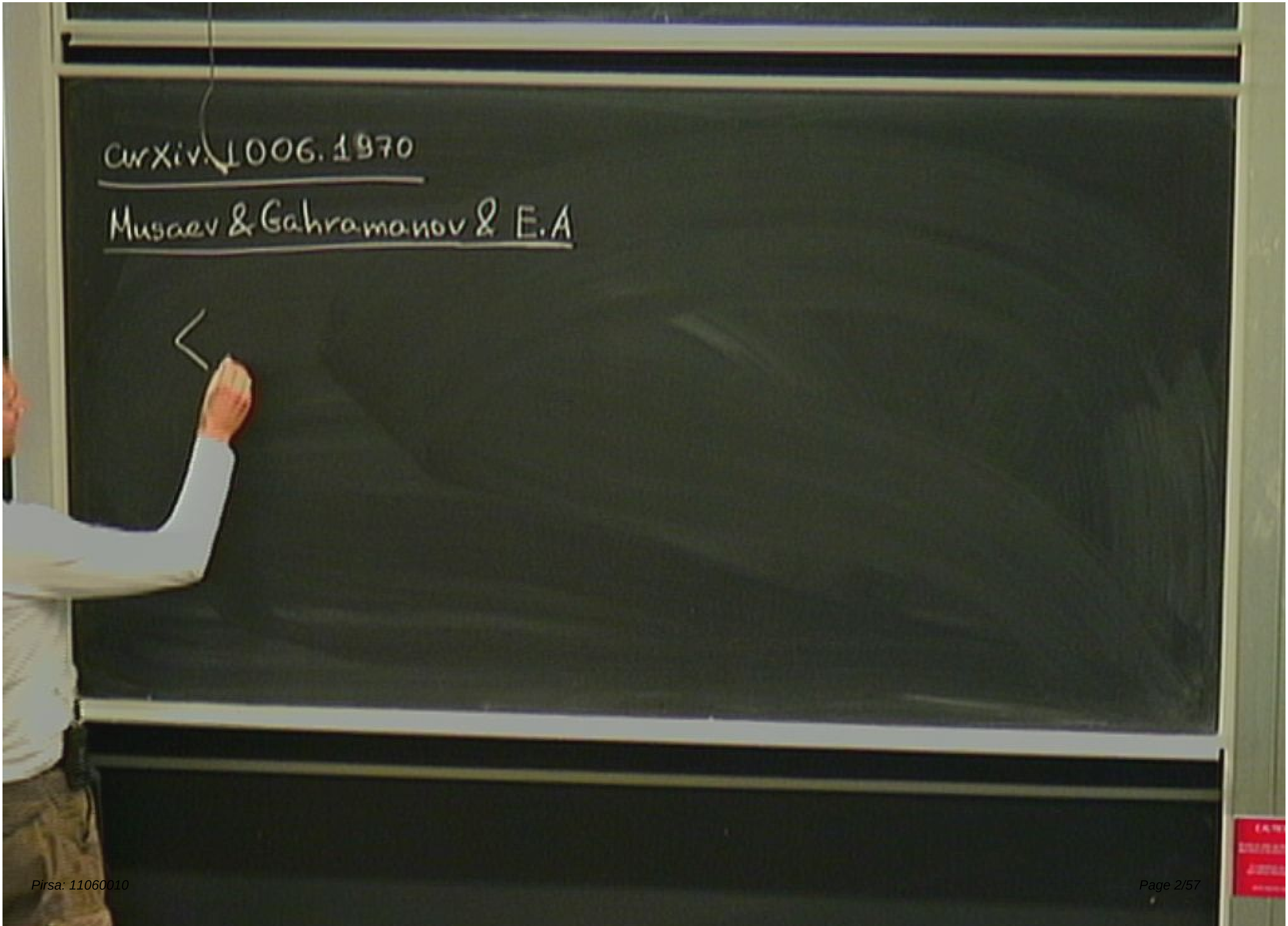
Title: Hints on integrability in the Holographic RG

Date: Jun 14, 2011 11:00 AM

URL: http://pirsa.org/11060010

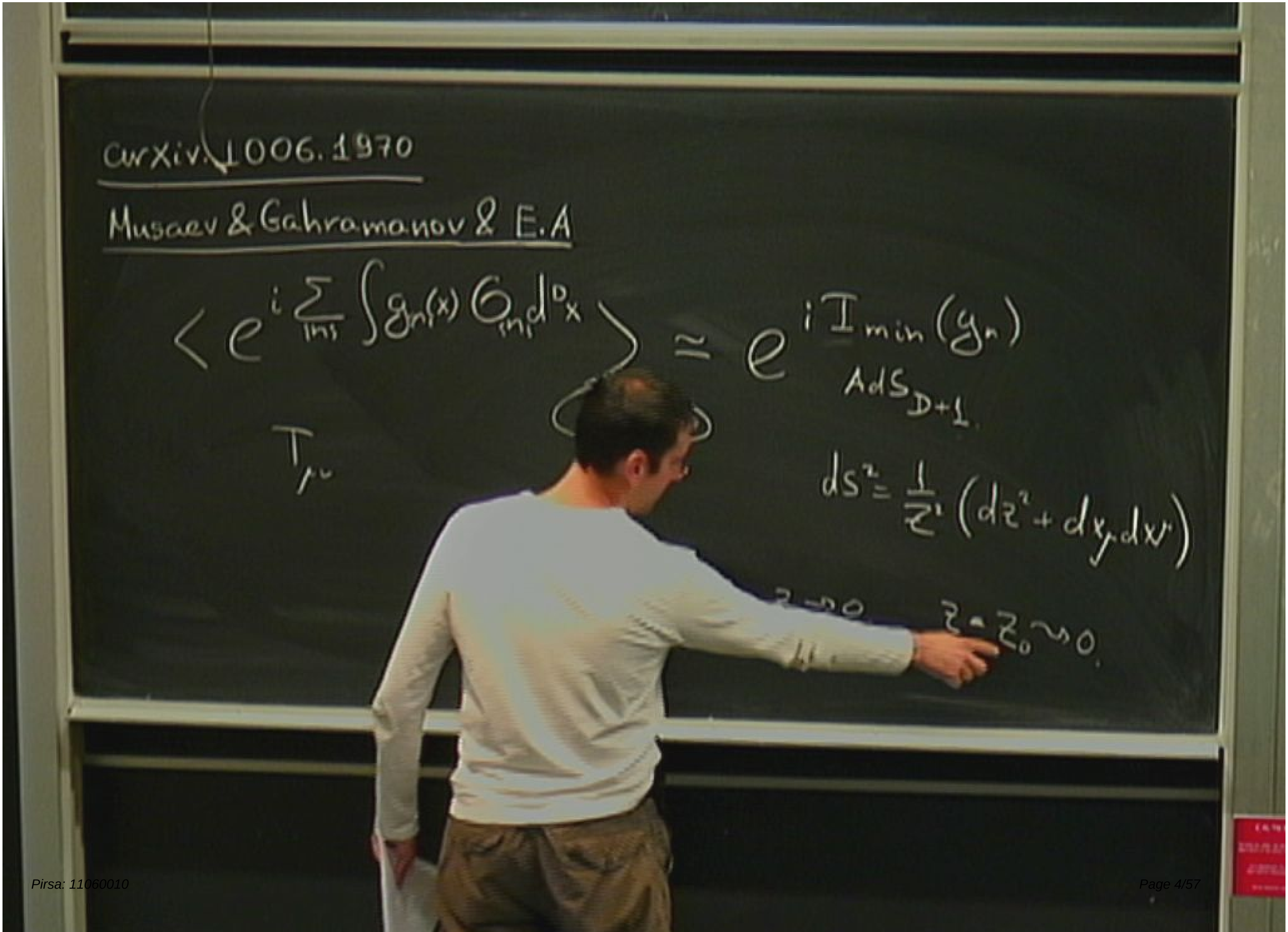
Abstract: The Polchinski equations for the Wilsonian renormalization group in the D--dimensional matrix scalar field theory can be written at large N in a Hamiltonian form. The Hamiltonian defines evolution along one extra holographic dimension (energy scale) and can be found exactly for the subsector of $Tr\phi^n$ (for all n) operators. We show that at low energies independently of the dimensionality D the Hamiltonian system in question reduces to the {\it integrable} effective theory. The obtained Hamiltonian system describes large wavelength KdV type (Burger--Hopf) equation with an external potential and is related to the effective theory obtained by Das and Jevicki for the matrix quantum mechanics.

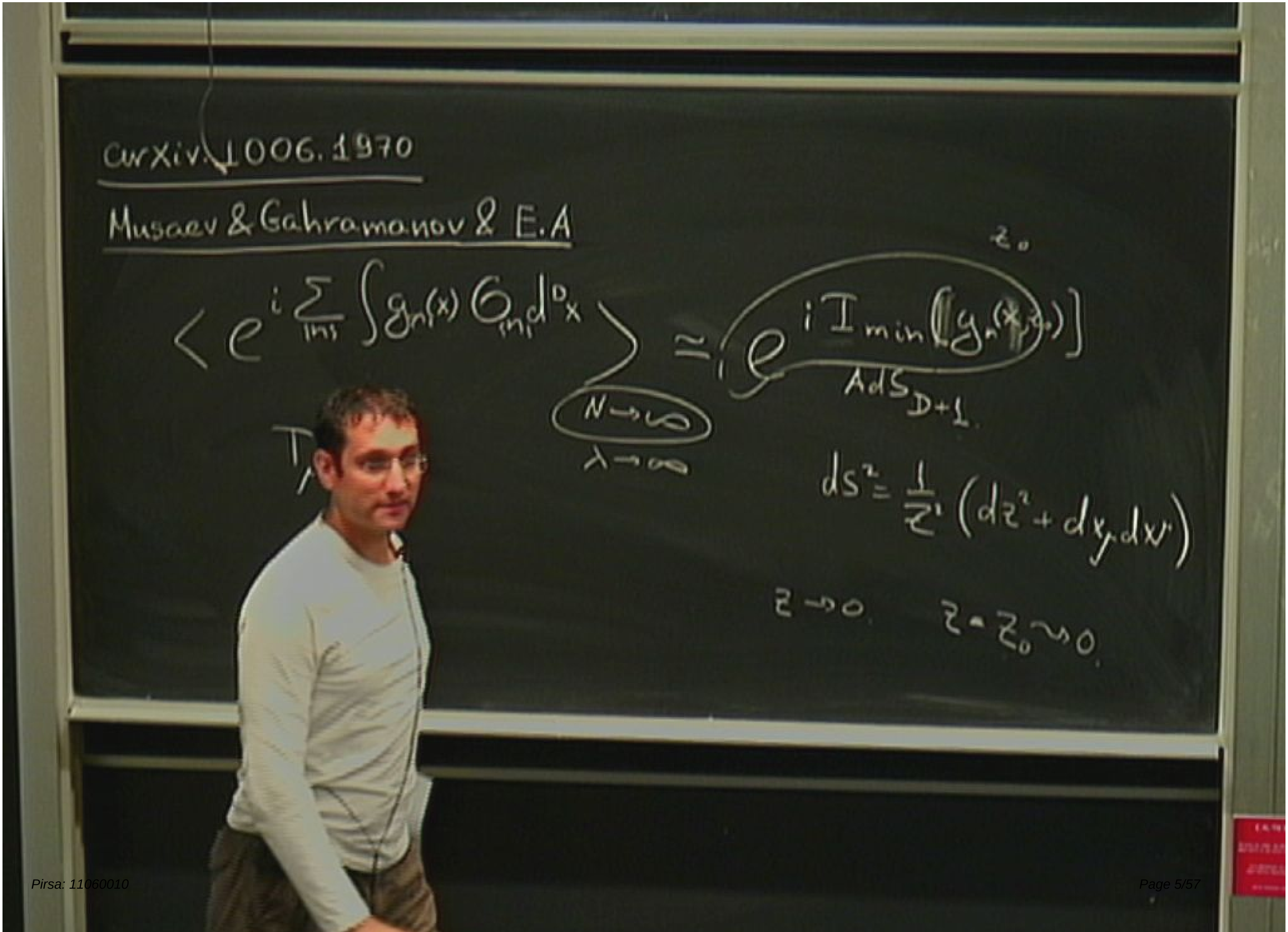

arXiv: 1006.1970
Musaev & Gahramanov & E.A

arXiv:1006.1970

Musaev & Gahramanov & E.A

$$\left\langle e^{i\sum_{\{n\}}\int g_n(x)\, \mathcal{O}_{\{n\}}\, d^D x} \right\rangle_{\substack{N\to\infty \\ \lambda\to\infty}} \simeq e^{i I_{min}(g_n)}\Big|_{AdS_{D+1}}$$


arXiv 1006.1970
Musaev & Gahramanov & E.A
$\langle e^{i \sum_{\{n\}} \int g_n(x) O_{\{n\}} d^D x} \rangle \simeq e^{i I_{min}(g_n)}$
AdS_{D+1}
$T_{\mu\nu}$
$ds^2 = \frac{1}{z^2}(dz^2 + dx_\mu dx^\mu)$
$z \to 0$
$z = z_0 \sim 0$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Musaev & Gahramanov & E.A
$\langle e^{i\sum_{\{n\}}\int g_n(x)\,\mathcal{O}_{\{n\}}\,d^Dx} \rangle \simeq e^{iI_{\min}[g_n(x,z_0)]}$
$N\to\infty$
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z_0
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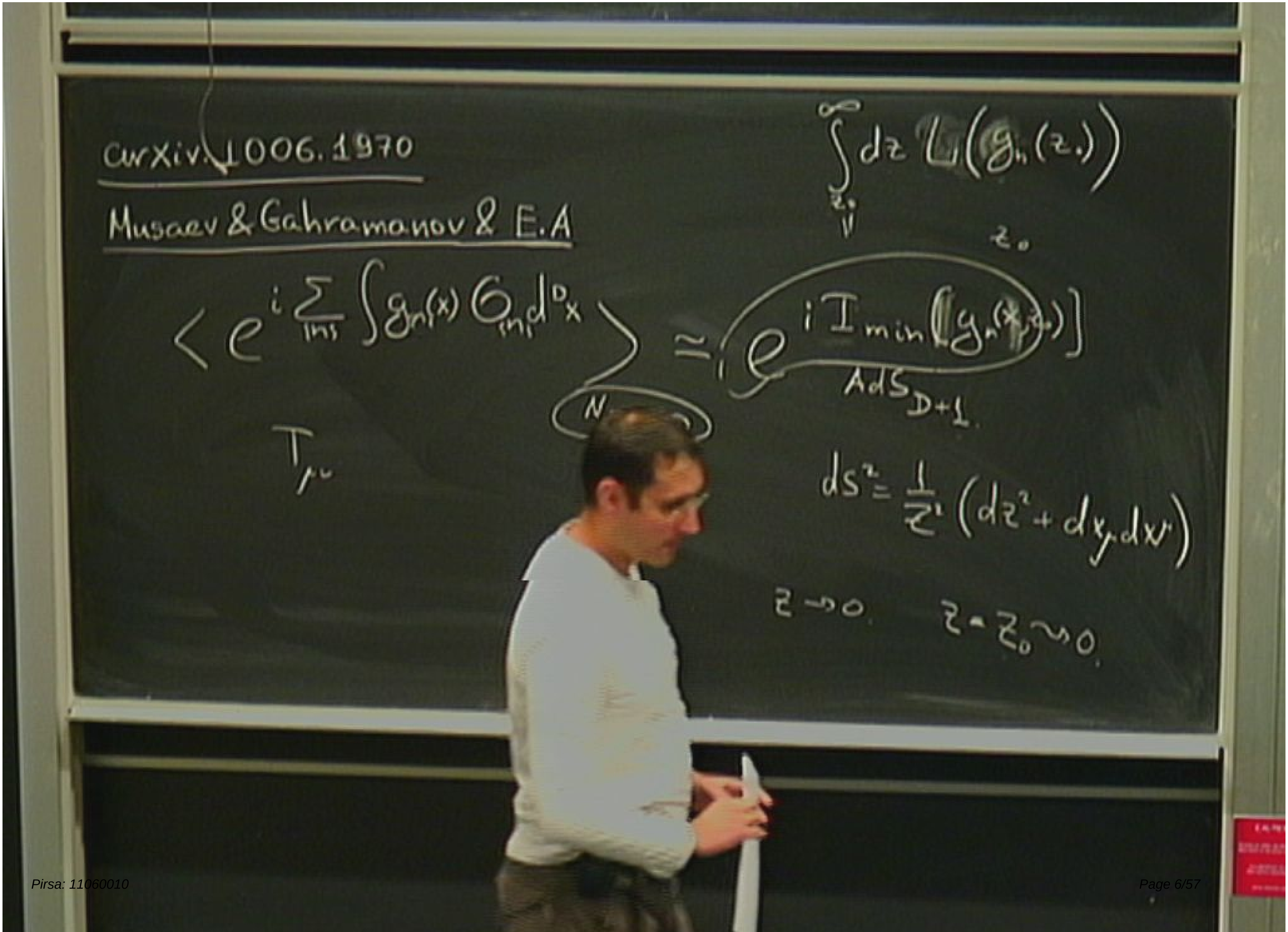
arXiv:1006.1970
Musaev & Gahramanov & E.A
$\langle e^{i\sum_{\{n\}}\int g_{n}(x)\,\mathcal{O}_{\{n\}}d^{D}x}\rangle_{N} \simeq e^{iI_{min}[g_n(x, z_0)]}$
AdS_{D+1}
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$\int_{z_0}^{\infty} dz\, L(g_n(z_0))$
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$ds^2 = \frac{1}{z^2}\left(dz^2 + dx_\mu dx^\mu\right)$
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Musaev & Gahramanov & E.A

$$\underbrace{\left\langle e^{i\sum_{\{n\}}\int g_n(x)\,\mathcal{O}_{\{n\}}\,d^Dx} \right\rangle}_{T_{\mu\nu}} \underset{\substack{N\to\infty \\ \lambda\to\infty}}{\simeq} e^{iI_{min}[g_n(x,z_0)]}_{AdS_{D+1}}$$

$$\int_{z_0}^{\infty} dz\, L(g_n(z_0))$$

z_0

$$ds^2 = \frac{1}{z^2}\left(dz^2 + dx_\mu dx^\mu\right)$$

$z \to 0$ $\qquad z = z_0 \to 0$

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$$\int_{z_0}^{\infty} dz\, L\left(g_n(z_0)\right)$$

$$z_0$$

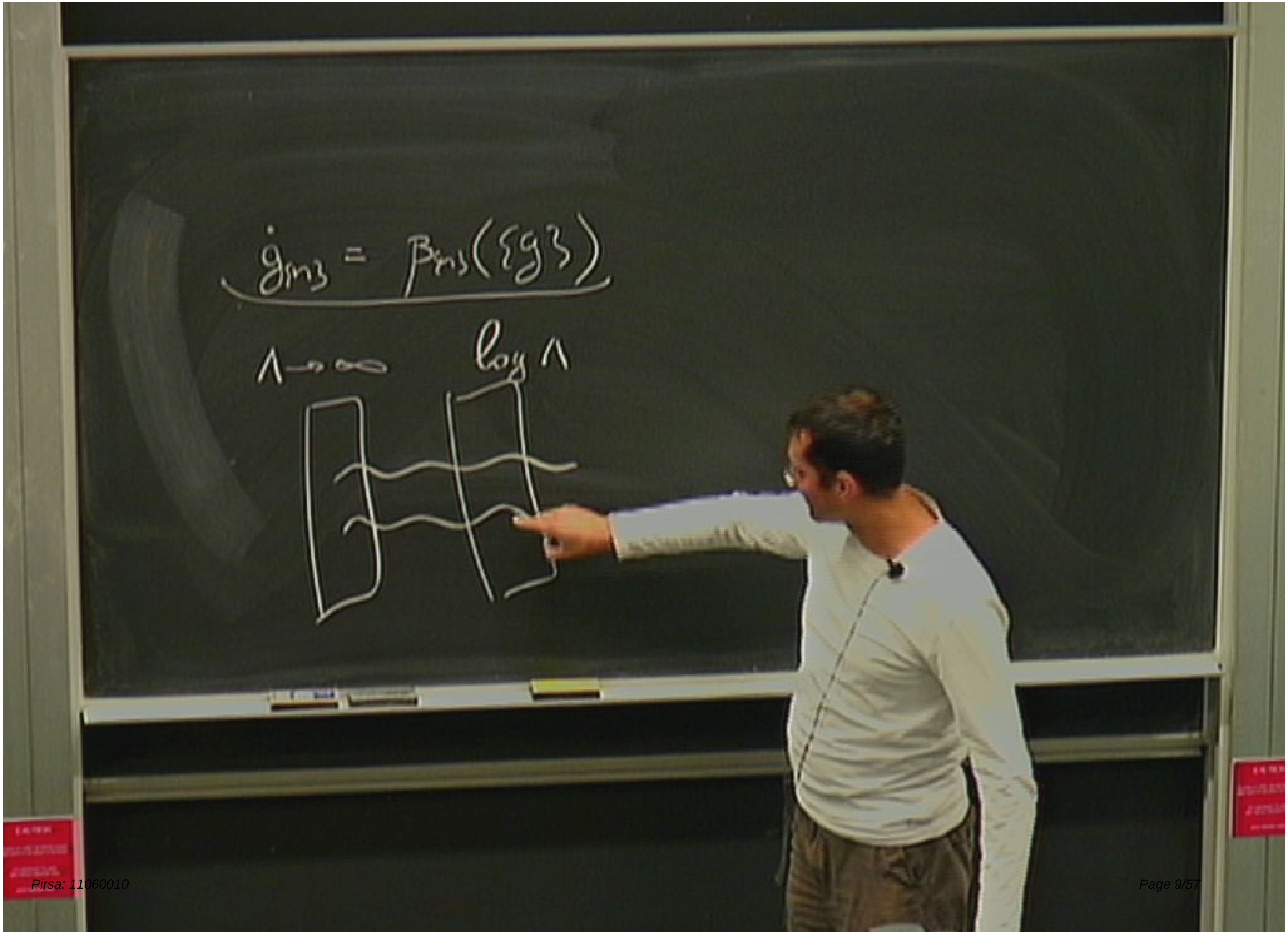
$$\Lambda\frac{\partial}{\partial\Lambda}\left\langle e^{i\sum_{\{n\}}\int \underline{g_n(x)}\, O_{\{n\}}\, d^D x}\right\rangle \underset{\substack{N\to\infty \\ \lambda\to\infty}}{\simeq} e^{i I_{min}[g_n(x,z_0)]}$$

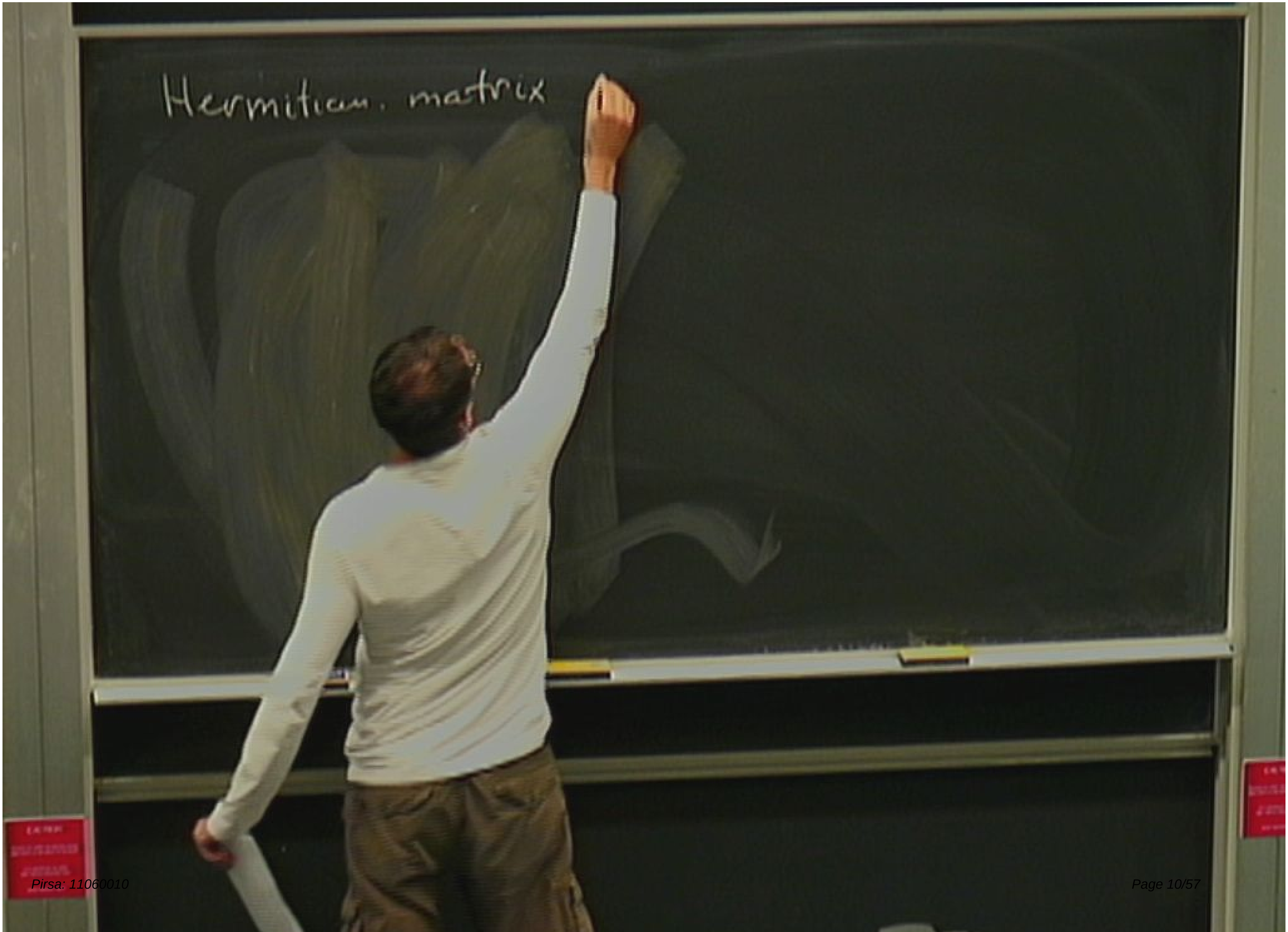
$$T_{\mu\nu}$$

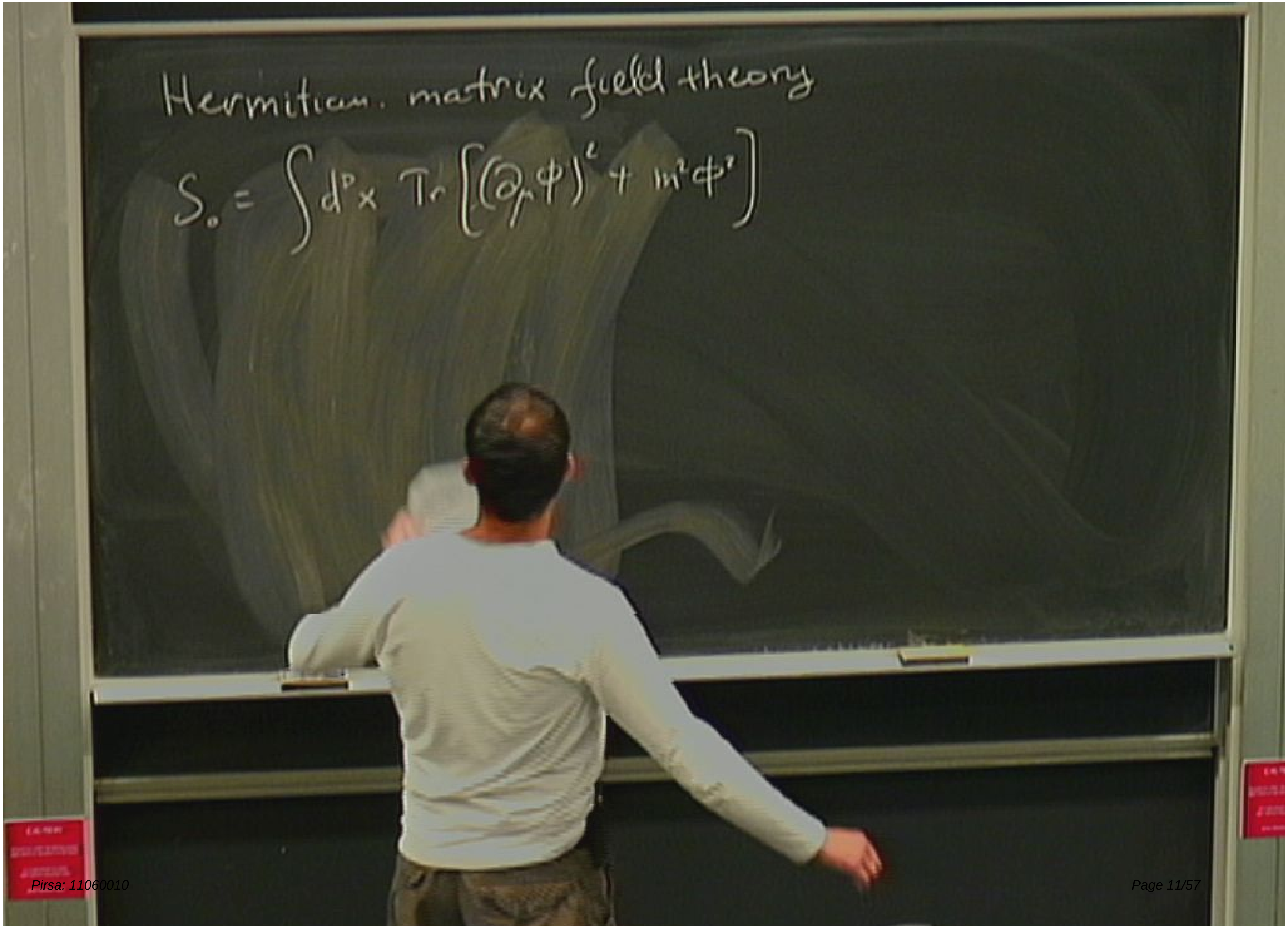
$$AdS_{D+1}$$

$$ds^2 = \frac{1}{z^2}\left(dz^2 + dx_\mu dx^\mu\right)$$

$z \to 0$ $\quad$ $z - z_0 \to 0$


$\dot{g}_{\{n\}} = \beta_{\{n\}}(\{g\})$
$\Lambda \to \infty$
$\log \Lambda$


Hermitian matrix

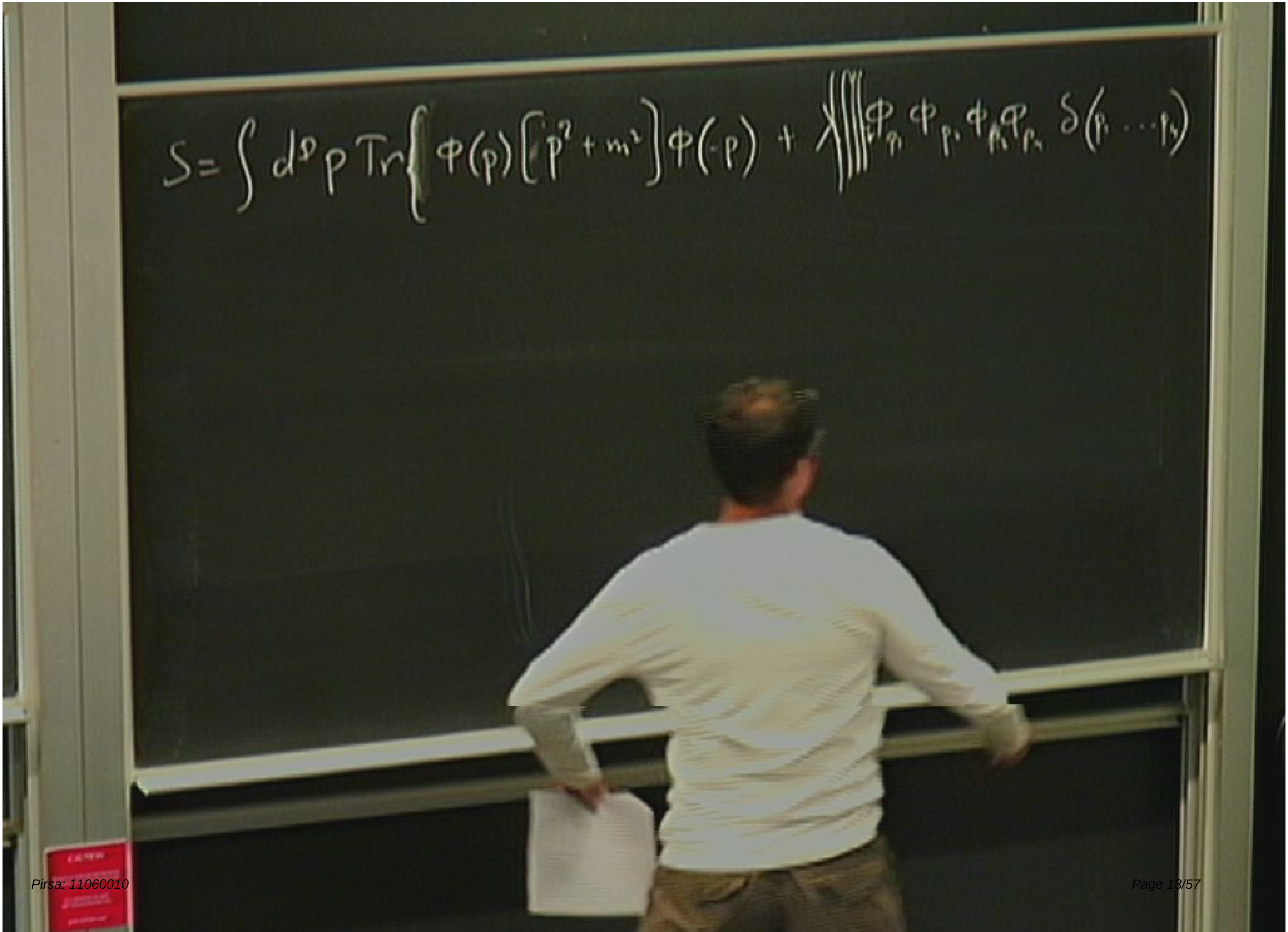

Hermitian matrix field theory
$S_0 = \int d^D x \, \mathrm{Tr}\left[(\partial_\mu \phi)^2 + m^2 \phi^2\right]$

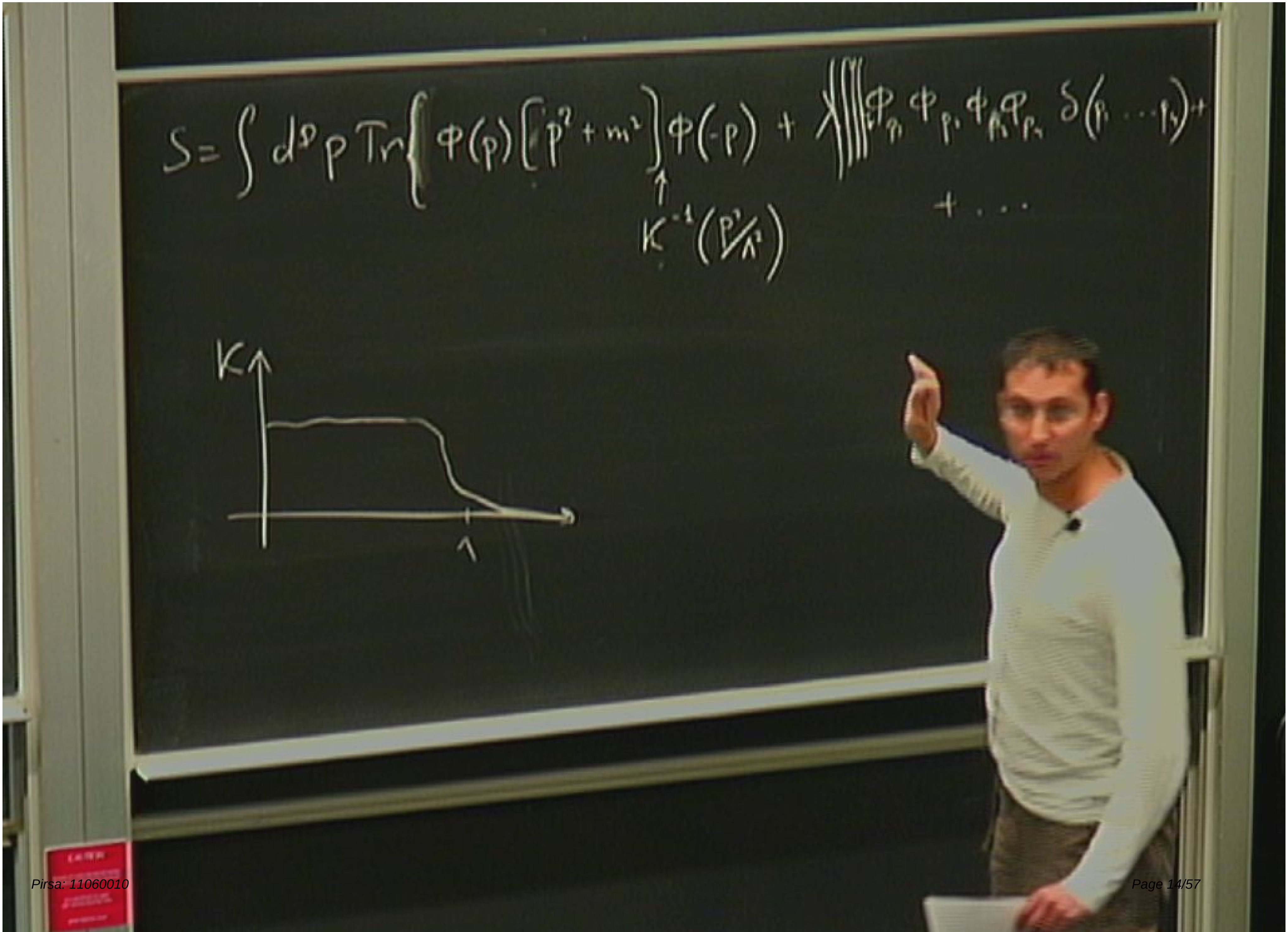
Hermitian matrix field theory

$$S = \int d^D x \, \mathrm{Tr}\left[(\partial_\mu \phi)^2 + m^2 \phi^2 + \lambda \phi^4\right] + i \sum_n \int g_n O_n$$

$$O_n \quad T_{\mu\nu} \quad \mathrm{Tr}\left[\partial_\mu \phi \partial_\nu \phi - \eta_{\mu\nu}(\ldots)\right]$$

$$e^{I_{eff}(g)} = \int \mathcal{D}\phi \, e^{-S}$$

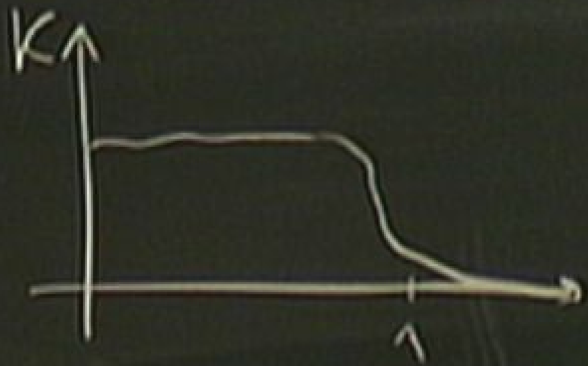

$S = \int d^D p \, \mathrm{Tr}\{ \phi(p)[p^2 + m^2]\phi(-p) + \lambda \int\!\!\int\!\!\int\!\!\int \phi_{p_1} \phi_{p_2} \phi_{p_3} \phi_{p_4} \delta(p_1 \dots p_4)$


$S = \int d^D p \, \mathrm{Tr} \{ \Phi(p) [p^2 + m^2] \Phi(-p) + \lambda \Phi_{p_1} \Phi_{p_2} \Phi_{p_3} \Phi_{p_4} \delta(p_1 \cdots p_4) +$
$K^{-1}(p^2/\Lambda^2)$
$+ \ldots$
K
Λ

$$S_\Lambda = \int d^D p \, \mathrm{Tr} \left\{ \phi(p) \left[p^2 + m^2 \right] \phi(-p) + \lambda \int \phi_{p_1} \phi_{p_2} \phi_{p_3} \phi_{p_4} \, \delta(p_1 \ldots p_4) + \ldots \right.$$

$$\left[p^2 + m^2 \right] \uparrow \; K^{-1}\left(p^2/\Lambda^2\right)$$

$$+ \ldots$$



$$\Lambda \partial_\Lambda I = 0$$

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$$\Lambda \partial_\Lambda S_I = -\frac{1}{2} \int \frac{d^D p}{p^2 + m^2} \, \Lambda \partial_\Lambda K(p^2/\Lambda^2) \times$$

$$\cdot \left(\frac{1}{N} \frac{\delta^2 S_I}{\delta \phi^{ij}(-p) \delta \phi^{ji}(p)} + \frac{\delta S_I}{\delta \phi^{ij}(p)} \frac{\delta S_I}{\delta \phi^{ji}(-p)} + \ldots \right)$$

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$$\cdot \left[\frac{1}{N} \frac{\delta^2 S_I}{\delta \varphi^{ij}(-p)\, \delta \varphi^{ji}(p)} + \frac{\delta S_I}{\delta \varphi^{ij}(p)} \frac{\delta S_I}{\delta \varphi^{ji}(-p)} + \dots \right]$$

$\lambda \partial_\lambda$

$$\int \sum_{\{n\}} \dot{g}_n \mathcal{O}_n = \int \left[\sum_{\{n\}} \alpha_n \mathcal{O}_n + \sum_{n,m} \gamma_{nm} \mathcal{O}_n \mathcal{O}_m \right]$$

$$\Lambda\partial_\Lambda \left\langle \int \sum_{\{n\}} \dot{g}_n \, \mathcal{O}_n \right\rangle = \left\langle \int \left[\sum_{\{n\}} \alpha_n \, \mathcal{O}_n + \sum_{n,m} \gamma_{nm} \underbrace{\mathcal{O}_n \mathcal{O}_m}_{C^{k}_{nm} \mathcal{O}_k} \right] \right\rangle$$

$$\phi(p)$$

$$\mu \le p \le \Lambda$$

$$\boxed{\dot{g}_n = \beta_n(g)}$$

$$\Lambda\partial_\Lambda \langle \int \sum_{\{n\}} \dot{g}_n \mathcal{O}_n \rangle = \left\langle \int \left[\sum_{\{n\}} \alpha_n \mathcal{O}_n + \sum_{n,m} \gamma_{nm} \underbrace{\mathcal{O}_n \mathcal{O}_m}_{C^k_{nm} \mathcal{O}_k} \right] \right\rangle$$

$\varphi(p)$

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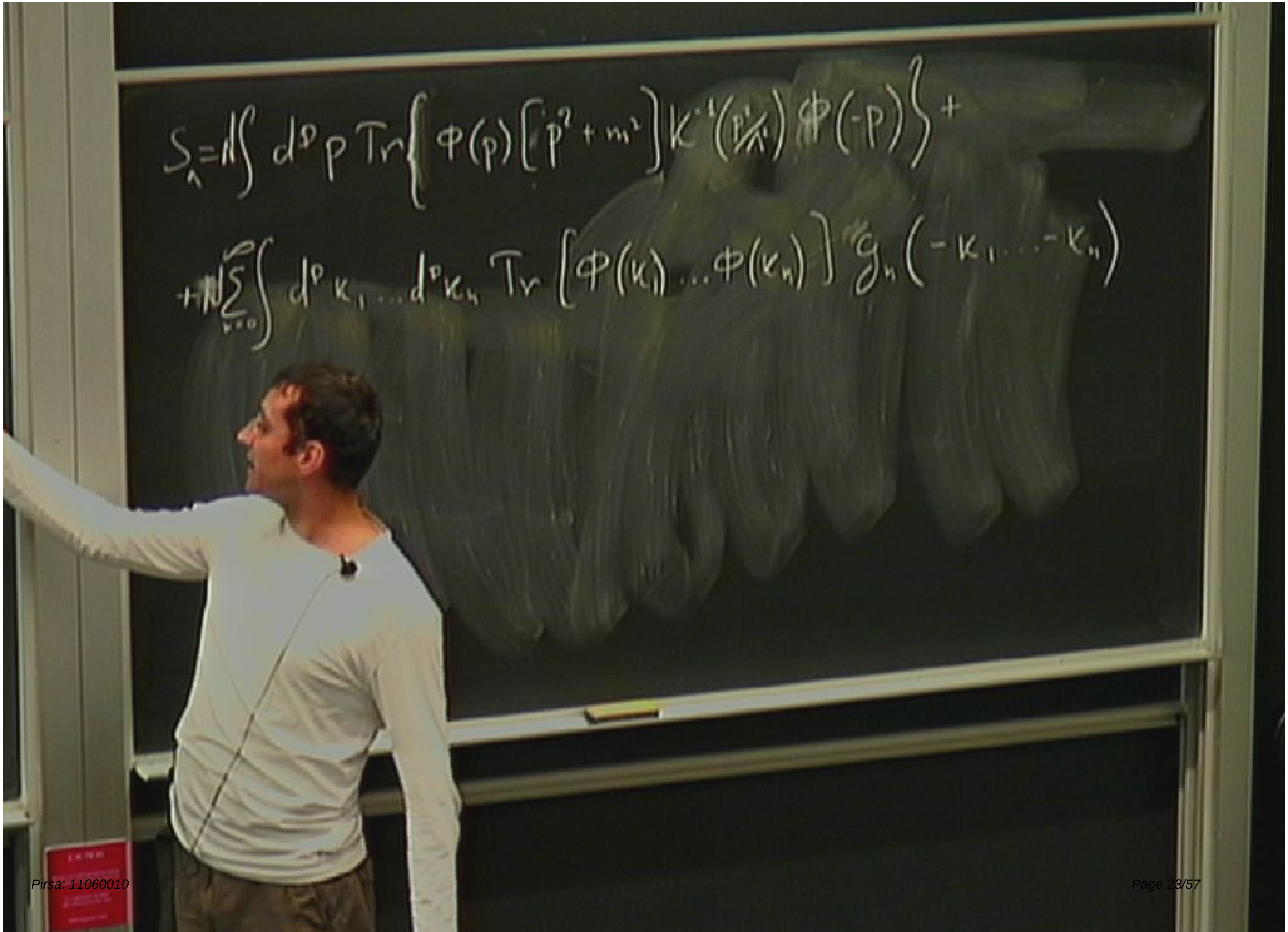
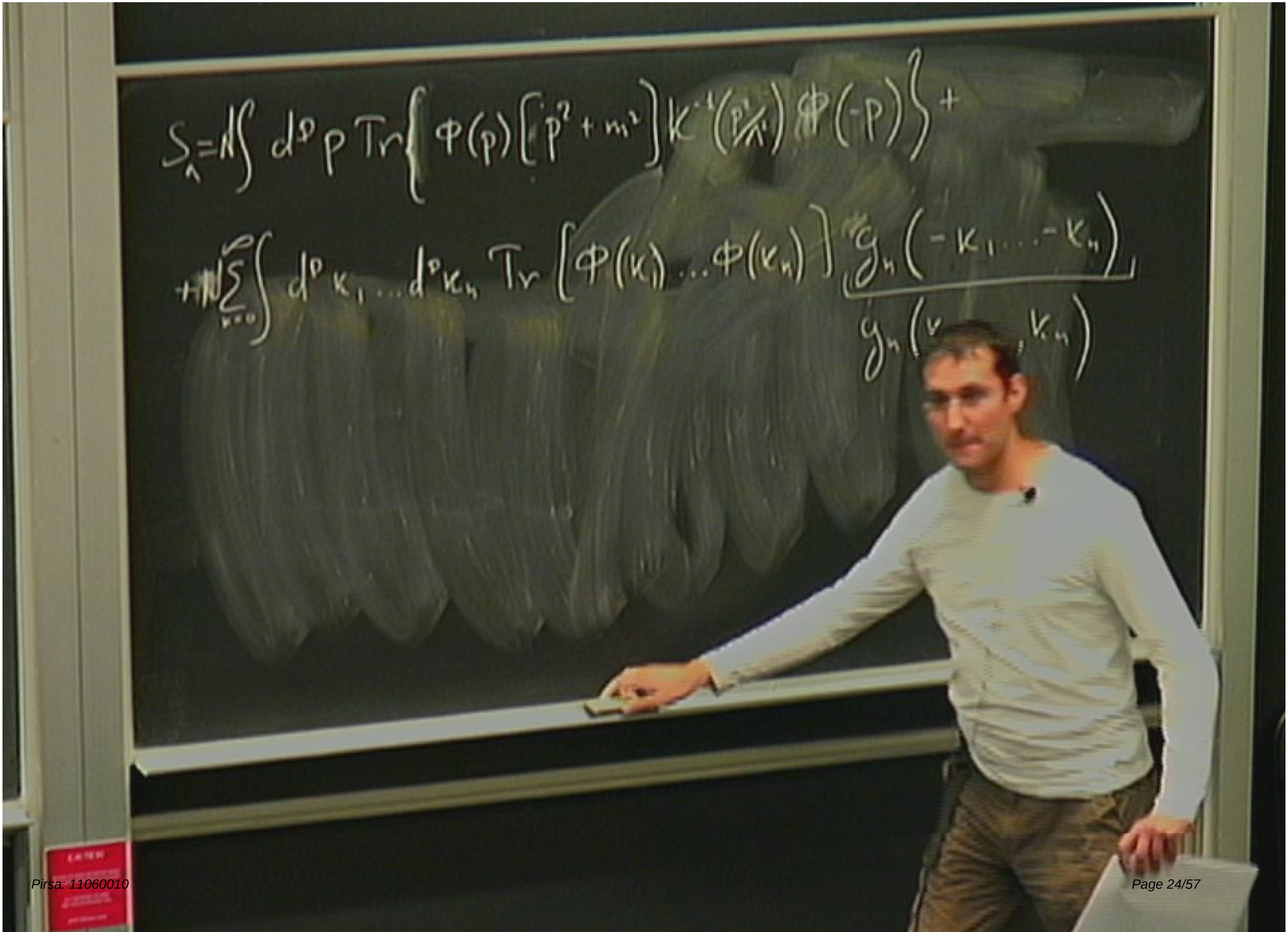
$\mu \leq p \leq \Lambda$

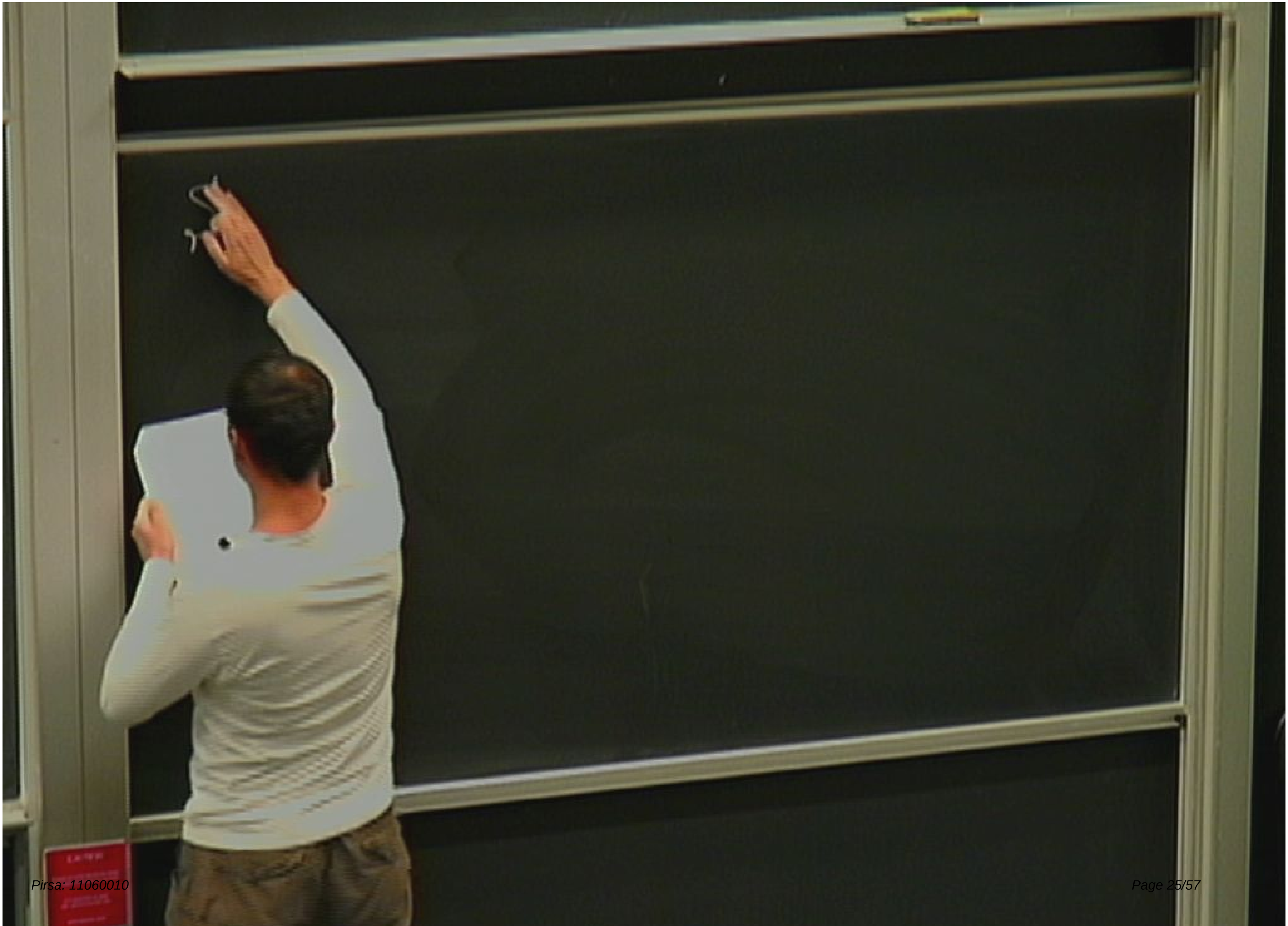
Hermitian matrix field theory

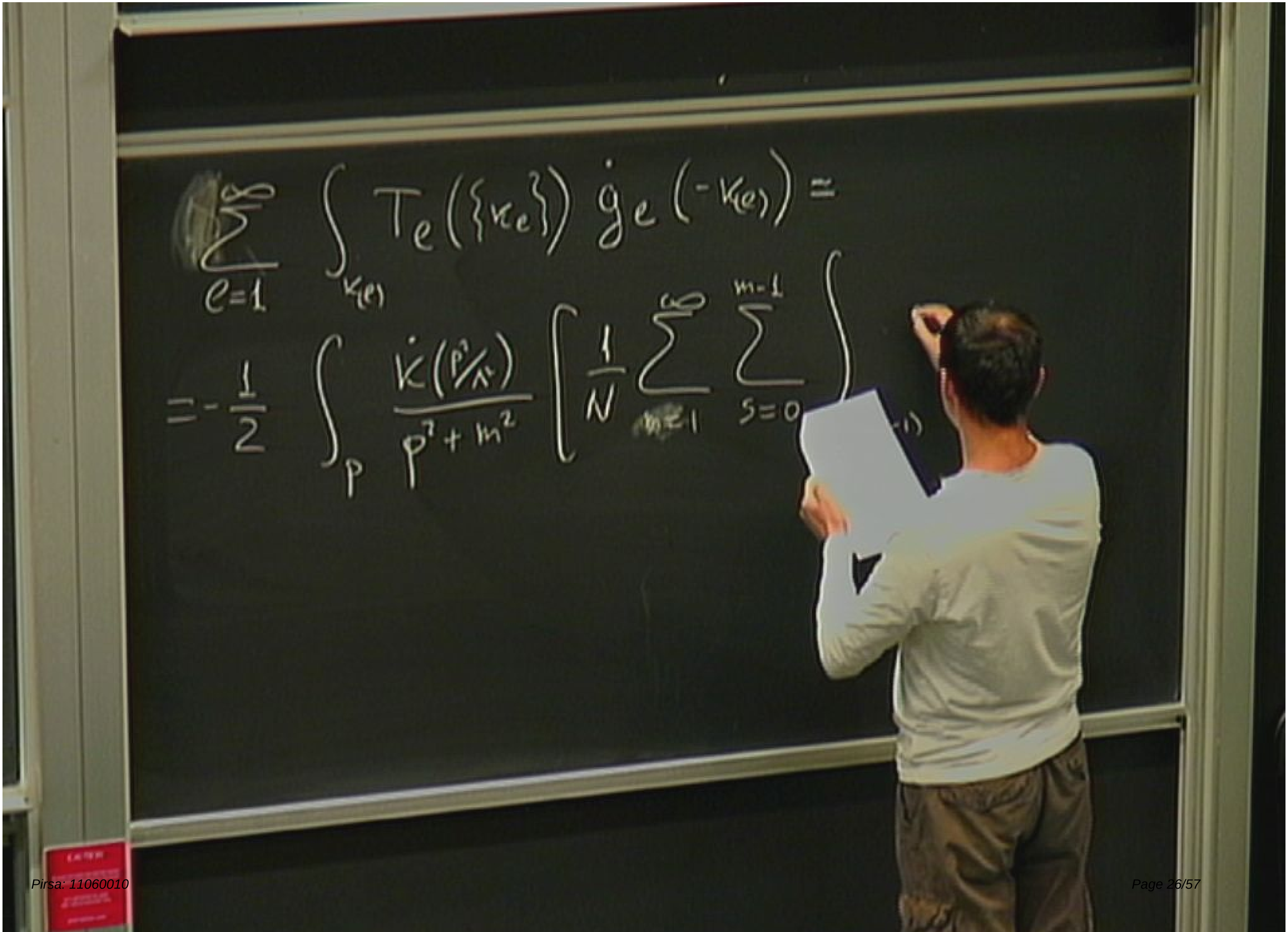
$$S = \int d^D x \, \mathrm{Tr}\left[(\partial_\mu \phi)^2 + m^2\phi^2\right] + \sum_n \int d^D x \, g_n(x)\, \mathrm{Tr}\,\phi^n(x)$$


$S_\Lambda = N \int d^D p \, \mathrm{Tr}\left\{ \Phi(p) \left[p^2 + m^2 \right] K^{-1}\left(p^2/\Lambda^2\right) \Phi(-p) \right\} +$
$+ N \sum_{n=0}^{\infty} \int d^D k_1 \ldots d^D k_n \, \mathrm{Tr}\left[\Phi(k_1) \ldots \Phi(k_n) \right] g_n(-k_1 \ldots -k_n)$



$S_\Lambda = N \int d^D p \, \mathrm{Tr} \left\{ \Phi(p) \left[p^2 + m^2 \right] K^{-1}\left(p^2/\Lambda^2 \right) \Phi(-p) \right\} +$
$+ N \sum_{n=0}^{\infty} \int d^D k_1 \ldots d^D k_n \, \mathrm{Tr} \left[\Phi(k_1) \ldots \Phi(k_n) \right] \frac{g_n(-k_1 \ldots -k_n)}{g_n(k_1 \ldots k_n)}$




$\sum_{e=1}^{\infty} \int_{k(e)} T_e(\{k_e\}) \, \dot{g}_e(-k(e)) =$
$= -\frac{1}{2} \int_p \frac{\dot{K}(p^2/\Lambda^2)}{p^2+m^2} \left[\frac{1}{N} \sum_{m=1}^{\infty} \sum_{s=0}^{m-1} \int \right.$

$$\sum_{\ell=1}^{\infty} \int_{K(\ell)} T_\ell\left(\{K_\ell\}\right) \dot{g}_\ell\left(-K(\ell)\right) =$$

$$= -\frac{1}{\quad} \int_p \frac{\dot{K}\left(p^2/\Lambda^2\right)}{p^2+m^2} \left[\frac{1}{N} \sum_{m=1}^{\infty} \sum_{s=0}^{m-1} \int_{K(m-1)} (m+1) \times \right.$$

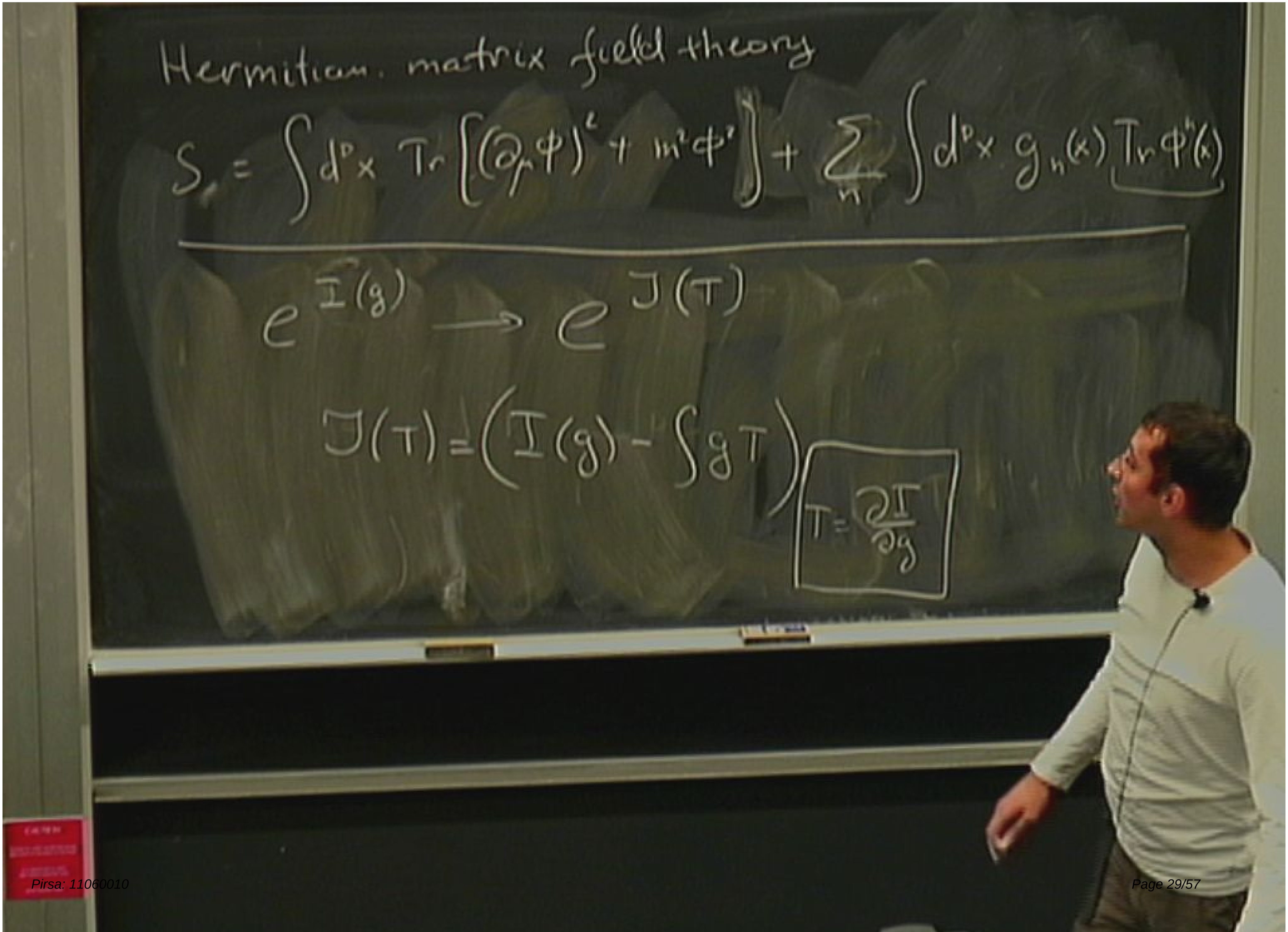
$$\quad {}_{s-1}\left(\{K_{m-s-1}\}\right) T_s\left(\{K_s\}\right) g_{m+1}\left(-K_{(m-1)}\right) +$$

$$\sum_{\ell=1}^{\infty} \int_{k_{(\ell)}} T_\ell(\{k_\ell\})\, \dot{g}_\ell(-k_{(\ell)}) =$$

$$= -\frac{1}{2} \int_p \frac{\dot{K}(p^2/\Lambda^2)}{p^2+m^2} \left[\frac{1}{N} \sum_{m=1}^{\infty} \sum_{s=0}^{m-1} \int_{k_{(m-1)}} (m+1) \times \right.$$

$$\times T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)}) +$$

$$+ \sum_{\ell,j=1}^{\infty} \int_{q_{(j-1)} k_{(\ell-1)}} (\ell j)\, T_{\ell+j-2}(\{k_{\ell-1}\},\{q_{j-1}\}) \times g_\ell(-k_{(\ell-1)}-p)\, g_j(-q_{(j-1)}+p)$$


Hermitian matrix field theory
$S = \int d^D x \, \mathrm{Tr}\left[(\partial_\mu \phi)^2 + m^2 \phi^2\right] + \sum_n \int d^D x \, g_n(x) \, \mathrm{Tr}\, \phi^n(x)$
$e^{I(g)} \longrightarrow e^{J(T)}$
$J(T) = \left(I(g) - \int g T\right)$
$\boxed{T = \frac{\partial I}{\partial g}}$

Hermitian matrix field theory

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$$e^{I(g)} \longrightarrow e^{J(T)} \qquad p = \frac{\partial S}{\partial q}$$

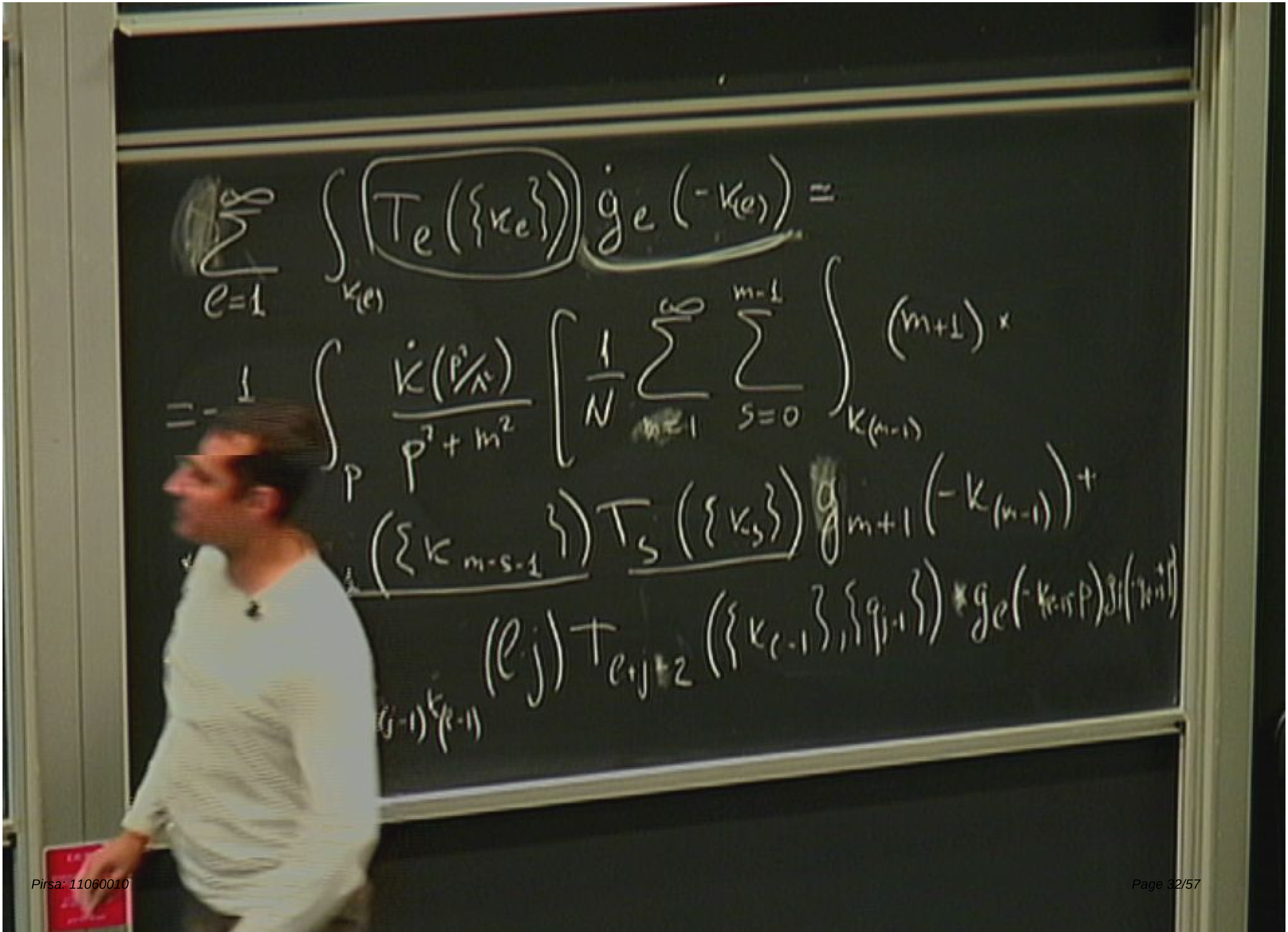
$$J(T) = \left(I(g) - \int g T\right)$$

$$\underline{T = \langle \mathrm{Tr}\, \phi \ldots \phi \rangle} = \mathrm{Tr}\, \phi_0^n \ldots \qquad \boxed{T = \frac{\partial I}{\partial g}}$$

$$+N\sum_{n=0}^{\infty}\int d^D k_1 \dots d^D k_n \,\mathrm{Tr}\left[\phi(k_1)\dots\phi(k_n)\right] g_n(-k_1 \dots -k_n)$$

$$\int \mathcal{D}\phi \; e^{-S_0 + \sum \int g_n(\Sigma k)\,\mathrm{Tr}\left[\phi \dots \phi\right]}$$

$$\sum_{l,j=1}\int_{k_{(j-1)}\,k_{(l-1)}} (l\,j)\, T_{l+j+2}\left(\{k_{l-1}\},\{q_{j-1}\}\right) * g_l(-k_{l-1}, p)\, g_j(-q_{j-1})$$

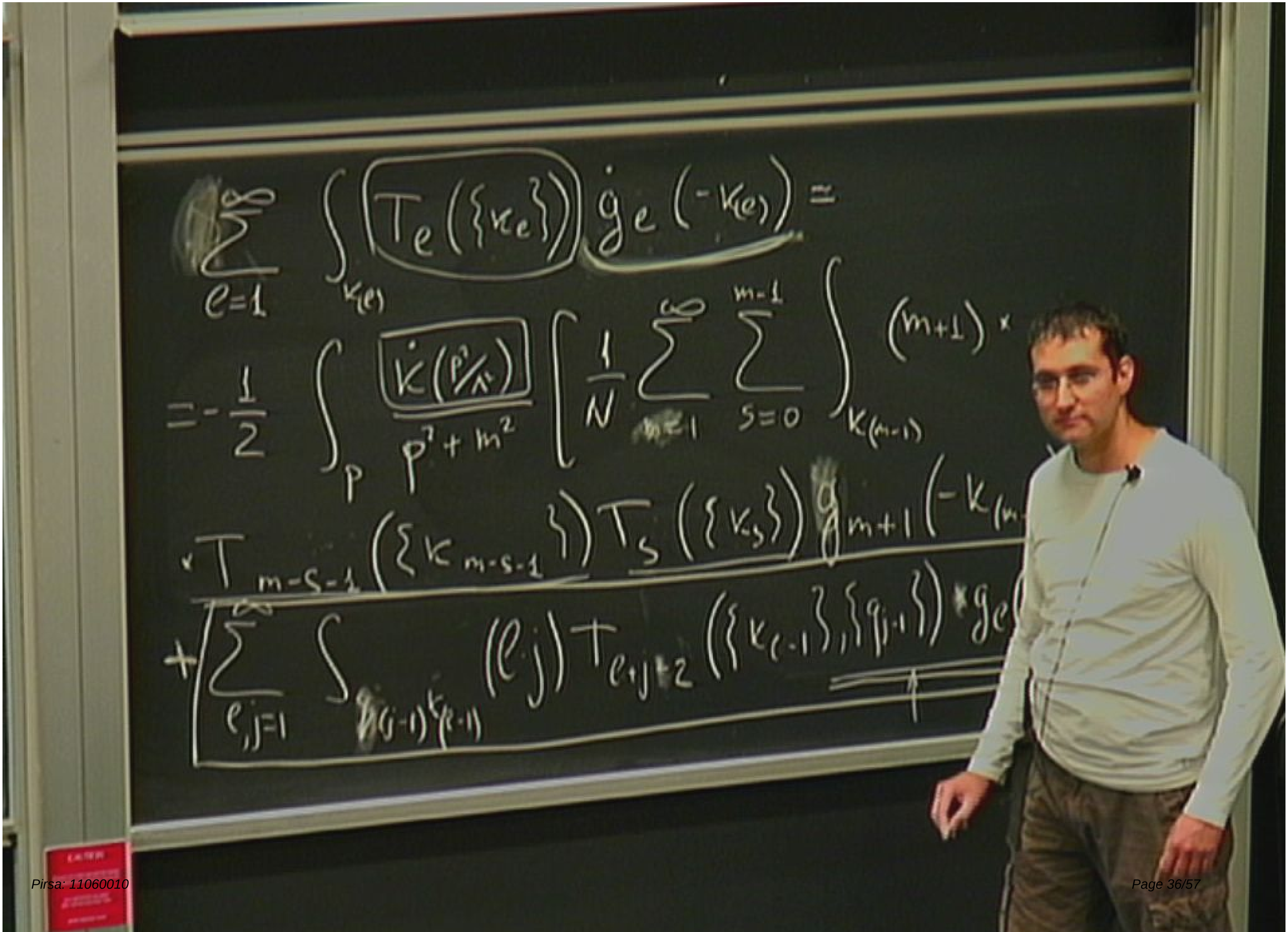

$\sum_{\ell=1}^{\infty} \int_{k(\ell)} T_\ell(\{k_\ell\})\, \dot g_\ell(-k(\ell)) =$
$= -\frac{1}{\;}\int_p \frac{\dot K(p^2/\Lambda^2)}{p^2+m^2}\Big[\frac{1}{N}\sum_{m=1}^{\infty}\sum_{s=0}^{m-1}\int_{k(m-1)} (m+1)\times$
$T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)})+$
$(\ell\, j)\, T_{\ell+j+2}(\{k_{\ell-1}\},\{q_{j-1}\})$

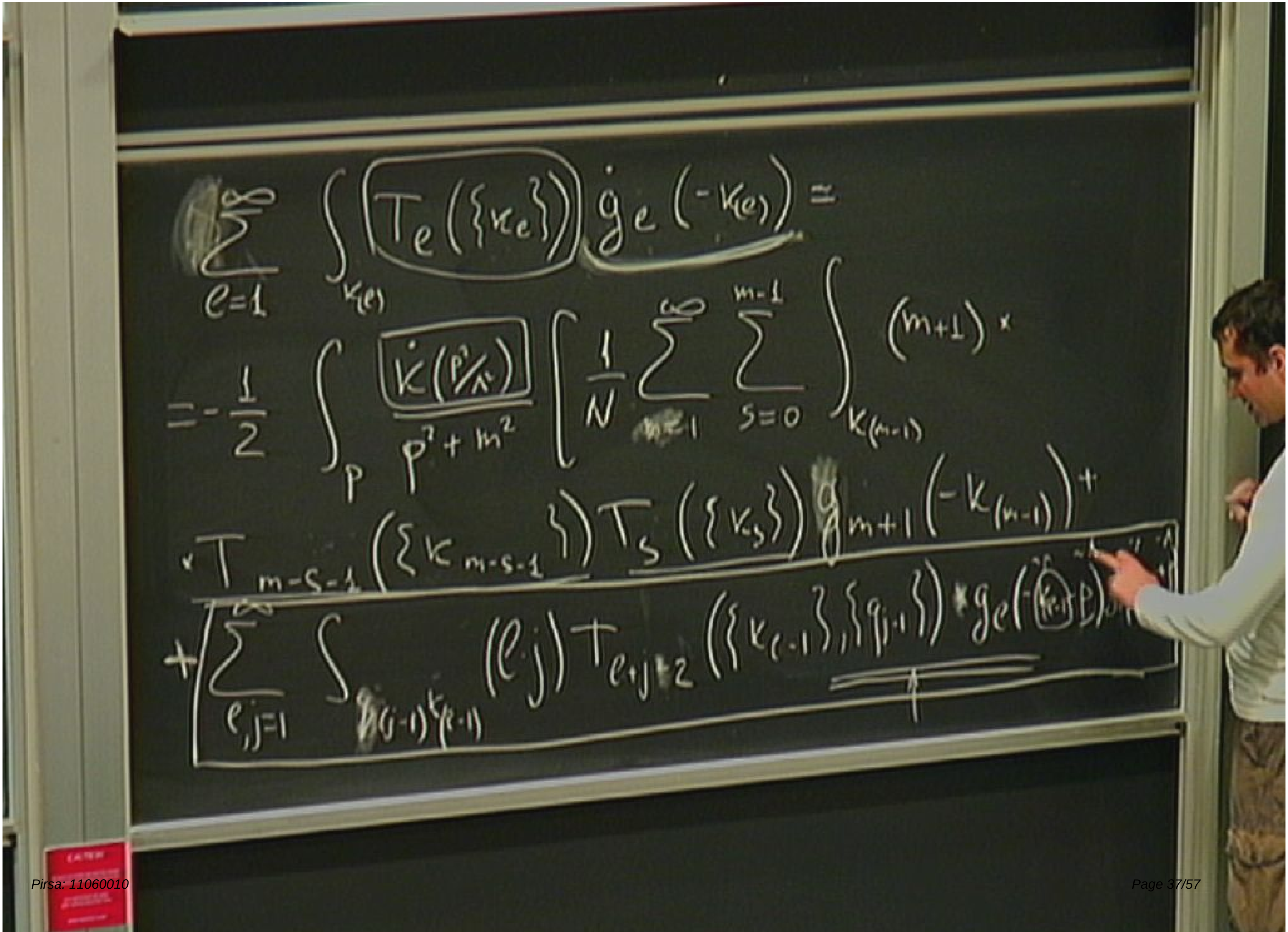
$$\begin{cases} \dot{\pi} = -\dfrac{\partial H(q,\pi)}{\partial q} \\ \dot{q} = \dfrac{\partial H(q,\pi)}{\partial \pi} \end{cases}$$

$$\begin{cases} \dot{\pi} = -\dfrac{\partial H(g,\pi)}{\partial g} \\ \dot{g} = \dfrac{\partial H(g,\pi)}{\partial \pi} \end{cases}$$

$$H = \int d^D k \left(\frac{}{} \right)$$

$$\delta(p^2 - \Lambda^2) \sim \dot{K}\left(p^2/\Lambda^2\right)$$


$\sum_{\ell=1}^{\infty} \int_{k(\ell)} \boxed{T_\ell(\{k_\ell\})}\, \dot{g}_\ell(-k(\ell)) =$
$= -\frac{1}{2} \int_p \frac{\boxed{\dot{K}(p^2/\Lambda^2)}}{p^2+m^2} \left[\frac{1}{N} \sum_{m=1}^{\infty} \sum_{s=0}^{m-1} \int_{k(m-1)} (m+1) \times \right.$
$\times T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m\ldots}$
$+ \sum_{\ell,j=1}^{\infty} \int_{q(j-1)\, k(\ell-1)} (\ell j)\, T_{\ell+j+2}(\{k_{\ell-1}\},\{q_{j-1}\})\, g_\ell($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$\times T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)}) +$
$+ \sum_{\ell,j=1}^{\infty} \int_{q(j-1) k(\ell-1)} (\ell j)\, T_{\ell+j+2}(\{k_{\ell-1}\},\{q_{j-1}\})\, g_\ell(-k_{\ell-1}\, p)$

$$\sum_{\ell=1}^{\infty} \int_{k_{(\ell)}} \boxed{T_\ell(\{k_\ell\})}\, \dot{g}_\ell(-k_{(\ell)}) =$$

$$= -\frac{1}{2} \int_p \frac{\boxed{\dot{K}(p^2/\Lambda^2)}}{p^2+m^2} \Bigg[\frac{1}{N} \sum_{m=1}^{\infty} \sum_{s=0}^{m-1} \int_{k_{(m-1)}} (m+1) \times$$

$$\times\, T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)}) +$$

$$+ \sum_{\ell,j=1}^{\infty} \int_{q_{(j-1)} k_{(\ell-1)}} (\ell j)\, T_{\ell+j+2}(\{k_{\ell-1}\},\{q_{j-1}\})\, g_\ell(-k_{(\ell-1)}-p)\, g_j(-q_{(j-1)}+p)$$

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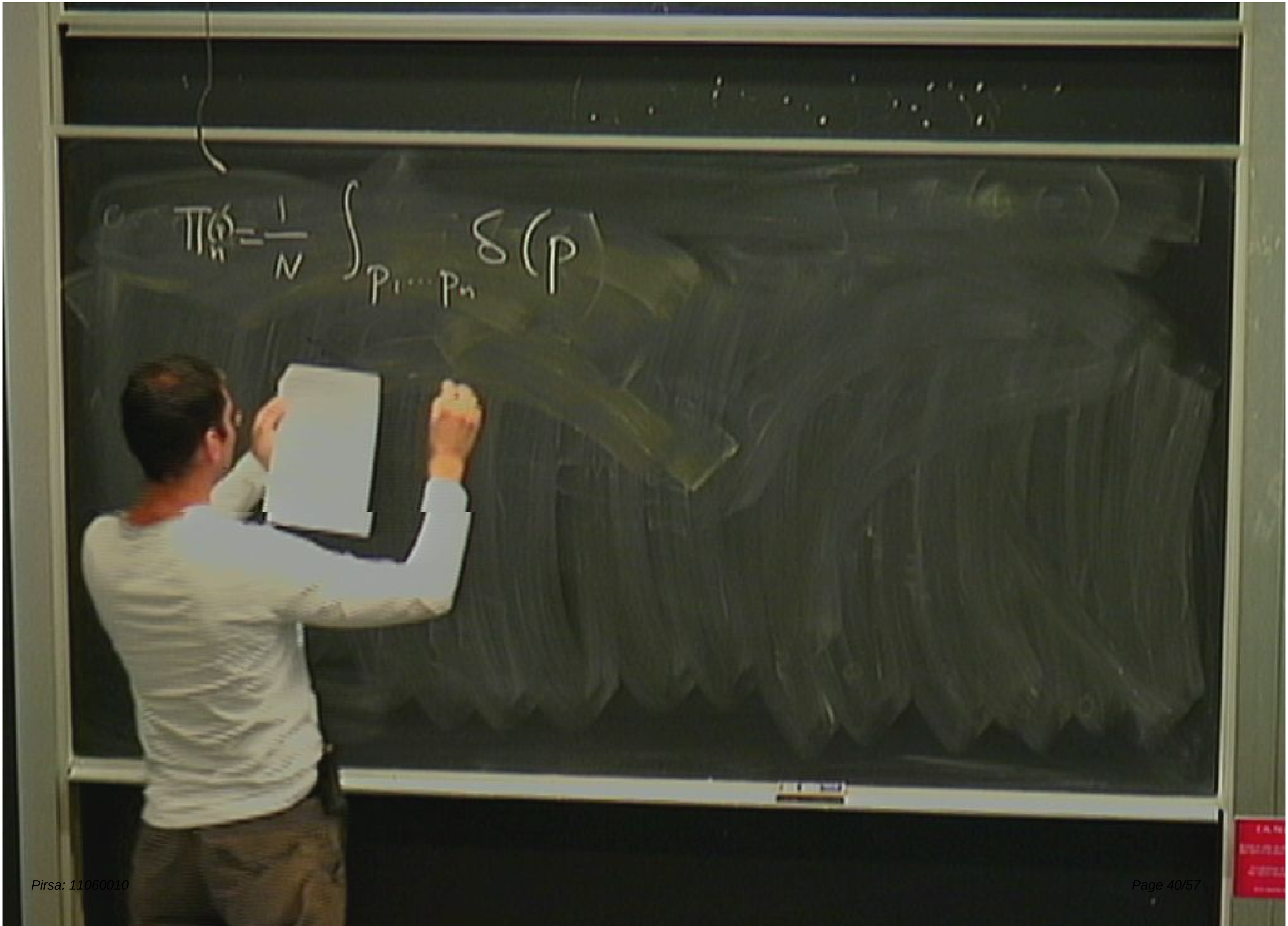
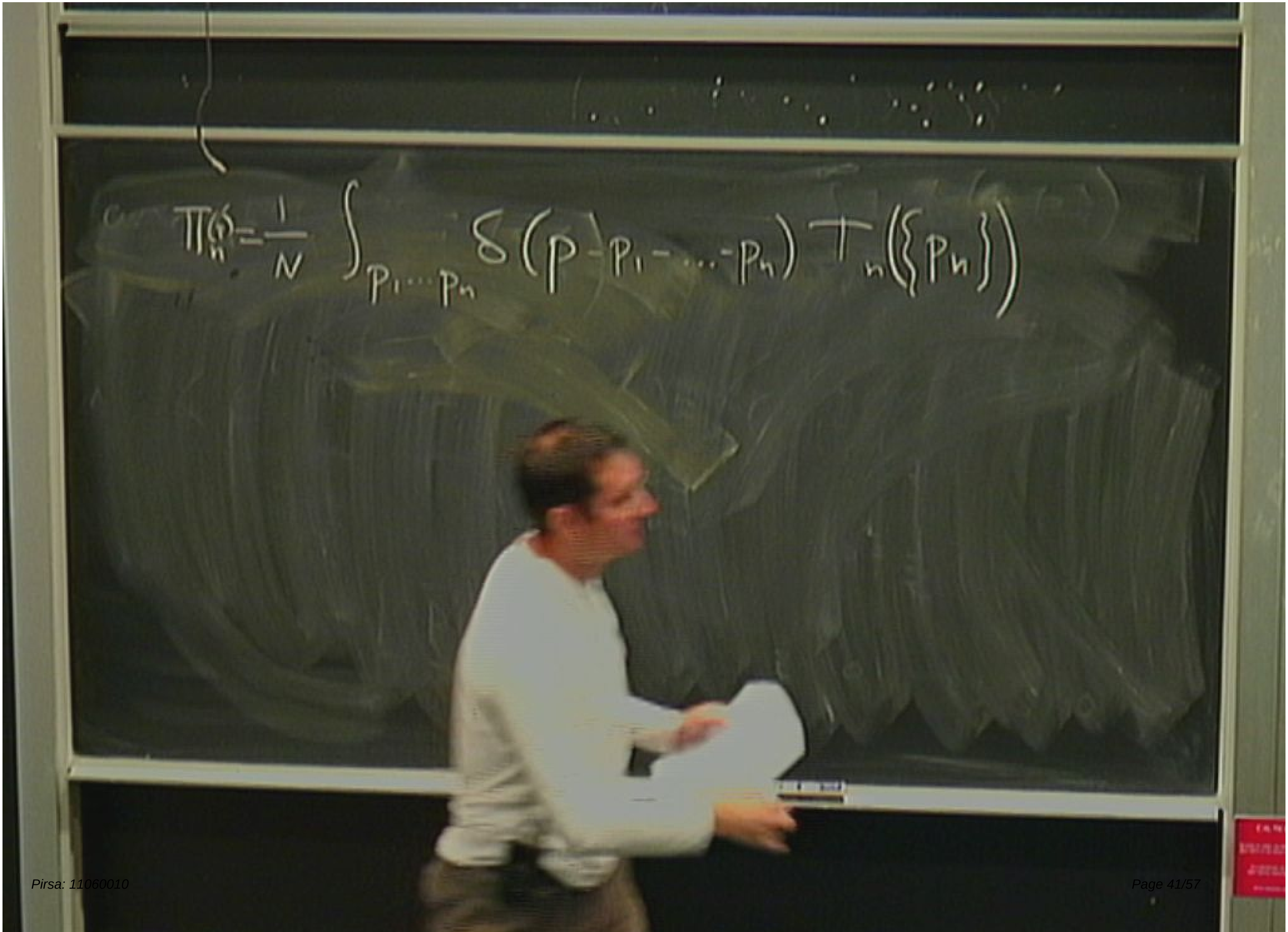
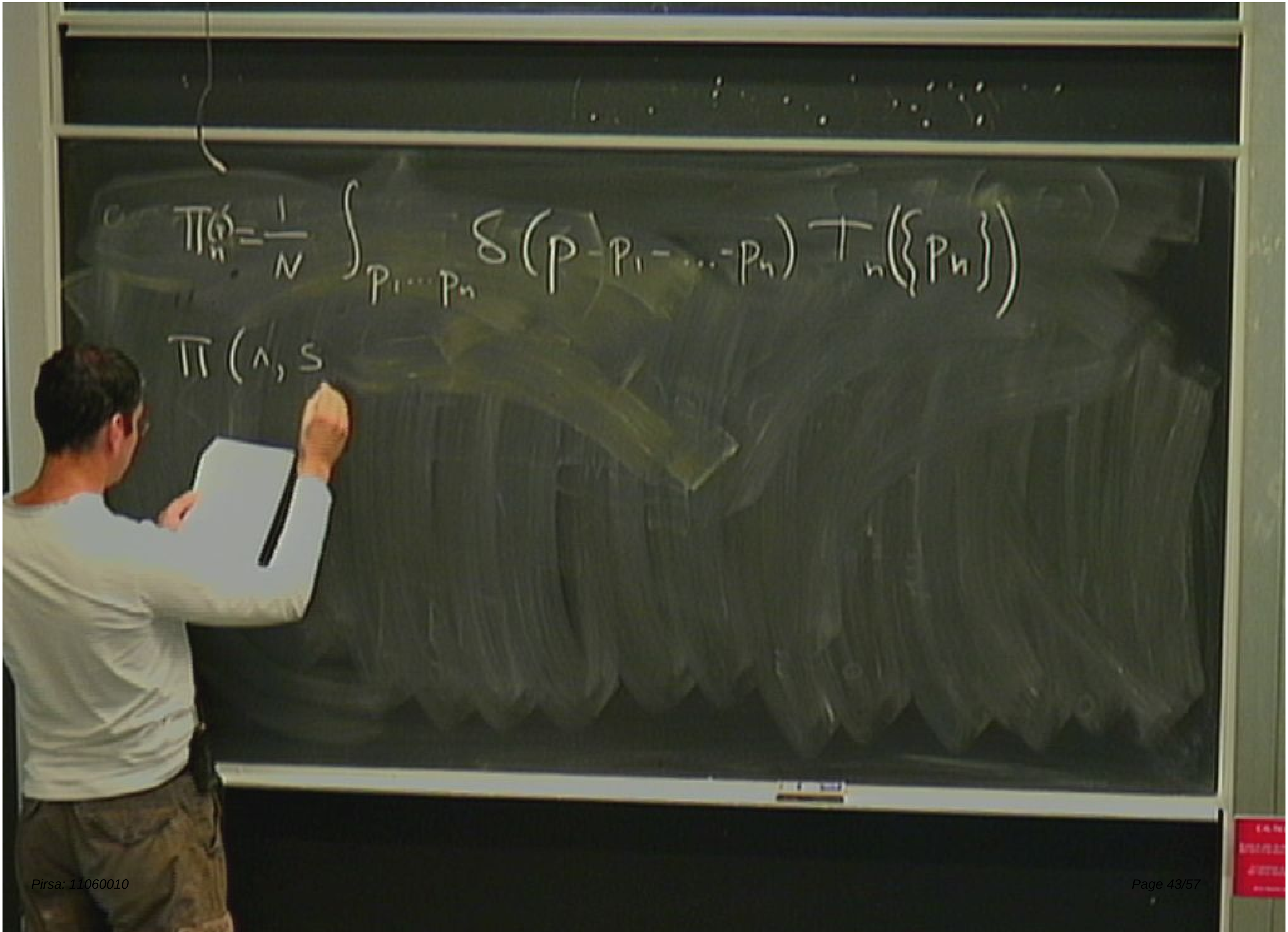
$$\times\, T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)}) \, +$$

$$+ \sum_{\ell, j=1}^{\infty} \int_{q(j-1)\, k(\ell-1)} (\ell j)\, \cancel{T_{\ell, j+2}(\{k_{\ell-1}\}, \{q_{j-1}\})}\; g_\ell(-k_{\ell-1}, p)\, g_j(-q_{j-1}, -p)$$


$\Pi_n(\zeta) = \frac{1}{N} \int_{p_1 \cdots p_n} \delta(p$


$\Pi_n(p) = \frac{1}{N}\int_{p_1\cdots p_n}\delta(p-p_1-\cdots-p_n)\,T_n(\{p_n\})$

$$\Pi_n(p) = \frac{1}{N} \int_{p_1 \cdots p_n} \delta(p - p_1 - \dots - p_n)\, T_n(\{p_n\})$$


$\Pi_n^{(s)} = \frac{1}{N} \int_{p_1 \cdots p_n} \delta(p - p_1 - \ldots - p_n)\, T_n(\{p_n\})$
$\Pi(n, s$

$$\Pi_n^{(p)} = \frac{1}{N}\int_{p_1\cdots p_n} \delta(p-p_1-\dots-p_n)\, T_n(\{p_n\})$$

$$\Pi(\lambda, \sigma, x) = \sum_k \sigma^{-(k+1)}\, \Pi_k(\lambda, x)$$

$$g(\lambda, \sigma, x) = \sum_k \sigma^k\, g_k(\lambda, x)$$

$$H = \int_{-\pi}^{\pi} d\sigma \int d^D x \, \Pi^2 \cdot g'$$

$$g' = \partial_\sigma g$$

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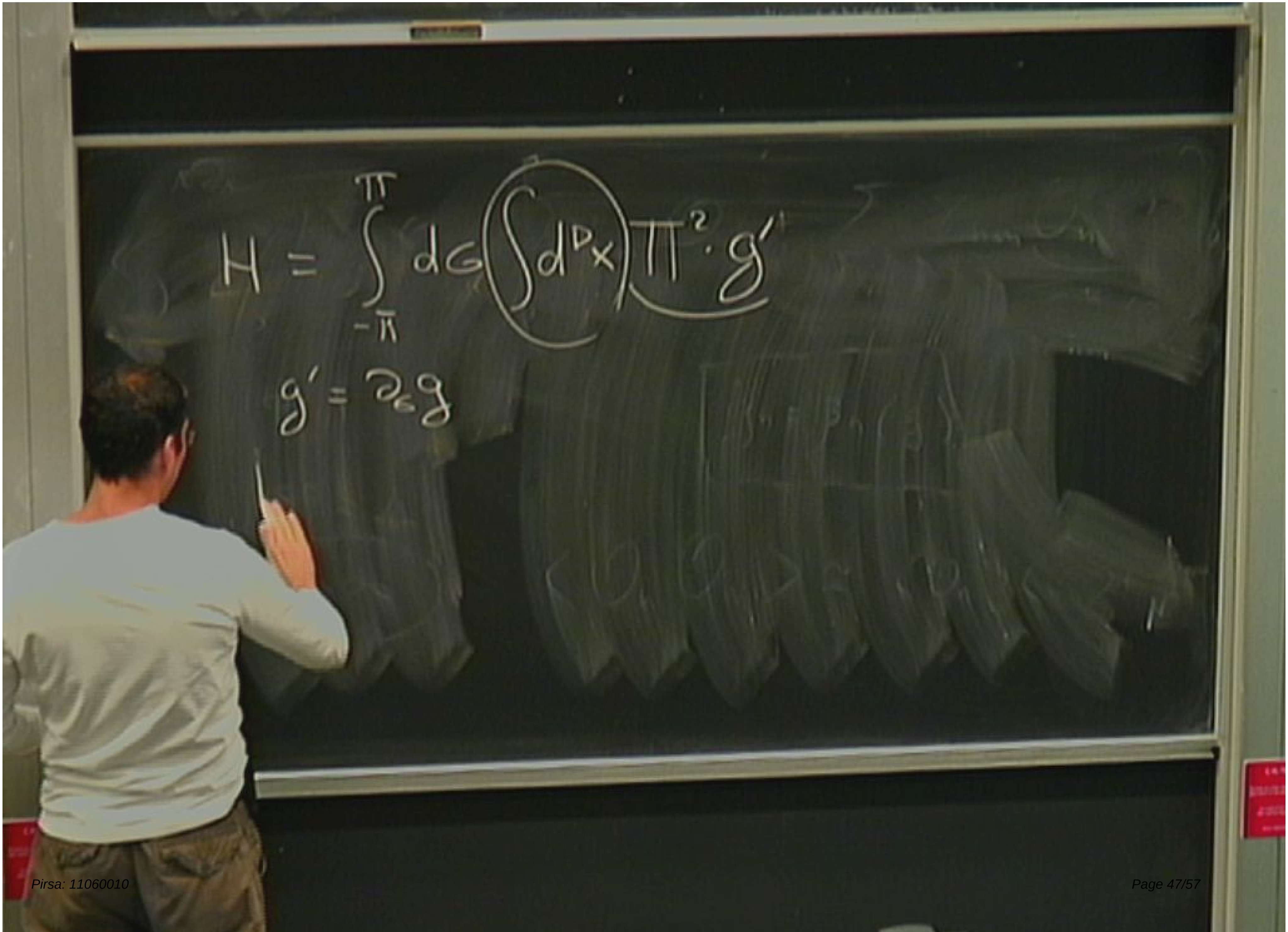
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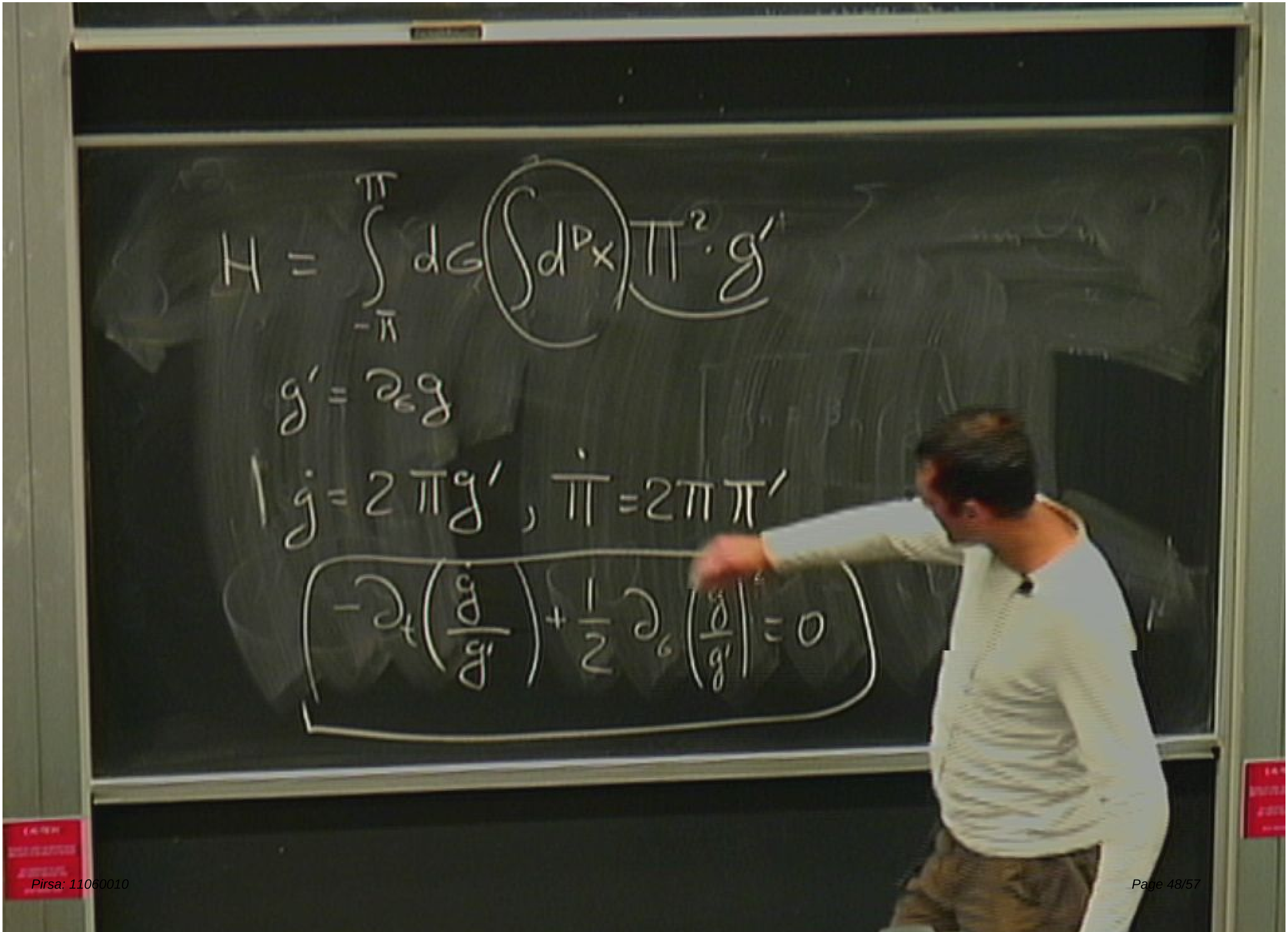

$H = \int_{-\pi}^{\pi} d\sigma \left(\int d^D x\right) \pi^2 \cdot g'$
$g' = \partial_\sigma g$
$\dot{g} = 2\pi g', \quad \dot{\pi} = 2\pi \pi'$
$-\partial_t\left(\frac{\dot{g}}{g'}\right) + \frac{1}{2}\partial_\sigma\left(\frac{\dot{g}}{g'}\right) = 0$

$$H = \int_{-\pi}^{\pi} d\sigma \left(\int d^D x\right) \pi^2 \cdot g'$$

$$g' = \partial_\sigma g$$

$$\dot{g} = 2\pi g' \,, \quad \dot{\pi} = 2\pi \pi'$$

$$-\partial_t\left(\frac{\dot{g}}{g'}\right) + \frac{1}{2}\partial_\sigma\left(\frac{\dot{g}}{g'}\right)^2 = 0$$

$$H = \int_{-\pi}^{\pi} d\sigma \left(\int d^D x\right) \pi^2 \cdot g'$$

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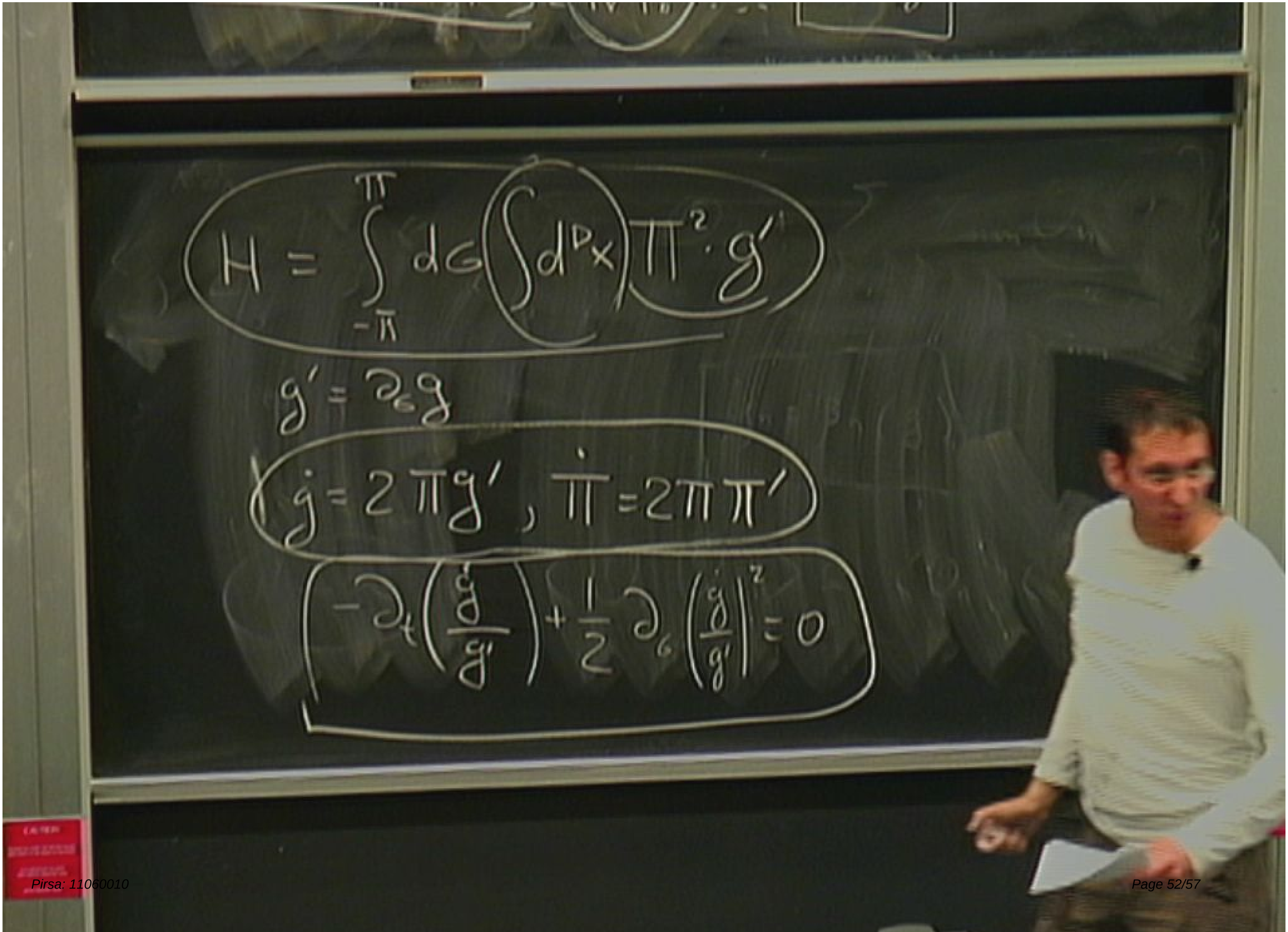
$$\boxed{-\partial_t\left(\frac{\dot{g}}{g'}\right) + \frac{1}{2}\partial_\sigma\left(\frac{\dot{g}}{g'}\right)^2 = 0}$$

$$\sum_{\ell=1}^{\infty} \int_{k(\ell)} T_\ell(\{k_\ell\})\, \dot{g}_\ell(-k_{(\ell)}) =$$

$$= -\frac{1}{2}\left(\int_p \frac{\boxed{\dot{K}(p^2/\Lambda^2)}}{p^2+m^2}\right)\left[\frac{1}{N}\sum_{m=1}^{\infty}\sum_{s=0}^{m-1}\int_{k_{(m-1)}} (m+1)\times\right.$$

$$\times T_{m-s-1}(\{k_{m-s-1}\})\, T_s(\{k_s\})\, g_{m+1}(-k_{(m-1)}) +$$

$$+\sum_{\ell,j=1}^{\infty}\int_{q_{(j-1)} k_{(\ell-1)}} (\ell\, j)\, T_{\ell+j}\cancel{{}_{+2}}(\{k_{\ell-1}\},\{q_{j-1}\})\, g_\ell(-k_{(\ell-1)} - p)\, g_j(-q_{(j-1)} + p)$$


$H = \int_{-\pi}^{\pi} d\sigma \left(\int d^D x \right) \pi^2 \cdot g'$
$g' = \partial_\sigma g$
$\dot{g} = 2\pi g', \quad \dot{\pi} = 2\pi \pi'$
$-\partial_t \left(\frac{\dot{g}}{g'} \right) + \frac{1}{2} \partial_\sigma \left(\frac{\dot{g}}{g'} \right)^2 = 0$

$g(\{k\})$

$T(\{k\})$

$-H$

$$\boxed{g(\{\kappa\})}$$

$$T(\{\kappa\})$$

$$H = \iint \left(T^2 g + g^2 T \right)$$

$$\boxed{g(\{k\})}$$

$$T(\{k\})$$

$$\underline{N \to \infty}$$

$$\boxed{H = \iint \left(T^2 g + g^2 T \right)}$$

$$\boxed{g(\{k\})}$$

$$T(\{k\})$$

$$\underline{N \to \infty}$$

$$p^2 x + x^2 p$$

$$\boxed{H = \iint \left(T^2 g + g^2 T\right)}$$

$$\{g, T\} = \delta(\quad)$$

$\boxed{g(\{x\})}$

$T(\{x\})$

$\underline{N \to \infty}$

$p^2 x + x^2 p$

$$\boxed{H = \iint \left(T^2 g + g^2 T \right)}$$

$\{g, T\} = \delta(\ \ )$