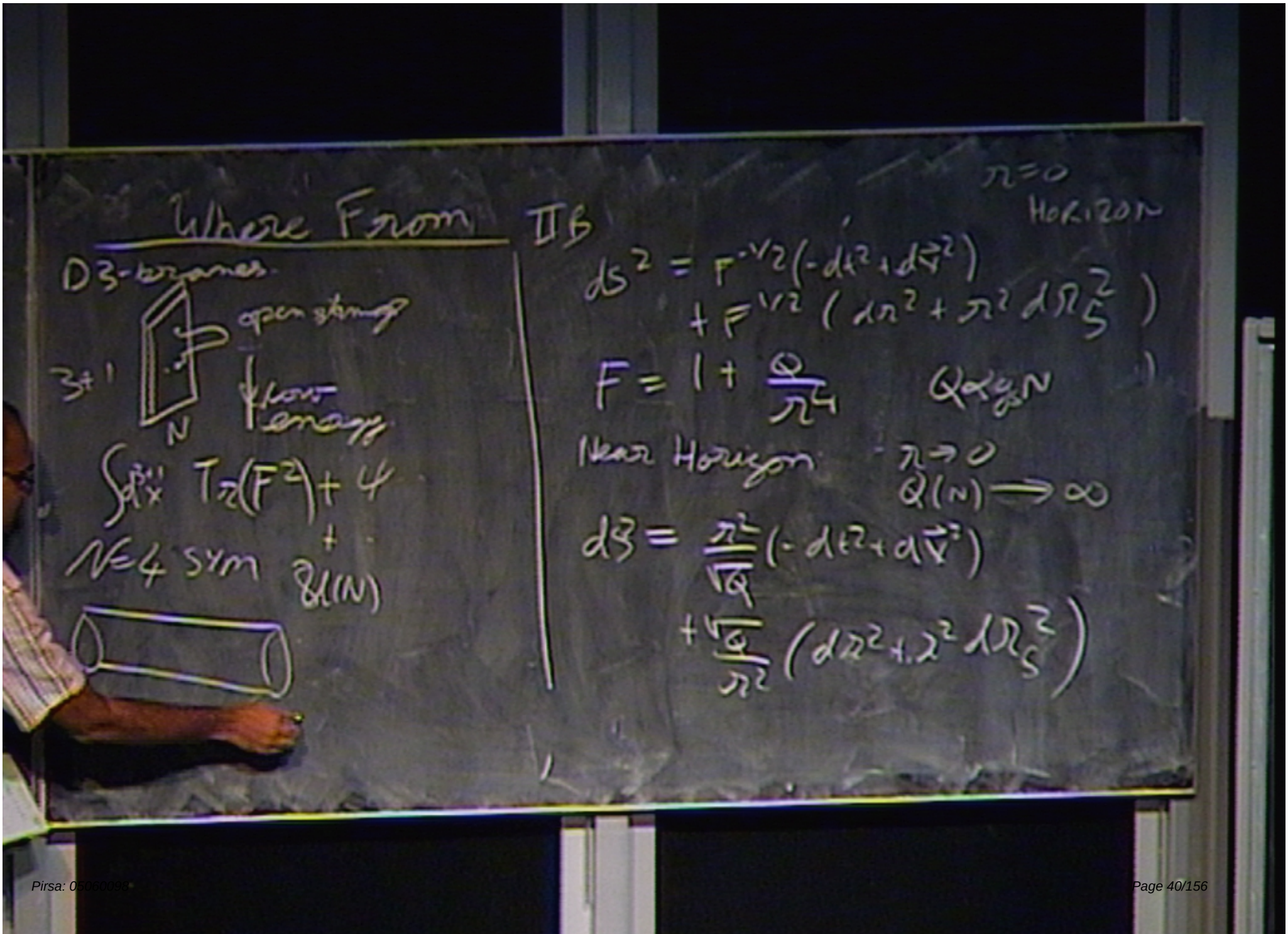
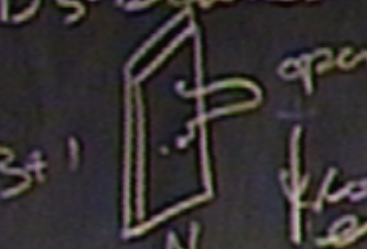

Where From
IIB
D3-branes
open strings
3+1
N
low energy
$\int d^{3+1}x \, Tr(F^2) + \psi$
$\mathcal{N}=4$ sym
$+ \, \mathcal{U}(N)$
$r=0$
HORIZON
$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$
$F = 1 + \frac{Q}{r^4}$
$Q \propto g_s N$
Near Horizon
$r \to 0$
$Q(N) \to \infty$
$ds^2 = \frac{r^2}{\sqrt{Q}}(-dt^2 + d\vec{x}^2) + \frac{\sqrt{Q}}{r^2}(dr^2 + r^2 d\Omega_5^2)$

Where From IIB

D3-branes.



$\int d^4x\ T_r(F^2) + 4$ + $\mathcal{N}=4$ SYM $U(N)$



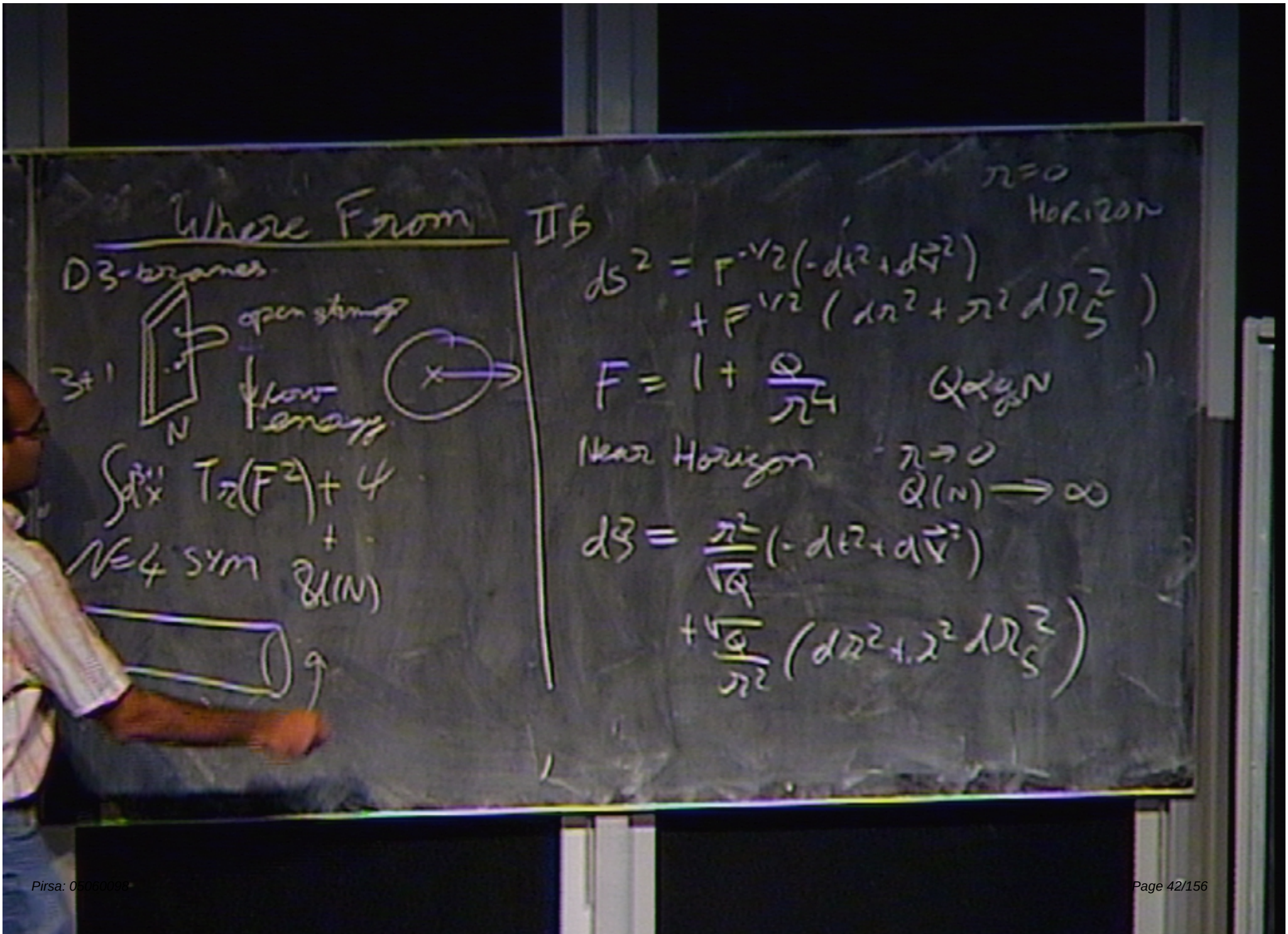
$r=0$ HORIZON

$$ds^2 = F^{-1/2}(-dt^2 + d\vec{x}^2) + F^{1/2}(dr^2 + r^2 d\Omega_5^2)$$

$$F = 1 + \frac{Q}{r^4} \qquad Q \propto g_s N$$

Near Horizon $r \to 0$, $Q(N) \to \infty$

$$ds^2 = \frac{r^2}{\sqrt{Q}}(-dt^2 + d\vec{x}^2) + \sqrt{Q}\left(\frac{dr^2}{r^2} + d\Omega_5^2\right)$$


Where From
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$r=0$
HORIZON
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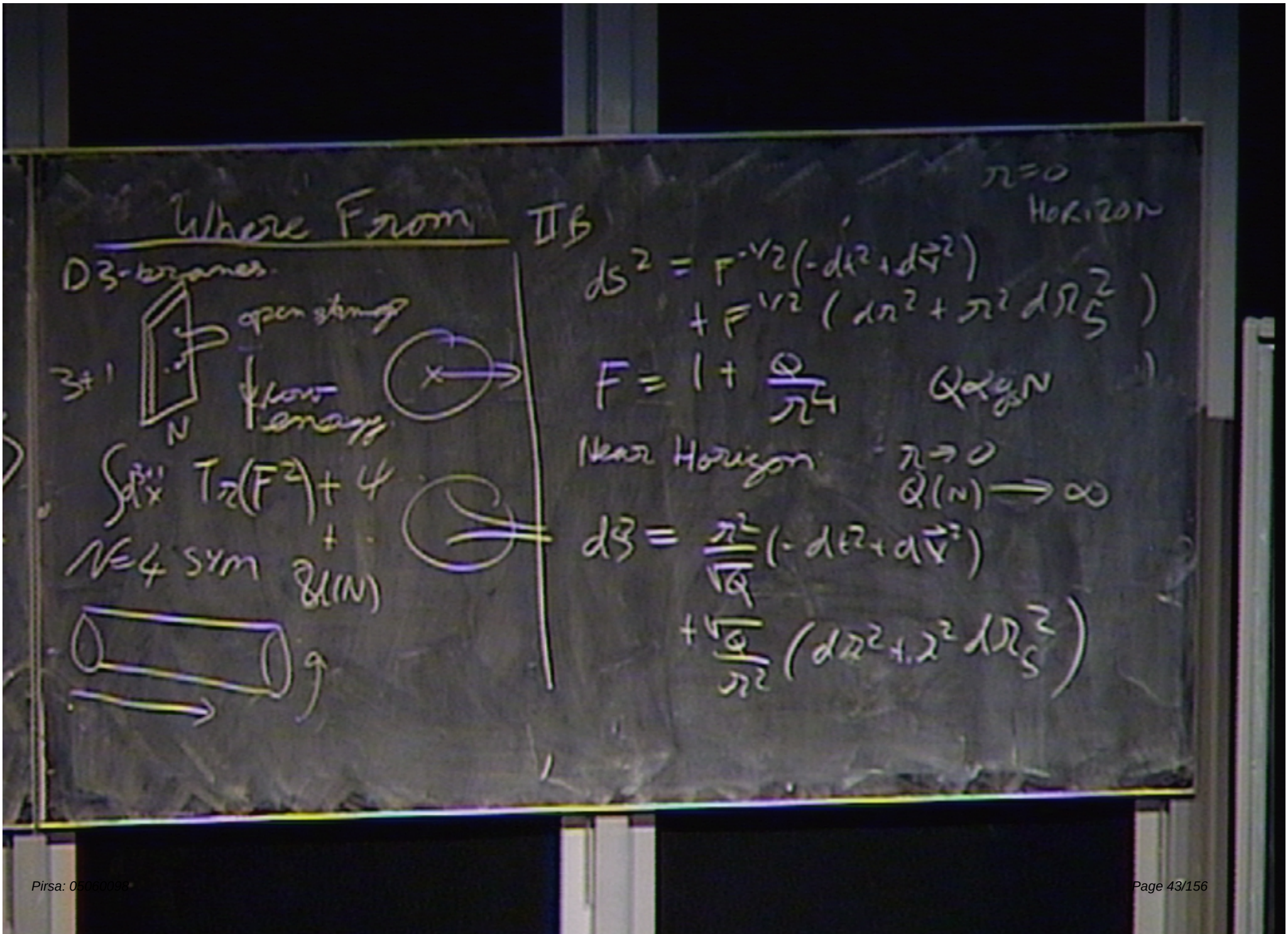
Where From IIB
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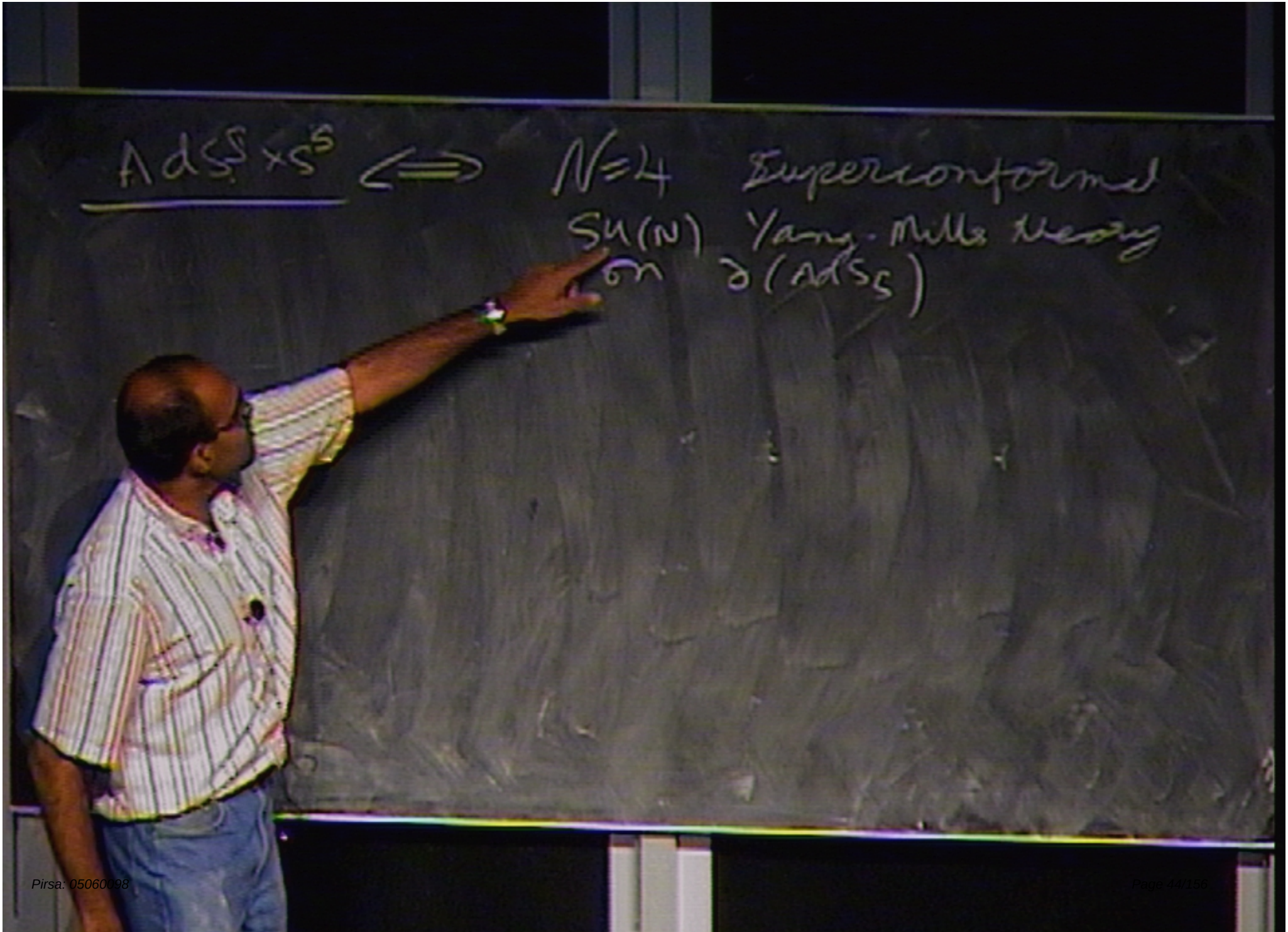
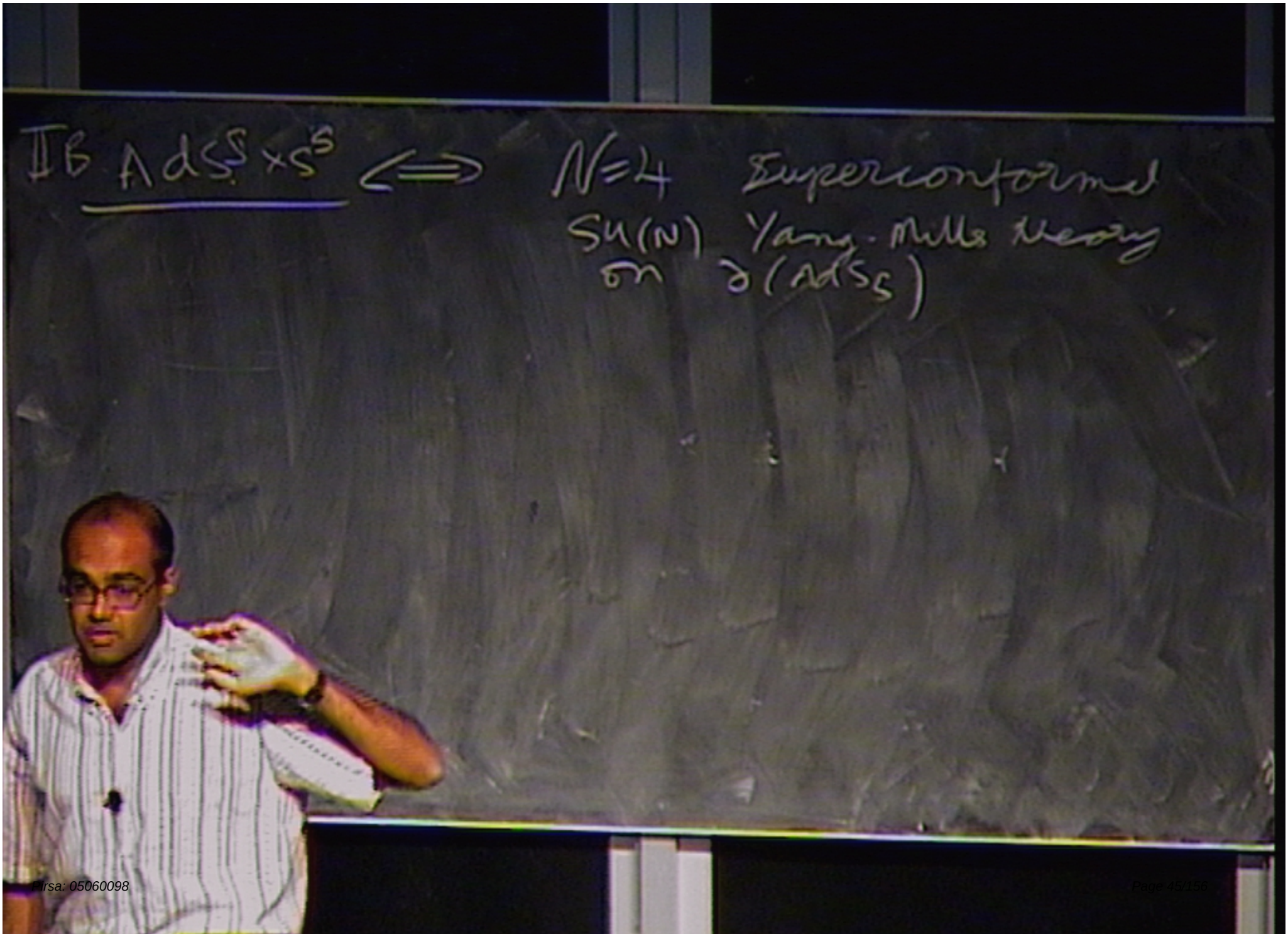

$AdS_5 \times S^5 \Longleftrightarrow$ $N=4$ Superconformal
$SU(N)$ Yang-Mills theory
on $\partial(AdS_5)$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IIB $AdS_5 \times S^5$ $\Longleftrightarrow$ $N=4$ Superconformal $SU(N)$ Yang-Mills theory on $\partial(AdS_5)$

IB $AdS_5 \times S^5$ $\Longleftrightarrow$ $N=4$ Superconformal $SU(N)$ Yang-Mills theory on $\partial(AdS_5)$

IB $AdS_5 \times S^5$ $\Longleftrightarrow$ $N=4$ Superconformal

R R

SU(N) Yang-Mills theory on $\partial(AdS_5)$

- $R = (g_s N)^{1/4} l_s$
- $g^2_{YM} = g_s$
- $g_s N =$ 't Hooft $= \lambda$

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IB $AdS_5 \times S^5$ $\Longleftrightarrow$ $N=4$ Superconformal

R l

SU(N) Yang-Mills theory on $\partial(AdS_5)$

- $l = (g_s N)^{1/4} l_s$
- $g^2_{YM} = g_s$
- $g_s N =$ 't Hooft $= \lambda$

IB $AdS_5 \times S^5$ $\Longleftrightarrow$ $N=4$ Superconformal

$l \quad l$

$SU(N)$ Yang-Mills theory on $\partial(AdS_5)$

- $l = (g_s N)^{1/4} l_s$
- $g^2_{YM} = g_s$
- $g_s N =$ 't Hooft $= \lambda$
- $SO(4,2) \times SO(6)$

  AdS_5 | S^5 |

  Conformal. R-Symmetry

IIB $AdS^5 \times S^5 \Longleftrightarrow \mathcal{N}=4$ Superconformal

$\ell \quad \ell$

$SU(N)$ Yang-Mills theory on $\partial(AdS_5)$

- $\ell = (g_s N)^{1/4} \, l_s$
- $g^2_{YM} = g_s$
- $g_s N =$ 't Hooft $= \lambda$
- $SO(4,2) \times SO(6)$

AdS $\quad$ S^5

Conformal $\quad$ R-Symmetry

$\begin{pmatrix} \cdot \end{pmatrix} \begin{pmatrix} Q_1 \\ Q_2 \end{pmatrix}$

SU(N) Yang-Mills theory
on $\partial(AdS_5)$

Semiclassical

$\frac{l}{l_s} \to \infty$ $\left(\begin{array}{l} \lambda \to 0 \\ N \to \infty \end{array}\right)$

S

λ

O(6)

R-Symmetry

SU(N) Yang-Mills theory
on $\partial(AdS_5)$

S

λ

O(6)

R-Symmetry

Semiclassical

$\frac{L}{l_s} \to \infty \quad \left(\begin{matrix} \hbar \to 0 \\ N \to \infty \end{matrix} \right)$

$$e^{iS_{cl}(J)} = e^{iW[J]}$$

Semiclassical

$$\frac{L}{l_s} \to \infty \quad \left(\begin{array}{c} \hbar \to 0 \\ N \to \infty \end{array} \right)$$

$$e^{iS_{cl}(J)} = e^{iW[J]}$$

$$\frac{1}{n!} \frac{\delta^n S_{cl}(J)}{\delta J^n} = \langle \theta\theta \cdots \theta \rangle$$

R-Symmetry

Semiclassical

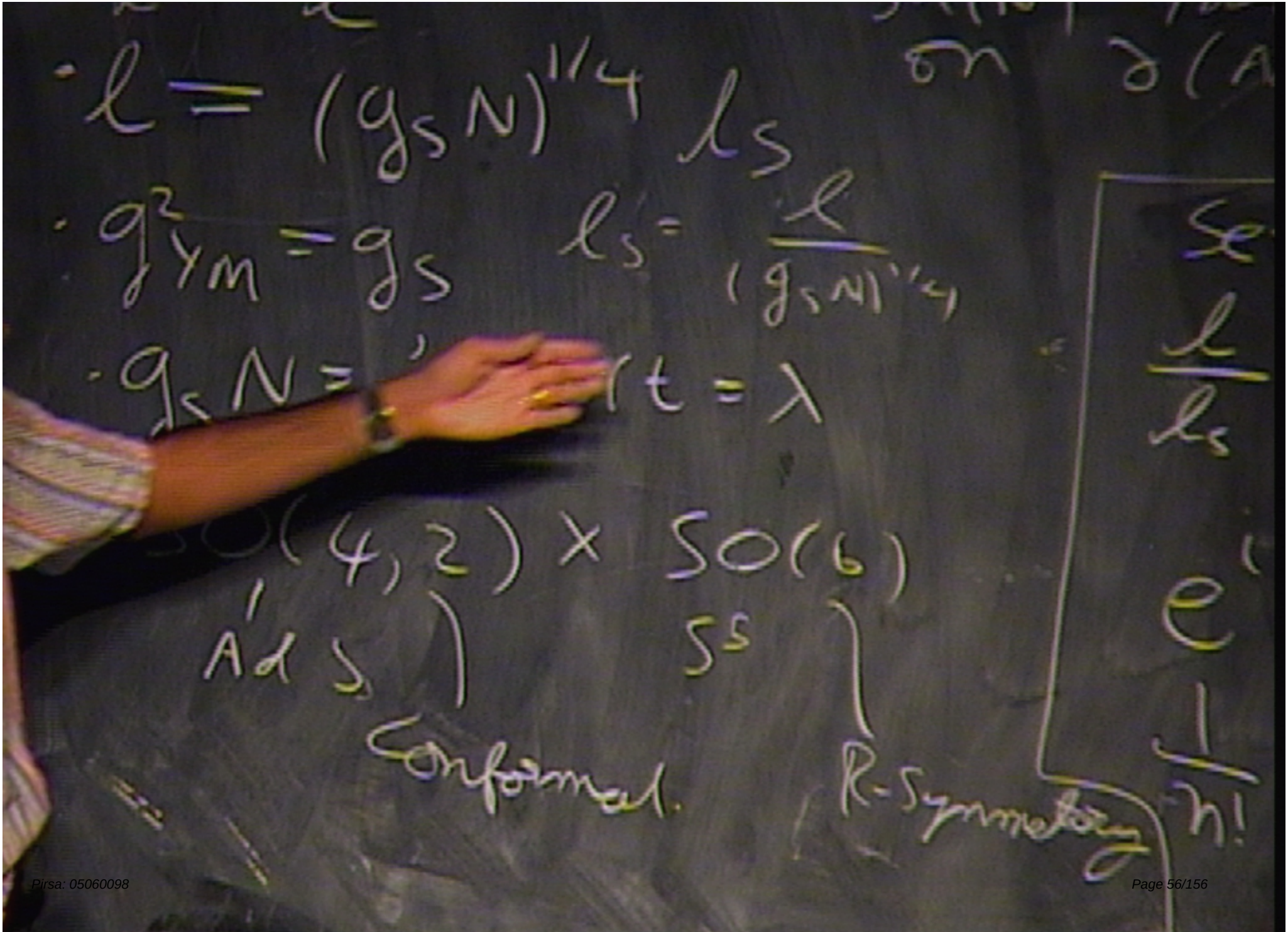
$$\frac{L}{l_s} \to \infty \quad \left(\begin{array}{l} \hbar \to 0 \\ N \to \infty \end{array} \right)$$

$$e^{i S_{cl}(J)} = e^{i W[J]}$$

$$\frac{1}{n!} \frac{\delta^n S_{cl}(J)}{\delta J^n} \Big|_{J=0} = \langle 0 | \phi \phi \cdots \phi | 0 \rangle$$

6)

R-Symmetry


$l = (g_s N)^{1/4} l_s$
$g^2_{YM} = g_s$
$l_s = \frac{l}{(g_s N)^{1/4}}$
$g_s N =$
$t = \lambda$
$SO(4,2) \times SO(6)$
AdS_5
S^5
Conformal.
R-Symmetry
$\frac{l}{l_s}$
$e^{(}$
$\frac{1}{n!}$

$\ell = (g_s N)^{1/4} l_s$

$g^2_{YM} = g_s \qquad l_s = \frac{\ell}{(g_s N)^{1/4}}$

$g_s N = $ 't Hooft $= \lambda$

$SO(4,2) \times SO(6)$

AdS_5 | S^5 |

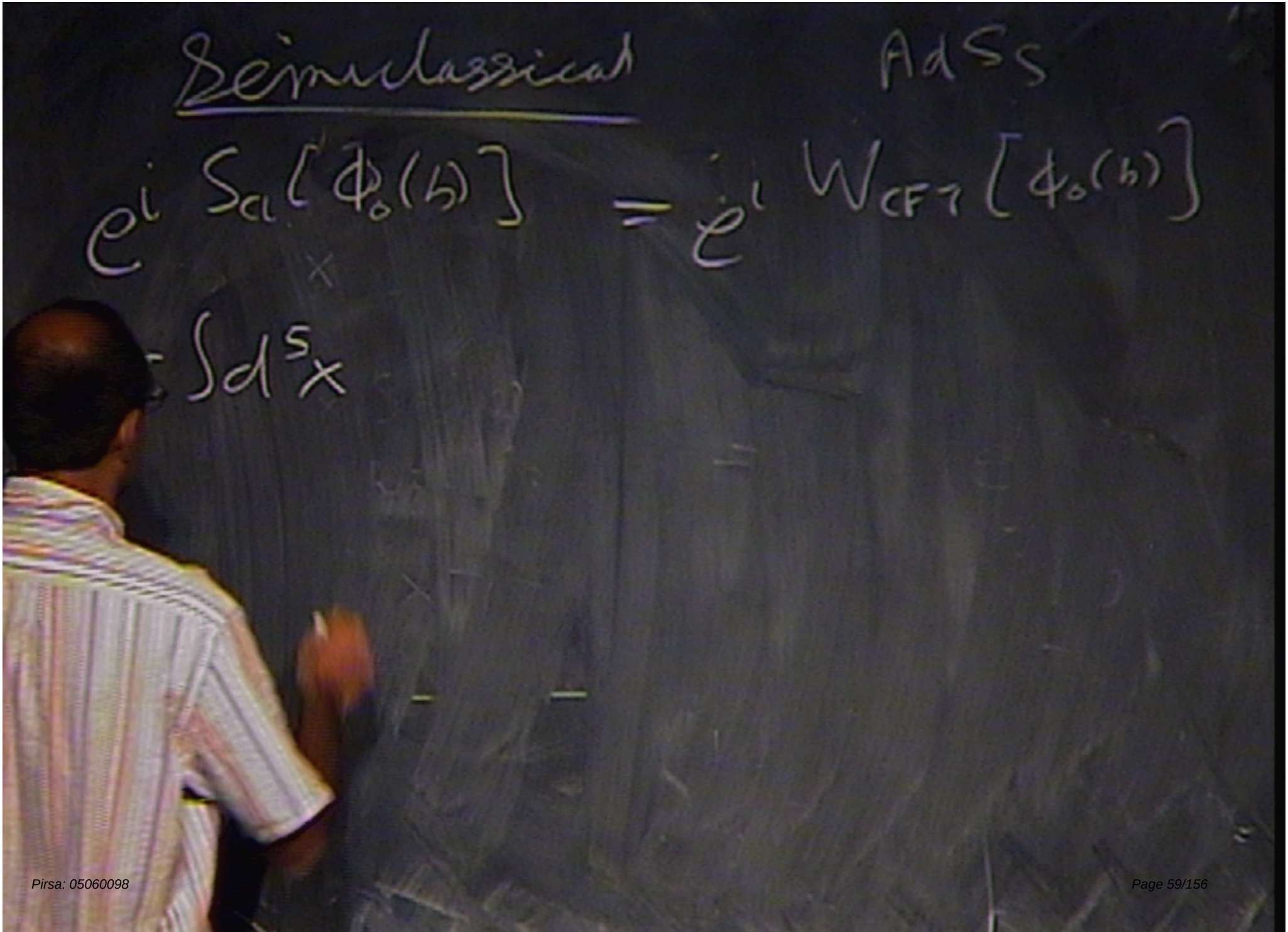
Conformal. R-Symmetry

$\frac{\ell}{l_s}$

$e^{\frac{1}{n!}}$

Semiclassical AdS5

$$e^{i S_{cl}[\phi_0(x)]} = e^{i W_{CFT}[\phi_0(x)]}$$


Semiclassical
AdS5
$e^{i S_{cl}[\phi_0(x)]} = e^{i W_{CFT}[\phi_0(x)]}$
$= \int d^5x$

Semiclassical AdS5

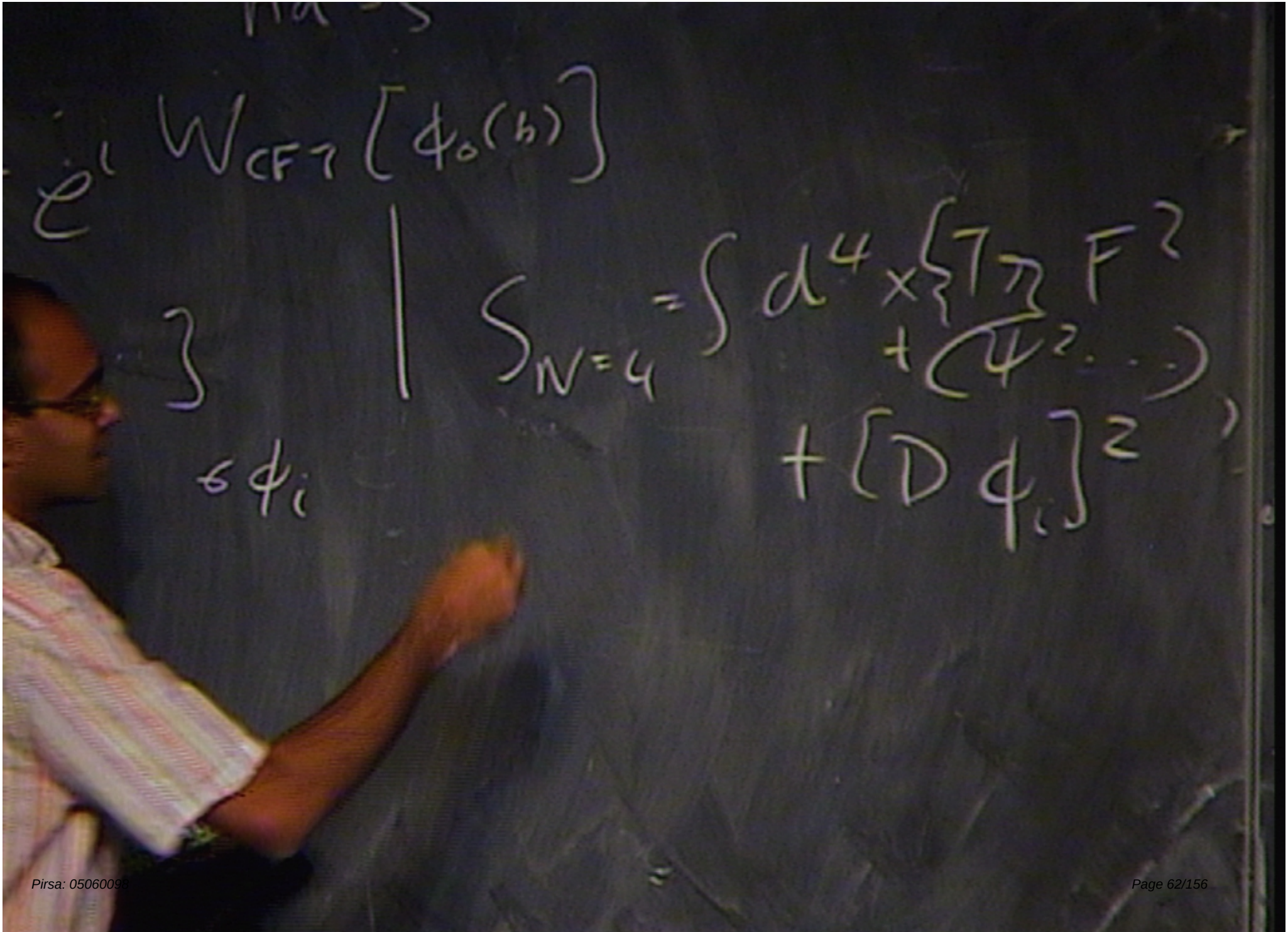
$$e^{i S_{cl}[\phi_0(b)]} = e^{i W_{CFT}[\phi_0(b)]}$$

$$S_{cl} = \int d^5x \sqrt{g} [R + \partial\phi^2 + \dots]$$

Semiclassical AdS5

$$e^{i S_{cl}[\phi_0(b)]} = e^{i W_{CFT}[\phi_0(b)]}$$

$$S_{cl} = \int d^5x \sqrt{g} [R + \partial\phi^2 + \dots]$$


$e^{i W_{CFT}[\phi_0(x)]}$
$= \int \mathcal{D}\phi_i \; e^{i S_{N=4}} = \int d^4x \{ \frac{1}{g^2} F^2 + (\phi^2 \ldots) + [D\phi_i]^2 \}$

AdS5

$$= e^{i W_{CFT}[\phi_0(h)]}$$

$$\ldots \partial\phi^2 + \ldots \}$$

$$\delta\phi_i$$

$$S_{N=4} = \int d^4x \{ \mathrm{Tr}\, F^2 + (\psi^2 \ldots) + [D\phi_i]^2 \}$$

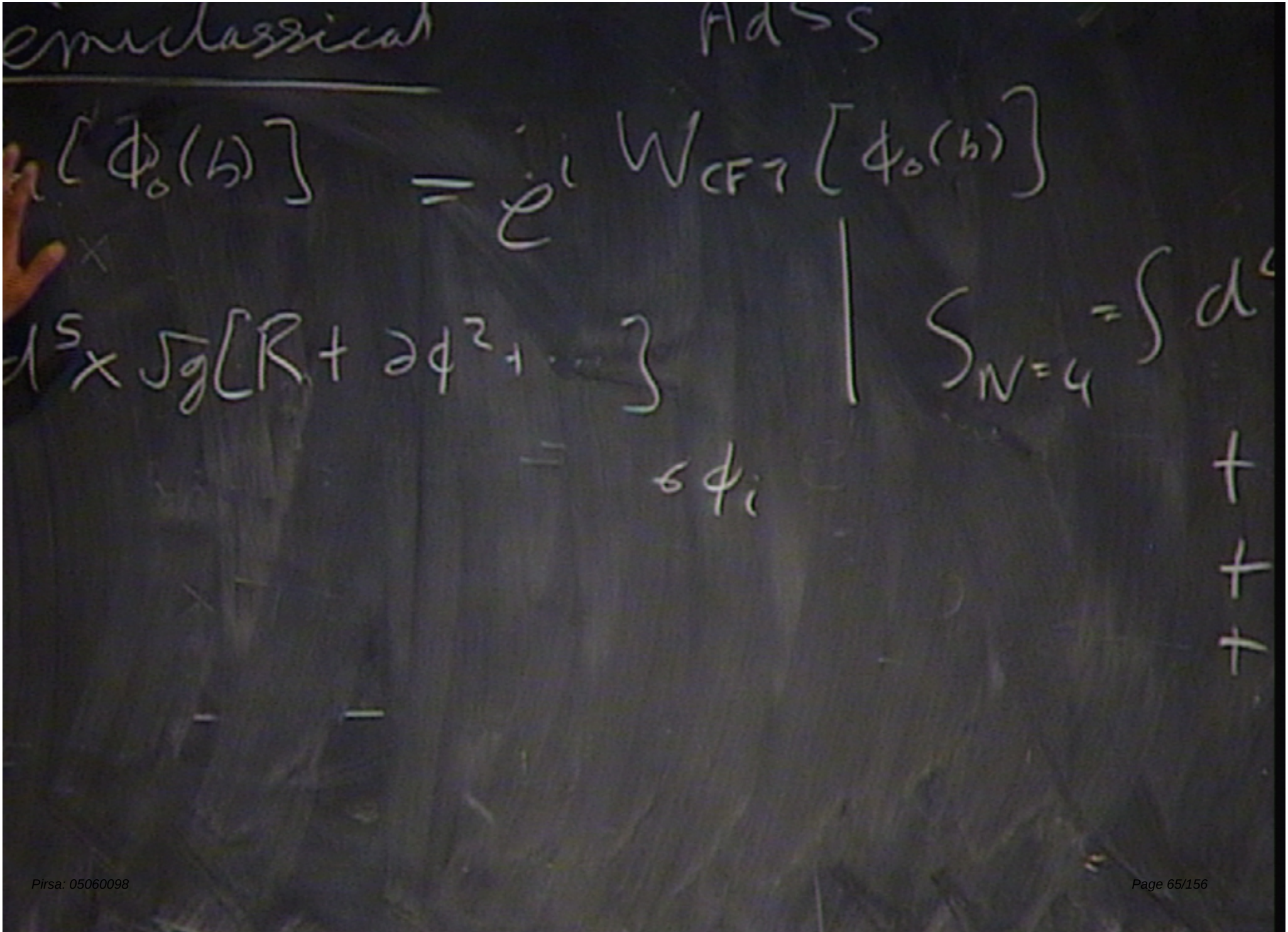
Semiclassical AdS_5

$$e^{i S_{cl}[\phi_0(b)]} = e^{i W_{CFT}[\phi_0(b)]}$$

$$S_{cl} = \int d^5x \sqrt{g}\,[R + \partial\phi^2 + \dots]$$

$$S_{N=4} = \int d^4x \{ \mathrm{Tr}\, F^2 + (\phi^2 \dots) + [D\phi_i]^2 + R(\phi)^2 + (\phi^4 \dots) \}$$

ϕ_i



emiclassical

AdS5

$[\phi_0(b)] = e^{i W_{CFT}[\phi_0(b)]}$

$d^5x \sqrt{g}[R + \partial\phi^2 + \dots]$

$S_{N=4} = \int d^4$

$\delta\phi_i$

$+$

$+$

$+$

Semiclassical

AdS5

$$i\, S_{cl}[\phi_0(b)] = e^{i\, W_{CFT}[\phi_0(b)]}$$

$$= \int d^5x \sqrt{g}\,[R + \partial\phi^2 + \dots]$$

$g_{\mu\nu}$, scalars etc.

gauge fields

$$S_{N=4} = \int d^4x \{ \quad + (\quad (\epsilon\phi_i) \quad + [D \quad + R \quad + (\quad$$

Semiclassical

AdS5

$$i\, S_{cl}[\phi_0(b)] = e^{i\, W_{CFT}[\phi_0(b)]}$$

$$= \int d^5x \sqrt{g}\,[R + \partial\phi^2 + \dots]$$

$g_{\mu\nu}$, scalars etc.

gauge fields

$$S_{N=4} = \int d^4x \{ \quad + (\quad (\phi_i) \quad + [D \quad + R \quad + (\quad$$

composite ops from A_μ, ψ, ϕ_i

$\hookrightarrow \theta = \mathrm{Tr}(F^2) =$

classical

AdS5

$(b)] = e^{i W_{CFT}[\phi_0(b)]}$

$\sqrt{g}[R + \partial\phi^2 + \dots]$

scalars etc.

ields

$S_{N=4} = \int d^4x \{ \mathrm{Tr}\, F^2 + (\psi^2 \dots) + [D\phi_i]^2 + R(\phi^i)^2 + [\dots[\dots]]$

$(6\phi_i)$

composite ops from A_μ, ψ, ϕ_i

$\hookrightarrow \theta = \mathrm{Tr}(F^2)$

AdS5

$$= e^{i W_{CFT}[\phi_0(b)]} \left| \frac{1}{n!} \frac{\delta^n S_{cl}}{\delta \phi_0^n} \right|_{\phi=0} = \langle O \cdots O \rangle$$

$$S_{N=4} = \int d^4x \left\{ \frac{1}{g^2} F^2 + (\psi^2 \cdots) + (\partial \phi_i)^2 + [D \phi_i]^2 + R(\phi)^2 + V(\phi) \right\}$$

composite ops from A_μ, ψ, ϕ_i

$\hookrightarrow \mathcal{O} = \mathrm{Tr}(F^2) =$

3+1

$\int d^{3+1}x$

$N=4$

AdS$_5$

$$e^{i W_{CFT}[\phi_0(b)]} = \left| \frac{1}{n!} \frac{\delta^n S_{cl}}{\delta \phi_0^n} \right|_{\phi=0} = \langle O \cdots O \rangle$$

$$S_{N=4} = \int d^4x \left\{ \frac{1}{g^2} F^2 + (\phi^2 \cdots) + (\partial \phi_i)^2 + [D \phi_i]^2 + R(\phi)^2 + [\phi^4 - (\cdots)] \right\}$$

$\phi^2 + \cdots \}$

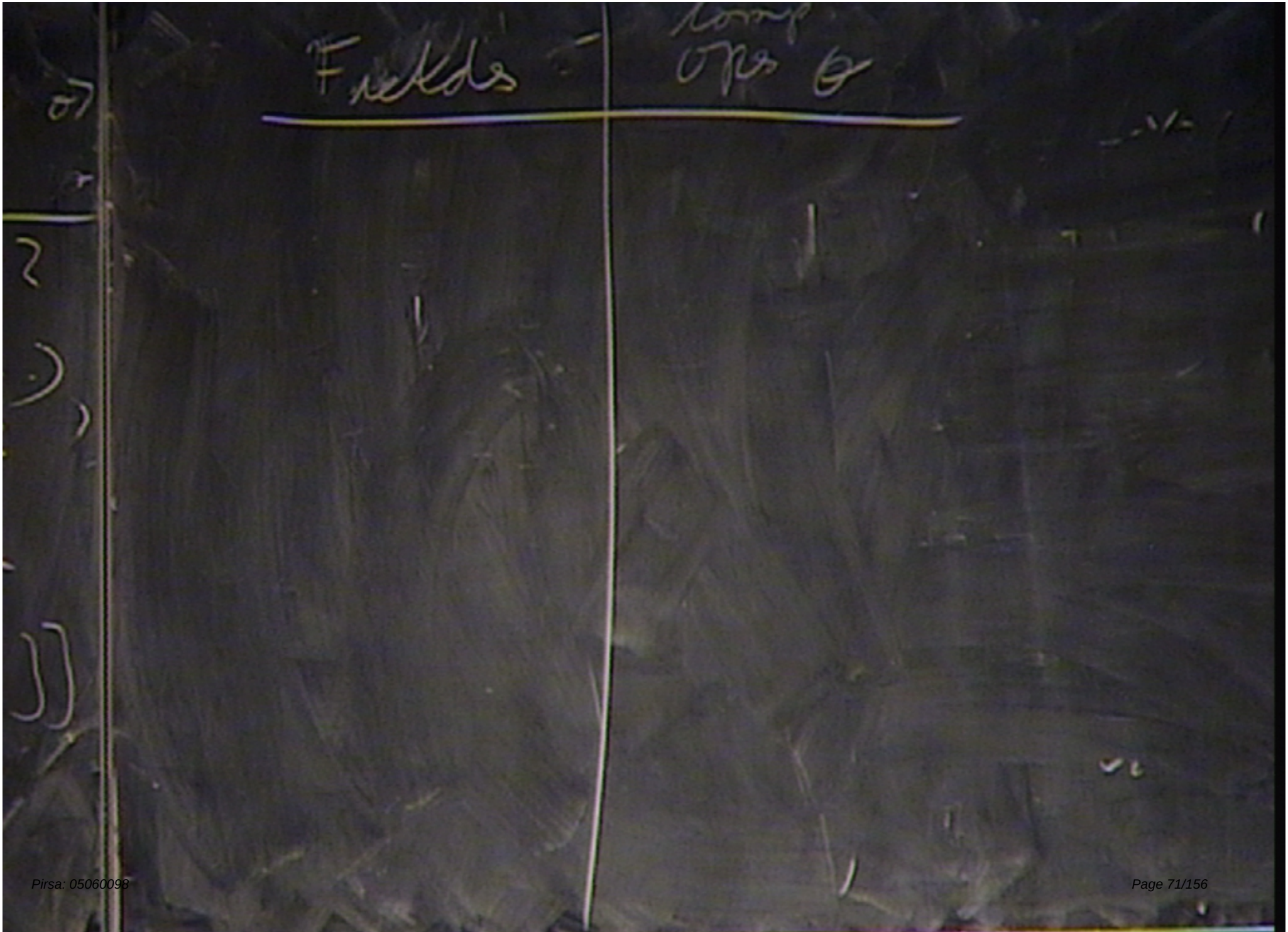
composite ops from A_μ, ψ, ϕ_i

$\hookrightarrow \theta = \mathrm{Tr}(F^2) =$

$3+1$

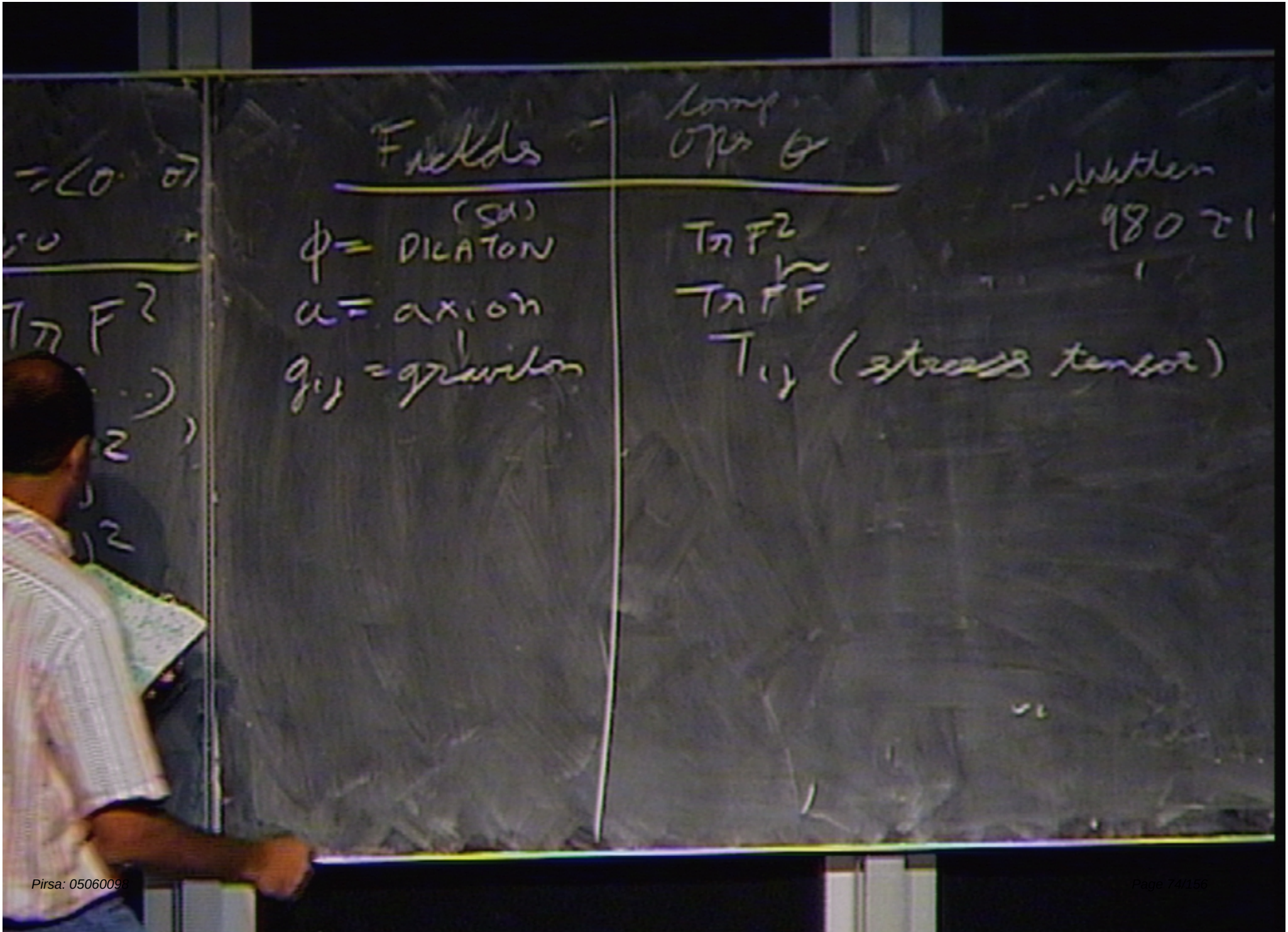
$\int d^{3+1}x$

$N=4$


Fields

Fields	Comp Ops
ϕ = DILATON (SM)	$\mathrm{Tr} F^2$
a = axion	$\mathrm{Tr} F \tilde{F}$

Fields	Loop Operator
ϕ = DILATON (SM)	$\mathrm{Tr} F^2$
a = axion	$\mathrm{Tr} F \tilde{F}$
$g_{\mu\nu}$ = graviton	$T_{\mu\nu}$ (stress tensor


Fields
Comp Ops
(SU)
φ = DILATON
a = axion
g_ij = graviton
Tr F²
Tr F F̃
T_ij (stress tensor)
Witten
98021

Fields	Ops
ϕ = DILATON (SM)	$T_n F^2$
a = axion	$T_n F\tilde{F}$
g_{ij} = graviton	T_{ij} (stress te
KK modes ϕ	

Fields	Ops θ
ϕ = DILATON (sd)	$\mathrm{Tr}\, F^2$
a = axion	$\mathrm{Tr}\, F\tilde{F}$
g_{ij} = graviton	T_{ij} (stress tensor)
modes ϕ	$\mathrm{Tr}(F^2 X^k)$

Witten 980 τ

$\langle O \cdots O \rangle$

F^2

$\ldots)$

$]^2$

$)^2$

$\ldots]]$

$+ i\phi^2$

Fields	Ops $\mathcal{O}$
ϕ = DILATON (sd)	$\mathrm{Tr}\, F^2$
a = axion	$\mathrm{Tr}\, F\tilde{F}$
g_{ij} = graviton	T_{ij} (stress
KK modes ϕ	$\mathrm{Tr}(F^2 X^k)$
Malik charges. masses symmetries	

ops θ

Witten

$\Delta(\mathrm{Tr}\, F^2)$ 9802150

$\mathrm{Tr}\, F^2$

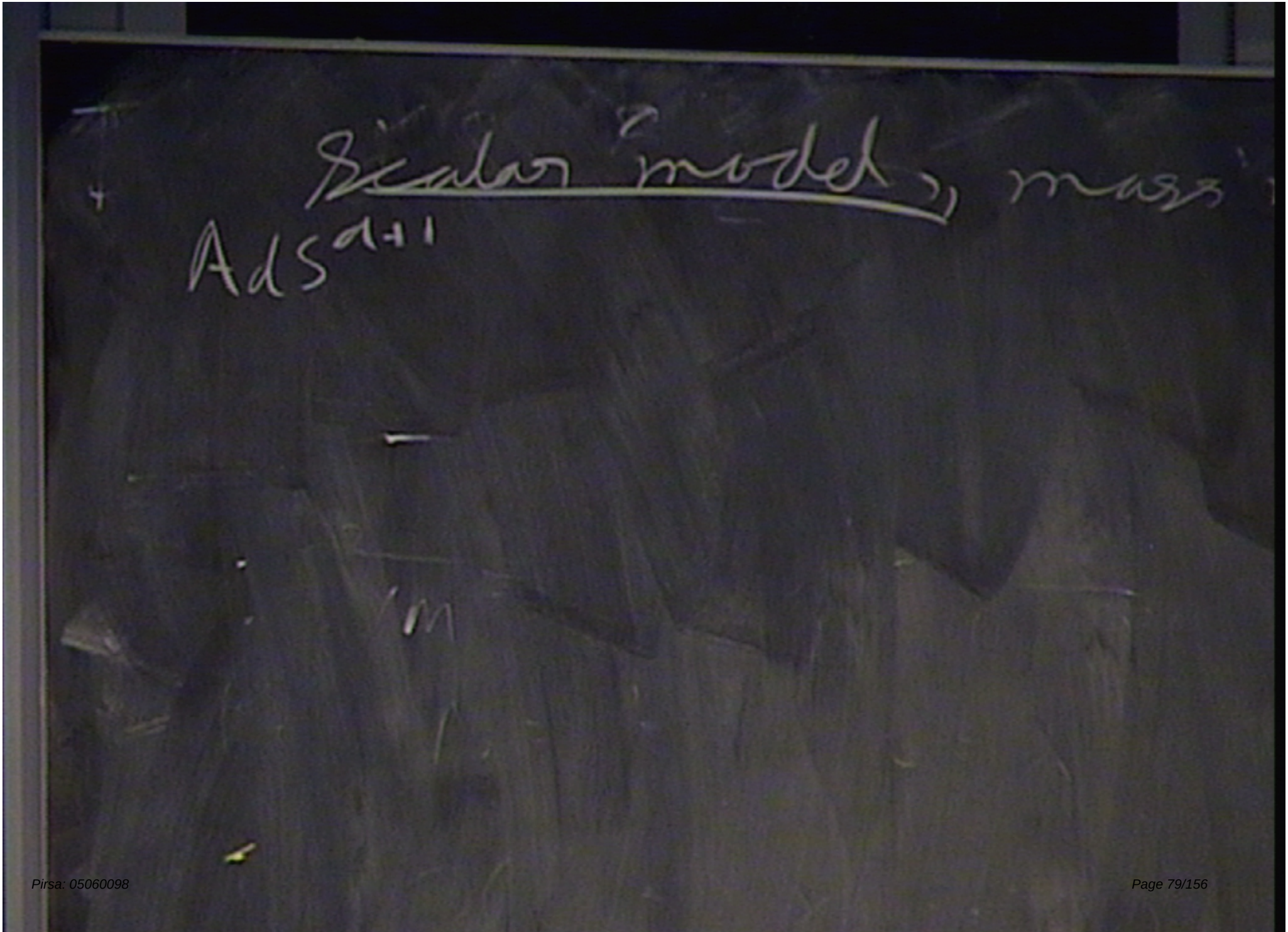
$\mathrm{Tr}\, F\tilde{F}$

T_{ij} (stress tensor)

$\mathrm{Tr}(F^2 X^k)$

Matching

masses $\Longleftrightarrow$ conf. dimension


Scalar model; mass
AdS^{d+1}

Scalar model; mass

$AdS^{d+1} \Rightarrow \Box\phi = m^2 \phi$

Scalar modes, mass m.

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré: $ds^2 = \frac{l^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\quad \phi = e^{i\vec{k}\cdot\vec{x} - \omega t} X$

Scalar wave, mass m

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré: $ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\quad \phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}\chi$

$$z^2\partial_z^2\chi + z\partial_z\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi = 0$$

Pirsa: 05060098

Scalar modes, mass m.

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré. $ds^2 = \frac{\ell^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}\chi$

Bessel $z^2\partial_z^2\chi + z\partial_z\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi = 0$

$\phi = e^{i\vec{k}\vec{x} - i\omega t} z^{d/2}\left[A J_\nu(|q|z) + \phi_0 Y_\nu(|q|z)\right]$ $q^2 = \vec{k}^2 - \omega^2$

Scalars in AdS, mass m

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré $ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}\chi$

Bessel $z^2\partial_z^2\chi + z\partial_z\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi = 0$

$\phi = e^{i\vec{k}\vec{x} - i\omega t}\, z^{d/2}\left[A\, J_\nu(|q|z) + B\, Y_\nu(|q|z)\right]$ $q^2 = \vec{k}^2 - \omega^2$

$\xrightarrow{z\to 0}$ $A z^{2h_+} e^{i\vec{k}\vec{x} - i\omega t} + B z^{2h_-} e^{i\vec{k}\vec{x} - i\omega t}$

$h_\pm = \frac{d}{2} \pm \nu$

$$2h_{\pm} = \frac{\alpha}{2} \pm \frac{\sqrt{\alpha^2 + 4m^2}}{2} = \frac{\alpha}{2} \pm \nu$$

Scalar model, mass m

$AdS^{d+1} \Rightarrow \Box\phi = m^2 \phi$

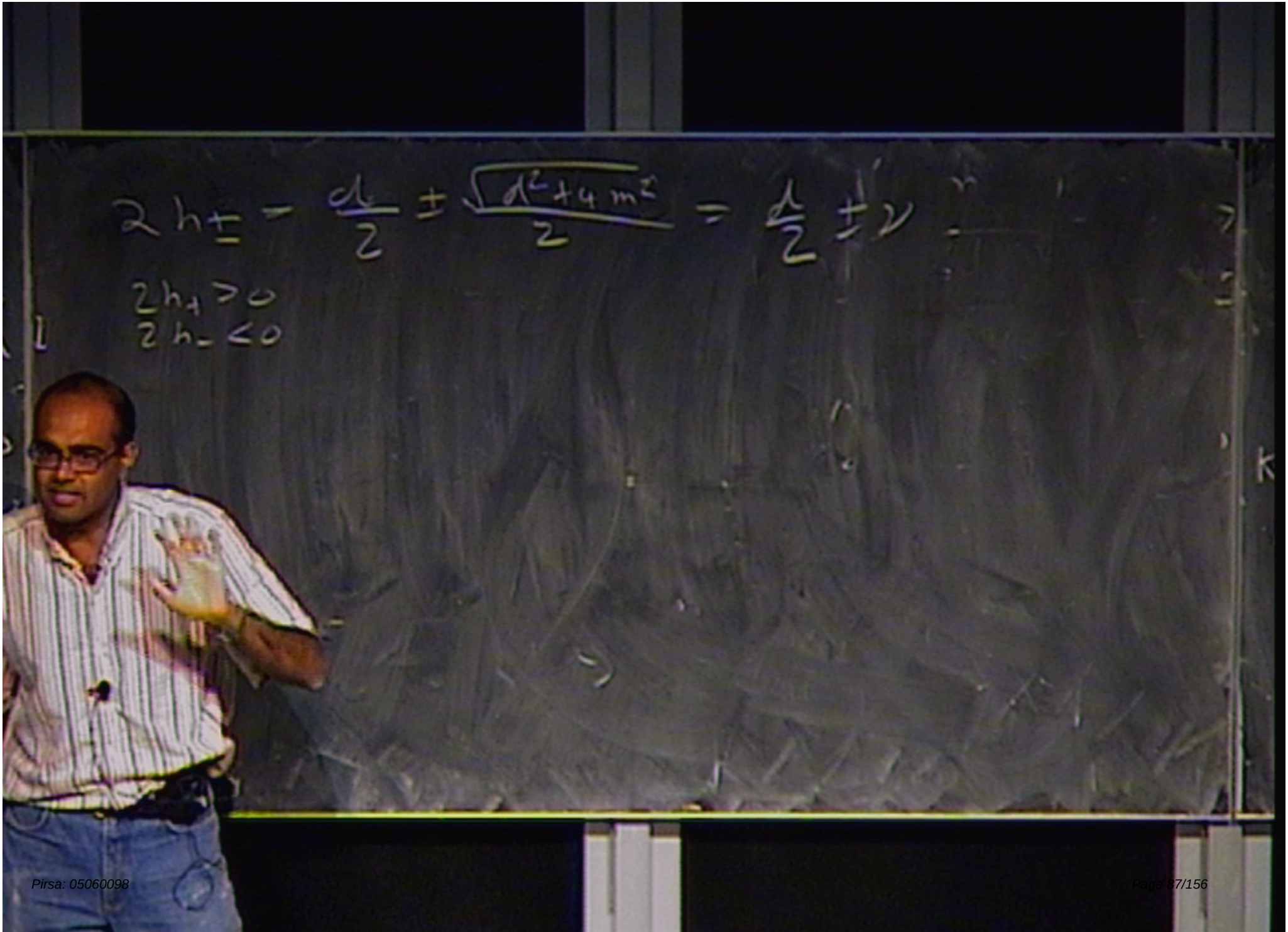
Poincaré: $ds^2 = \frac{\ell^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\quad \phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}\chi$

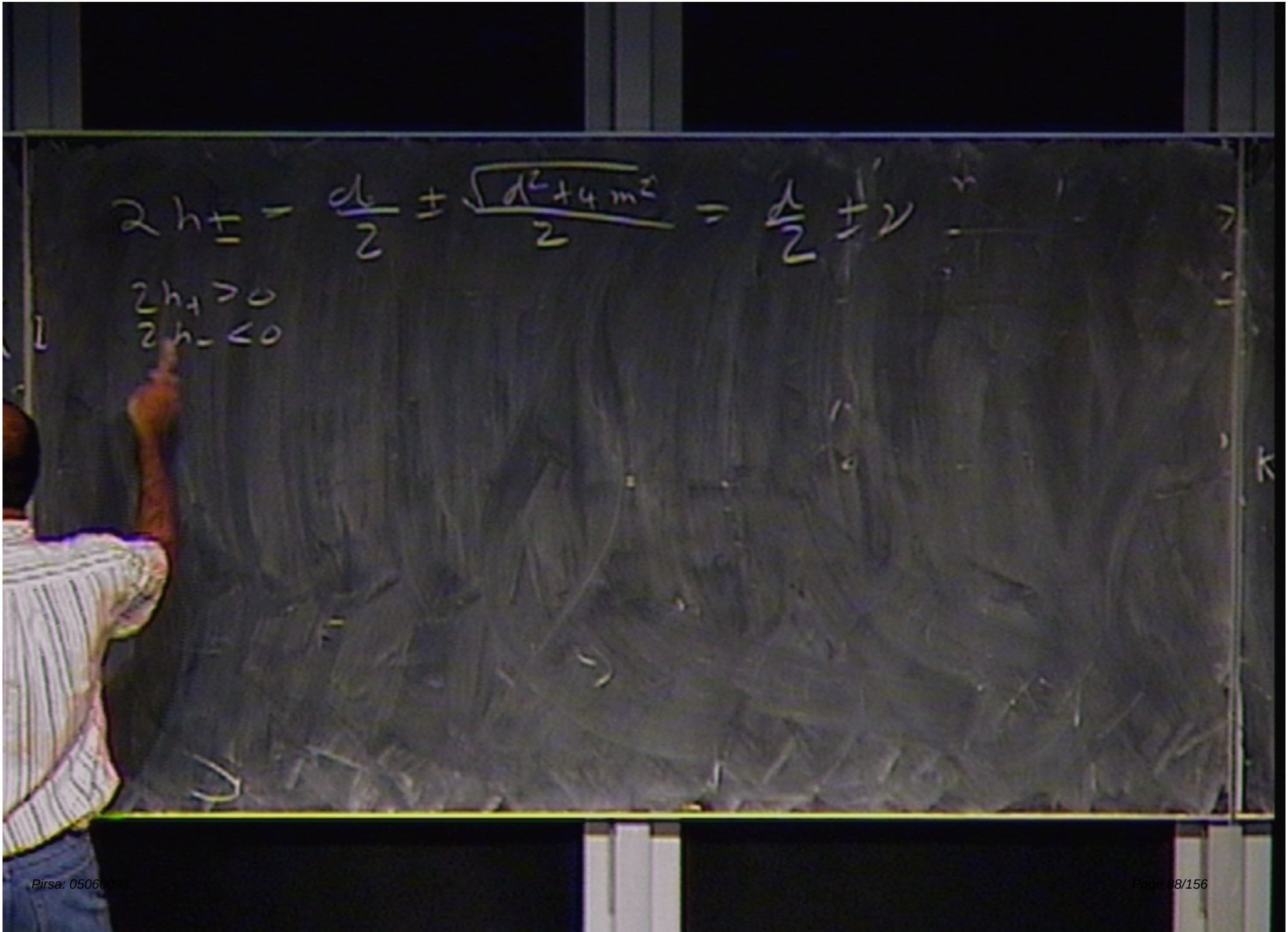
Bessel: $z^2 \partial_z^2 \chi + z\partial_z \chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2) z^2\right]\chi = 0$

$q^2 = \vec{k}^2 - \omega^2$

$$\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t} z^{d/2}\left[A J_\nu(|q|z) + J Y_\nu(|q|z)\right]$$

$$\xrightarrow{z\to 0} A z^{2h_+} e^{ikx - i\omega t} + J z^{2h_-} e^{ikx - i\omega t}$$


$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2+4m^2}}{2} = \frac{d}{2} \pm \nu$
$2h_+ > 0$
$2h_- < 0$


$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2+4m^2}}{2} = \frac{d}{2} \pm \nu$
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$$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2+4m^2}}{2} = \frac{d}{2} \pm \nu$$

$2h_+ > 0$
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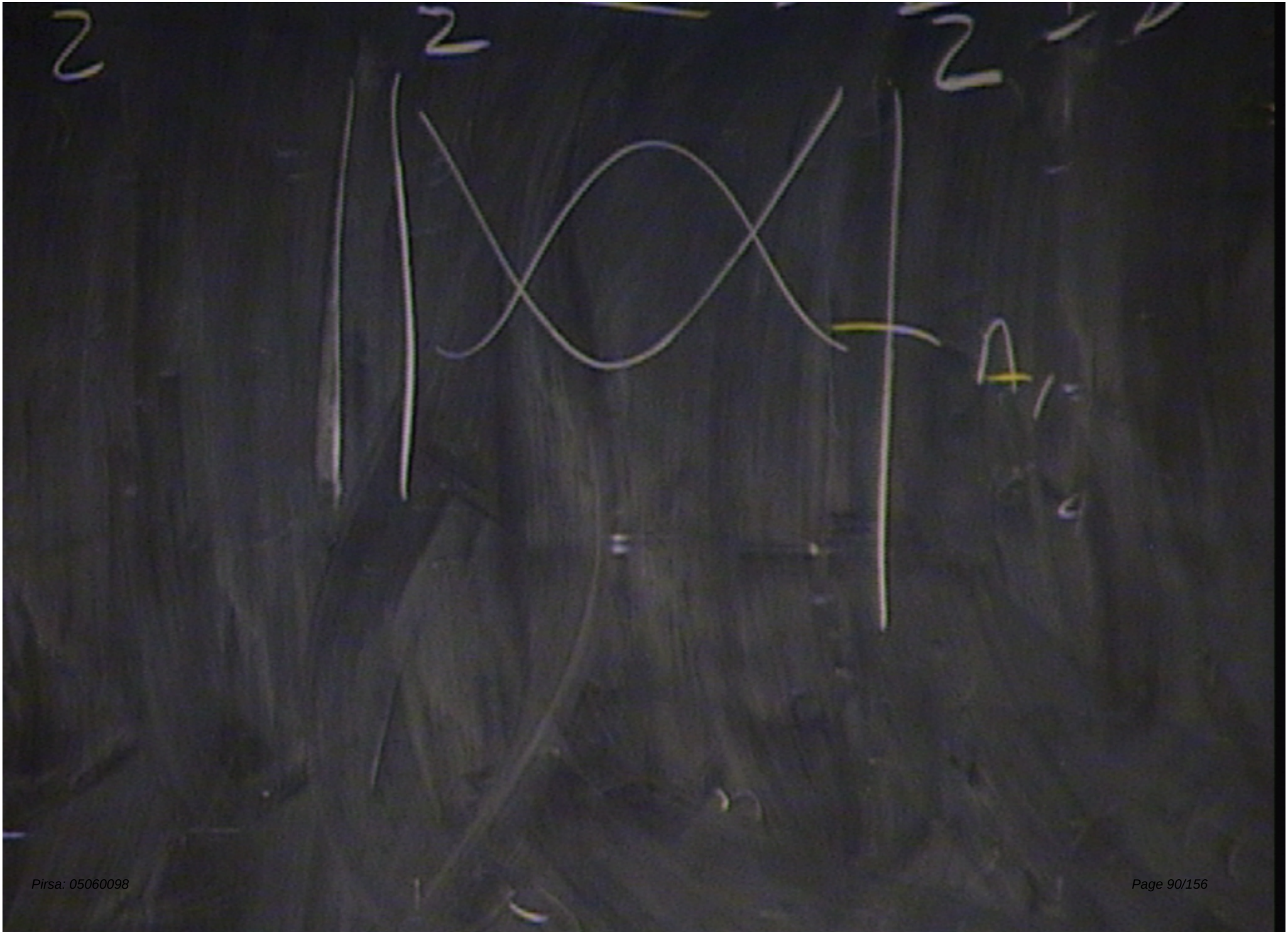
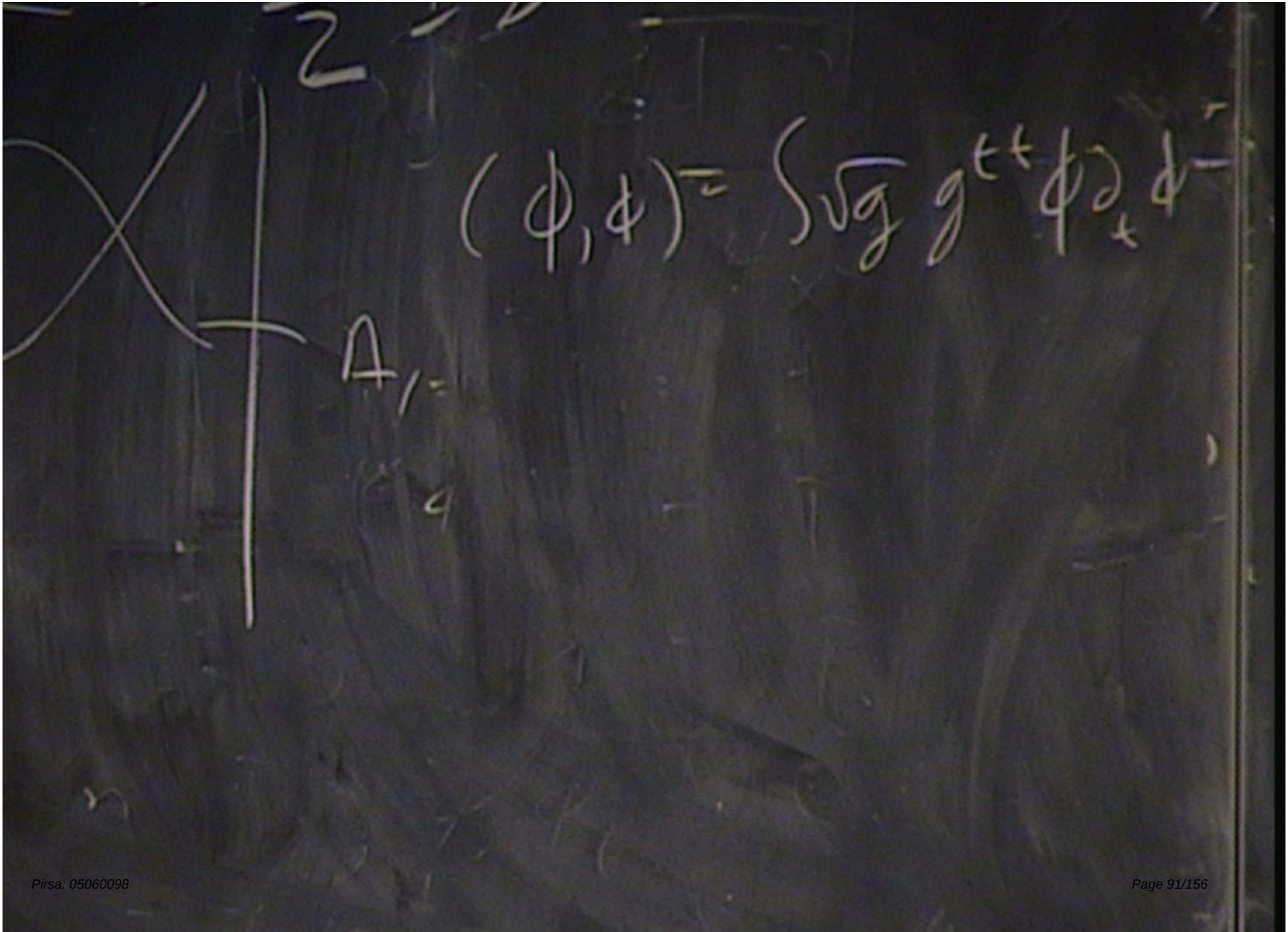
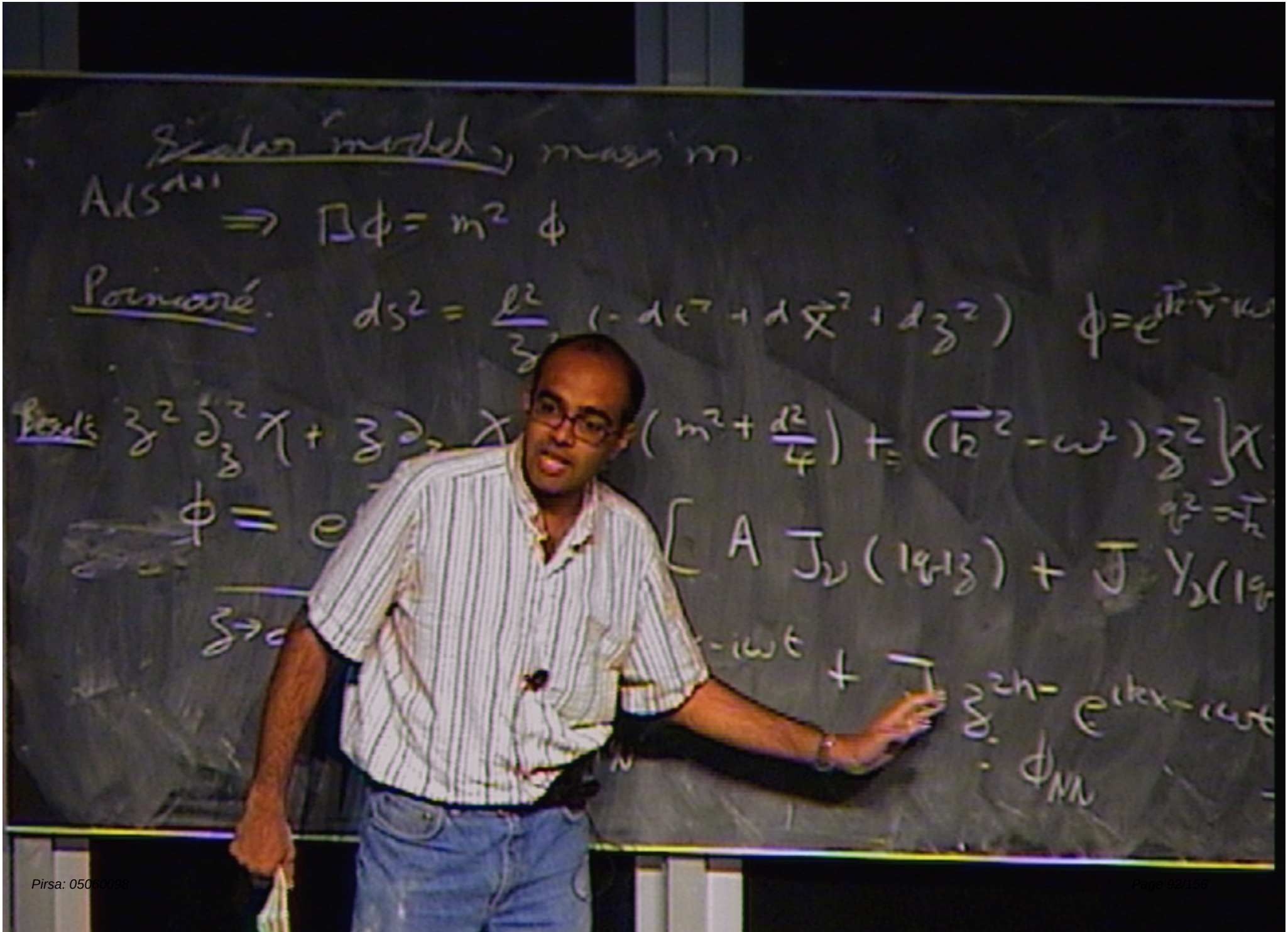
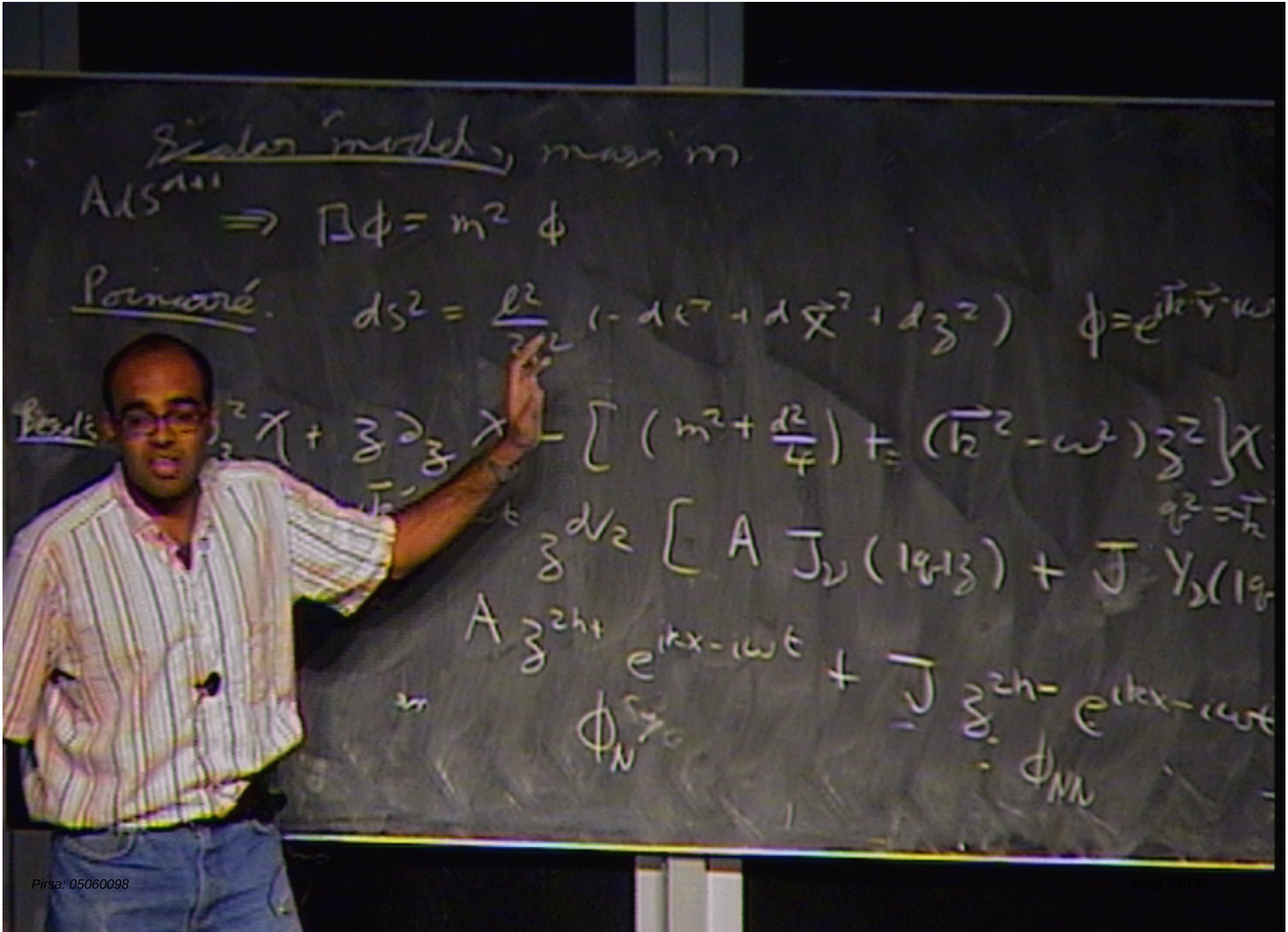
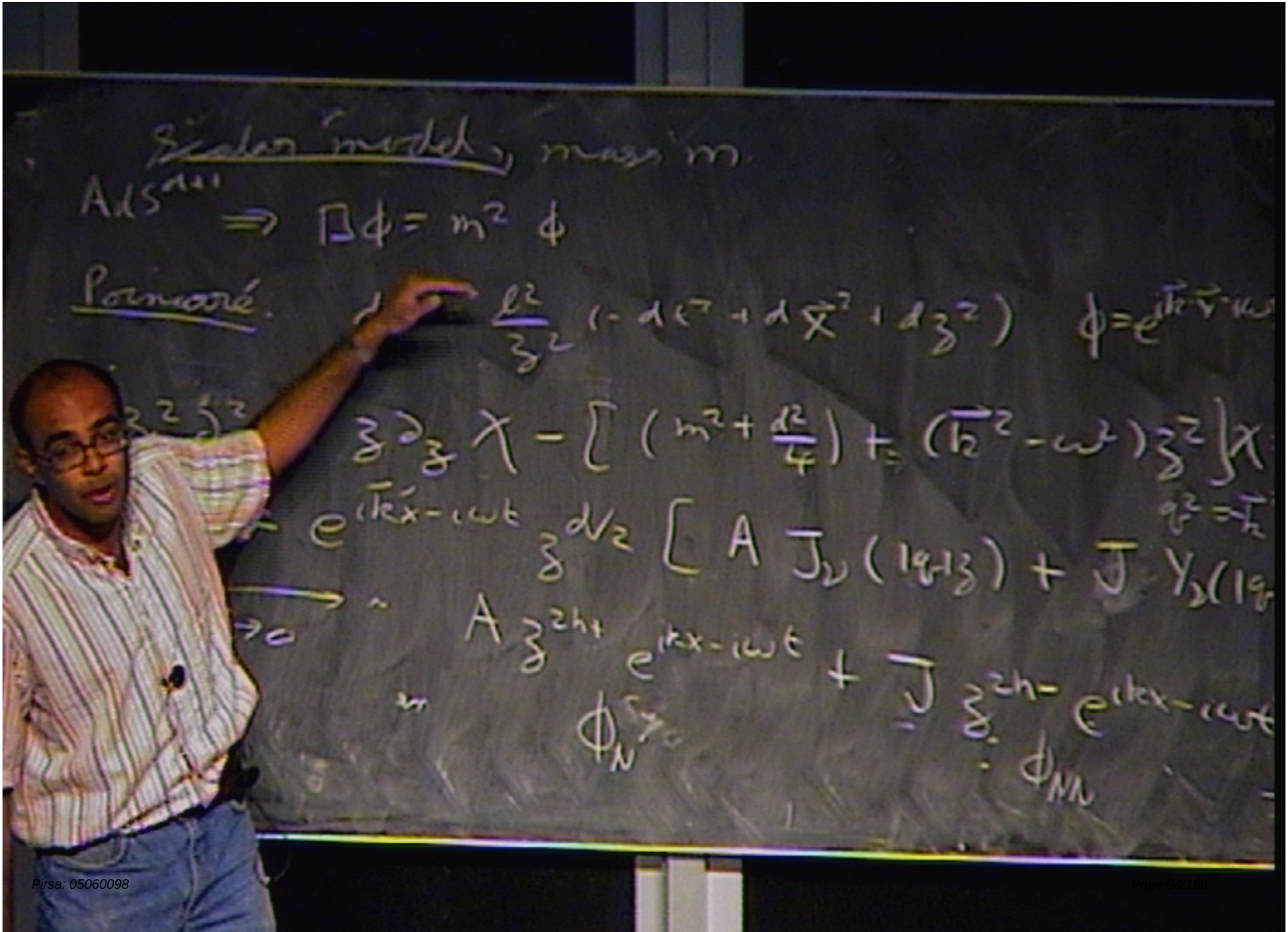
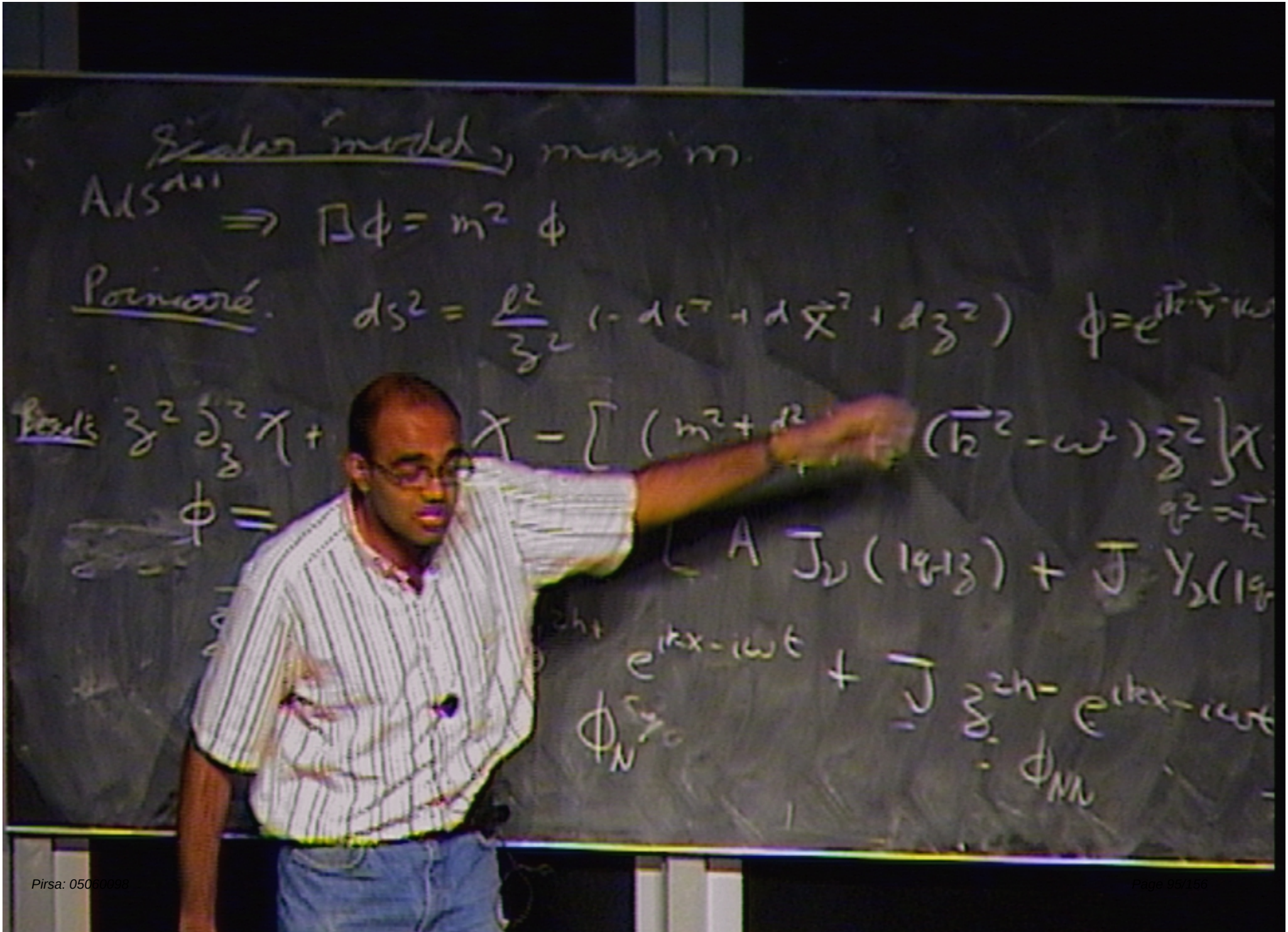


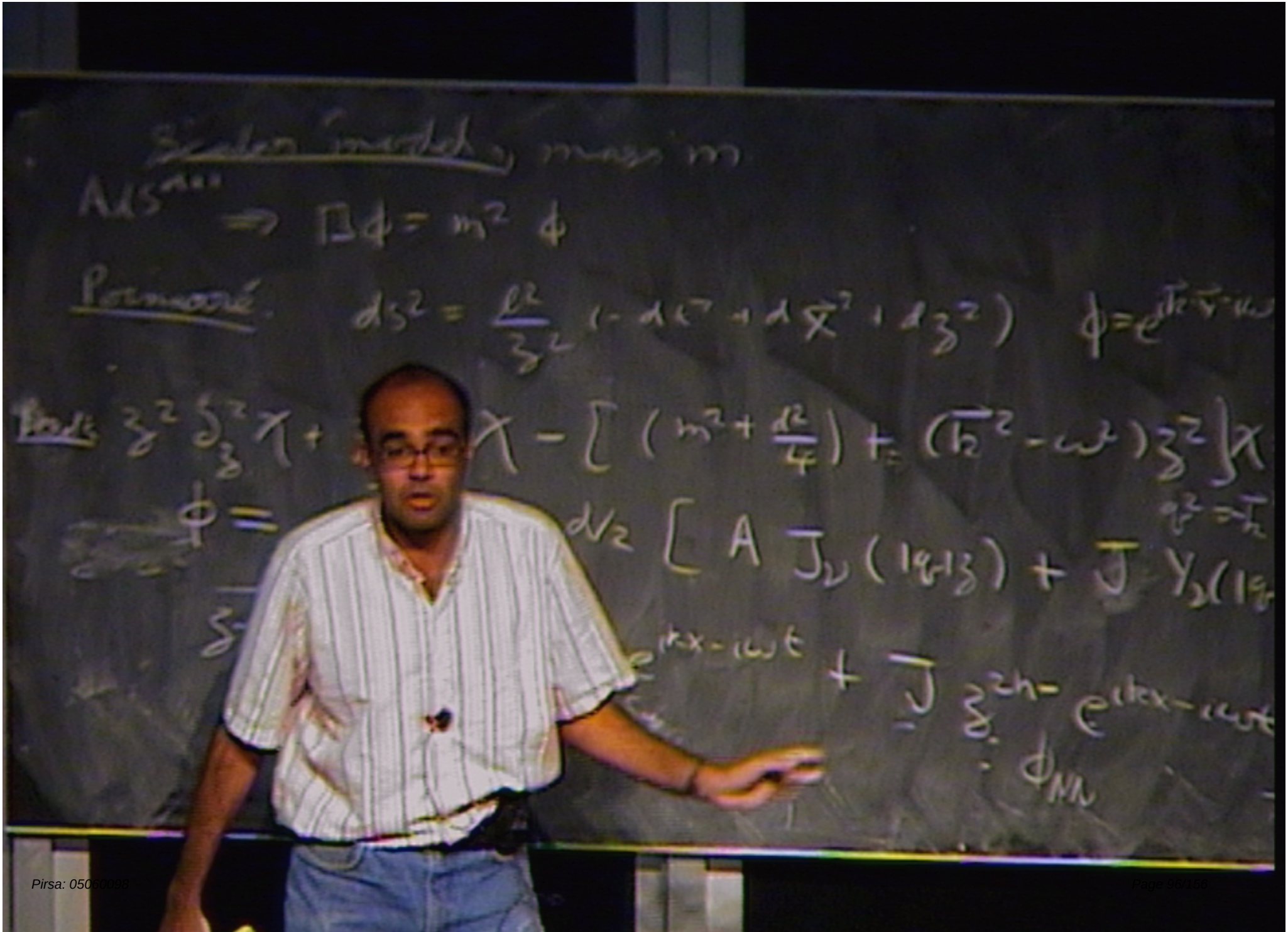

$(\phi, \phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$
$A_1 =$

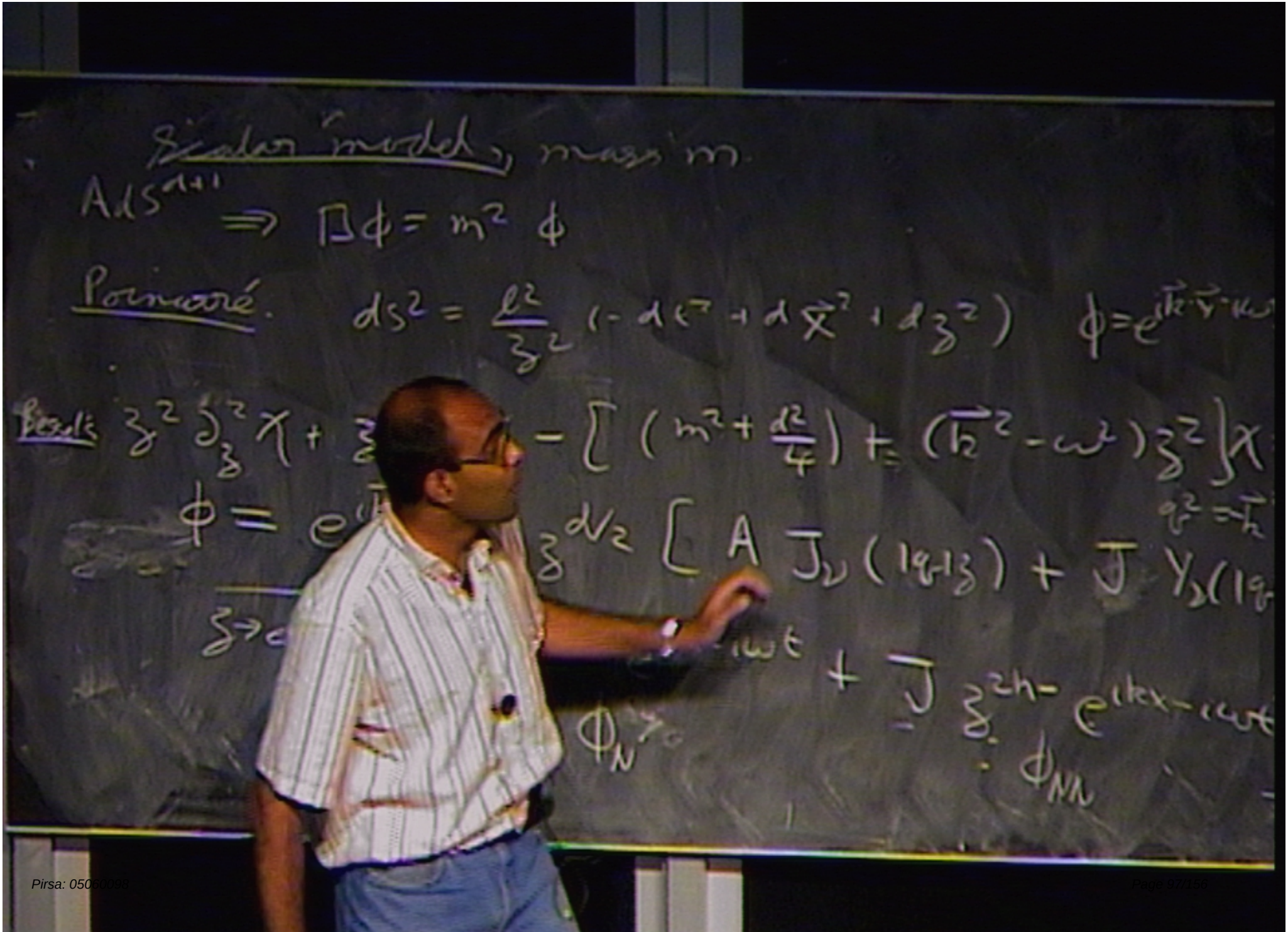

Scalar model, mass m.
AdS^{d+1} ⇒ □φ = m² φ
Poincaré.
ds² = ℓ²/z² (−dt² + dx⃗² + dz²)
φ = e^{ik·x⃗ − iω
Bessel
z² ∂_z² χ + z ∂_z χ
(m² + d²/4) + (k⃗² − ω²) z²] χ
φ = e
[A J_ν(|q|z) + J Y_ν(|q
z → 0
−iωt
+ J z^{2h−} e^{ikx−iωt
φ_NN


Scalars in AdS, mass m
$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$
Poincaré
$ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$
$\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t} z^{d/2} [A J_\nu(kz) + B Y_\nu(kz)]$
$A z^{2h_+} e^{ikx - i\omega t} + B z^{2h_-} e^{ikx - i\omega t}$
ϕ_N
ϕ_{NN}


Scalar field, mass m
$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$
Poincaré
$ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$
$\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}$
$z^2\partial_z^2\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi$
$q^2 = \vec{k}^2$
$e^{i\vec{k}\cdot\vec{x} - i\omega t}\, z^{d/2}\left[A\, J_\nu(|q|z) + B\, Y_\nu(|q|z)\right.$
$\to A\, z^{2h_+} e^{ikx - i\omega t} + B\, z^{2h_-} e^{ikx - i\omega t}$
ϕ_N
ϕ_{NN}


Scalar model, mass m.
AdS^{d+1} ⇒ □φ = m² φ
Poincaré.
ds² = ℓ²/z² (−dt² + dx⃗² + dz²)
φ = e^{ik⃗·x⃗ − iω
Bessel
z² ∂_z² χ + χ − [(m² + d² (k⃗² − ω²) z²] χ
φ =
A J_ν (|q|z) + J Y_ν (|q
e^{ikx − iωt} + J z^{2h−} e^{ikx − iωt}
φ_N
φ_NN


Scalar modes, mass m
AdS
Poincaré
Bosonic


Scalar model, mass m.
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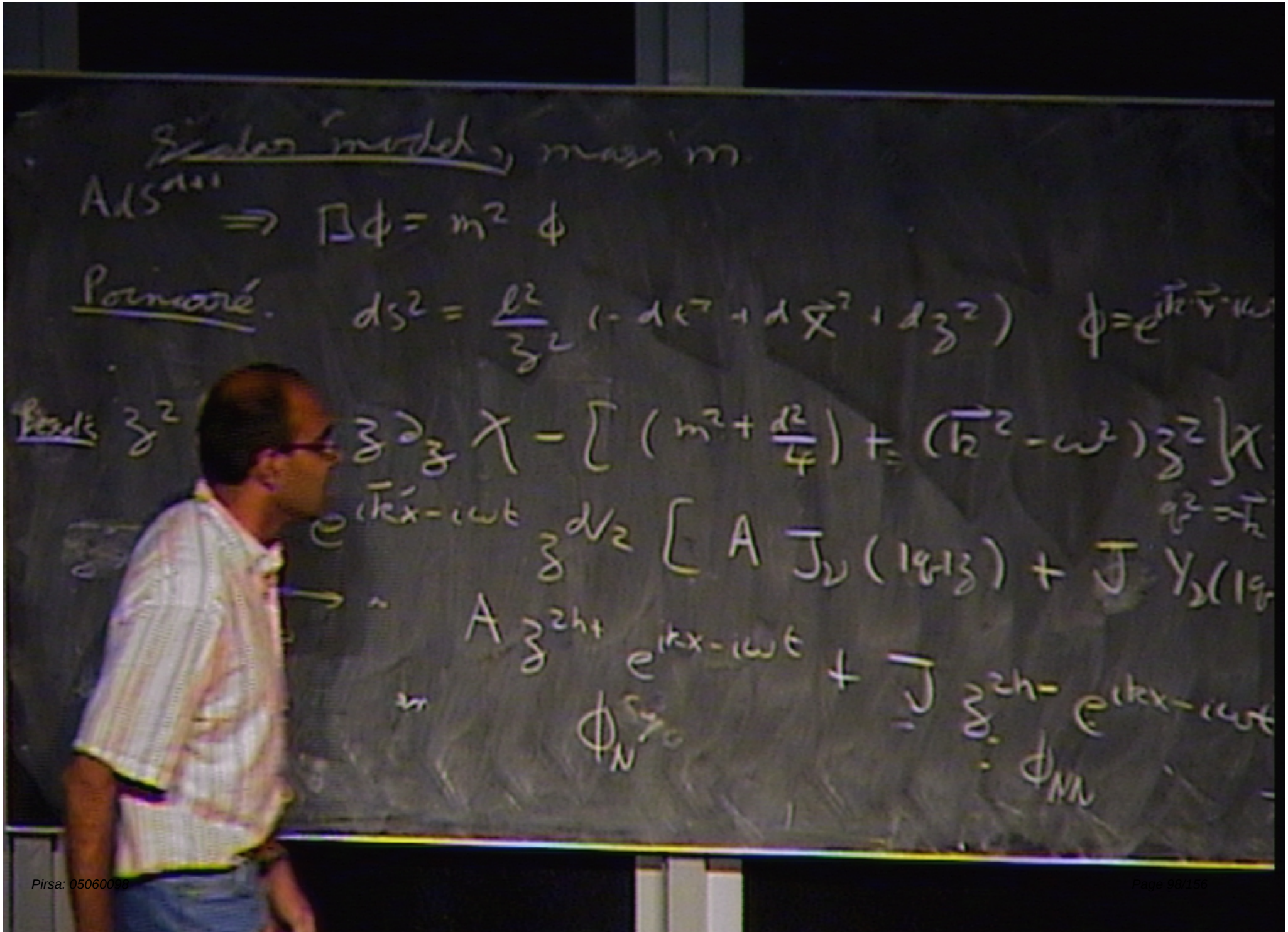
z^{d/2} [A J_ν(|q|z) + J Y_ν(|q
+ J z^{2h−} e^{ikx−iωt}
φ_N
φ_NN


Scalar model, mass m
AdS^{d+1} ⇒ □φ = m² φ
Poincaré.
ds² = ℓ²/z² (−dt² + dx² + dz²)
Bessel
z²
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e^{ikx−iωt} z^{d/2} [A J_ν(|q|z) + J Y_ν(|q
A z^{2h+} e^{ikx−iωt} + J z^{2h−} e^{ikx−iωt}
φ_N
φ_NN

Scalar "mesons", mass m.

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré: $ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}$

Bessel: $z^2\partial_z^2\chi + z\partial_z\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi$

$\phi = e^{i\vec{k}\vec{x} - i\omega t} z^{d/2}\left[A J_\nu(|q|z) + B Y_\nu(|q|z)\right]$ $q^2 = -k^2$

$\xrightarrow{z\to 0}$ $A z^{2h_+} e^{ikx - i\omega t} + B z^{2h_-} e^{ikx - i\omega t}$

ϕ_N ϕ_{NN}

Scalar probe, mass m.

$AdS^{d+1} \Rightarrow \Box\phi = m^2\phi$

Poincaré. $ds^2 = \frac{L^2}{z^2}(-dt^2 + d\vec{x}^2 + dz^2)$ $\phi = e^{i\vec{k}\cdot\vec{x} - i\omega t}$

Bessel $z^2\partial_z^2\chi + z\partial_z\chi - \left[\left(m^2 + \frac{d^2}{4}\right) + (\vec{k}^2 - \omega^2)z^2\right]\chi$

$\phi = e^{i\vec{k}\vec{x} - i\omega t} z^{d/2}\left[A J_\nu(|q|z) + B Y_\nu(|q|z)\right]$ $q^2 = -k^2$

$\xrightarrow{z\to 0}$ $A z^{2h_+} e^{ikx - i\omega t} + B z^{2h_-} e^{ikx - i\omega t}$

ϕ_N ϕ_{NN}

$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2 + 4m^2}}{2} = \frac{d}{2} \pm \nu$

$2h_+ > 0$
$2h_- < 0$

$(\phi, \phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$



$\phi_N \leftrightarrow \mathcal{O}|0\rangle$

$$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2 + 4m^2}}{2} = \frac{d}{2} \pm \nu$$

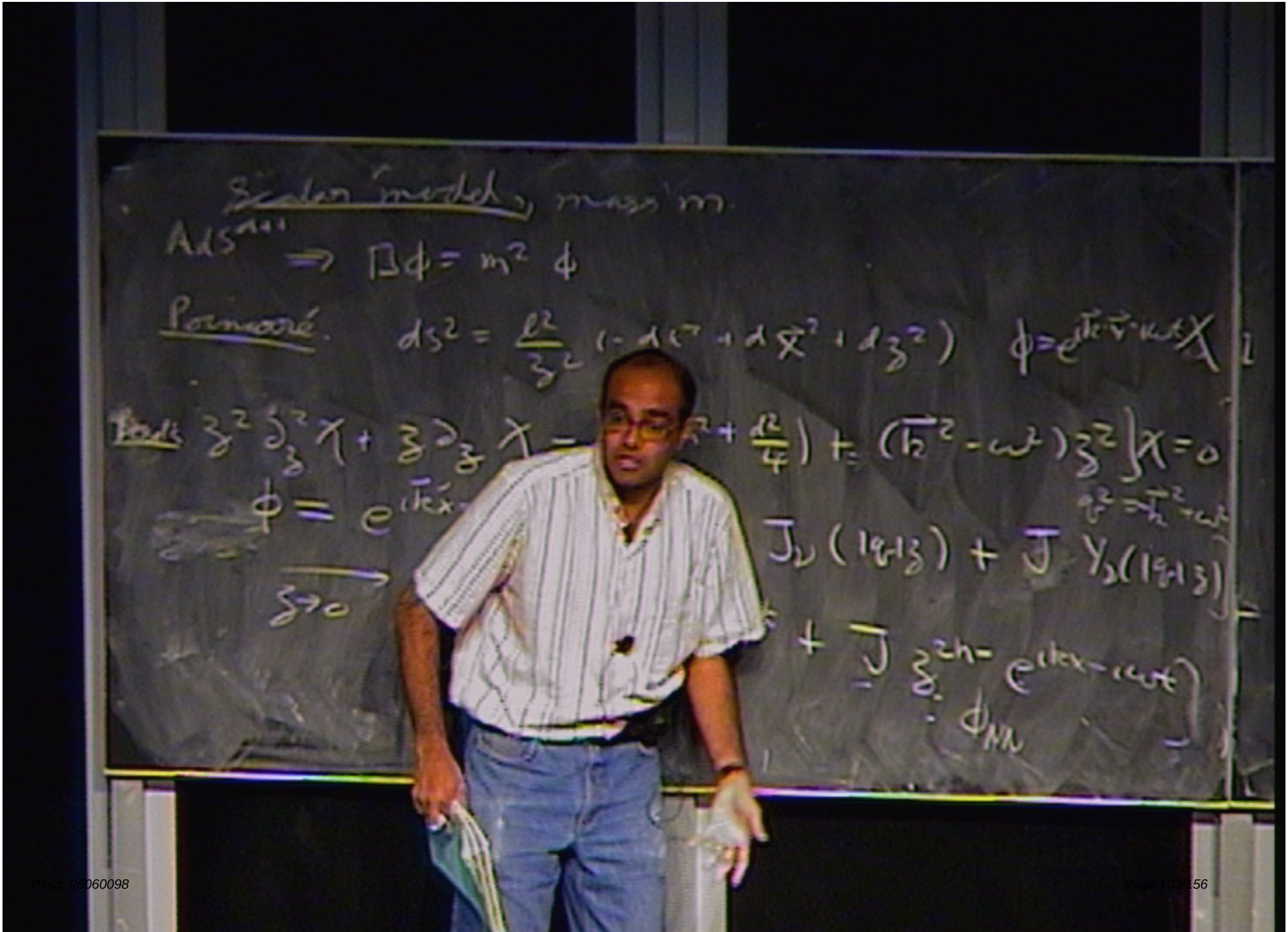
$2h_+ > 0$
$2h_- < 0$

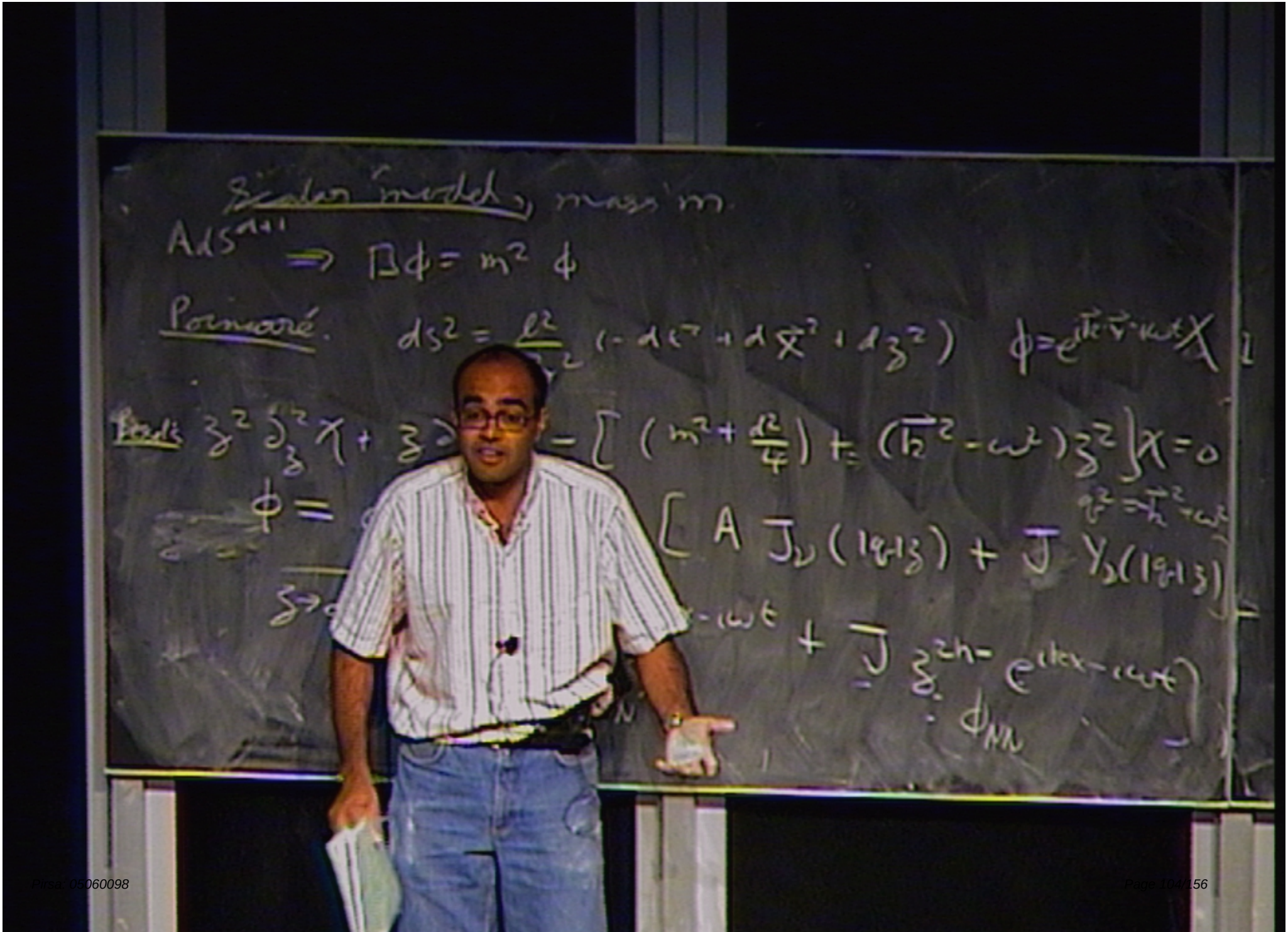
$$(\phi, \phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$$

Δ_+

$\phi_N \leftrightarrow \mathcal{O}|0\rangle$

$\phi_{NN} \longleftrightarrow S_{CFT} \Rightarrow S_{CFT} + \int \mathcal{J}\mathcal{O}$


Scalar model, mass m.
AdS^{d+1} ⇒ □φ = m² φ
Poincaré.
ds² = ℓ²/z² (-dt² + dx² + dz²)
φ = e^{ik·x - iωt} χ
z → 0
J_ν(|q|z) + J Y_ν(|q|z)
+ J z^{2h-} e^{ikx - iωt}
φ_NN


Scalar model, mass m
AdS^{d+1} ⇒ □φ = m² φ
Poincaré
ds² = ℓ²/z² (-dt² + dx² + dz²)
φ = e^{ik·x - iωt} χ
Bessel
z² ∂_z² χ + z ∂ - [(m² + d²/4) + (k² - ω²) z²] χ = 0
φ =
[A J_ν(|q|z) + J Y_ν(|q|z)]
q² = k² - ω²
+ J z^{2h-} e^{ikx - iωt}
φ_NN

$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2 + 4m^2}}{2} = \frac{d}{2} \pm \nu$

$2h_+ > 0$
$2h_- < 0$

$(\phi, \phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$

Δ_+

$\phi_N \leftrightarrow \mathcal{O}|0\rangle$

$\phi_{NN} \Longleftrightarrow S_{CFT} \Rightarrow S_{CFT} + \int \mathcal{J}\mathcal{O}$

$$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2 + 4m^2}}{2} = \frac{d}{2} \pm \nu$$

$2h_+ > 0$
$2h_- < 0$

$$(\phi, \phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$$



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$2h_+ = \Delta =$ conf. dim.

2d CFT

Euc $ds^2 = dr^2 + r^2 d\theta^2$ $\quad \Delta \sim r\partial_r$

Lorentzian: $r = e^t \Rightarrow ds^2 = \cancel{e^{2t}}\left[dt^2 + d\theta^2\right]$

$\xrightarrow[t \to it]{} \left[-dt^2 + d\theta^2\right]$

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$\Delta = r \partial_r \longrightarrow \partial_t = H$; $t \to \vec{it}$ (-

2 d CFT

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Lorentzian: $r = e^t \Rightarrow ds^2 = e^{2t}$

$\Delta = r \partial_r \longrightarrow \partial_t = H$; $\quad t \to it$ (-

$M \longrightarrow M\ell = \Delta$

Spatial slice

2 d CFT

Euc $ds^2 = dr^2 + r^2 d\theta^2$ $\quad \Delta \sim r \partial_r$

Lorentzian: $r = e^t \Rightarrow ds^2 = e^{2t}$

$\Delta = r \partial_r \longrightarrow \partial_t = H$; $t \to \vec{it}$ (-

$M \longrightarrow M\ell = \Delta$

Spatchcock

$r^2 d\theta^2$ $\quad \Delta \sim r\partial_r$

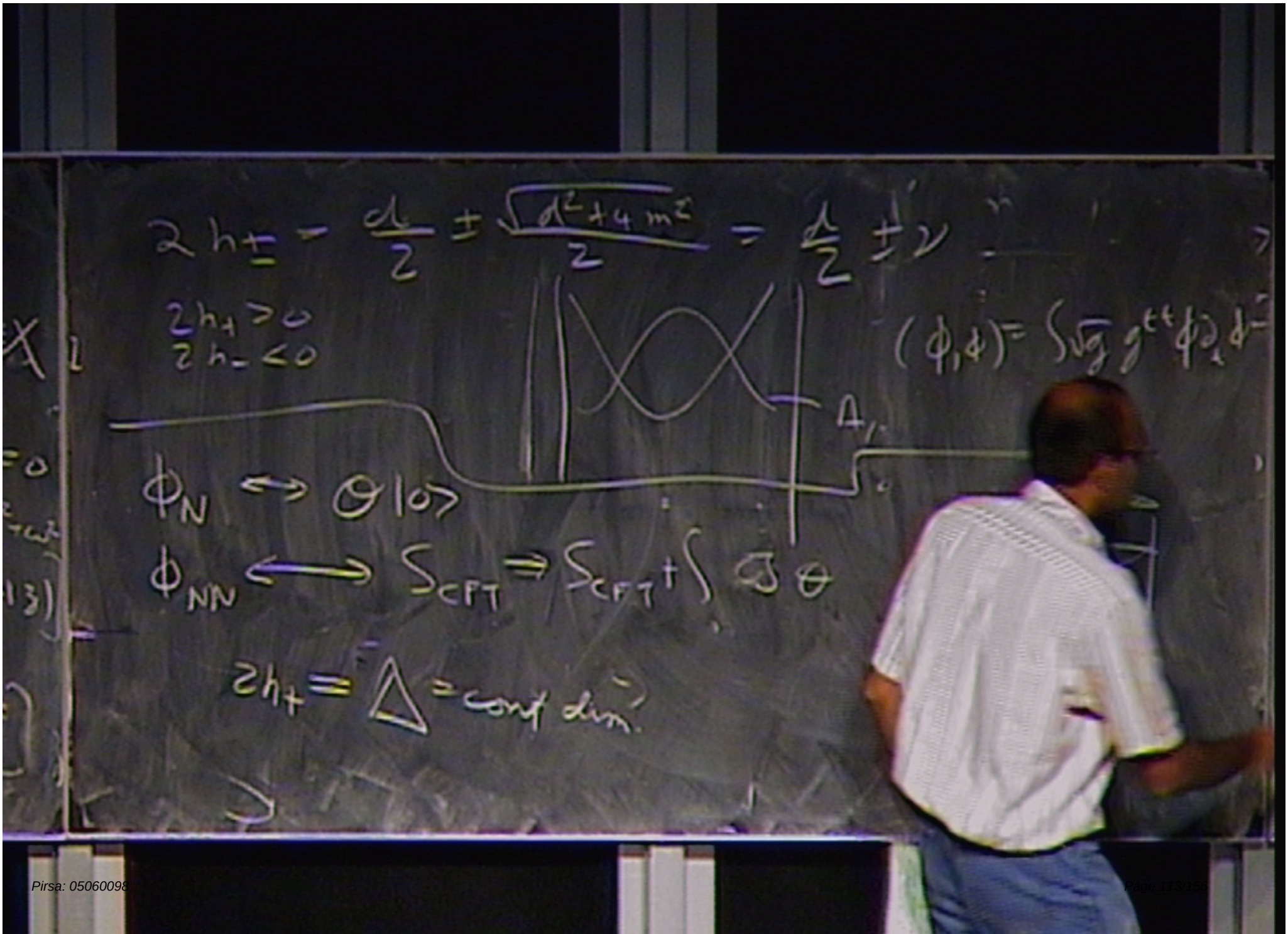
$e^t \Rightarrow ds^2 = \cancel{e^{2t}}\left[dt^2 + d\theta^2\right]$

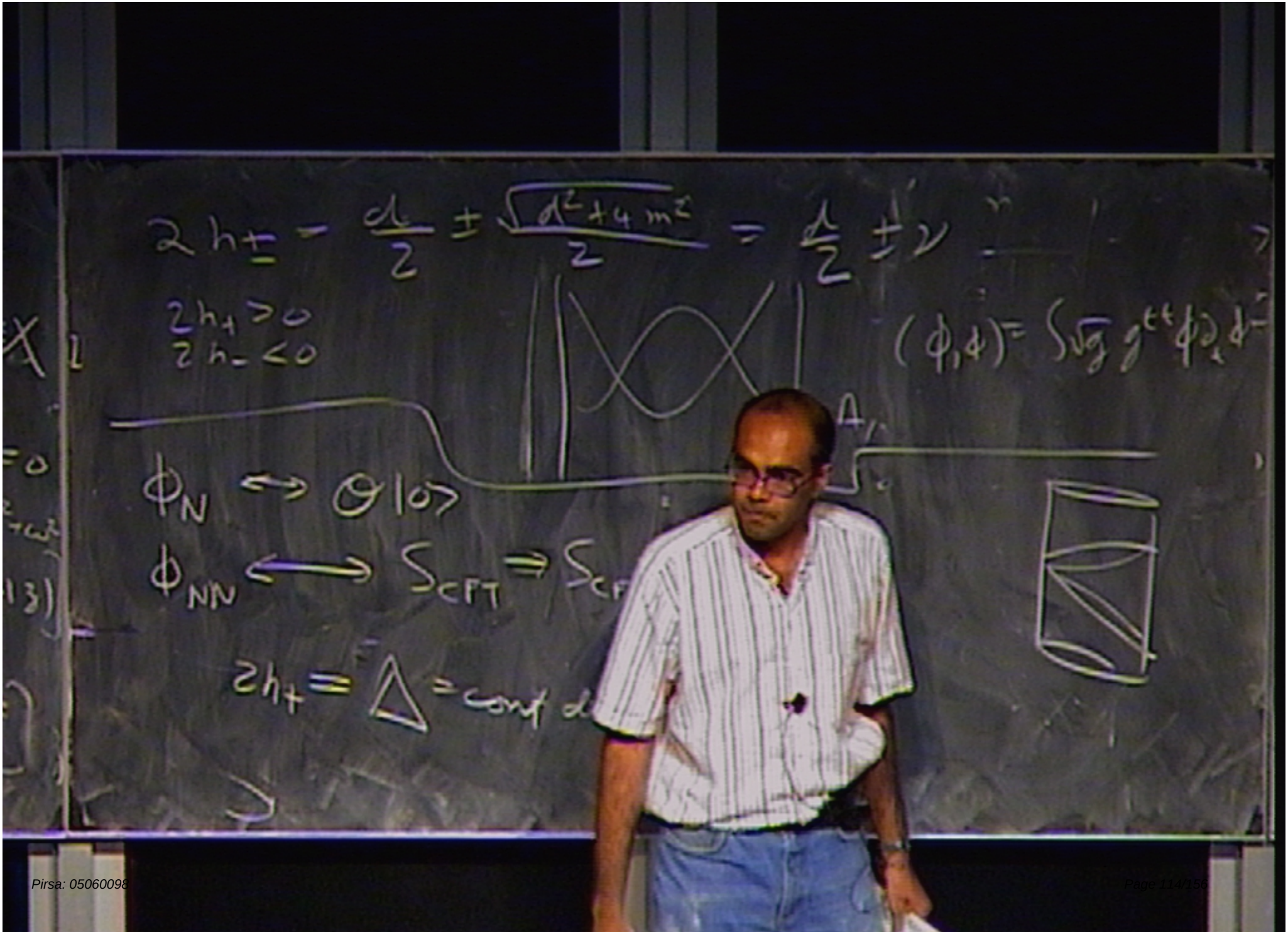
$\xrightarrow{t \to it} \left(-dt^2 + d\theta^2\right)$

$t = H$

$\Rightarrow M\ell = \Delta$

$$ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2}$$


$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2+4m^2}}{2} = \frac{d}{2} \pm \nu$
$2h_+ > 0$
$2h_- < 0$
$(\phi,\phi) = \int \sqrt{g}\, g^{tt} \phi \partial_t \phi$
$\phi_N \leftrightarrow \mathcal{O}|0\rangle$
$\phi_{NN} \longleftrightarrow S_{CFT} \Rightarrow S_{CFT} + \int \mathcal{O}\,\theta$
$2h_+ = \Delta$ = conf dim.


$2h_\pm = \frac{d}{2} \pm \frac{\sqrt{d^2 + 4m^2}}{2} = \frac{d}{2} \pm \nu$
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$2h_- < 0$
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$\phi_N \leftrightarrow \mathcal{O}|0\rangle$
$\phi_{NN} \longleftrightarrow S_{CFT} \Rightarrow S_{CF}$
$2h_+ = \Delta =$ cont

2d CFT

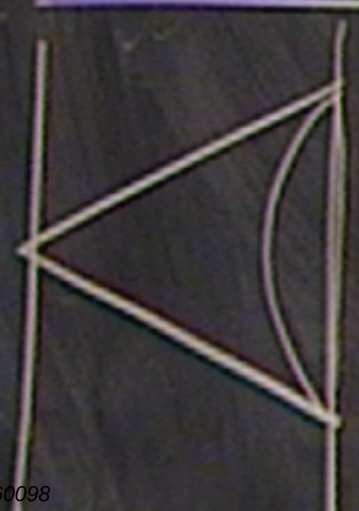
Euc: $ds^2 = dr^2 + r^2 d\theta^2$ $\qquad \Delta \sim r$

Lorentzian: $r = e^t \Longrightarrow ds^2 =$

$\Delta = r\,\partial_r \longrightarrow \partial_t = H$ $\qquad t \to it$

$M \longrightarrow M\ell = \Delta$ $\qquad ds$

Spacetime



$z = \xi$

2d CFT

Euc: $ds^2 = dr^2 + r^2 d\theta^2$ $\qquad \Delta \sim r$

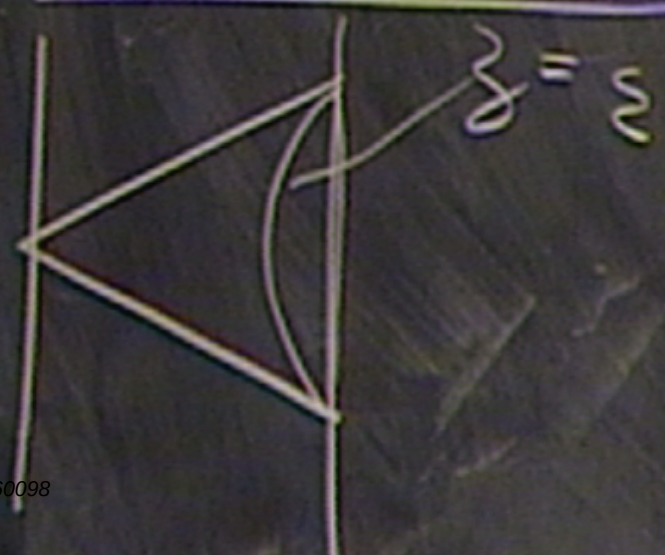
Lorentzian: $r = e^t \Longrightarrow ds^2 =$

$\Delta = r\,\partial_r \longrightarrow \partial_t = H$ $\qquad t \to it$

$M \longrightarrow M\ell = \Delta$ $\qquad ds$

Spacetime

$\phi_{NN} = J\, z^{2h-}[\ldots$



$r^2 d\theta^2 \qquad \Delta \sim r\partial_r$

$= e^t \Rightarrow ds^2 = \cancel{e^{2t}}\left[dt^2 + d\theta^2\right]$

$\xrightarrow[t \to it]{} \left(-dt^2 + d\theta^2\right)$

$t = H$

$\Rightarrow M\ell = \Delta$

$ds^2 = \dfrac{-dt^2 + d\vec{x}^2 + dz^2}{z^2}$

$\phi_{NN} = J z^{2h} - [\ldots]$

roposal: $S \to S + \int_{\partial M} d^{dx}\sqrt{h}$

$r^2 d\theta^2$ $\Delta \sim \pi \partial_\pi$

$= e^t \Rightarrow ds^2 = e^{2t} \cdot [dt^2 + d\theta^2]$

$t = H$; $t \to it \Rightarrow [-dt^2 + d\theta^2]$

$\Rightarrow M\ell = \Delta \int ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2}$

$\phi_{NN} = J z^{2h} \cdot [\dots]$

Propagator $S \to S + \int_{\partial m} d^d x \sqrt{h} [\phi_{NN} \theta]$

$$\Rightarrow ds^2 = \cancel{e^{2t}}\left[dt^2 + d\theta^2\right]$$

$$\xrightarrow[t \to it]{} \left(-dt^2 + d\theta^2\right)$$

$$\boxed{\mathcal{M}\ell = \Delta} \qquad ds^2 = \frac{-dt^2 + d\vec{x}^2 + \cancel{dz^2}}{z^2}$$

$$J\, z^{2h-}\left[\ldots\right]$$

$$\ldots 1.\ S \to S + \int_{\partial M} d^{dx}\sqrt{h}\,\left[\phi_{NN}\,\mathcal{O}\right]$$

$$\boxed{M\ell = \Delta} \quad ds^2 = \frac{-dt^2 + d\vec{x}}{z}$$

$$= J z^{2h-}[\ldots\ldots]$$

$$\text{sal}: S \to S + \int_{\partial M} d^{dx} \sqrt{h}\, [\phi_{NN}\, \theta$$

$$\varepsilon^{-d}$$

$$\Delta \left[ds^2 = \frac{-dt^2 + d\vec{x}^2 + dz^2}{z^2} \right]$$

$$h - [\ldots]$$

$$S + \int_{\partial m} d^{d}x \sqrt{h} \left[\phi_{NN} \mathcal{O} \right]$$

$$\varepsilon^{-d} \quad \varepsilon^{2h-} \quad \varepsilon^{\alpha}$$

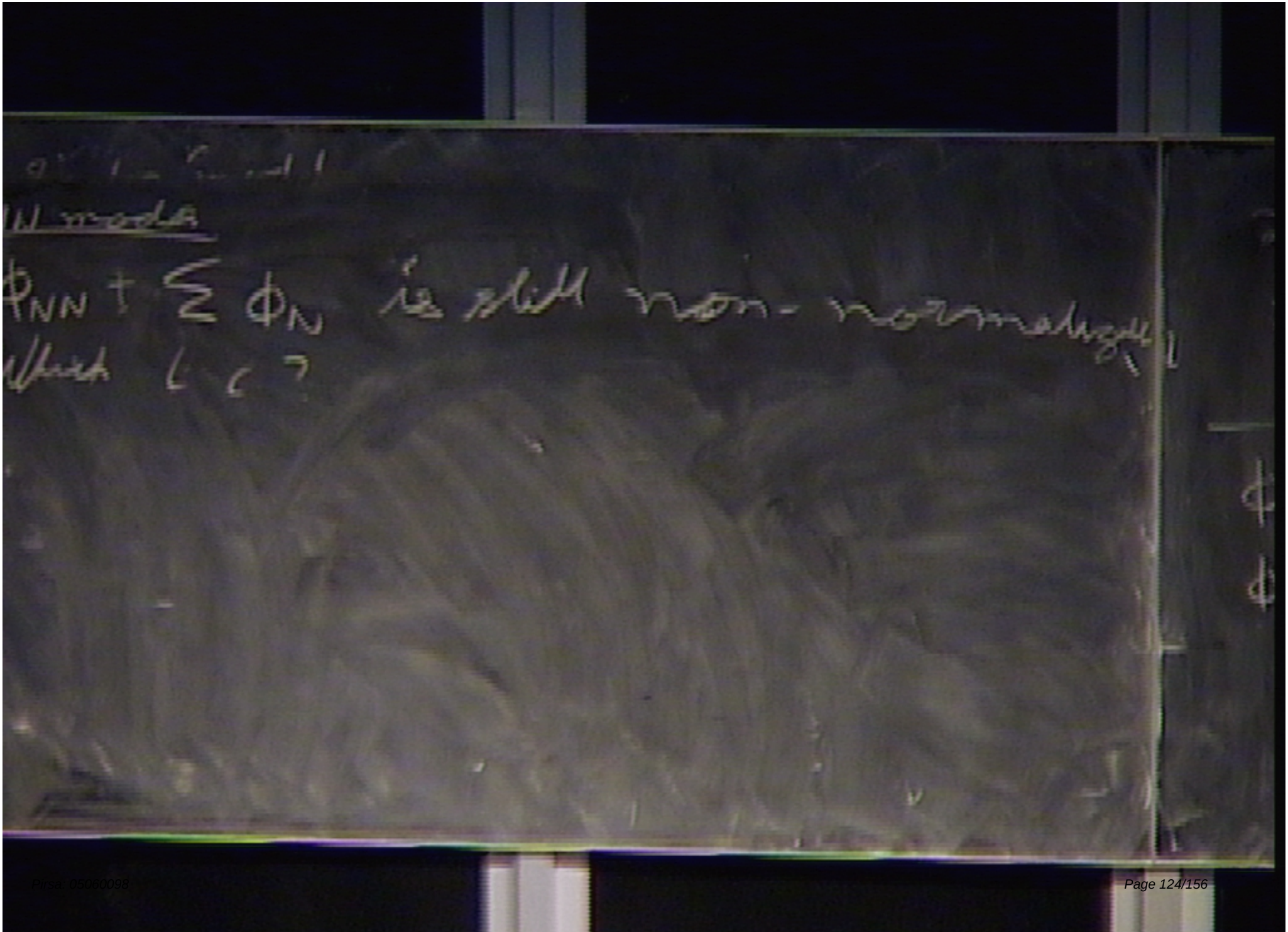
$$-d + 2h_- + \alpha = 0$$

$$\alpha = d - \left(\frac{d}{2} - \nu\right)$$

$$= \frac{d}{2} + \nu = 2h_+$$

NN mode

$\phi_{NN} + \sum \phi_N$ is still non-norma


N mode
$\phi_{NN} + \sum \phi_N$ is still non-normalized
which $\langle\ \rangle$?

NN mode

$\phi_{NN} + \sum \phi_N$ is still non-normalizable

Which ℓ c?

$$\phi \sim A\, J_\nu(qz) + J\, Y_\nu(qz$$

$$\sim J\left[\underbrace{\frac{A}{J}}_{B} J_\nu(qz) + Y_\nu\right]$$

In general Y_ν in singular

NN modes

$\phi_{NN} + \sum \phi_N$ is still non-normaliz

Which ι ι ?

$$\phi \sim A\, J_\nu(qz) + J\, Y_\nu(qz$$

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In general Y_ν in singular

NN mode

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Which ℓ ℓ ?

$$\phi \sim A\, J_\nu(q z) + J\, Y_\nu(q z)$$

$$\sim J \left[\underbrace{\frac{A}{J}}_{B} J_\nu(q z) + Y_\nu \right]$$

In general Y_ν in singular

$L \quad C \; ?$

$$A \, J_\nu(qz) + J \, Y_\nu(qz)$$

$$J \left[\underbrace{\frac{A}{J}}_{B} J_\nu(qz) + Y_\nu \right]$$

ck nonsingular combination

$\rightarrow G_{BJ}$ = BULK-BOUNDARY

$\phi_{NN} + \sum \phi_N$ is still non-

Which l.c.?

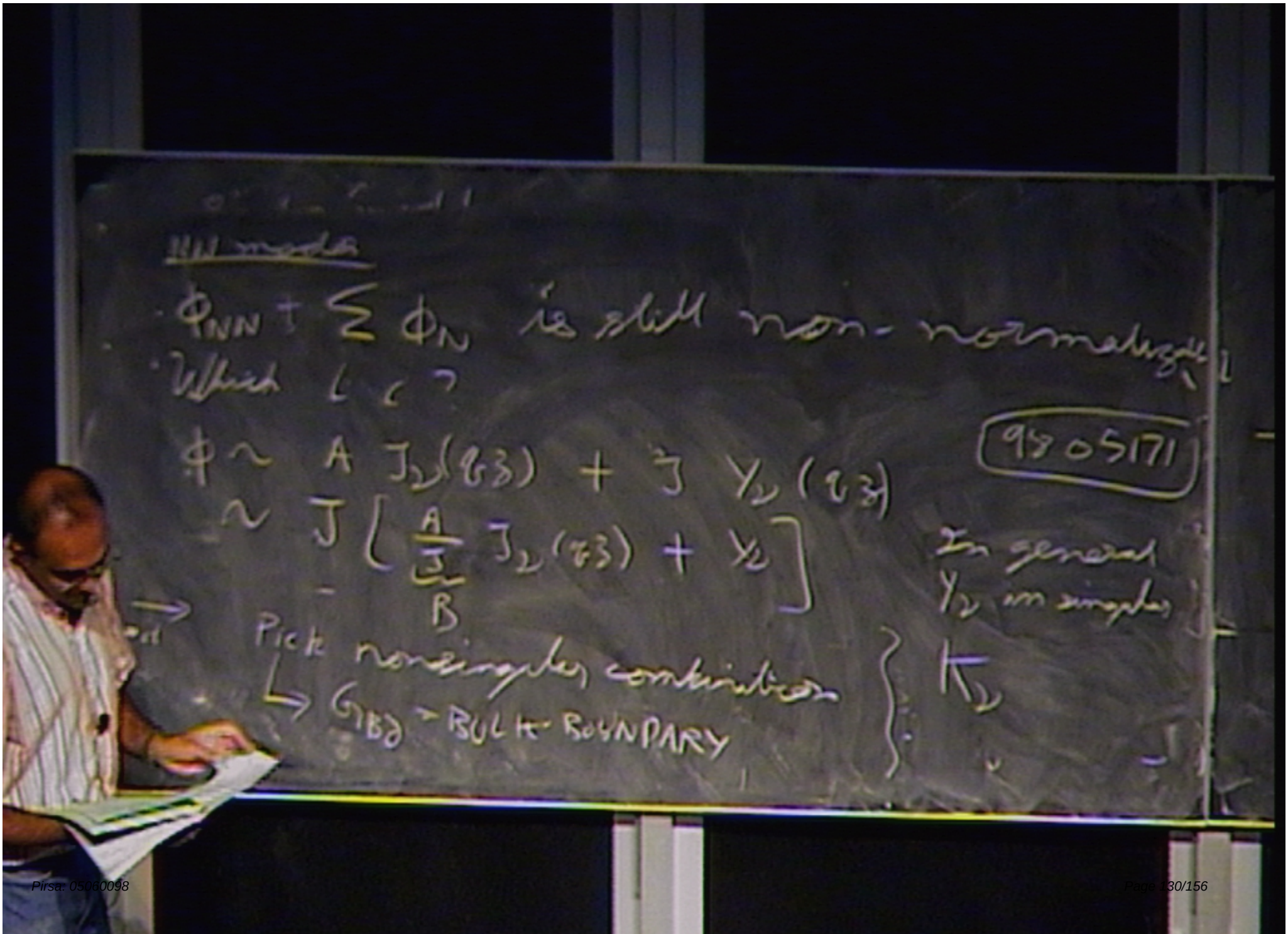
$$\phi \sim A\, J_\nu(qz) + J\, Y_\nu(qz)$$

$$\sim J \left[\underbrace{\frac{A}{J}}_{B} J_\nu(qz) + Y_\nu \right]$$

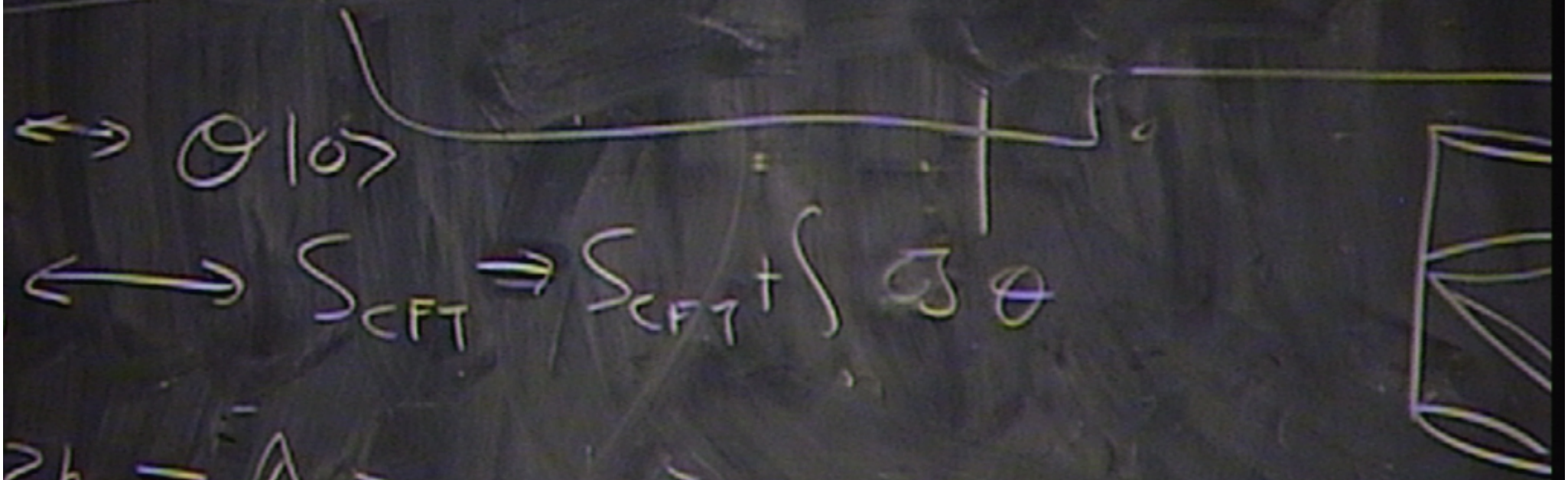
$\to$ it

Pick nonsingular combination

$\hookrightarrow G_{BJ}$ = BULK-BOUNDARY


NN modes
$\phi_{NN} + \sum \phi_N$ is still non-normalizable
Which ((?
$\phi \sim A J_\nu(qz) + J Y_\nu(qz)$
$\sim J \left[\frac{A}{J} J_\nu(qz) + Y_\nu \right]$
B
9805171
In general
Y_ν in singular
Pick nonsingular combination
G_{BJ} - BULK-BOUNDARY
K_ν

Repeat in global AdS_3



$\longleftrightarrow \mathcal{O}|0\rangle$

$\longleftrightarrow S_{CFT} \Rightarrow S_{CFT} + \int \phi_0 \mathcal{O}$

$2h_+ = \Delta =$ cont dim?

Ex Repeat in global AdS

[Solve wave eqn, hypergeometric,

Norm vs Non-norm

$\phi_N \leftrightarrow \mathcal{O}|0\rangle$

$\phi_{NN} \longleftrightarrow S_{CFT} \Rightarrow S_{CFT} + \int \phi_0 \mathcal{O}$



$2h_+ = \Delta =$ conf dim

Ex Repeat in global AdS

[Solve wavefn, hypergeometric,

Norm vs Non-normalized

QFT

Ex: Repeat in global AdS

[Solve wavefn, hypergeometric,

Norm vs Non-norm

QFT $|0\rangle$

Ex: Repeat in global AdS_3

[Solve wave eqn; hypergeometric, Norm vs Non-norm

QFT: $|0\rangle$

$G_F(b, z, b z')$



Ex: Repeat in global AdS

[Solve wavefn, hypergeometric,

Norm vs Non-norm

QFT

- $|0\rangle$
- $G_F(b, z, b' z')$
- $\lim_{z \to 0} z^{-2h+} G_F(b z, b' z') = G_{BJ}$



Ex Repeat in global AdS

[Solve wavefn, hypergeometric,

Norm vs Non-norm

FT

- $|0\rangle$
- $G_F(b, z, b' z')$



- $\lim_{z \to 0} z^{-2h+} G_F(b z) b' z') = G_{BJ}$



$\langle \mathcal{O}(b_1) \cdots \mathcal{O}(b_n) \rangle = \int [G_{BJ}(b_1, x_1) \cdots G_{BJ}(b_2, x_2) \cdots$

Ex Repeat in global AdS

[Solve wavefn, hypergeometric,

Norm vs Non-norm

FT

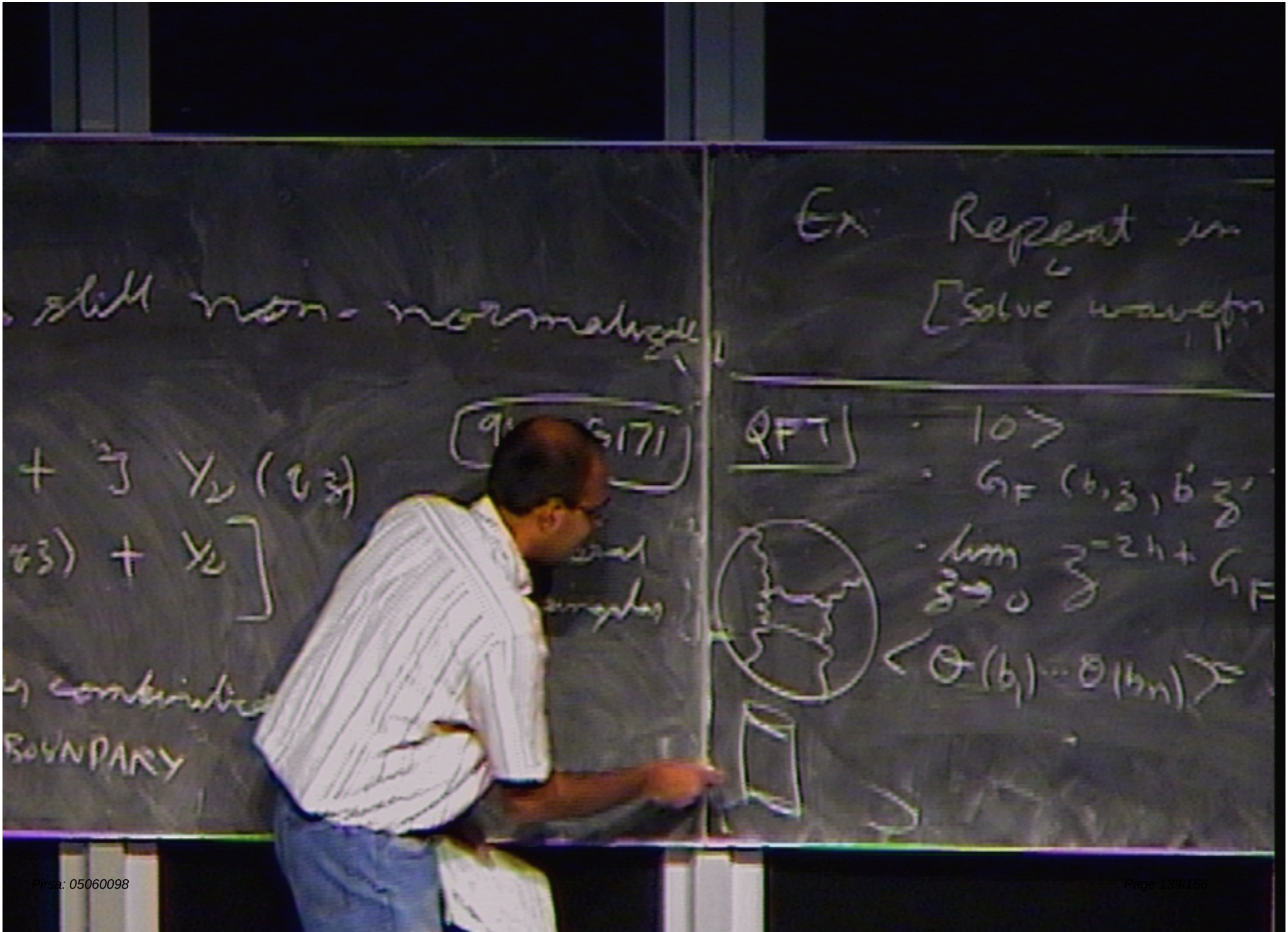
- $|0\rangle$
- $G_F(b, z, b' z')$

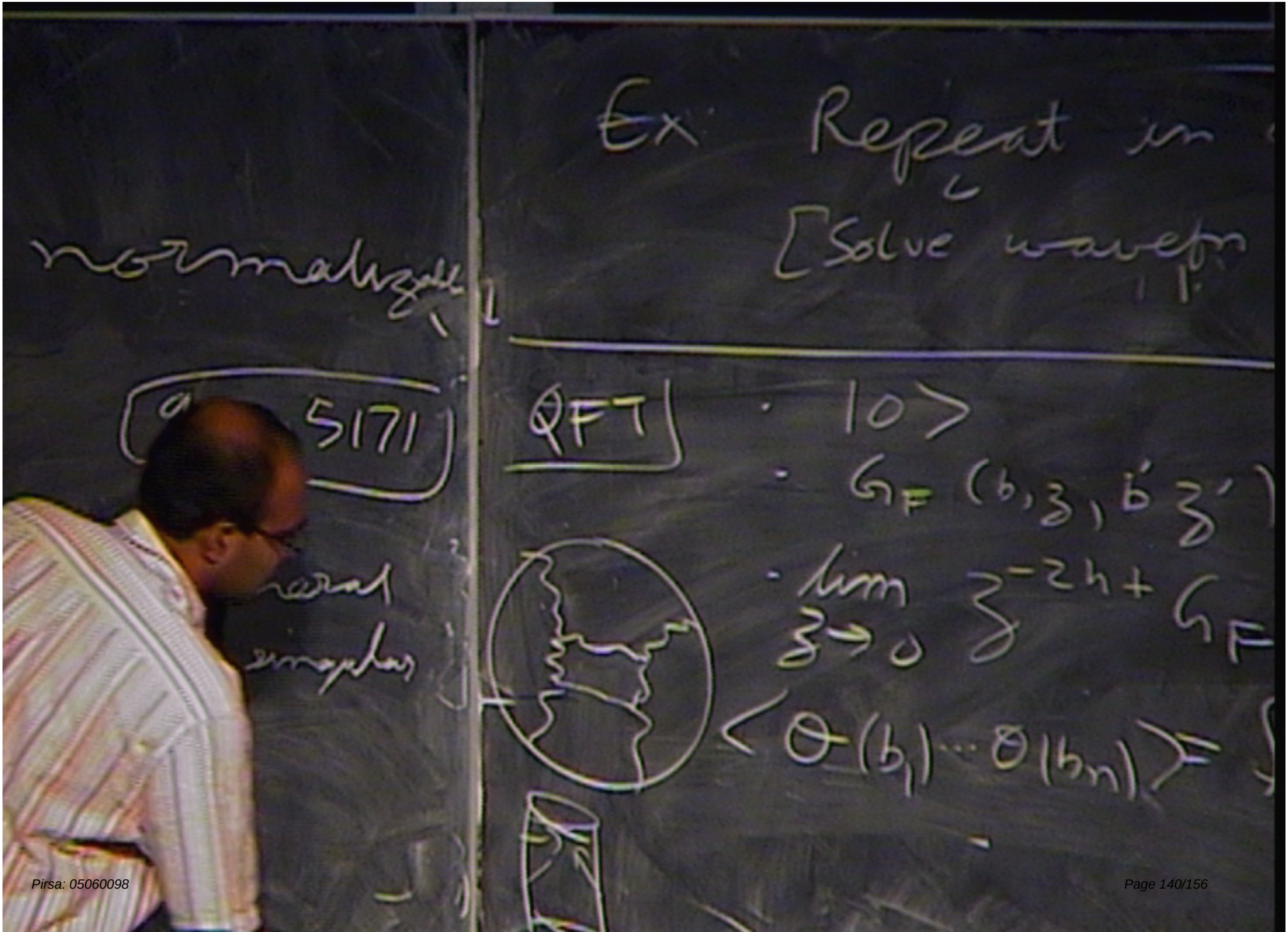


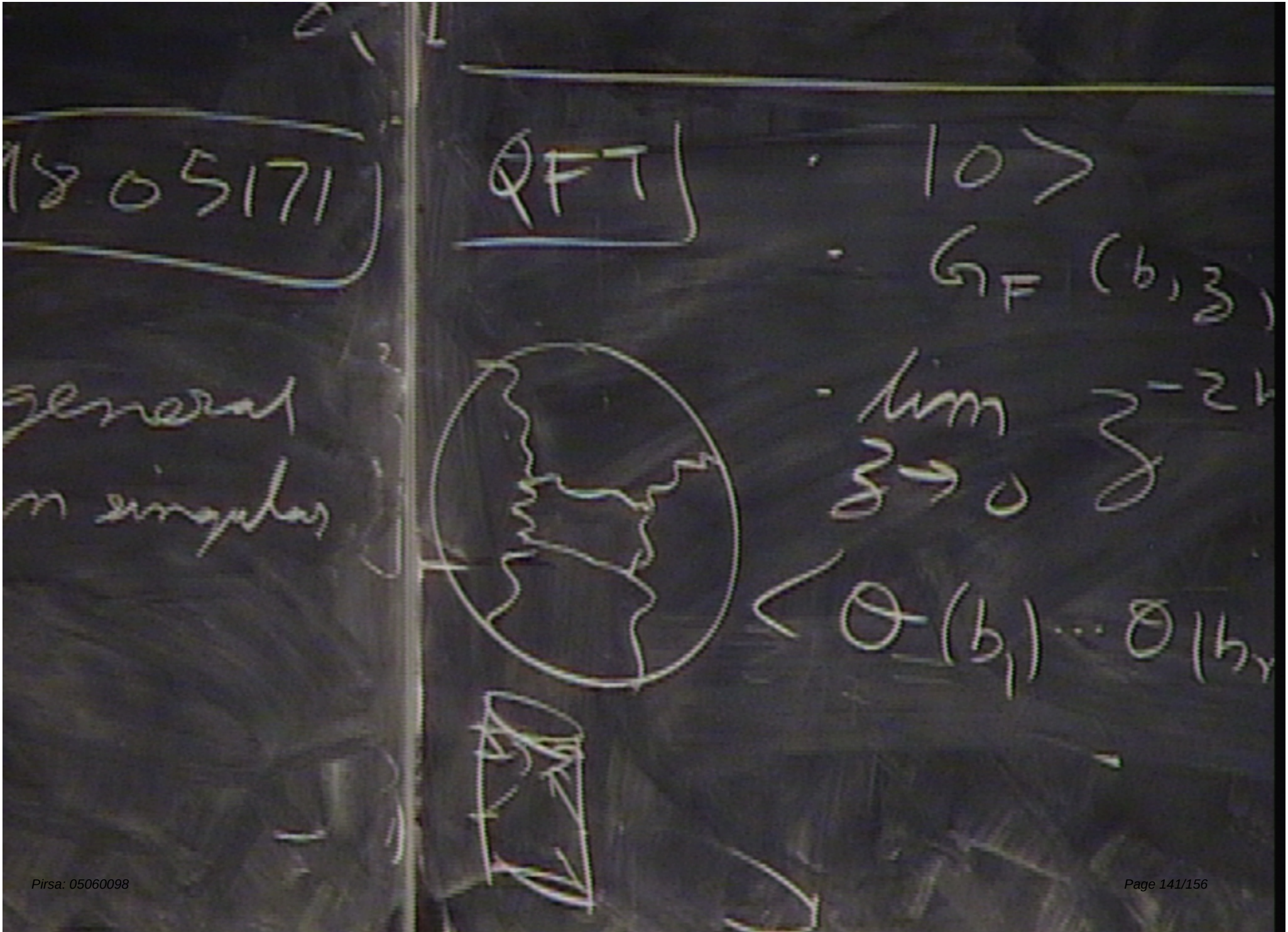


- $\lim_{z \to 0} z^{-2h+} G_F(b z) b' z') = G_{BJ}$

$$\langle \mathcal{O}(b_1) \cdots \mathcal{O}(b_n) \rangle = \int [G_{BJ}(b_1, x_1) \cdots G_{BJ}(b_2, x_2) \cdots \times G_F(x_1, x_2) \times \text{vertex}$$


Ex Repeat in
[Solve
QFT
$|0\rangle$
$G_F(b,3,b'3'$
$\lim_{\xi \to 0} \xi^{-2h_+} G_F$
$\langle \Theta(b_1) \cdots \Theta(b_M) \rangle$
BOUNDARY


Ex: Repeat in
[Solve wavefn
normalization
5171
QFT
· |0>
· G_F (b, z, b' z')
· lim z→0 z^{-2h} + G_F
<O(b_1) ··· O(b_n)> =



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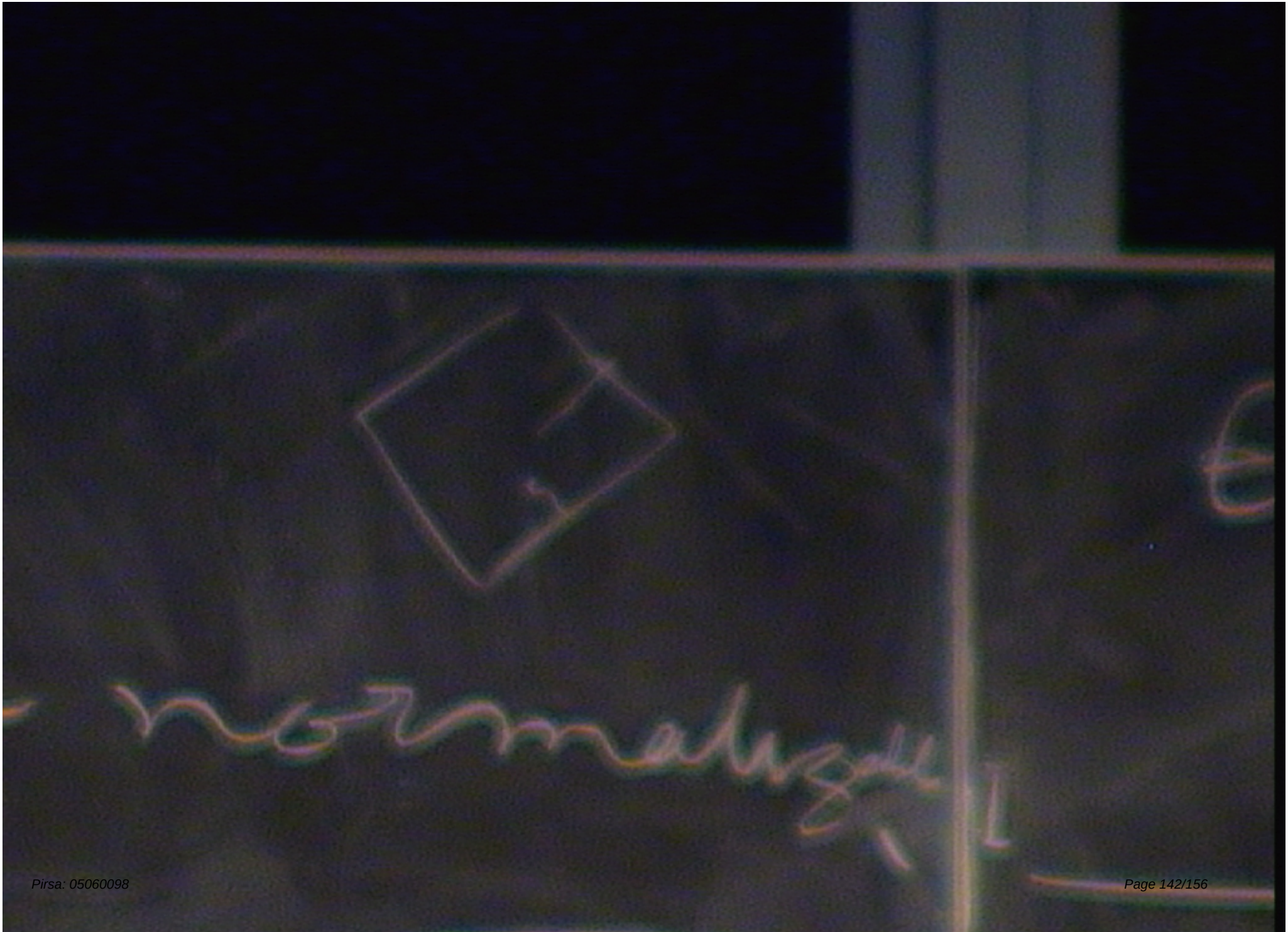
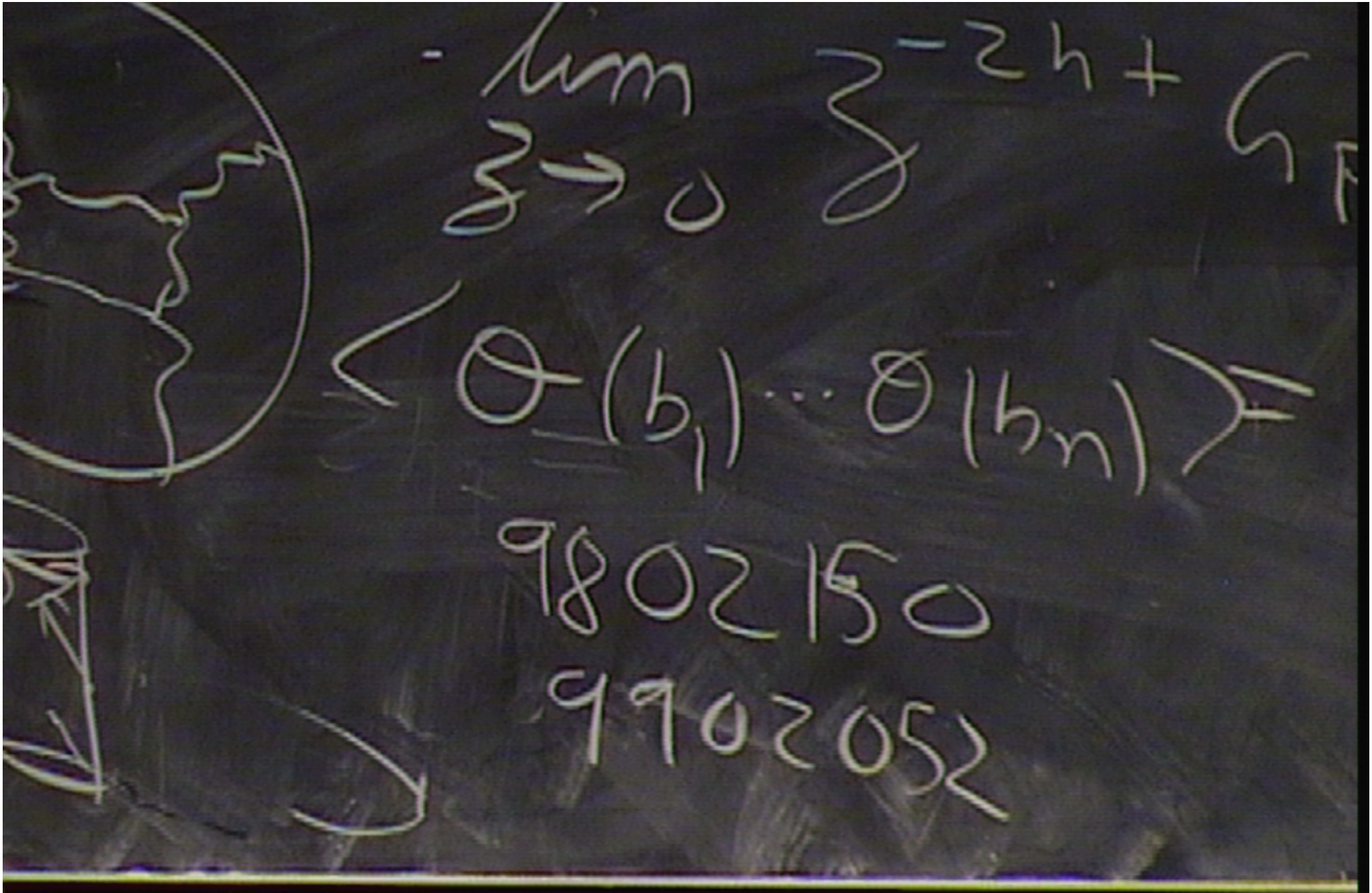
QFT
· |0>
· G_F (b, z)
general
n singular
· lim z→0 z^-2h
< Θ(b_1) ··· Θ(b_n




$\lim_{z \to 0} z^{-2h+} G_F$
$\langle \Theta(b_1) \cdots \Theta(b_n) \rangle =$
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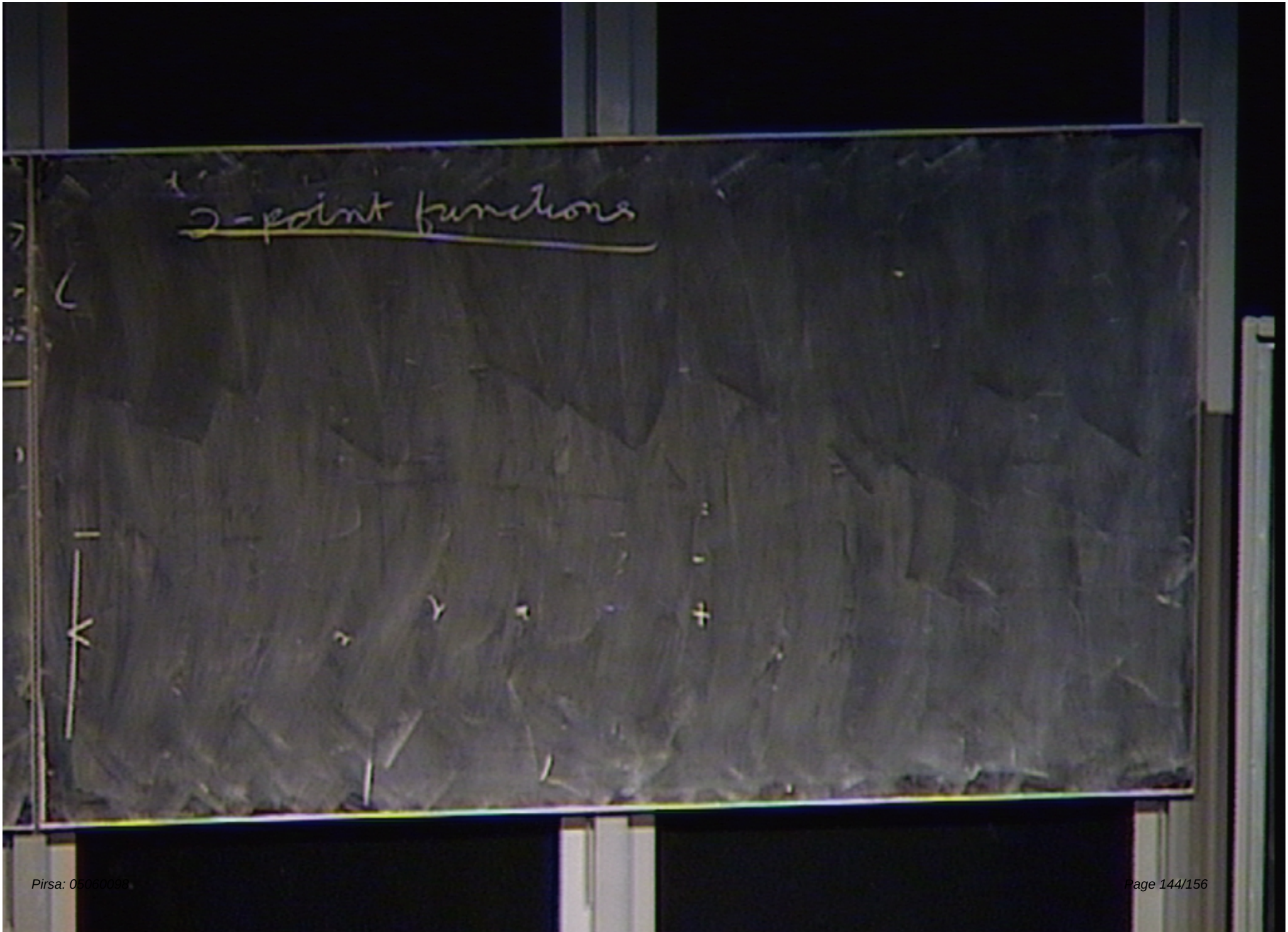
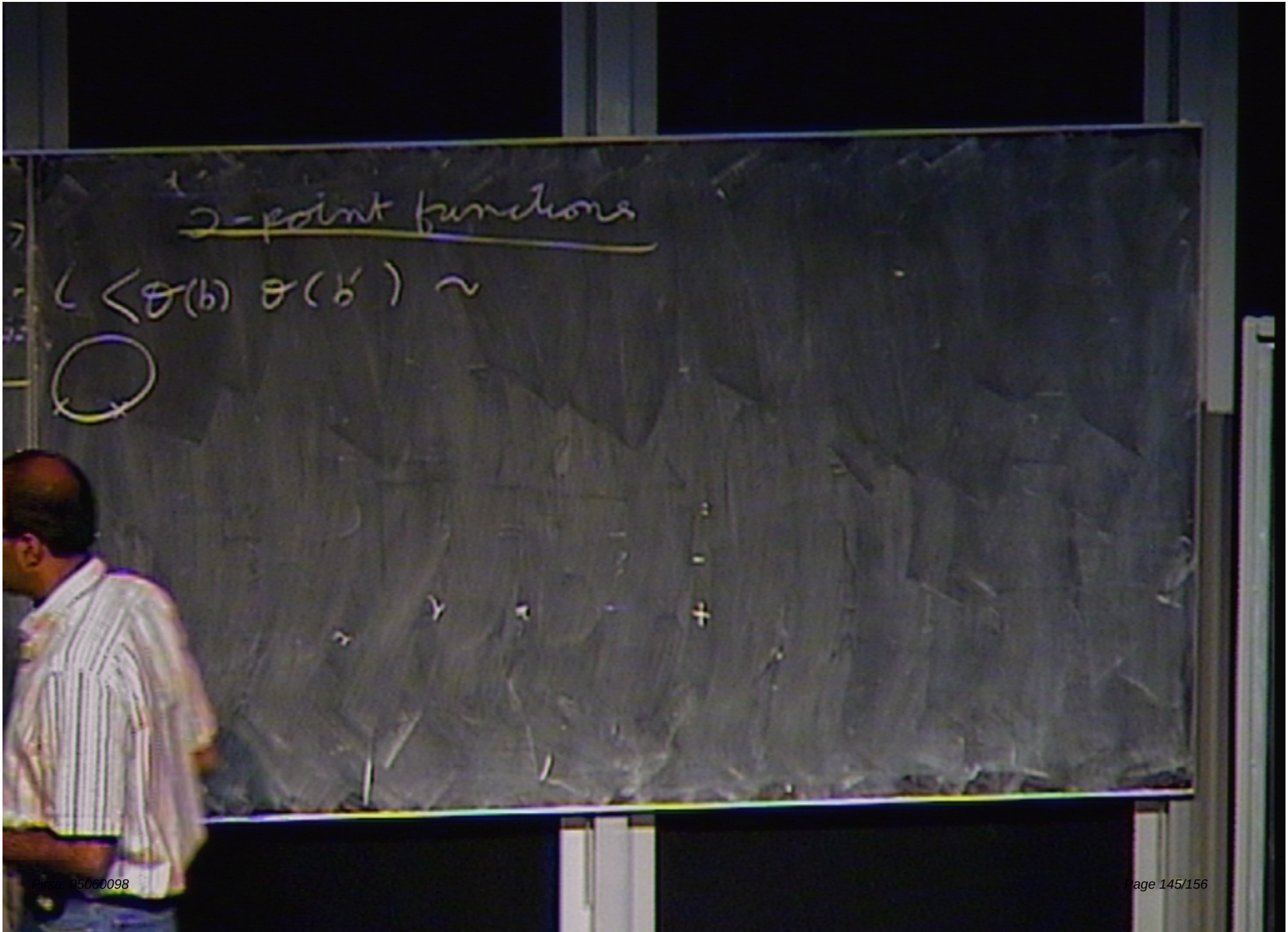
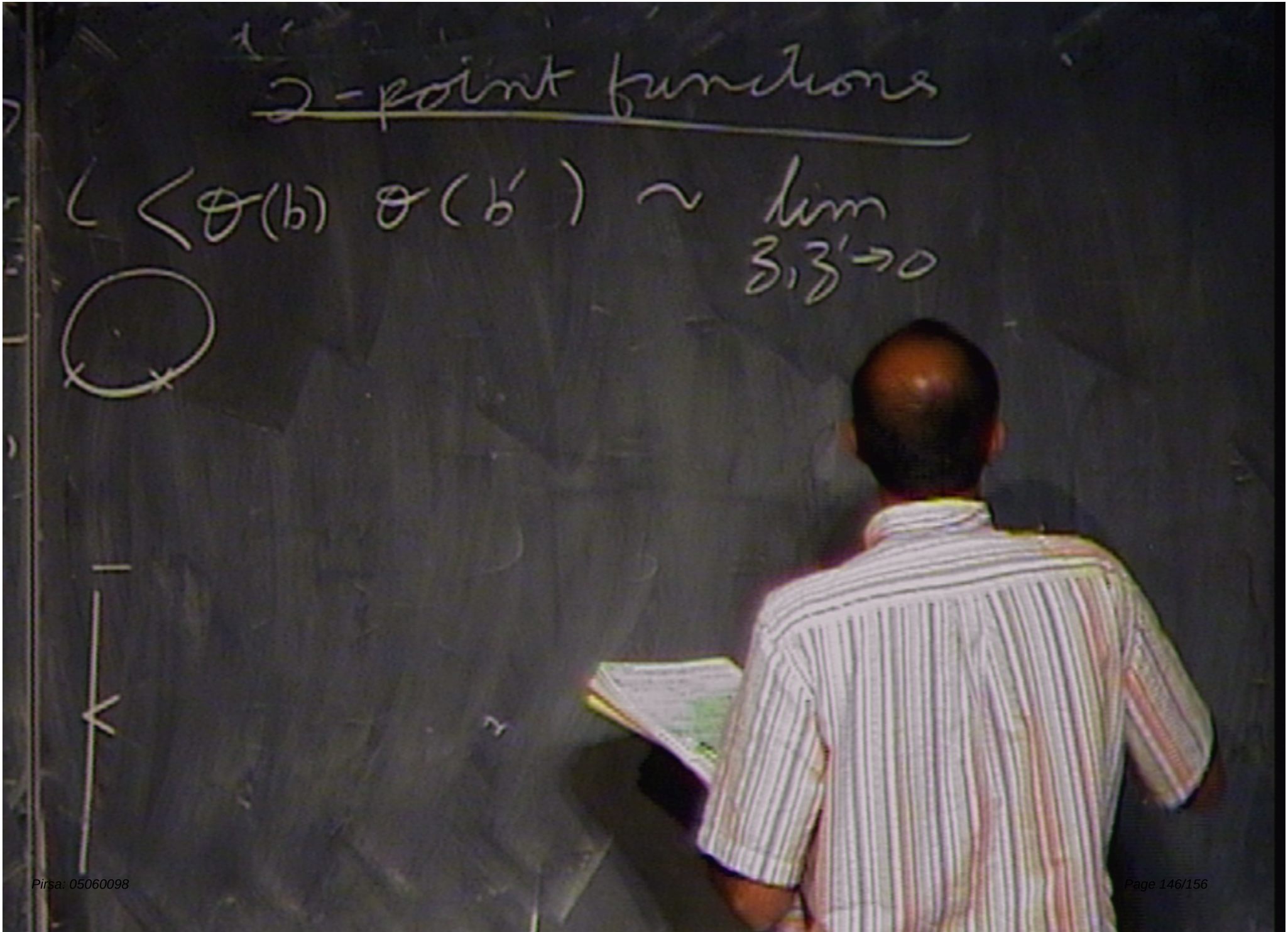

2-point functions

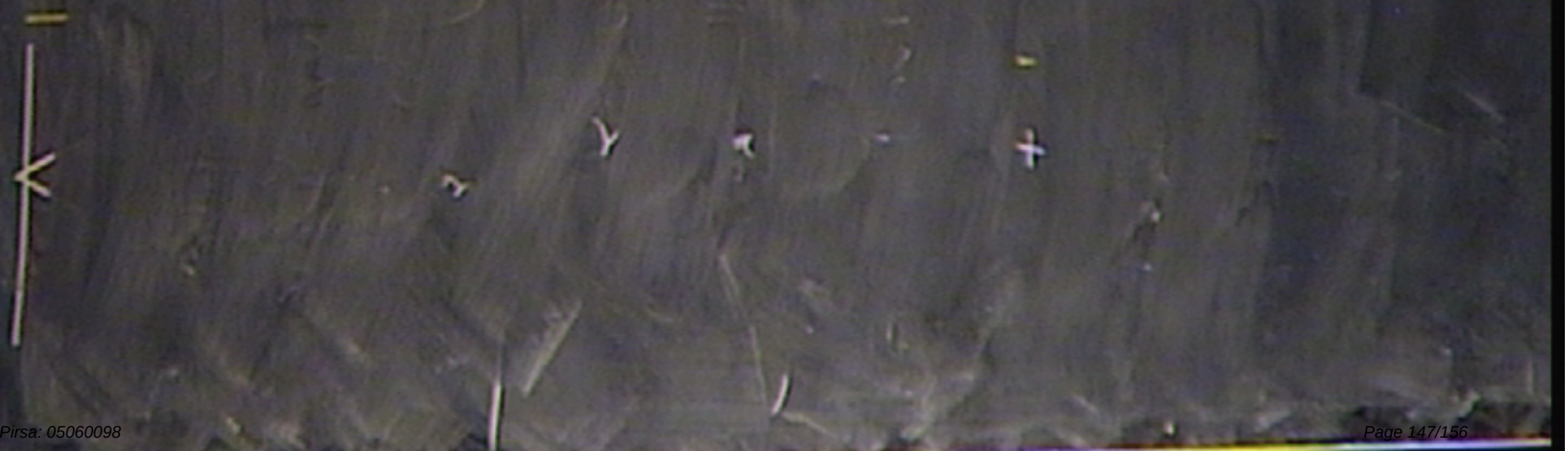

2-point functions
$\langle \theta(b)\, \theta(b') \sim$


2-point functions
$\langle \theta(b)\, \theta(b') \rangle \sim \lim_{\beta,\beta' \to 0}$

2-point functions

$$\langle \sigma(b)\,\sigma(b') \rangle \sim \lim_{\beta,\beta' \to 0} G_F(b,b',\beta,\beta')$$





2-point functions

$\langle \sigma(b)\, \sigma(b') \rangle \sim \lim_{\beta, \beta' \to 0} G_F(b, b', \beta, \beta')$



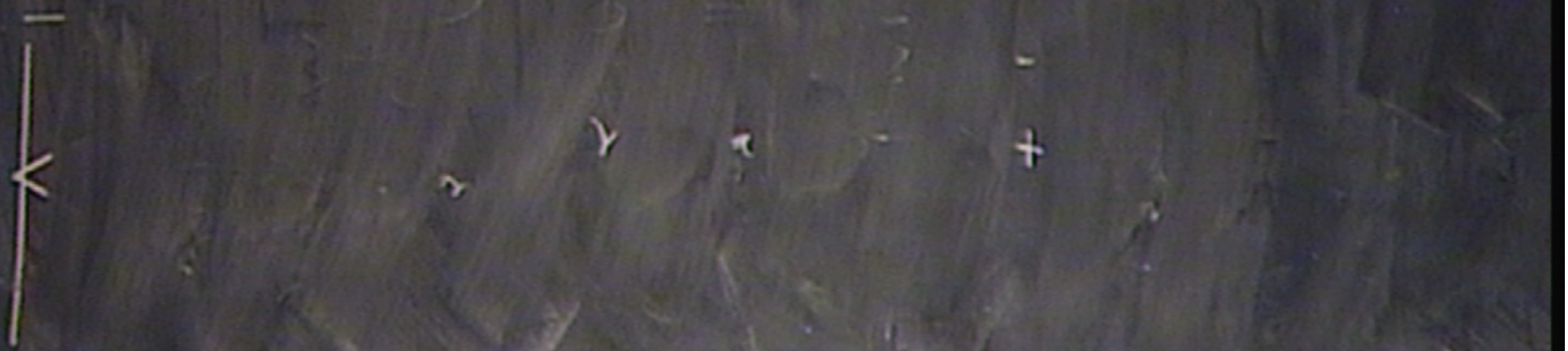
$\sim \int \mathcal{D}P$

2-point functions

$$\langle \Phi(b)\,\Phi(b') \rangle \sim \lim_{\beta,\beta' \to 0} G_F(b,b',\beta,\beta')$$



$\sim \int \mathcal{D}P$



2-point functions

(b) $\sigma(b') \sim \lim_{\beta,\beta' \to 0} G_F(b,b',\beta,\beta')$

$\mathcal{M} \sim \left[\int \mathcal{D}P\, e^{i\frac{m}{\hbar}\int dt \sqrt{\partial x^\mu \partial x^\nu g_{\mu\nu}}}\right]$

2-point functions

(b) $\theta(b') \sim \lim_{\beta,\beta' \to 0} G_F(b,b',\beta,\beta')$

$\mathcal{M} \underset{\hbar \to 0}{\sim} \left[\int \mathcal{D}P\, e^{\frac{i}{\hbar} \int dt \sqrt{\partial x^\mu \partial x^\nu g_{\mu\nu}}}\right]$

$\langle \theta\, \theta \rangle$

2-point functions

$$\mathcal{O}(b)\,\mathcal{O}(b') \sim \lim_{\beta,\beta'\to 0} G_F(b,b',\beta,\beta')$$

$$\sim \left[\int \mathcal{D}P\, e^{i\frac{m}{\hbar}\int dt \sqrt{\partial x^\mu \partial x^\nu g_{\mu\nu}}}\right]$$

$$\hbar \to 0$$

$$\langle \mathcal{O}\,\mathcal{O}\rangle \sim \sum_g e^{i\frac{m}{\hbar}\ell(g)}$$

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2-point functions

$$\langle \phi(b)\,\phi(b') \rangle \sim \lim_{\beta,\beta' \to 0} G_F(b,b',\beta,\beta')$$

$$\sim \left[\int \mathcal{D}P\, e^{i \frac{m}{\hbar} \int dt \sqrt{\partial x^\mu \partial x^\nu g_{\mu\nu}}} \right]$$

$\hbar \to 0$

$$\langle \phi\,\phi \rangle \sim \sum_{g\text{-geodesics}} e^{i \frac{m}{\hbar} l(g)}$$

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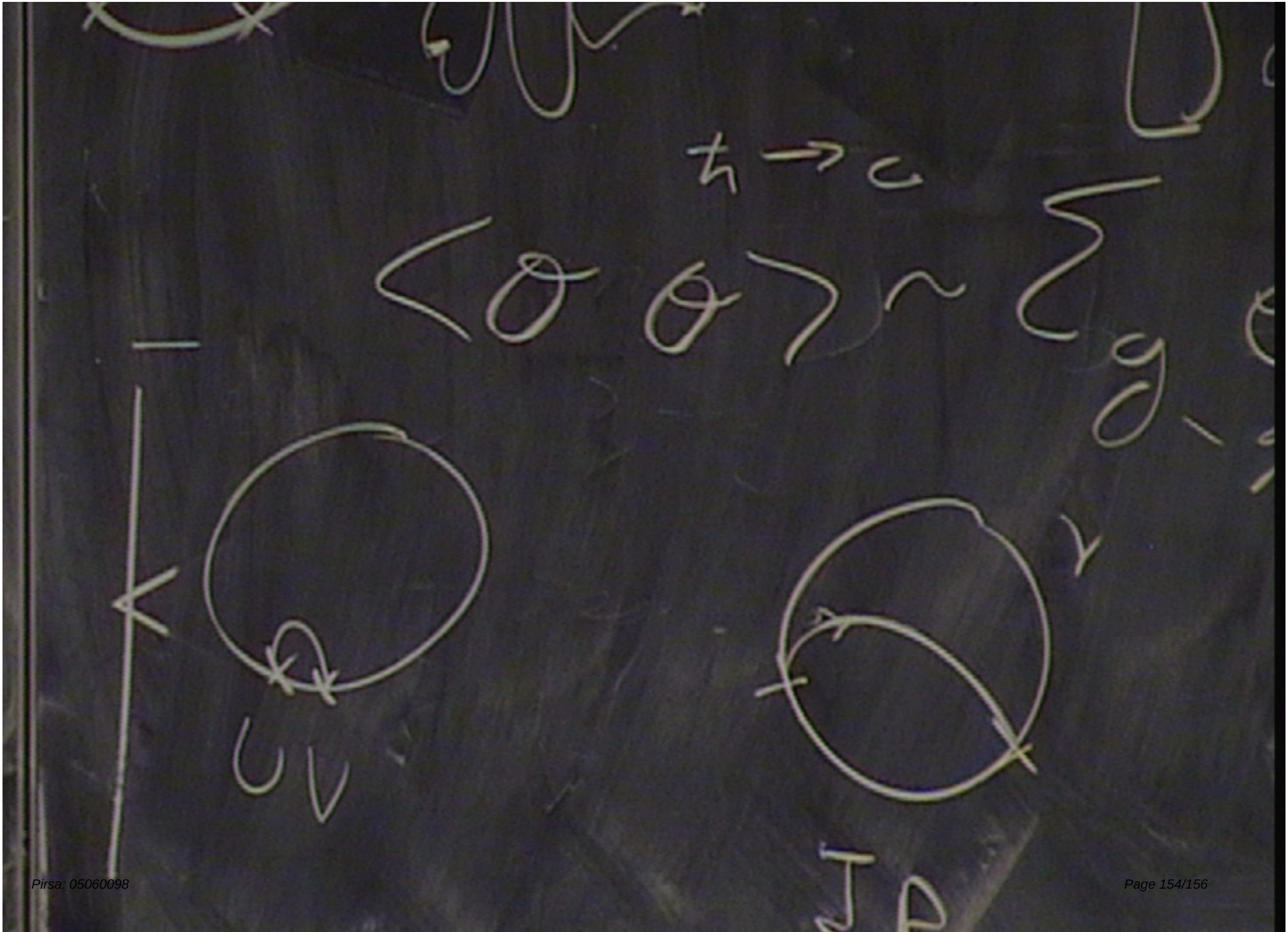
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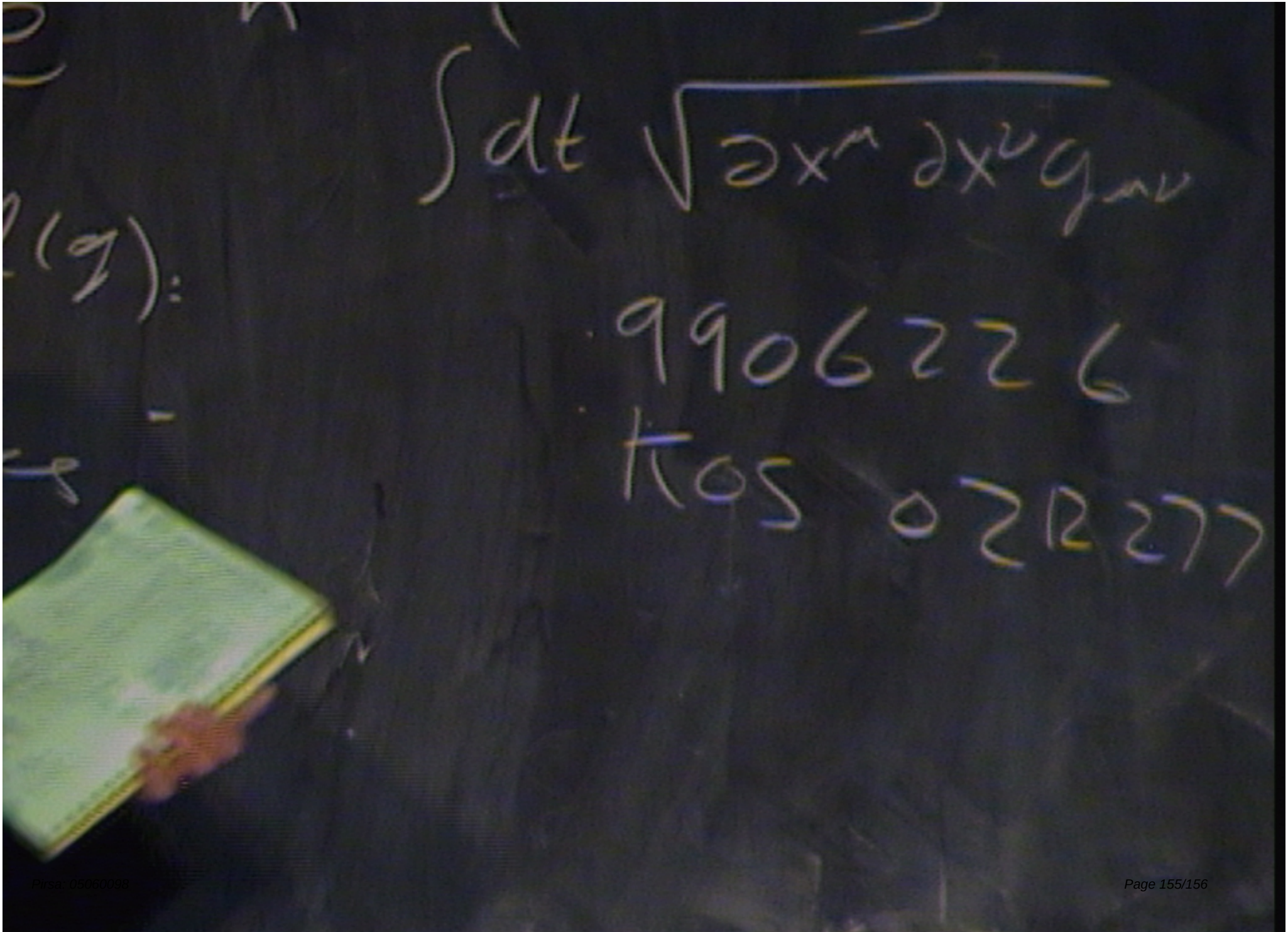
$\int dt \sqrt{\partial x^m \partial x^\nu g_{m\nu}}$
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$$\int dt \sqrt{\partial x^\mu \partial x^\nu g_{\mu\nu}}$$

(g):

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