Title: The Konishi multiplet at strong coupling

Date: Mar 01, 2011 11:00 AM

URL: http://pirsa.org/11030078

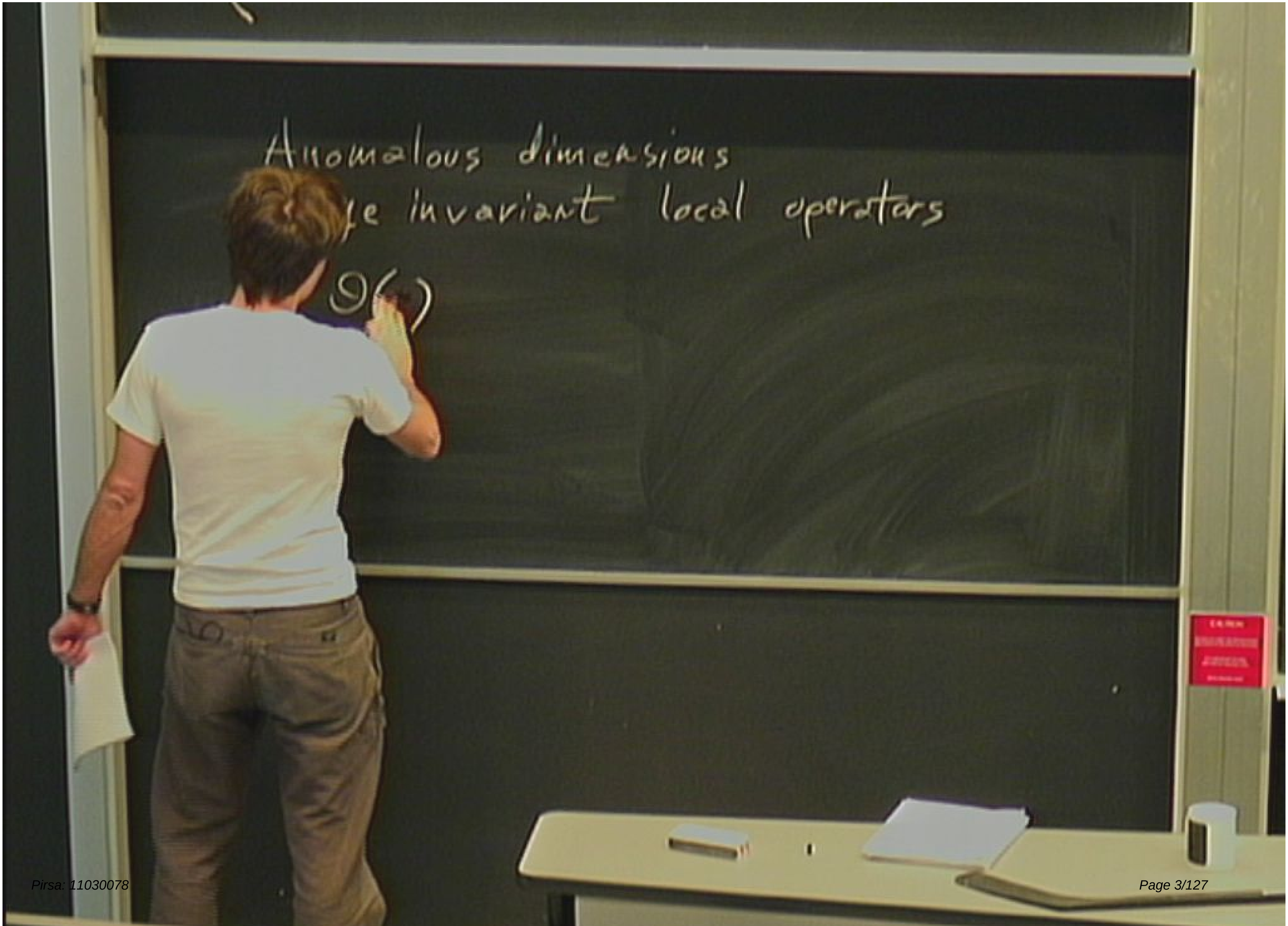
Abstract: I will describe a method to compute from first principles the anomalous dimension of short operators in N=4 super Yang-Mills theory at strong coupling, where they are described in terms of superstring vertex operators in an anti-de Sitter background. I will focus on the Konishi multiplet, dual to the first massive level of the superstring, and compute the one-loop correction to its anomalous dimension at strong coupling, using the pure spinor formalism for the superstring.

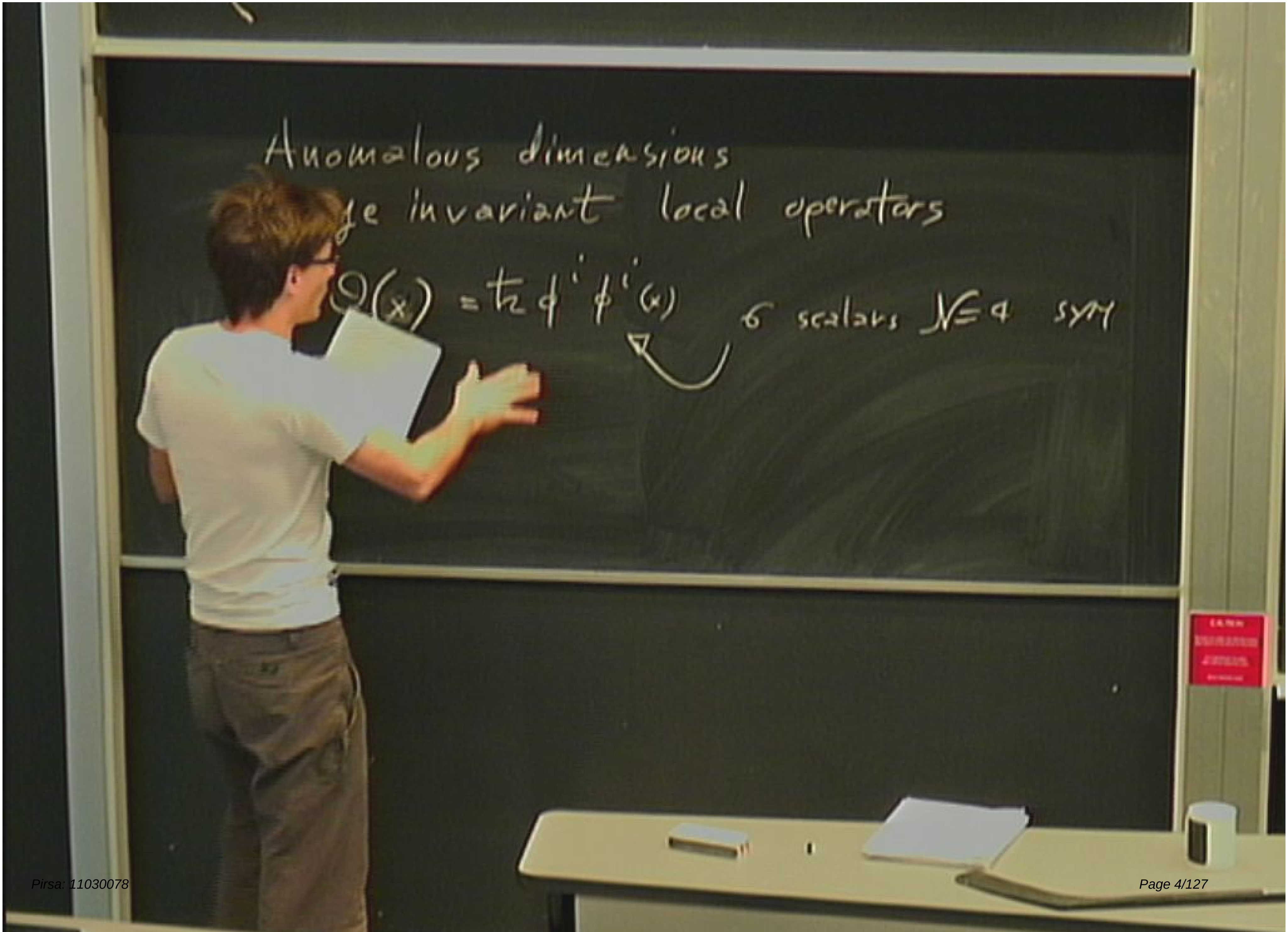
The Konishi multiplet @ strong coupling

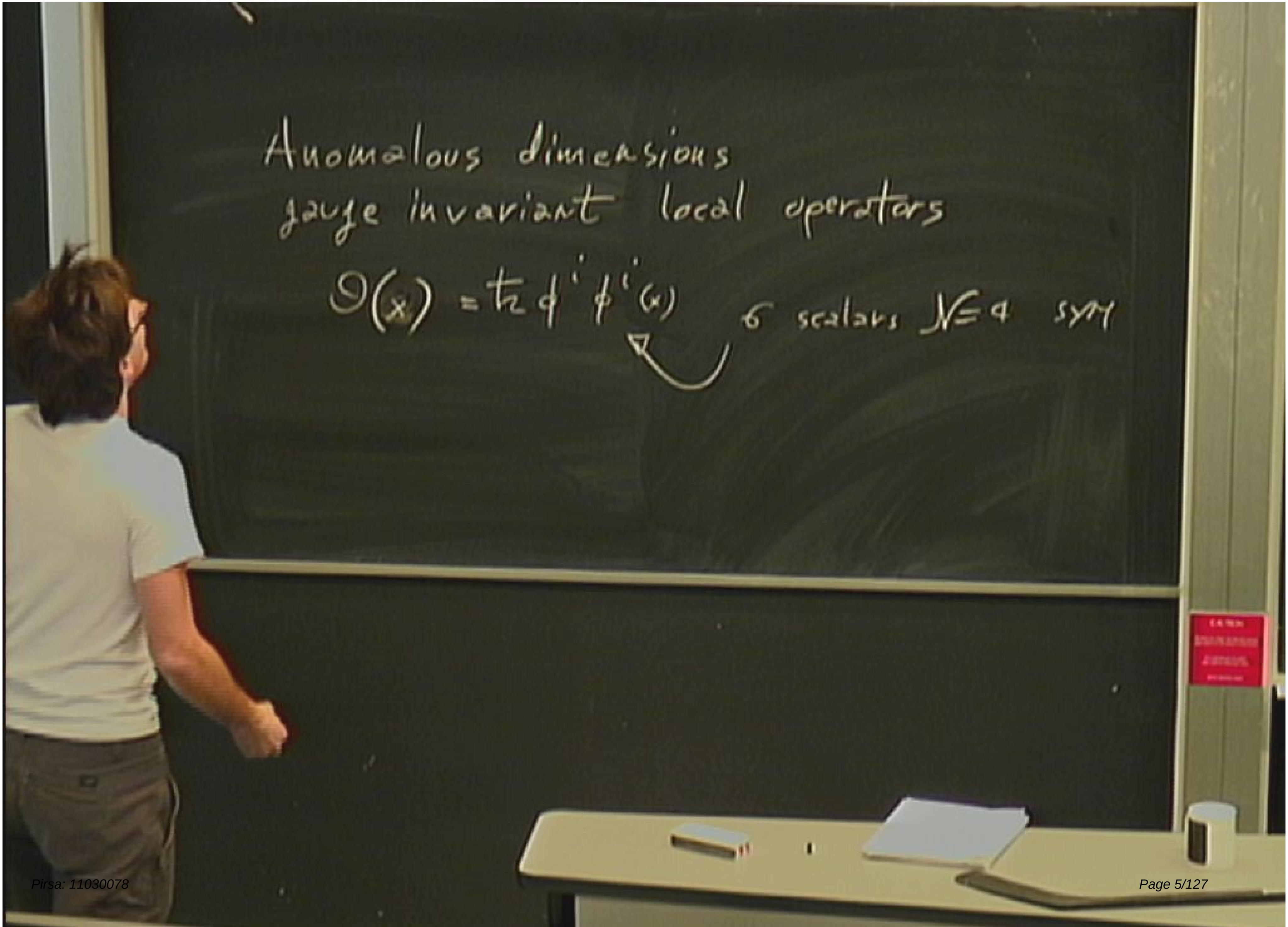
with BRENNO CARLINI VALLILO

arxiv: 1102.1219

$$\Delta - \Delta_0 = 2\sqrt[4]{\lambda} - 4 + \frac{2}{\sqrt[4]{\lambda}}$$


Anomalous dimensions
invariant local operators


Anomalous dimensions
ge invariant local operators
$O(x) = \mathrm{tr}\, \phi^i \phi^i (x)$
6 scalars $\mathcal{N}=4$ SYM


Anomalous dimensions
gauge invariant local operators
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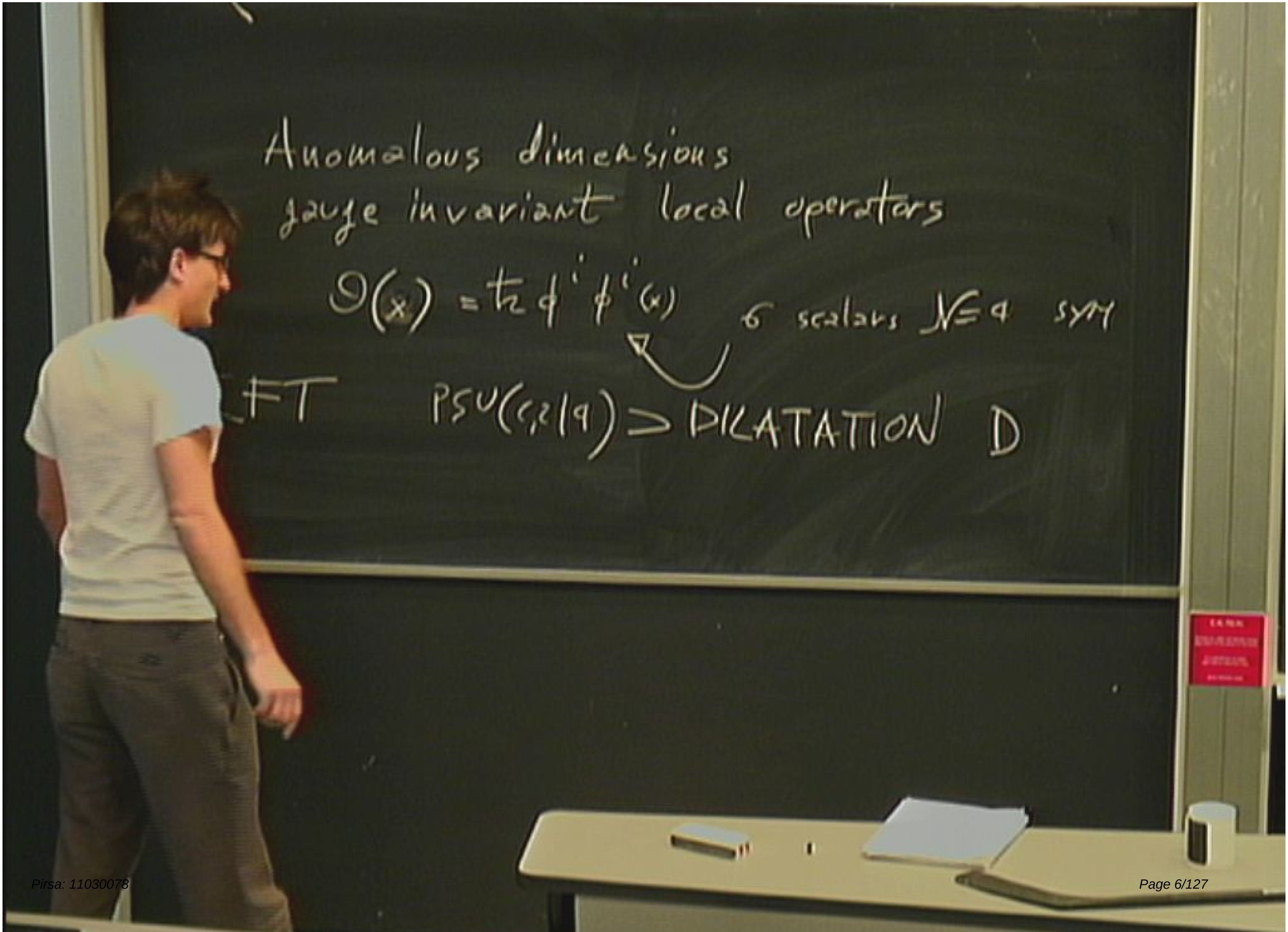
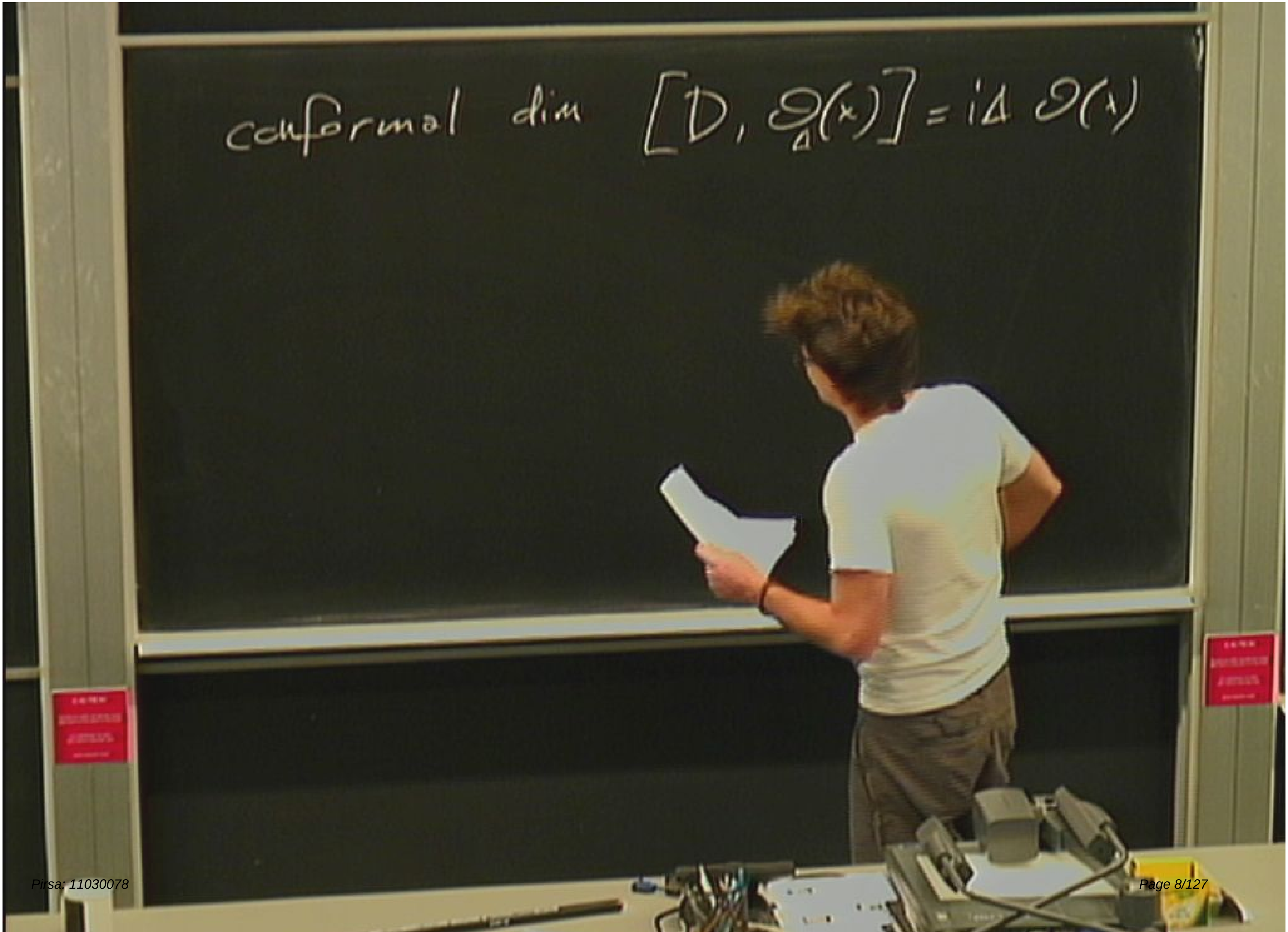

Anomalous dimensions
gauge invariant local operators
$\mathcal{O}(x) = \mathrm{tr}\, \phi^i \phi^i (x)$
6 scalars $\mathcal{N}=4$ SYM
FT
$PSU(2,2|4) \supset$ DILATATION D

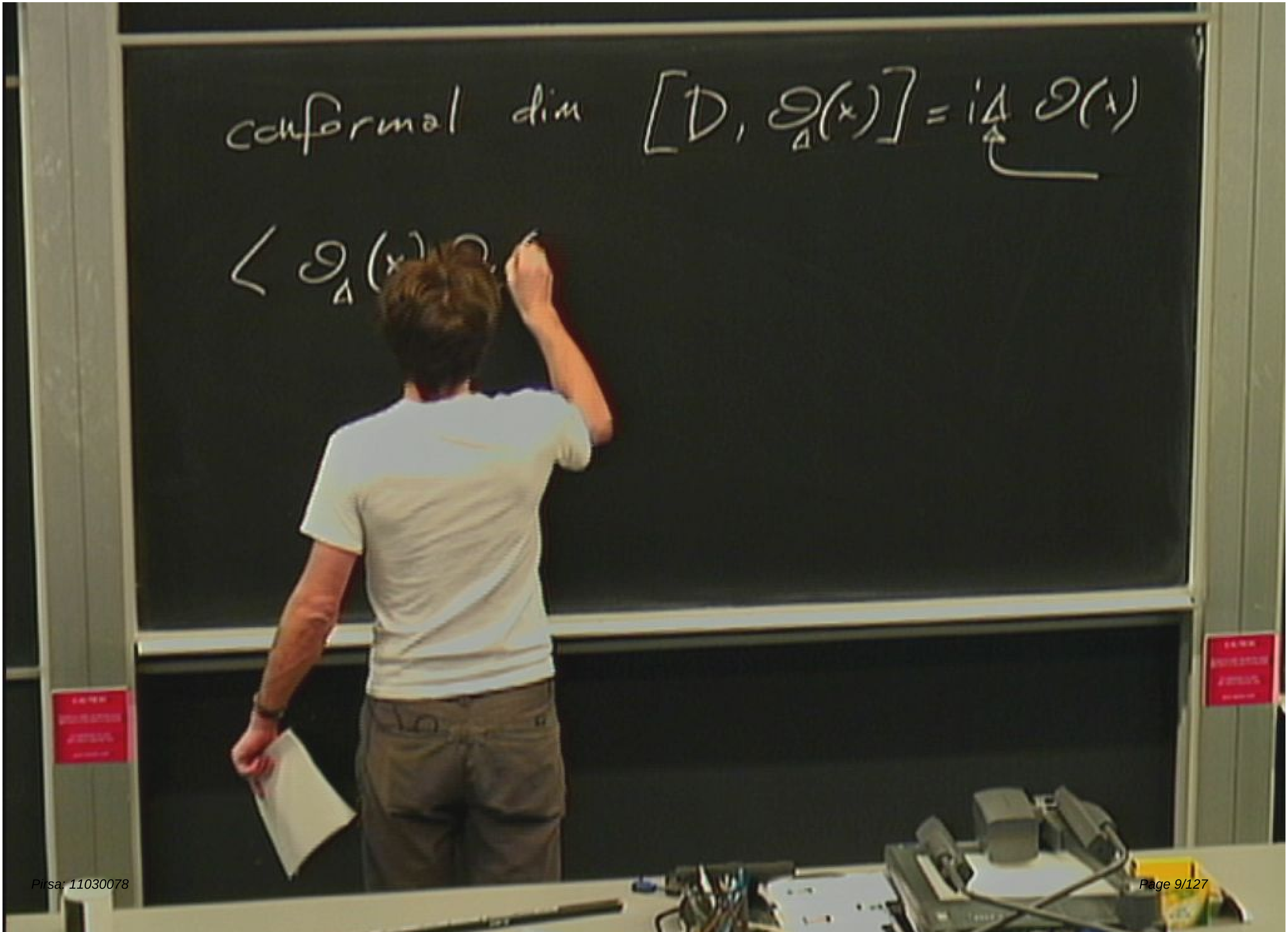
Anomalous dimensions

gauge invariant local operators

$\mathcal{O}(x) = \mathrm{tr}\,\phi^i \phi^i(x)$ 6 scalars $\mathcal{N}=4$ SYM

CFT $PSU(2,2|4) \supset$ DILATATION D


conformal dim $[D, \mathcal{O}_\Delta(x)] = i\Delta\, \mathcal{O}(x)$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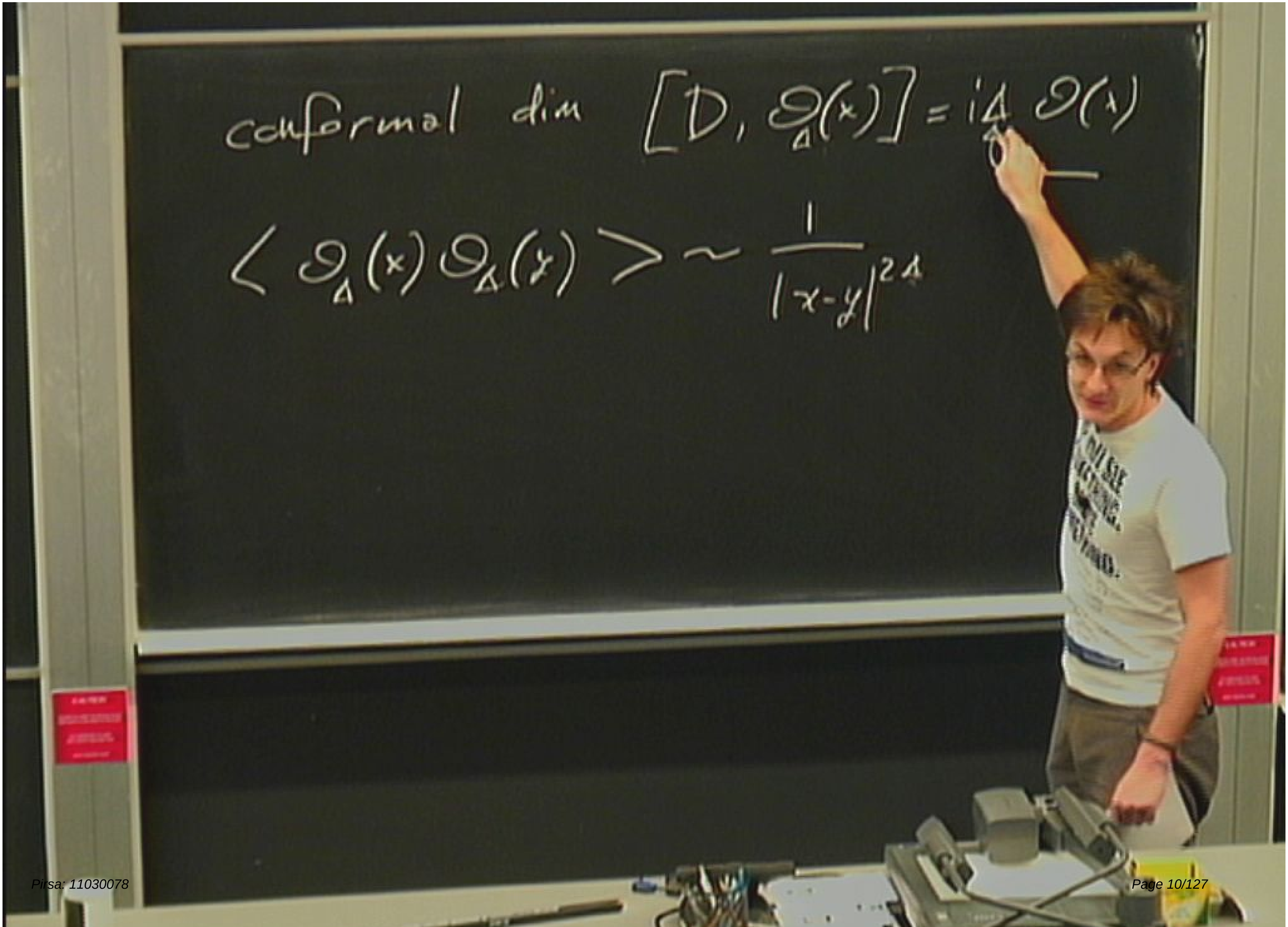
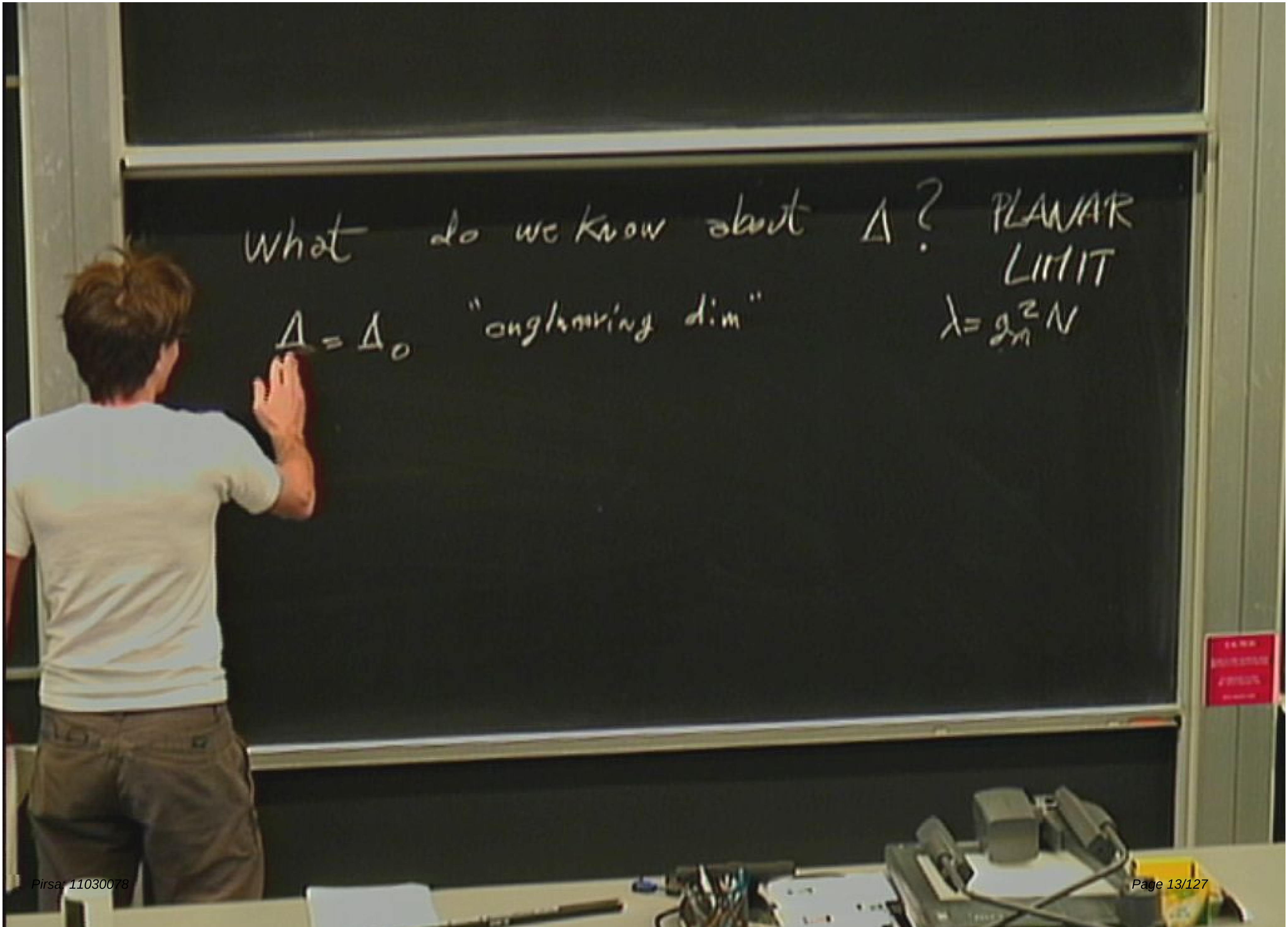
$\langle \mathcal{O}_\Delta(x)$

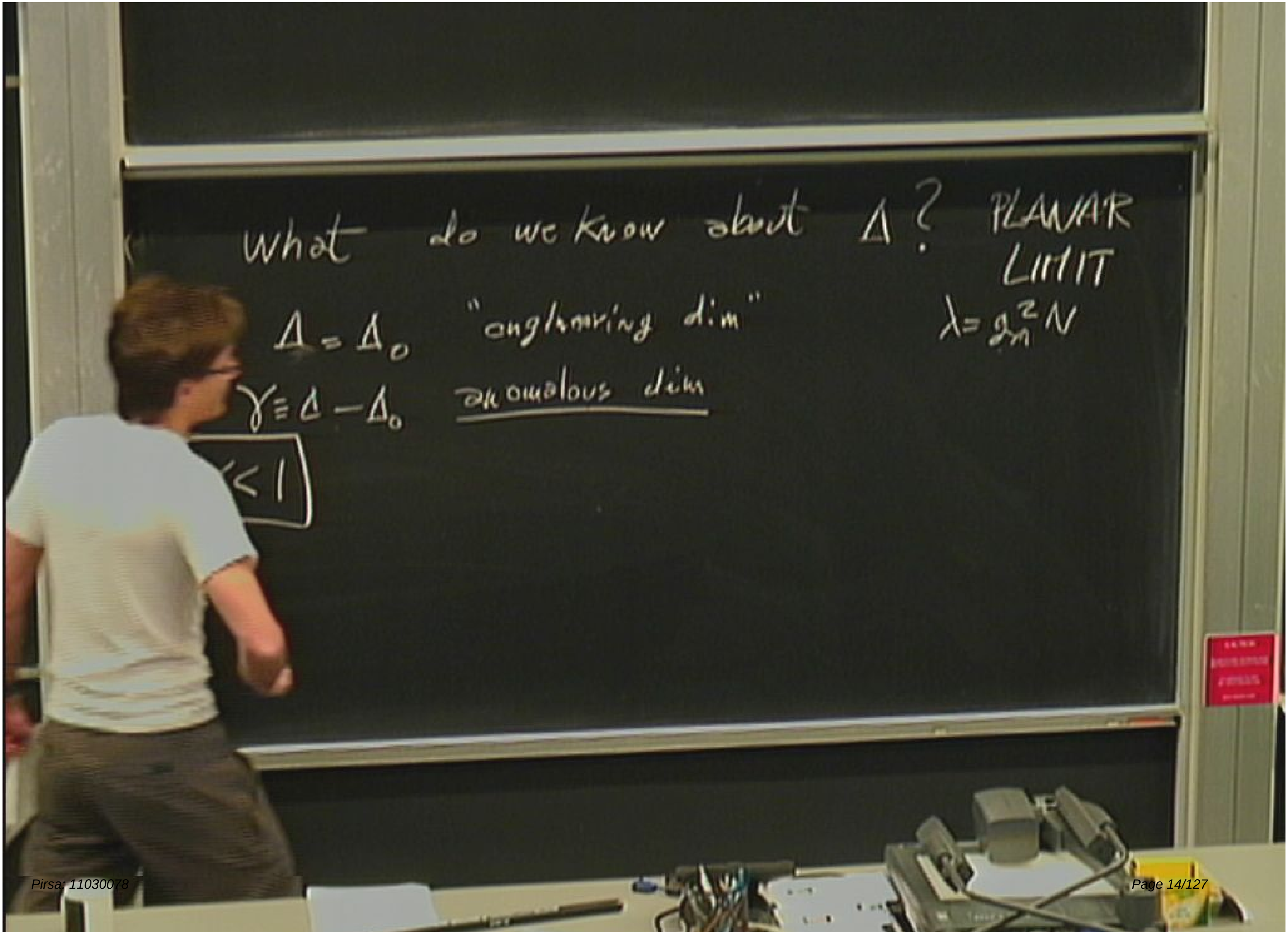

conformal dim $[D, \mathcal{O}_\Delta(x)] = i\Delta\, \mathcal{O}(x)$
$\langle \mathcal{O}_\Delta(x)\, \mathcal{O}_\Delta(y) \rangle \sim \frac{1}{|x-y|^{2\Delta}}$

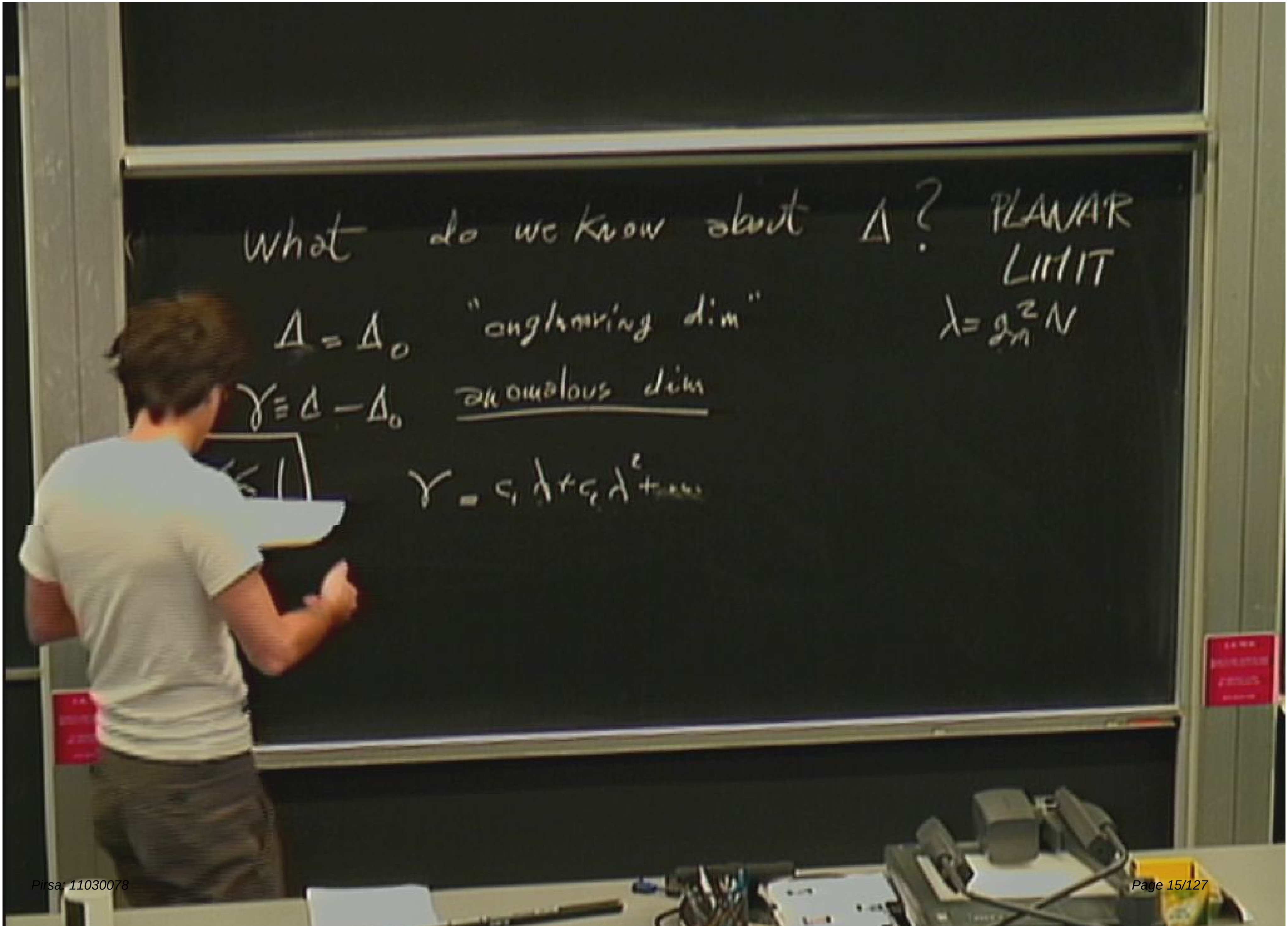
What do we know about Δ? PLANAR LIMIT

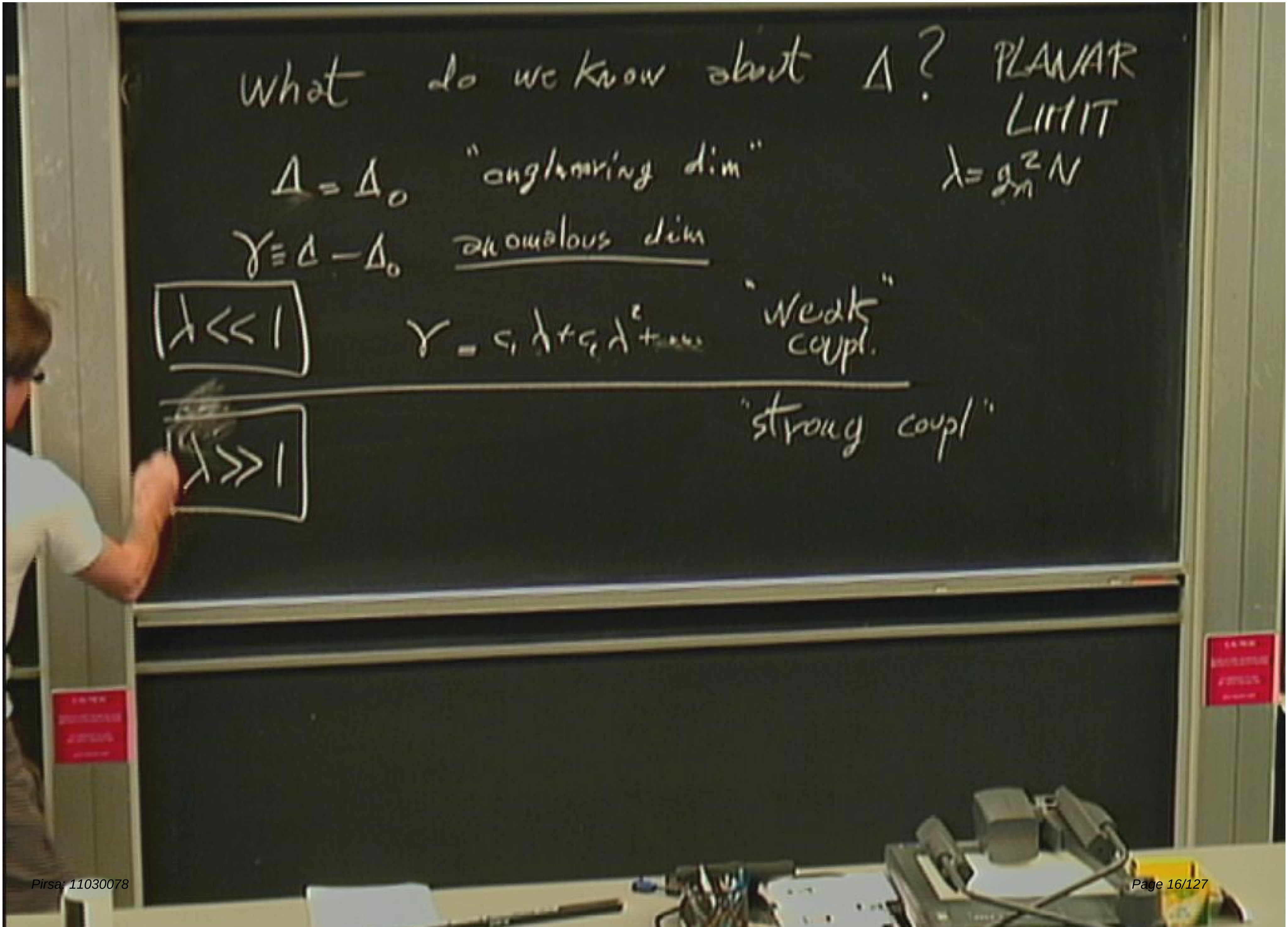
What do we know about Δ? PLANAR LIMIT

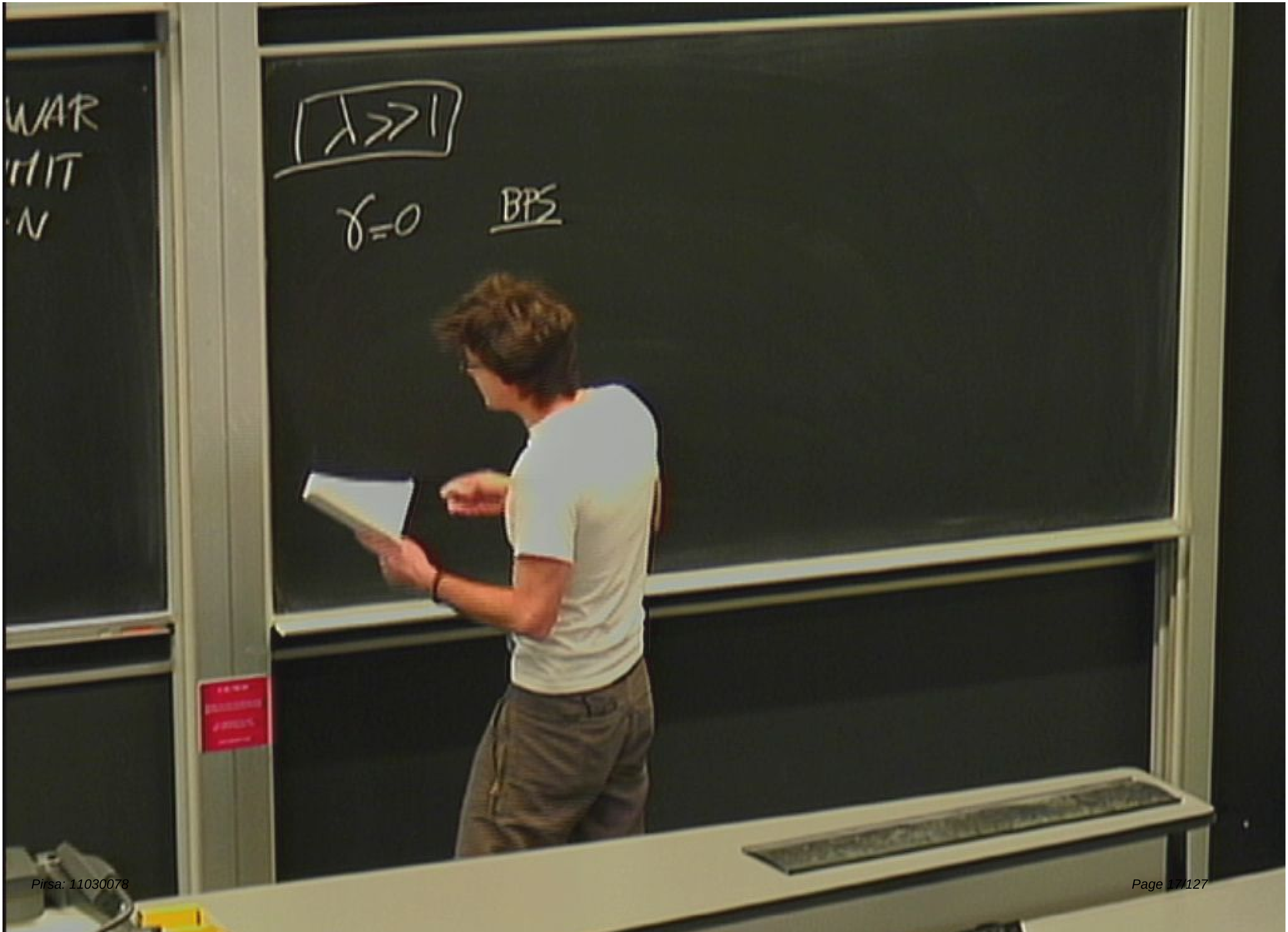
$\Delta = \Delta_0$ "engineering dim"

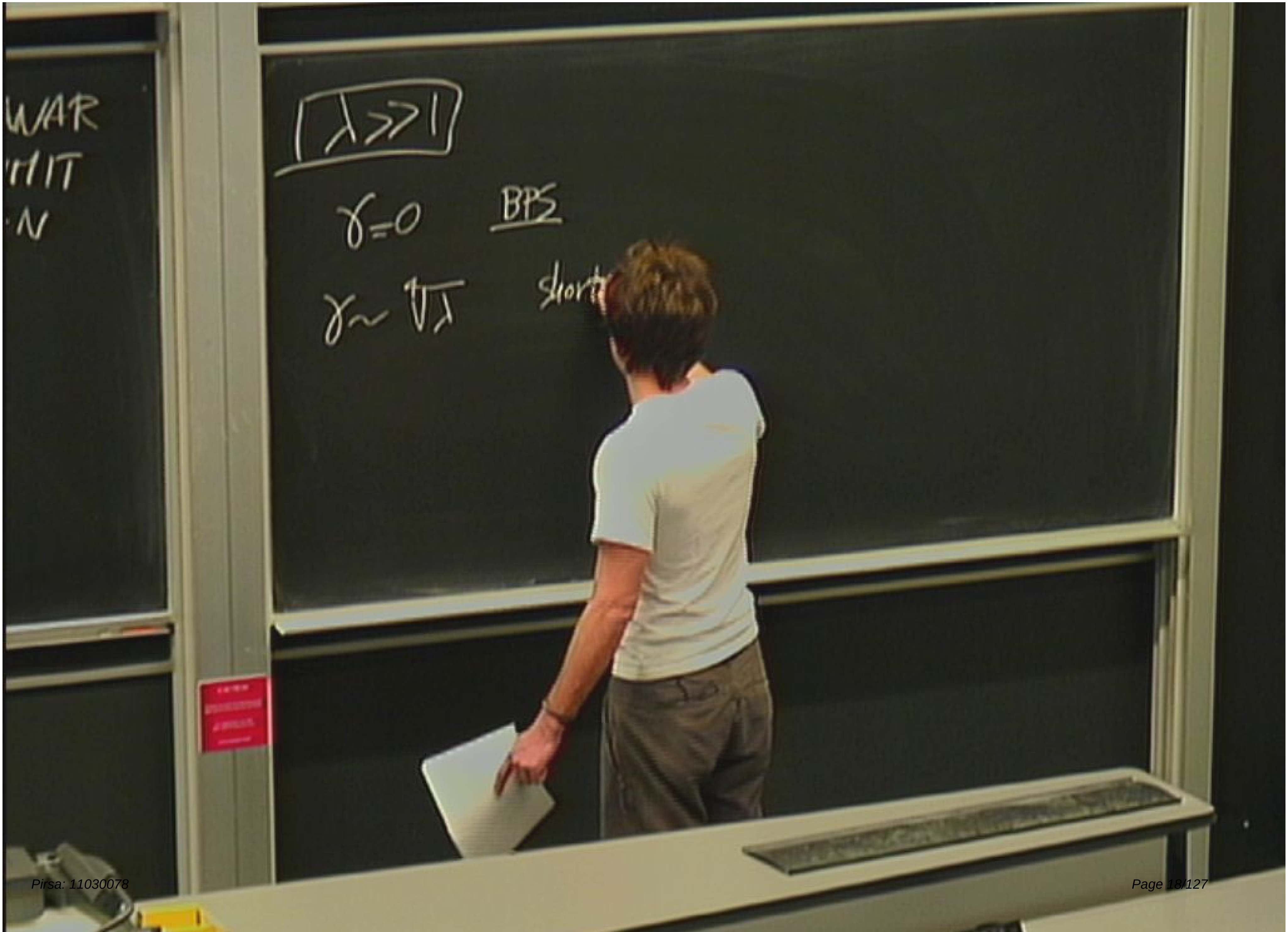

What do we know about Δ? PLANAR LIMIT
Δ = Δ₀ "engineering dim"
λ = g²ₘ N

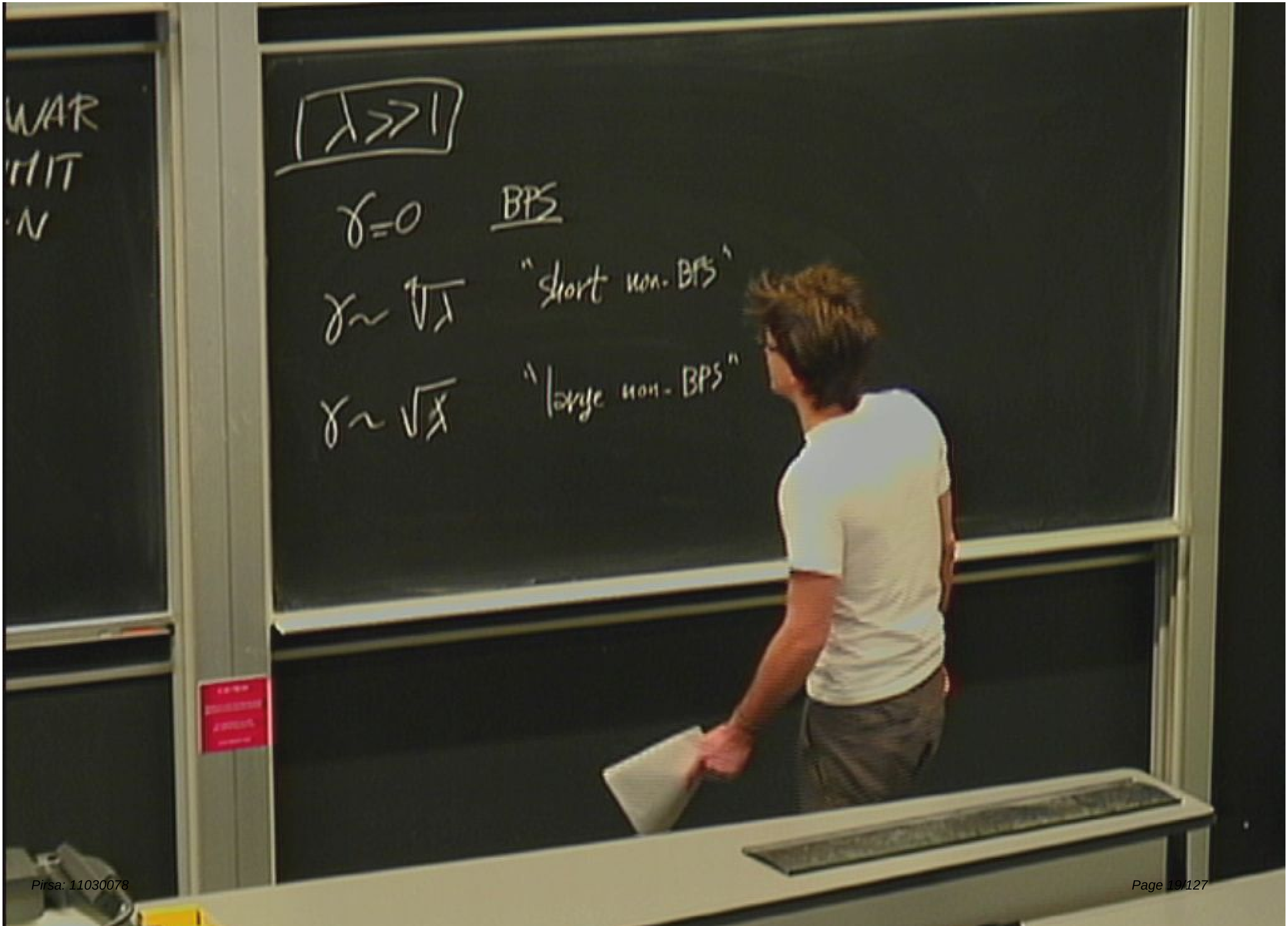

What do we know about Δ?
PLANAR LIMIT
λ = g²N
Δ = Δ₀ "engineering dim"
γ ≡ Δ − Δ₀ anomalous dim
< 1

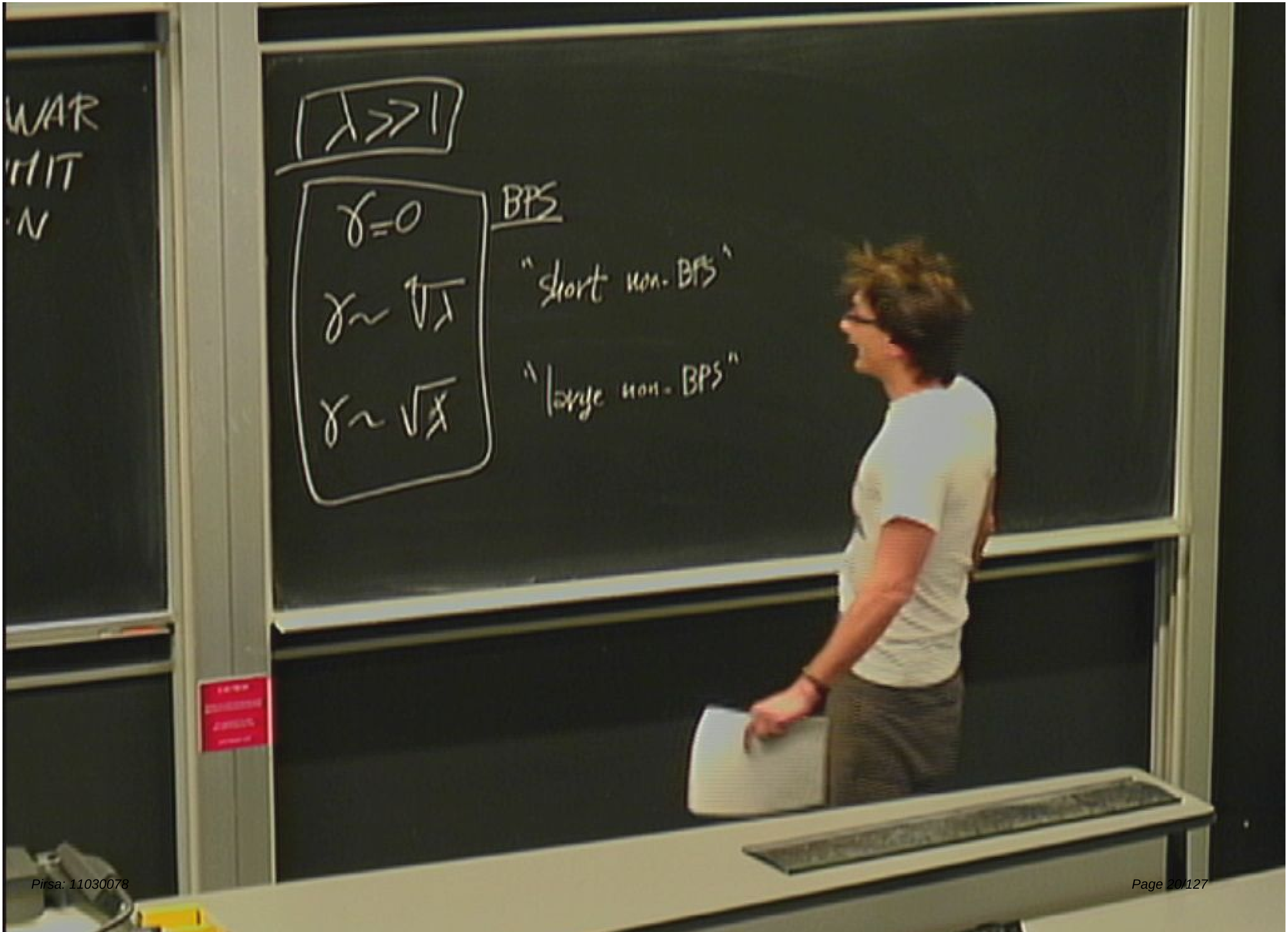

What do we know about Δ?
PLANAR LIMIT
$\lambda = g_{YM}^2 N$
$\Delta = \Delta_0$ "engineering dim"
$\gamma \equiv \Delta - \Delta_0$ anomalous dim
$\gamma = c_1 \lambda + c_2 \lambda^2 + \ldots$


What do we know about Δ?
PLANAR LIMIT
Δ = Δ0 "engineering dim"
λ = g2N
γ ≡ Δ − Δ0 anomalous dim
λ << 1
γ = c1 λ + c2 λ2 + ...
"weak" coupl.
λ >> 1
"strong coupl"


λ>>1
γ=0
BPS


λ>>1
γ=0 BPS
γ~ ⁴√λ short


λ>>1
γ=0 BPS
γ~ ⁴√λ "short non-BPS"
γ~ √λ "large non-BPS"


λ>>1
γ=0
BPS
γ~ ⁴√λ
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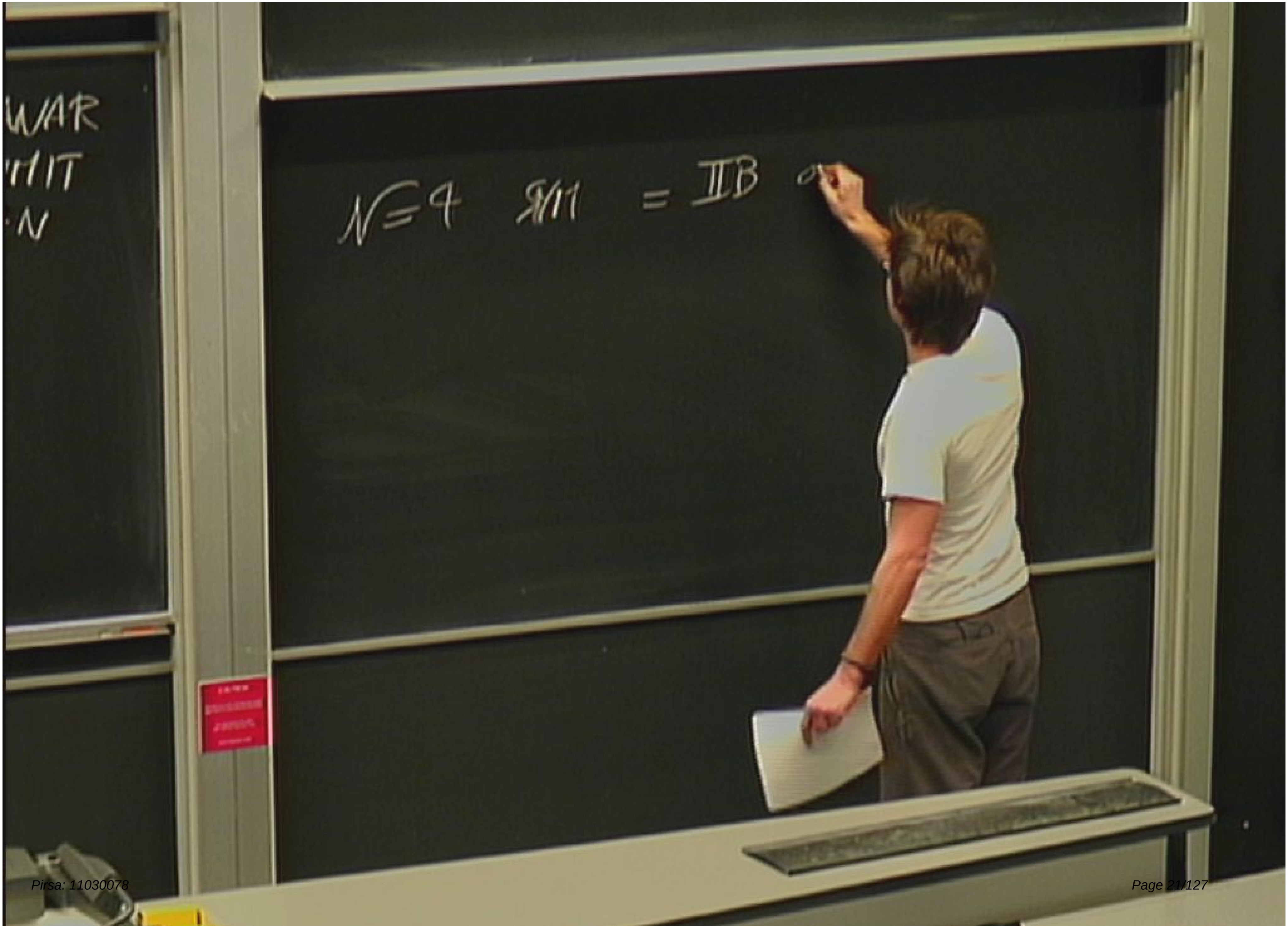
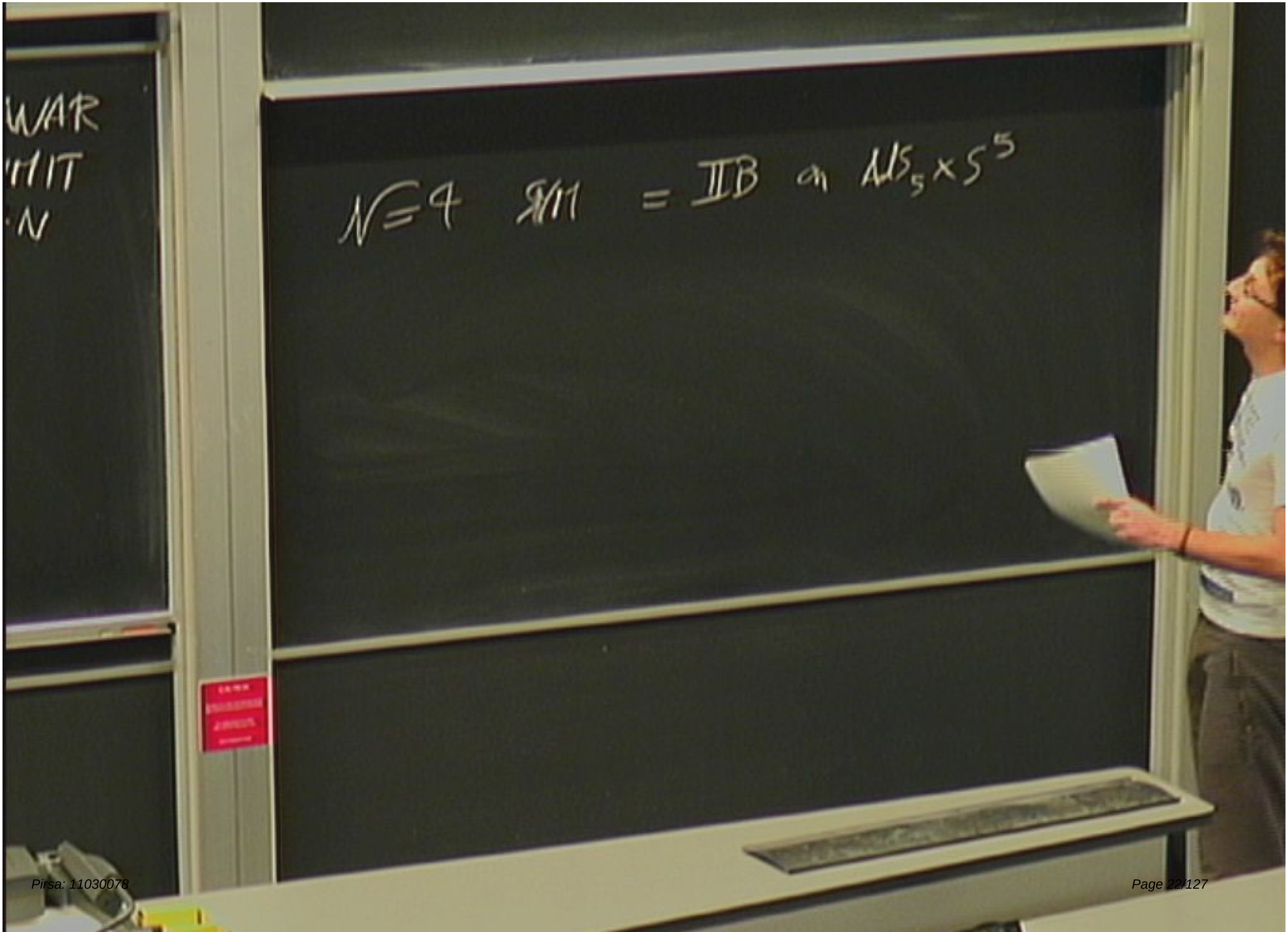
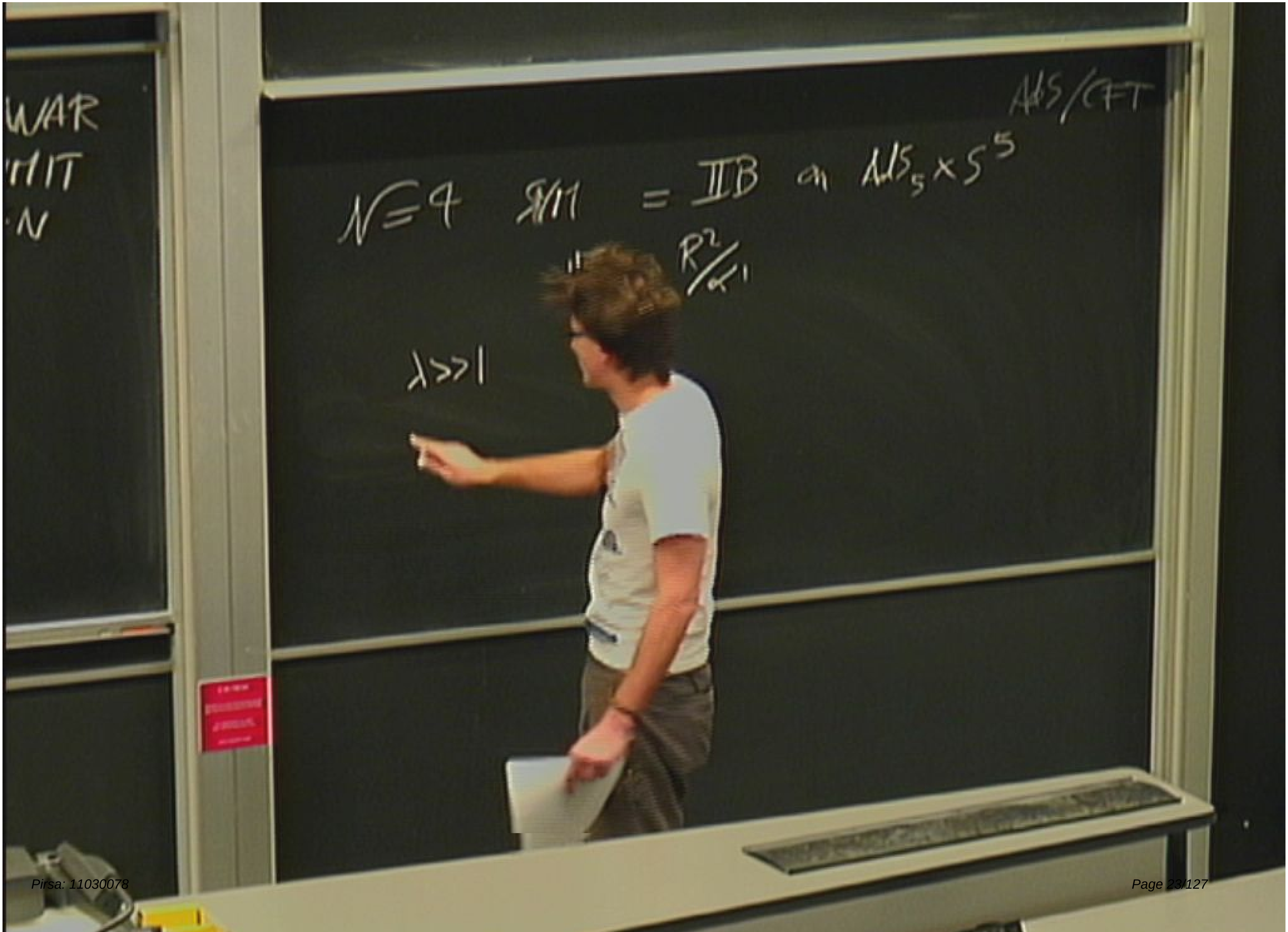
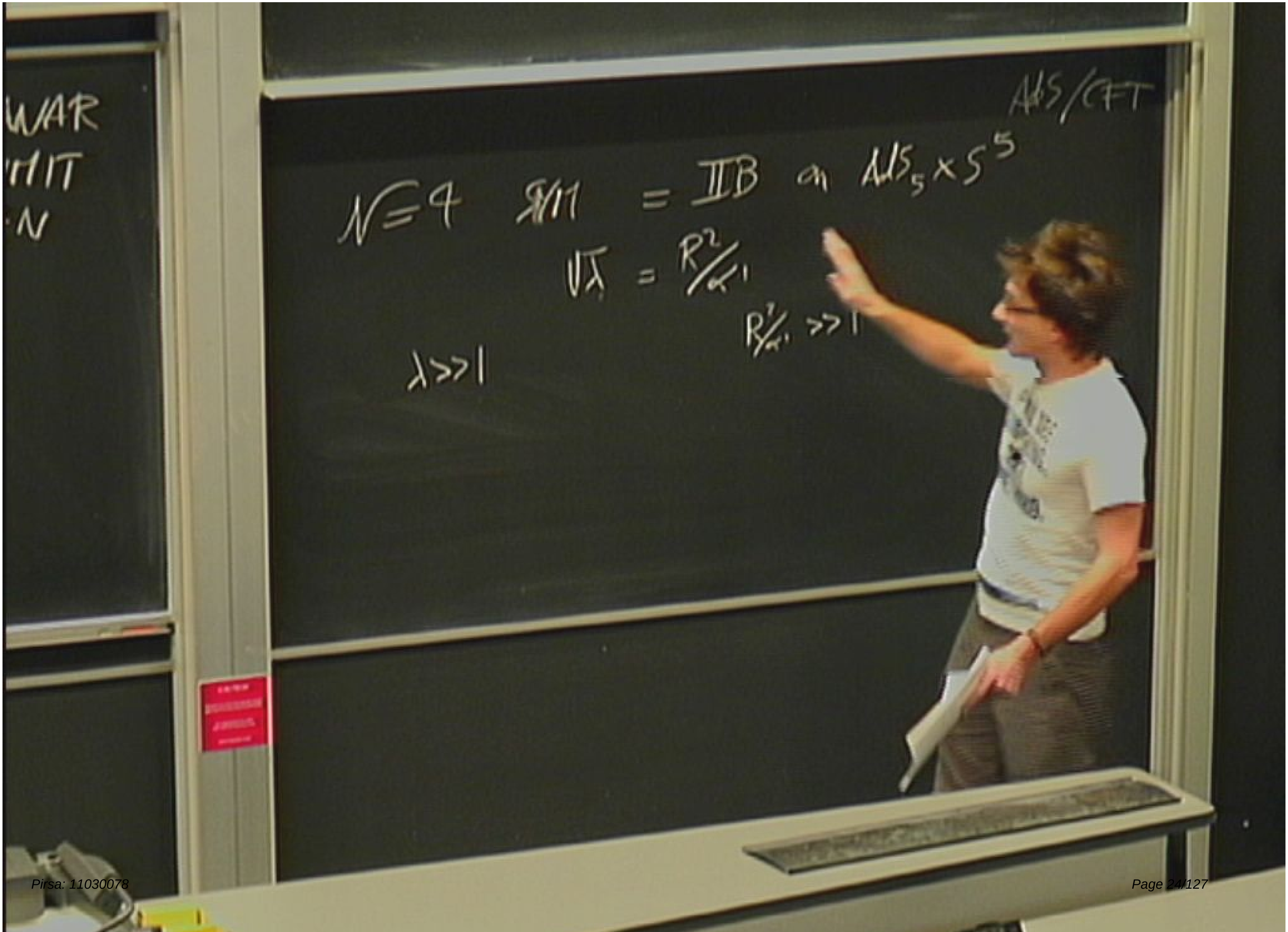
γ~ √λ
"large non-BPS"


N=4 SYM = IIB


$\mathcal{N}=4$ SYM = IIB on $AdS_5 \times S^5$


AdS/CFT
N=4 SYM = IIB on AdS5 × S5
R2/α'
λ>>1


AdS/CFT
N=4 SYM = IIB on AdS5 × S5
√λ = R²/α'
R²/α' >> 1
λ >> 1

WAR
MIT
N

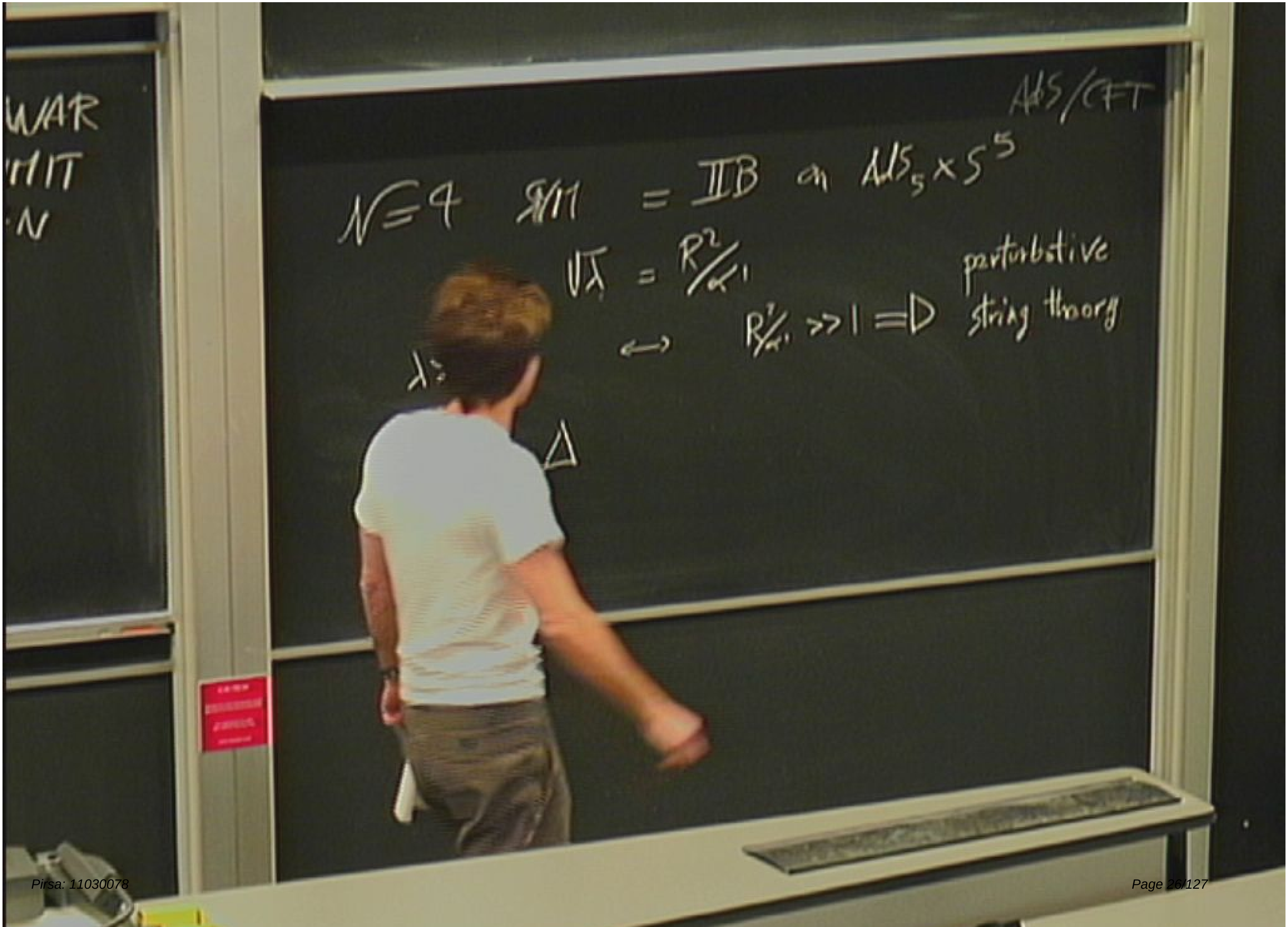
AdS/CFT

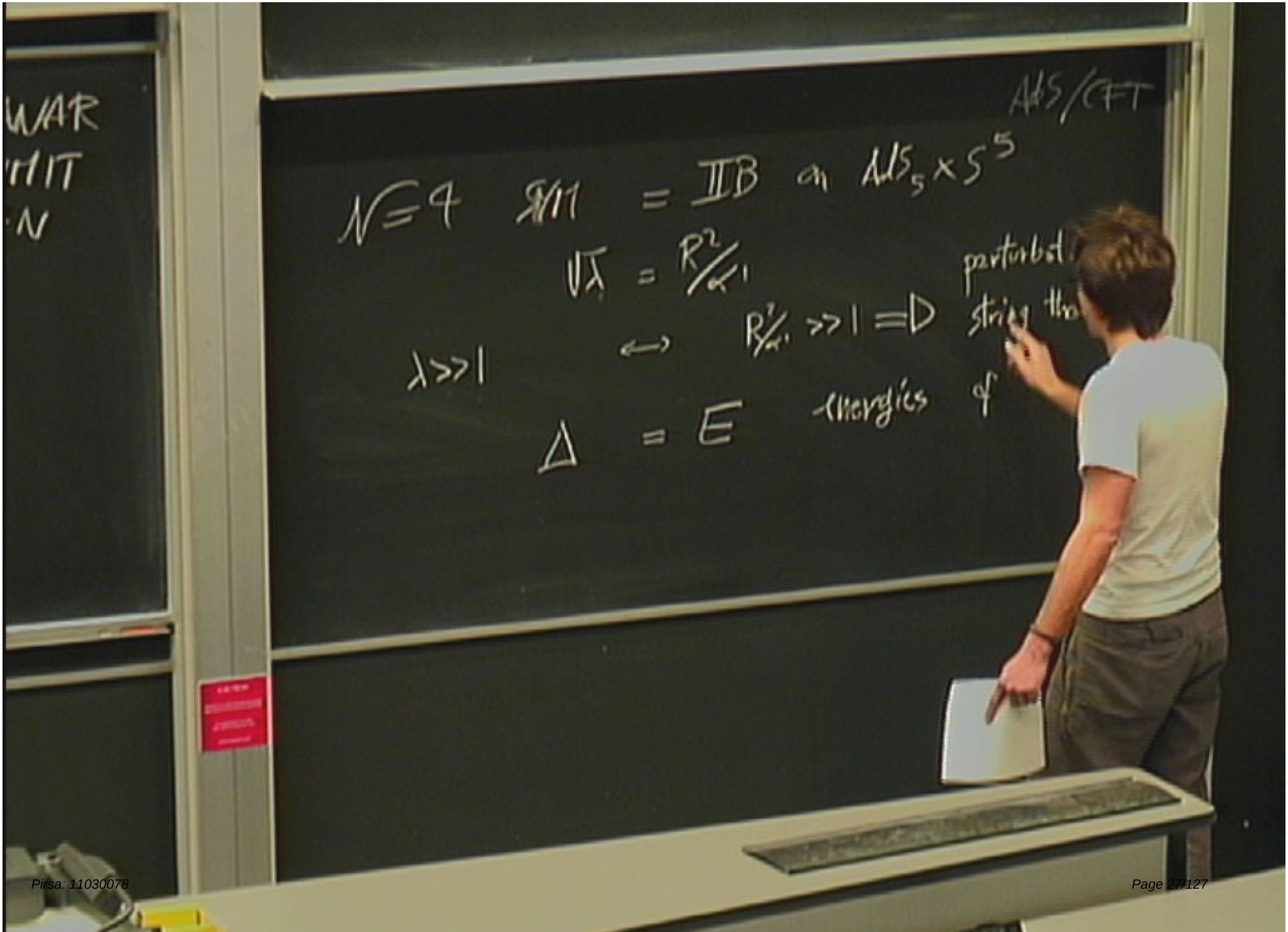
$\mathcal{N}=4$ SYM $=$ IIB on $AdS_5 \times S^5$

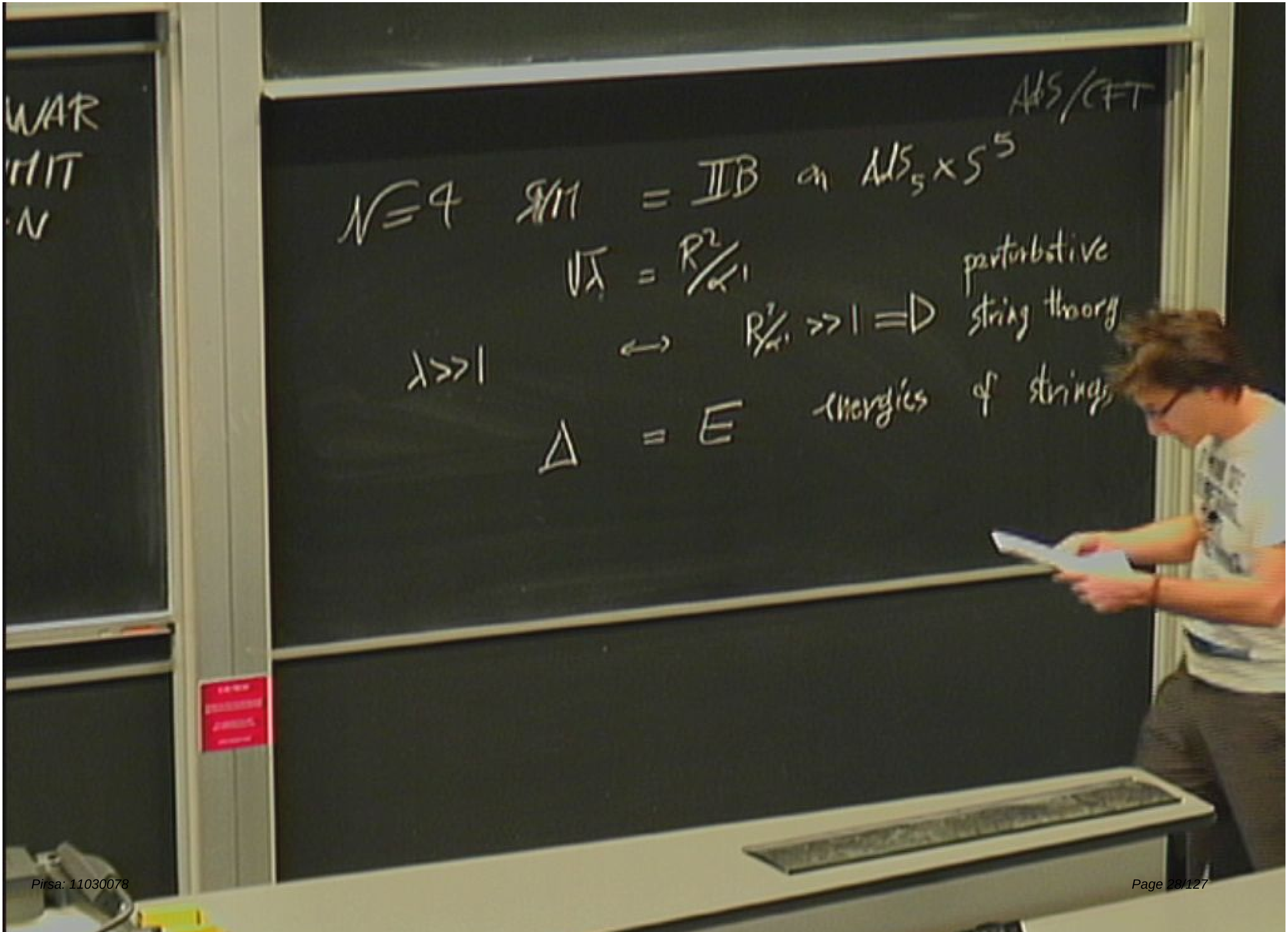
$\sqrt{\lambda} = R^2/\alpha'$

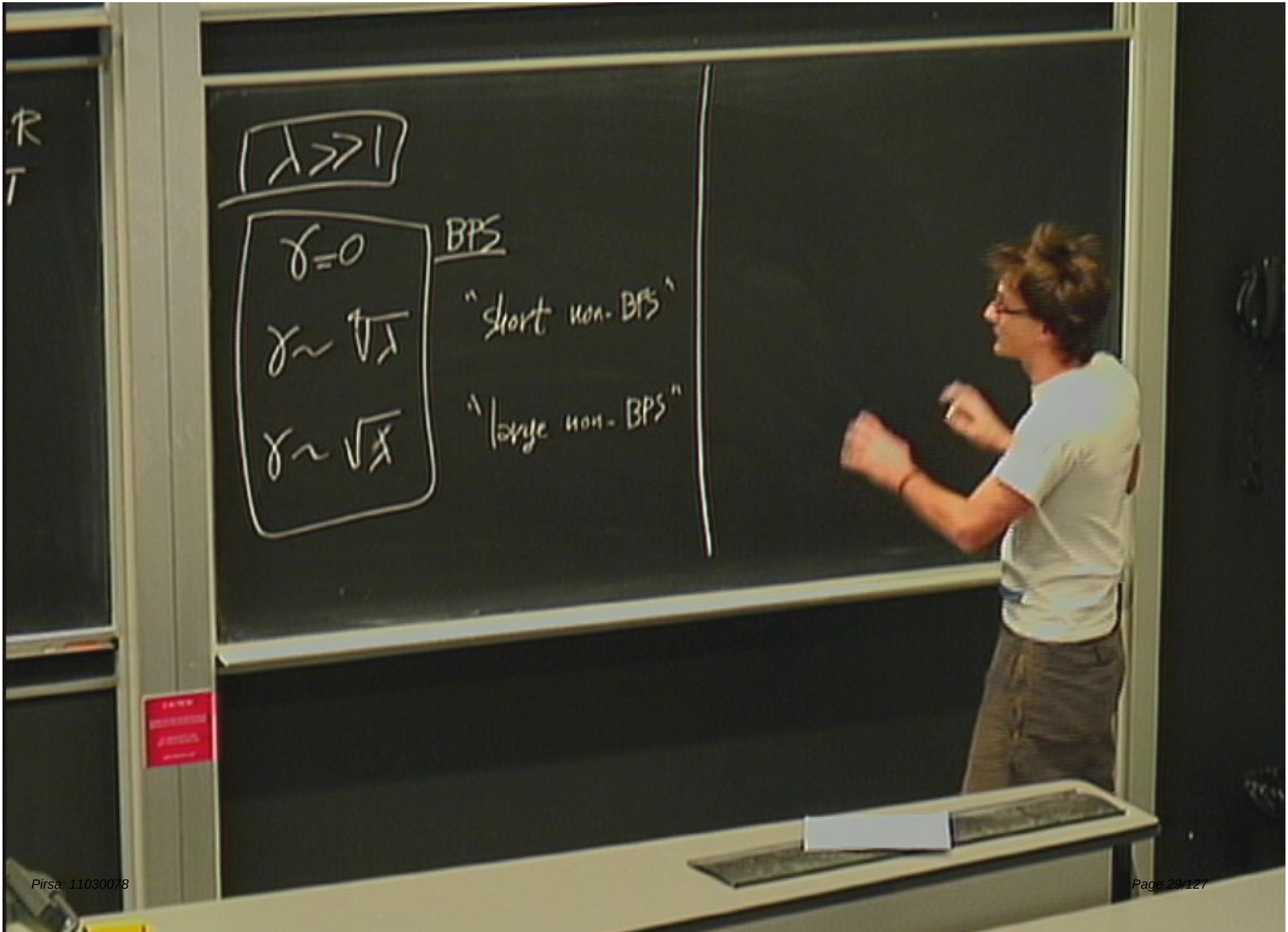
$R^2/\alpha' \gg 1 \Longrightarrow$ perturbative string theory

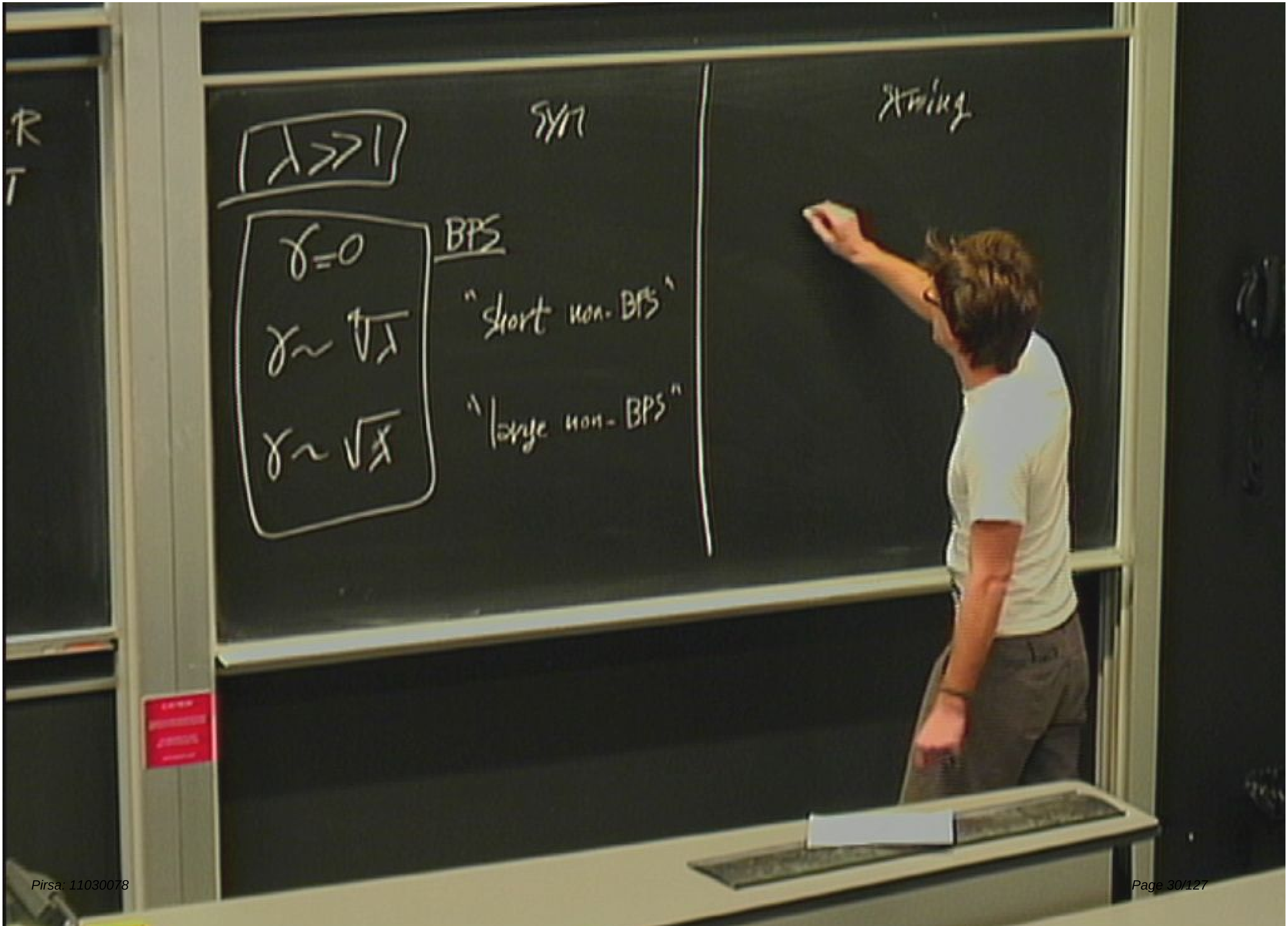
$\lambda \gg 1$


AdS/CFT
N=4 SYM = IIB on AdS5 x S5
√λ = R²/α'
R²/α' >> 1 ⟹ perturbative string theory

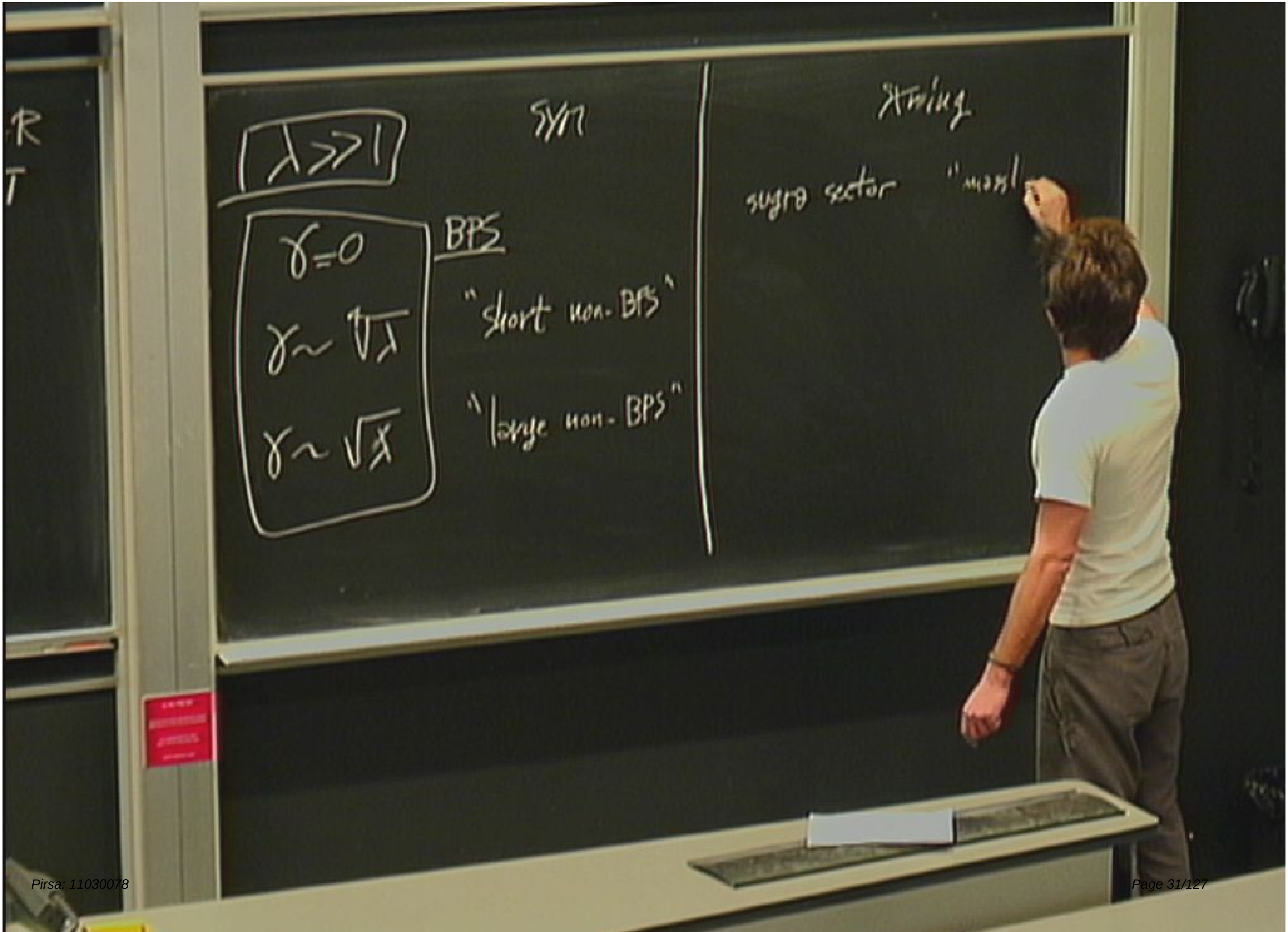

AdS/CFT
N=4 SYM = IIB on AdS5 x S5
√λ = R²/α'
perturbat
λ>>1 ⟷ R²/α' >>1 ⟹ string th
Δ = E energies of

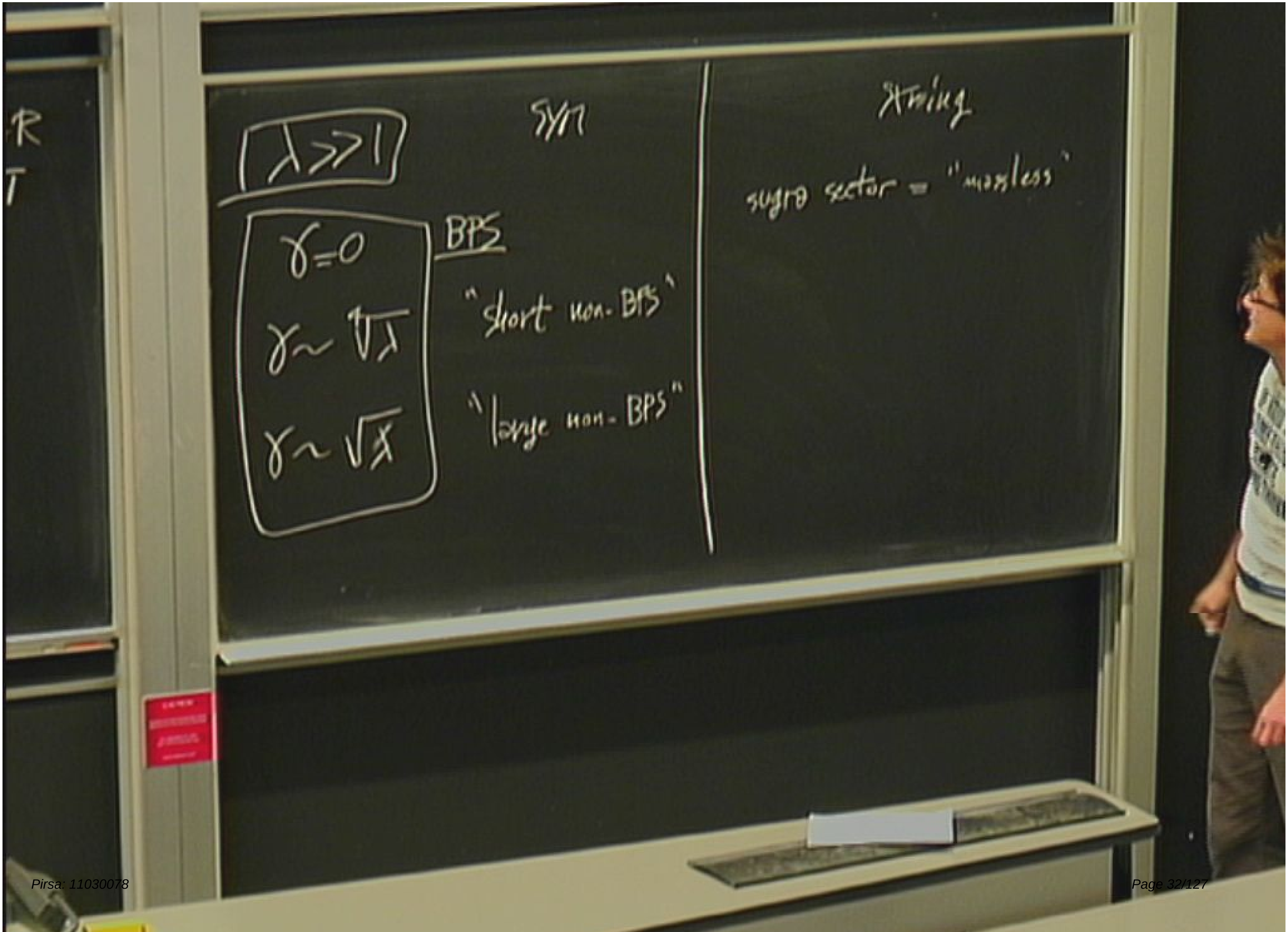

AdS/CFT
N=4 SYM = IIB on AdS5 × S5
√λ = R²/α'
perturbative
λ>>1 ⟷ R²/α' >>1 ⟹ string theory
Δ = E energies of strings

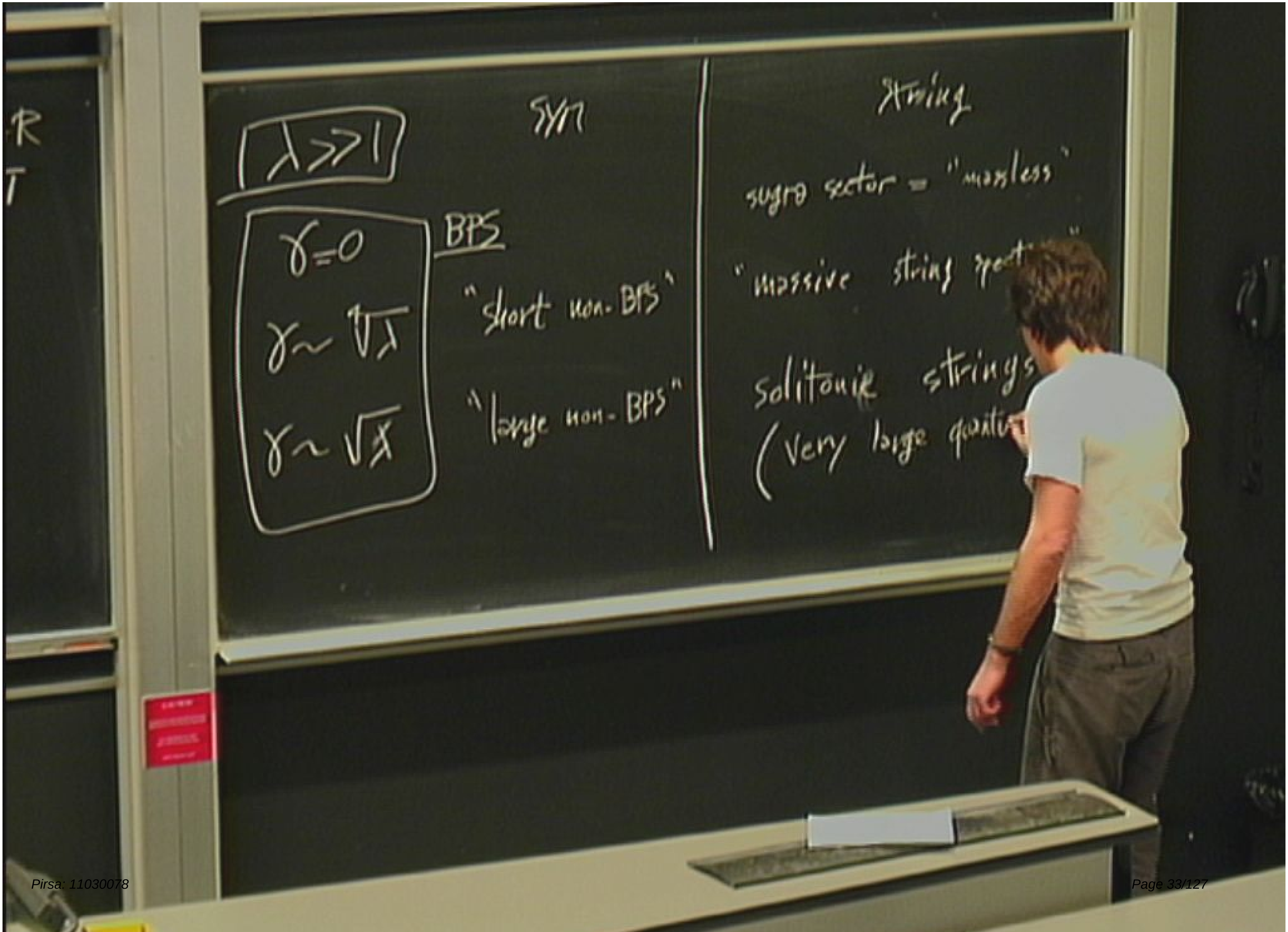

λ>>1
γ=0
BPS
γ~ ∜λ
"short non-BPS"
γ~ √λ
"large non-BPS"



$\lambda \gg 1$
sym
string
$\gamma = 0$
$\gamma \sim \sqrt[4]{\lambda}$
$\gamma \sim \sqrt{\lambda}$
BPS
"short non-BPS"
"large non-BPS"


λ>>1
SYM
string
BPS
γ=0
γ~ ⁴√λ
γ~ √λ
"short non-BPS"
"large non-BPS"
sugra sector


$\boxed{\lambda \gg 1}$
SYM
String
sugra sector = "massless"
BPS
$\gamma = 0$
$\gamma \sim \sqrt[4]{\lambda}$
"short non-BPS"
$\gamma \sim \sqrt{\lambda}$
"large non-BPS"


λ>>1
SYM
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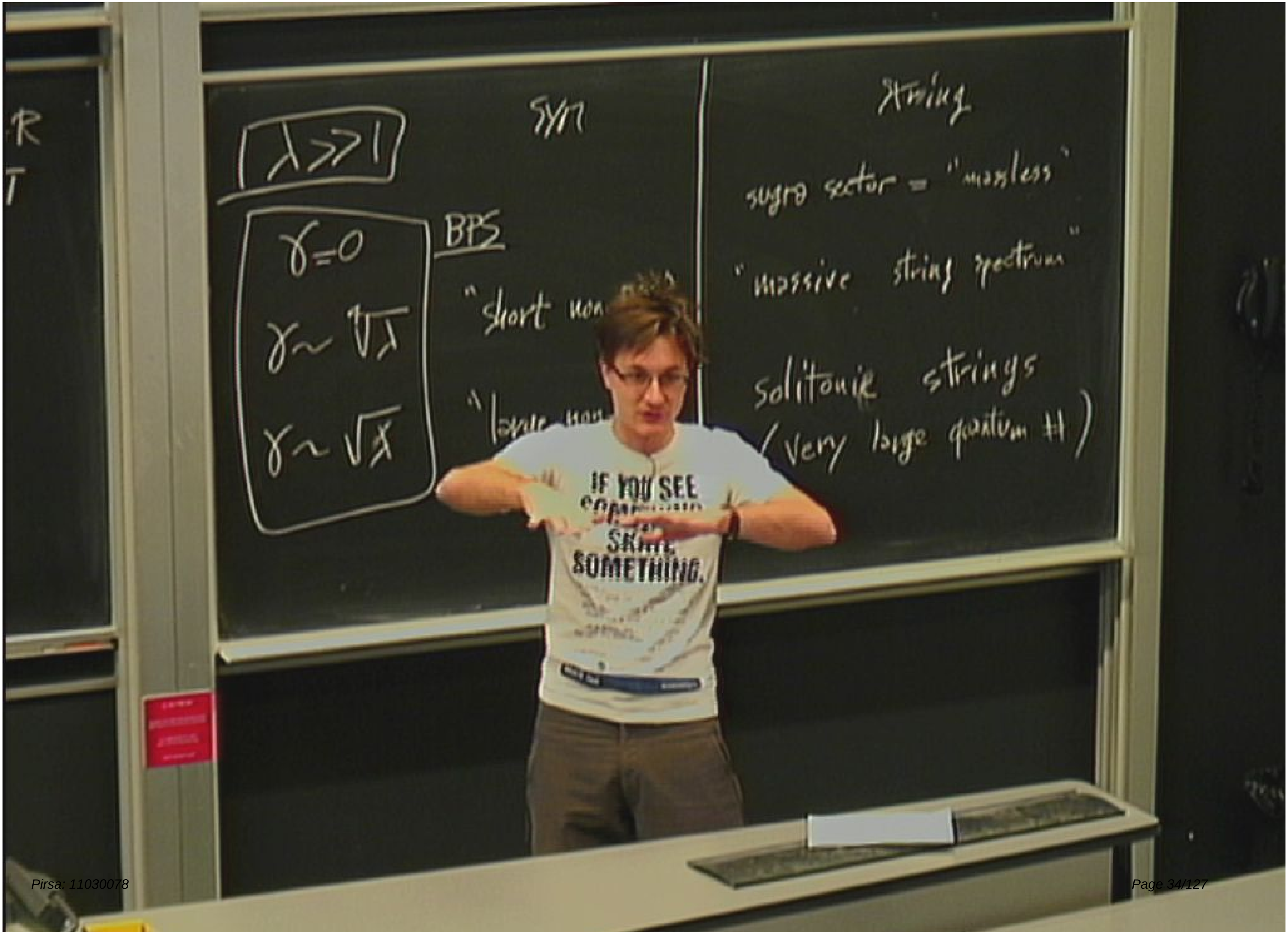
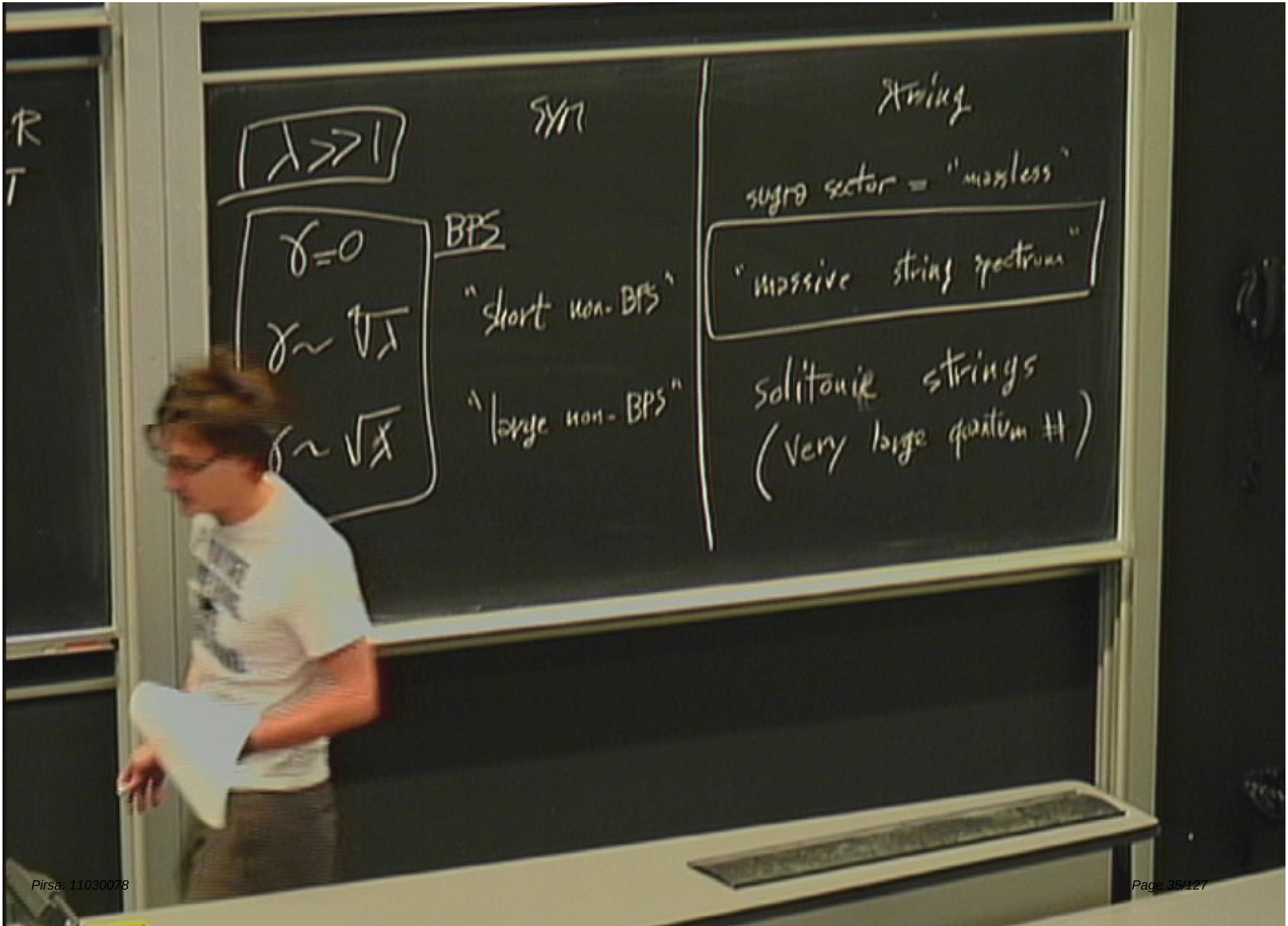
γ~ √λ
sugra sector = "massless"
"massive string
solitonic strings
(very large


λ>>1
sym
string
sugra sector = "massless"
BPS
γ=0
γ~ ⁴√λ
γ~√λ
"short
"massive string spectrum"
solitonic strings
(very large quantum #)
IF YOU SEE
SOMETHING.


λ>>1
SYM
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"short non-BPS"
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sugra sector = "massless"
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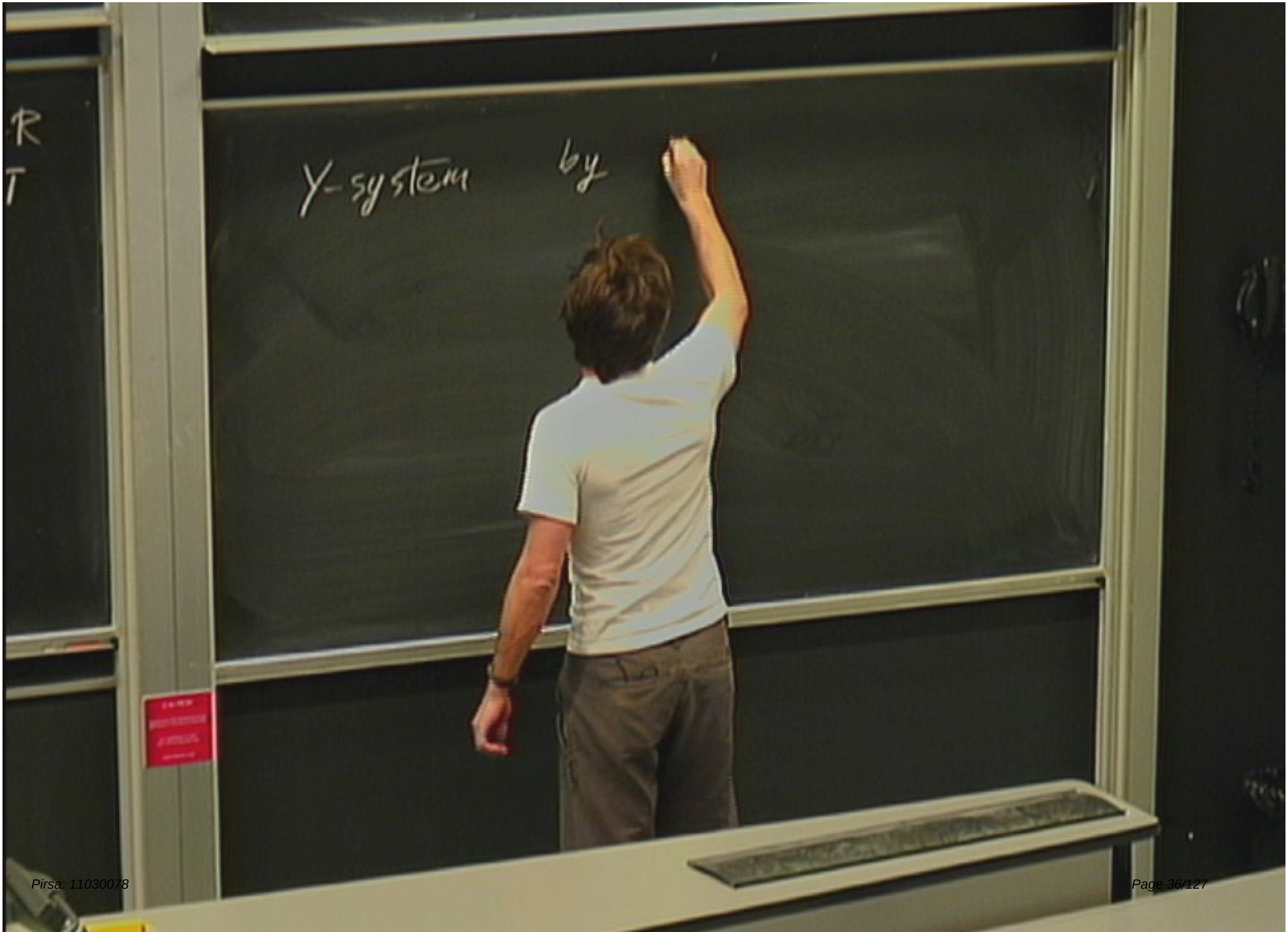
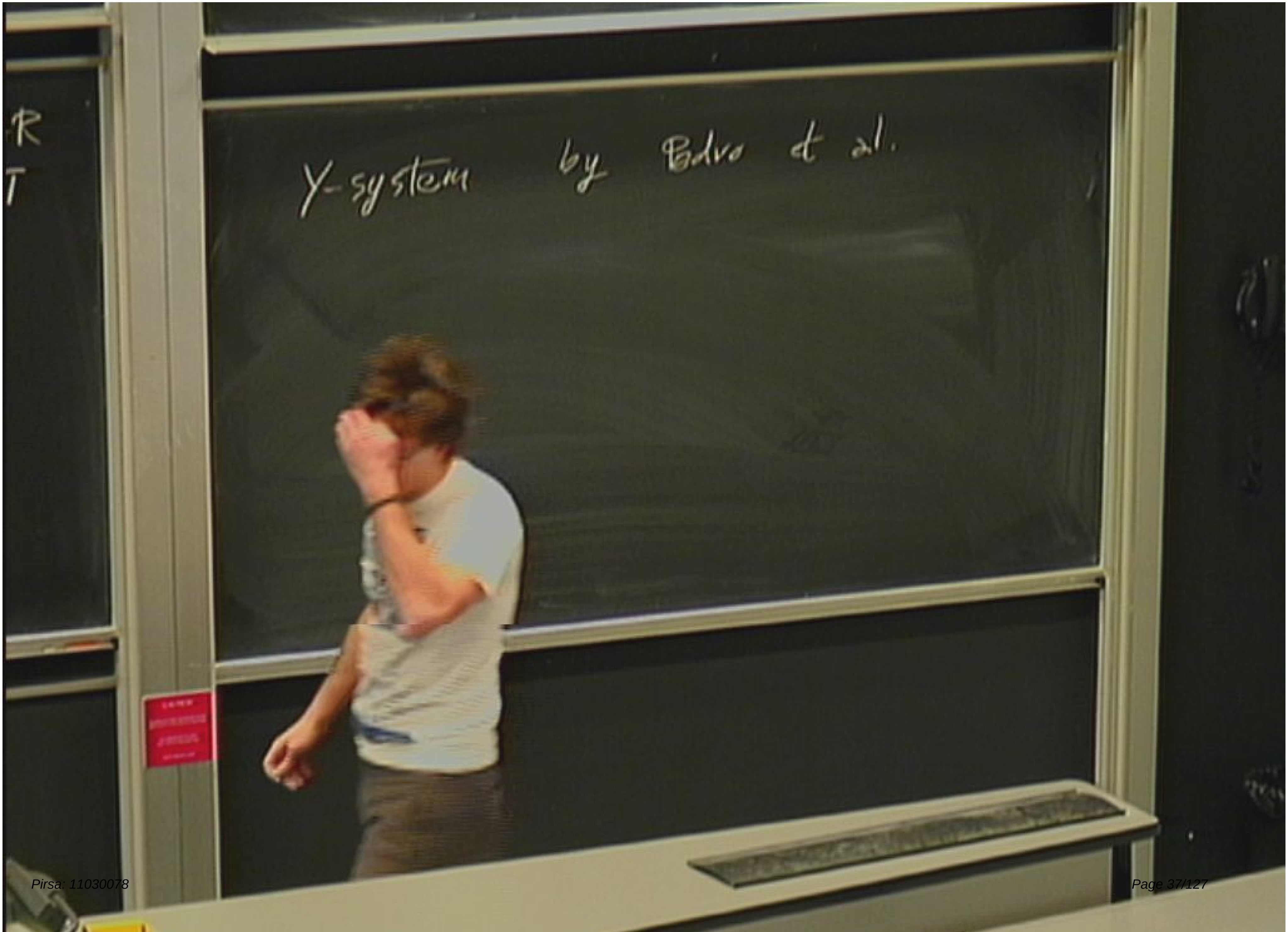
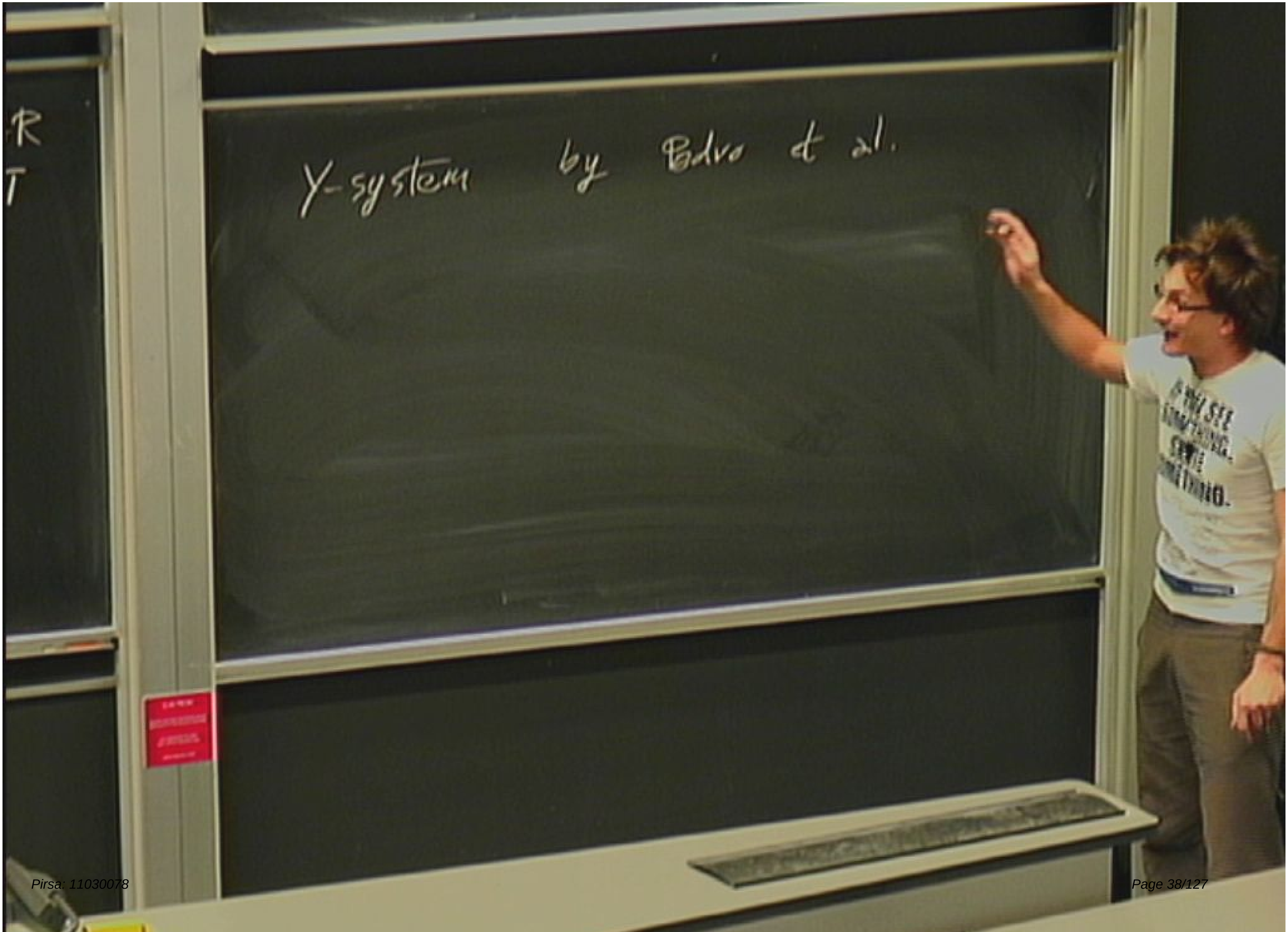
solitonic strings
(very large quantum #)


Y-system by


Y-system by Bdvo et al.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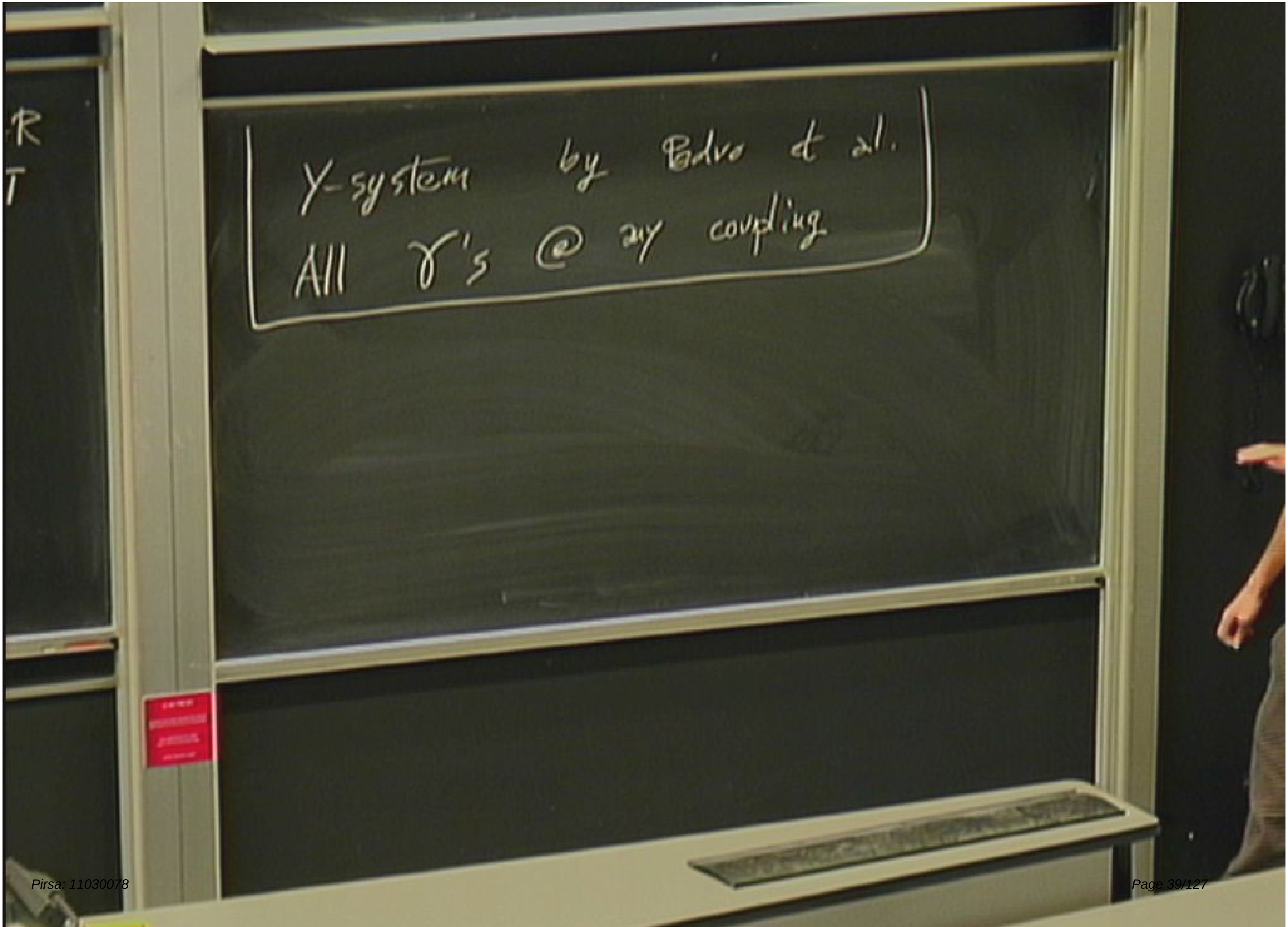
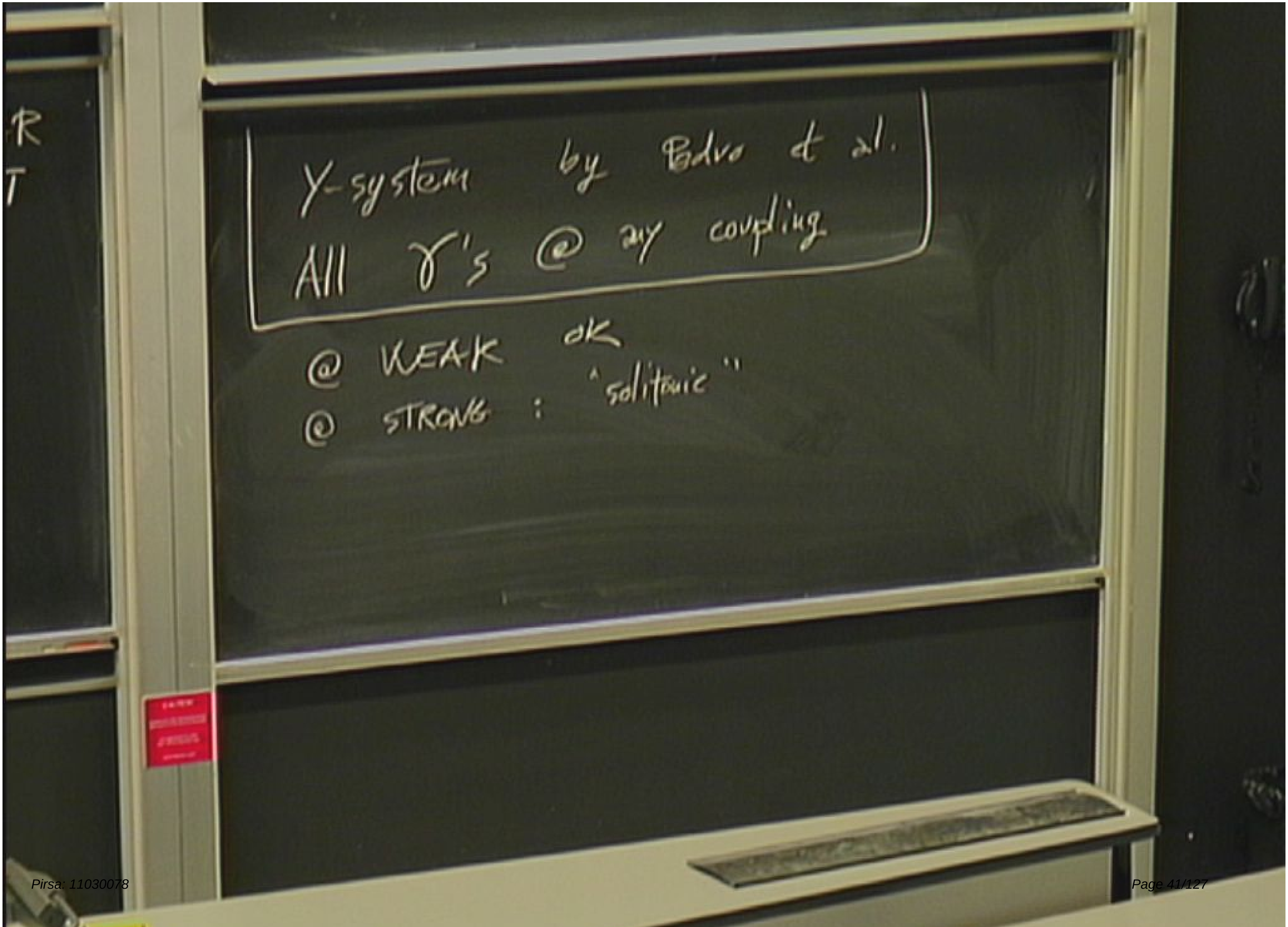

Y-system by Pedro et al.
All γ's @ any coupling

Y-system by Pedro et al.

All γ's @ any coupling

@ WEAK ok

@ STRONG : "solitonic"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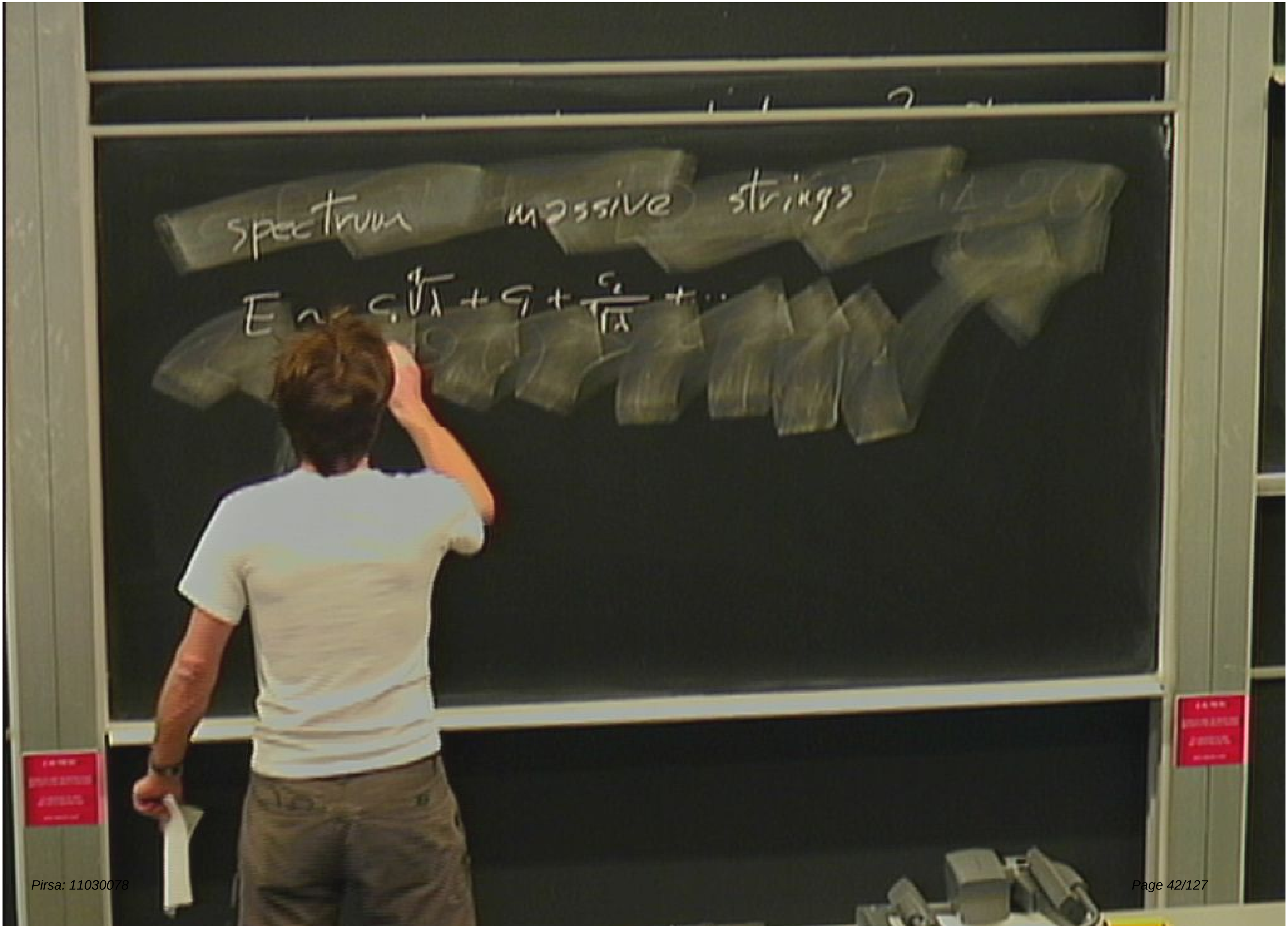
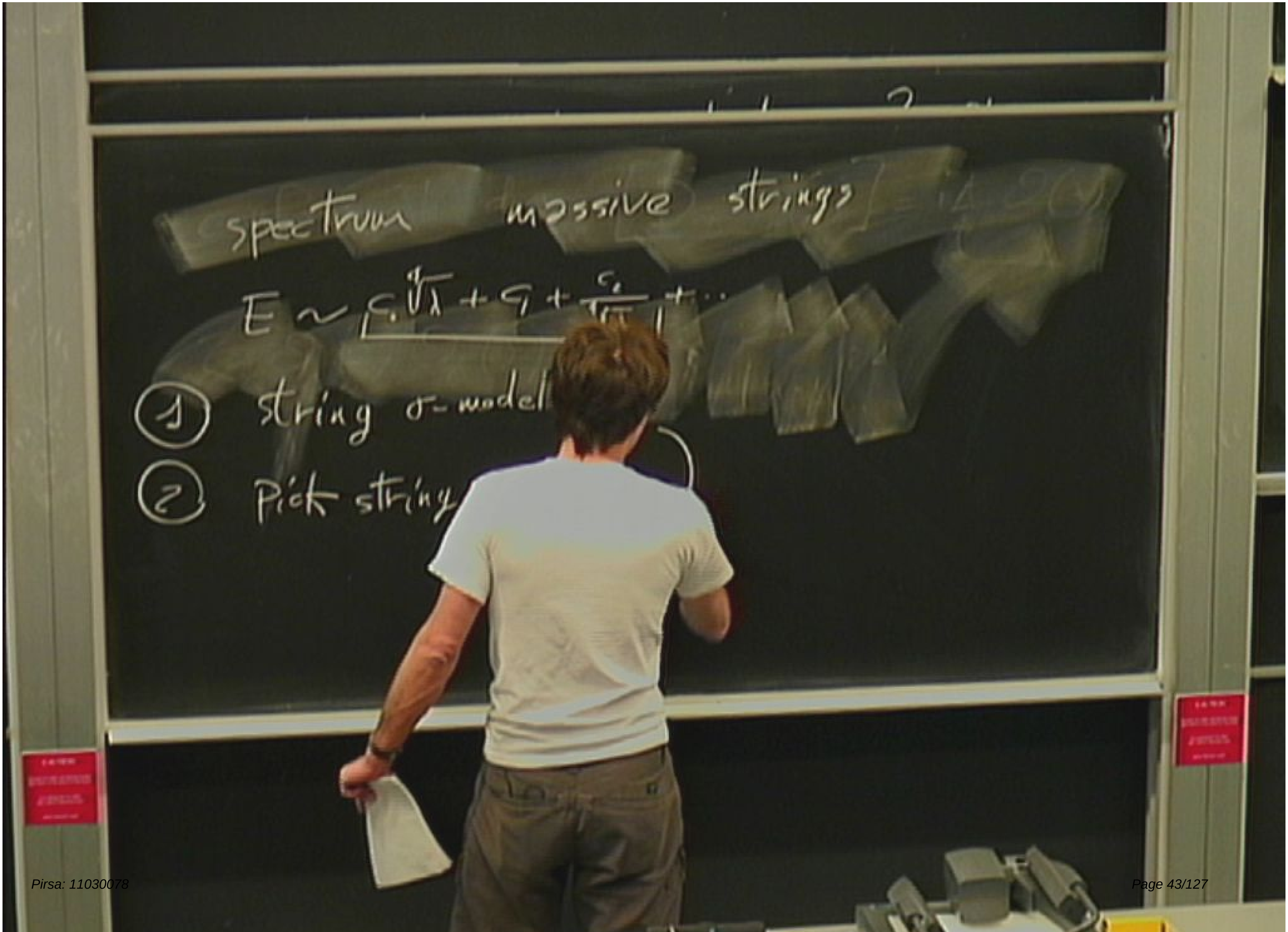
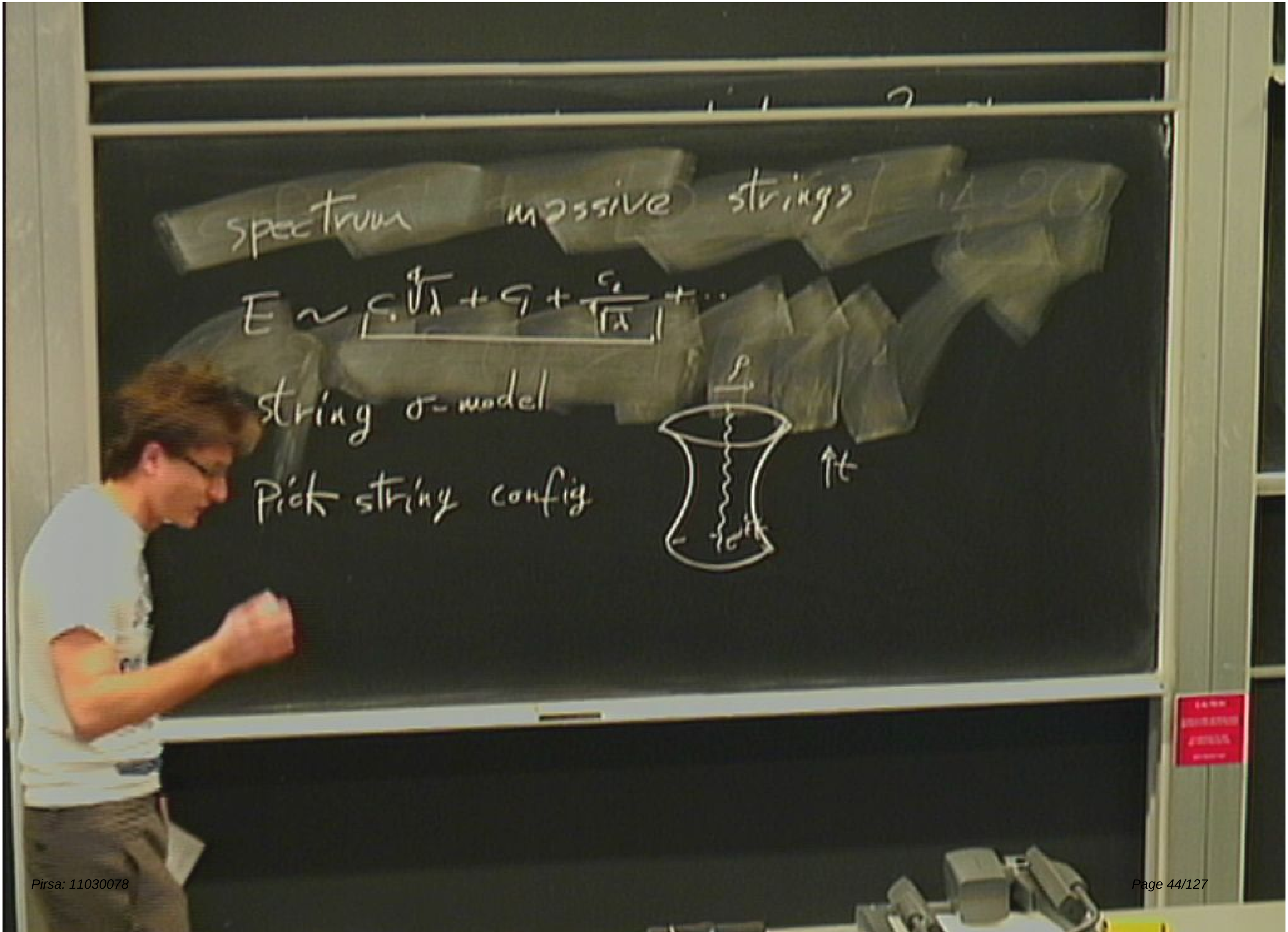
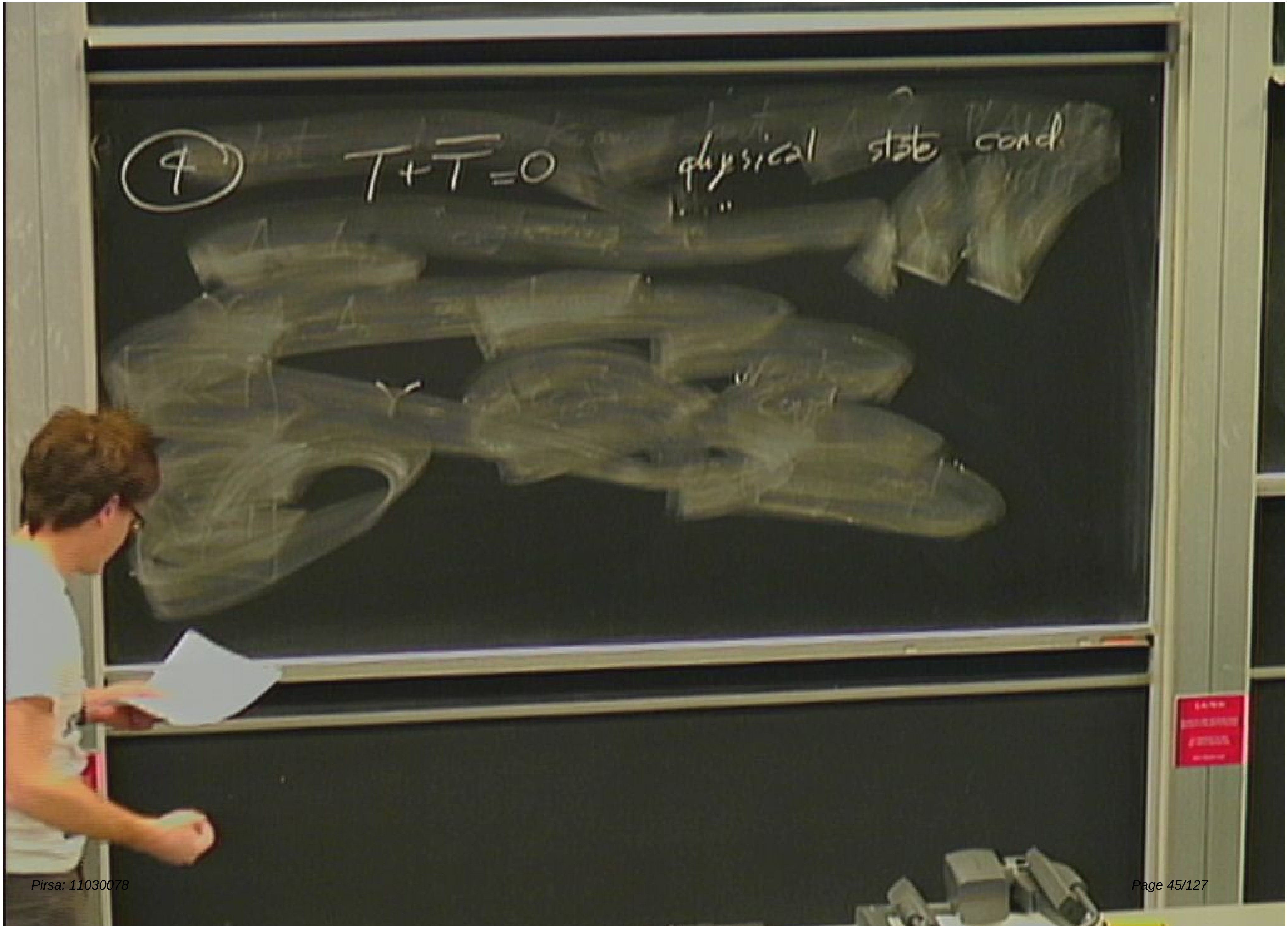
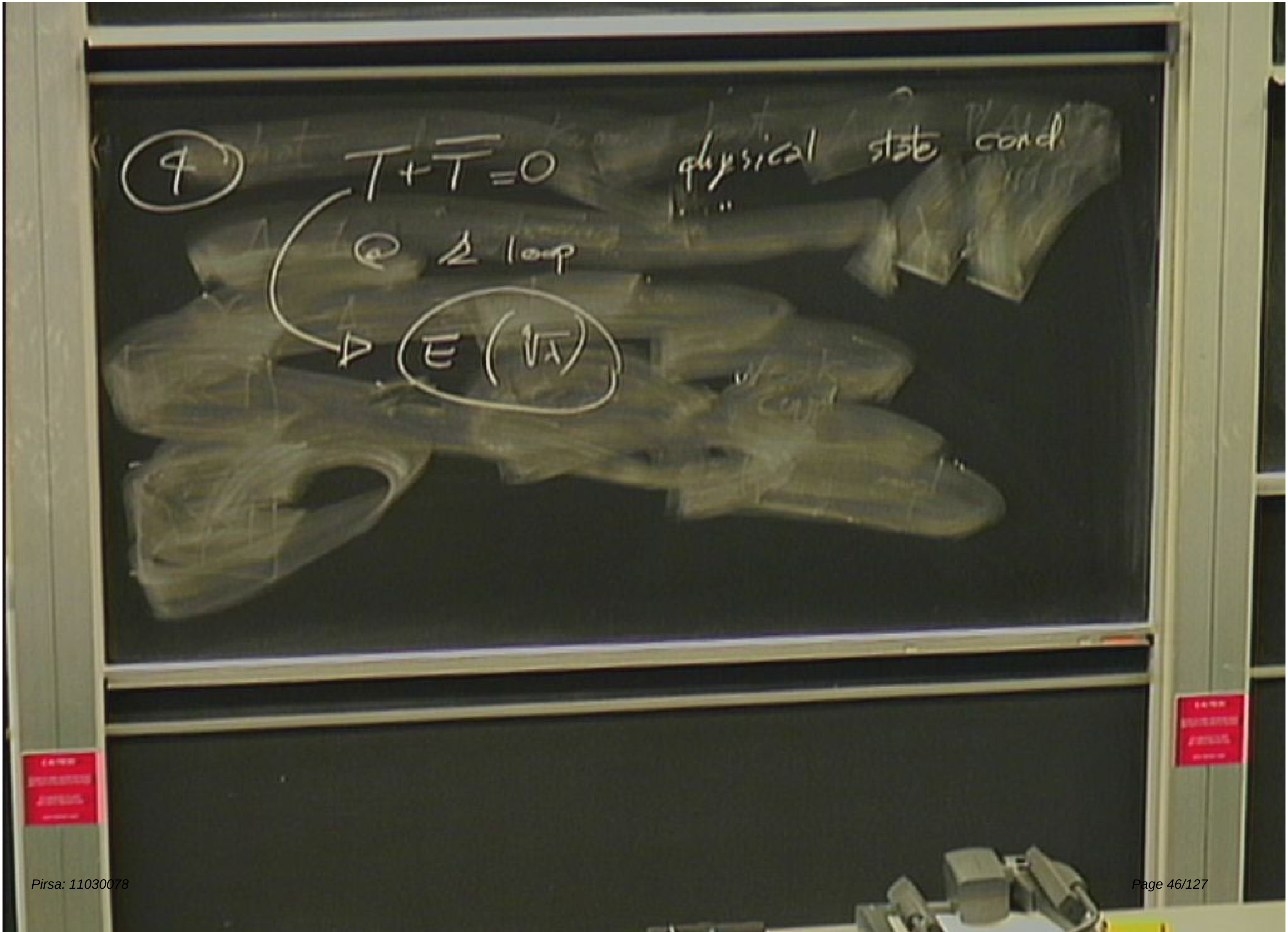

spectrum massive strings
$E \sim c_1 \sqrt[4]{\lambda} + c_2 + \frac{c_3}{\sqrt[4]{\lambda}} + \cdots$

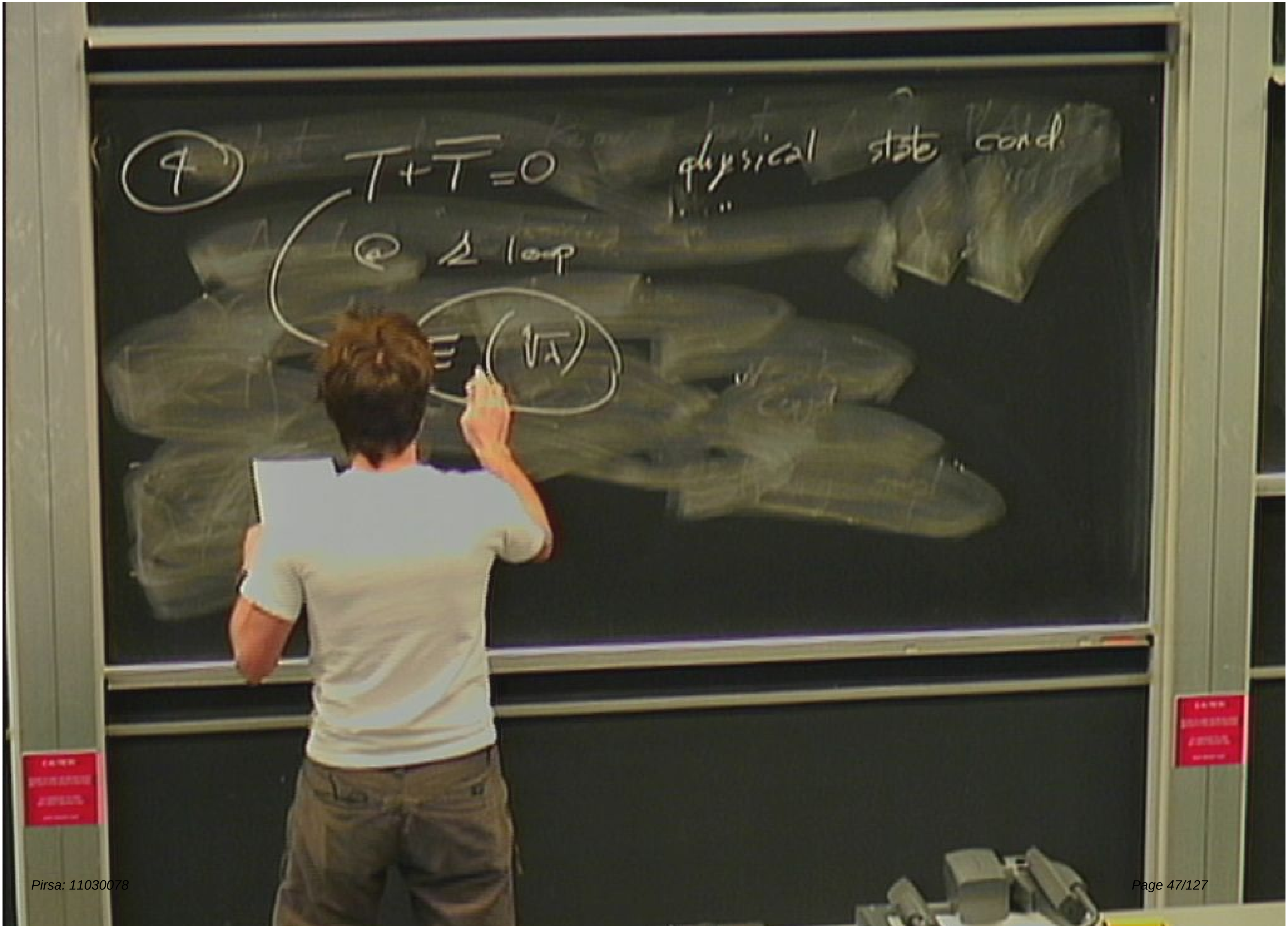

spectrum massive strings
E ~ c₀ ⁴√λ + c₁ + c₂/⁴√λ + ...
1 string σ-model
2 Pick string

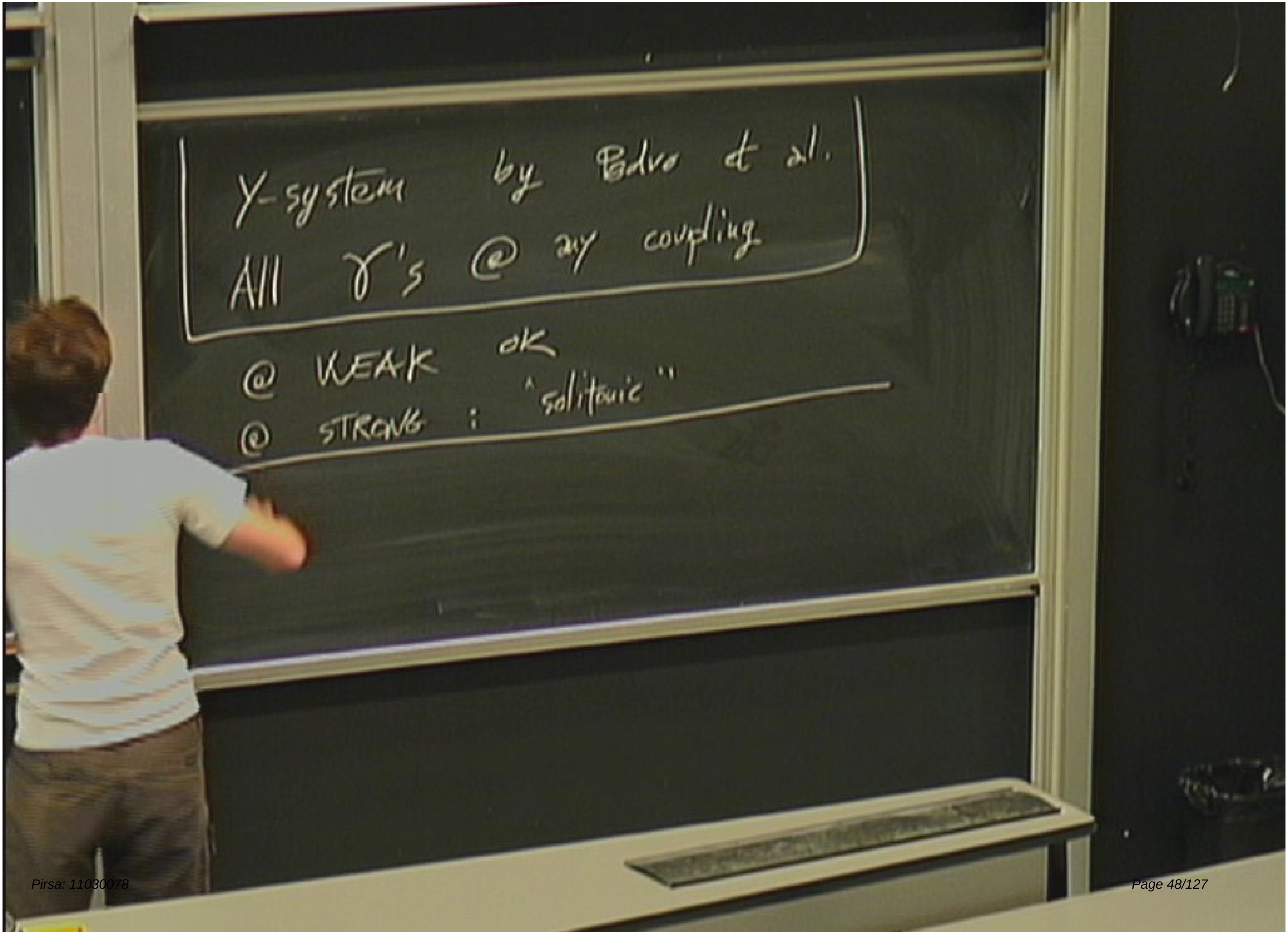

spectrum massive strings
E ~ c0 ⁴√λ + c1 + c2/√λ + ...
string σ-model
Pick string config
t



4
T+T̄=0 physical state cond.


4
$T+\bar{T}=0$ physical state cond
@ 2 loop
$E(\sqrt{\lambda})$


4
$T+\bar{T}=0$
physical state cond.
@ 2 loop
$\sqrt{\lambda}$


Y-system by
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All γ's @ any coupling
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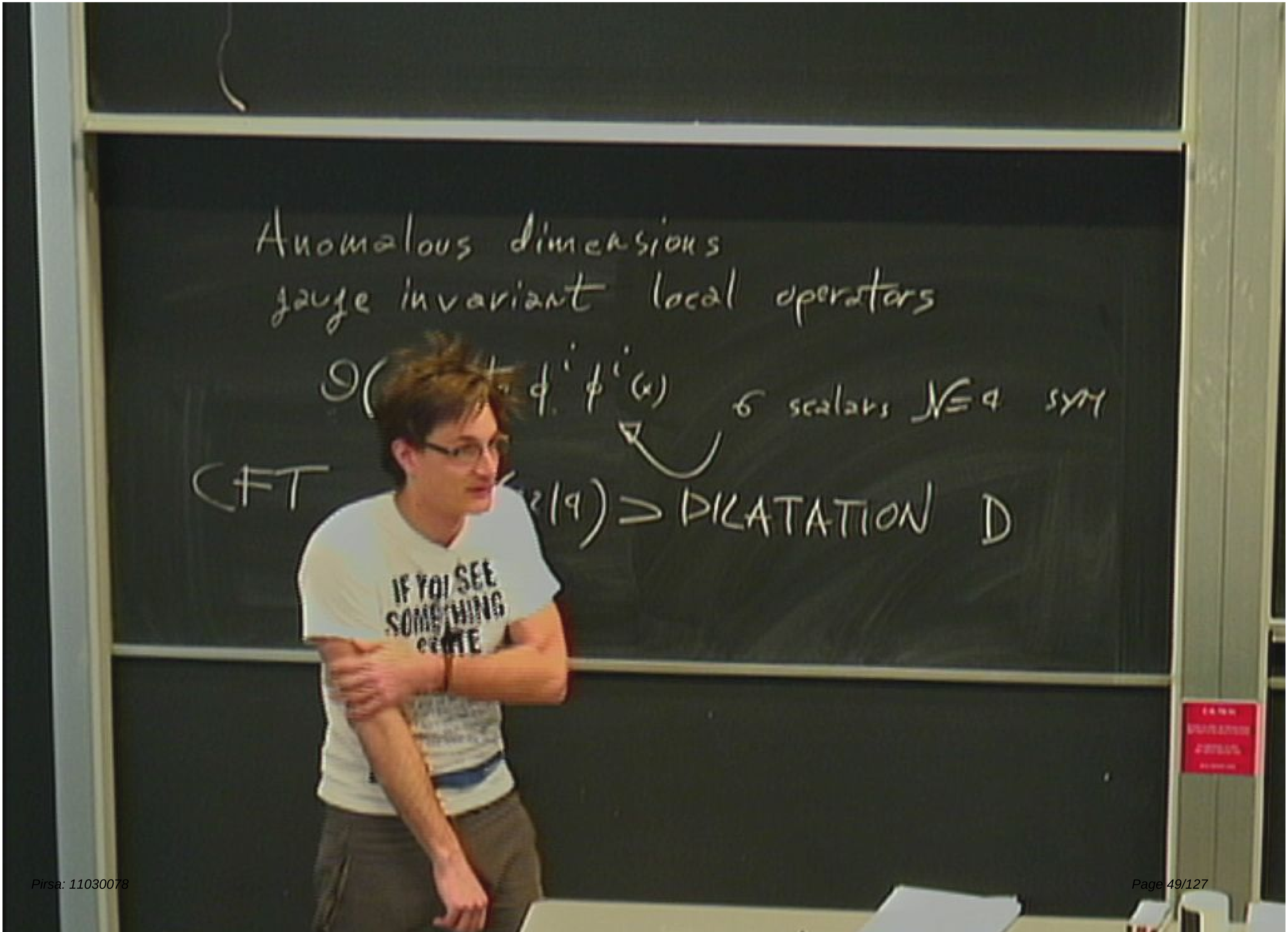
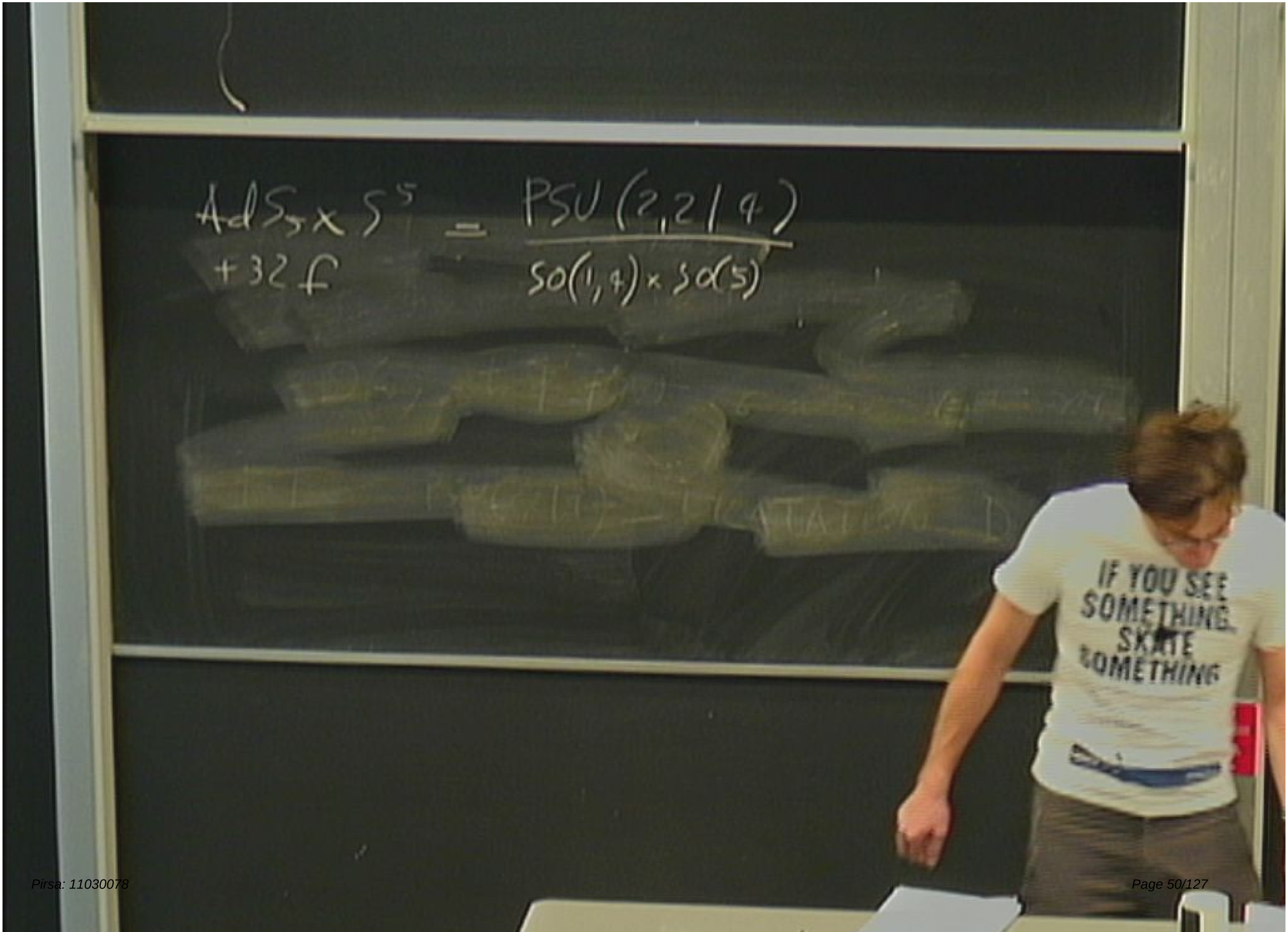
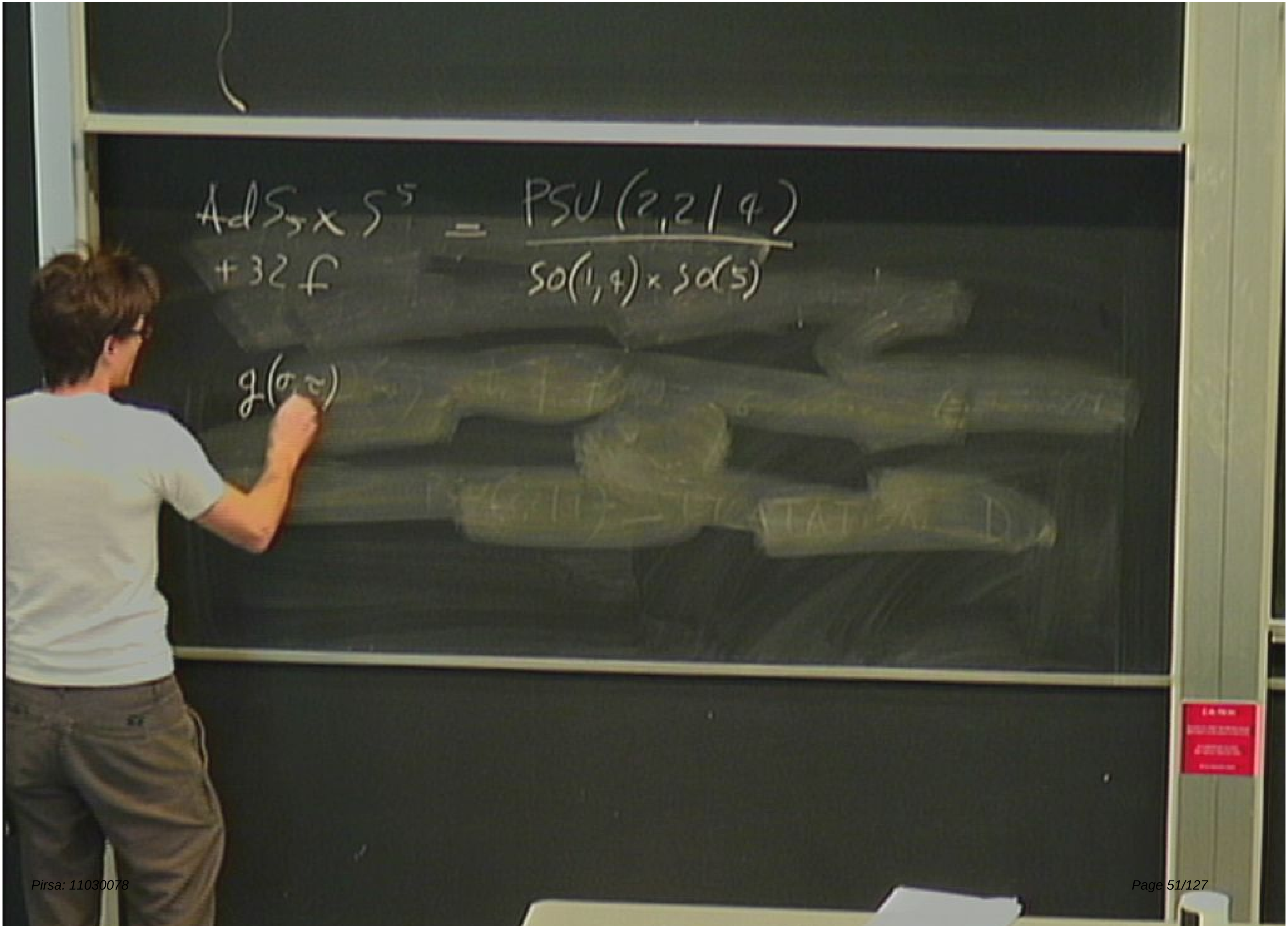
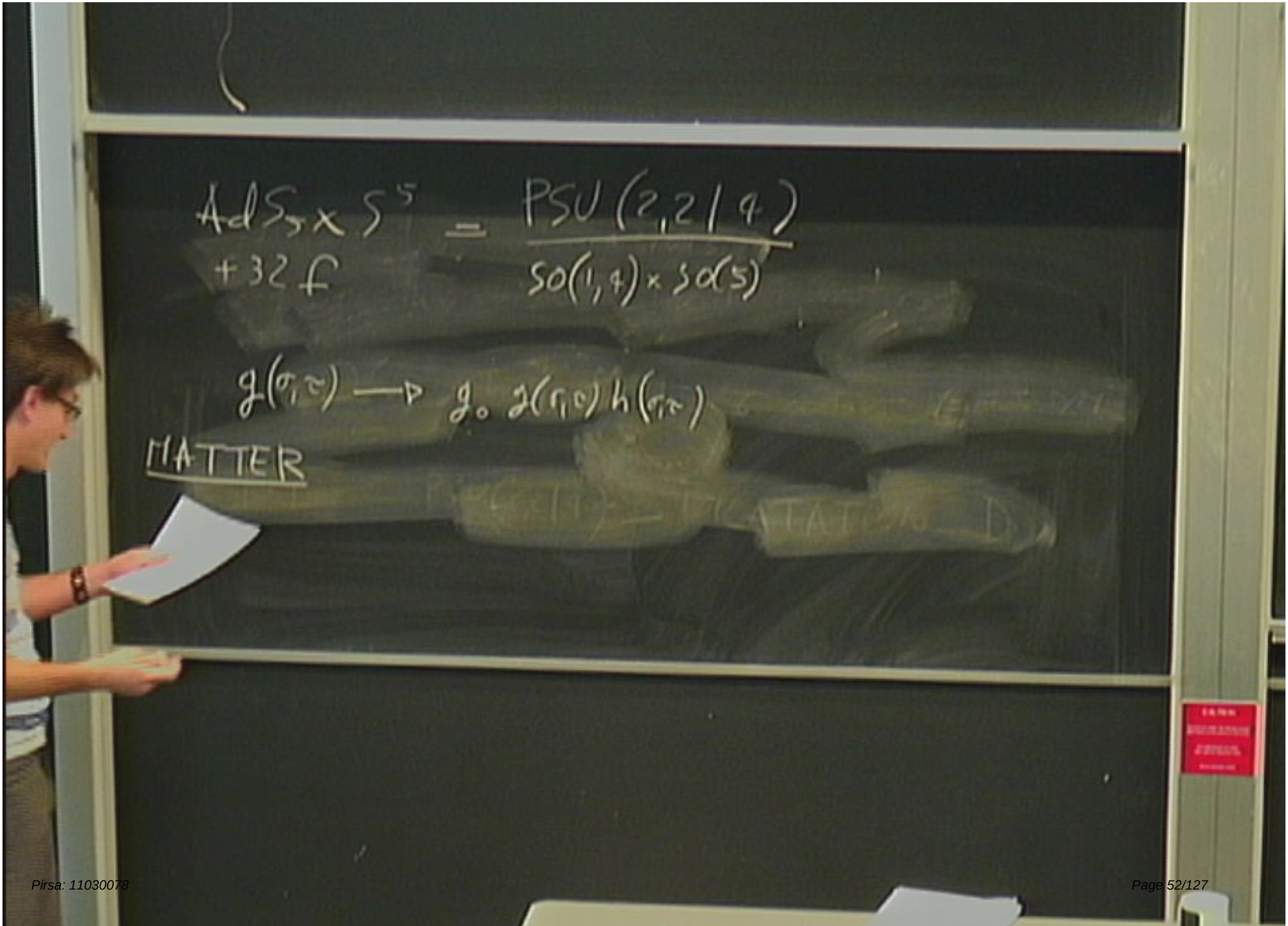
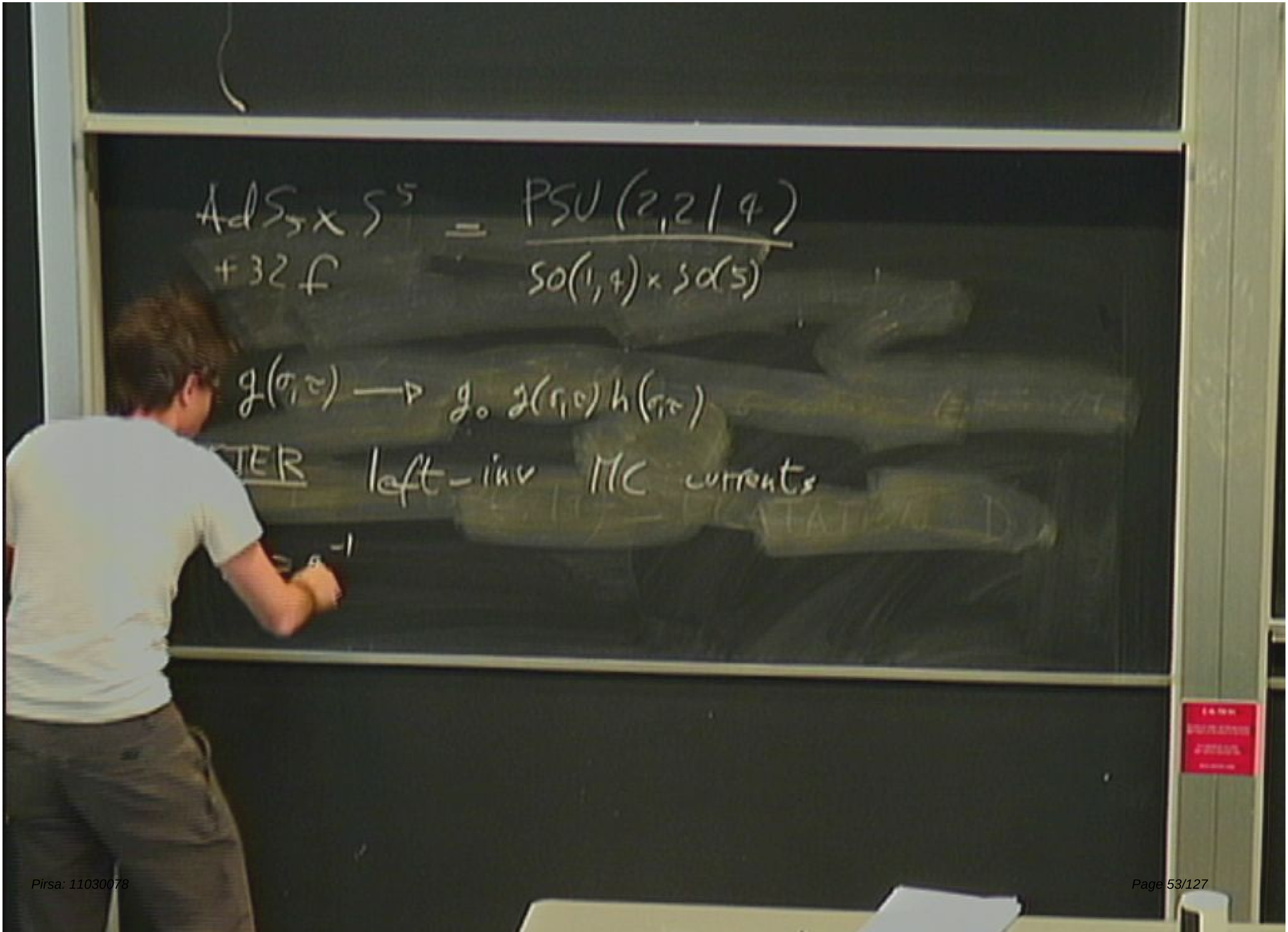

Anomalous dimensions
gauge invariant local operators
6 scalars N=4 SYM
CFT
DILATATION D
IF YOU SEE
SOMETHING


$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4) \times SO(5)}$
+ 32 f
IF YOU SEE SOMETHING, SKATE SOMETHING


$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4) \times SO(5)}$
$+ 32 f$
$g(\sigma, \tau)$


$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4) \times SO(5)}$
$+ 32 f$
$g(\sigma,\tau) \longrightarrow g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$
MATTER


AdS5 x S5 = PSU(2,2|4) / SO(1,4) x SO(5)
+32 f
g(σ,τ) → g0 g(σ,τ) h(σ,τ)
left-inv MC currents

$$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4)\times SO(5)} \longleftarrow \mathbb{Z}_4 \text{ grading}$$

$+32f$

$$g(\sigma,\tau) \longrightarrow g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$$

<u>TTER</u> left-inv MC currents

$$J = g^{-1} dg$$

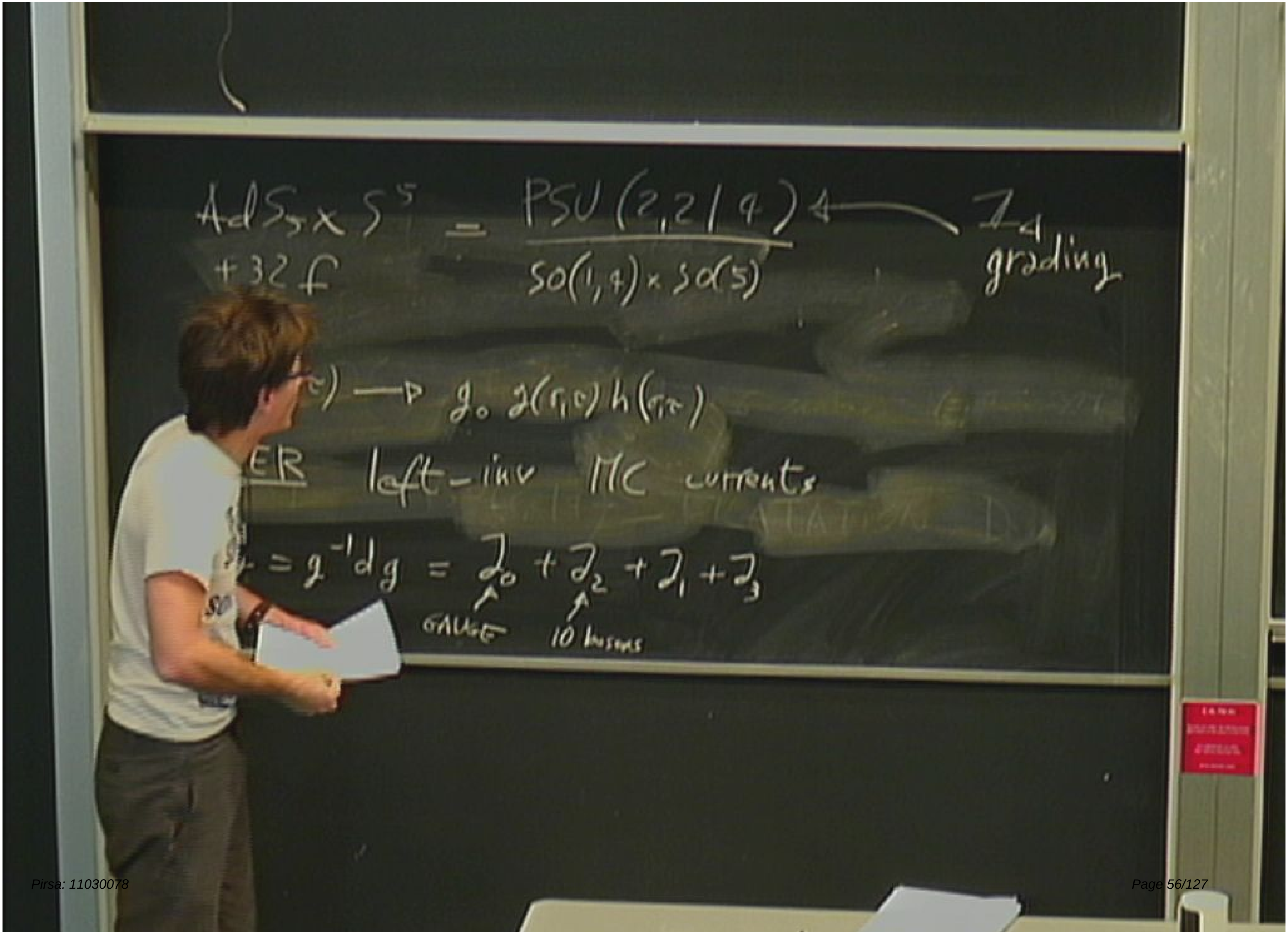
$$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4)\times SO(5)} \longleftarrow \mathbb{Z}_4 \text{ grading}$$

$+32f$

$$g(\sigma,\tau) \quad g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$$

MA… …t-inv MC currents

$$= J_0 + J_2 + J_1 + J_3$$



AdS5 x S5 = PSU(2,2|4) / SO(1,4) x SO(5)
+32 f
Z4 grading
) → g0 g(r,τ) h(r,τ)
ER left-inv MC currents
= g^-1 dg = J0 + J2 + J1 + J3
GAUGE
10 bosons

$$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4)\times SO(5)} \longleftarrow \mathbb{Z}_4 \text{ grading}$$

$+32f$

$$g(\sigma,\tau) \longrightarrow g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$$

MATTER left-inv MC currents

$$J = g^{-1}dg = \underset{\text{GAUGE}}{J_0} + \underset{\text{10 bosons}}{J_2} + \underbrace{J_1 + J_3}_{\text{32 fermions}}$$

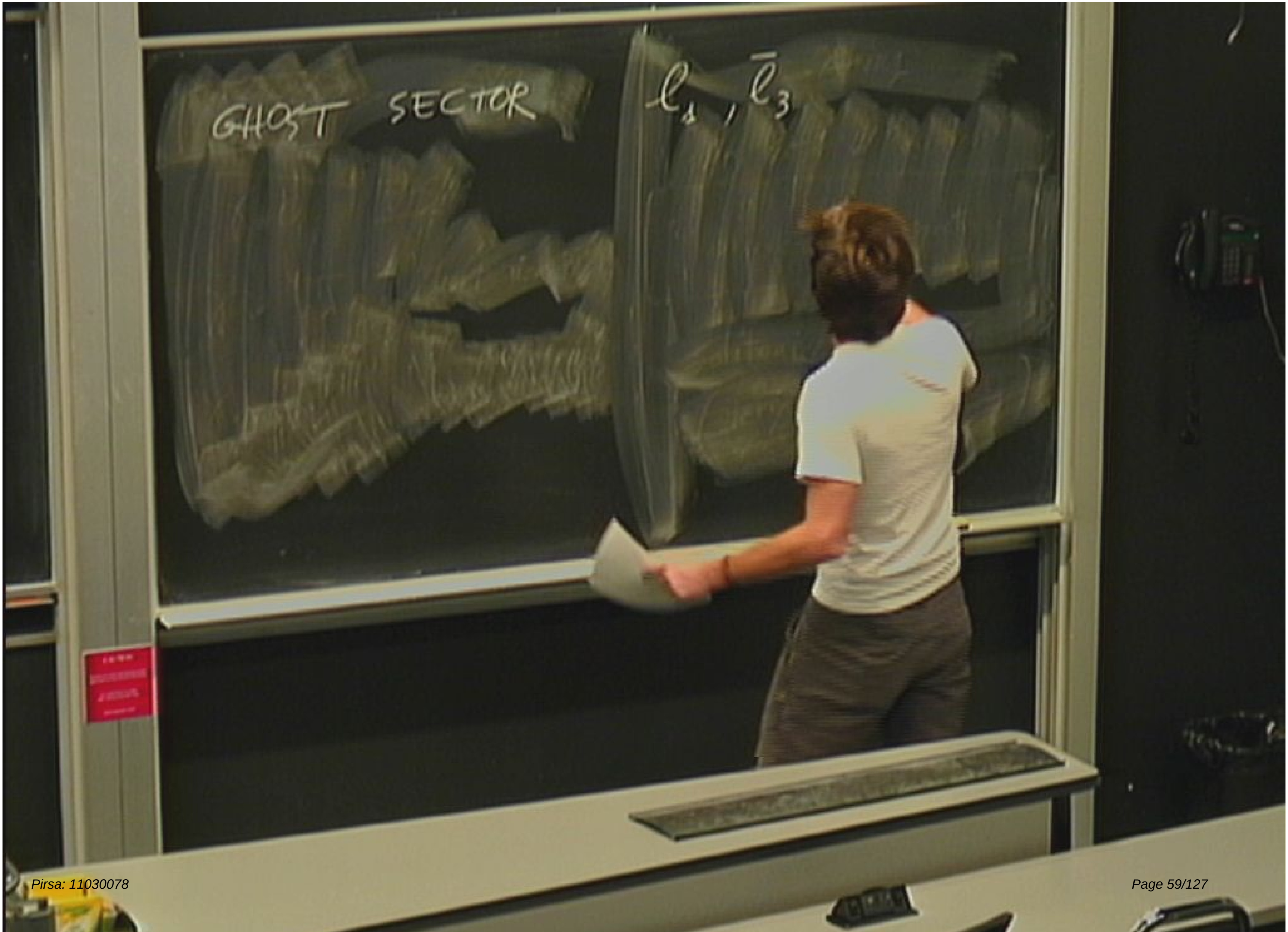
$$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4)\times SO(5)} \longleftarrow \mathbb{Z}_4 \text{ grading}$$

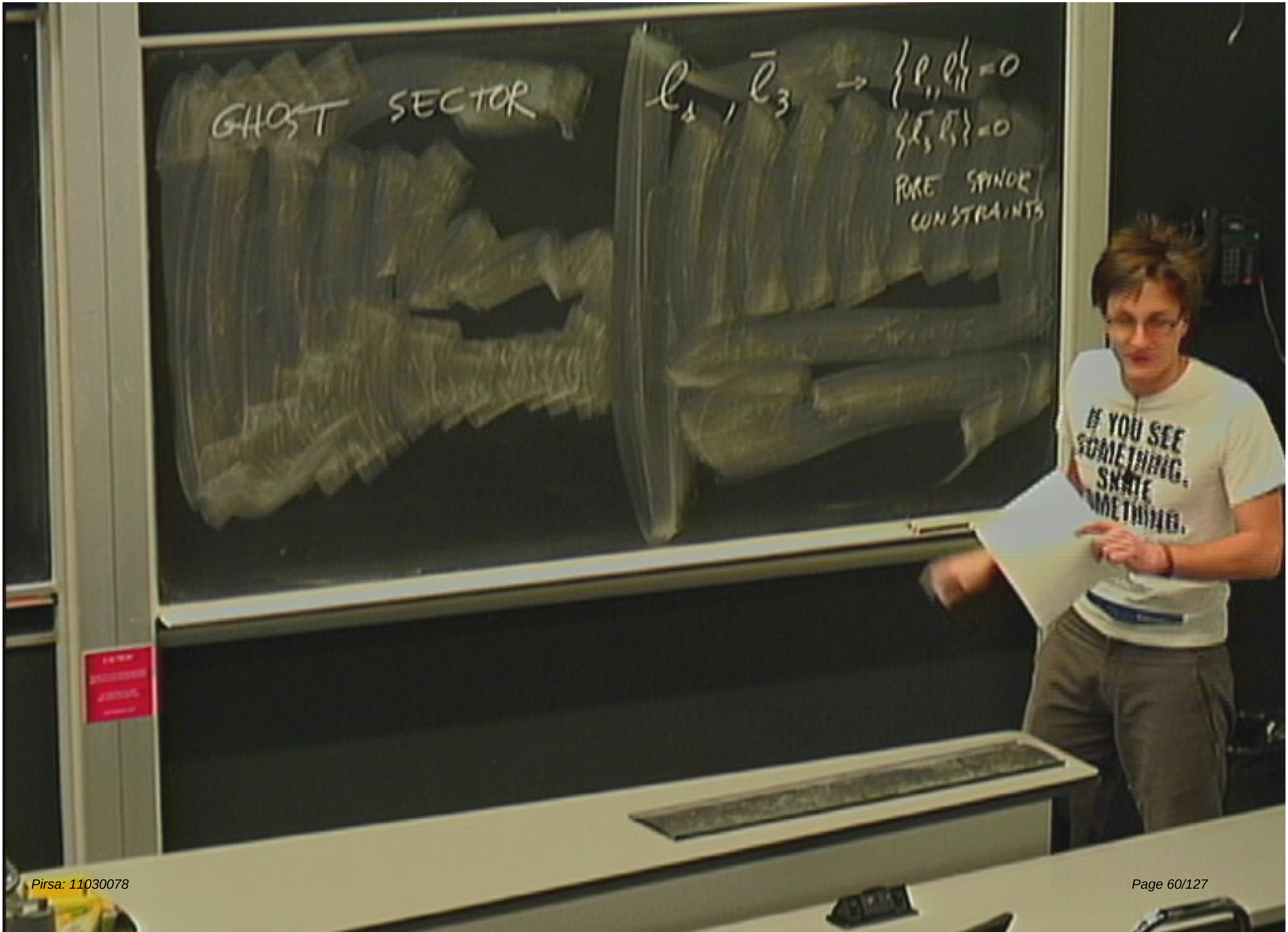
$+32f$

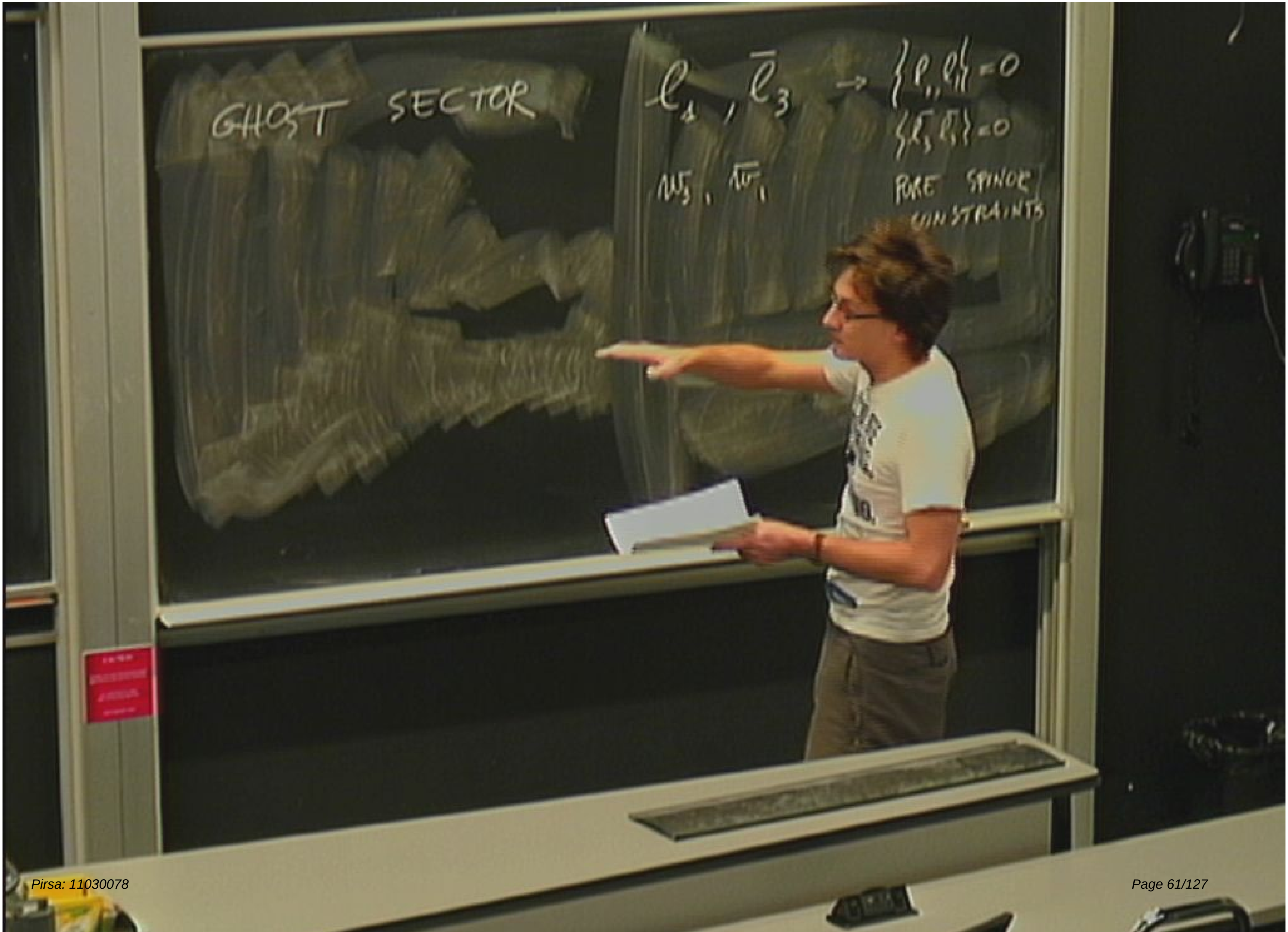
$$g(\sigma,\tau) \longrightarrow g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$$

MATTER left-inv MC currents

$$J = g^{-1}dg = \underbrace{J_0}_{\text{GAUGE}} + \underbrace{J_2}_{10 \text{ bosons}} + \underbrace{J_1 + J_3}_{32 \text{ fermions}}$$


GHOST SECTOR


GHOST SECTOR
ℓ1 , ℓ̄3 → {ℓ1, ℓ1} = 0
{ℓ̄3, ℓ̄3} = 0
PURE SPINOR CONSTRAINTS


GHOST SECTOR
$\ell_1, \bar{\ell}_3 \rightarrow \{\ell_1, \ell_1\} = 0$
$\{\bar{\ell}_3, \bar{\ell}_3\} = 0$
PURE SPINOR CONSTRAINTS

GHOST SECTOR

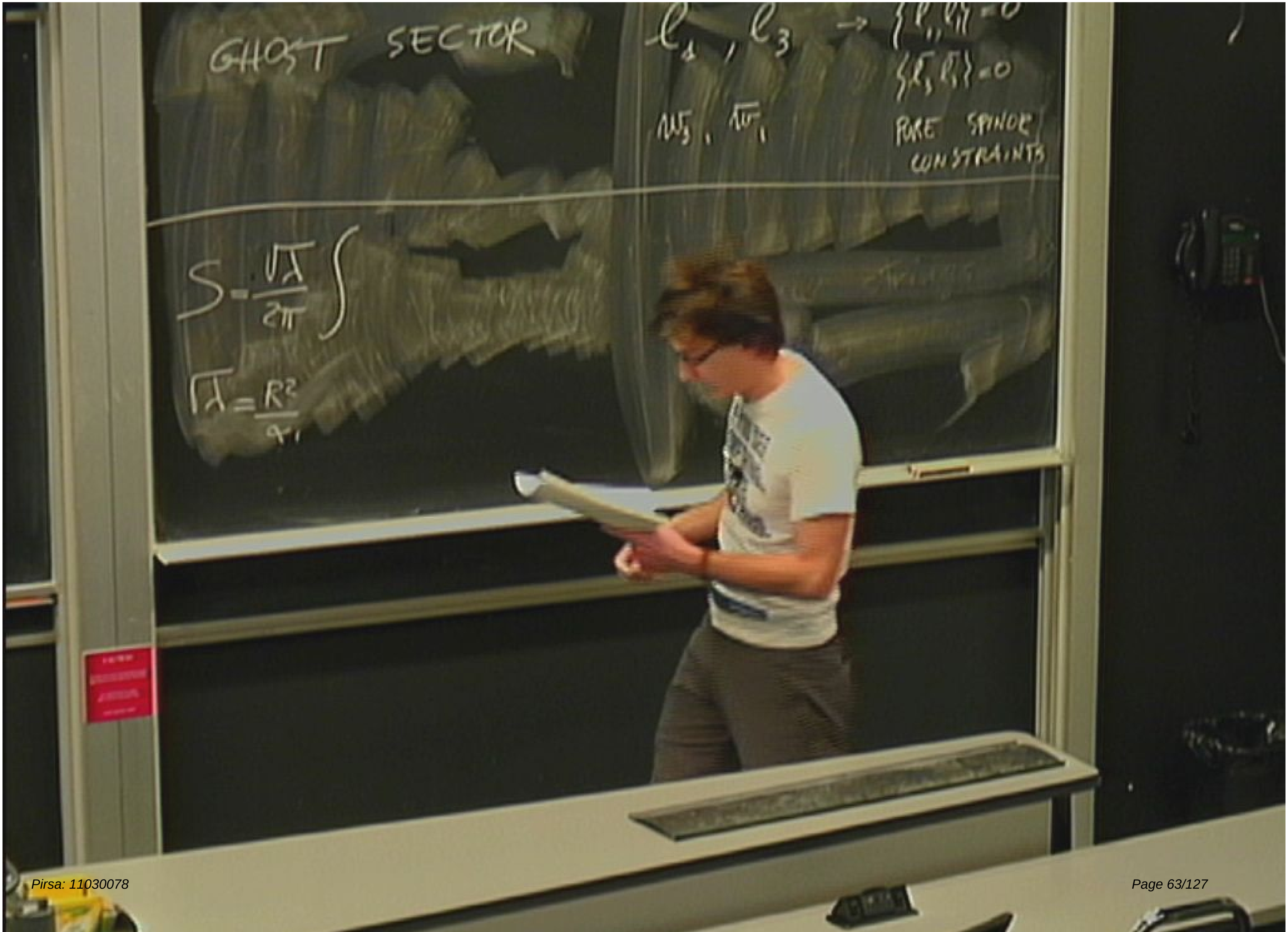
$\ell_1 \, , \, \bar{\ell}_3 \rightarrow \{\ell_1, \ell_1\} = 0$

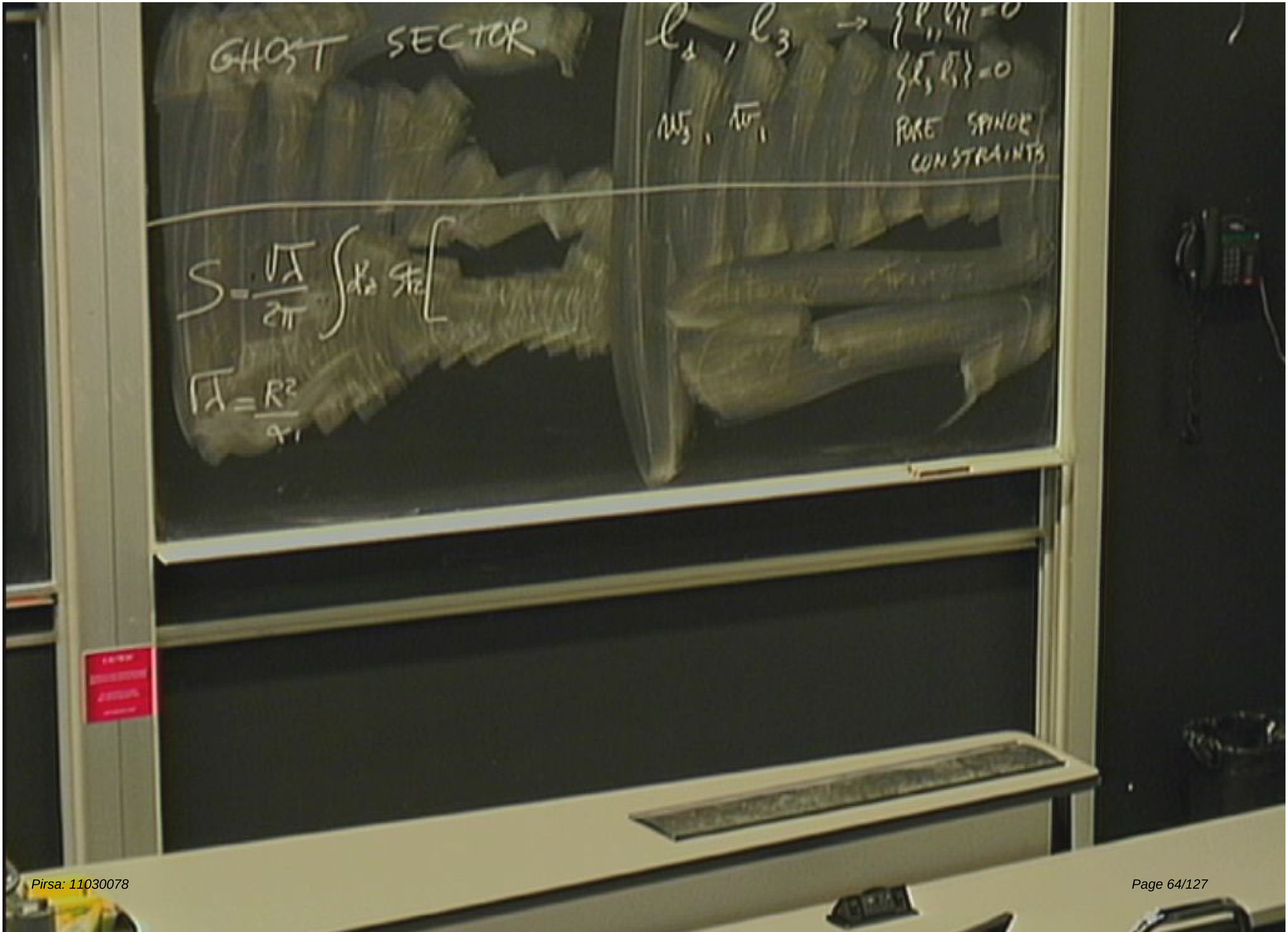
$\{\bar{\ell}_3, \bar{\ell}_3\} = 0$

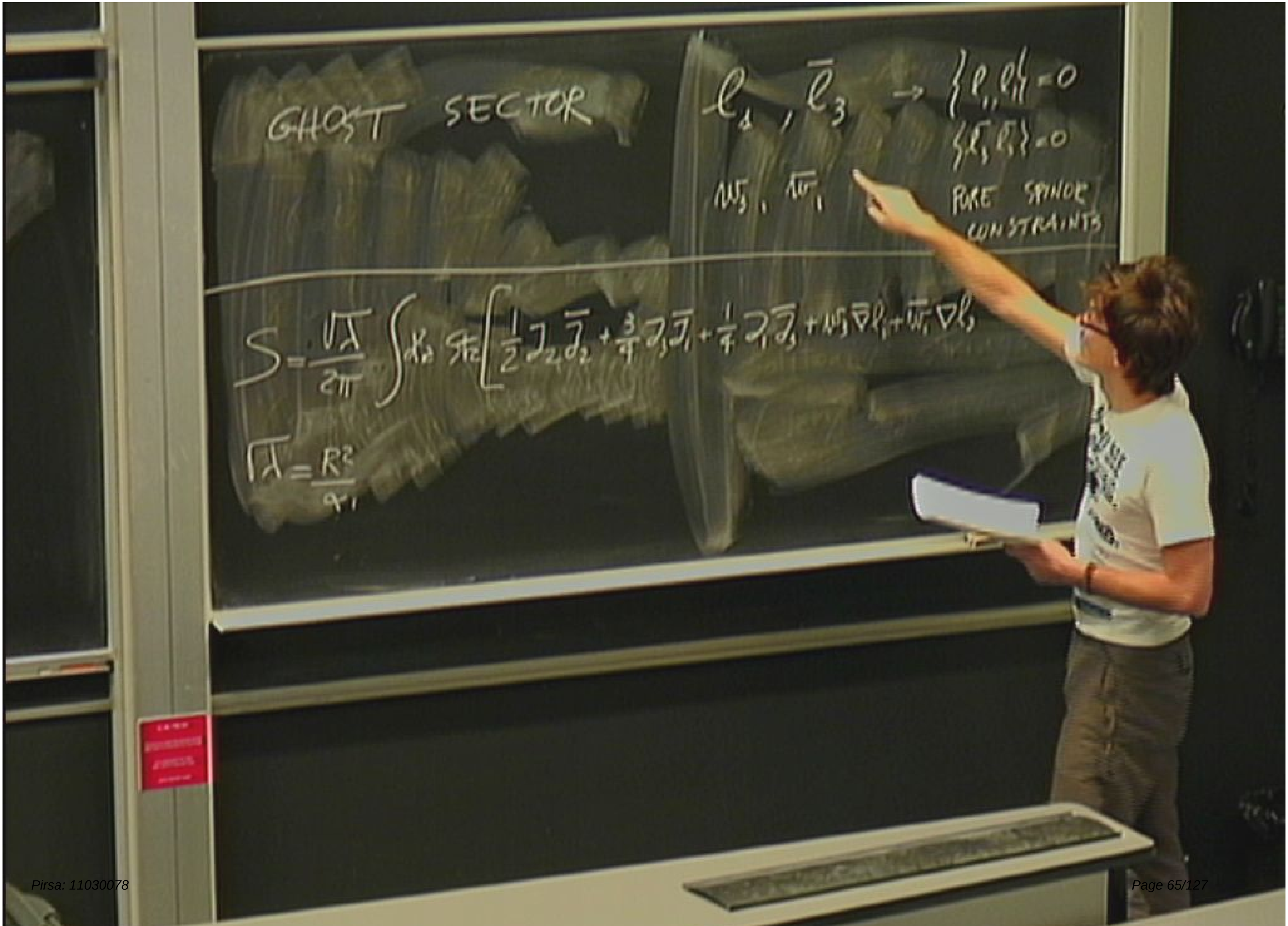
$w_3 \, , \, \bar{w}_1$

PURE SPINOR CONSTRAINTS

$S = \frac{\sqrt{\lambda}}{2\pi} \int$


GHOST SECTOR
PURE SPINOR
CONSTRAINTS


GHOST SECTOR
PURE SPINOR
CONSTRAINTS


GHOST SECTOR
PURE SPINOR
CONSTRAINTS

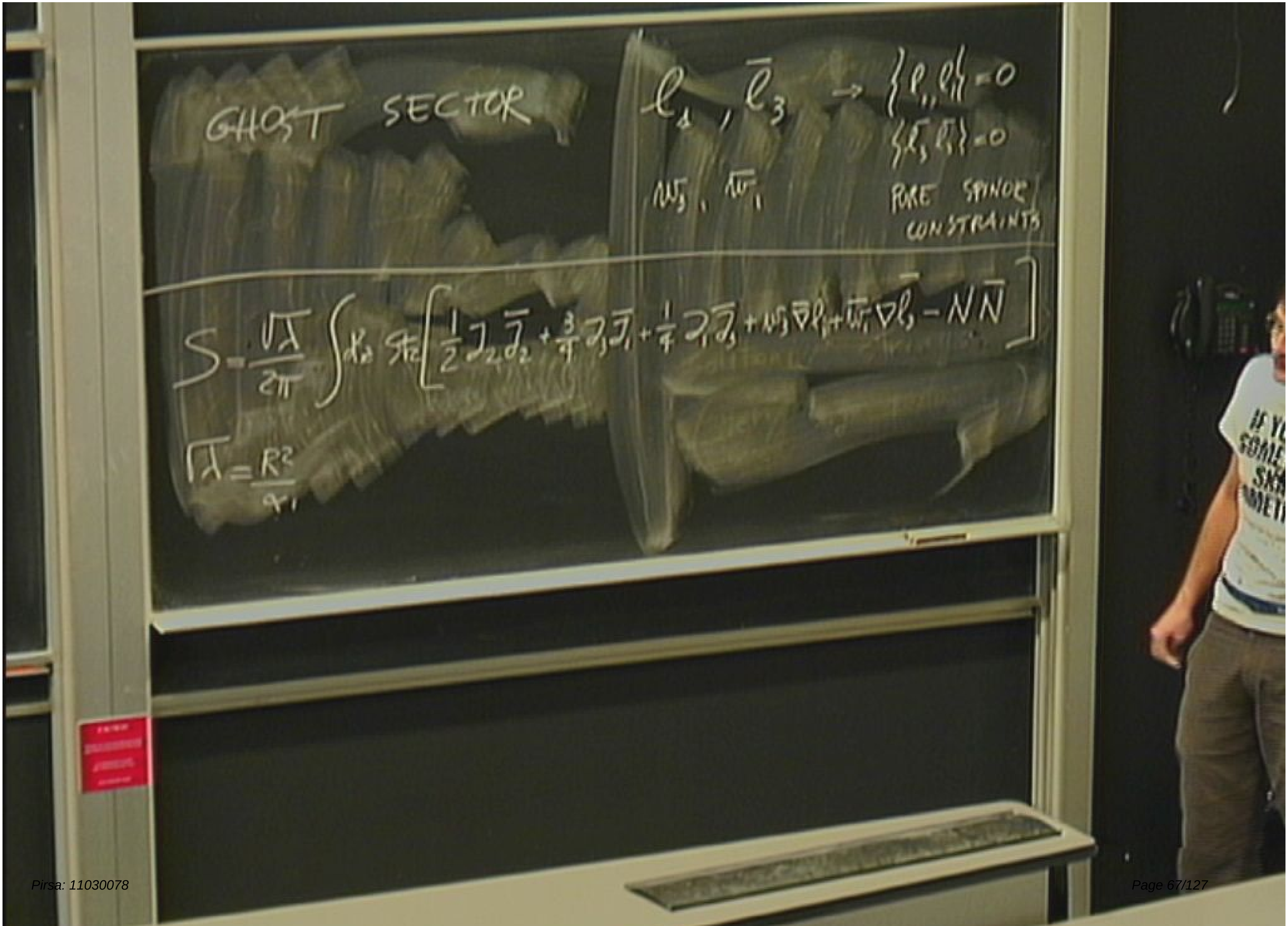
$$AdS_5 \times S^5 = \frac{PSU(2,2|4)}{SO(1,4) \times SO(5)} \xleftarrow{} \mathbb{Z}_4 \text{ grading}$$

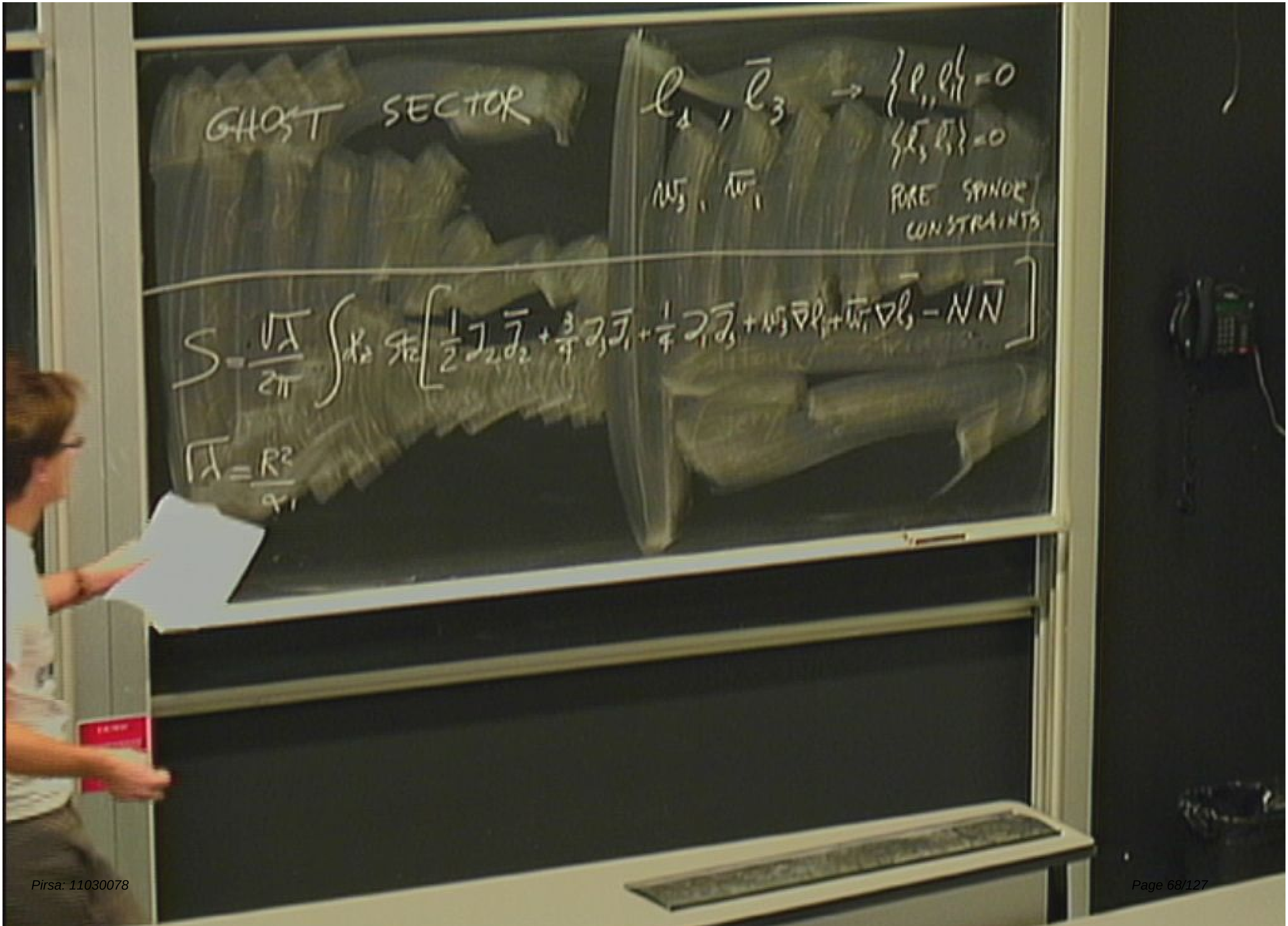
$+ 32 f$

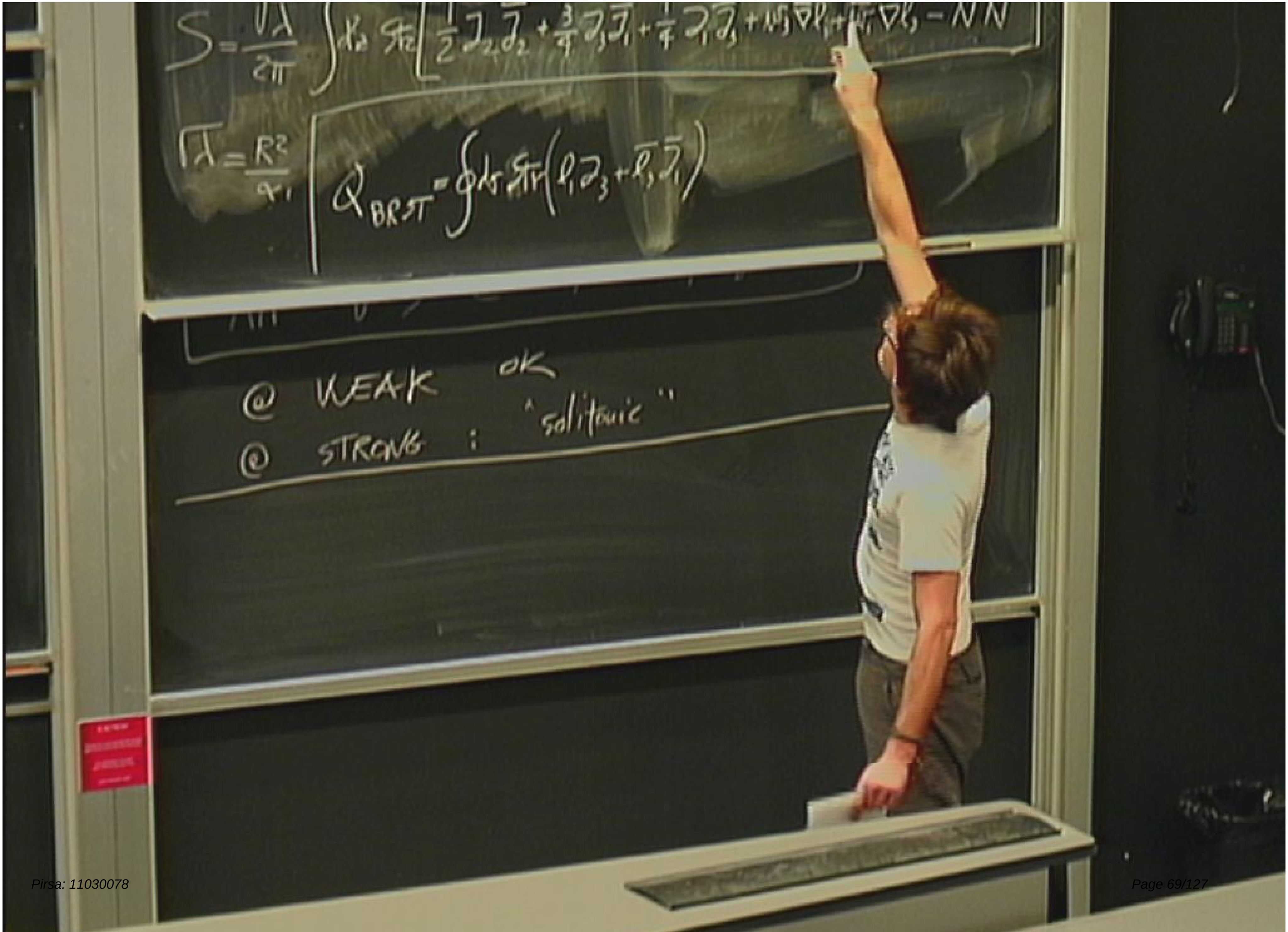
$$g(\sigma,\tau) \longrightarrow g_0\, g(\sigma,\tau)\, h(\sigma,\tau)$$

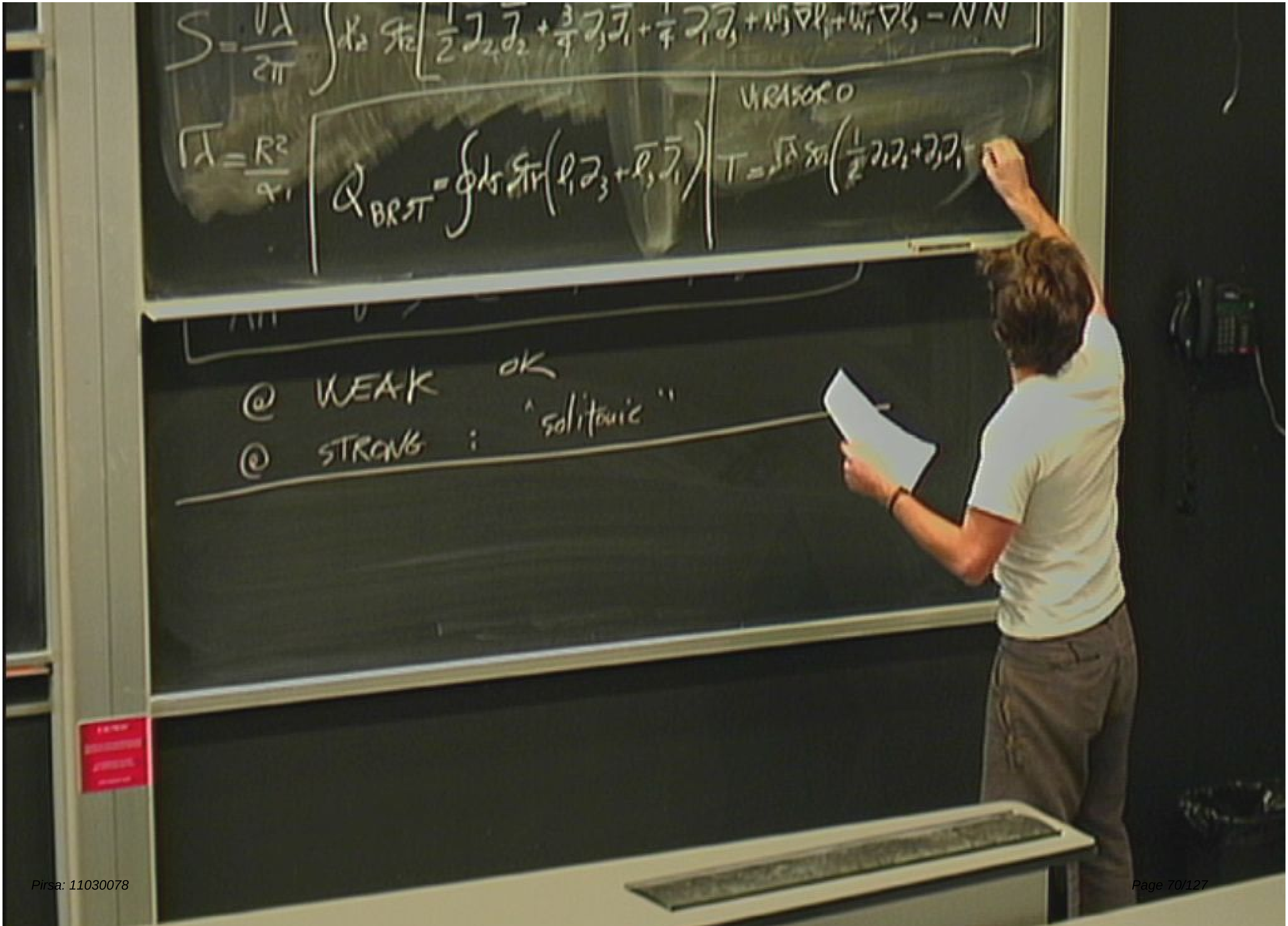
MATTER left-inv MC currents

$$J = g^{-1} dg = \underbrace{J_0}_{\text{GAUGE}} + \underbrace{J_2}_{\text{10 bosons}} + \underbrace{J_1 + J_3}_{\text{32 fermions}}$$


GHOST SECTOR
PURE SPINOR
CONSTRAINTS


GHOST SECTOR
PURE SPINOR CONSTRAINTS


@ WEAK ok
@ STRONG : "solitonic"


VIRASORO
@ WEAK ok
@ STRONG : "solitonic"

$$\frac{\sqrt{\lambda}}{2\pi}\int d^2z\, \mathrm{Str}\left[\frac{1}{2}J_2\bar{J}_2+\frac{3}{4}J_3\bar{J}_1+\frac{1}{4}J_1\bar{J}_3+w_3\bar{\nabla}\lambda_1+\bar{w}_1\nabla\bar{\lambda}_3-N\bar{N}\right]$$

$$\frac{R^2}{\alpha'}$$

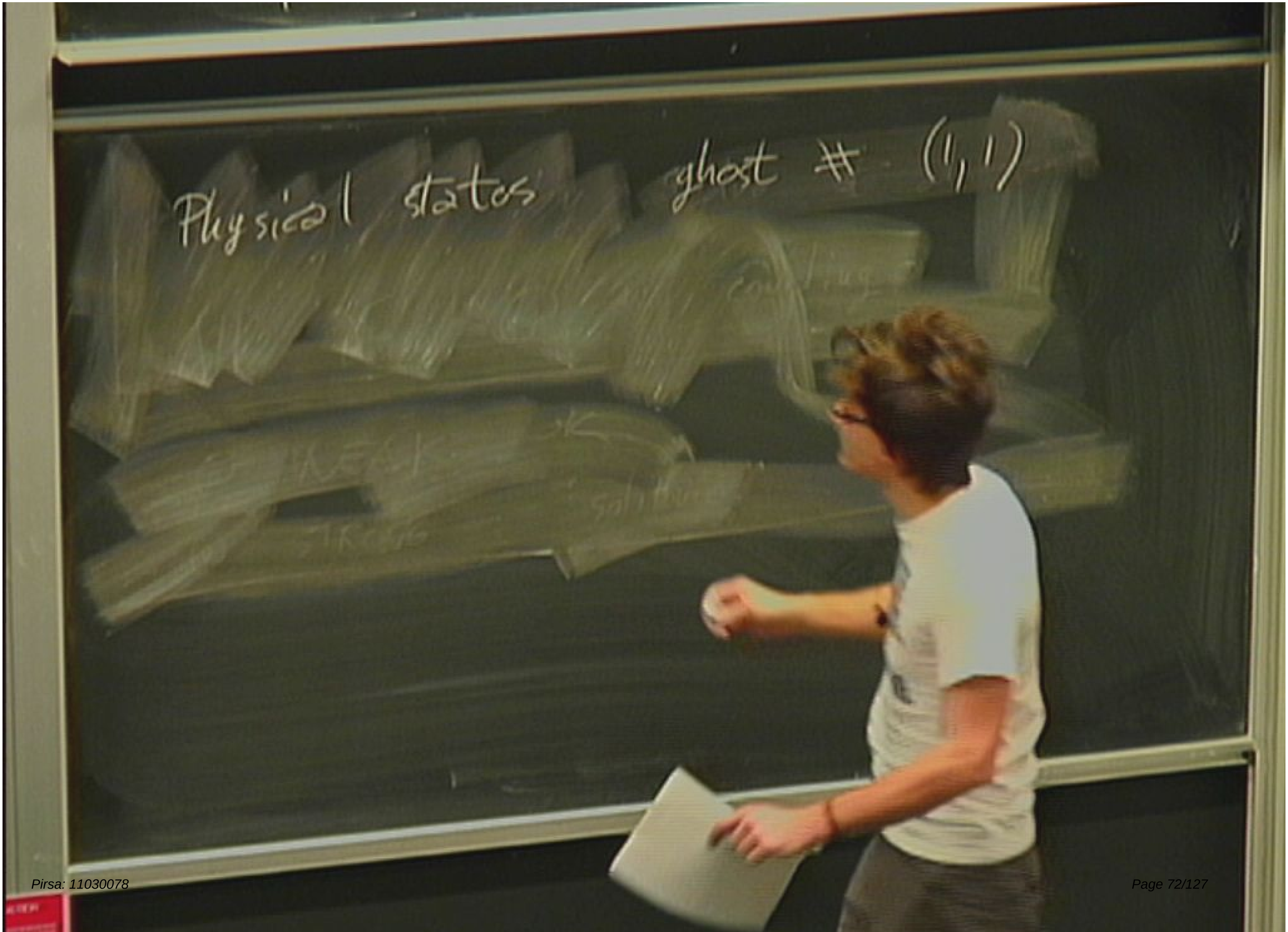
$$\boxed{Q_{BRST}=\oint d\sigma\, \mathrm{Str}\left(\lambda_1 J_3+\bar{\lambda}_3\bar{J}_1\right)}$$

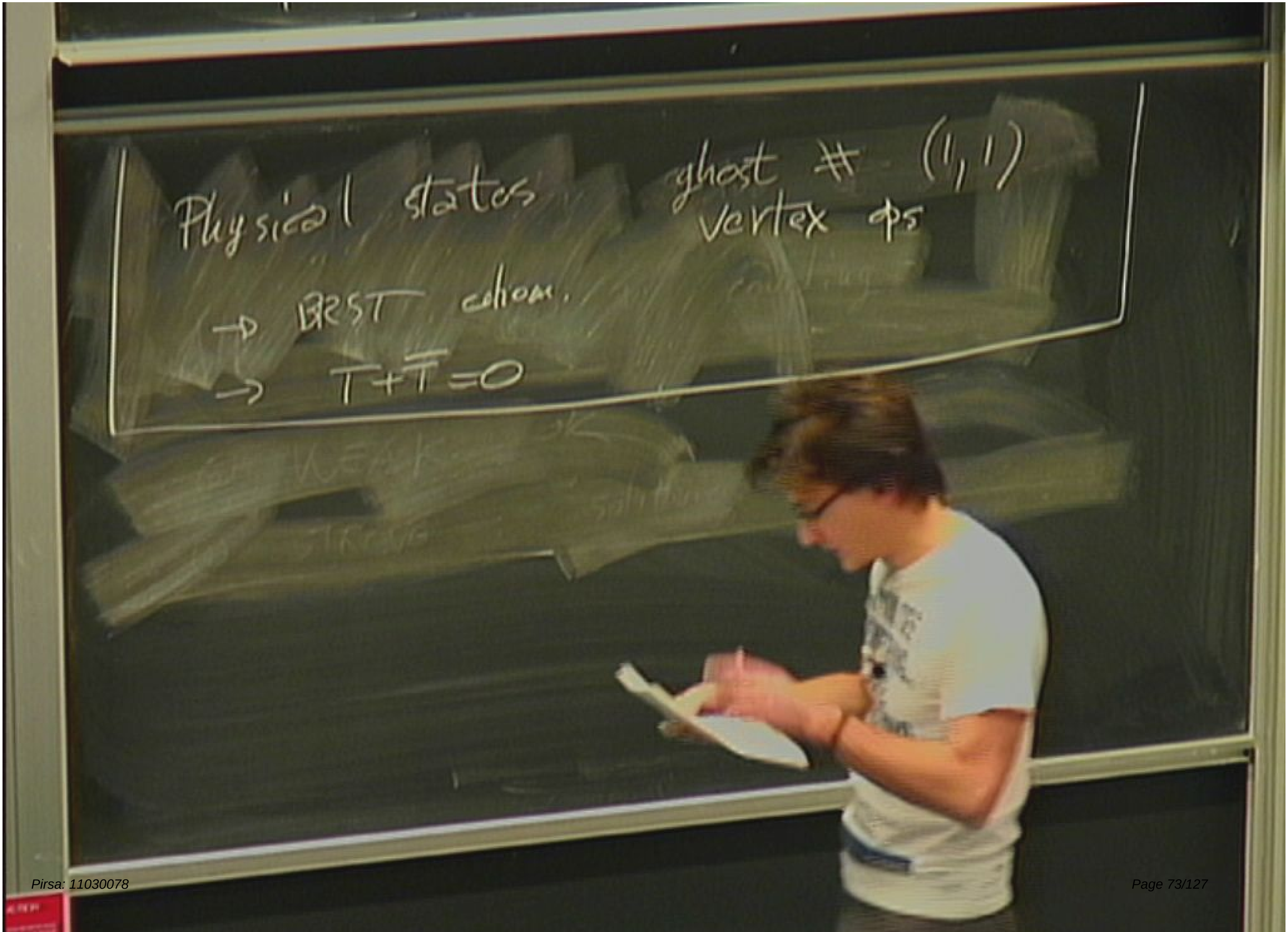
VIRASORO

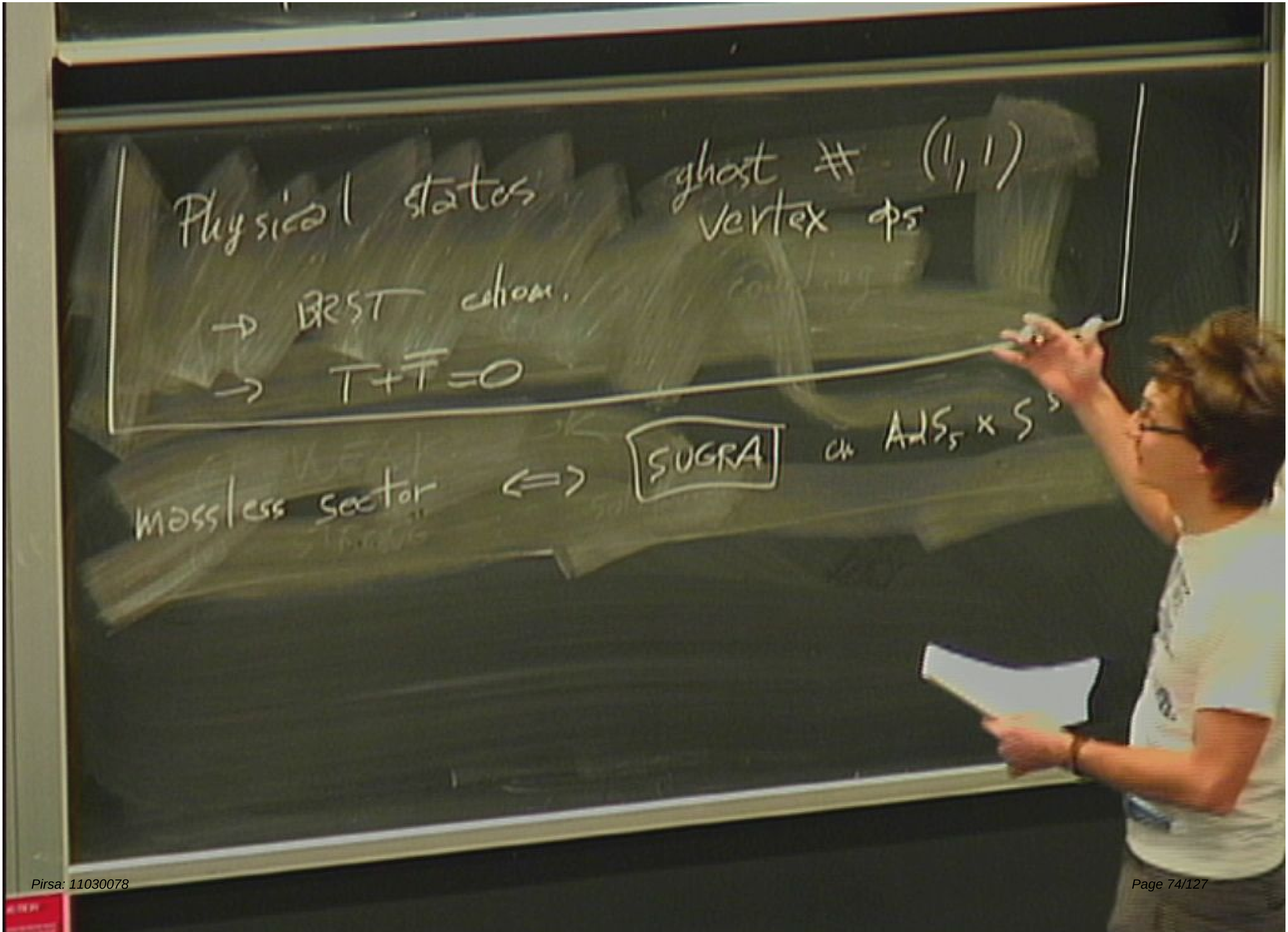
$$T=\sqrt{\lambda}\,\mathrm{Str}\left(\frac{1}{2}J_2J_2+J_3J_1-w_3\nabla\lambda_1\right)$$

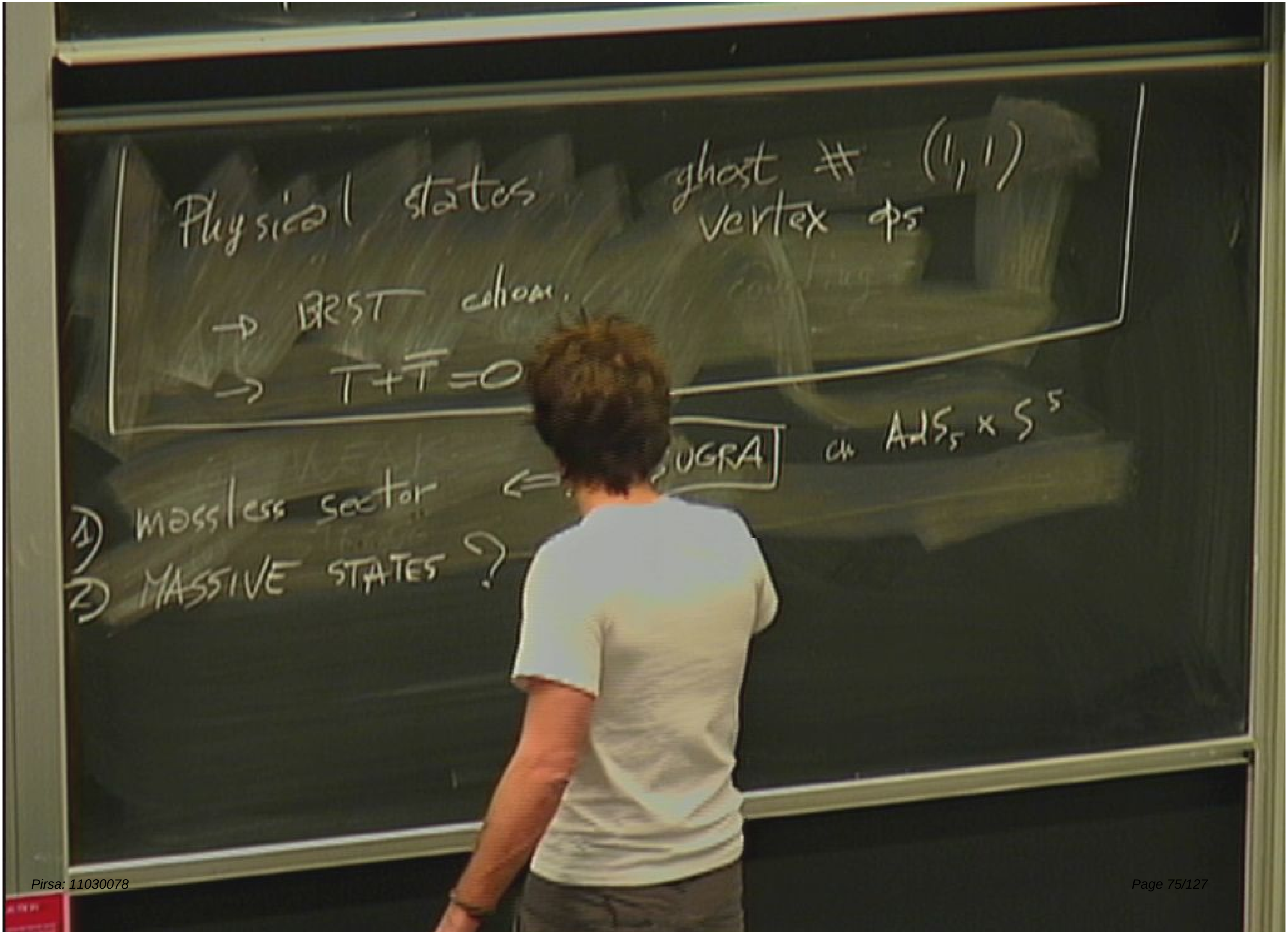
① WEAK ok

② STRONG : "solitonic"


Physical states
ghost # (1,1)


Physical states
ghost # (1,1)
vertex ops
→ BRST cohom.
→ $T+\bar{T}=0$


Physical states
ghost # (1,1)
vertex ops
→ BRST cohom.
→ T+T̄=0
massless sector ⟺ SUGRA on AdS5 × S5



Physical states
ghost # (1,1)
vertex ops
→ BRST cohom.
→ T+T̄=0
UGRA on AdS5 x S5
1 massless sector ⇐
2 MASSIVE STATES ?

Physical states ghost # (1, 1)
vertex ops

→ BRST cohom.

→ $T + \bar{T} = 0$

① massless sector ⟺ $\boxed{\text{SUGRA}}$ on $AdS_5 \times S^5$

② MASSIVE STATES ? — AdS global $ds^2 = -\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho\, d\Omega_3^2$

Physical states — ghost # $(1,1)$

vertex ops

$\rightarrow$ BRST cohom.

$\rightarrow$ $T+\bar{T}=0$

(1) massless sector $\Longleftrightarrow$ $\boxed{\text{SUGRA}}$ on $AdS_5 \times S^5$

(2) MASSIVE STATES ? — AdS global $\quad ds^2 = -\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho \ldots$

string $\rho \sim 0$

Physical states ghost # (1,1)
vertex ops

→ BRST cohom.

→ $T + \bar{T} = 0$

$\boxed{\text{SUGRA}}$ on $AdS_5 \times S^5$

1) massless sector $\Longleftrightarrow$ $\boxed{\text{SUGRA}}$

2) MASSIVE STATES ? — AdS global $ds^2 = -\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho\, d\Omega_3^2$

string $\rho \sim 0$

$$\boxed{\tilde{g}(\sigma,\tau) = \exp\left(-\tau E \frac{T}{\sqrt{\lambda}}\right)}$$

Physical states — ghost # (1,1)
vertex ops

→ BRST cohom.

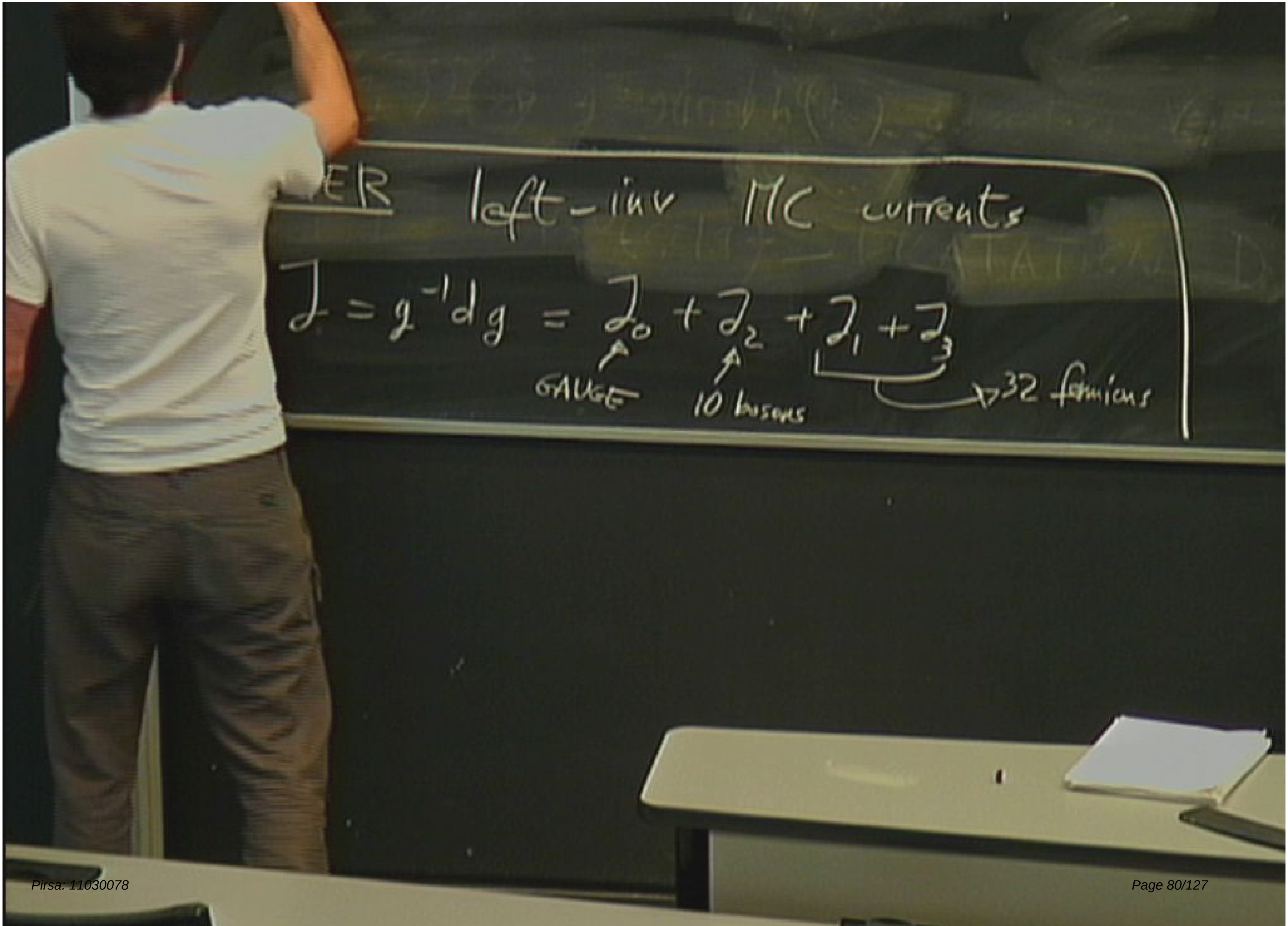
→ $T+\bar{T}=0$

① massless sector $\Longleftrightarrow$ $\boxed{\text{SUGRA}}$ on $AdS_5 \times S^5$

② MASSIVE STATES ? — AdS global $ds^2 = -\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho\, dS_3^2$

string $\rho \sim 0$

$$\boxed{\tilde{g}(\sigma,\tau) = \exp\left(-\tau E \frac{T}{\sqrt{\lambda}}\right)}$$


ER left-inv MC currents
J = g^{-1}dg = J_0 + J_2 + J_1 + J_3
GAUGE
10 bosons
32 fermions

$\tilde{J}_t =$

MATTER left-inv MC currents

$$J = g^{-1}dg = J_0 + J_2 + \underbrace{J_1 + J_3}_{32 \text{ fermions}}$$

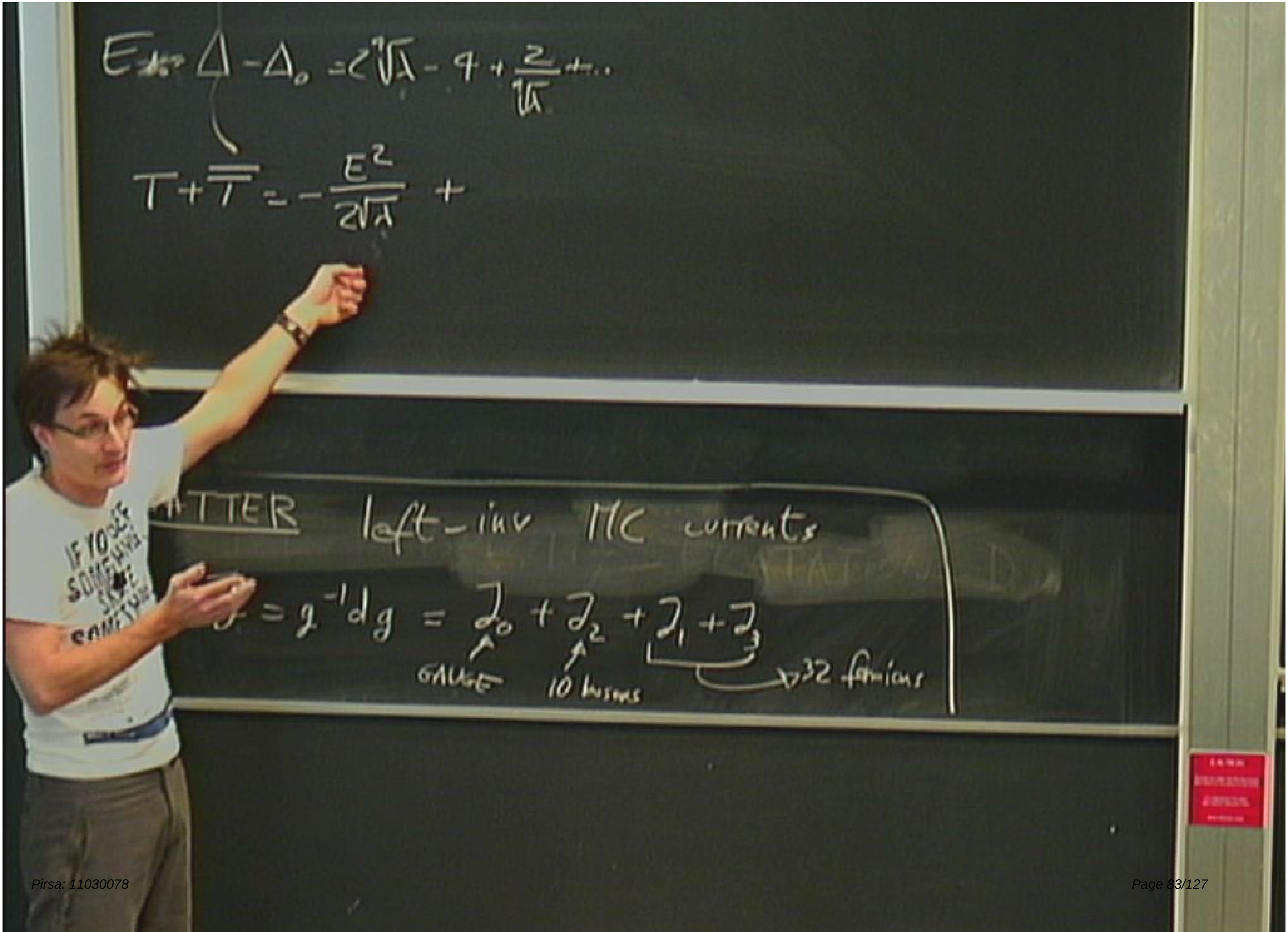
GAUGE 10 bosons

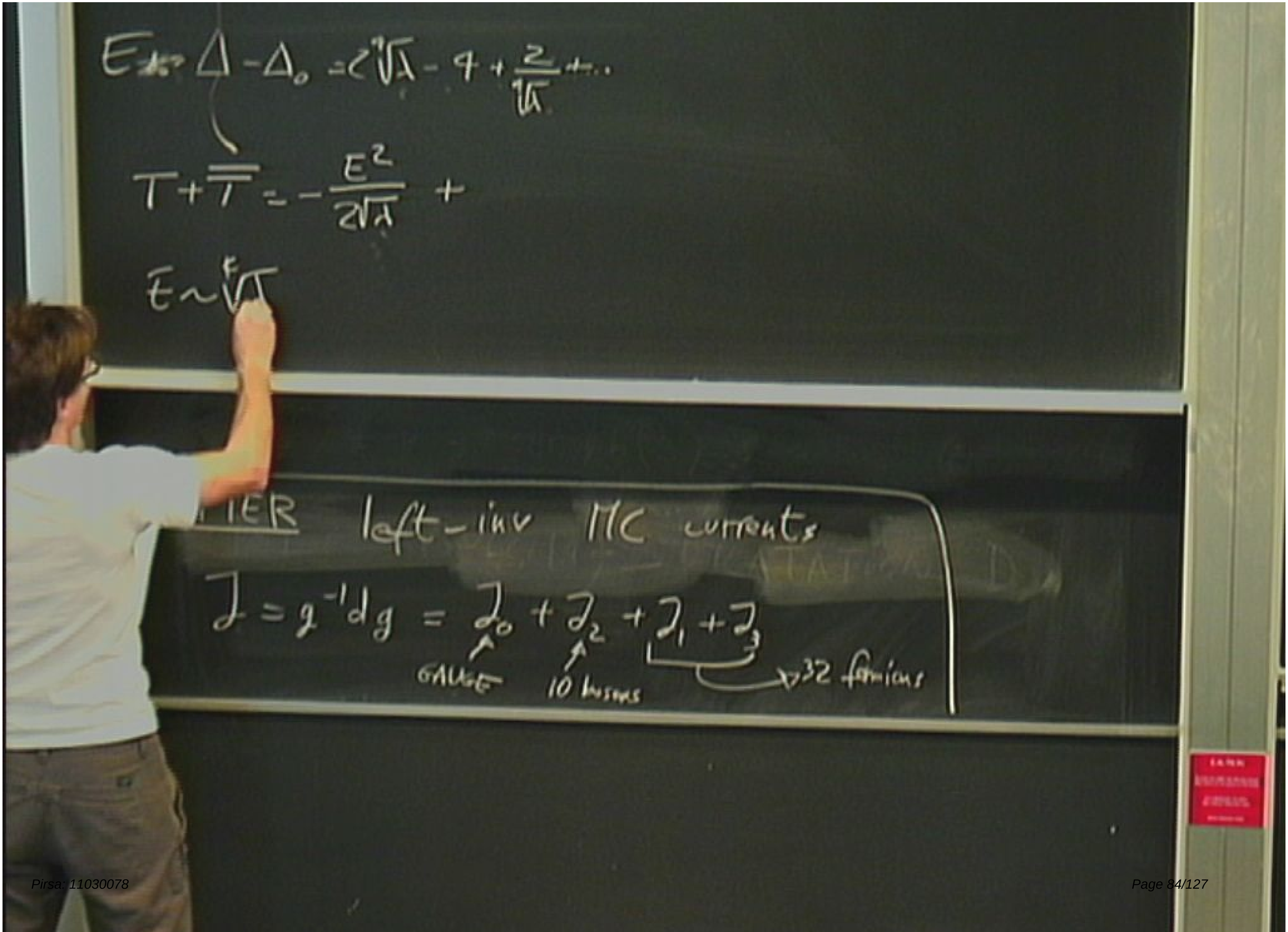
$$E = \Delta - \Delta_0 = 2\sqrt[4]{\lambda} - 4 + \frac{2}{\sqrt[4]{\lambda}} + \dots$$

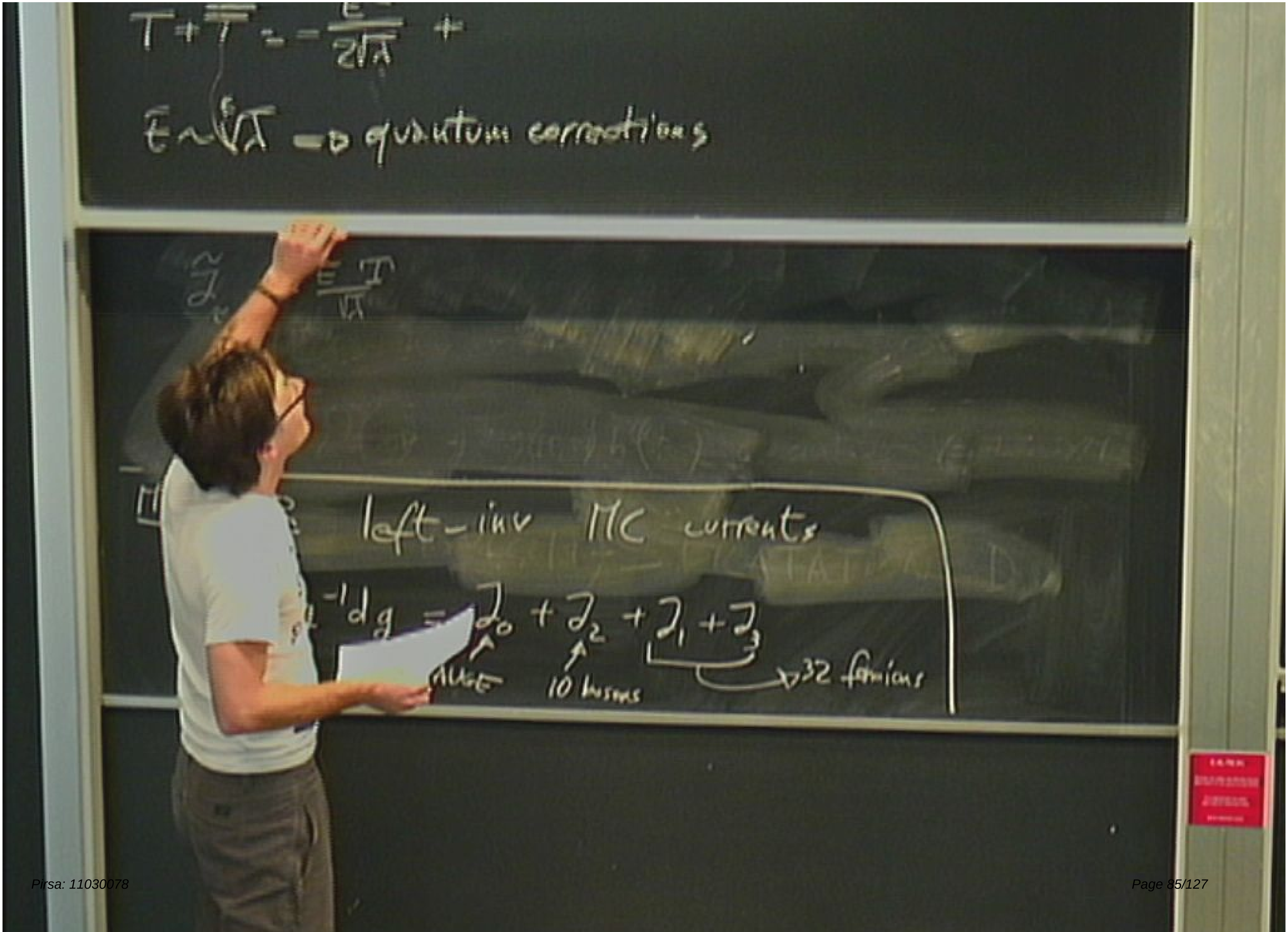
$$T + \bar{T} = -\frac{E^2}{2\sqrt{\lambda}}$$

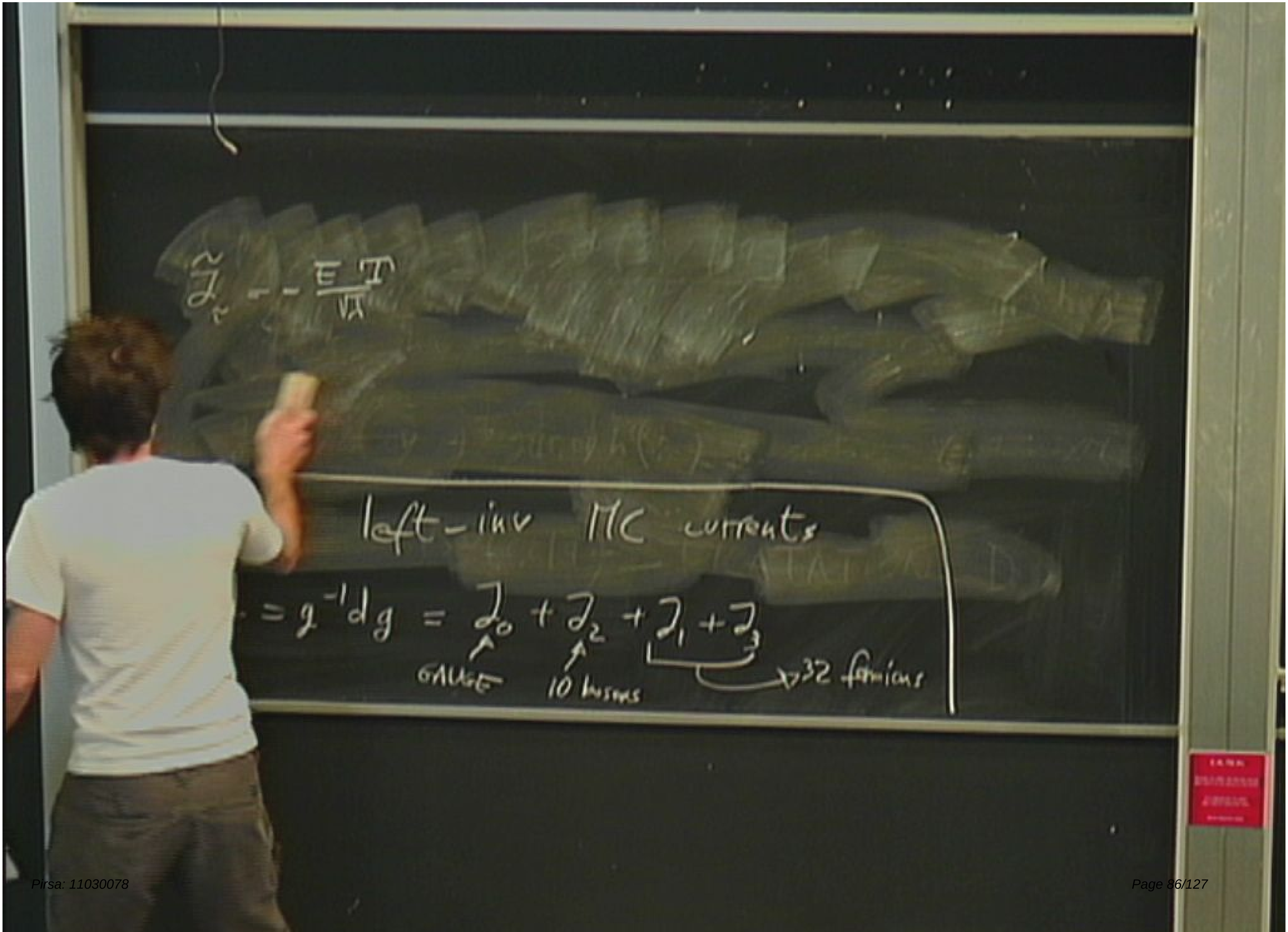
MATTER left-inv MC currents

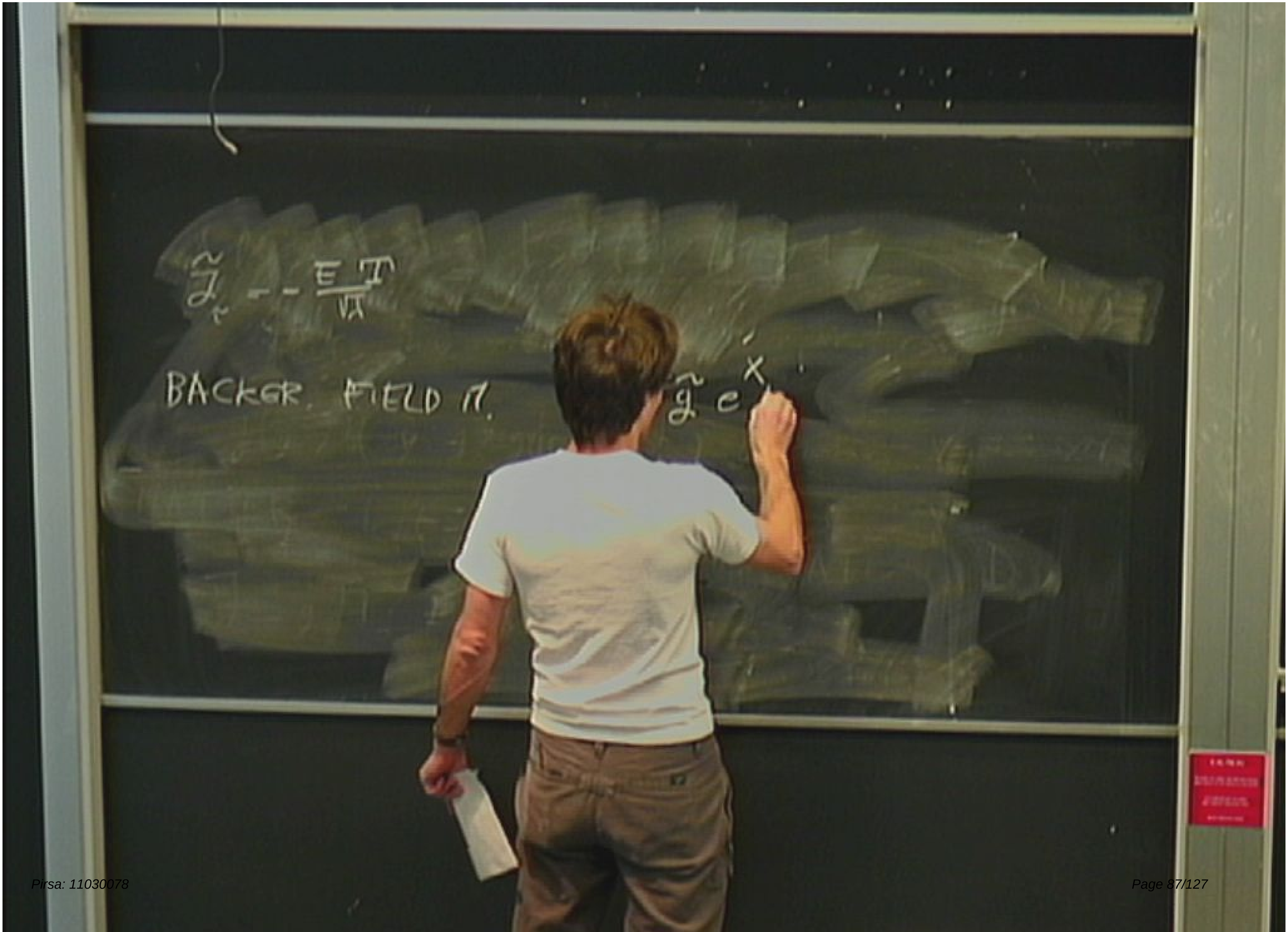
$$J = g^{-1} dg = \underset{\text{GAUGE}}{J_0} + \underset{\text{10 bosons}}{J_2} + \underbrace{J_1 + J_3}_{\text{32 fermions}}$$

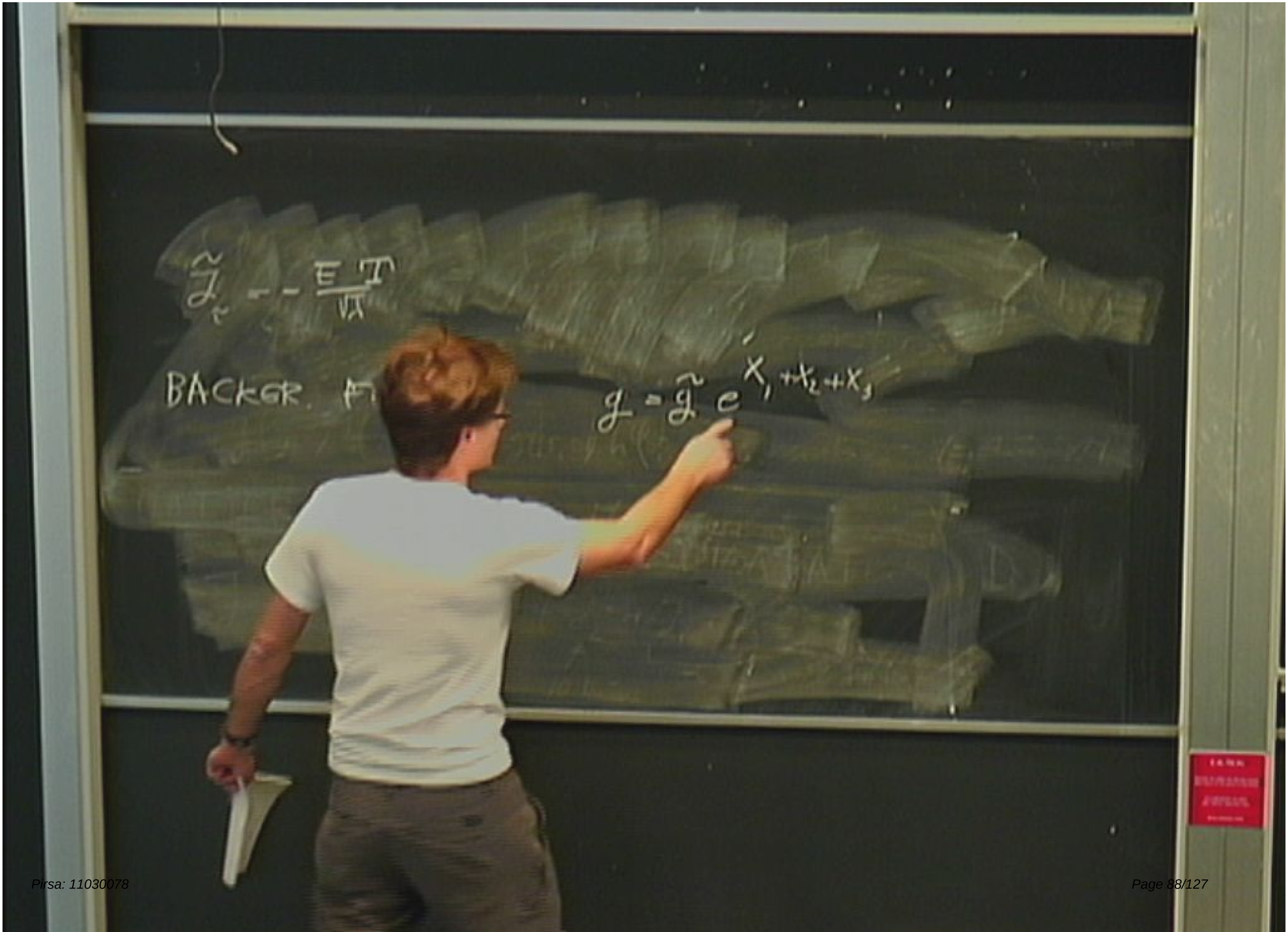

$E = \Delta - \Delta_0 = 2\sqrt{\lambda} - 4 + \frac{2}{\sqrt{\lambda}} + \ldots$
$T + \bar{T} = -\frac{E^2}{2\sqrt{\lambda}} +$
TTER left-inv MC currents
$J = g^{-1}dg = J_0 + J_2 + J_1 + J_3$
GAUGE
10 bosons
32 fermions

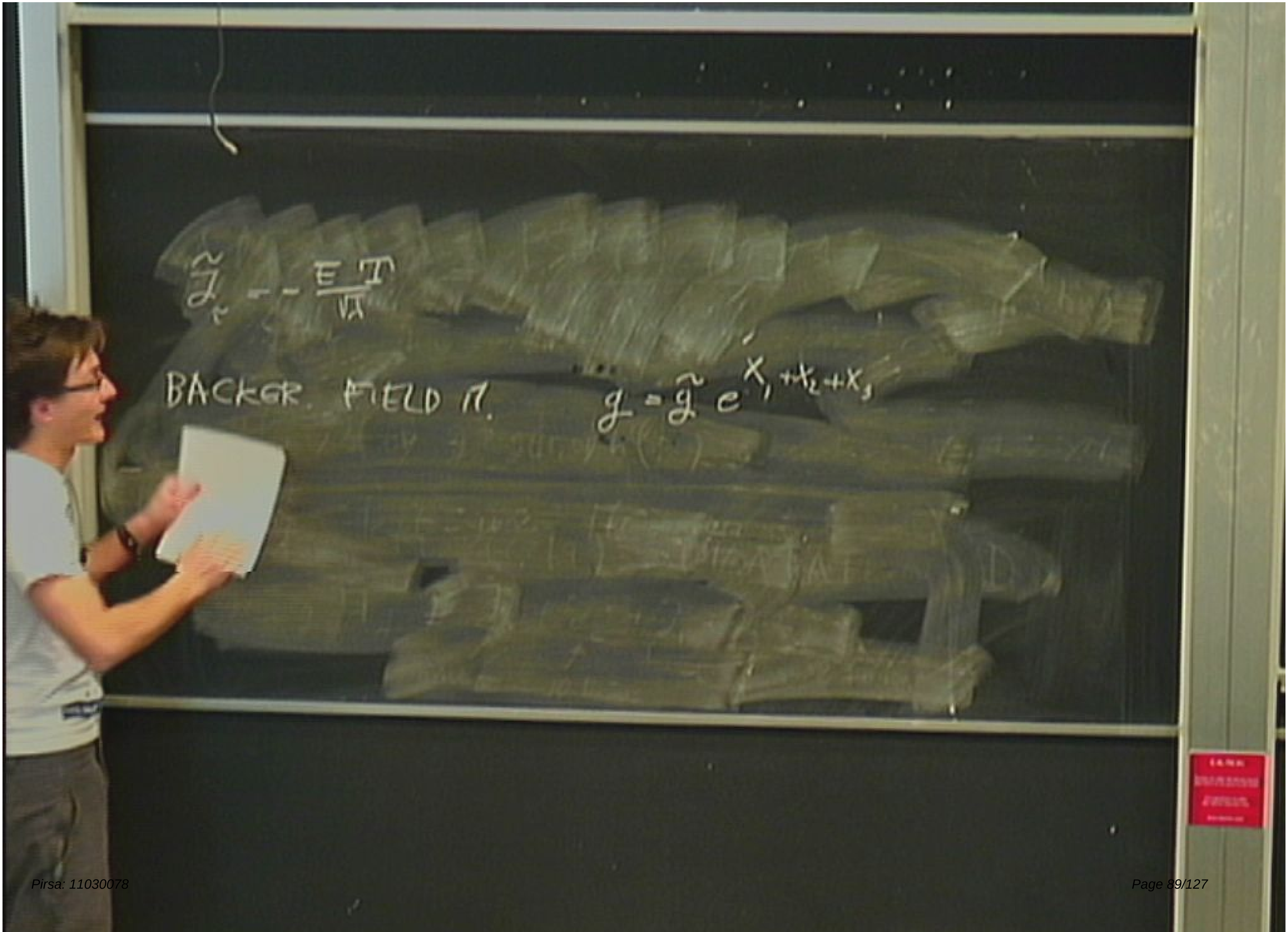

$E = \Delta - \Delta_0 = 2\sqrt[4]{\lambda} - 4 + \frac{2}{\sqrt[4]{\lambda}} + \dots$
$T + \bar{T} = -\frac{E^2}{2\sqrt{\lambda}} +$
$E \sim \sqrt[4]{\lambda}$
left-inv MC currents
$J = g^{-1}dg = J_0 + J_2 + J_1 + J_3$
GAUGE
10 bosons
32 fermions

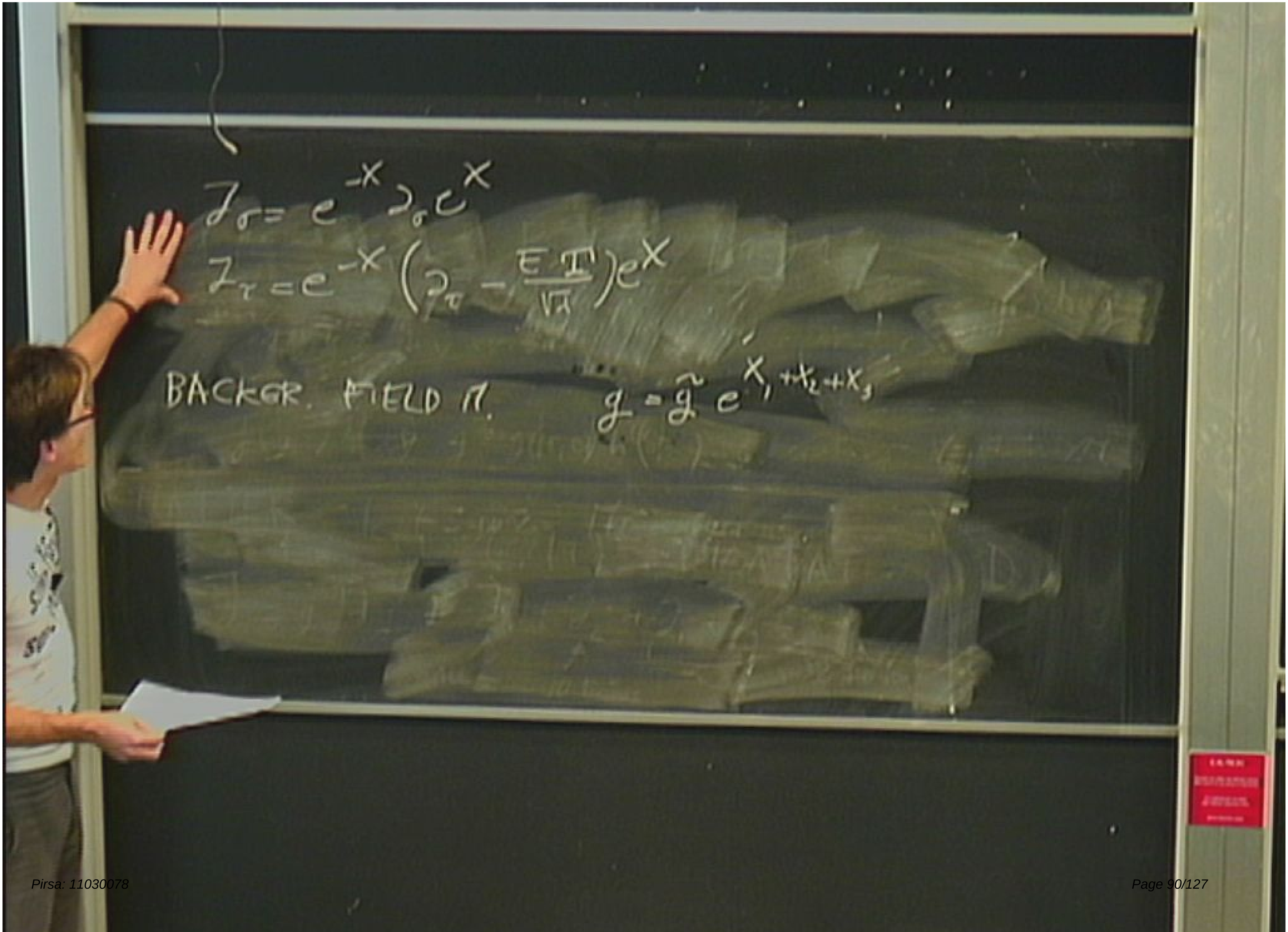

quantum corrections
left-inv MC currents
10 bosons
32 fermions


$\tilde{J}_z = -\frac{E}{\sqrt{\lambda}} I$
left-inv MC currents
$= g^{-1}dg = J_0 + J_2 + J_1 + J_3$
GAUGE
10 bosons
32 fermions


BACKGR. FIELD π.


BACKGR.
$g = \tilde{g}\, e^{X_1 + X_2 + X_3}$


BACKGR. FIELD M.
g = g̃ e^{X_1+X_2+X_3}

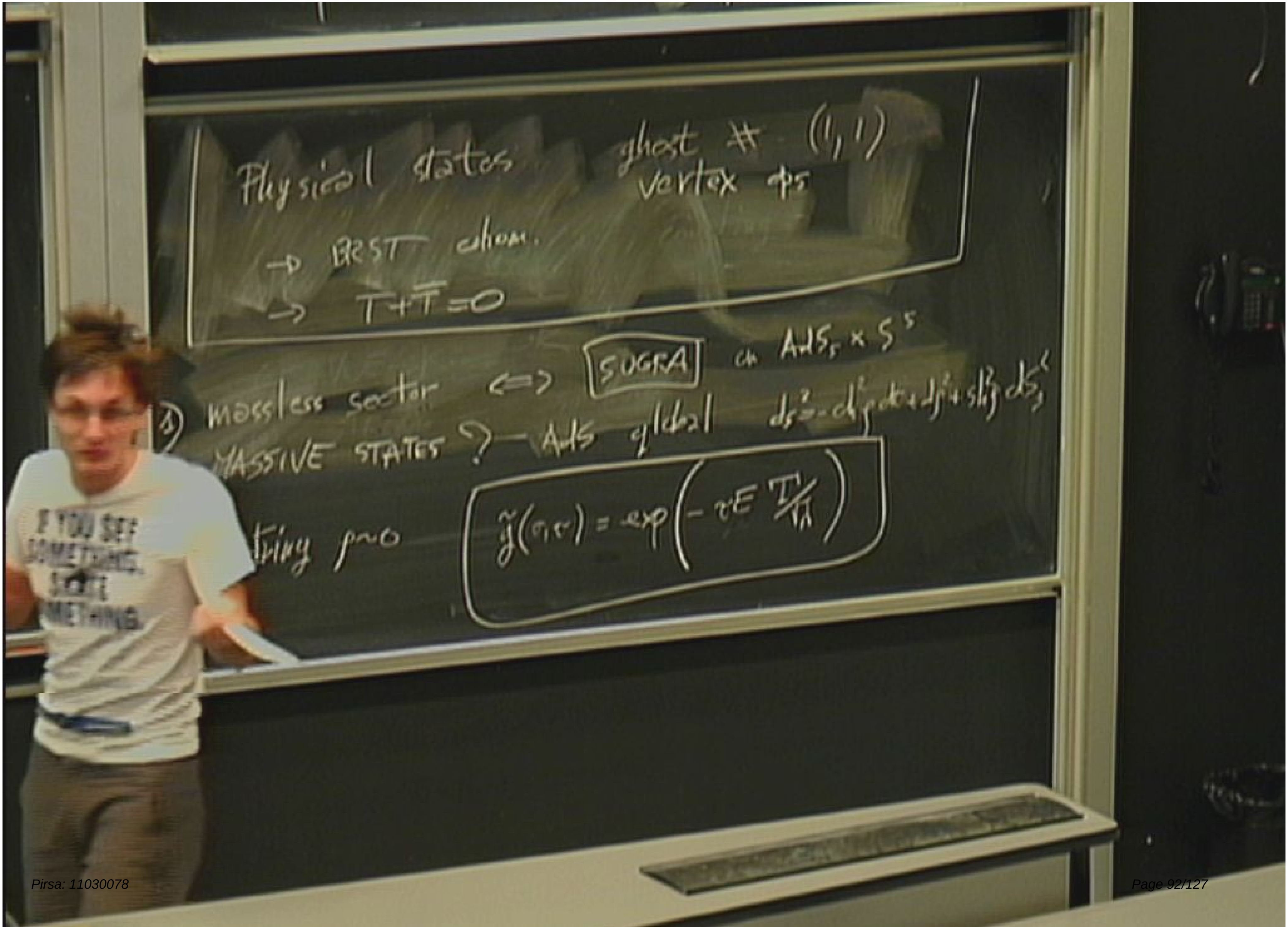


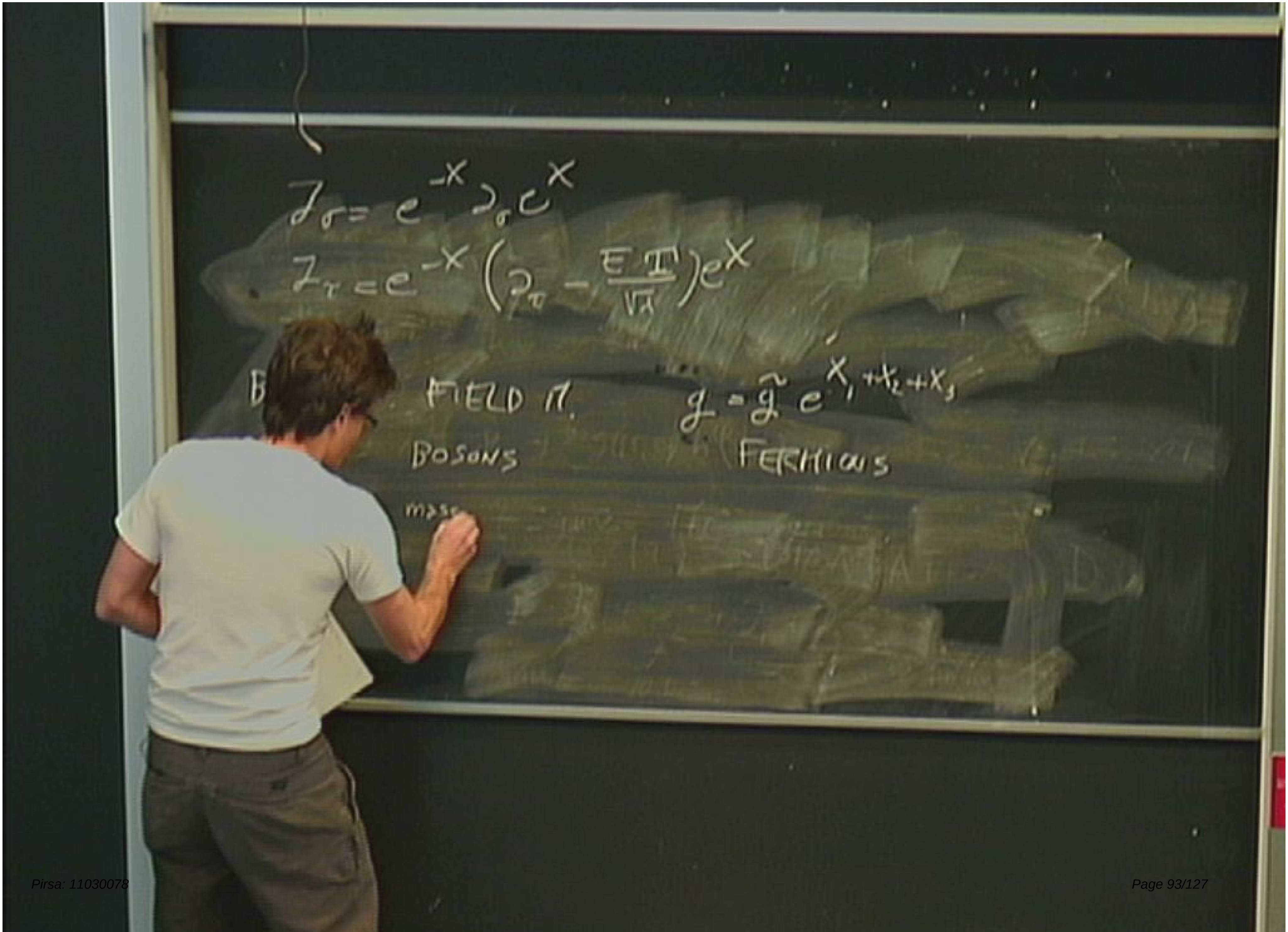
$\partial_\sigma = e^{-X}\partial_\sigma e^{X}$
$\partial_\tau = e^{-X}\left(\partial_\tau - \frac{E\,I}{\sqrt{2}}\right)e^{X}$
BACKGR. FIELD M.
$g = \tilde{g}\, e^{X_1+X_2+X_3}$

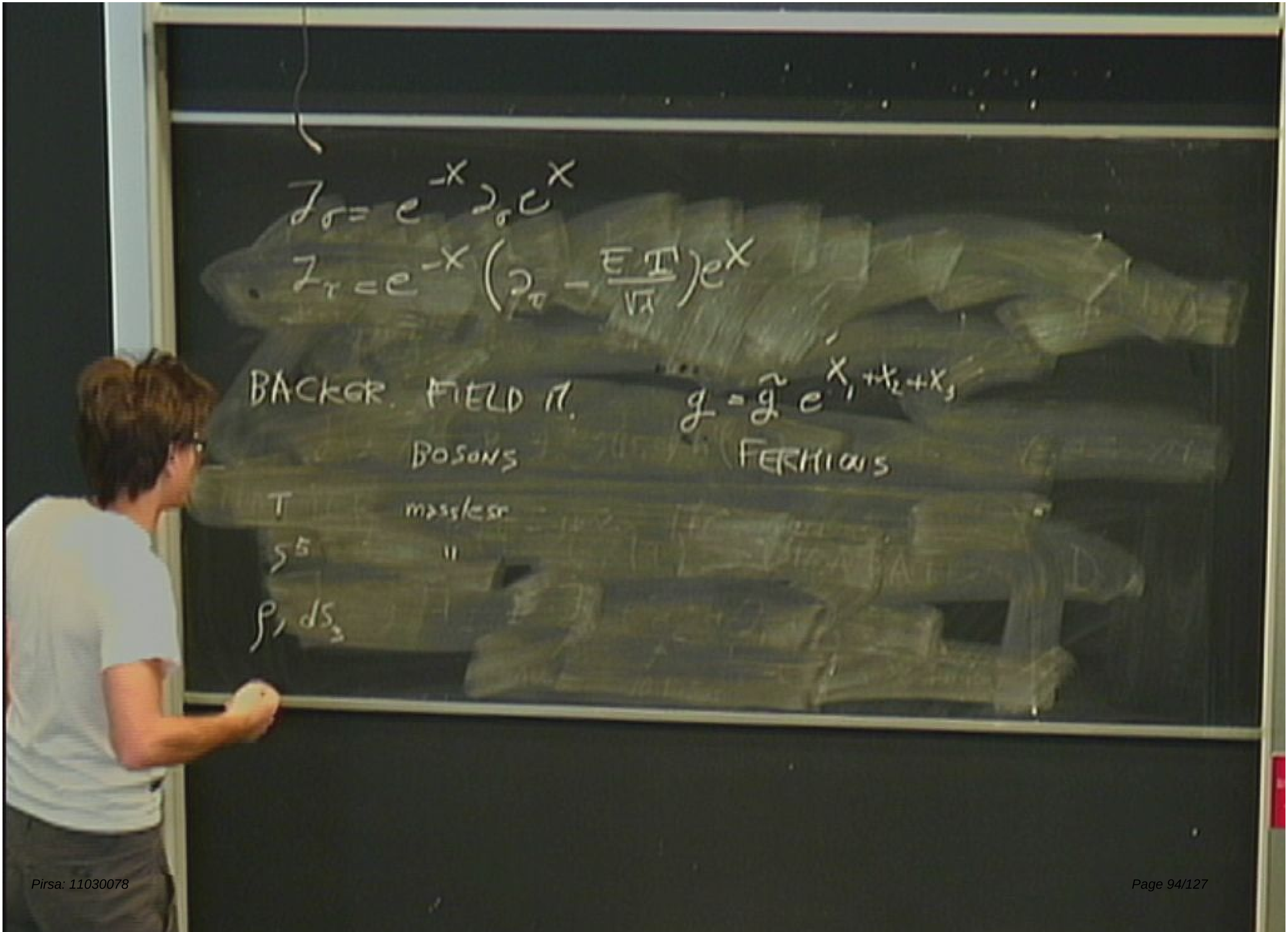
$$\partial_\sigma = e^{-X} \partial_\sigma e^{X}$$

$$\partial_\tau = e^{-X}\left(\partial_\tau - \frac{E\,\mathcal{I}}{\sqrt{2}}\right)e^{X}$$

BACKGR. FIELD M. $\quad g = \tilde{g}\, e^{X_1 + X_2 + X_3}$


Physical states
ghost # (1,1)
vertex ops
→ BRST cohom.
→ T+T̄=0
SUGRA on AdS5 × S5
massless sector ⟺ SUGRA
MASSIVE STATES ? — AdS global
string p~0


$J_\sigma = e^{-X} \partial_\sigma e^{X}$
$J_\tau = e^{-X} \left(\partial_\tau - \frac{E\,\Pi}{\sqrt{2}} \right) e^{X}$
FIELD Π.
$g = \tilde{g}\, e^{X_1 + X_2 + X_3}$
BOSONS
FERMIONS
mass

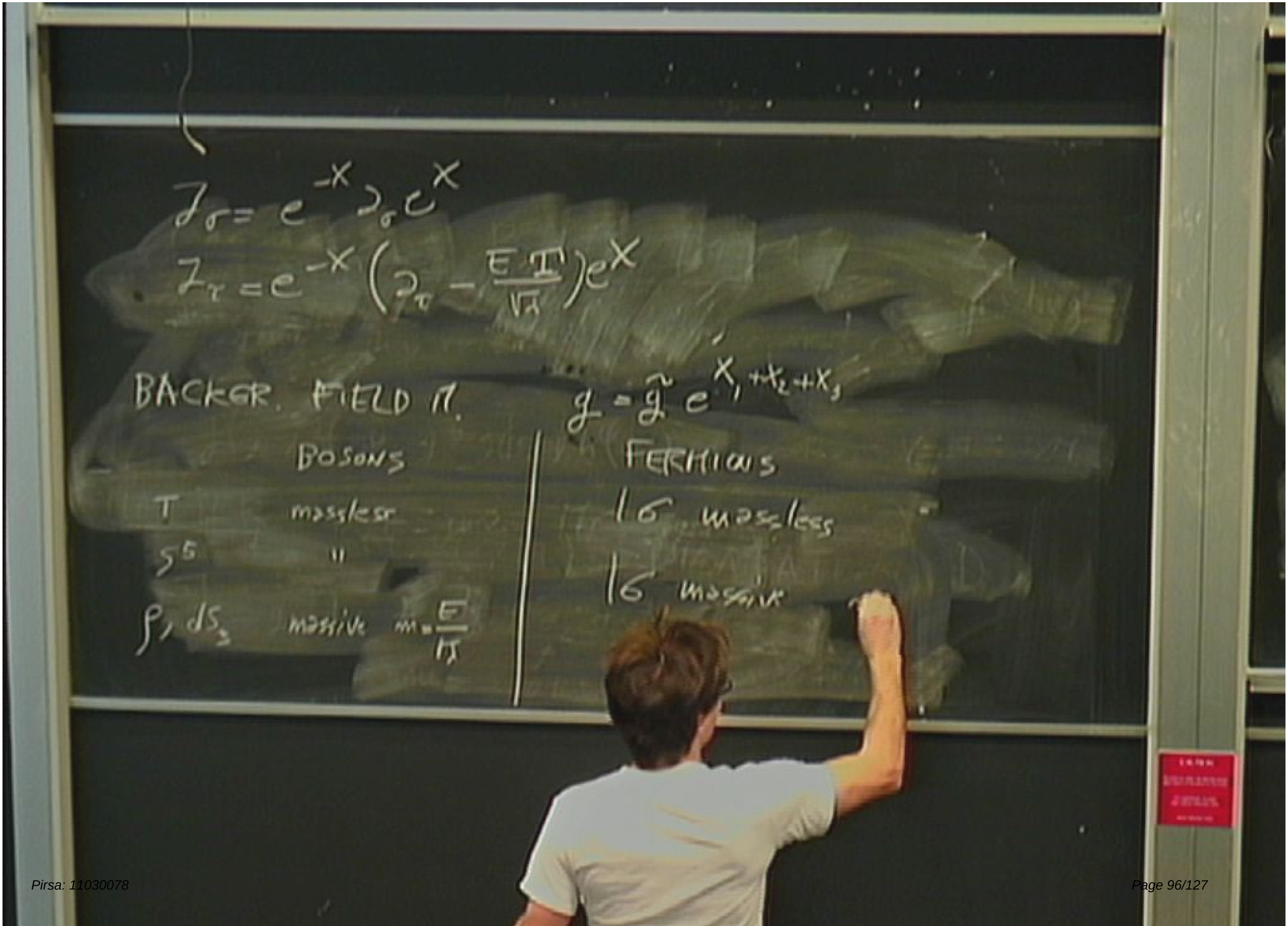

$J_\sigma = e^{-X}\partial_\sigma e^{X}$
$J_\tau = e^{-X}\left(\partial_\tau - \frac{E\,I}{\sqrt{2}}\right)e^{X}$
BACKGR. FIELD Π.
$g = \tilde{g}\, e^{X_1+X_2+X_3}$
BOSONS
FERMIONS
T
massless
S^5
"
$\rho,\ dS_3$

$$J_\sigma = e^{-X}\partial_\sigma e^{X}$$

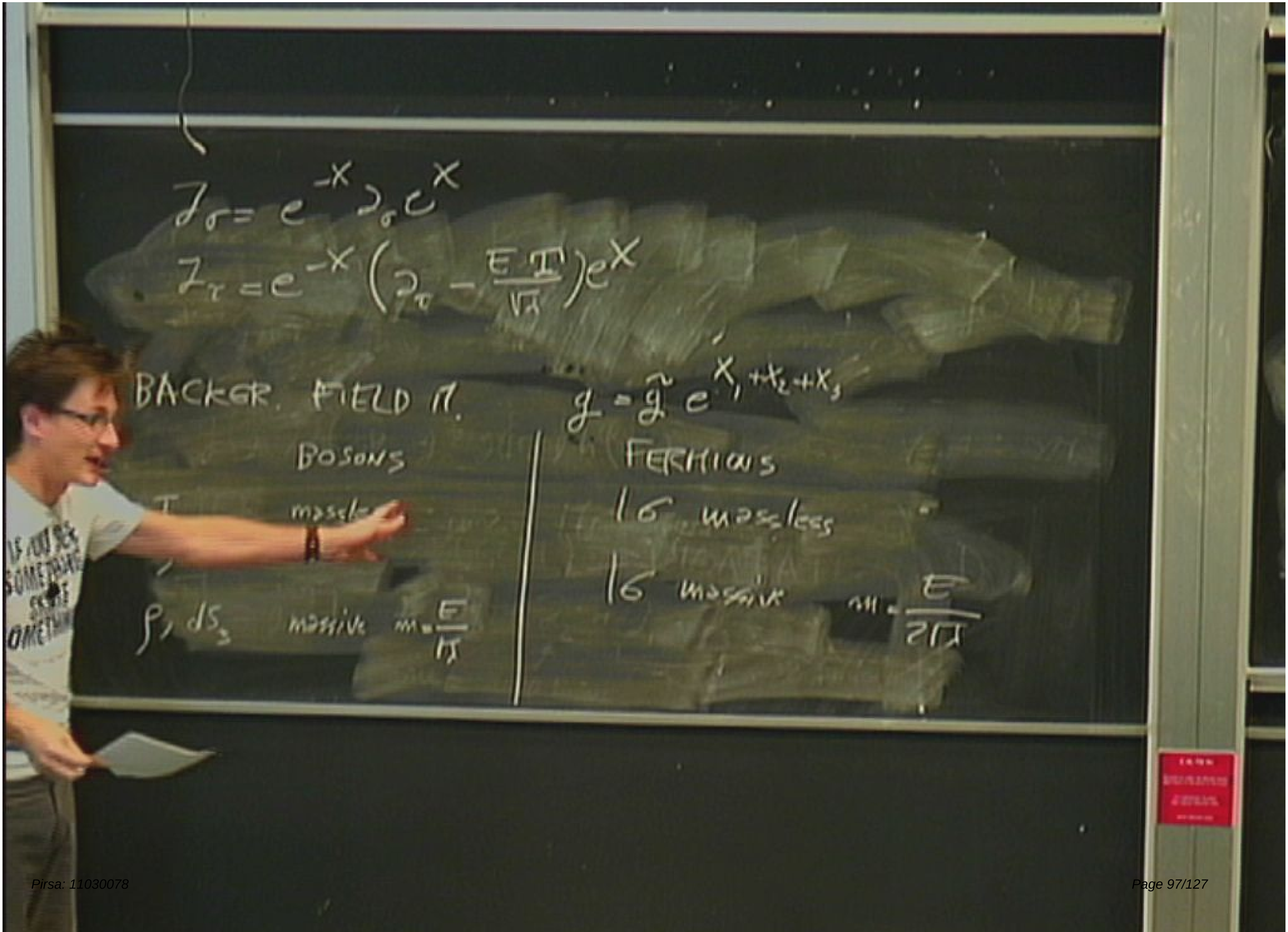
$$J_\tau = e^{-X}\left(\partial_\tau - \frac{E\,T}{\sqrt{2}}\right)e^{X}$$

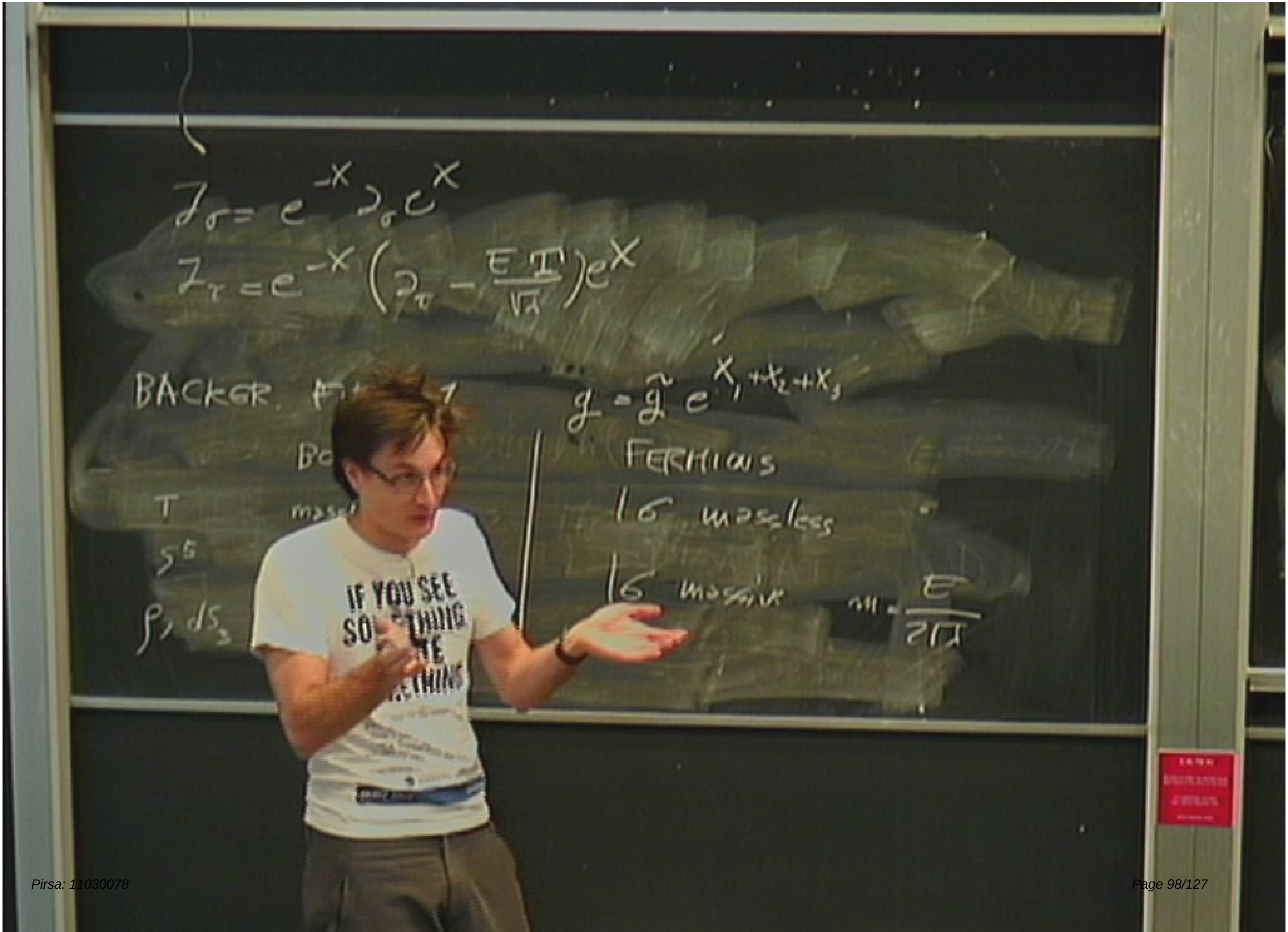
BACKGR. FIELD Π. $\quad g = \tilde{g}\, e^{X_1+X_2+X_3}$

	BOSONS	FERMIONS
T	massless	
S^5	"	
ρ, dS_3	massive $m = \frac{E}{\sqrt{2}}$	



$\partial_\sigma = e^{-X} \partial_\sigma e^{X}$
$\partial_\tau = e^{-X} \left(\partial_\tau - \frac{E\, T}{\sqrt{2}}\right) e^{X}$
BACKGR. FIELD
$g = \tilde{g}\, e^{X_1 + X_2 + X_3}$
BOSONS
FERMIONS
T massless
16 massless
S^5 "
16 massive
ρ, dS_3 massive $m = \frac{E}{\sqrt{2}}$


BACKGR. FIELD
BOSONS
massless
massive
FERMIONS
16 massless
16 massive


BACKGR.
FERMIONS
16 massless
16 massive

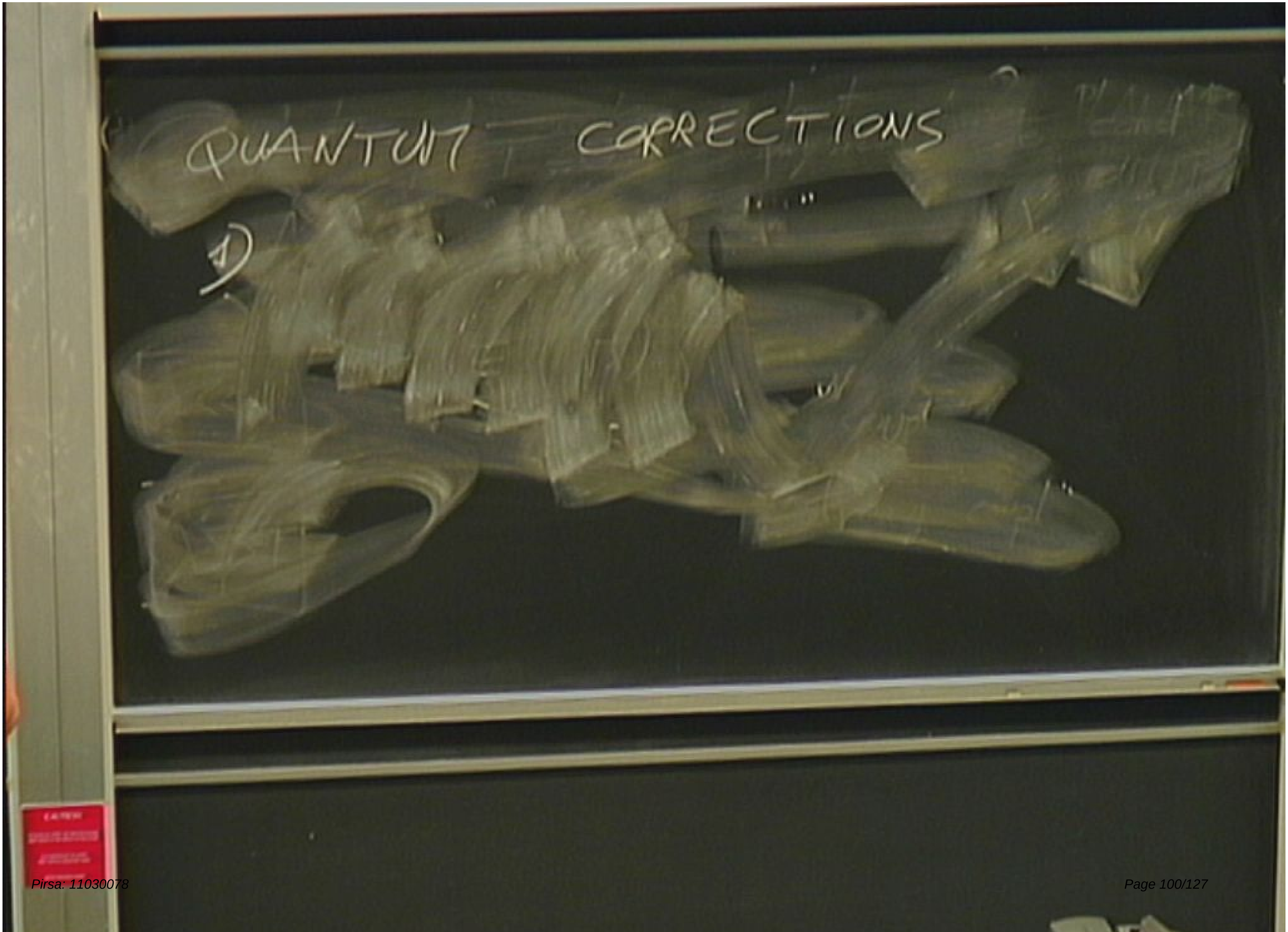
$$\mathcal{D}_\sigma = e^{-X}\partial_\sigma e^{X}$$

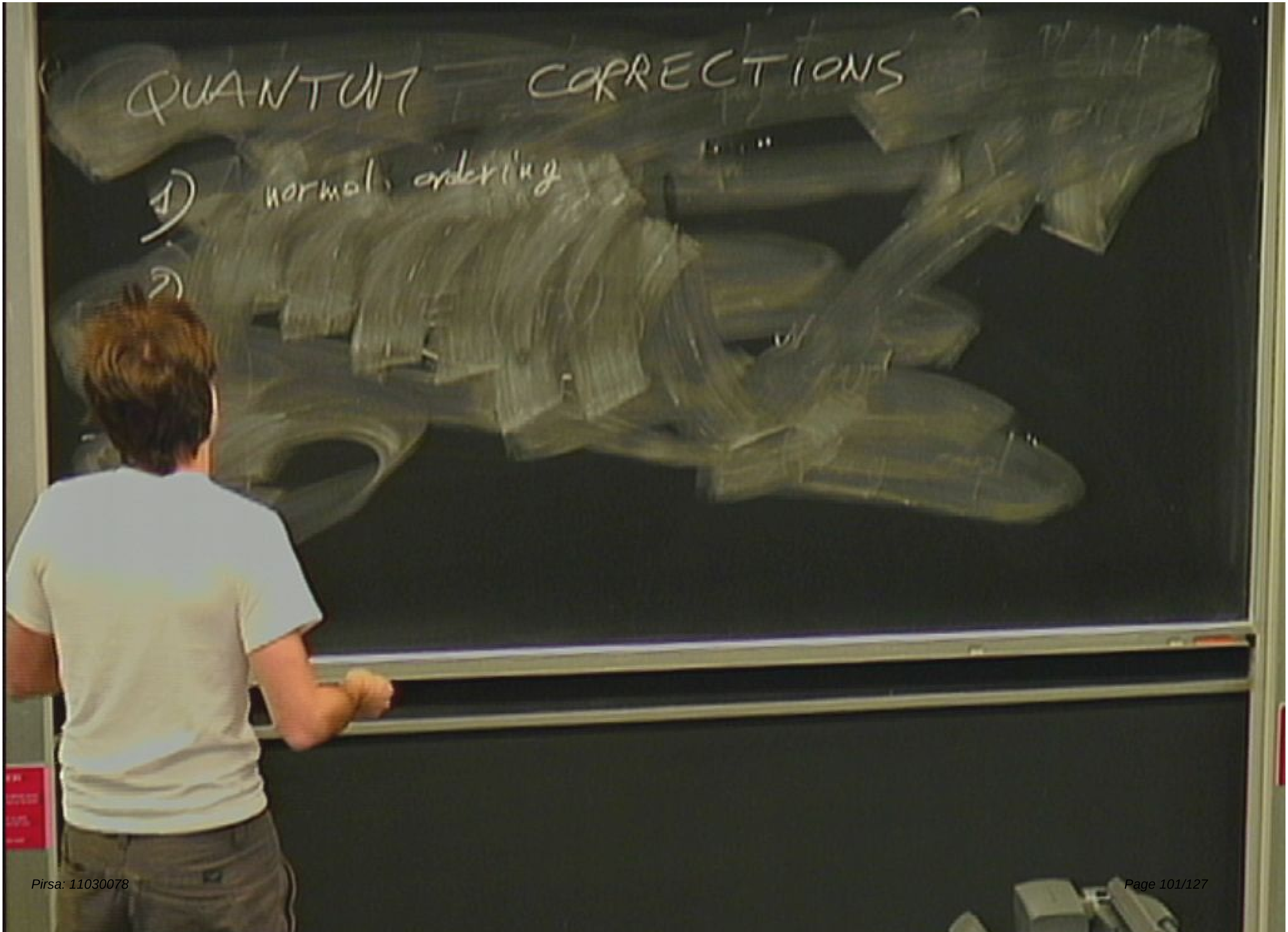
$$\mathcal{D}_\tau = e^{-X}\left(\partial_\tau - \frac{E\,T}{\sqrt{\lambda}}\right)e^{X}$$

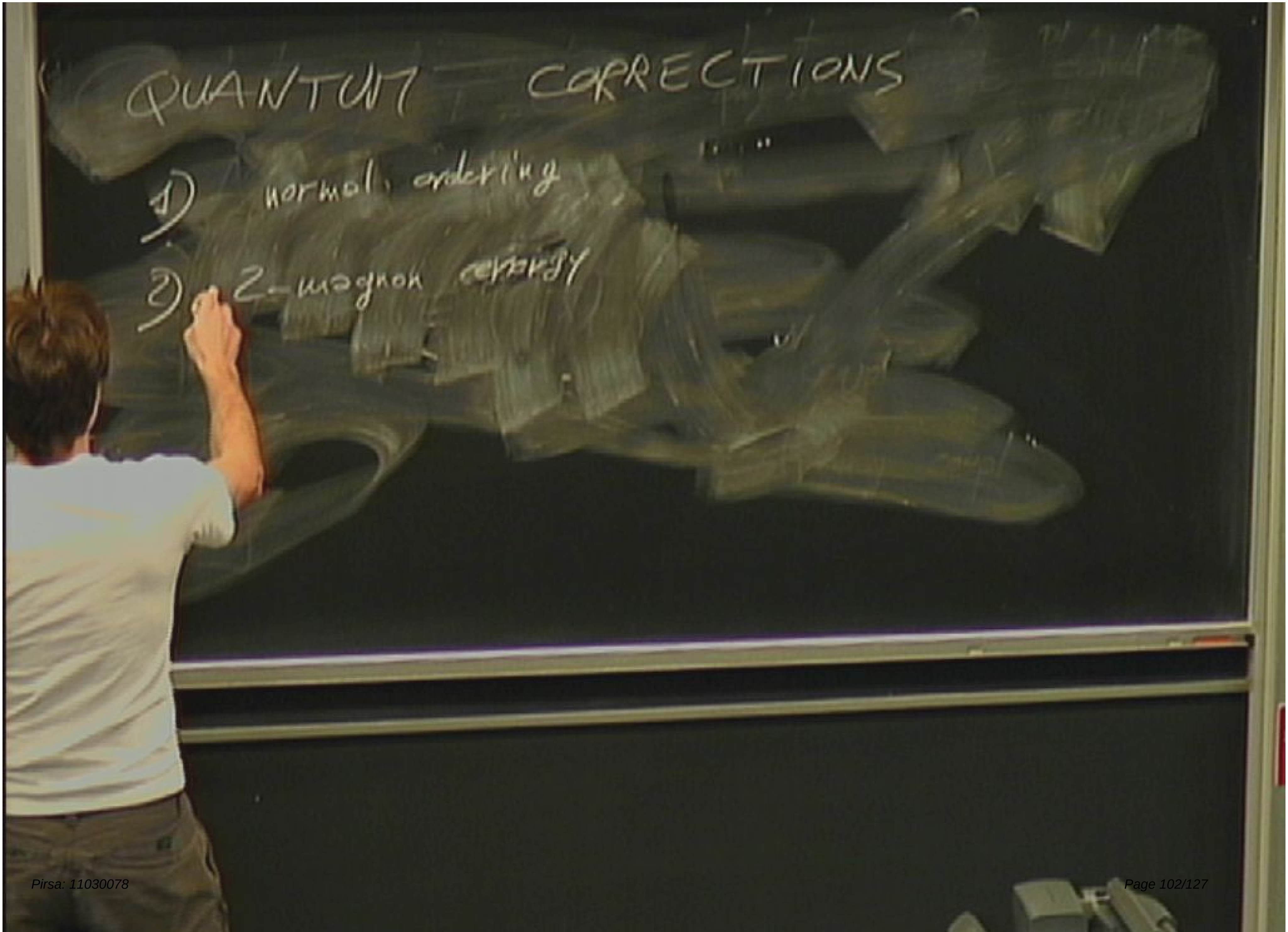
BACKGR. FIELD A.

$$g = \tilde{g}\, e^{X_1 + X_2 + X_3}$$

	BOSONS	FERMIONS
T	massless	16 massless
S^5	"	16 massive $m = \frac{E}{2\sqrt{\lambda}}$
ρ, dS_3	massive $m = \frac{E}{\sqrt{\lambda}}$	


QUANTUM CORRECTIONS
1)


QUANTUM CORRECTIONS
1) normal ordering
2)

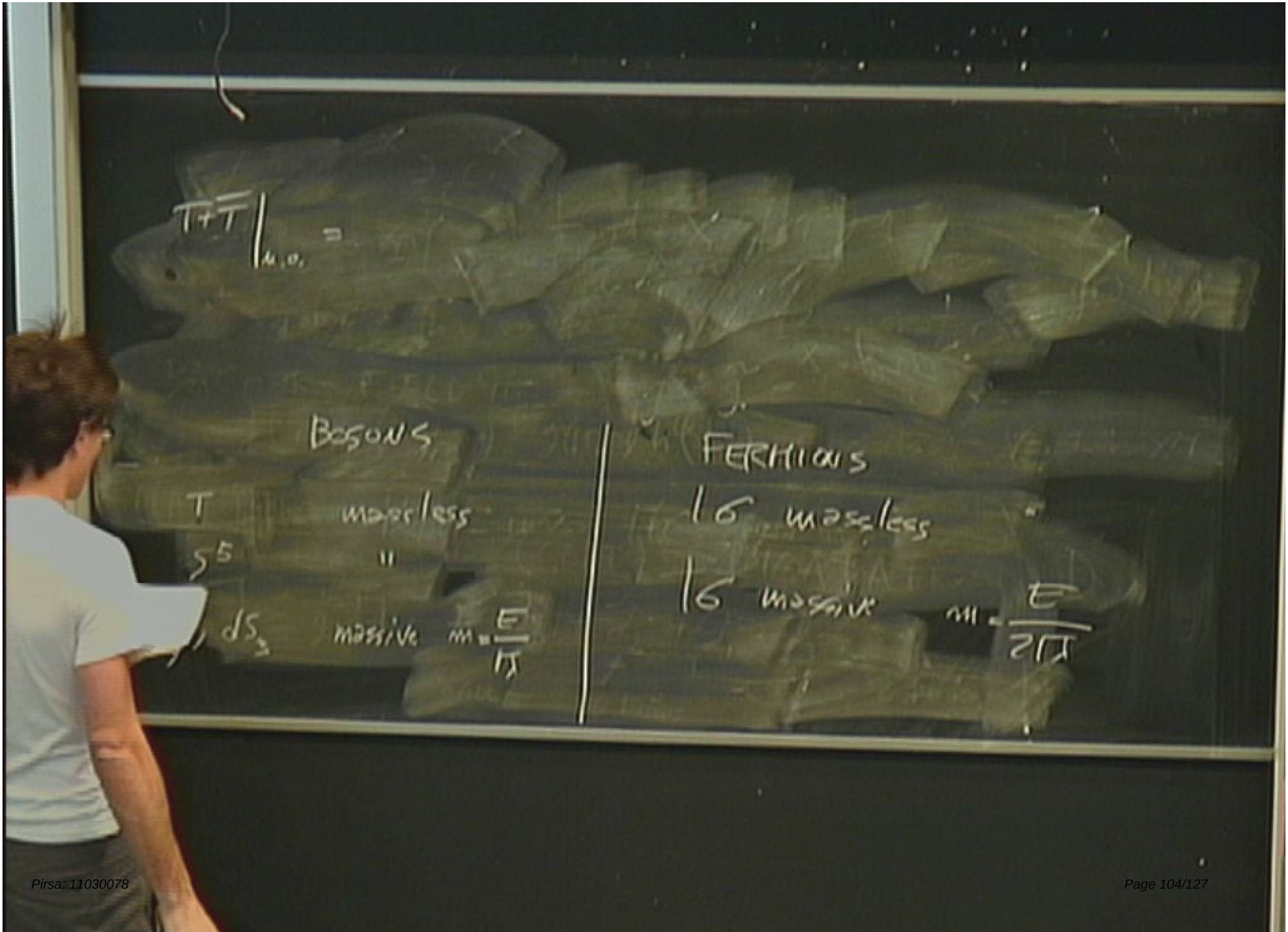

QUANTUM CORRECTIONS
1) normal ordering
2) 2-magnon energy

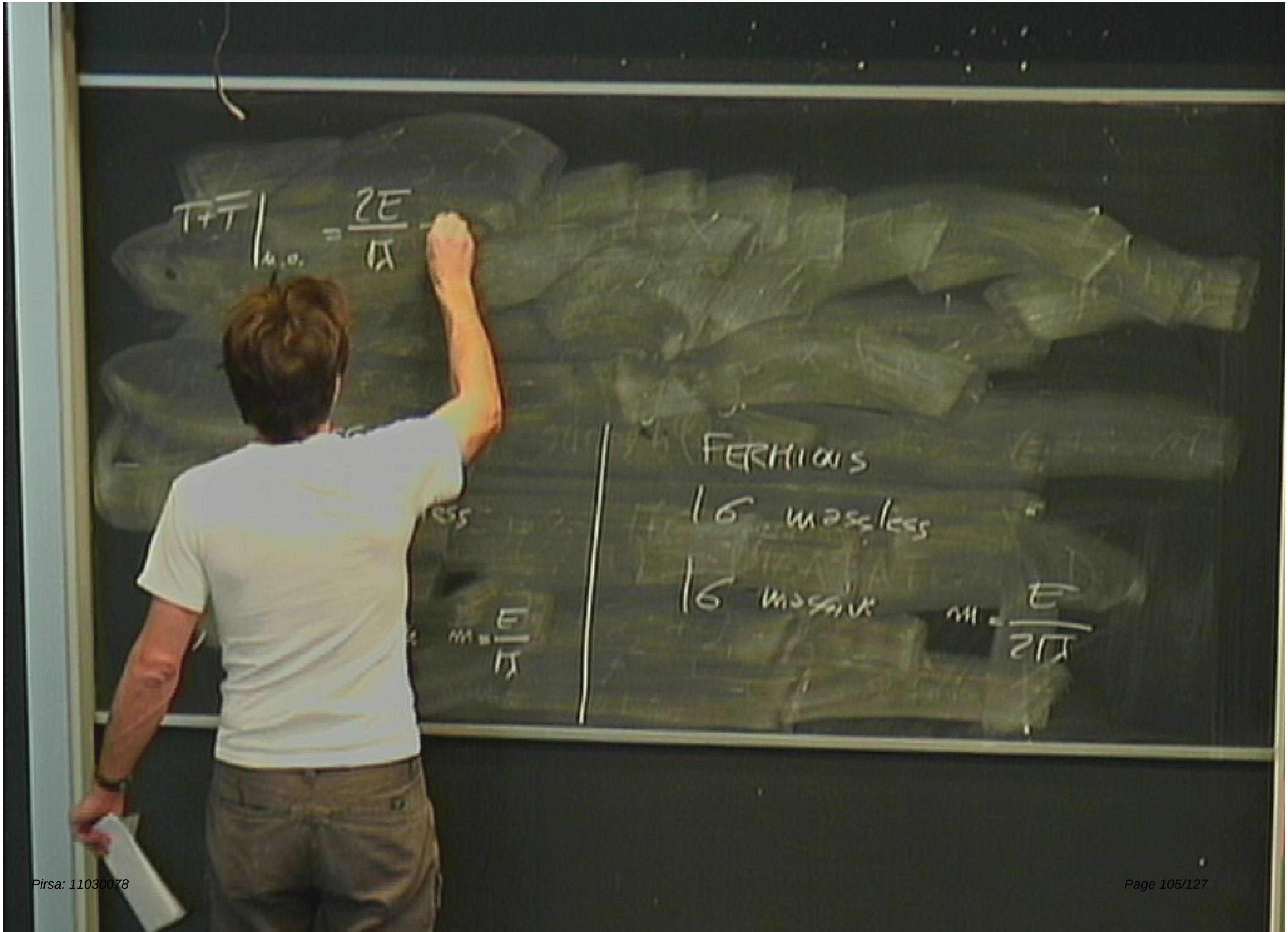
QUANTUM CORRECTIONS

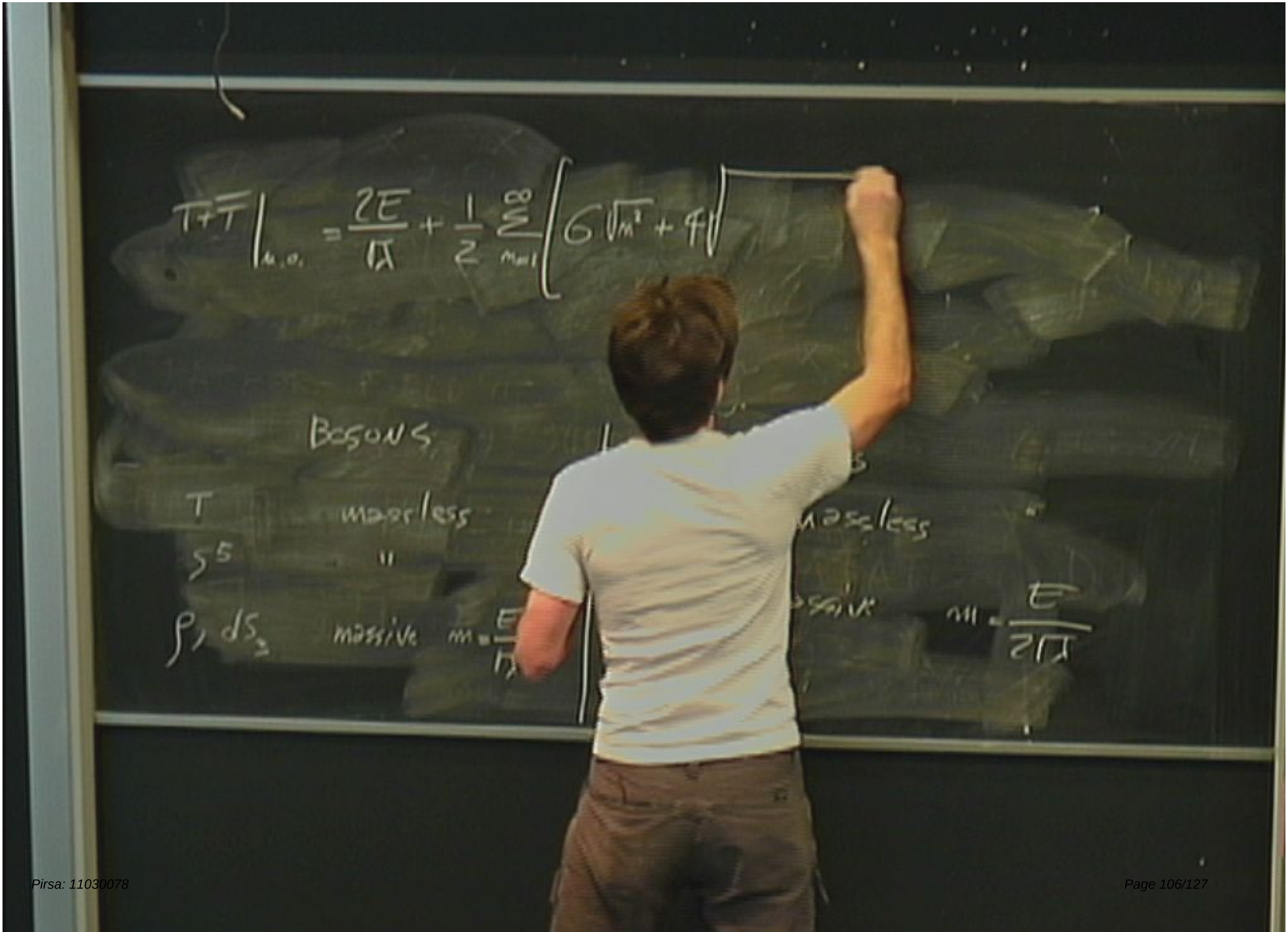
1) normal ordering

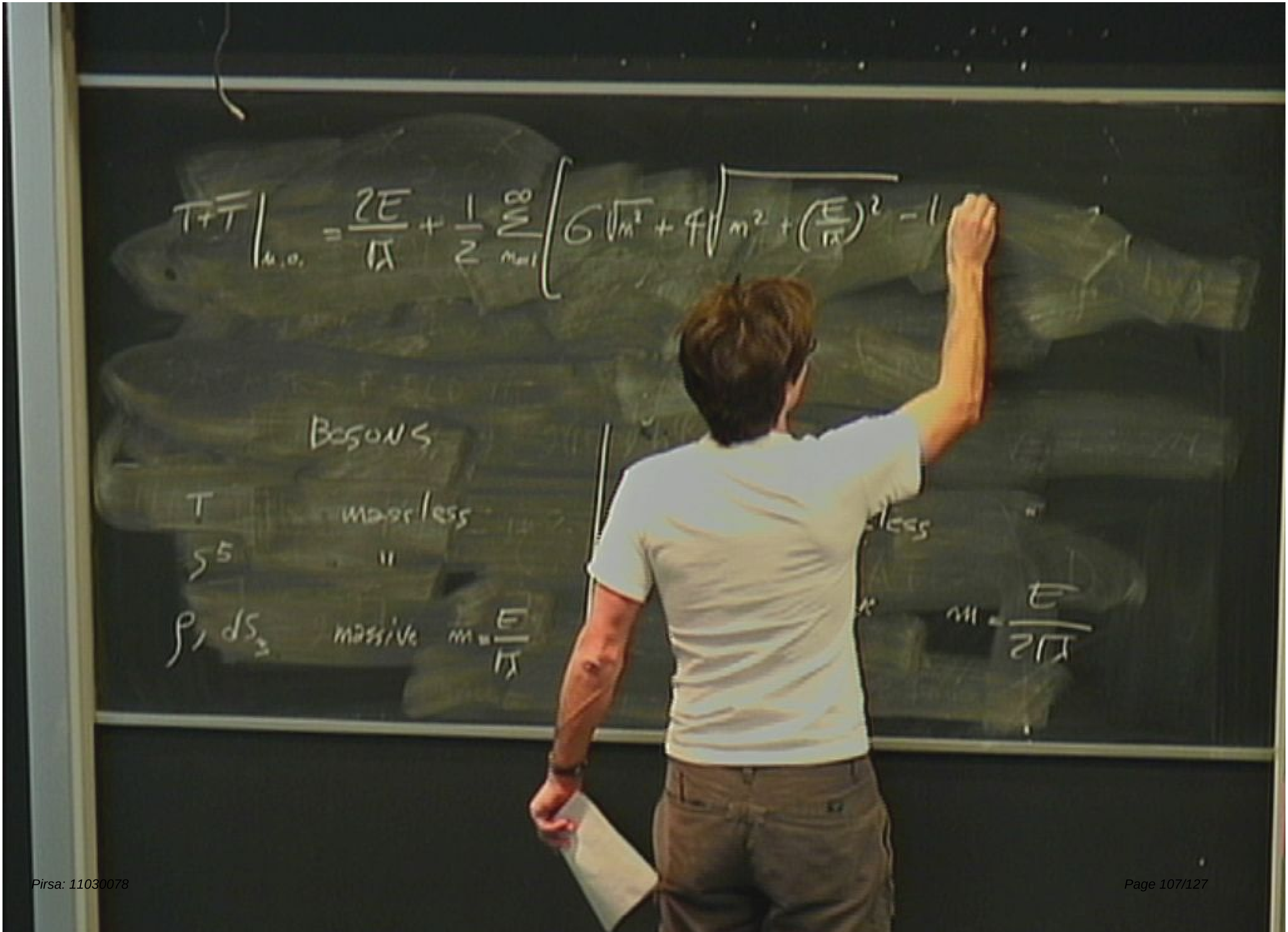
2) 2-magnon energy

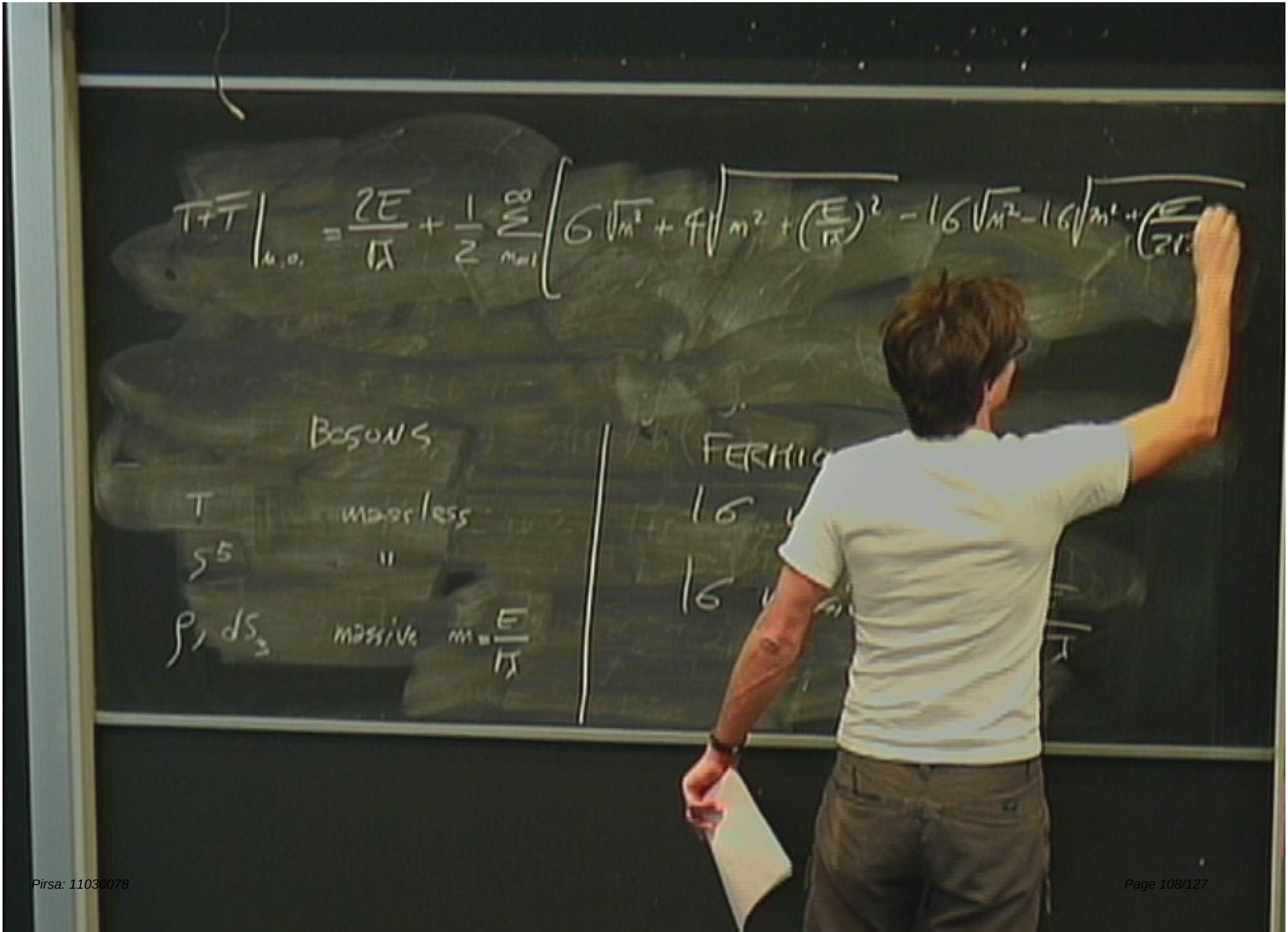
3) quartic corrections

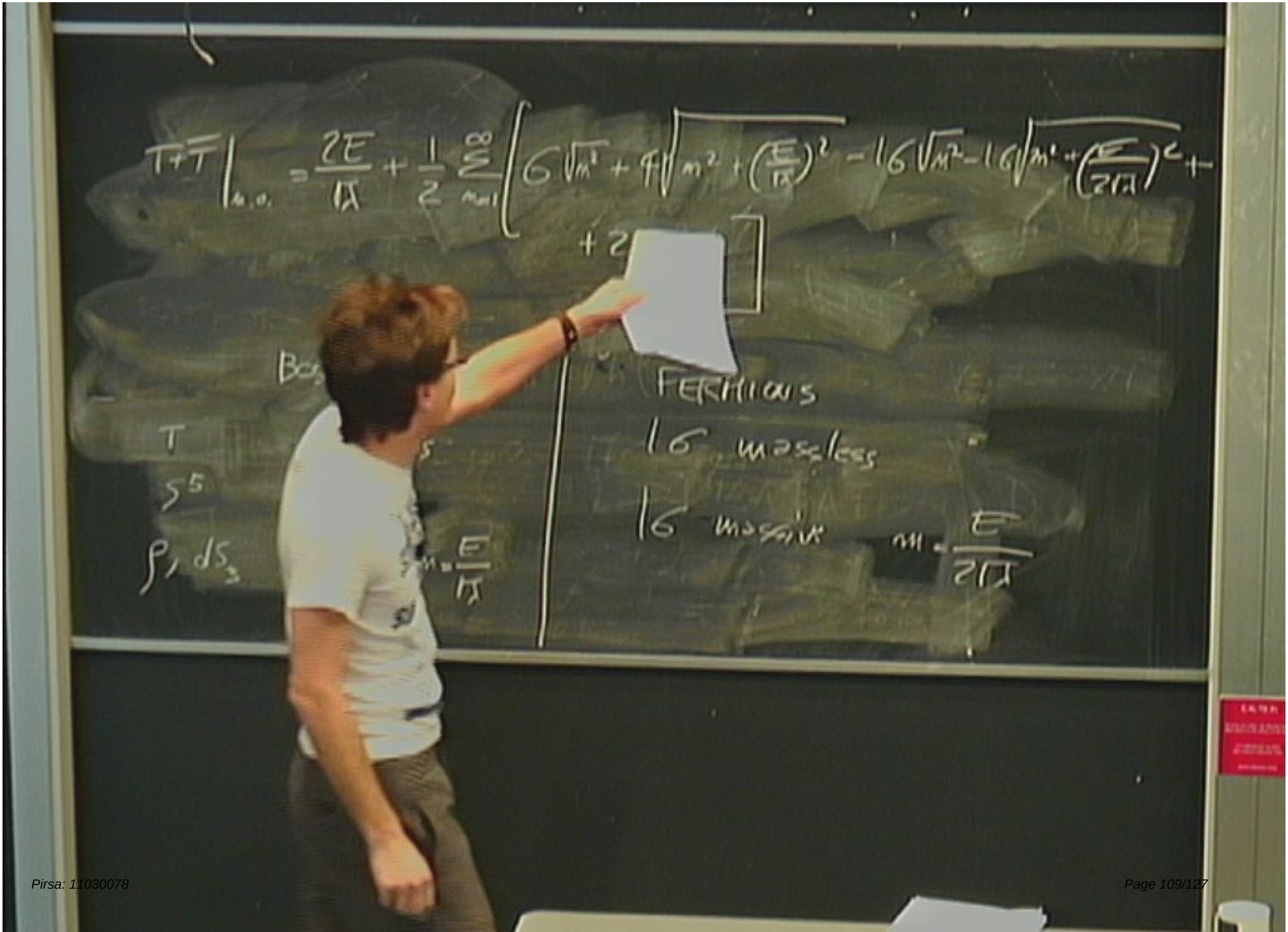

T+T |h.o. =
Bosons
T massless
S5 "
dS5 massive m = E/√λ
Fermions
16 massless
16 massive m = E/2√λ

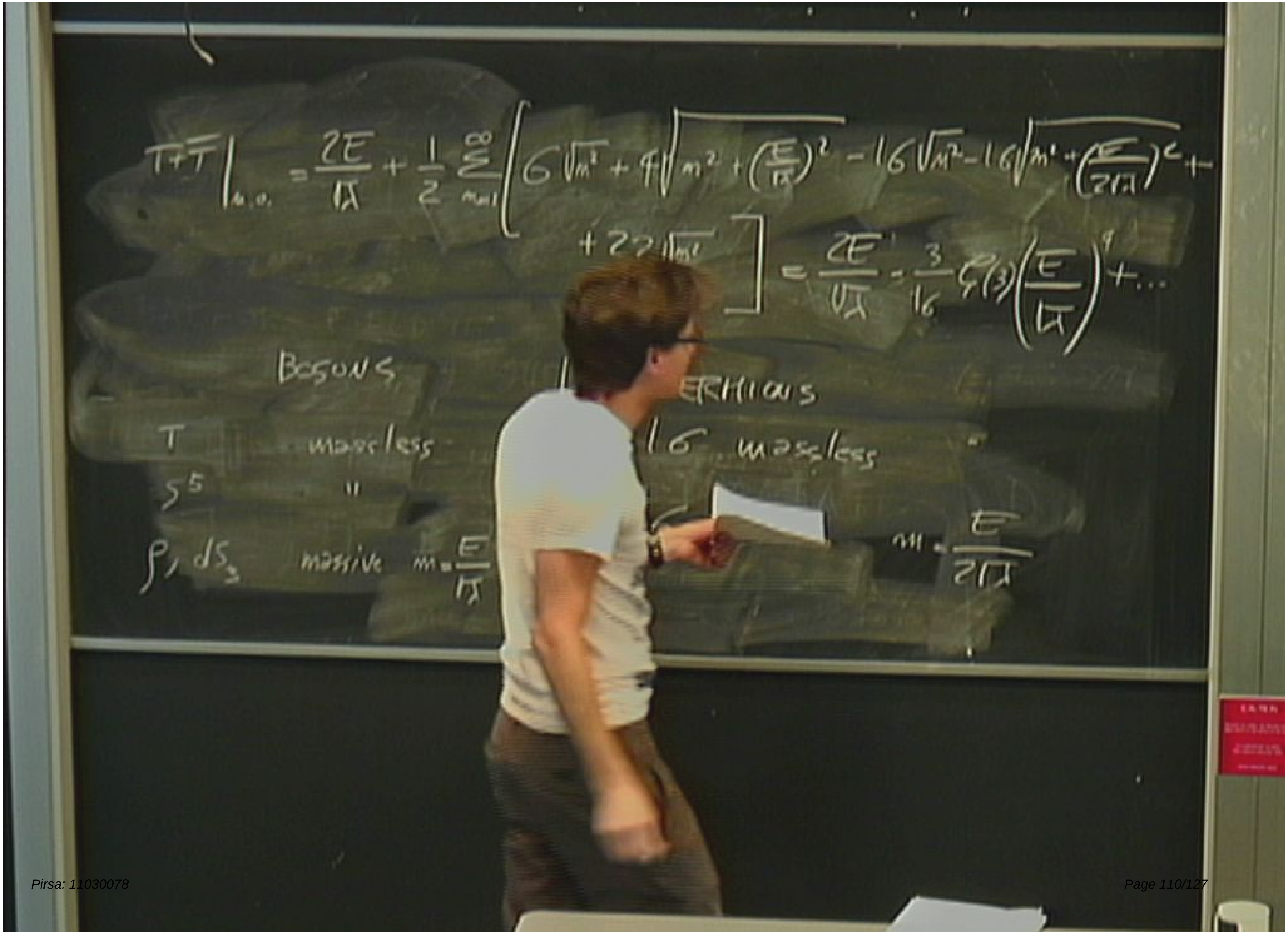

FERMIONS
16 massless
16 massive

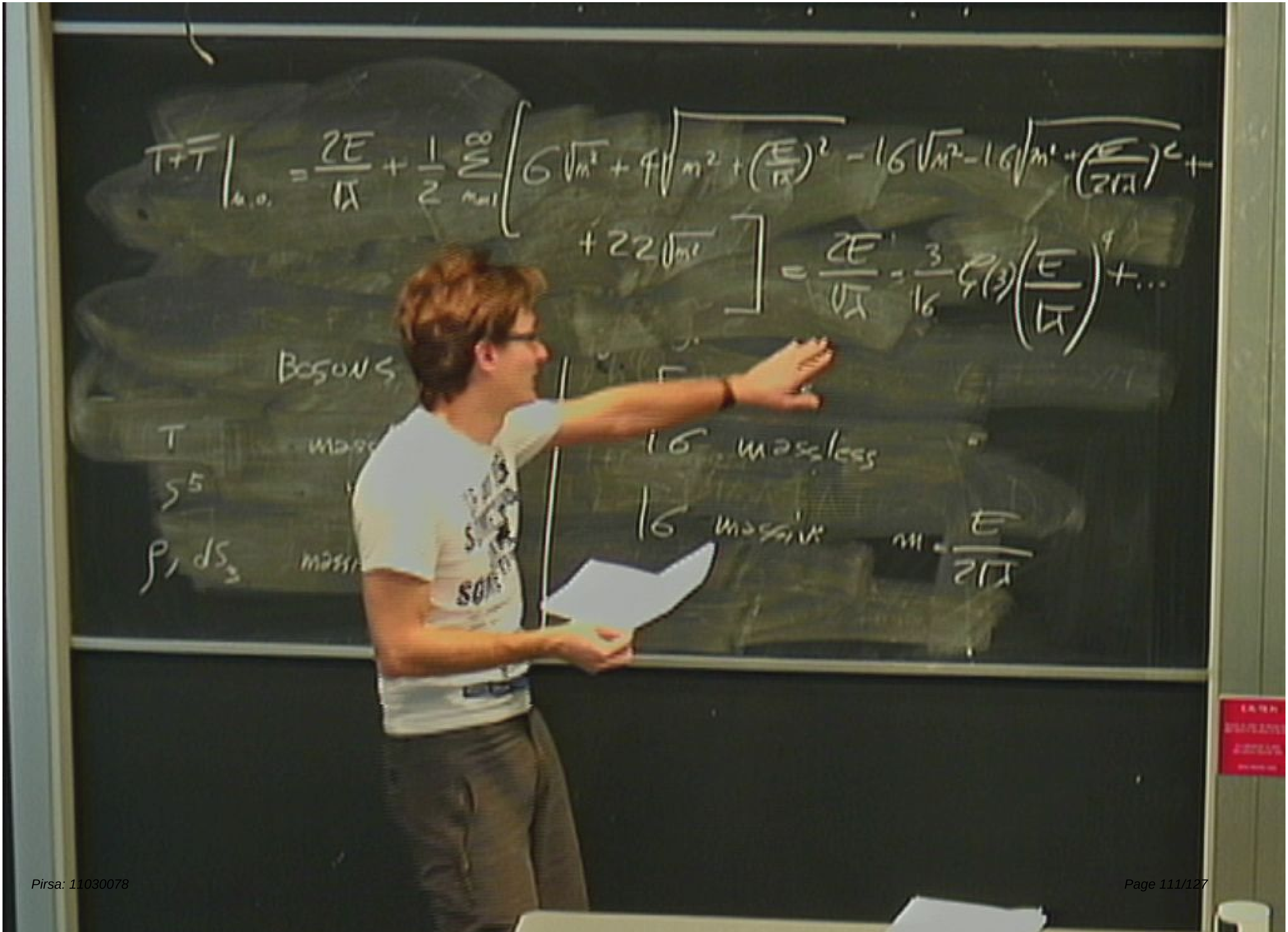

Bosons
T massless
S5 "
ρ, dS3 massive
massless
massive

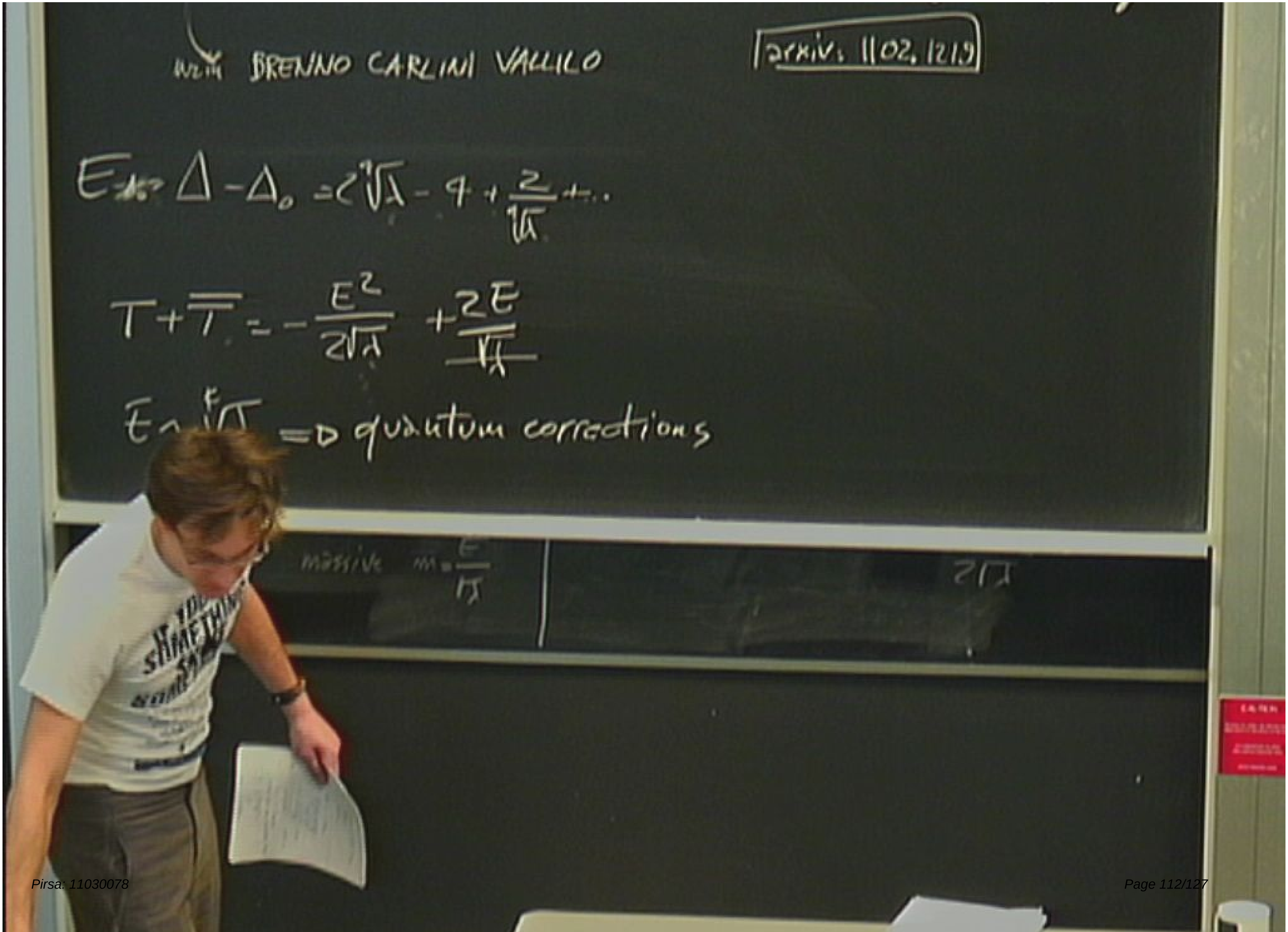

T+T |n.o. = 2E/√λ + 1/2 Σ n=1 ∞ (6√m² + 4√m² + (E/√λ)² − 1
Bosons
T massless
S5 "
ρ, dS3 massive m = E/√λ
less
m = E/2√λ


BOSONS
T massless
S^5 "
ρ, dS_3 massive m = E/√λ

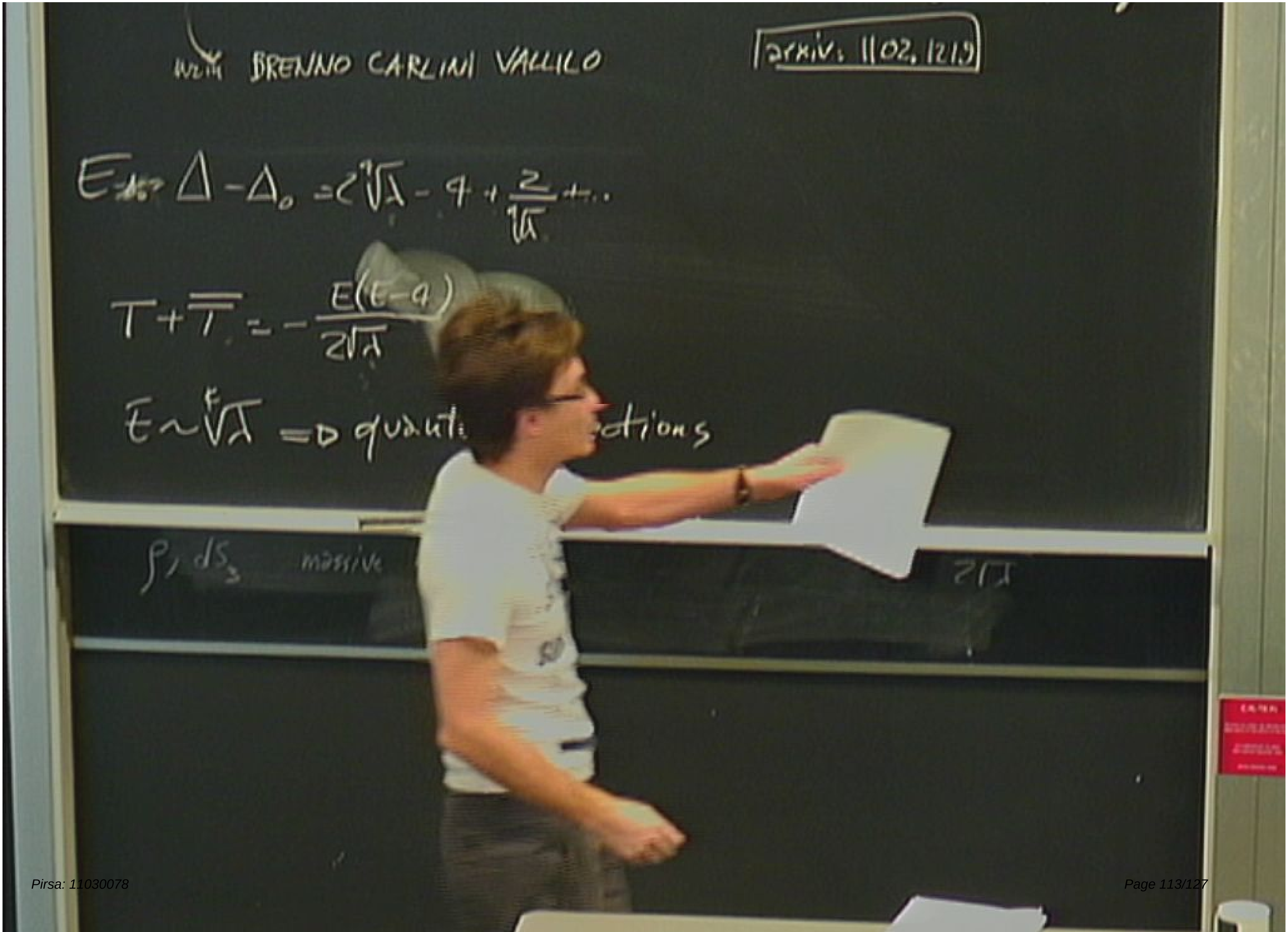

FERMIONS
16 massless
16 massive

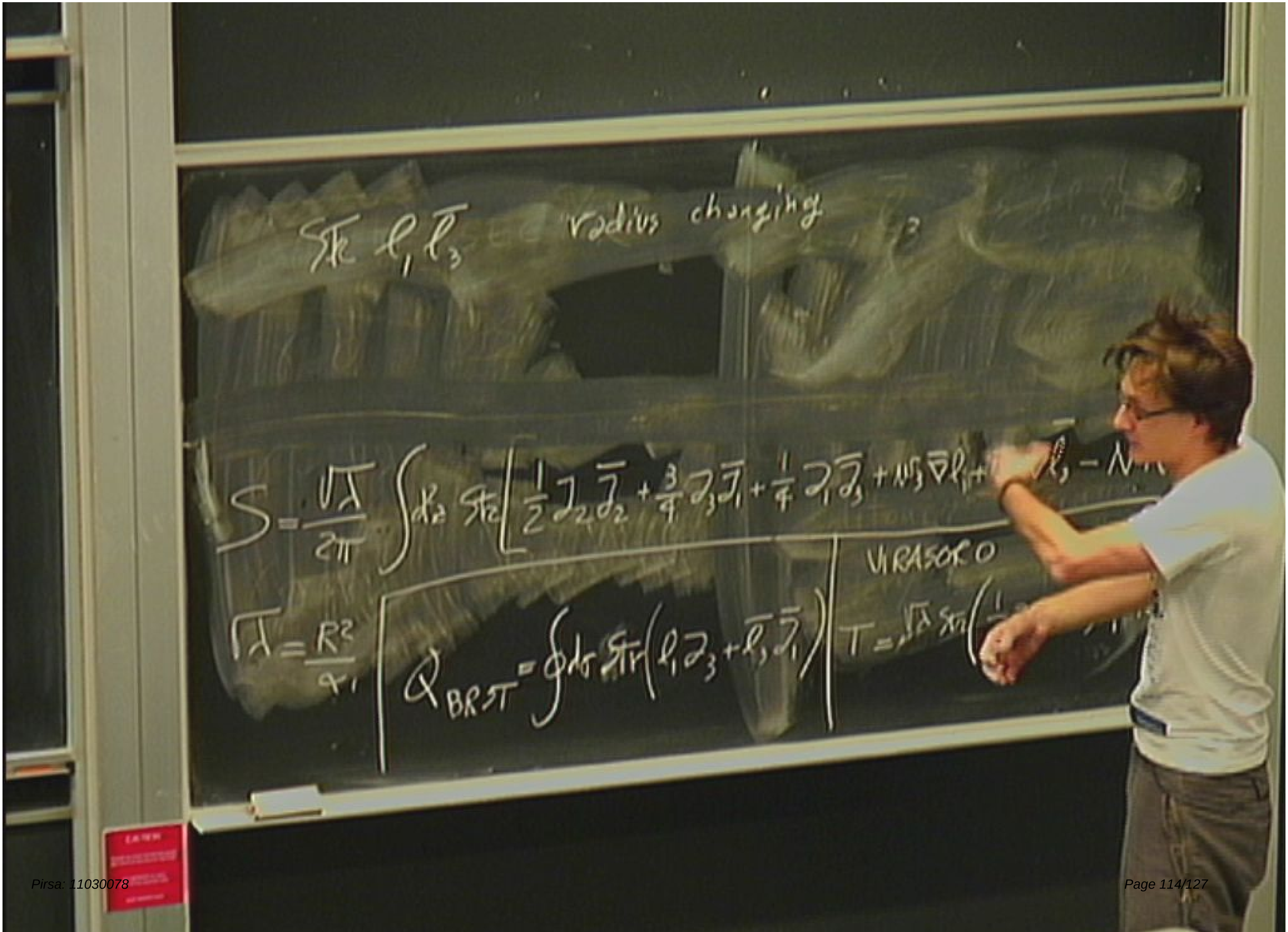

T+T |n.o. = 2E/√λ + 1/2 Σ_{m=1}^∞ [6√m² + 4√(m² + (E/√λ)²) − 16√m² − 16√(m² + (E/2√λ)²) + ...
+ 22√m²] = 2E/√λ − 3/16 ζ(3) (E/√λ)^4 + ...
BOSONS
ERMIONS
T massless
16 massless
S^5 "
ρ, dS_3 massive m = E/√λ
m = E/2√λ

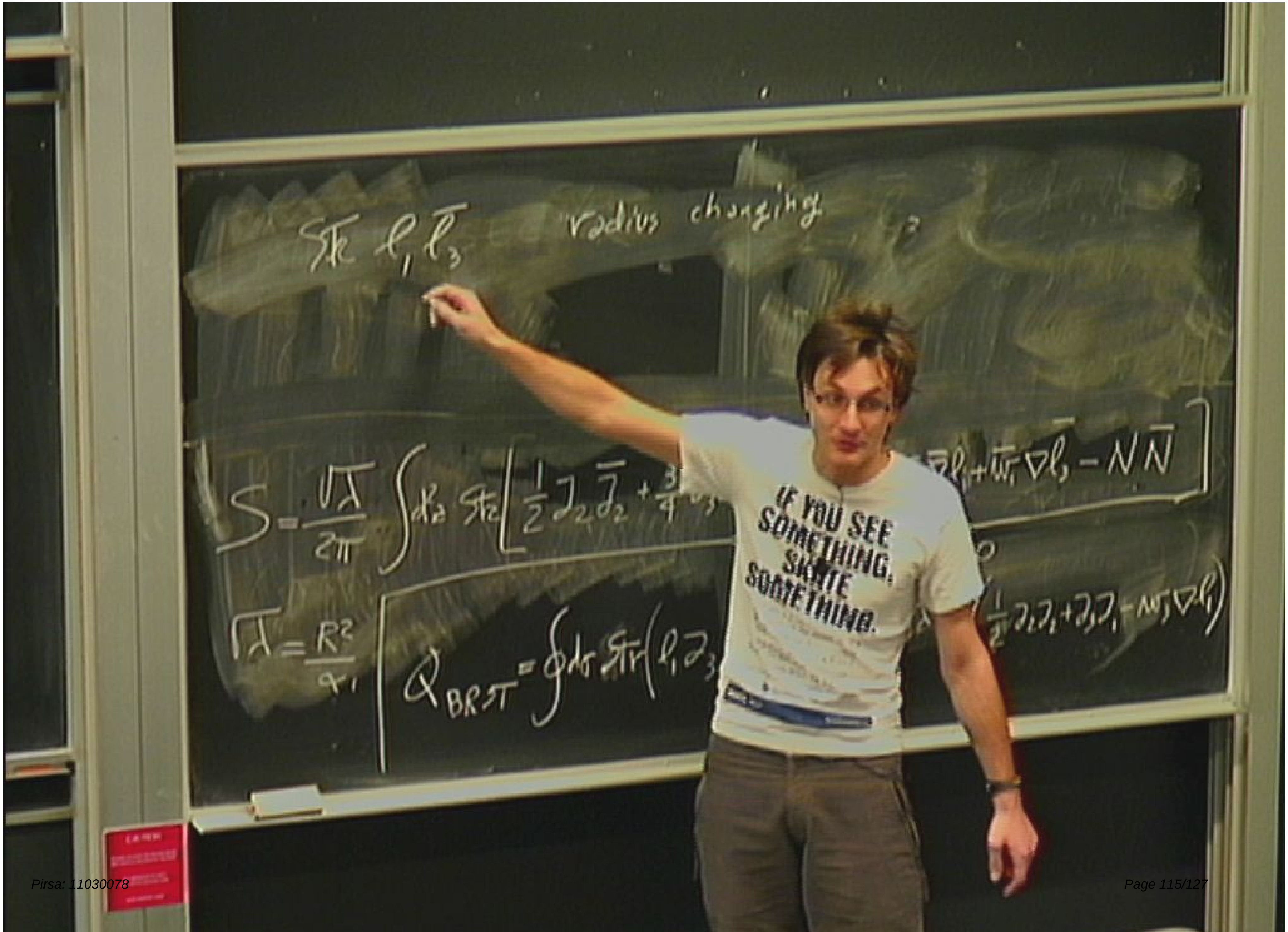

Bosons
16 massless
16 massive

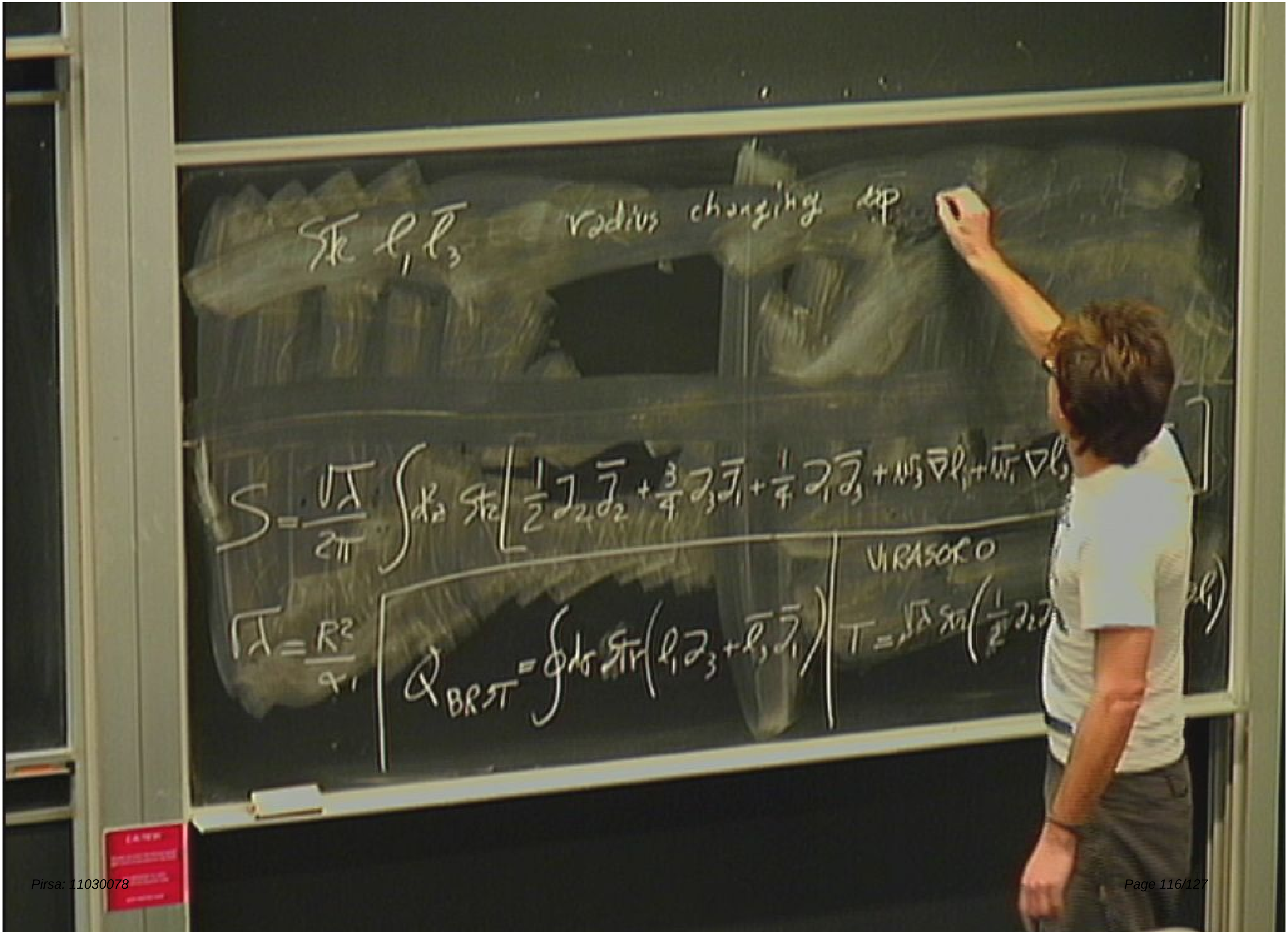


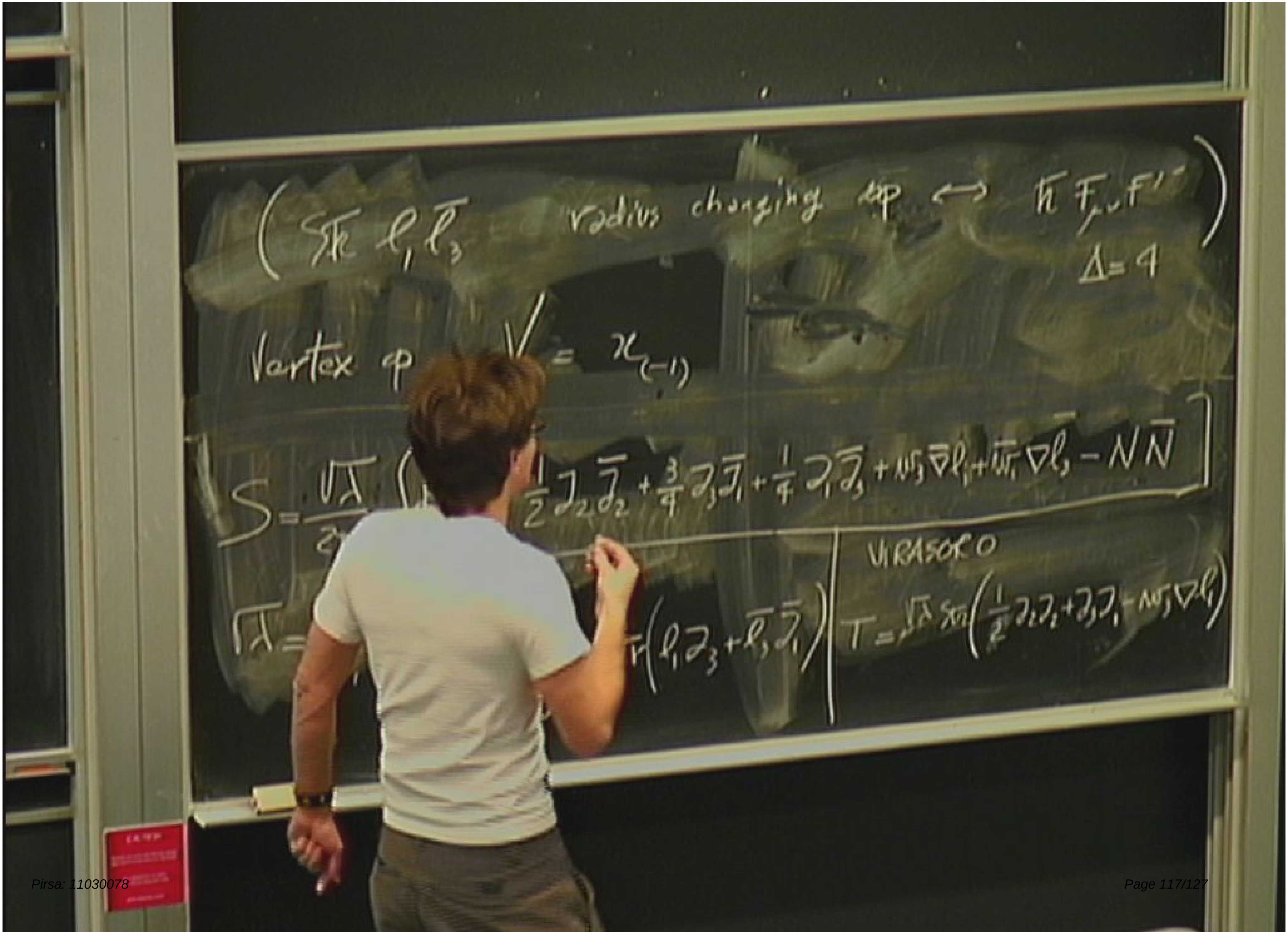
with BRENNO CARLINI VALLILO
arxiv: 1102.1219
E = Δ − Δ0 = 2 ⁴√λ − 4 + 2/⁴√λ + ...
T + T̄ = − E²/2√λ + 2E/√λ
E ~ ⁴√λ => quantum corrections
massive m = E/√λ


with BRENNO CARLINI VALLILO
arxiv: 1102.1219
E = Δ − Δ₀ = 2 ⁴√λ − 4 + 2/⁴√λ + ...
T + T̄ = − E(E−4)/2√λ
E ~ ⁴√λ ⟹ quant ctions
massive


radius changing
VIRASORO


radius changing


radius changing op
VIRASORO


radius changing op
Δ = 4
Vertex op
VIRASORO

$\left(\mathrm{STr}\, \ell_1 \bar{\ell}_3 \quad \text{radius changing op} \longleftrightarrow \mathrm{tr}\, F_{\mu\nu}F^{\mu\nu} \right)$

$\Delta = 4$

Vertex op $\quad V = X^+_{(-1)} \bar{X}^+_{(-1)}\, \mathrm{STr}\, \ell_1 \bar{\ell}_3\, |G\rangle$

$X^+ = x' + ix'$

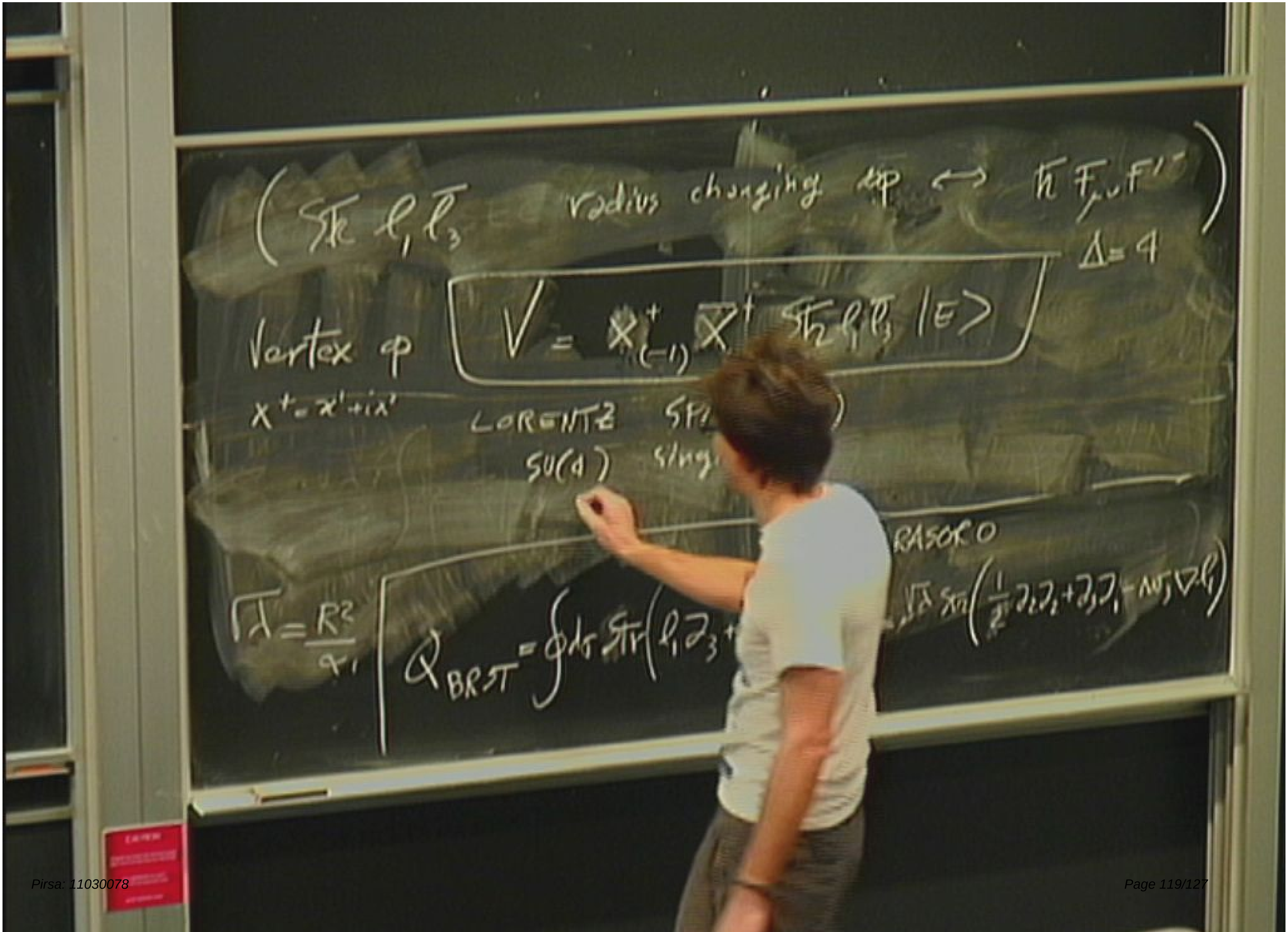
$$S = \frac{\sqrt{\lambda}}{2\pi} \int d^2z\, \mathrm{STr}\left[\frac{1}{2} J_2 \bar{J}_2 + \frac{3}{4} J_3 \bar{J}_1 + \frac{1}{4} J_1 \bar{J}_3 + w_3 \bar{\nabla} \ell_1 + \bar{w}_1 \nabla \ell_3 - N\bar{N} \right]$$

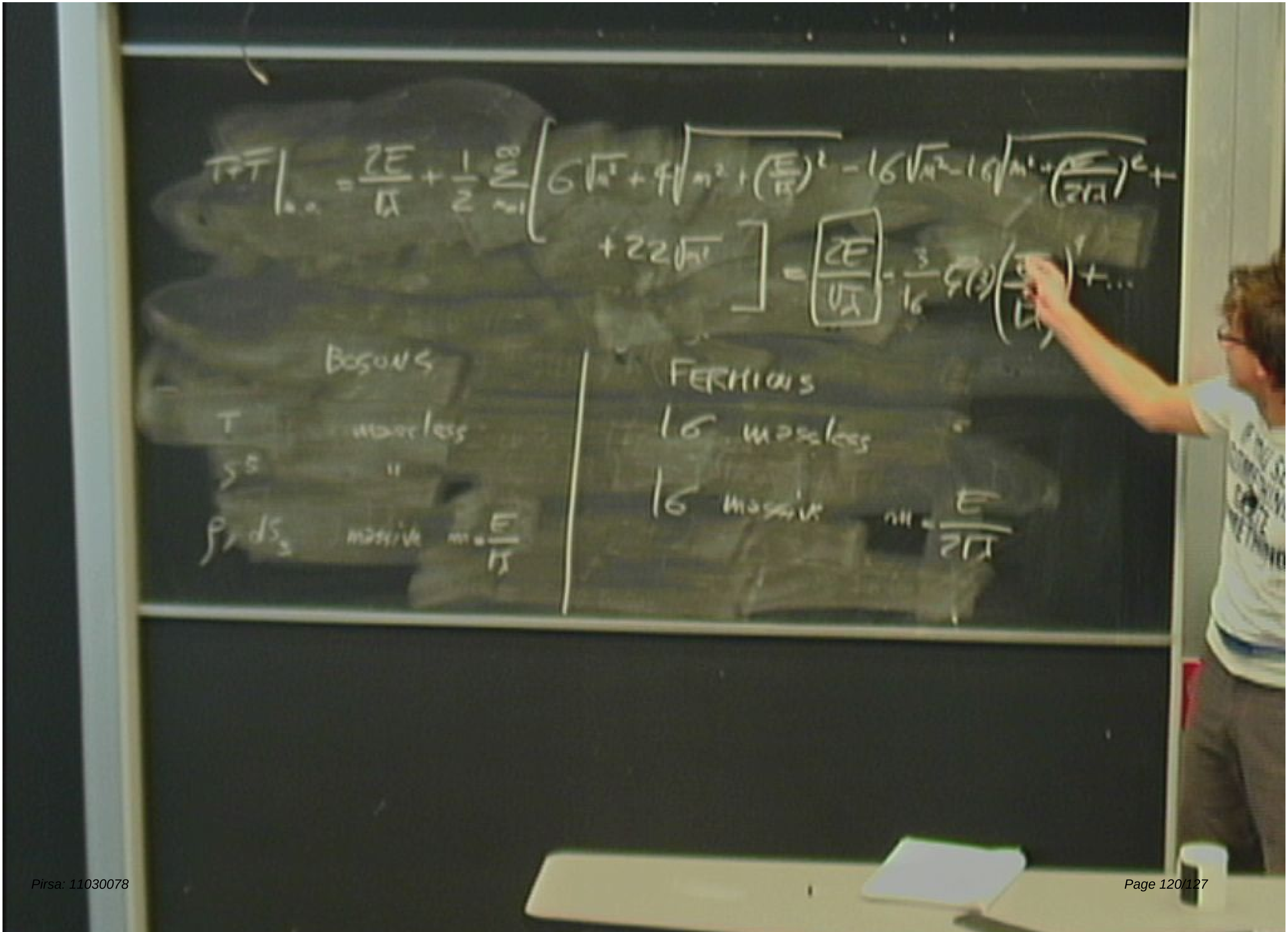
$$\sqrt{\lambda} = \frac{R^2}{\alpha'}$$

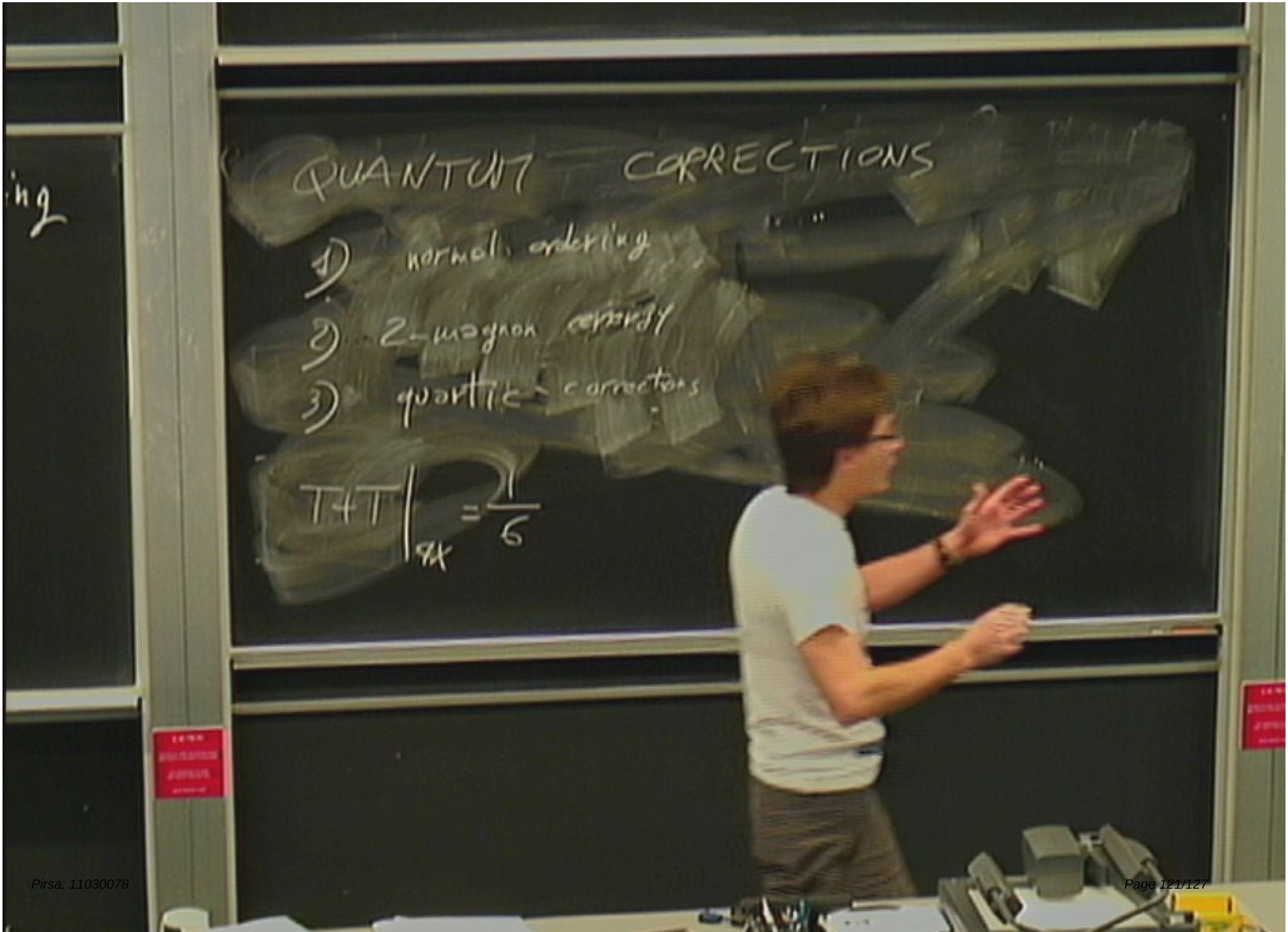
$$Q_{BRST} = \oint d\sigma\, \mathrm{STr}\left(\ell_1 J_3 + \bar{\ell}_3 \bar{J}_1 \right)$$

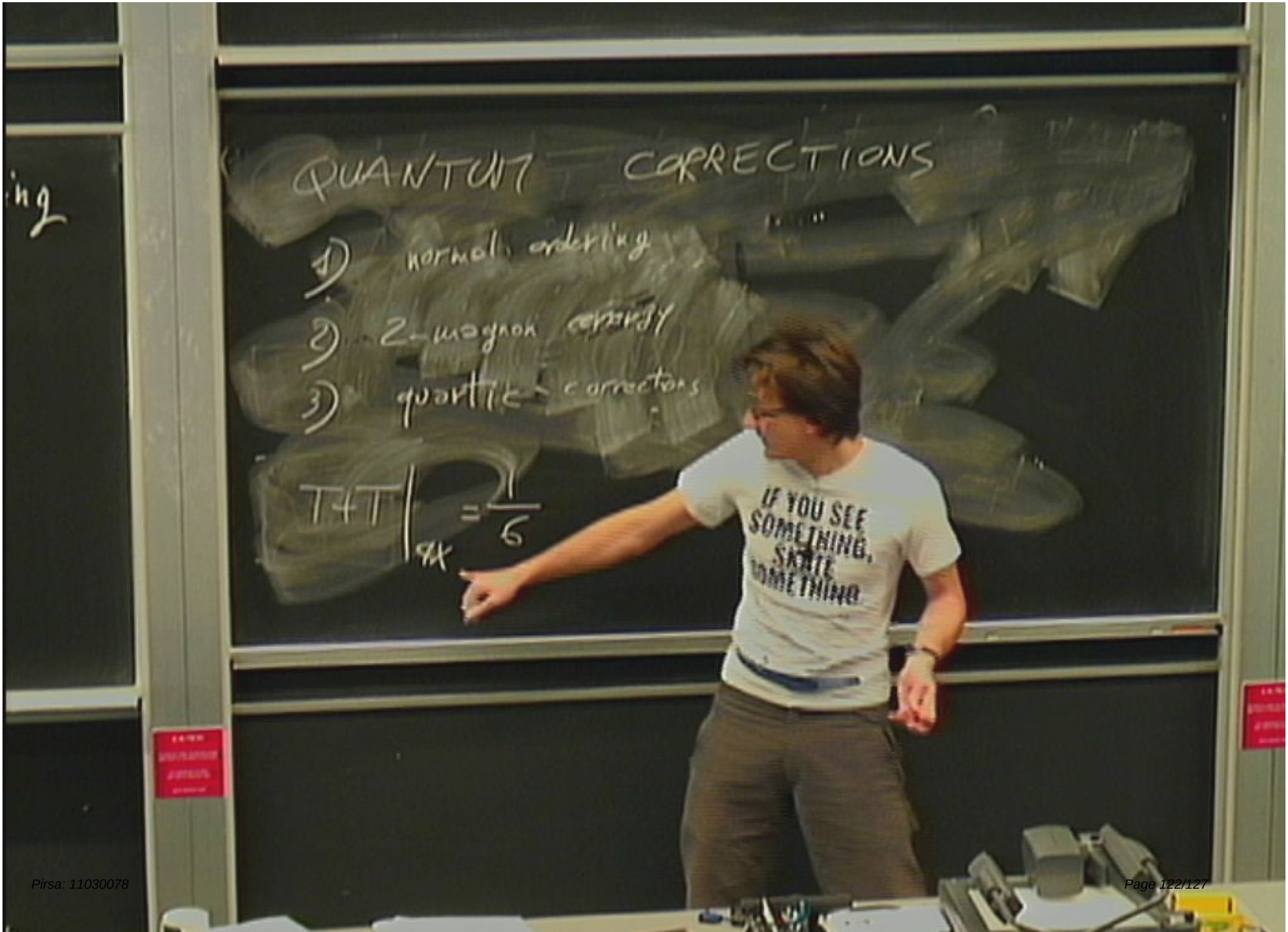
VIRASORO

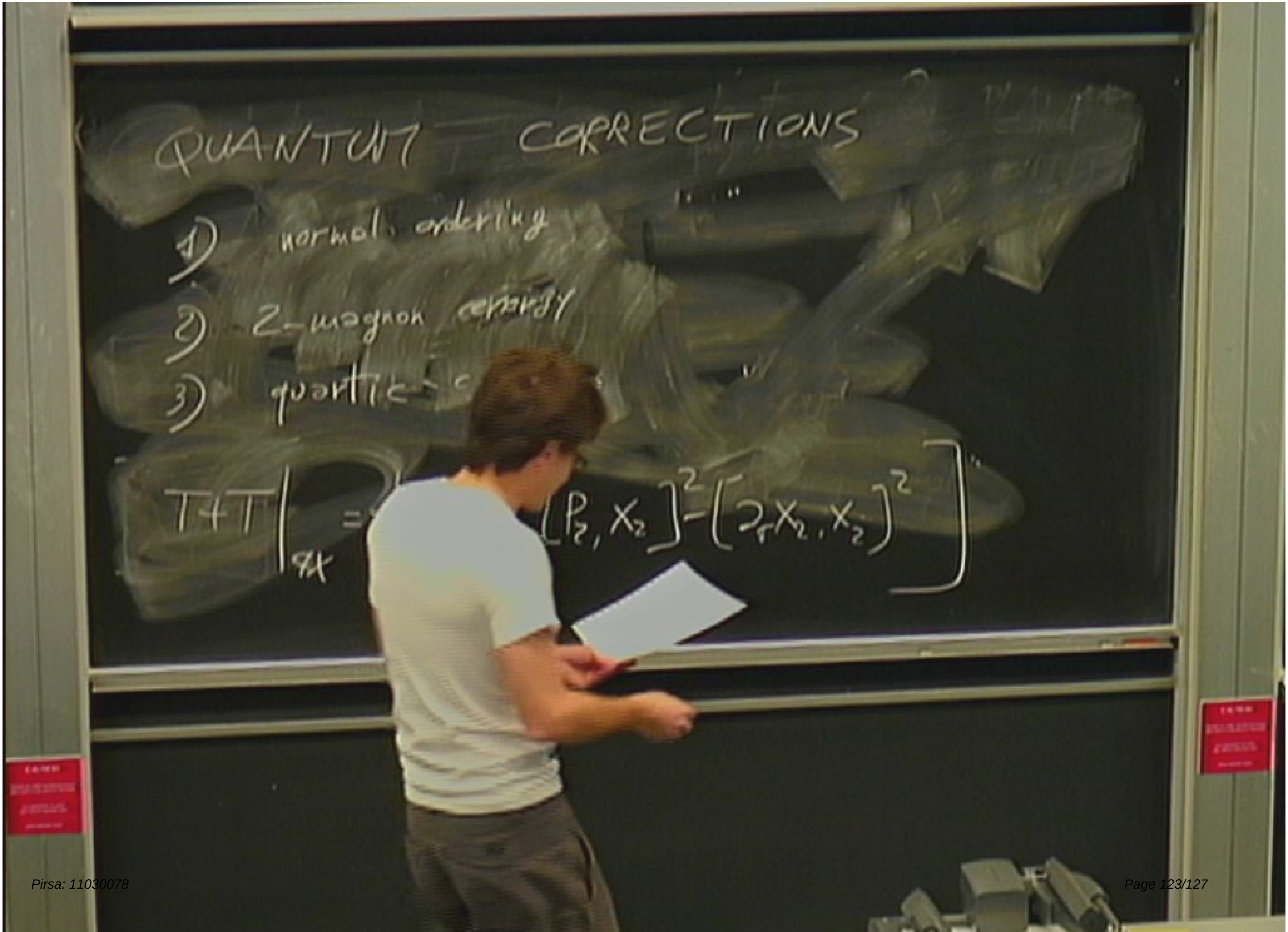
$$T = \sqrt{\lambda}\, \mathrm{STr}\left(\frac{1}{2} J_2 J_2 + J_3 J_1 - w_3 \nabla \ell_1 \right)$$

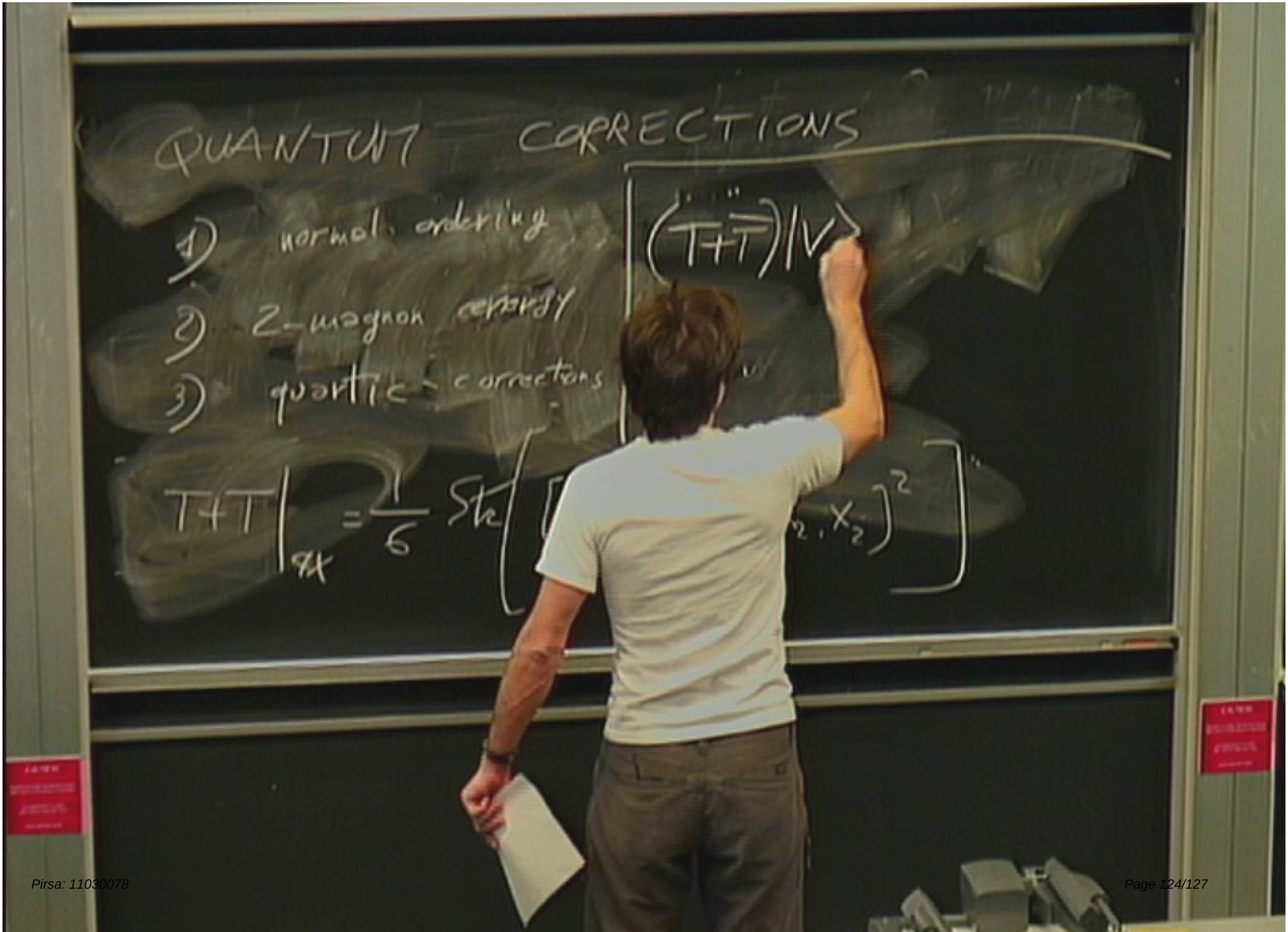

radius changing op
Δ = 4
Vertex op
V = X+(−1) X̄+ Str ℓ1 ℓ̄3 |E>
x+ = x1 + ix2
LORENTZ
SU(4)
RASORO
√λ = R²/α'
Q_BRST = ∮dσ Str(ℓ1∂3


BOSONS
FERMIONS
massless
16 massless
massive
16 massive


QUANTUM CORRECTIONS
1) normal ordering
2) 2-magnon energy
3) quartic corrections
= 1/6


QUANTUM CORRECTIONS
1) normal ordering
2) 2-magnon energy
3) quartic corrections
IF YOU SEE SOMETHING, SKATE SOMETHING


QUANTUM CORRECTIONS
1) normal ordering
2) 2-magnon energy
3) quartic

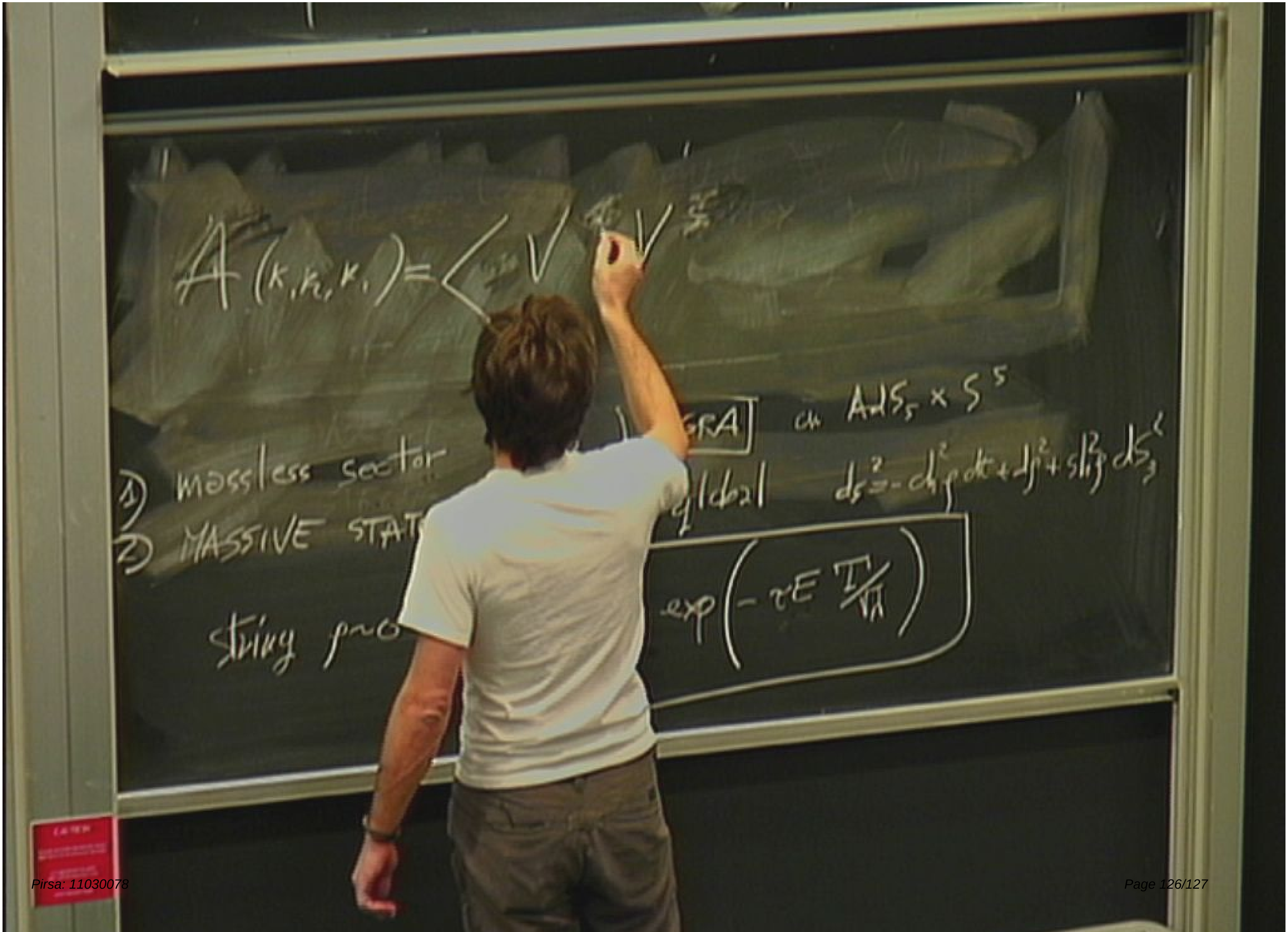

QUANTUM CORRECTIONS
1) normal ordering
2) 2-magnon energy
3) quartic corrections

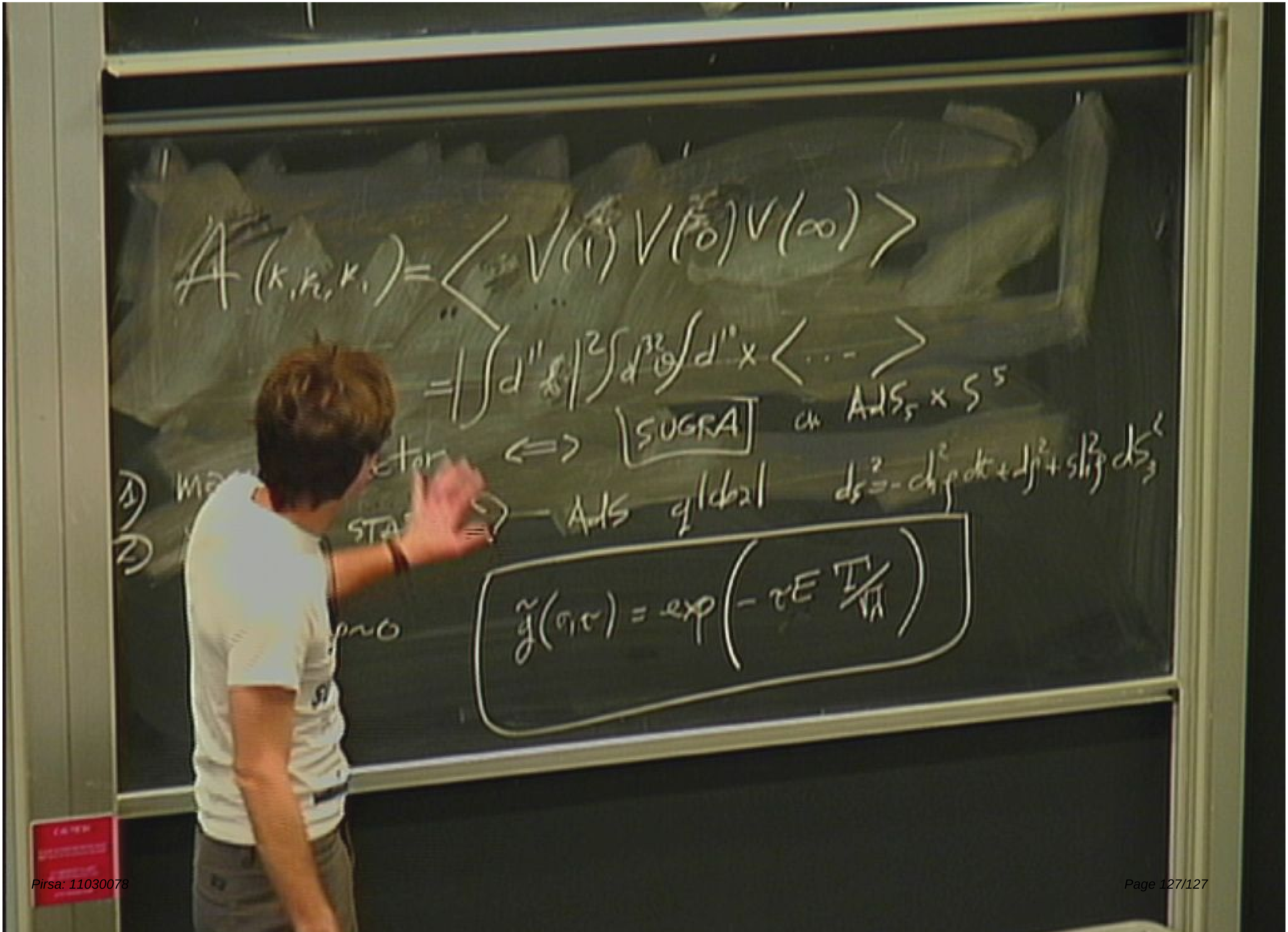
QUANTUM CORRECTIONS

1) normal ordering
2) 2-magnon energy
3) quartic corrections

$$(T+T)|V\rangle = -\frac{2}{\sqrt{5}}|V\rangle$$

$$T+T\Big|_{4X} = \frac{1}{6}\,\mathrm{Str}\left(\left[P_2, X_2\right]^2 - \left[\partial_\tau X_2, X_2\right]^2\right]$$


massless sector
MASSIVE
global


SUGRA
$AdS_5 \times S^5$
AdS
$\tilde{g}(\sigma,\tau) = \exp\left(-\tau E \frac{T}{\sqrt{\lambda}}\right)$