Title: Introduction to Low Energy Supersymmetry

Date: Aug 09, 2007 11:00 AM

URL: http://pirsa.org/07080011

Abstract:

$$\mathcal{L} = \int d^4\theta \; \Phi^\dagger \Phi + \int d^2\theta \, W(\phi)$$

$$\Phi(y,\theta) = \phi(y) + \sqrt{2}\,\theta\psi(y) + \theta^2 F(y)$$

$$\mathcal{L} = \int d^4\theta \; \Phi^\dagger \Phi + \int d^2\theta \, W(\varphi)$$

$$\Phi(y,\theta) = \varphi(y) + \sqrt{2}\,\theta\psi(y) + \theta^2 F(y)$$

$$y^\mu = x^\mu + i\theta\sigma^\mu\bar{\theta}$$

$$\mathcal{L} = \int d^4\theta\ \Phi^\dagger \Phi + \int d^2\theta\ W(\Phi)$$

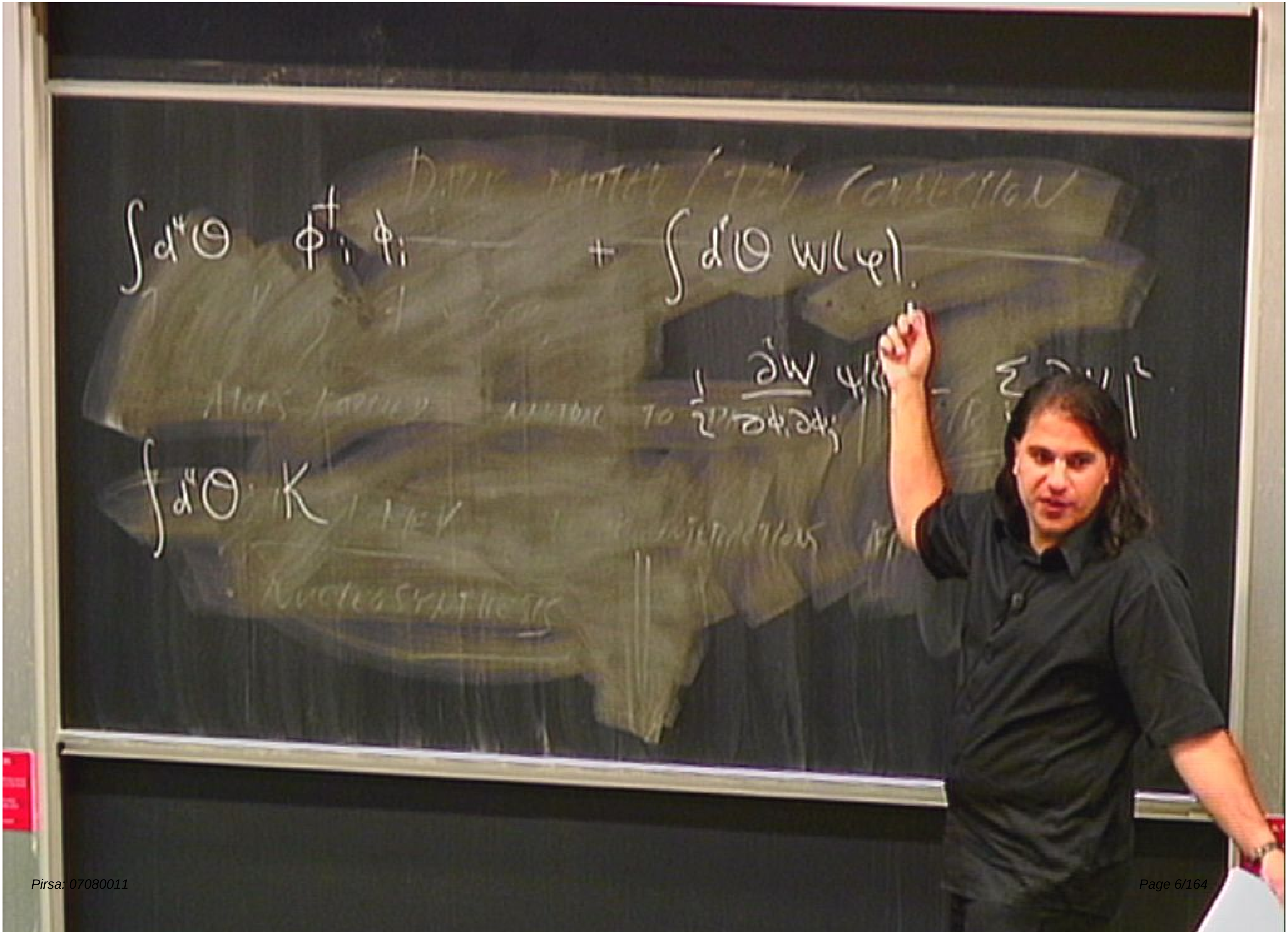
$$\Phi(y,\theta) = \varphi(y) + \sqrt{2}\,\theta\psi(y) + \theta^2 F(y).$$

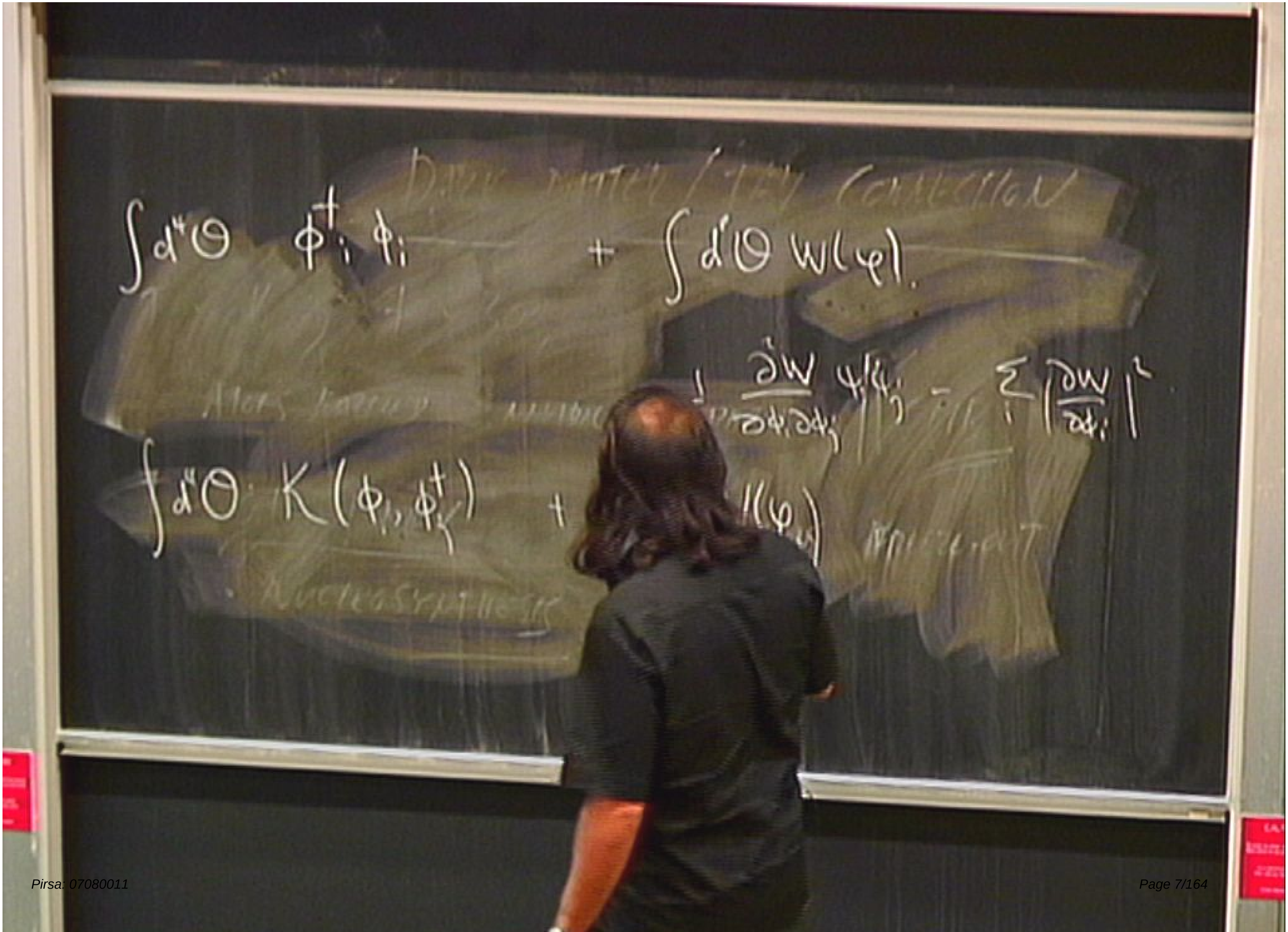
$$y^\mu = x^\mu + i\theta\sigma^\mu\bar\theta$$

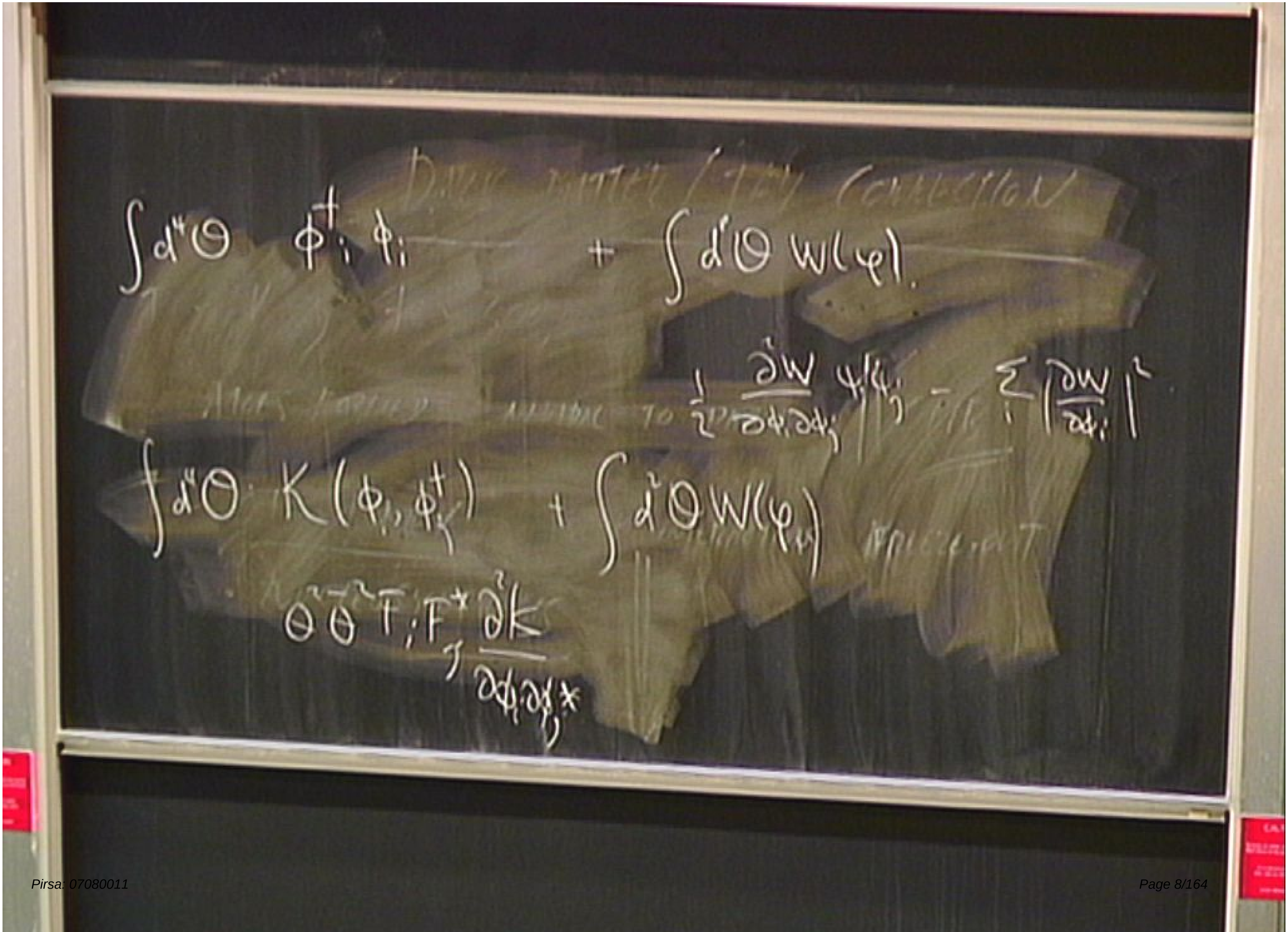
$$\mathcal{L} = |\partial\varphi|^2 + \bar\psi\, i\,\bar\sigma\,\partial\psi + \frac{1}{2}\psi\psi\frac{\partial^2 W}{\partial\phi^2} - \left|\frac{\partial W}{\partial\phi}\right|^2$$

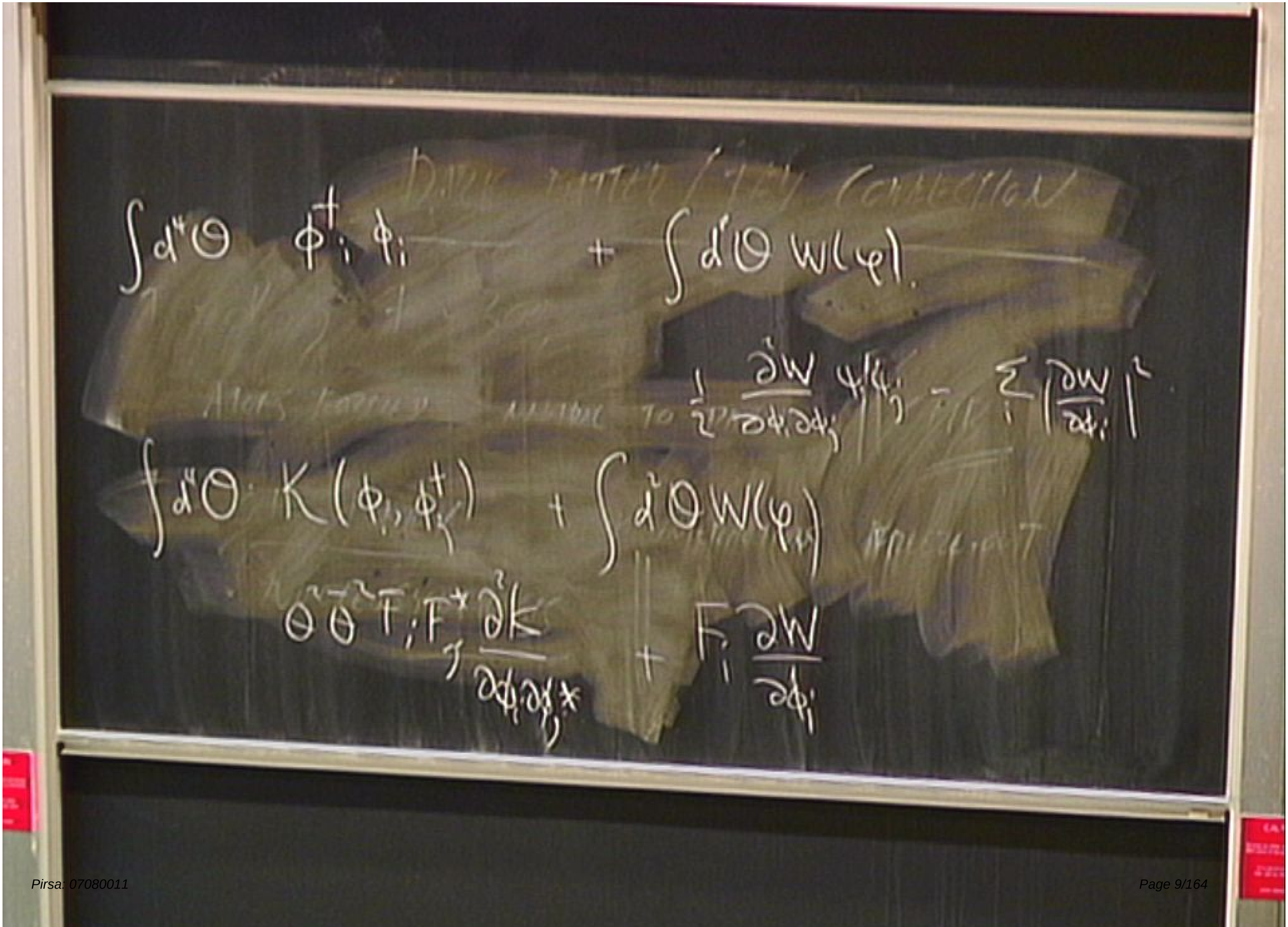
$$\int d^4\theta \; \phi_i^\dagger \phi_i \; + \int d^2\theta \, W(\varphi).$$

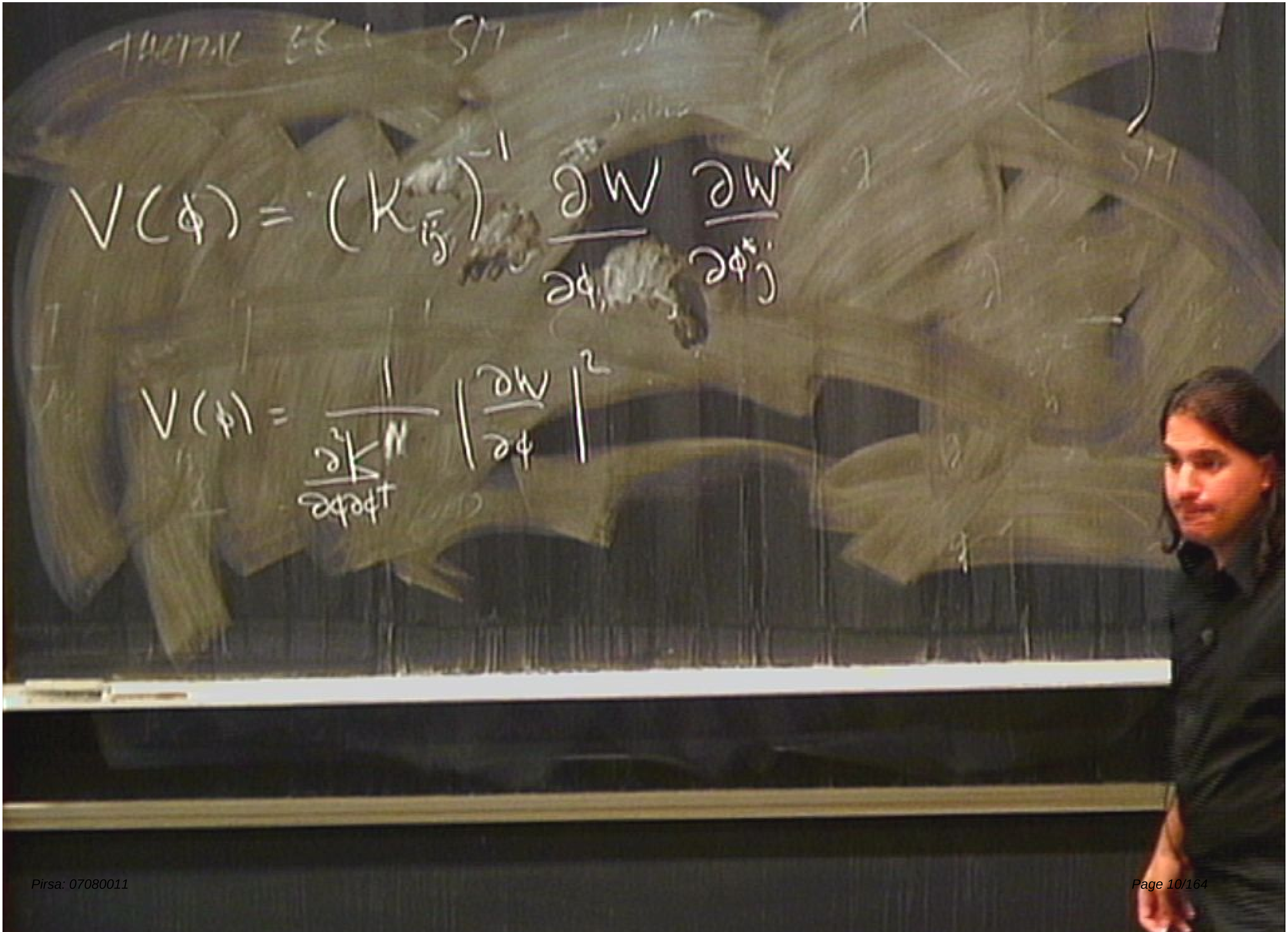
$$\frac{1}{2}\frac{\partial^2 W}{\partial\phi_i \partial\phi_j}\psi_i\psi_j - \sum_i \left|\frac{\partial W}{\partial\phi_i}\right|^2$$

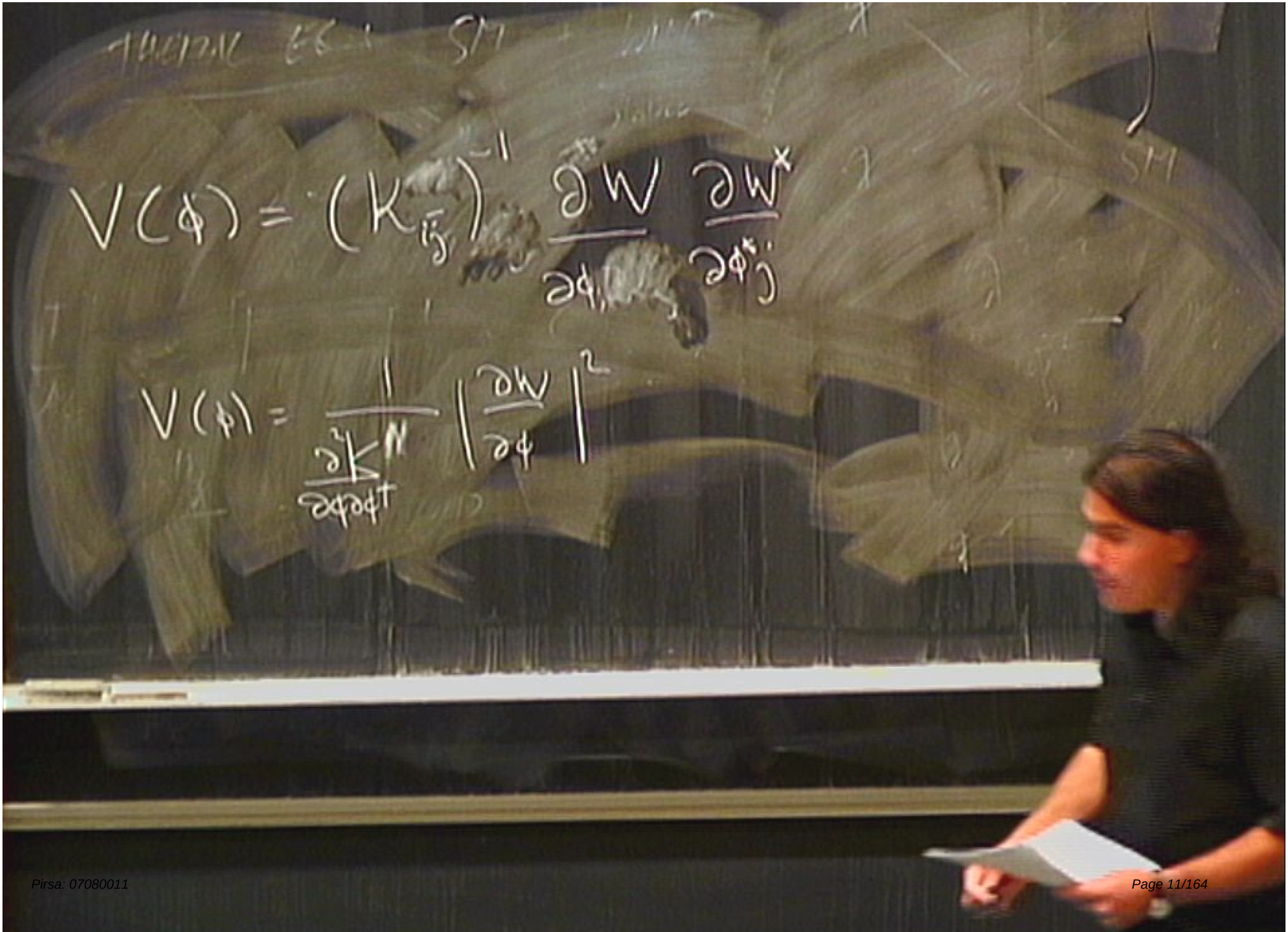

∫d⁴θ φ†ᵢ φᵢ + ∫d²θ W(φ)
∫d⁴θ K


∫d⁴Θ φ†ᵢ φᵢ + ∫d²Θ W(φ).
∫d⁴Θ K(φᵢ, φⱼ†) +


$\int d^4\theta \ \phi_i^\dagger \phi_i + \int d^2\theta \ W(\varphi)$.
$\frac{1}{2}\frac{\partial^2 W}{\partial\phi_i\partial\phi_j}\psi_i\psi_j - \sum_i \left|\frac{\partial W}{\partial\phi_i}\right|^2$
$\int d^4\theta \ K(\phi_i, \phi_j^\dagger) + \int d^2\theta \ W(\varphi_i)$
$\theta^2\bar{\theta}^2 F_i F_j^* \frac{\partial^2 K}{\partial\phi_i \partial\phi_j^*}$

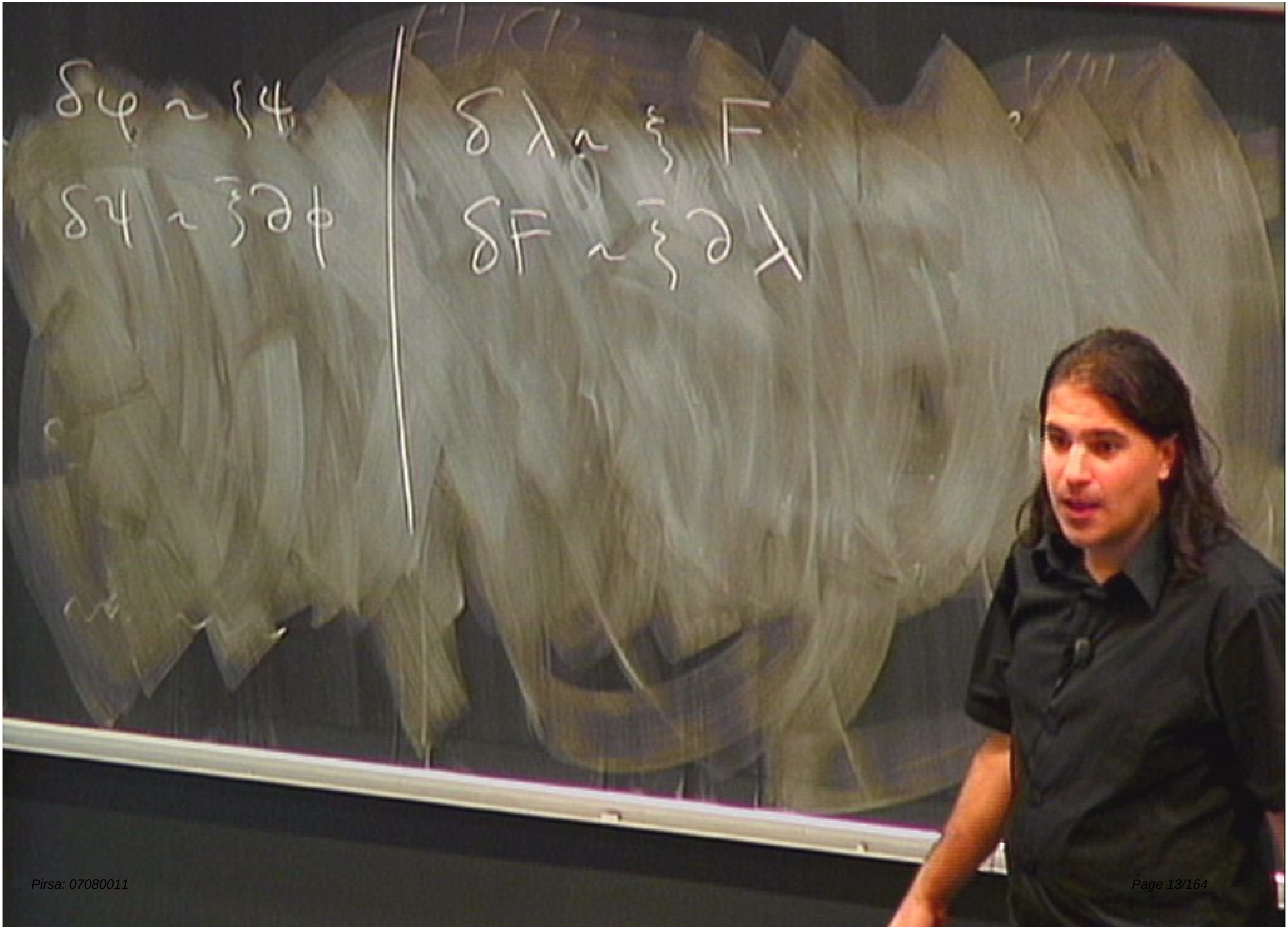

∫d⁴θ φ_i^† φ_i + ∫d²θ W(φ).
1/2 ∂²W/∂φ_i∂φ_j ψ_iψ_j − Σ_i |∂W/∂φ_i|²
∫d⁴θ K(φ_i, φ_j^†) + ∫d²θ W(φ_i)
θθθ̄θ̄ F_i F_j^* ∂²K/∂φ_i∂φ_j^* + F_i ∂W/∂φ_i

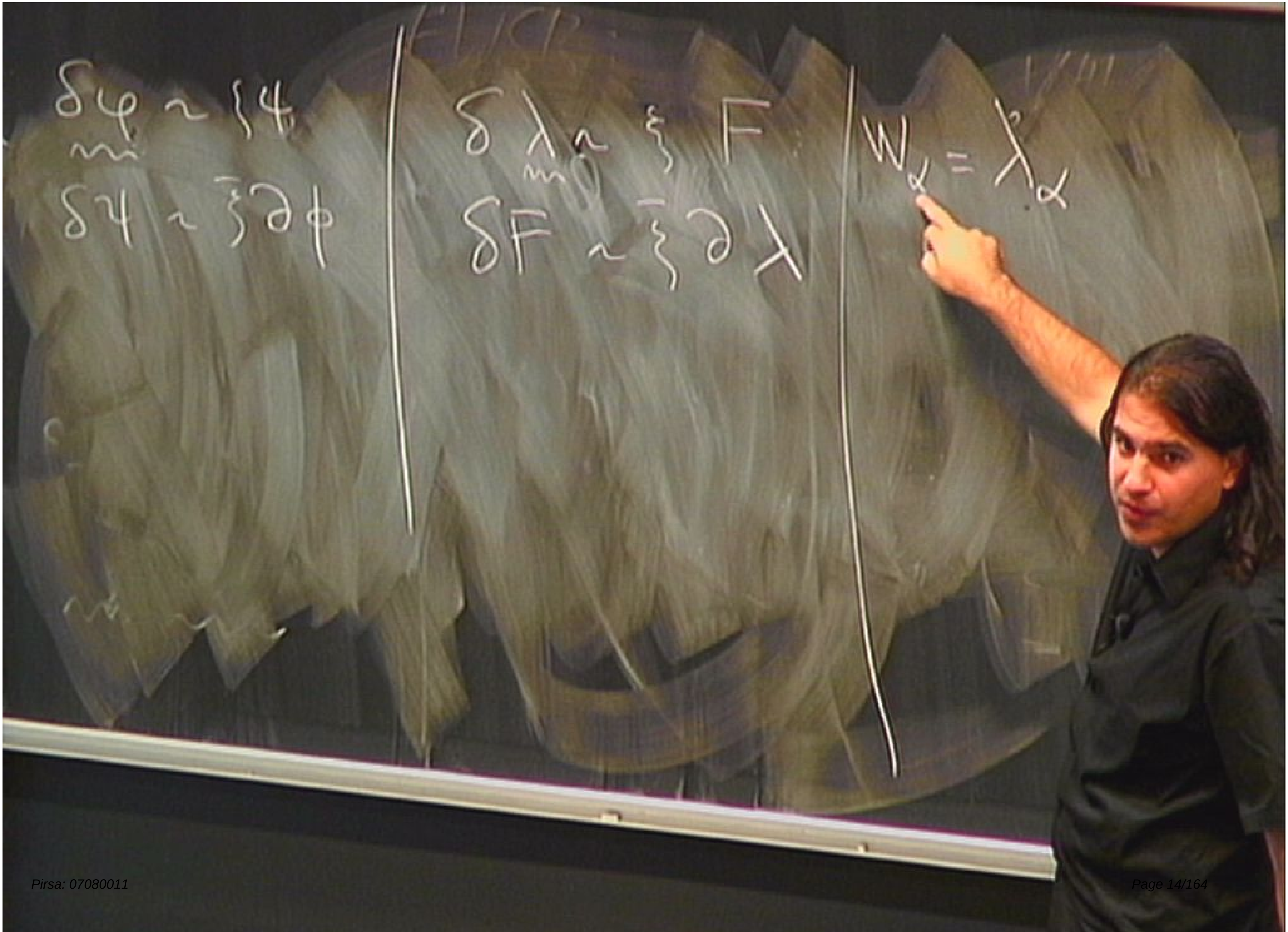

$V(\phi) = (K_{i\bar{j}})^{-1} \frac{\partial W}{\partial \phi_i} \frac{\partial W^*}{\partial \phi^*_j}$
$V(\phi) = \frac{1}{\frac{\partial^2 K}{\partial \phi \partial \phi^\dagger}} \left| \frac{\partial W}{\partial \phi} \right|^2$


V(φ) = (K_{ij})^{-1} ∂W/∂φ_i ∂W*/∂φ*_j
V(φ) = 1/(∂²K/∂φ∂φ†) |∂W/∂φ|²

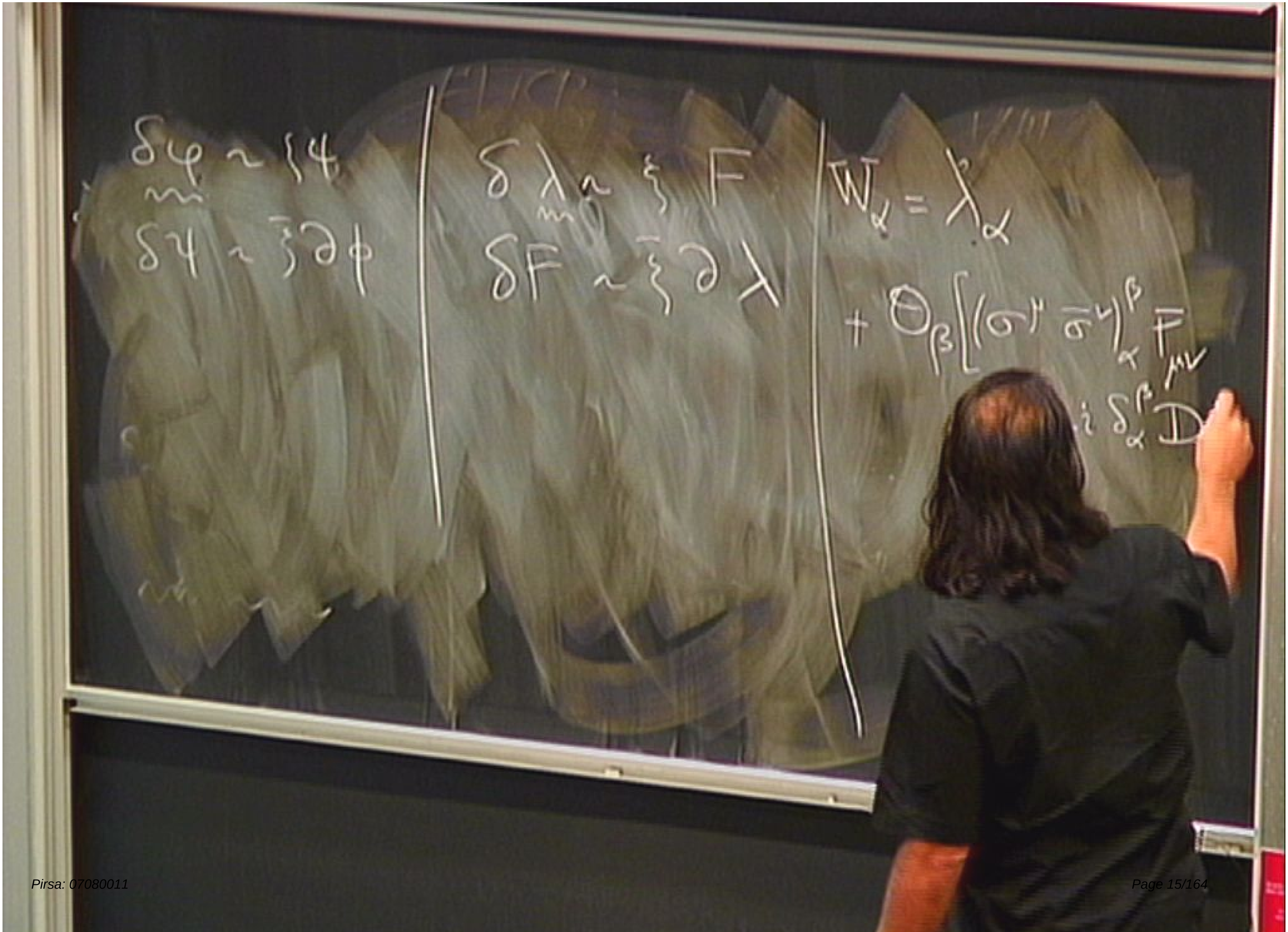
$$V(\phi) = (K_{i\bar{j}})^{-1} \frac{\partial W}{\partial \phi_i} \frac{\partial W^*}{\partial \phi^*_j}$$

$$V(\phi) = \frac{1}{\frac{\partial^2 K}{\partial \phi \partial \phi^\dagger}} \left| \frac{\partial W}{\partial \phi} \right|^2$$


$\delta\varphi \sim \xi\psi$
$\delta\psi \sim \bar{\xi}\partial\phi$
$\delta\lambda \sim \xi F$
$\delta F \sim \bar{\xi}\partial\lambda$



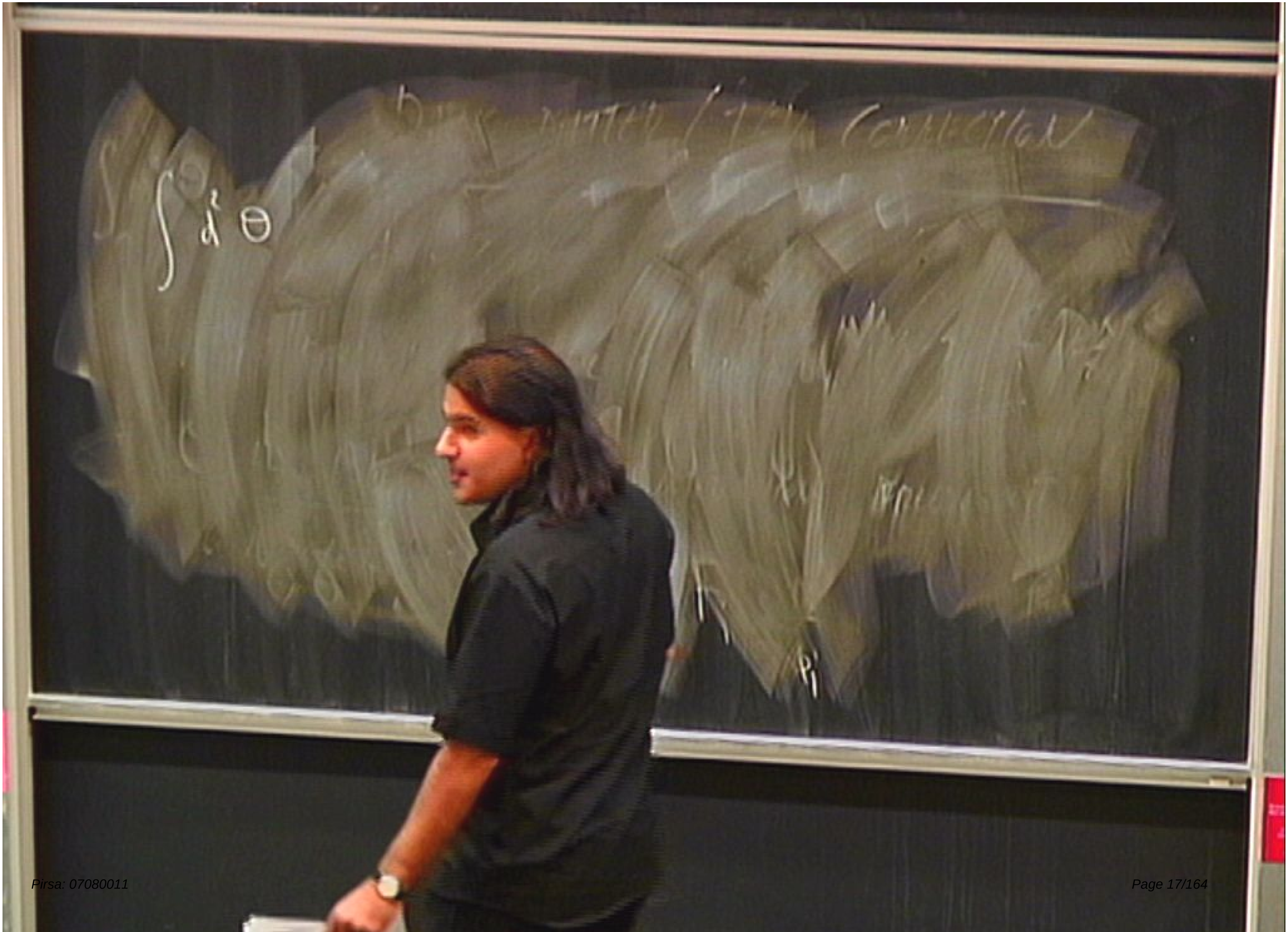
δφ ~ ξψ
δψ ~ ξ̄∂φ
δλ ~ ξF
δF ~ ξ̄∂λ
W_α = λ_α

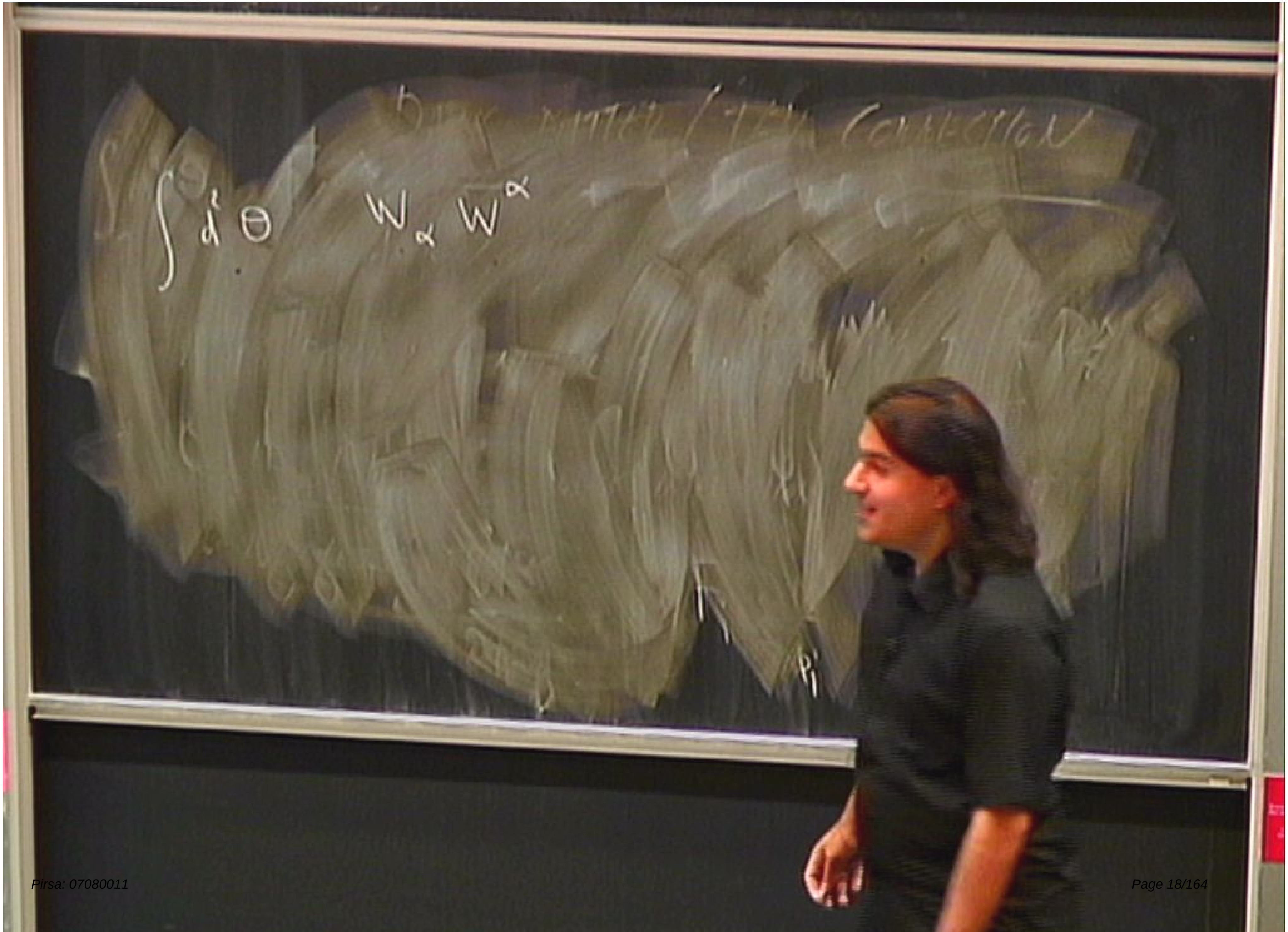

δφ ~ ξψ
δψ ~ ξ̄∂φ
δλ ~ ξF
δF ~ ξ̄∂λ
W_α = λ_α
+ θ_β[(σ^μ σ̄^ν)_α^β F_μν
i δ_α^β D

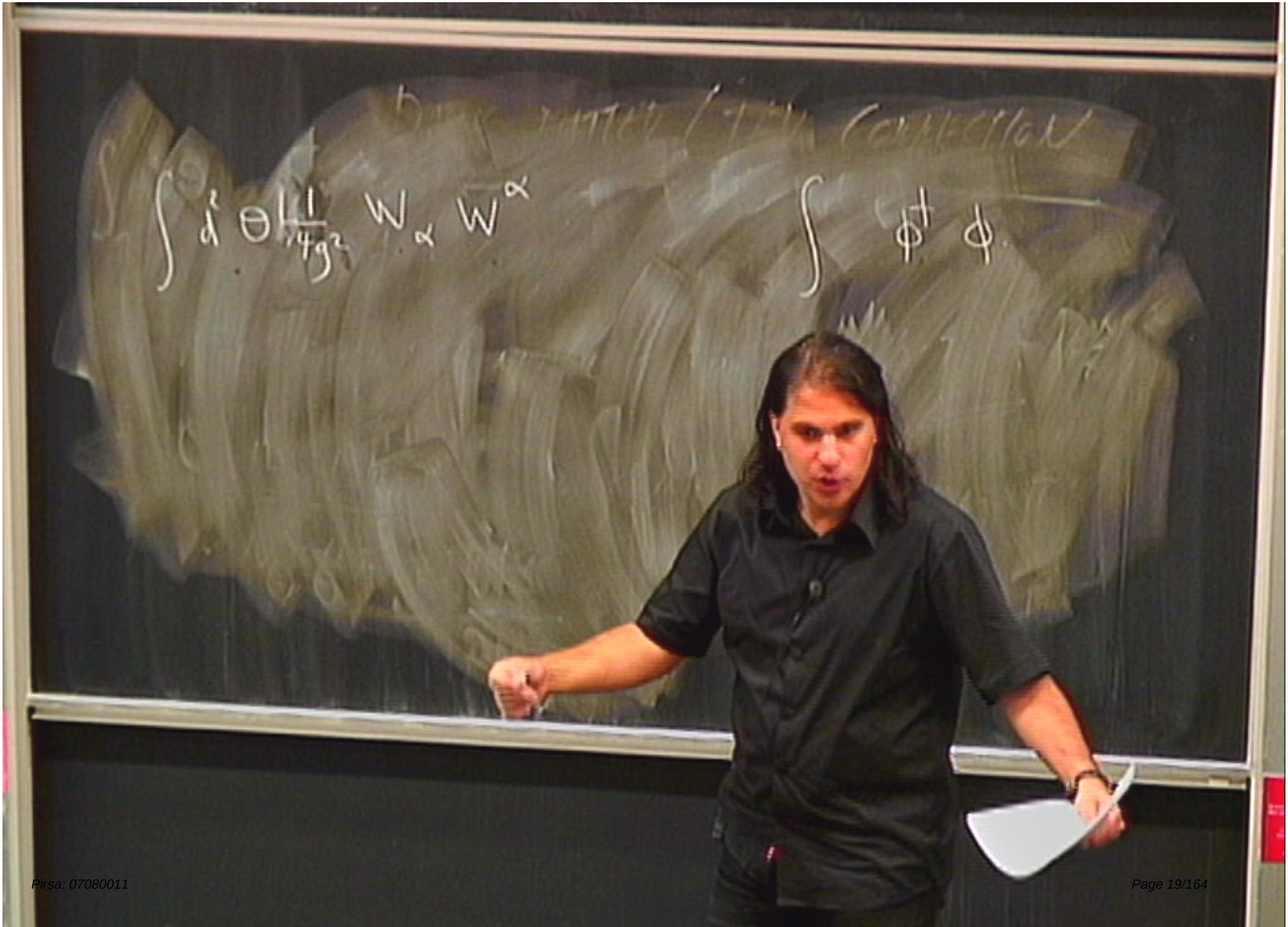
$$\delta \phi \sim \xi \psi$$
$$\delta \psi \sim \bar{\xi} \partial \phi$$

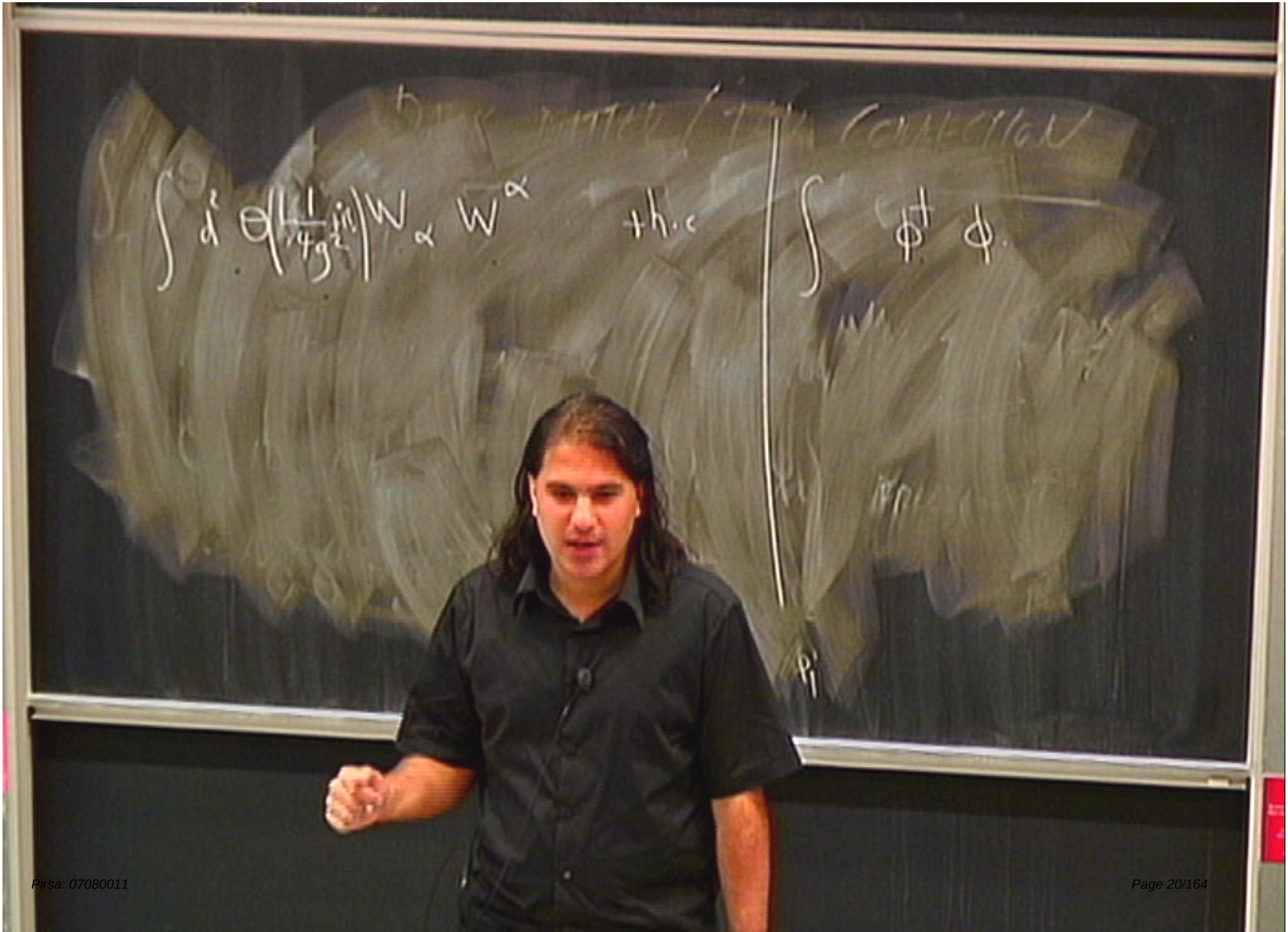
$$\delta \lambda \sim \xi F$$
$$\delta F \sim \bar{\xi} \partial \lambda$$

$$W_\alpha = \lambda_\alpha + \theta_\beta \left[(\sigma^\mu \bar{\sigma}^\nu)_\alpha{}^\beta F_{\mu\nu} + i \delta_\alpha^\beta D \right] + \theta^2 \sigma^\mu_{\alpha\dot{\alpha}} \partial_\mu \bar{\lambda}^{\dot{\alpha}}$$




$\int d^2\theta \; W_\alpha W^\alpha$

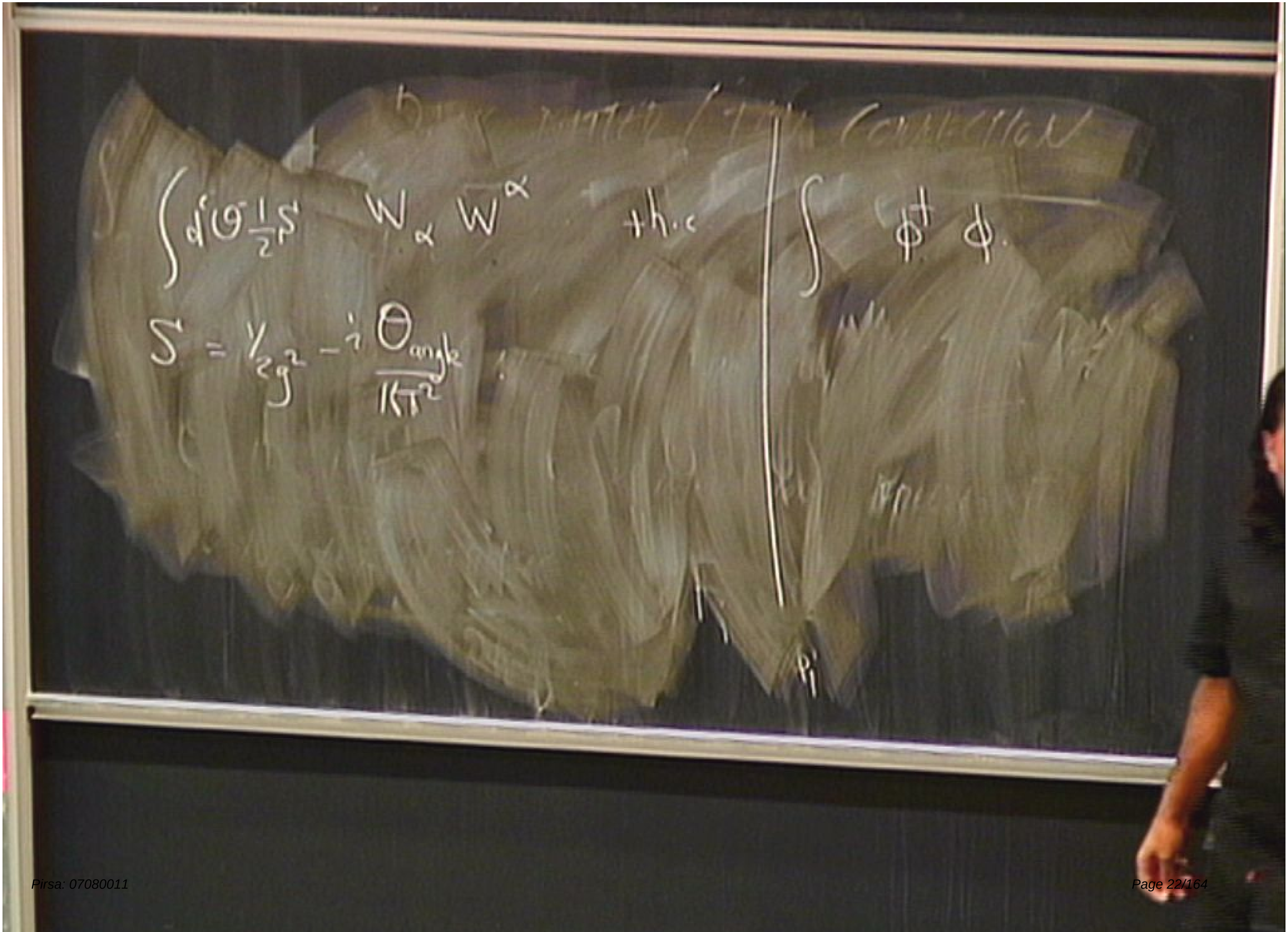

$\int d^2\theta \frac{1}{4g^2} W_\alpha W^\alpha$
$\int \phi^\dagger \phi.$



CORRECTION
+ h.c

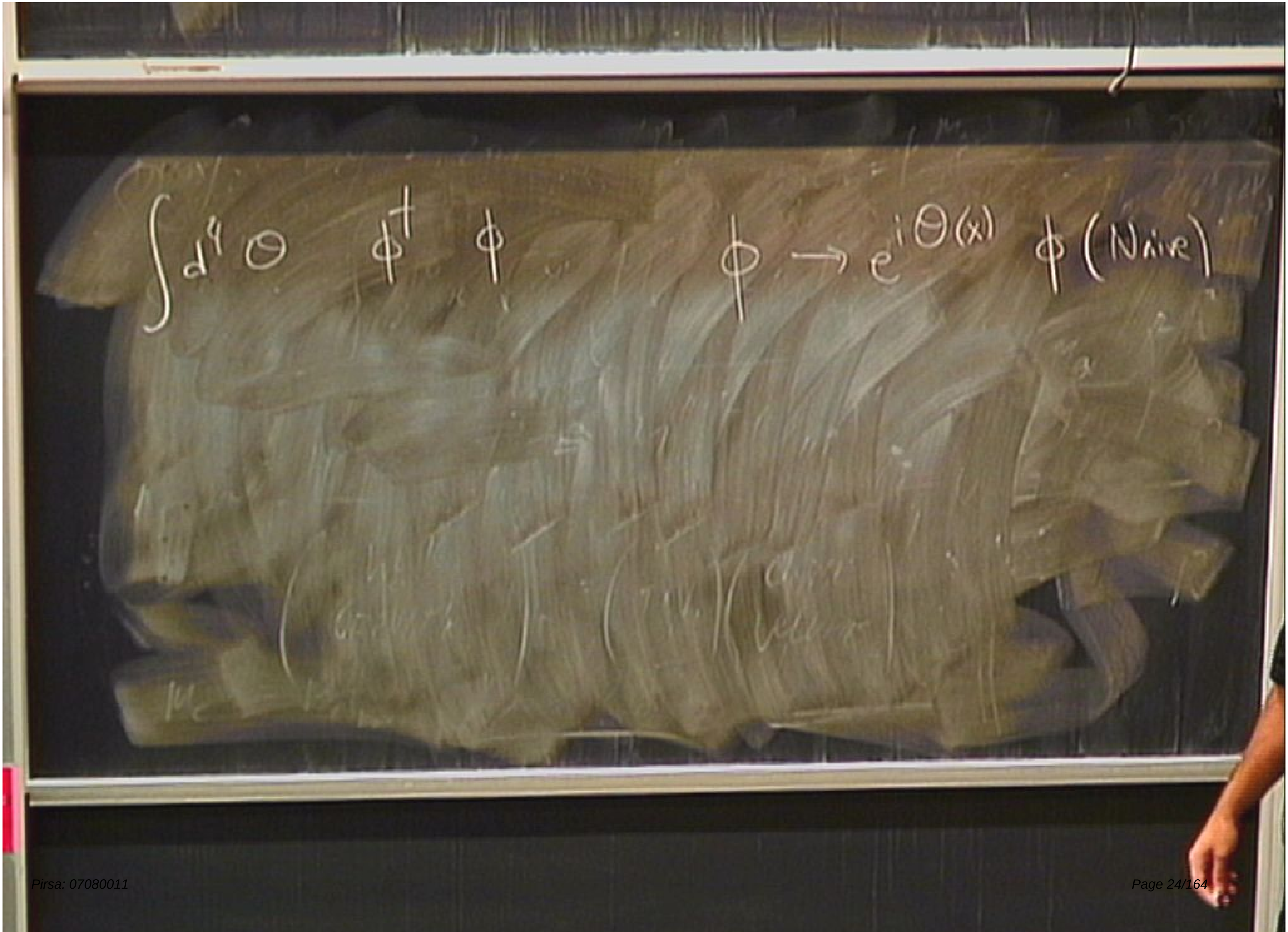
$$\int d^2\theta \left(\frac{1}{4g^2} [illegible]\right) W_\alpha W^\alpha + h.c.$$

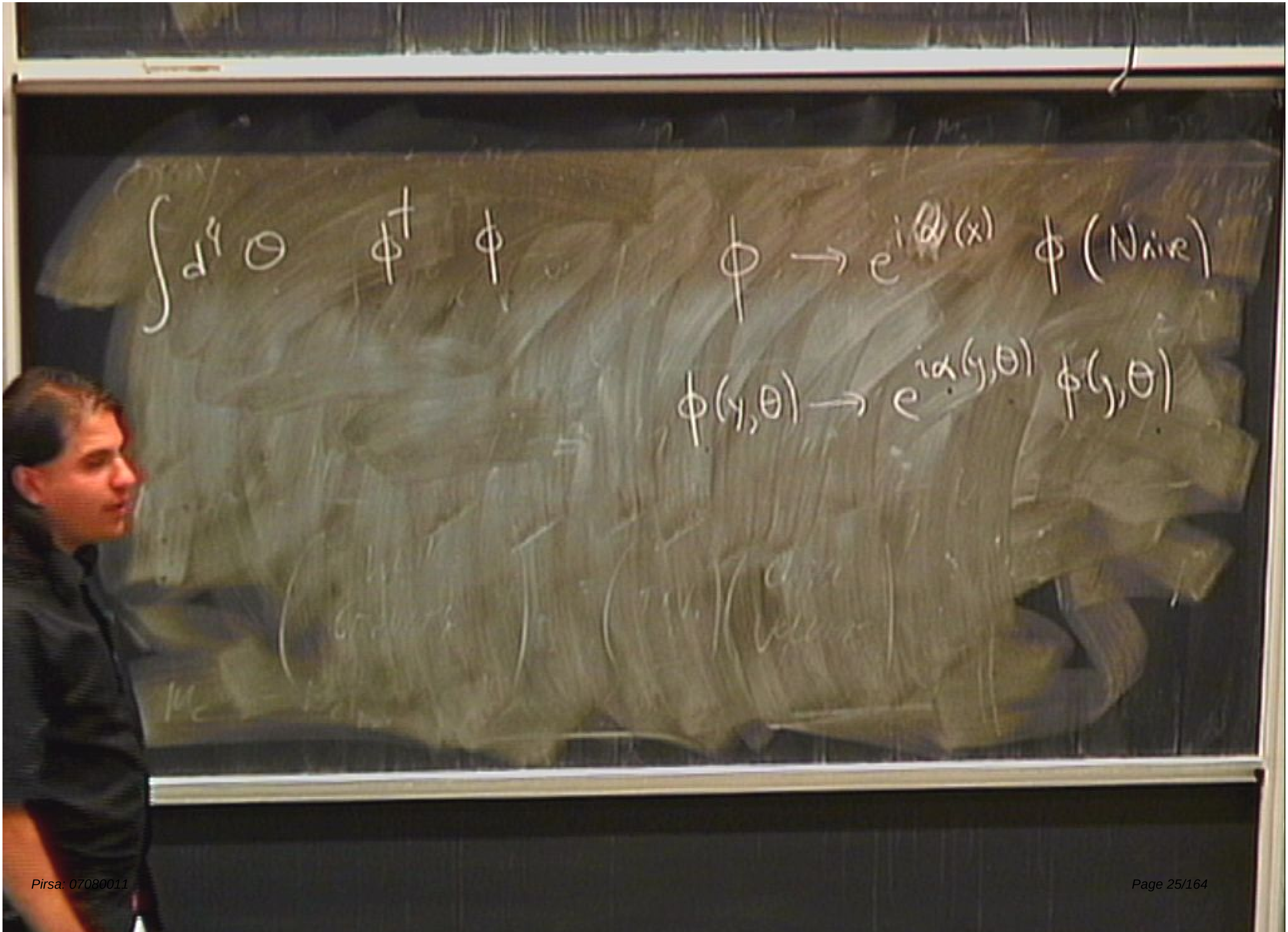
$$\int \phi^\dagger \phi.$$

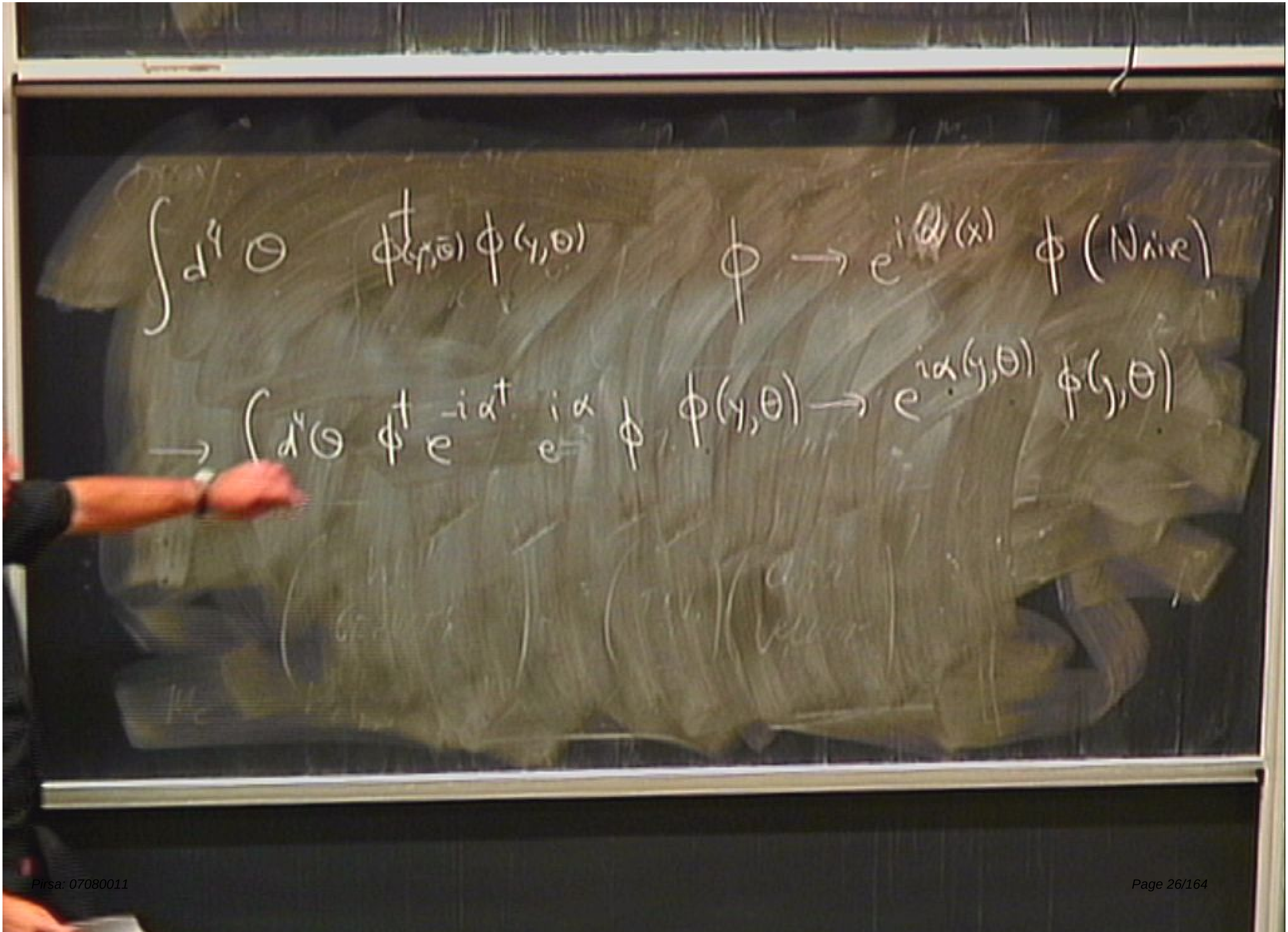

∫ d²θ ½ S W_α W^α + h.c
∫ Φ† Φ.
S = 1/2g² − i θ_angle/16π²

$$\int d^2\theta \, \frac{1}{2} S \; W_\alpha W^\alpha \; + h.c. \qquad \Big| \qquad \int \phi^\dagger \phi$$

$$S = \frac{1}{2g^2} - i \frac{\Theta_{angle}}{16\pi^2}$$

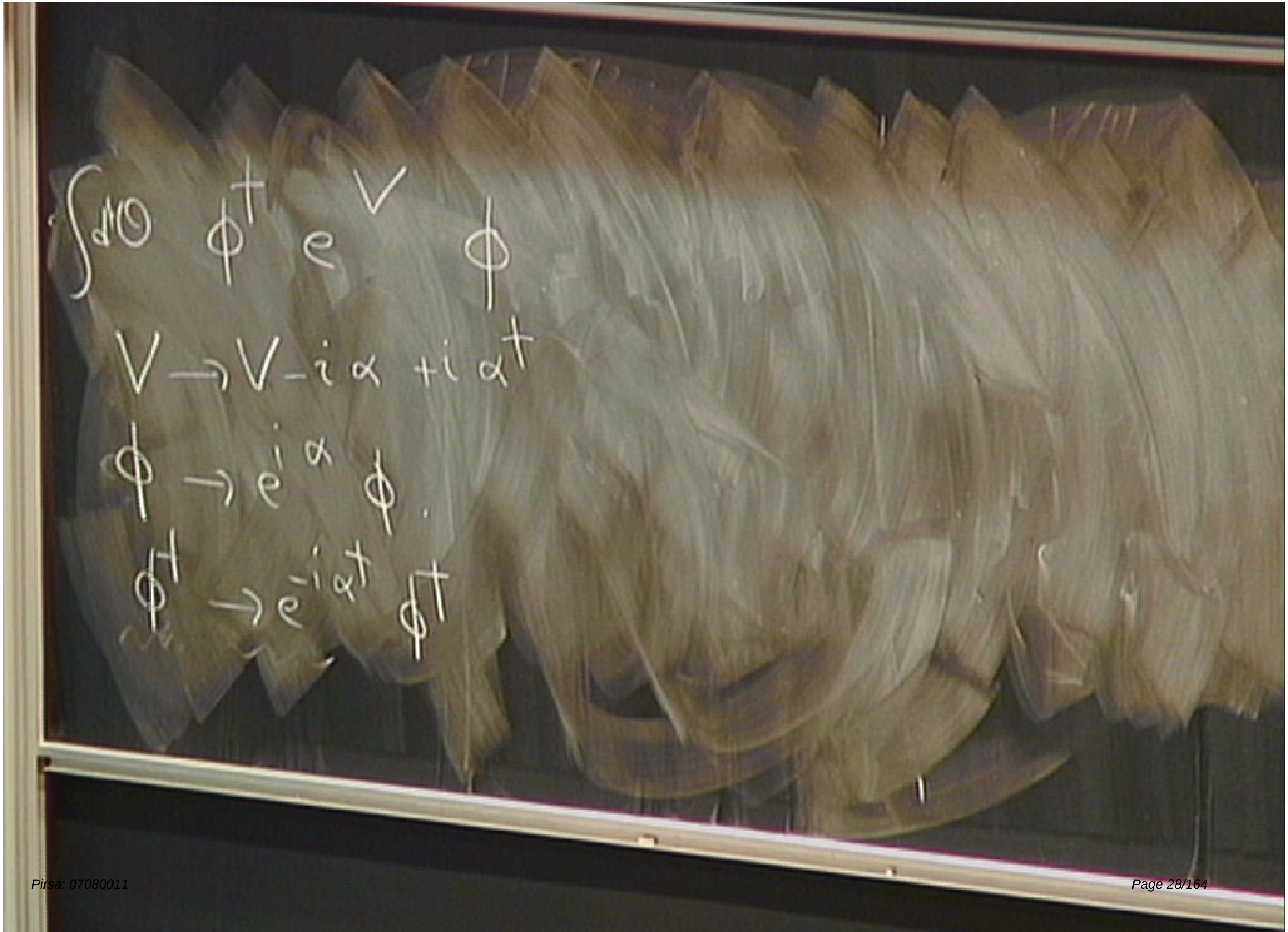

∫d⁴θ φ† φ
φ → e^{iθ(x)} φ (Naive)

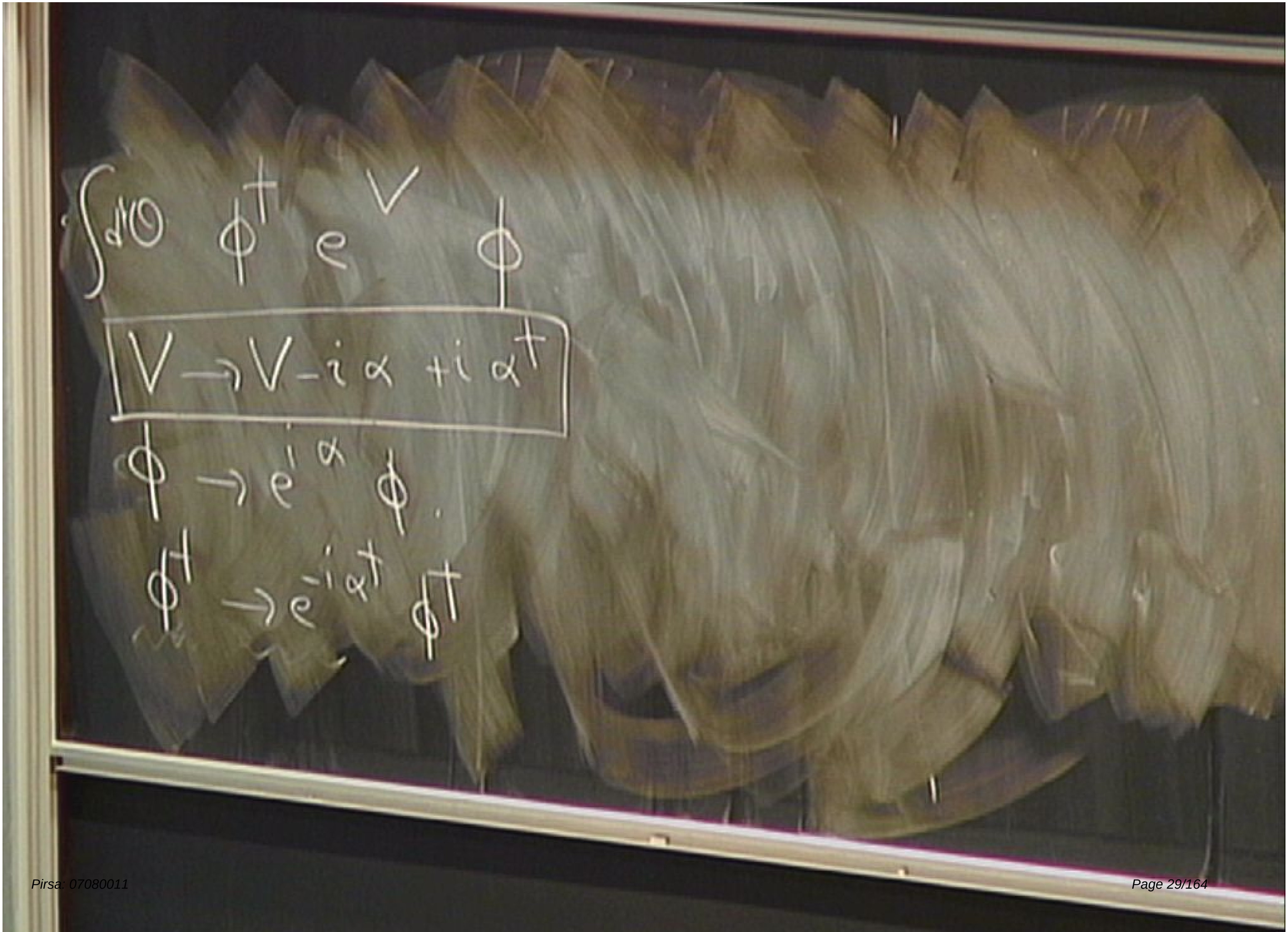

$\int d^4\theta \quad \phi^\dagger \phi$
$\phi \to e^{i\alpha(x)} \phi$ (Naive)
$\phi(y,\theta) \to e^{i\alpha(y,\theta)} \phi(y,\theta)$

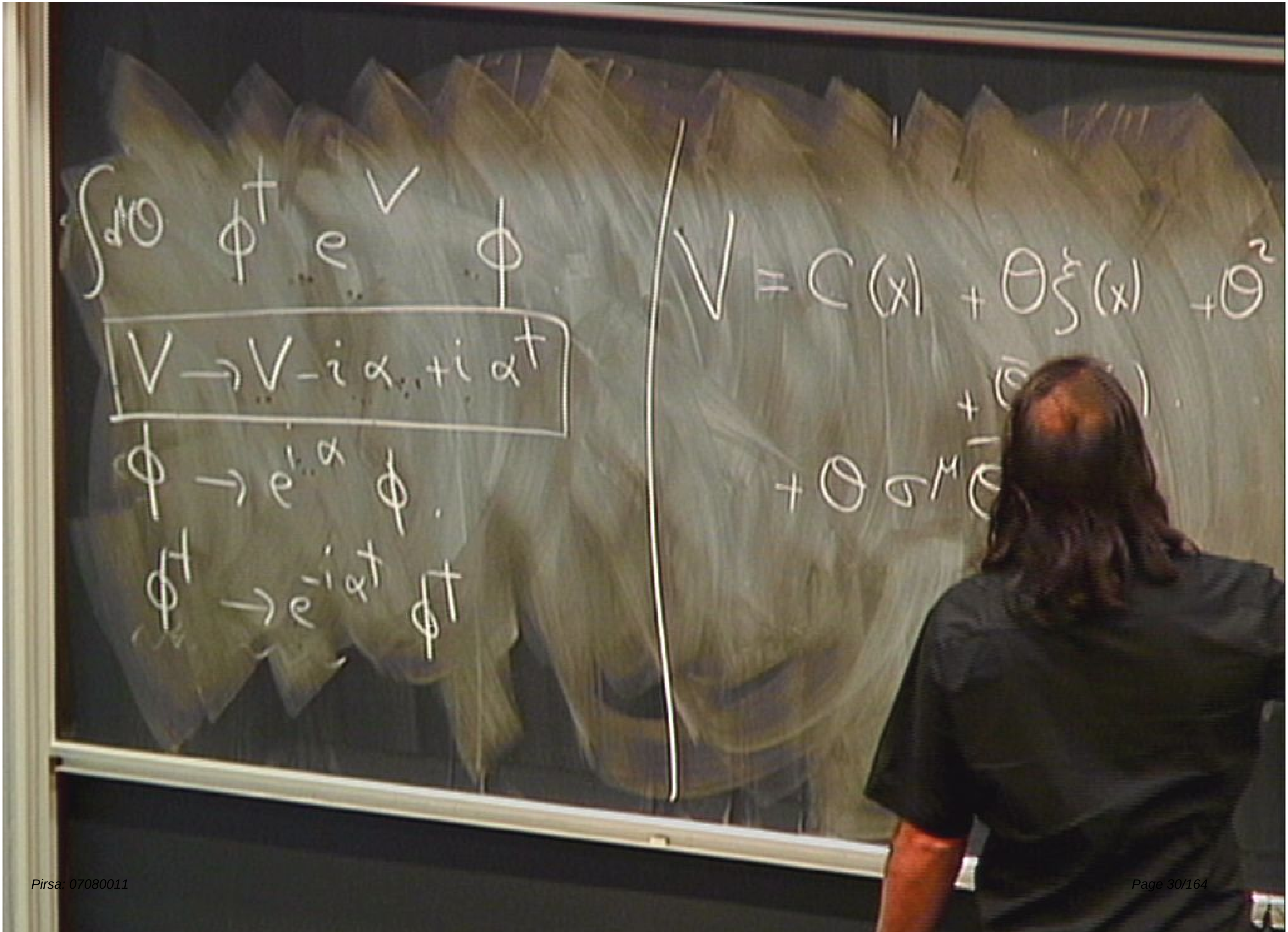

∫d⁴θ φ†(y,θ̄) φ(y,θ)
φ → e^{iα(x)} φ (Naive)
→ ∫d⁴θ φ† e^{-iα†} e^{iα} φ
φ(y,θ) → e^{iα(y,θ)} φ(y,θ)

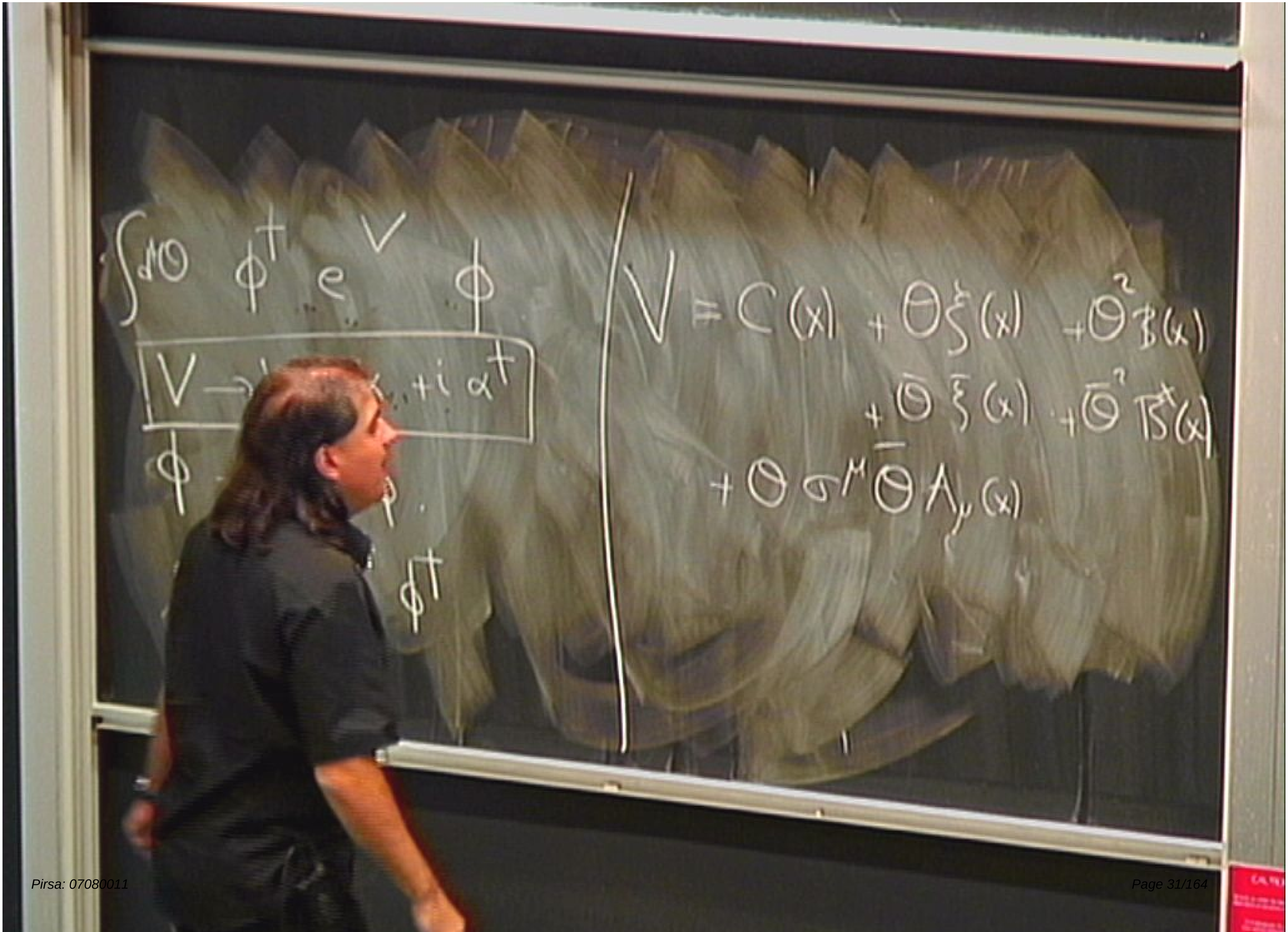
$$\int d^4\theta \;\; \phi^\dagger(y,\bar{\theta})\,\phi(y,\theta) \qquad \phi \to e^{i\alpha(x)}\,\phi \;\;(\text{Naive})$$

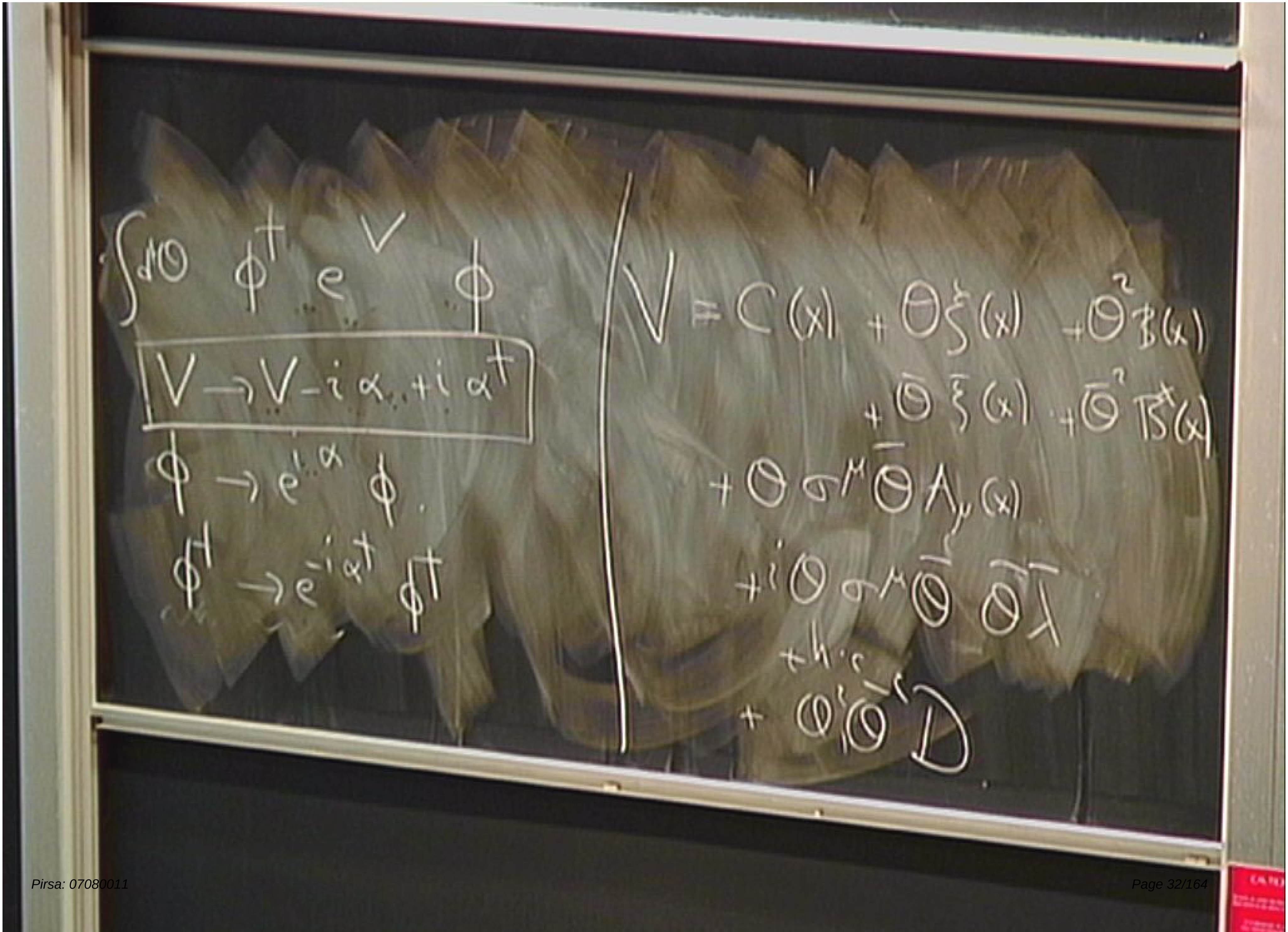
$$\to \int d^4\theta \;\; \phi^\dagger\, e^{-i\alpha^\dagger}\, e^{i\alpha}\, \phi \qquad \phi(y,\theta) \to e^{i\alpha(y,\theta)}\,\phi(y,\theta)$$


$\int d\Theta \; \phi^\dagger e^V \phi$
$V \to V - i\alpha + i\alpha^\dagger$
$\phi \to e^{i\alpha} \phi$.
$\phi^\dagger \to e^{-i\alpha^\dagger} \phi^\dagger$


$\int d^4\theta \ \phi^\dagger e^V \phi$
$V \to V - i\alpha + i\alpha^\dagger$
$\phi \to e^{i\alpha} \phi$
$\phi^\dagger \to e^{-i\alpha^\dagger} \phi^\dagger$

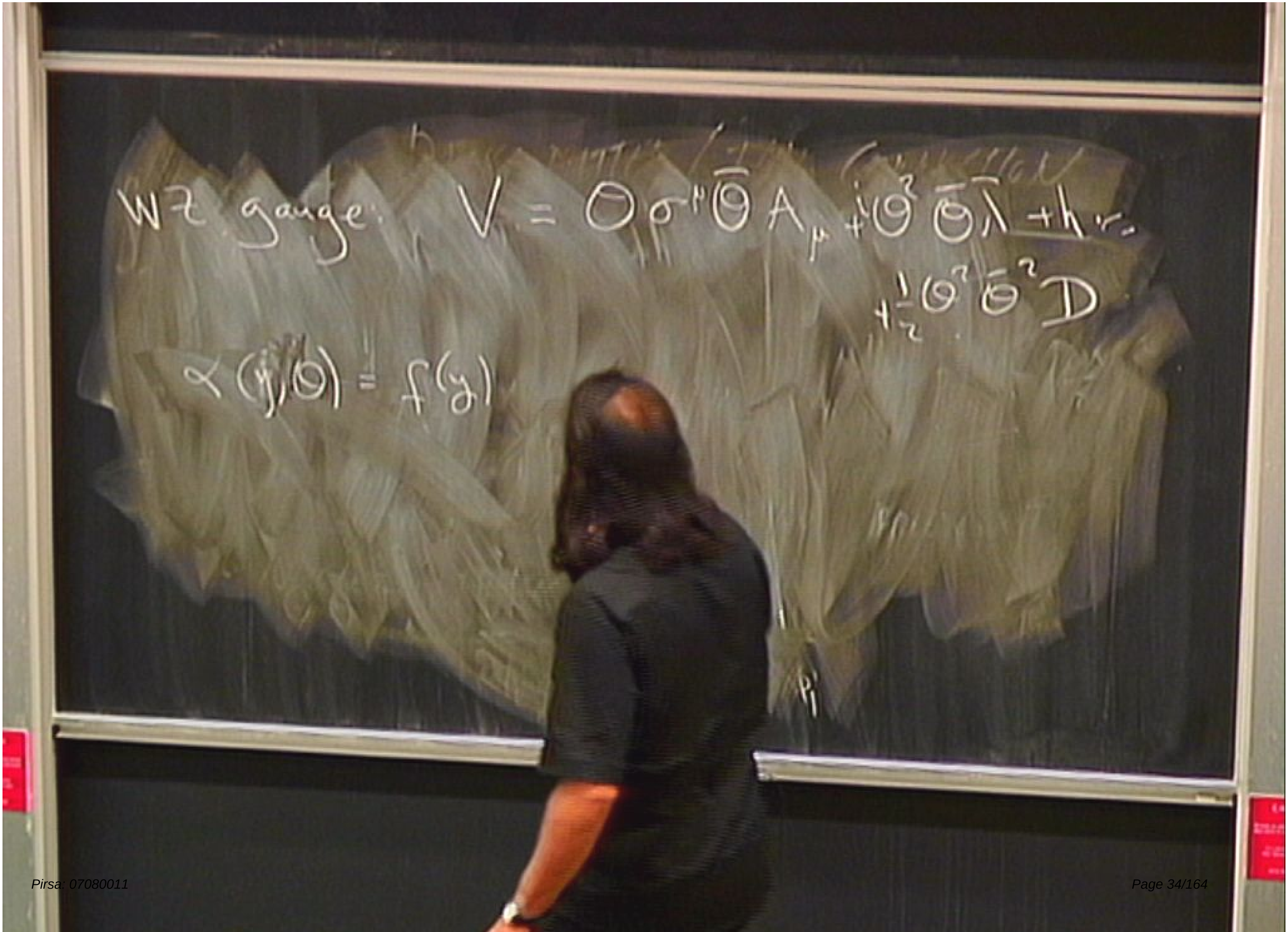

∫dθ φ† e^V φ
V → V − iα + iα†
φ → e^{iα} φ
φ† → e^{−iα†} φ†
V = C(x) + θξ(x) + θ²

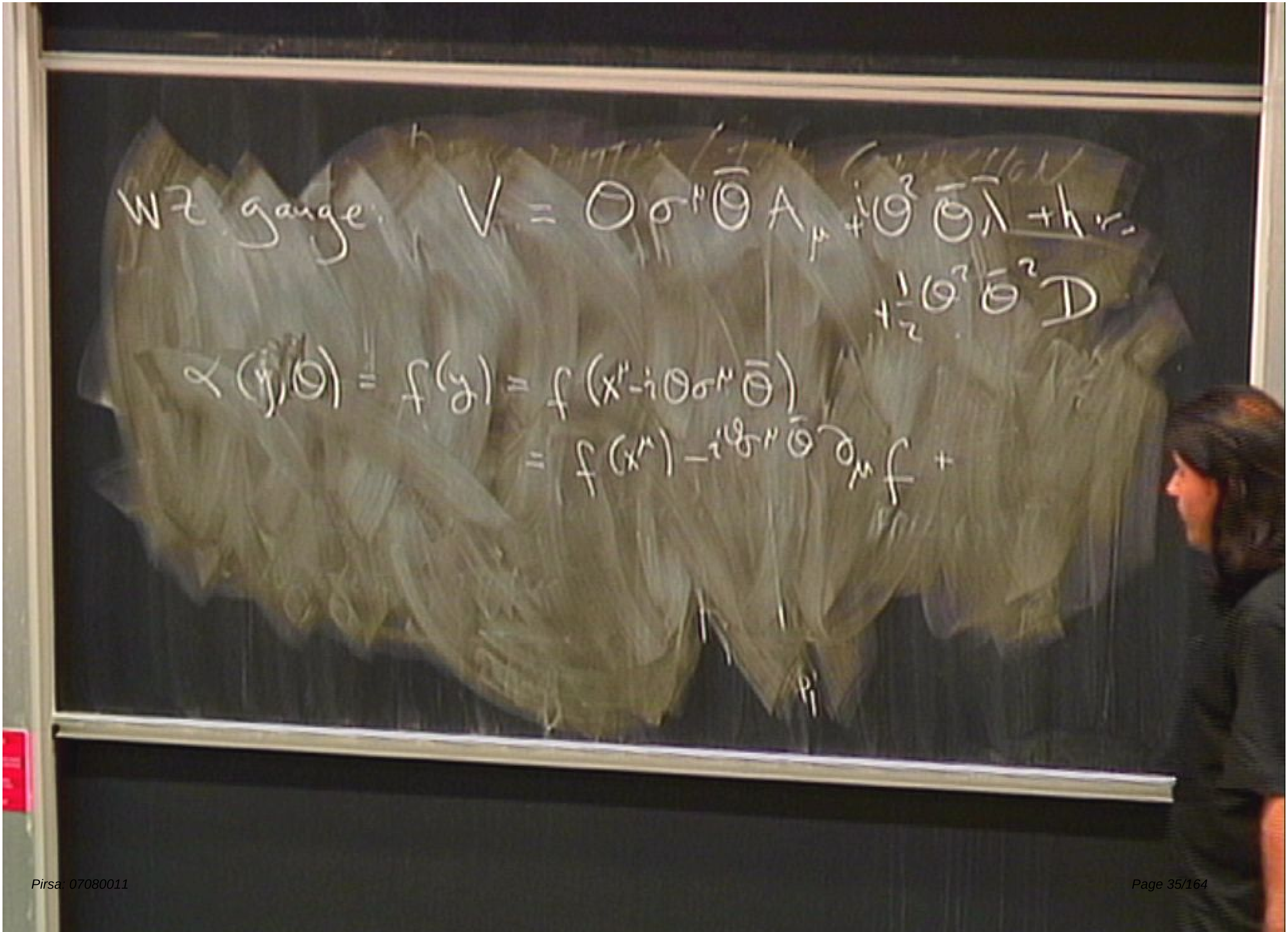

∫d⁴θ φ† e^V φ
V → V + iΛ − iΛ†
V = C(x) + θξ(x) + θ²B(x)
+ θ̄ ξ̄(x) + θ̄² B†(x)
+ θσ^μ θ̄ A_μ(x)



$\int d^4\theta \; \phi^\dagger e^V \phi$
$V \to V - i\alpha + i\alpha^\dagger$
$\phi \to e^{i\alpha} \phi$
$\phi^\dagger \to e^{-i\alpha^\dagger} \phi^\dagger$
$V = C(x) + \theta \xi(x) + \theta^2 B(x)$
$+ \bar\theta \bar\xi(x) + \bar\theta^2 B^\dagger(x)$
$+ \theta \sigma^\mu \bar\theta A_\mu(x)$
$+ i \theta \sigma^\mu \bar\theta \; \bar\theta \bar\lambda$
$+ h.c.$
$+ \theta^2 \bar\theta^2 D$

WZ gauge: $V = \theta\sigma^\mu\bar\theta A_\mu + i\theta^2\bar\theta\bar\lambda + h.c. + \theta^2\bar\theta^2 D$


WZ gauge: $V = \theta\sigma^\mu\bar\theta A_\mu + i\theta^2\bar\theta\bar\lambda + h.c. + \frac{1}{2}\theta^2\bar\theta^2 D$
$\alpha(y,\theta) = f(y)$


WZ gauge: V = θσ^μθ̄ A_μ + iθ²θ̄λ̄ + h.c. + ½ θ²θ̄² D
Φ(y,θ) = f(y) = f(x^μ − iθσ^μθ̄)
= f(x^μ) − iθσ^μθ̄ ∂_μ f +

WZ gauge: $V = \theta\sigma^\mu\bar{\theta} A_\mu + i\theta^2\bar{\theta}\bar{\lambda} + h.c.$

$$+ \frac{1}{2}\theta^2\bar{\theta}^2 D$$

$$\alpha(y,\theta) = f(y) = f(x^\mu - i\theta\sigma^\mu\bar{\theta})$$

$$= f(x^\mu) - i\theta\sigma^\mu\bar{\theta}\,\partial_\mu f + \dots$$

$$i\alpha - i\alpha^\dagger = (\quad) + \theta\sigma^\mu\bar{\theta}(\partial_\mu \mathrm{Im}\, f) + \dots$$

WZ gauge: $V = \theta\sigma^\mu\bar{\theta} A_\mu + i\theta^2\bar{\theta}\bar{\lambda} + h.c.$

$$+ \frac{1}{2}\theta^2\bar{\theta}^2 D$$

$$\alpha(y,\theta) = f(y) = f(x^\mu - i\theta\sigma^\mu\bar{\theta})$$

$$= f(x^\mu) - i\theta\sigma^\mu\bar{\theta}\,\partial_\mu f + \dots$$

$$i\alpha - i\alpha^\dagger = (\quad) + \theta\sigma^\mu\bar{\theta}(\partial_\mu \mathrm{Im} f) + \dots$$

$$A_\mu \to A_\mu + \partial_\mu(\mathrm{Im} f)$$

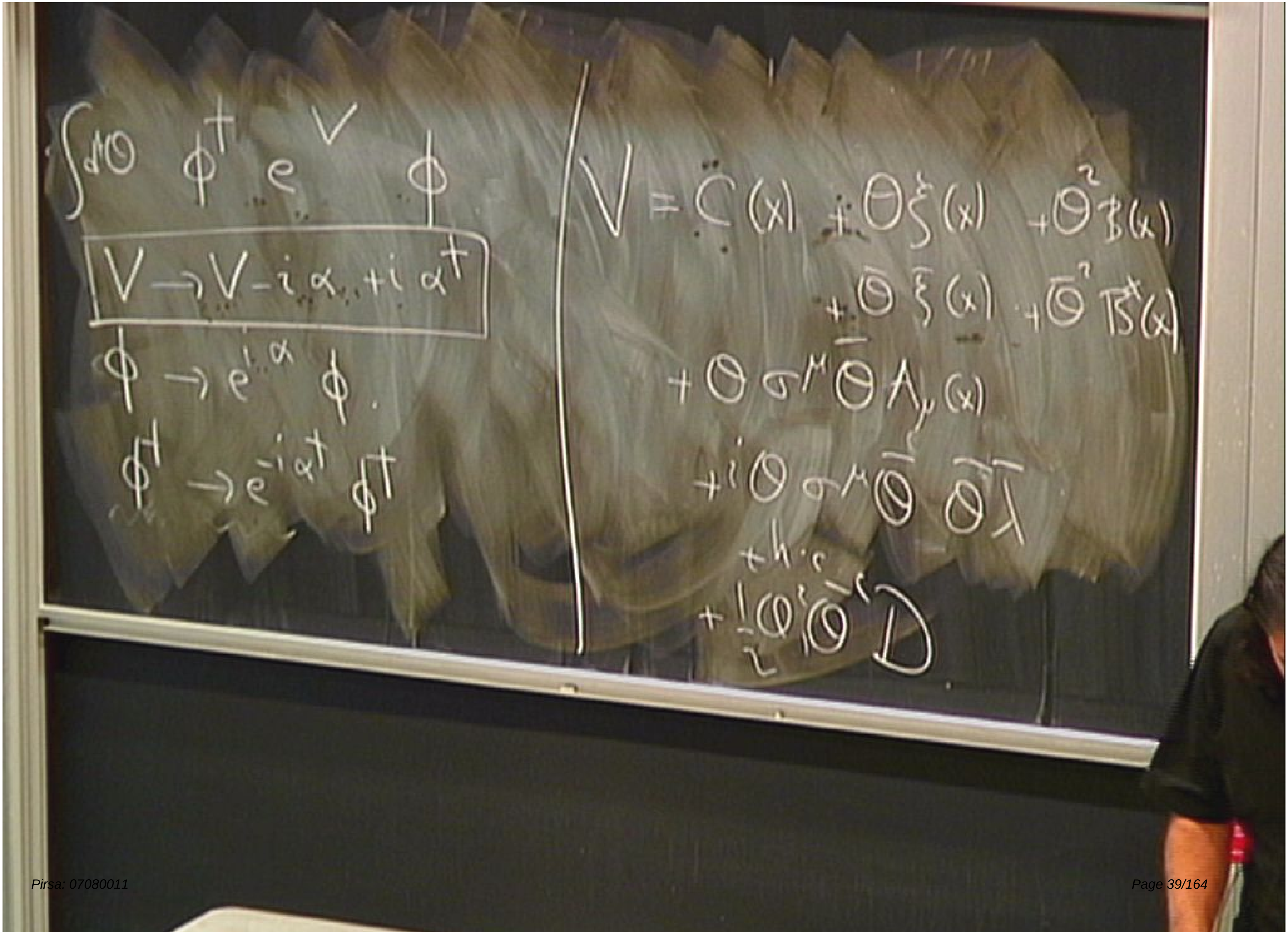
WZ gauge: $V = \theta\sigma^\mu\bar\theta A_\mu + i\theta^2\bar\theta\bar\lambda + h.c. + \frac{1}{2}\theta^2\bar\theta^2 D$

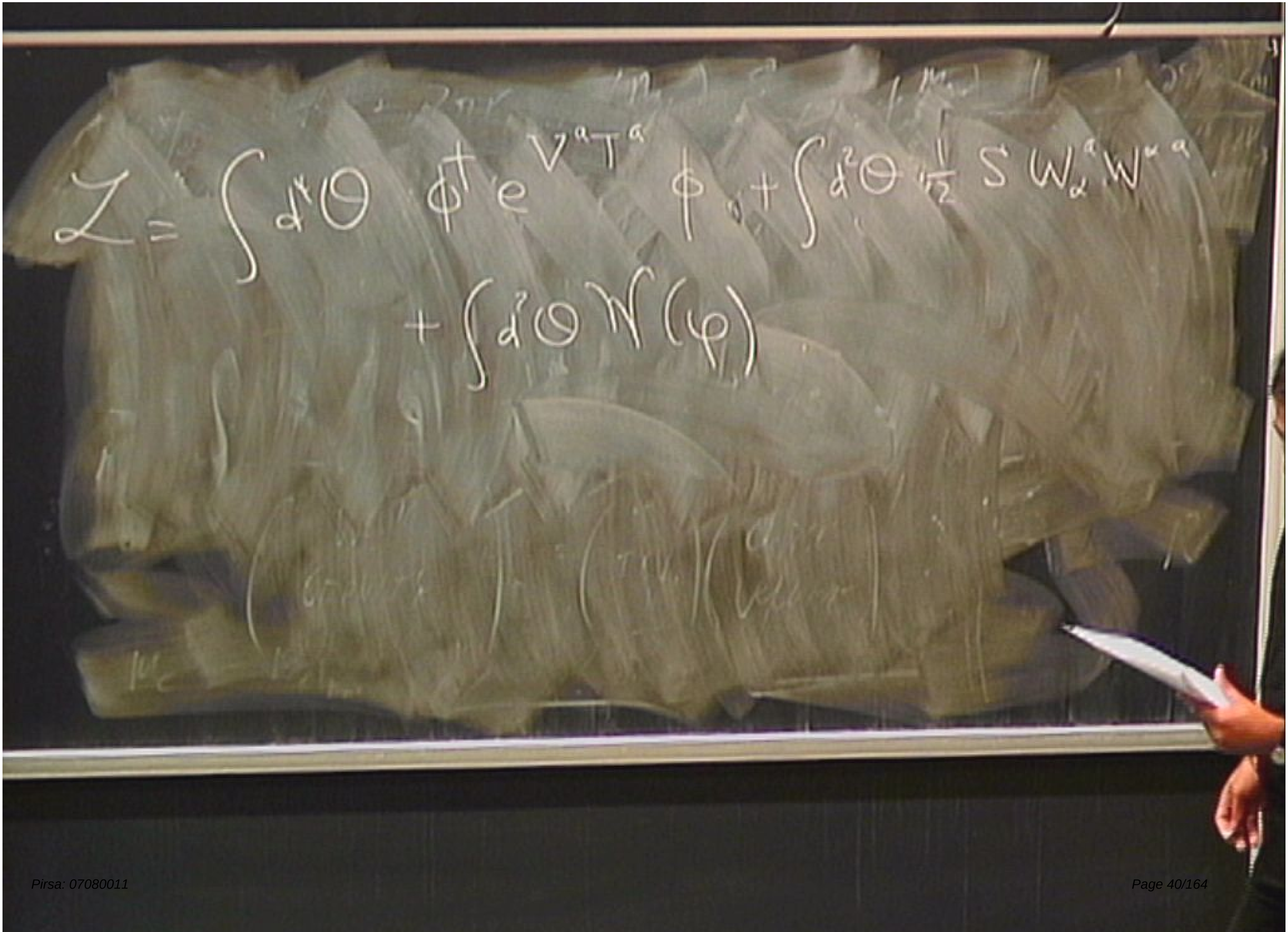
$$\alpha(y,\theta) = f(y) = f(x^\mu - i\theta\sigma^\mu\bar\theta)$$

$$= f(x^\mu) - i\theta\sigma^\mu\bar\theta\,\partial_\mu f + \ldots$$

$$i\alpha - i\alpha^\dagger = (\quad) + \theta\sigma^\mu\bar\theta(\partial_\mu \operatorname{Im} f) + \ldots$$

$$A_\mu \to A_\mu + \partial_\mu(\operatorname{Im} f)$$

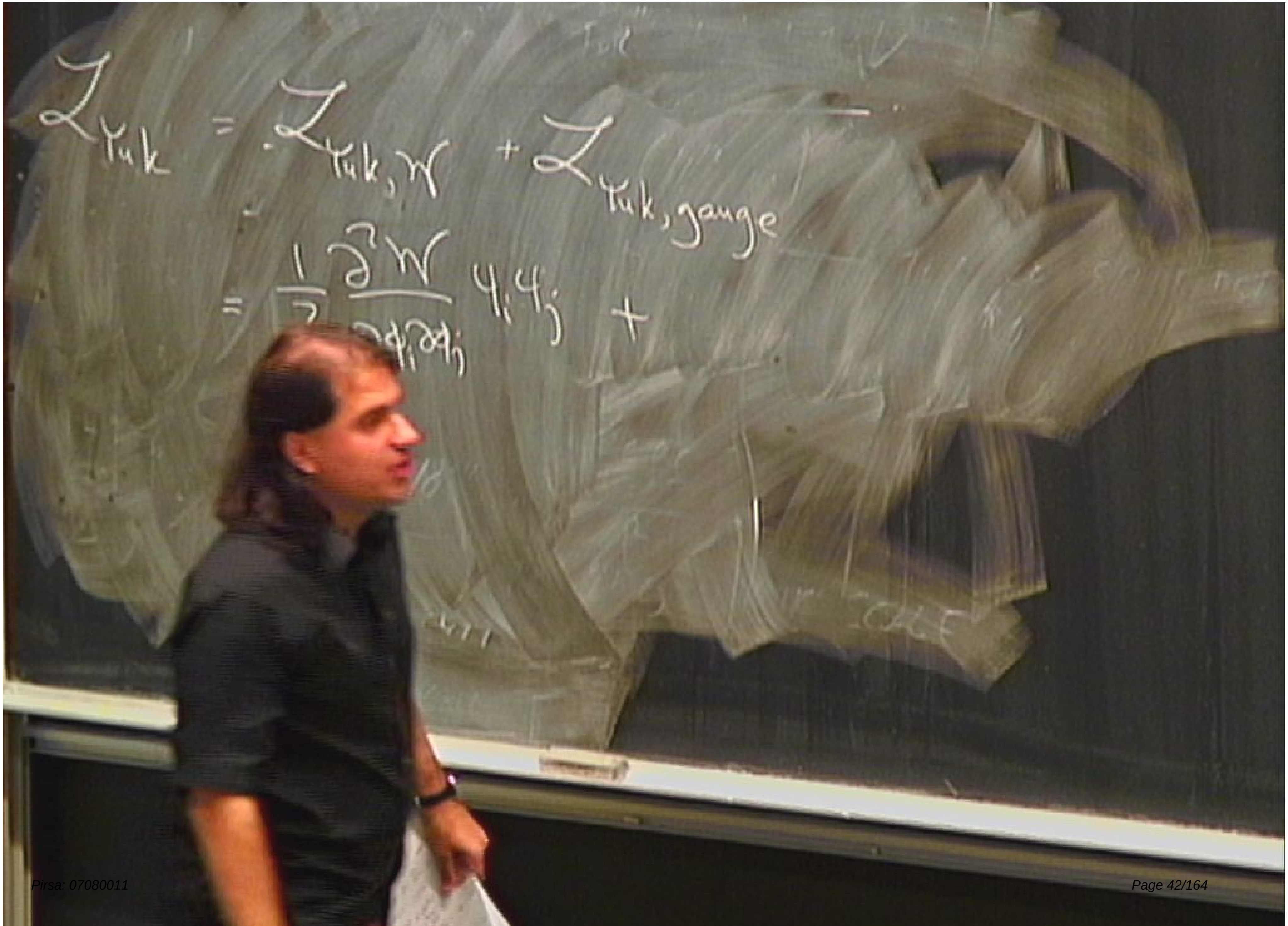

∫d⁴θ φ† e^V φ
V → V − iα + iα†
φ → e^{iα} φ
φ† → e^{−iα†} φ†
V = C(x) + θξ(x) + θ²B(x)
+ θ̄ξ̄(x) + θ̄²B†(x)
+ θσ^μθ̄ A_μ(x)
+ h.c.
+ ½ θ²θ̄² D


$\mathcal{L} = \int d^4\theta \, \phi^\dagger e^{V^a T^a} \phi + \int d^2\theta \, \frac{1}{g^2} S W_\alpha^a W^{\alpha a}$
$+ \int d^2\theta \, W(\varphi)$

$$\mathcal{L} = \int d^4\theta \, \phi^\dagger e^{V^a T^a} \phi + \int d^2\theta \, \frac{1}{g^2} S \, W_\alpha^a W^{\alpha a}$$

$$+ \int d^2\theta \, W(\phi)$$

$$\mathcal{L} = \mathcal{L}_{\substack{\text{Gauge} \\ \text{kin}}} + \mathcal{L}_{\text{Yuk}} - V(\phi)$$



$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,W} + \mathcal{L}_{Yuk,gauge}$
$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i\partial\phi_j}\psi_i\psi_j +$

$$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,W} + \mathcal{L}_{Yuk,gauge}$$

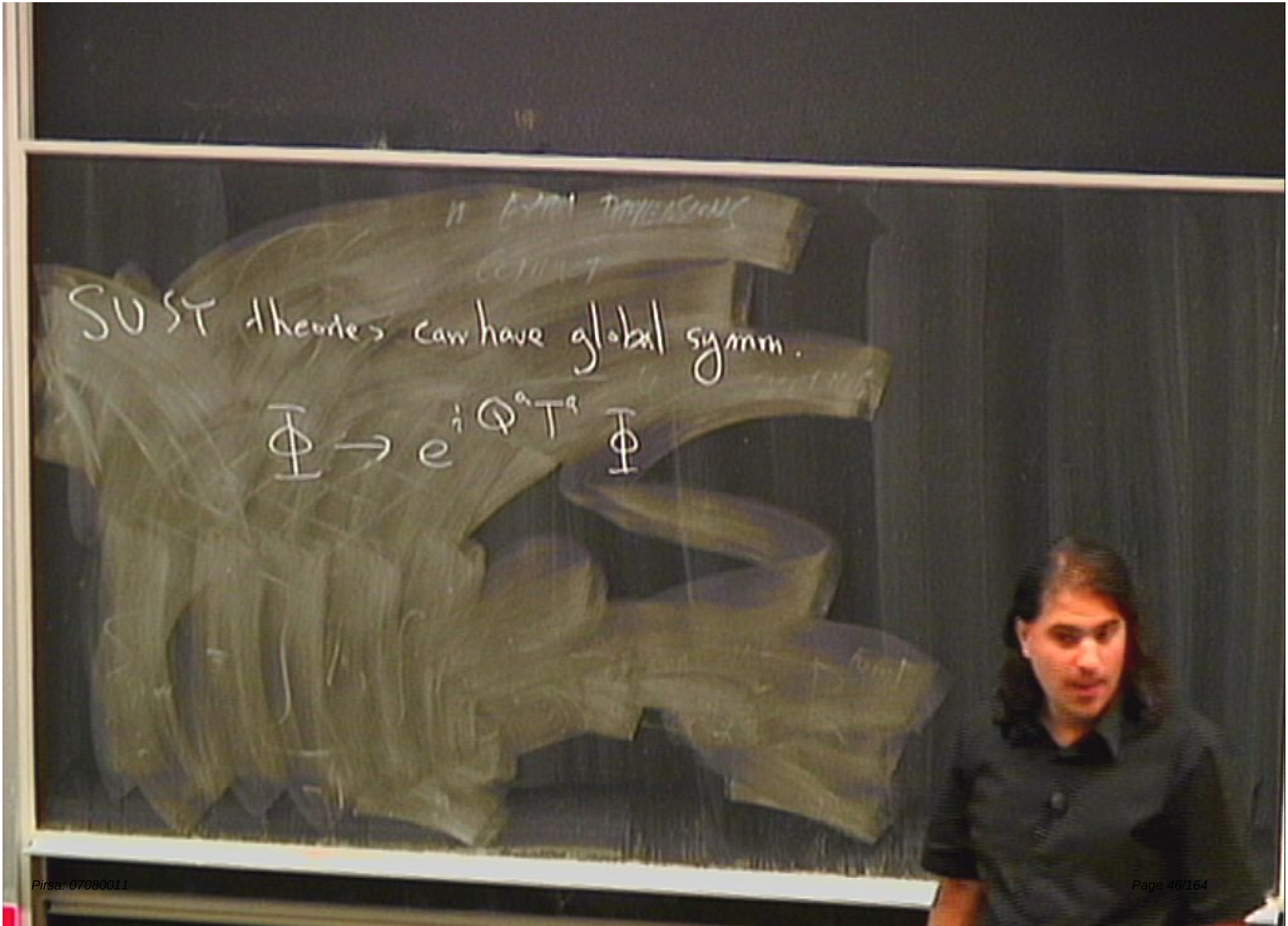
$$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i\partial\phi_j}\psi_i\psi_j +$$

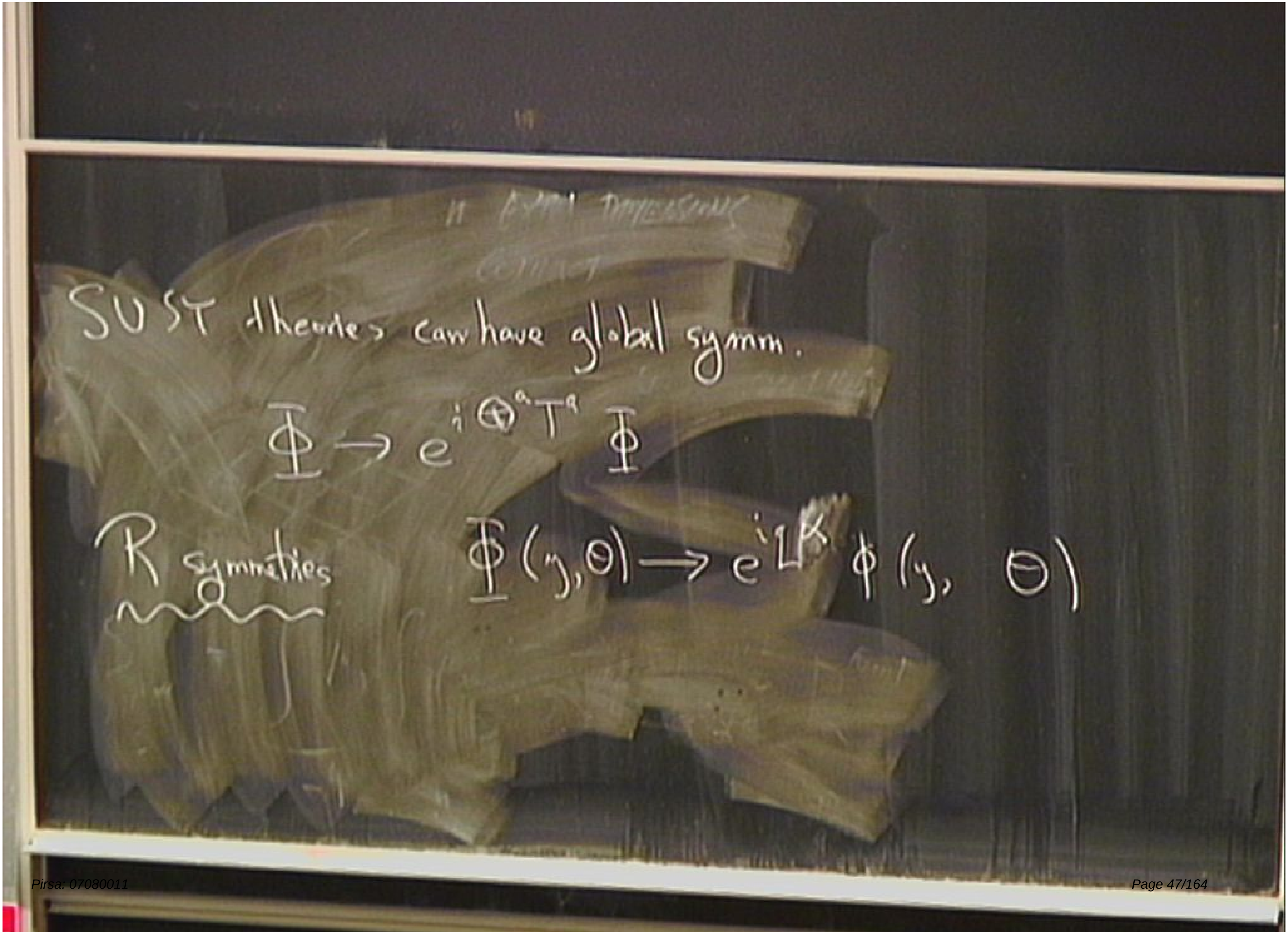
$$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,W} + \mathcal{L}_{Yuk,gauge}$$

$$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i \partial\phi_j}\psi_i\psi_j + \sqrt{2}\, g\, \lambda^a \phi^\dagger T^a \psi + h.c.$$

$$\mathcal{L} = \int d^4\theta \, \phi^\dagger e^{V^a T^a} \phi + \int d^2\theta \, \frac{1}{2} S \, W_\alpha^a W^{\alpha a} + \int d^2\theta \, W(\phi)$$

$$\mathcal{L} = \mathcal{L}_{kin}^{gauge} + \mathcal{L}_{Yuk} - V(\phi)$$


SUSY theories can have global symm.
$\Phi \to e^{i Q^a T^a} \Phi$


SUSY theories can have global symm.
$\Phi \to e^{i\Theta^a T^a}\,\Phi$
R symmetries
$\Phi(y,\theta) \to e^{iLK}\,\phi(y,\ \theta)$

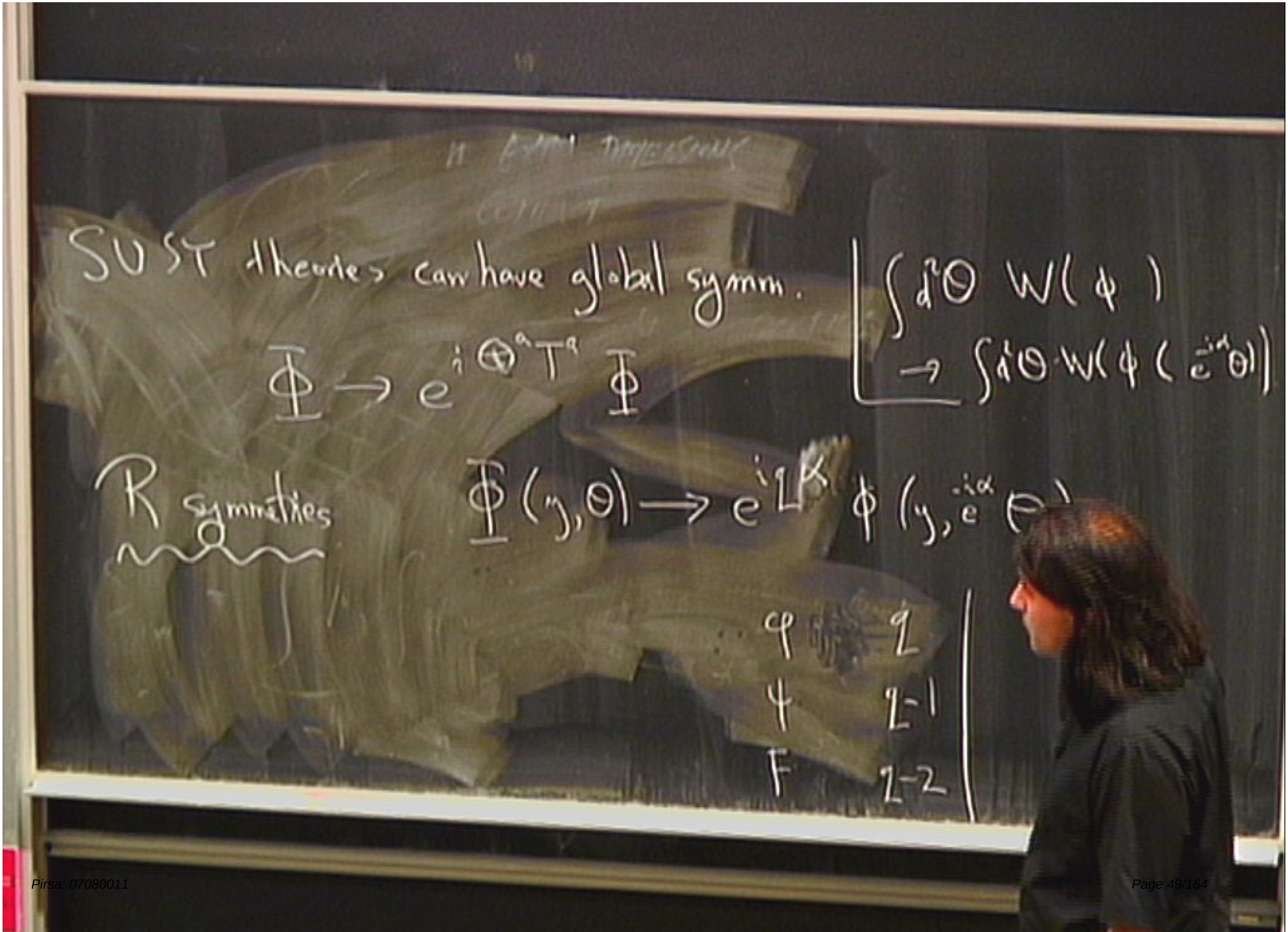
SUSY theories can have global symm.

$$\Phi \to e^{i\Theta^a T^a}\,\Phi$$

R symmetries

$$\Phi(y,\theta) \to e^{i2\alpha}\,\phi(y, e^{-i\alpha}\theta)$$

φ	z
ψ	z^{-1}
F	z^{-2}


SUSY theories can have global symm.
Φ → e^{iΘ^a T^a} Φ
R symmetries
Φ(y,θ) → e^{i2K} φ(y, e^{-iα} θ)
∫d²θ W(φ)
→ ∫d²θ W(φ(e^{-iα}θ))
φ 2
ψ 2-1
F 2-2

SUSY theories can have global symm.

$$\Phi \to e^{i\Theta^a T^a}\,\Phi$$

R symmetries

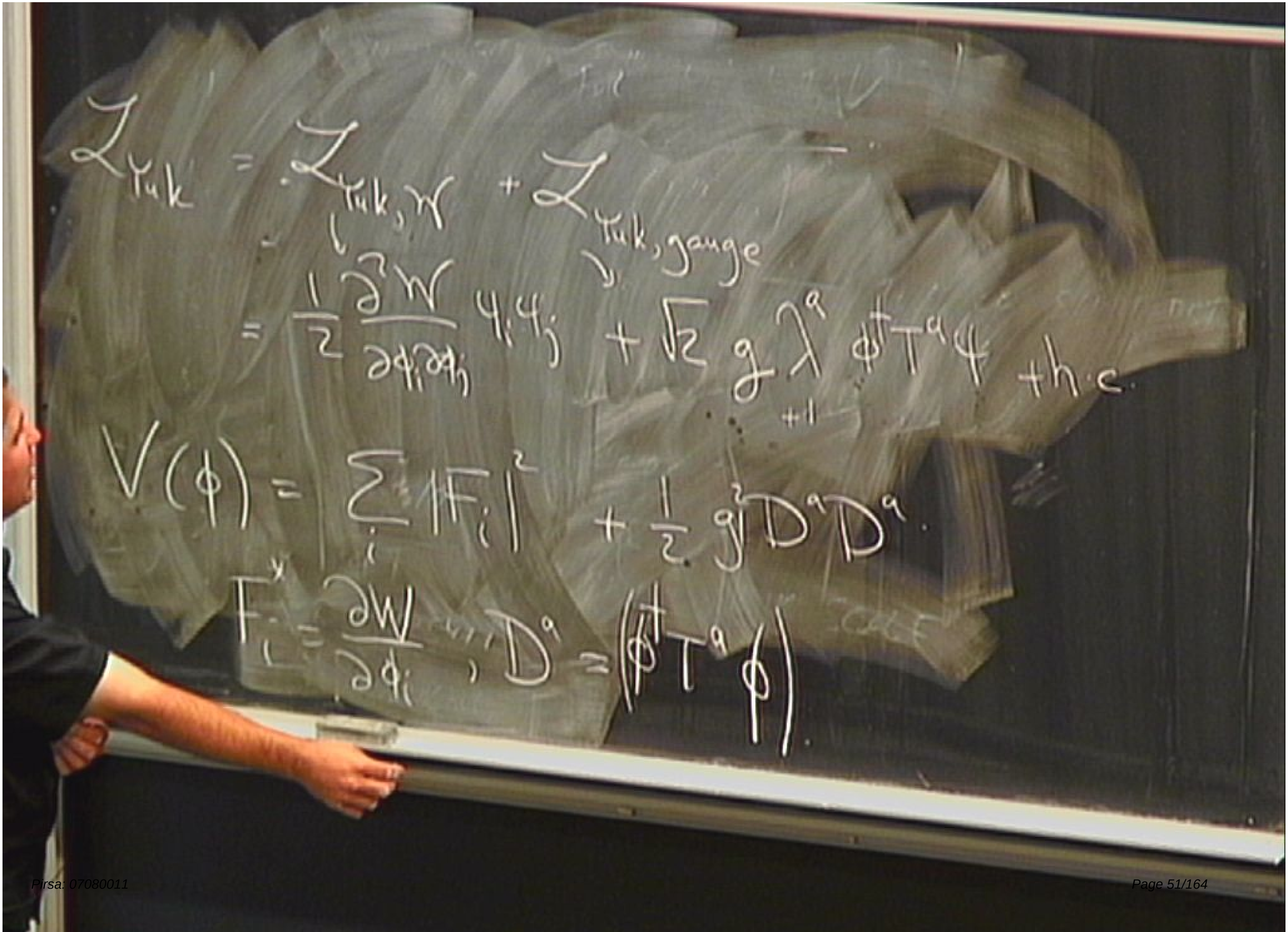
$$\Phi(y,\theta) \to e^{i2K}\,\phi(y, e^{-i\alpha}\theta)$$

ϕ	2
ψ	$2-1$
F	$2-2$

$$\int d^2\theta\, W_\alpha^2$$

$$\int d^2\theta\, W(\phi)$$

$$\to \int d^2\theta\, W(\phi(e^{-i\alpha}\theta))$$


$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,\psi} + \mathcal{L}_{Yuk,gauge}$
$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i\partial\phi_j}\psi_i\psi_j + \sqrt{2}\, g \lambda^a \phi^\dagger T^a \psi + h.c.$
$V(\phi) = \sum_i |F_i|^2 + \frac{1}{2} g^2 D^a D^a$
$F_i^* = \frac{\partial W}{\partial \phi_i}, \quad D^a = (\phi^\dagger T^a \phi)$

$$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,W} + \mathcal{L}_{Yuk,gauge}$$

$$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i\,\partial\phi_j}\psi_i\psi_j + \sqrt{2}\, g\, \lambda^a\, \phi^\dagger T^a \psi + h.c.$$

+1 −2 2−1

$$V(\phi) = \sum_i |F_i|^2 + \frac{1}{2} g^2 D^a D^a$$

$$F_i^* = \frac{\partial W}{\partial \phi_i}, \quad D^a = (\phi^\dagger T^a \phi)$$

$$\mathcal{L}_{Yuk} = \mathcal{L}_{Yuk,W} + \mathcal{L}_{Yuk,gauge}$$

$$= \frac{1}{2}\frac{\partial^2 W}{\partial\phi_i \partial\phi_j}\psi_i\psi_j + \sqrt{2}\, g\, \lambda^a \phi^\dagger T^a \psi + h.c.$$

$$V(\phi) = \sum_i |F_i|^2 + \frac{1}{2} g^2 D^a D^a$$

$$F_i = \frac{\partial W}{\partial \phi_i}, \quad D^a = \left(\phi^\dagger T^a \phi\right)$$

SUSY theories can have global symm.

$$\Phi \to e^{i\Theta^a T^a}\,\Phi$$

$$\int d^2\theta\, W^a_\alpha$$

$$\int d^2\theta\, W(\phi)$$

$$\to \int d^2\theta\, W(\phi(e^{-i\alpha}\theta))$$

R symmetries

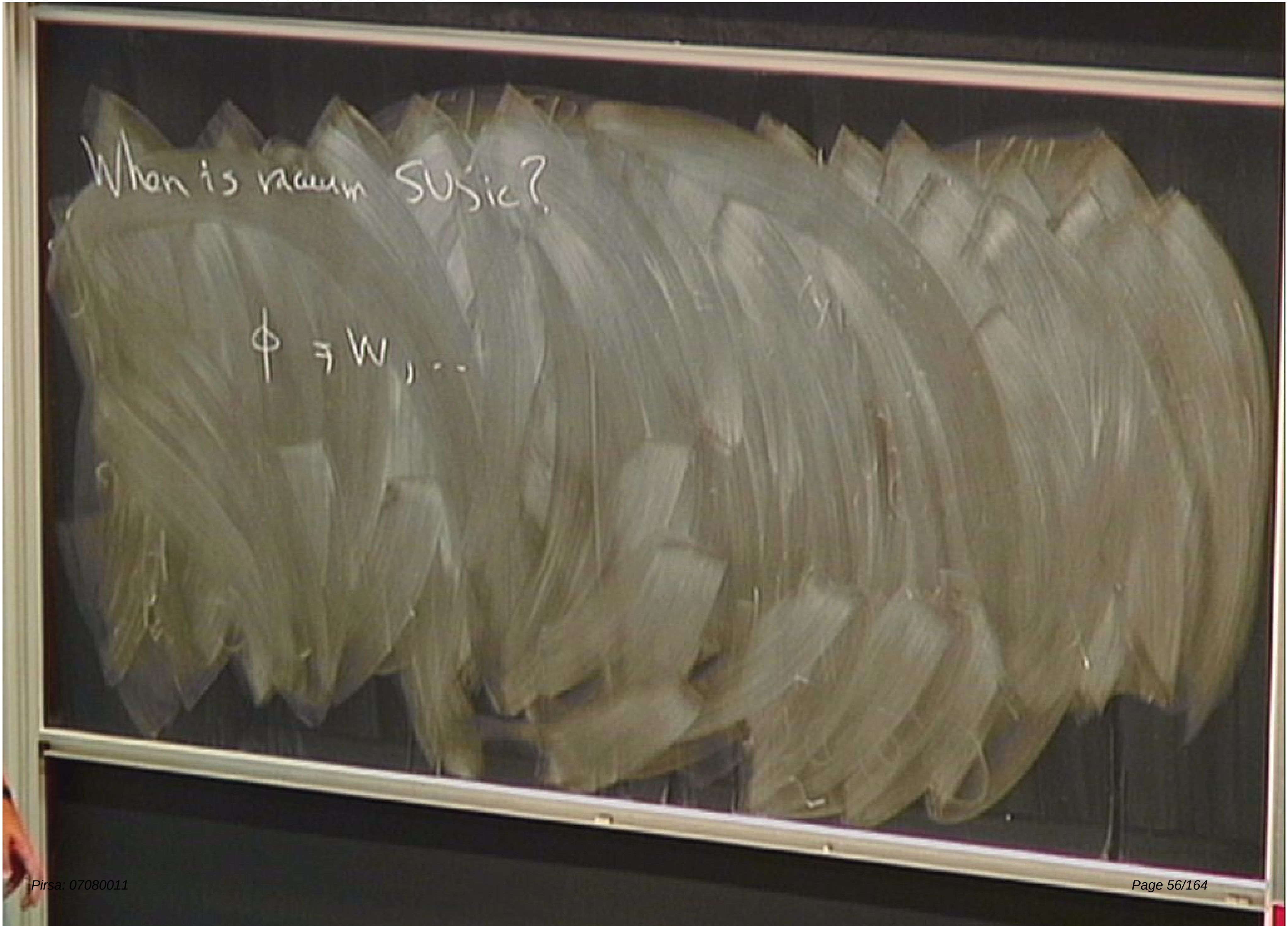
$$\Phi(y,\theta) \to e^{iq\alpha}\,\phi(y, e^{-i\alpha}\theta)$$

φ_i	q_i
ψ_i	$q_i - 1$
λ	1

W charge 2

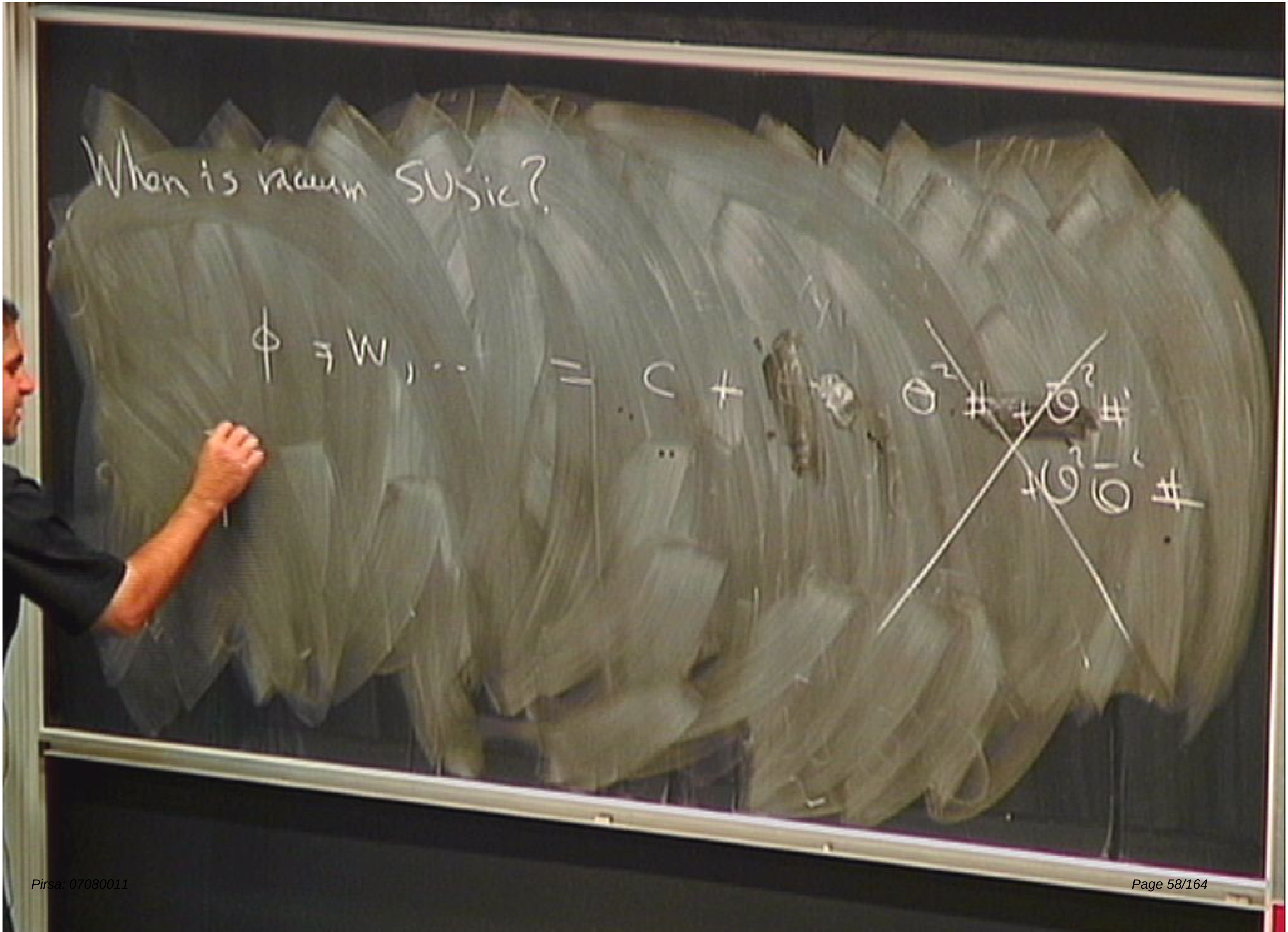
φ	q
ψ	$q-1$
F	$q-2$


When is vacuum SUSic?


When is vacuum SUSic?
ϕ ∃ W, ...

When is vacuum SUSic?

$$\phi, W, \ldots = c + \ldots \theta^2 \# + \bar{\theta}^2 \# + \theta^2 \bar{\theta}^2 \#$$

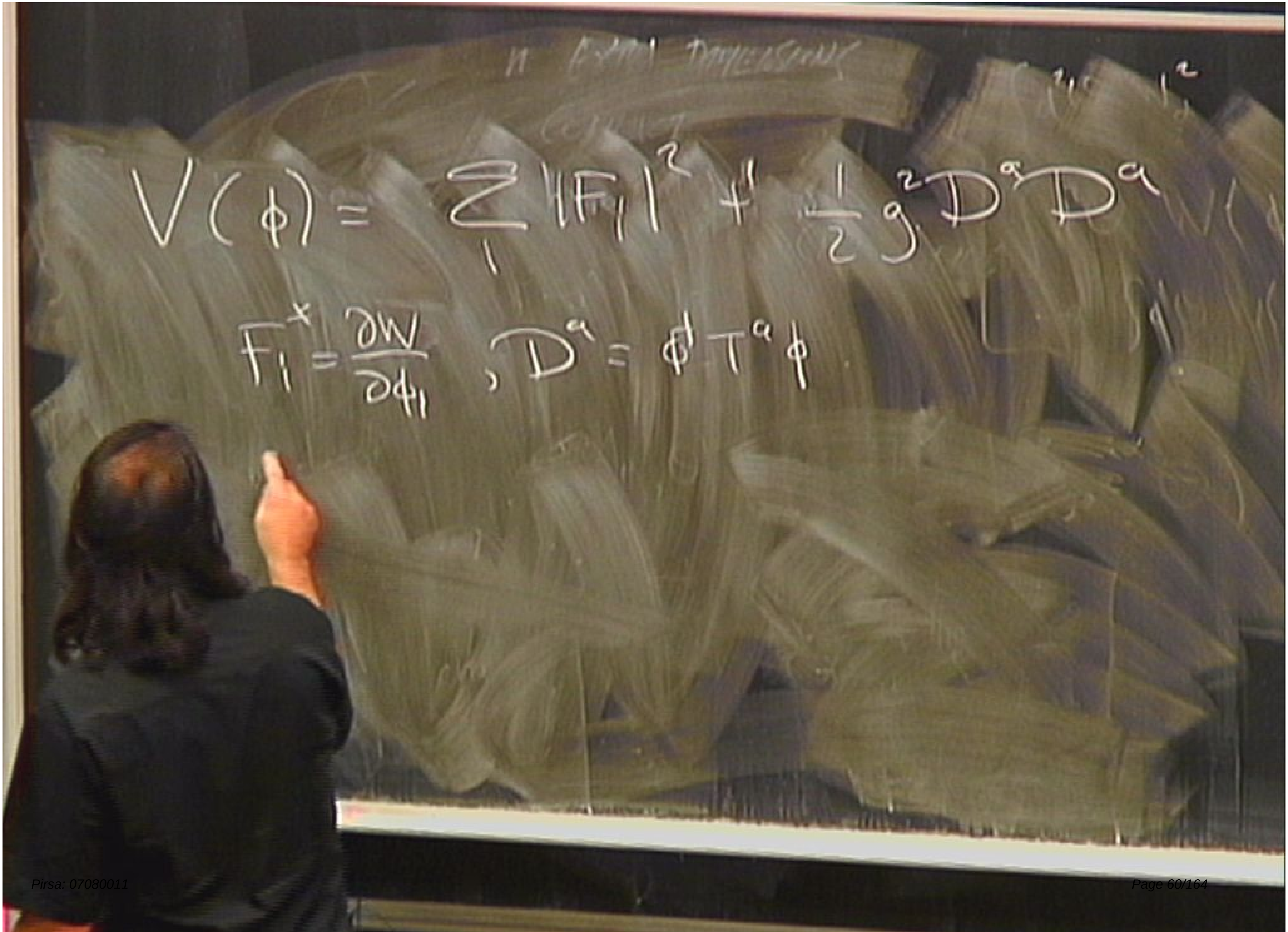

When is vacuum SUSic?

When is vacuum SUSic?

$\Phi \ni W, \ldots = c + \ldots \theta^2 \# + \bar{\theta}^2 \# + \theta^2 \bar{\theta}^2 \#$

$\Phi = \ldots + \theta^2 F$

$V = \ldots \theta^2 \bar{\theta}^2 D$ | SUSY $\Rightarrow F_i, D^a = 0$


V(ϕ) = Σ_i |F_i|^2 + 1/2 g^2 D^a D^a
F_i^* = ∂W/∂ϕ_i , D^a = ϕ† T^a ϕ

$$V(\phi) = \sum_i |F_i|^2 + \frac{1}{2} g^2 D^a D^a$$

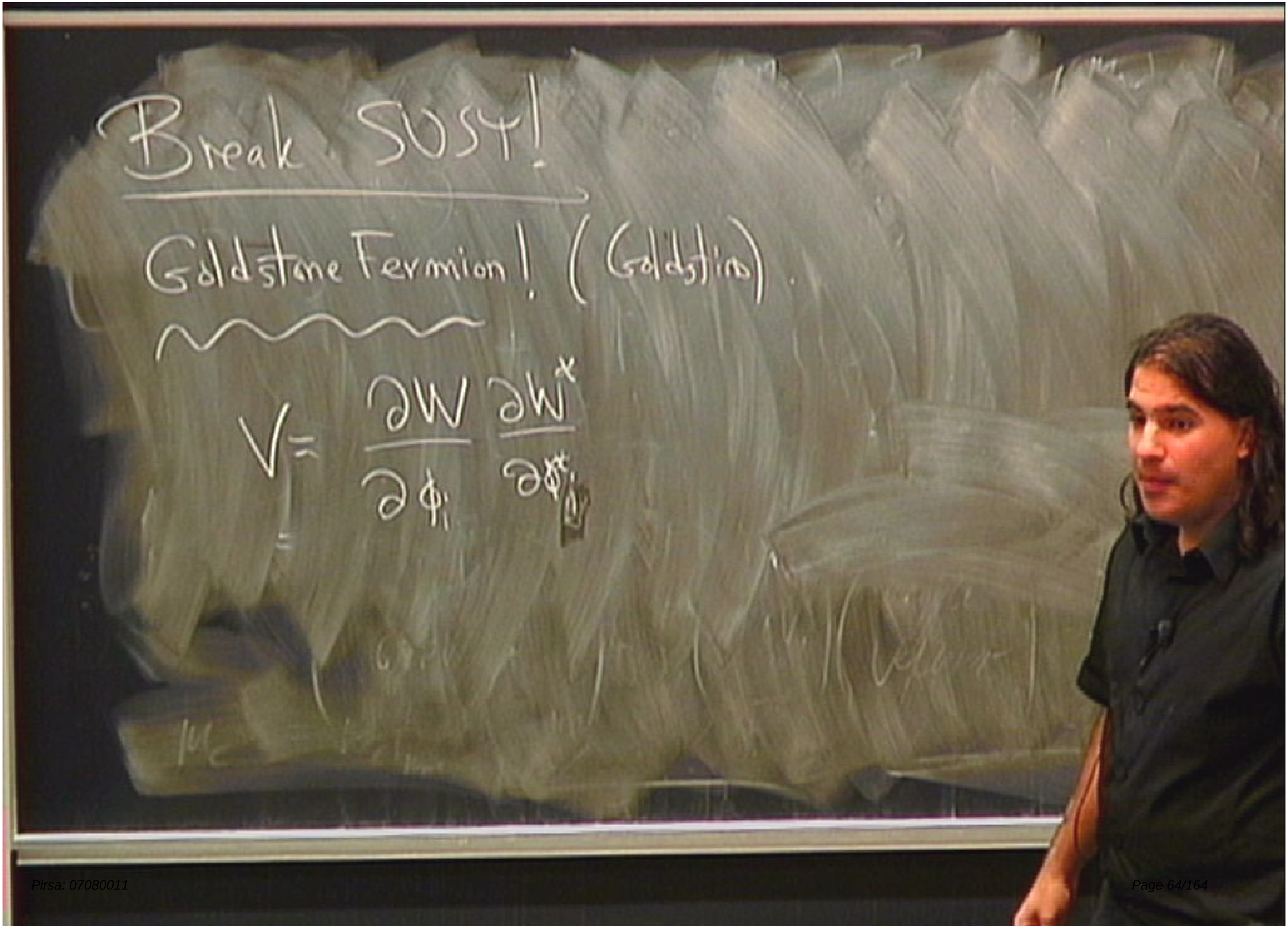
$$F_i^* = \frac{\partial W}{\partial \phi_i}\ , \quad D^a = \phi^\dagger T^a \phi$$

$$\text{SUSY} \Longleftrightarrow V = 0$$

Break SUSY!

Break SUSY!

Goldstone Fermion! (Goldstino).


Break SUSY!
Goldstone Fermion! (Goldstino)
$V = \frac{\partial W}{\partial \phi_i} \frac{\partial W^*}{\partial \phi^*_i}$

Break SUSY!

Goldstone Fermion! (Goldstino)

$$V = \frac{\partial W}{\partial \phi_i} \frac{\partial W^*}{\partial \phi_i^*}$$

$$\frac{\partial V}{\partial \phi_j} = 0 \Rightarrow \frac{\partial^2 W}{\partial \phi_i \partial \phi_j} \frac{\partial W^*}{\partial \phi_i^*} =$$

Break SUSY!

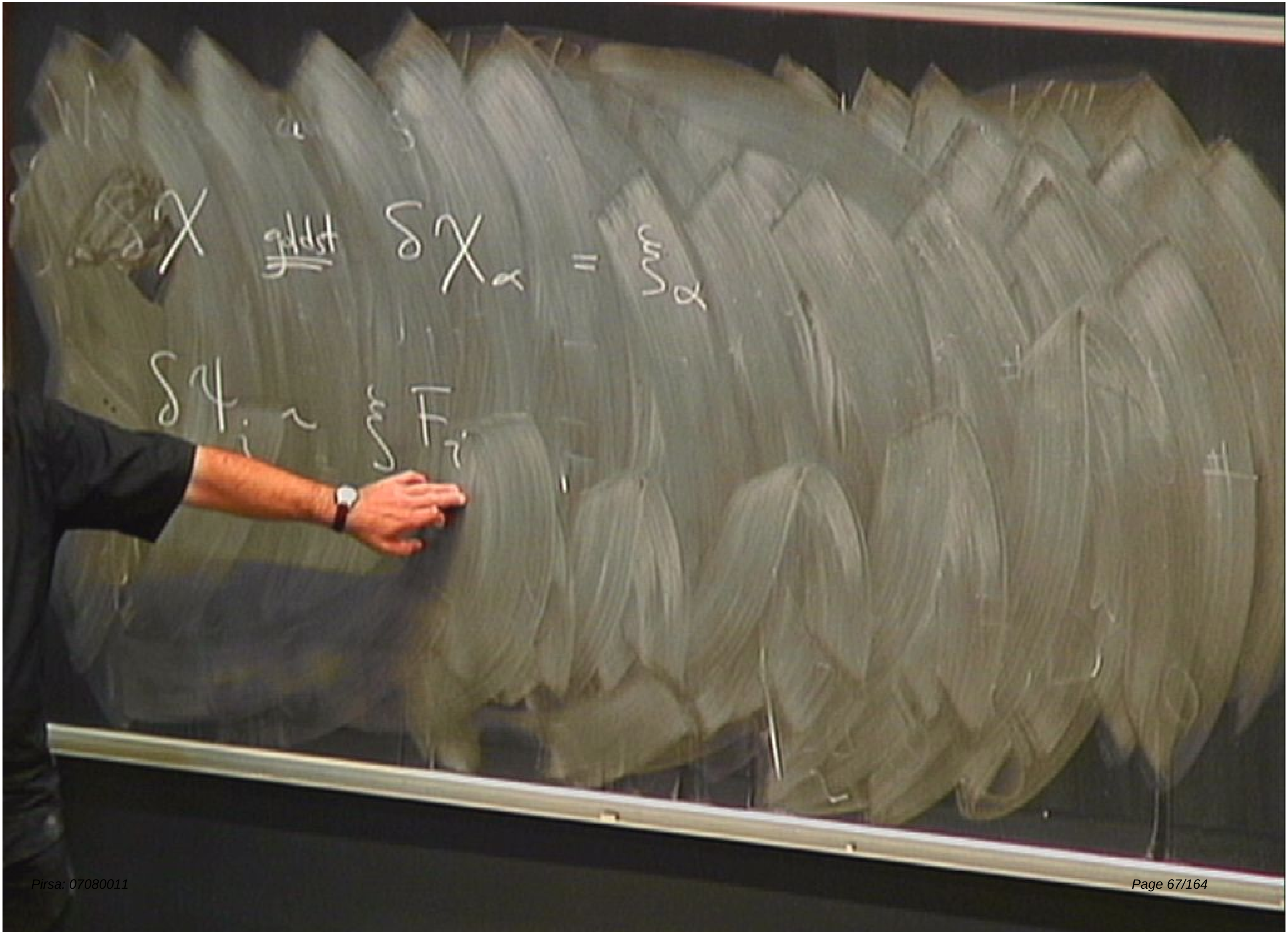
Goldstone Fermion! (Goldstino)

$$F_i = \frac{\partial W^*}{\partial \phi^*_i}$$

$$V = \frac{\partial W}{\partial \phi_i}\frac{\partial W^*}{\partial \phi^*_i}$$

$$\frac{\partial V}{\partial \phi_j} = 0 \rightarrow \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}\frac{\partial W^*}{\partial \phi^*_i} = 0$$

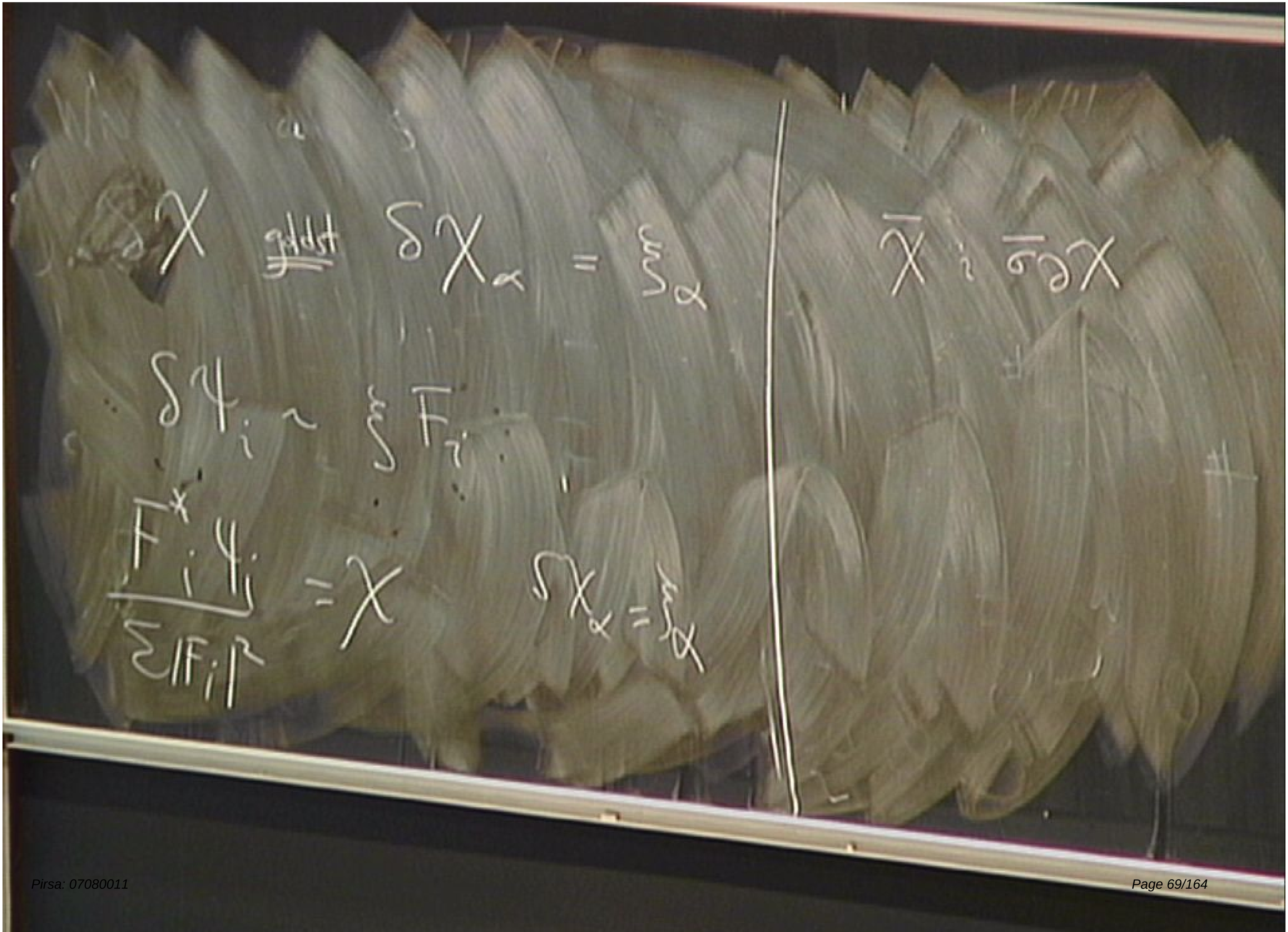
$$\therefore \frac{\partial^2 W}{\partial \phi_j \partial \phi_i} F_i = 0$$



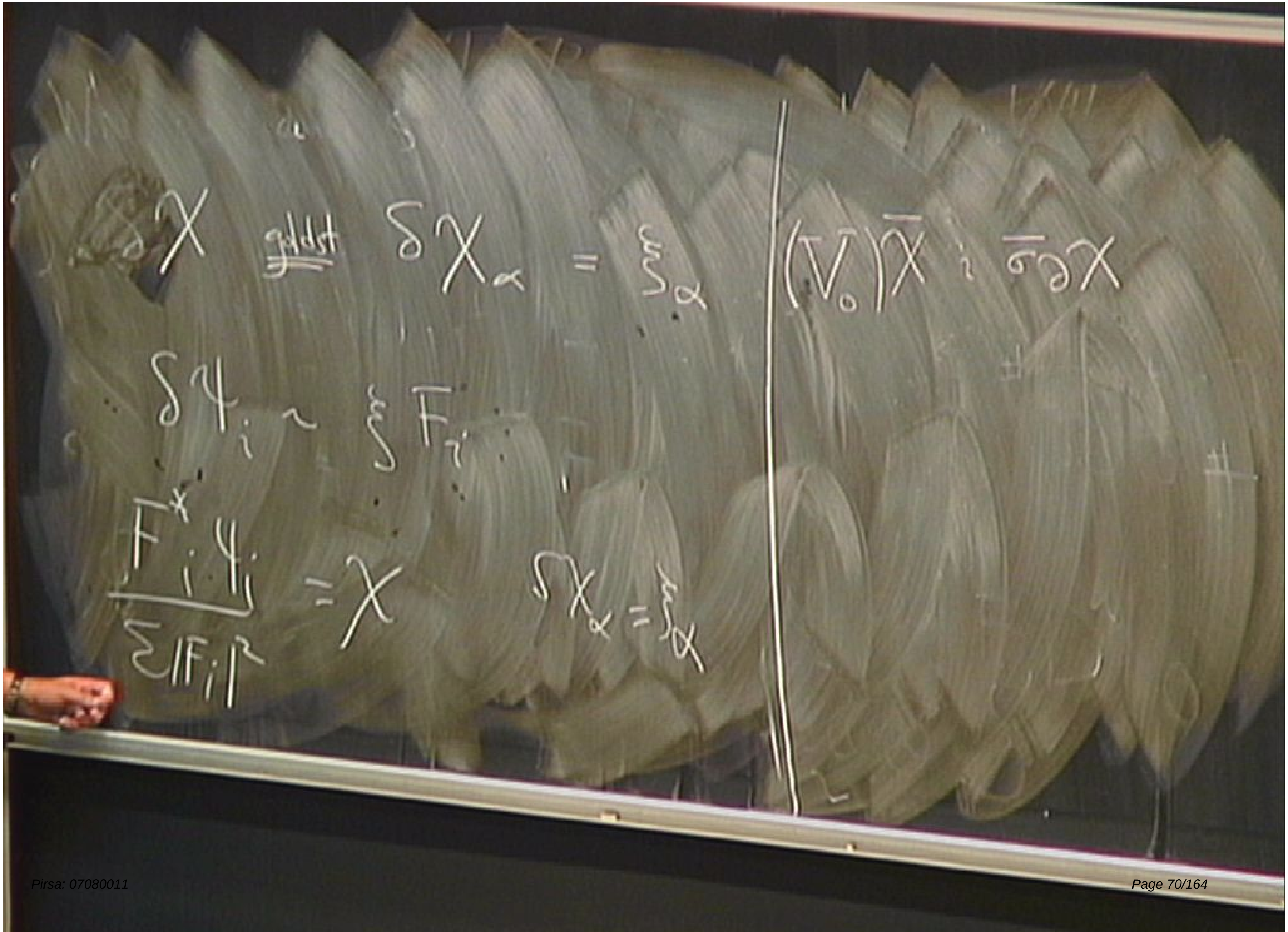
$\delta\chi$ gldst $\delta\chi_\alpha = \xi_\alpha$

$\delta\psi_i \sim \xi F_i$

$F^*_i \psi_i$



δψ_i ~ ε F_i
Σ|F_i|^2

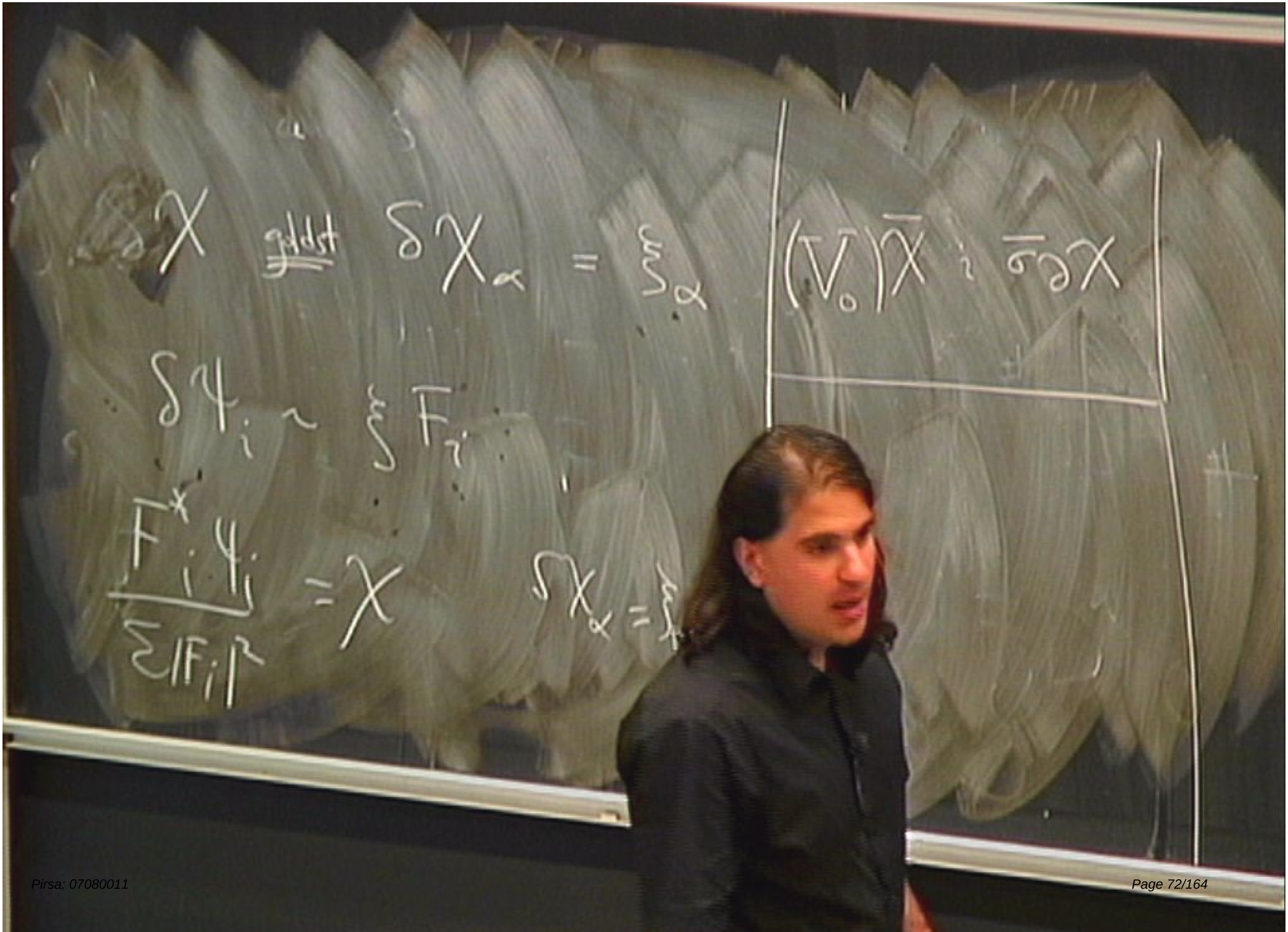


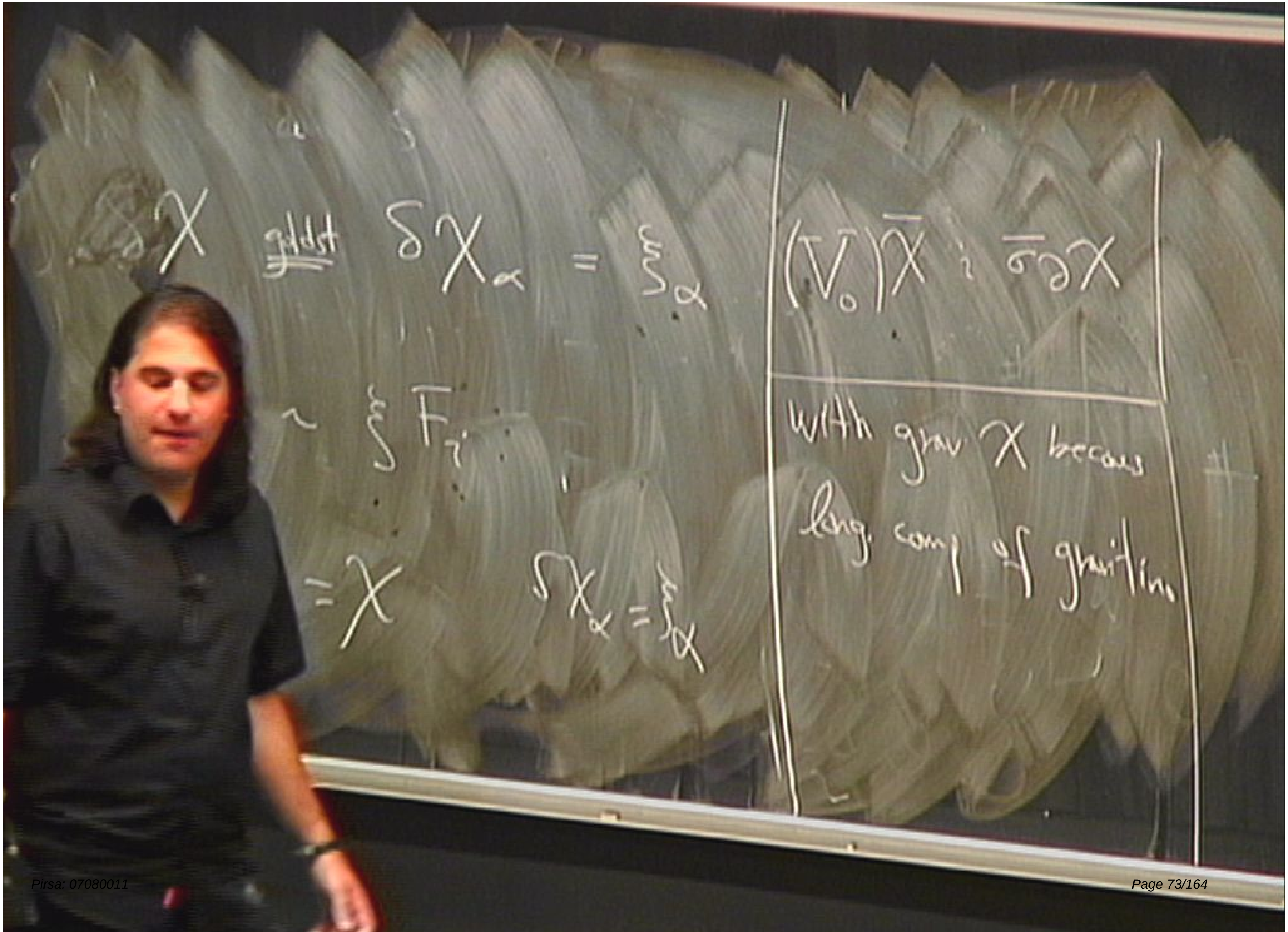
χ goldst $\quad \delta\chi_\alpha = \xi_\alpha$

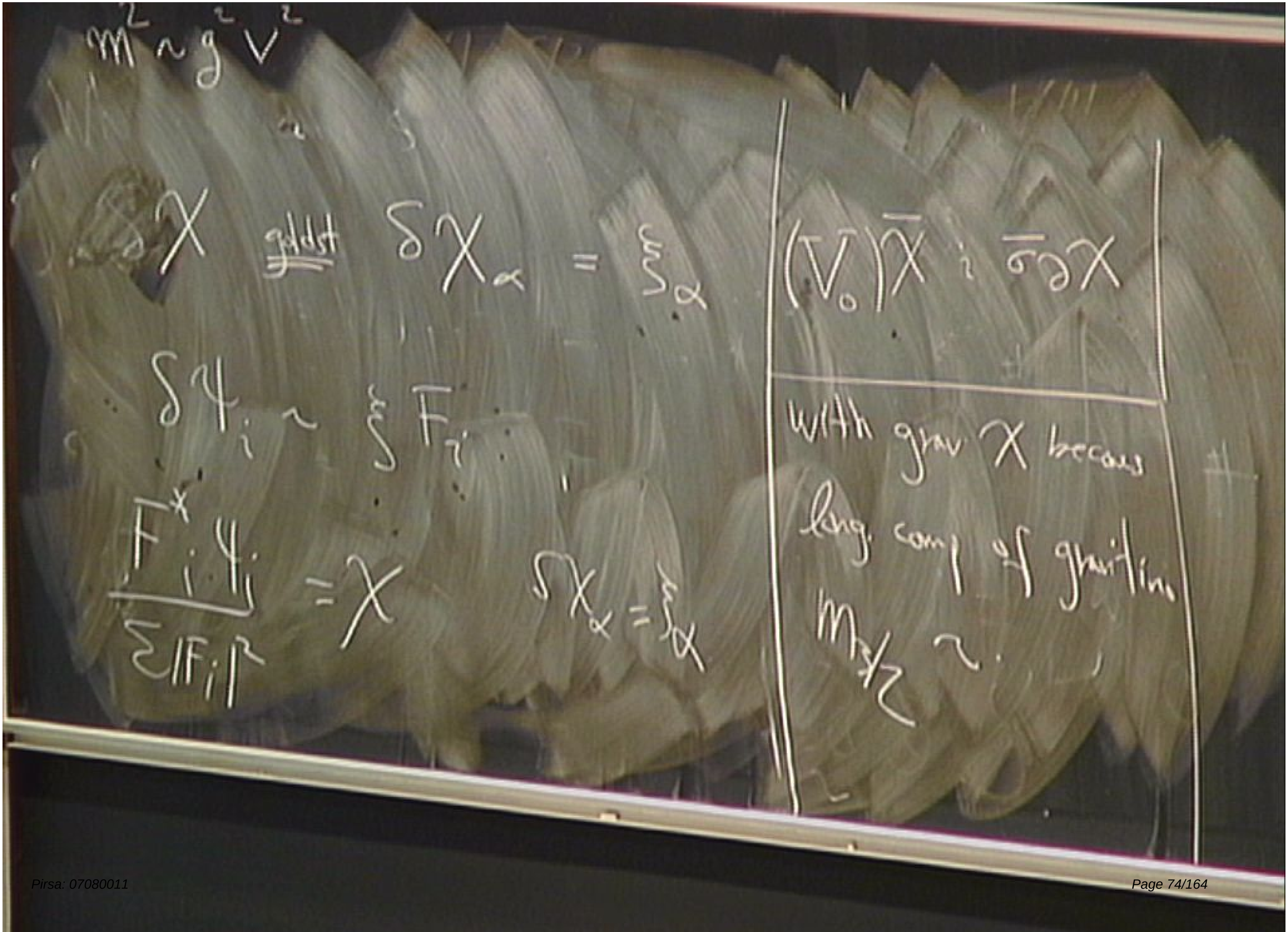
$(V_0)\,\bar\chi\, i\,\bar\sigma\partial\chi$

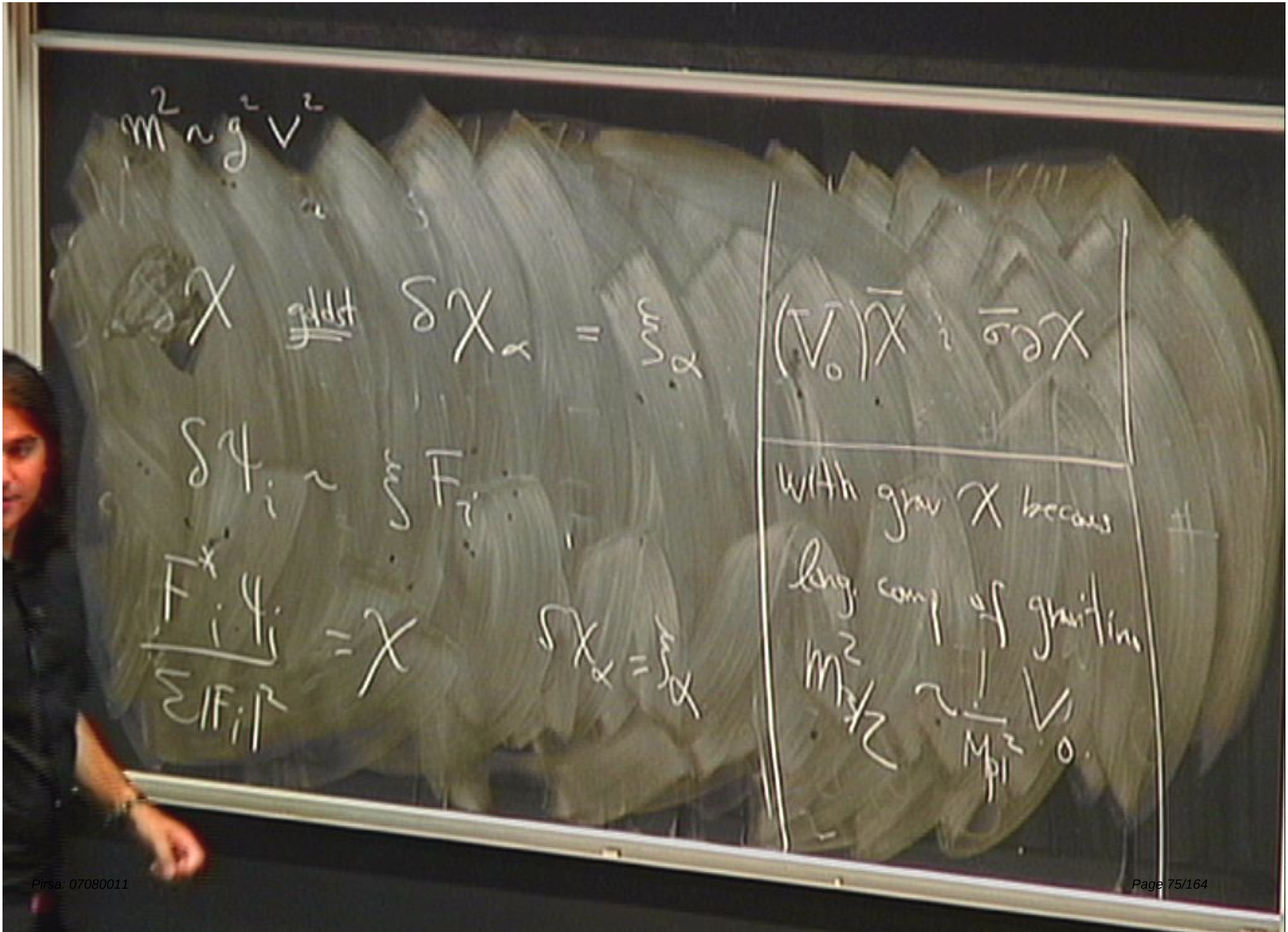
$\delta\psi_i \sim \xi F_i$

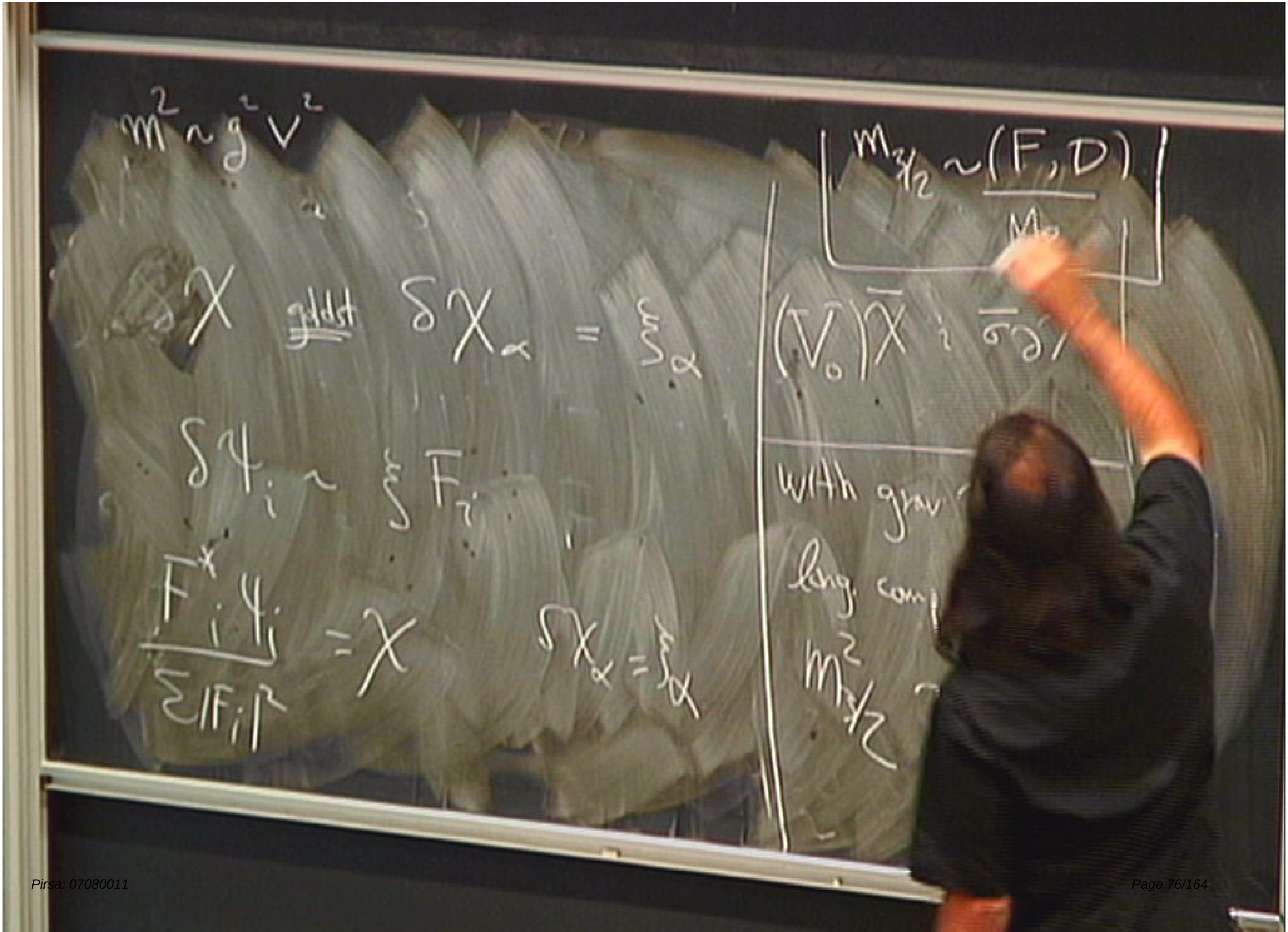
$\dfrac{F_i^* \psi_i}{\sum |F_i|^2} = \chi \qquad \delta\chi_\alpha = \xi_\alpha$




with grav χ becomes
long. comp of gravitino


$m^2 \sim g^2 v^2$
$\delta\chi$ goldst $\delta\chi_\alpha = \xi_\alpha$
$(V_0)\,\bar{\chi}\, i\, \bar{\sigma}\partial\chi$
$\delta\psi_i \sim \xi F_i$
$\frac{F_i^* \psi_i}{\Sigma|F_i|^2} = \chi$
$\delta\chi_\alpha = \xi_\alpha$
with grav χ becomes
long. comp of gravitino
$m_{3/2} \sim$


m² ~ g² V²
χ goldst δχ_α = ξ_α
δψ_i ~ ξ F_i
F_i* ψ_i / Σ|F_i|² = χ
δχ_α = ξ_α
(V_0) χ̄ σ̄ ∂ χ
With grav χ becomes
long. comp of gravitino
m_3/2² ~ 1/M_pl² V_0


m² ~ g²v²
m3/2 ~ (F, D)/M
χ goldst δχα = ξα
δψi ~ ξ Fi
Fi* ψi / Σ|Fi|² = χ   δχα = ξα
with grav
long. comp
m²3/2

$m^2 \sim g^2 v^2$

$\delta\chi$ goldst $\delta\chi_\alpha = \xi_\alpha$

$\delta\psi_i \sim \xi F_i$

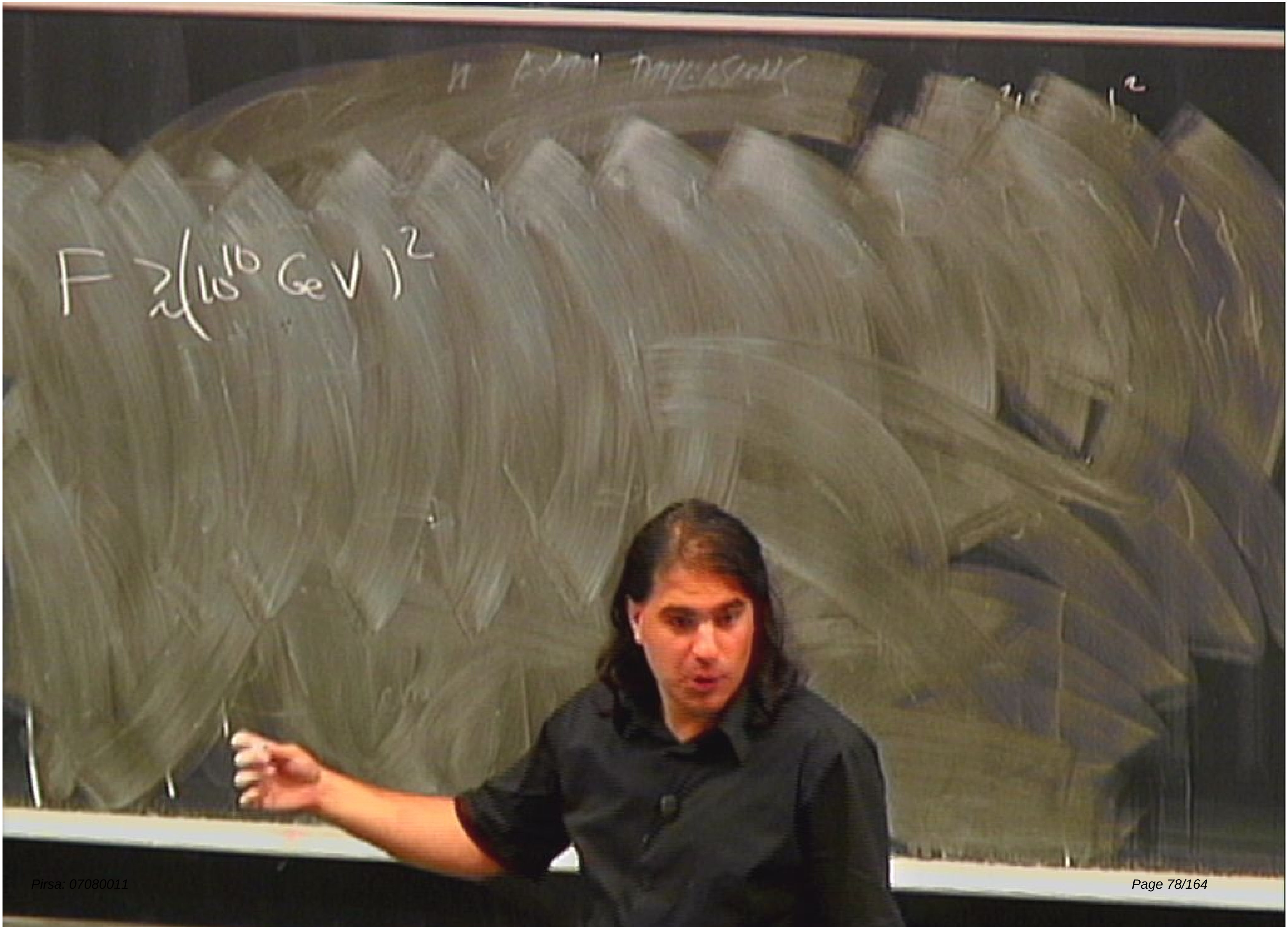
$\frac{F_i^* \psi_i}{\sum |F_i|^2} = \chi \qquad \delta\chi_\alpha = \xi_\alpha$

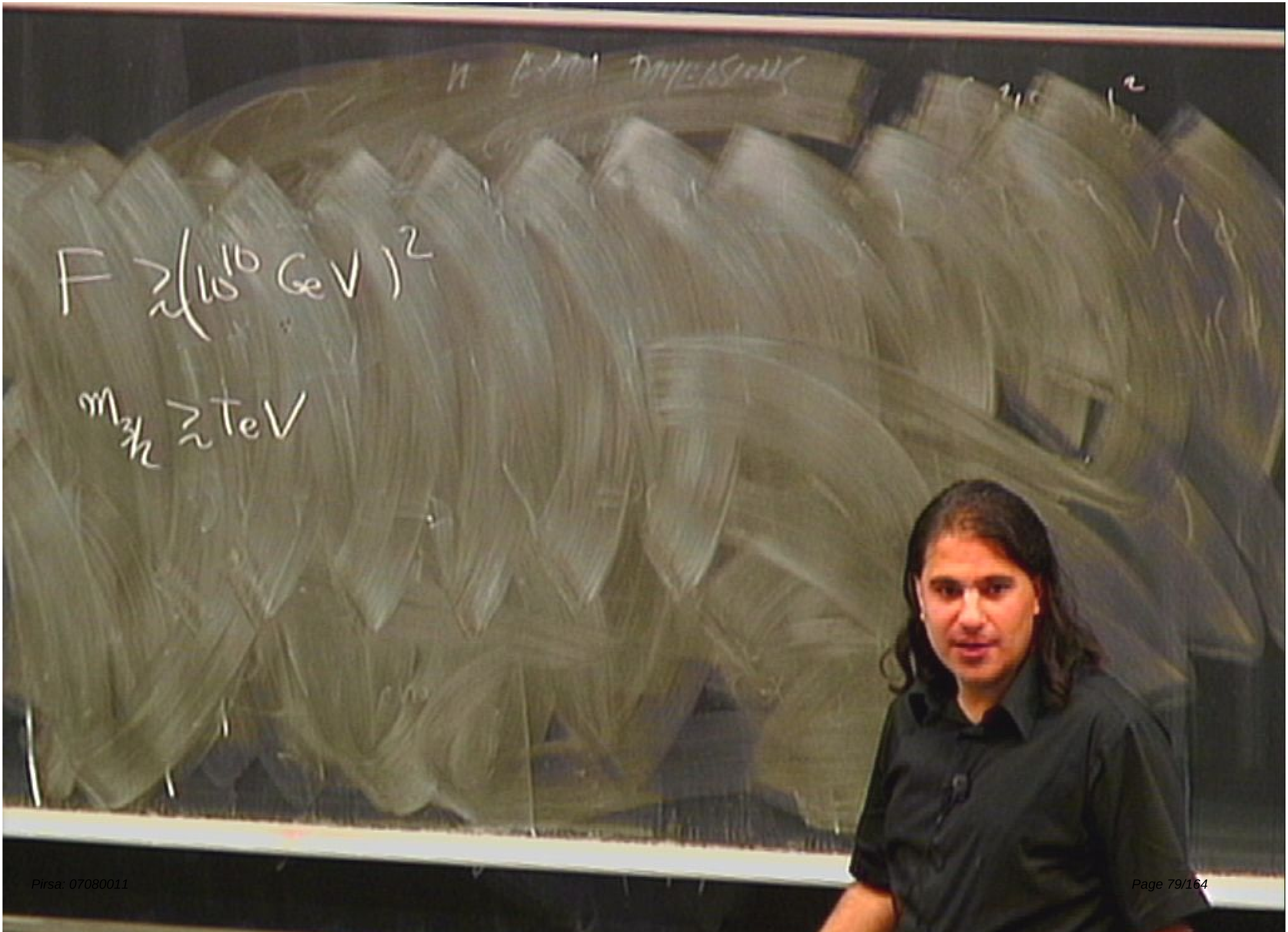
$m_{3/2} \sim \frac{(F, D)}{M_p}$

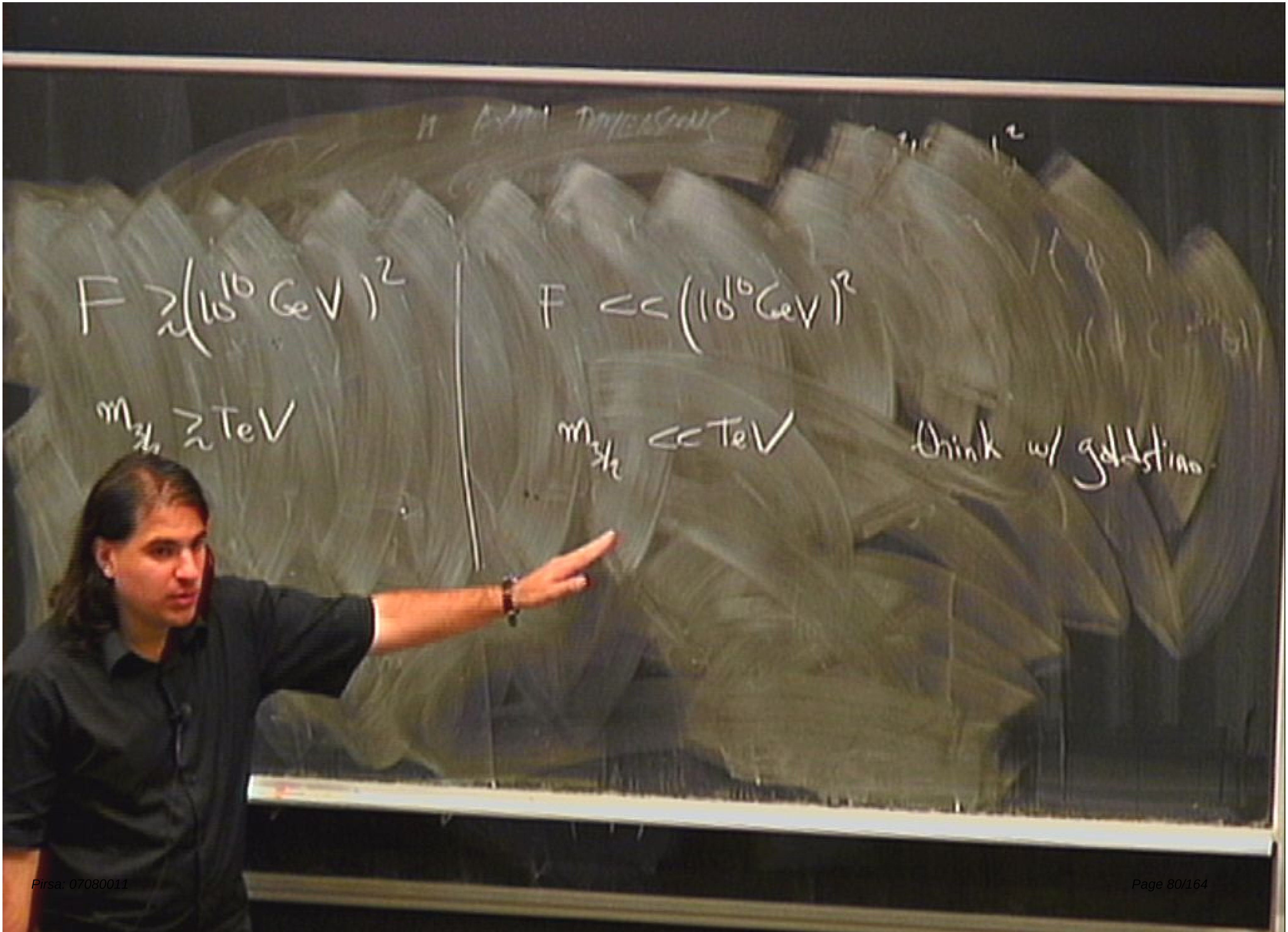
$(V_0)\bar{\chi}\ \bar{\sigma}\partial\chi$

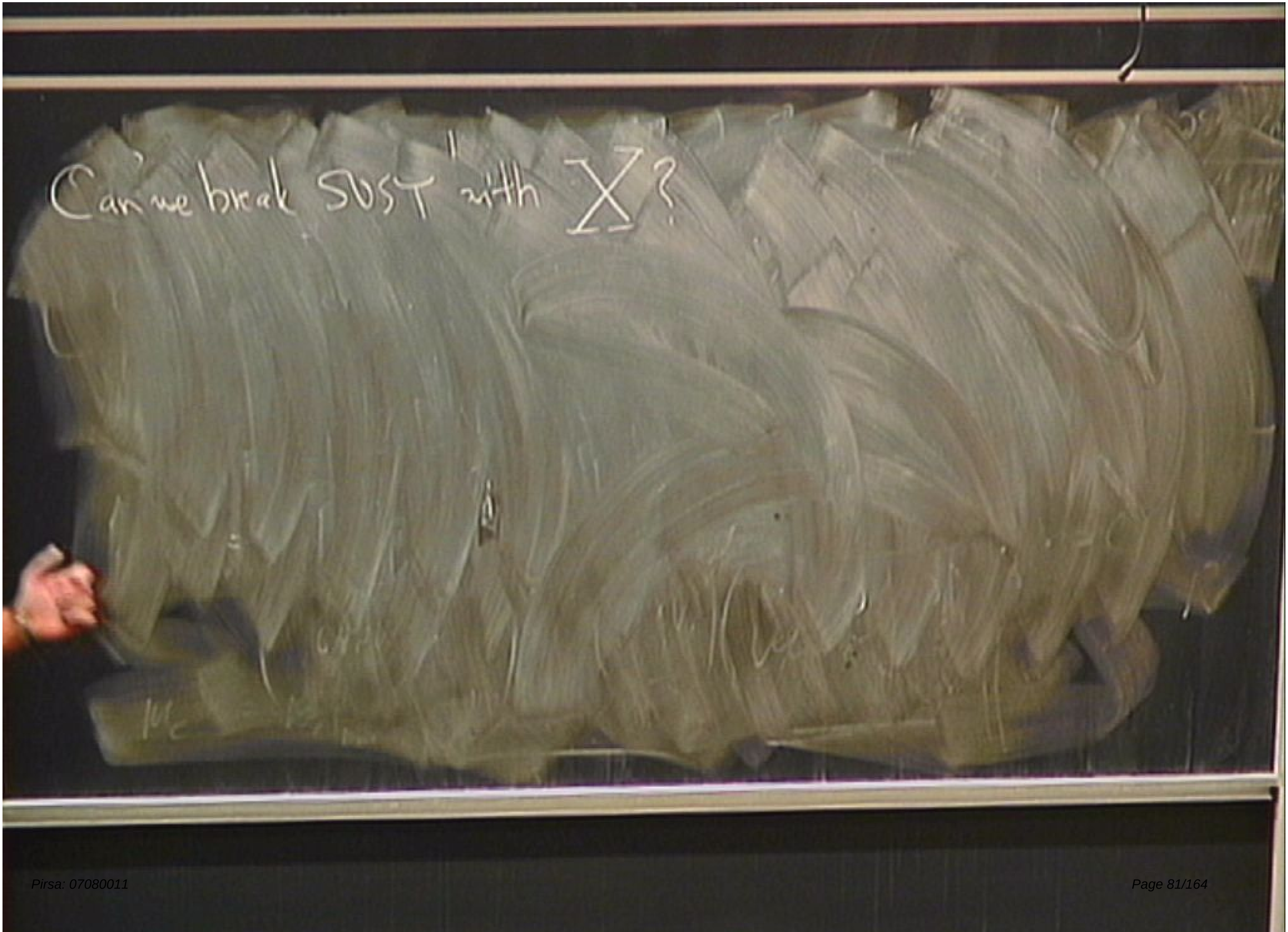
with grav χ becomes long. comp of gravitino

$m_{3/2}^2 \sim \frac{1}{M_{pl}^2} V_0$.


$F \gtrsim (10^{10}\,GeV)^2$

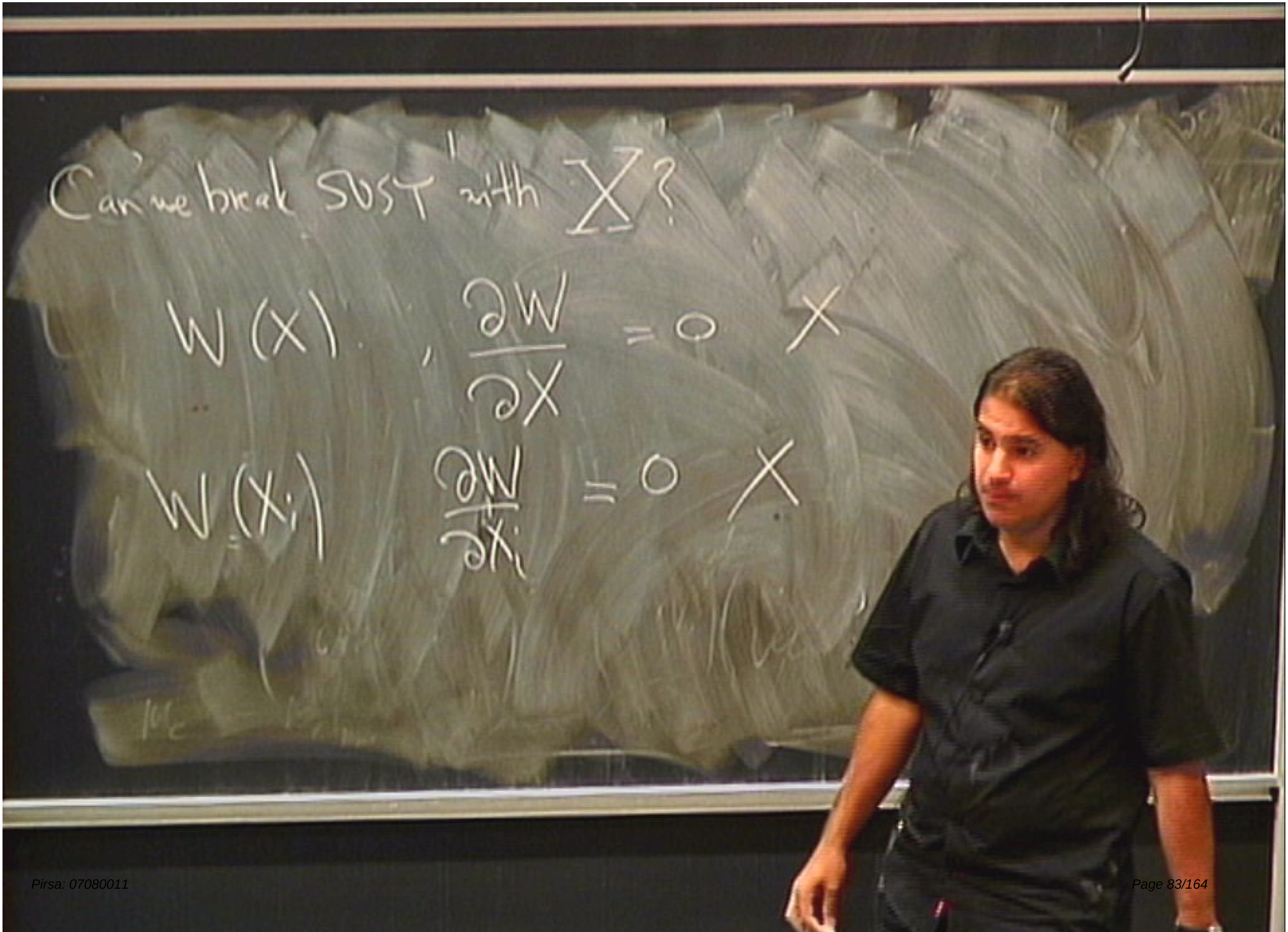

F ≳ (10^10 GeV)^2
m_3/2 ≳ TeV

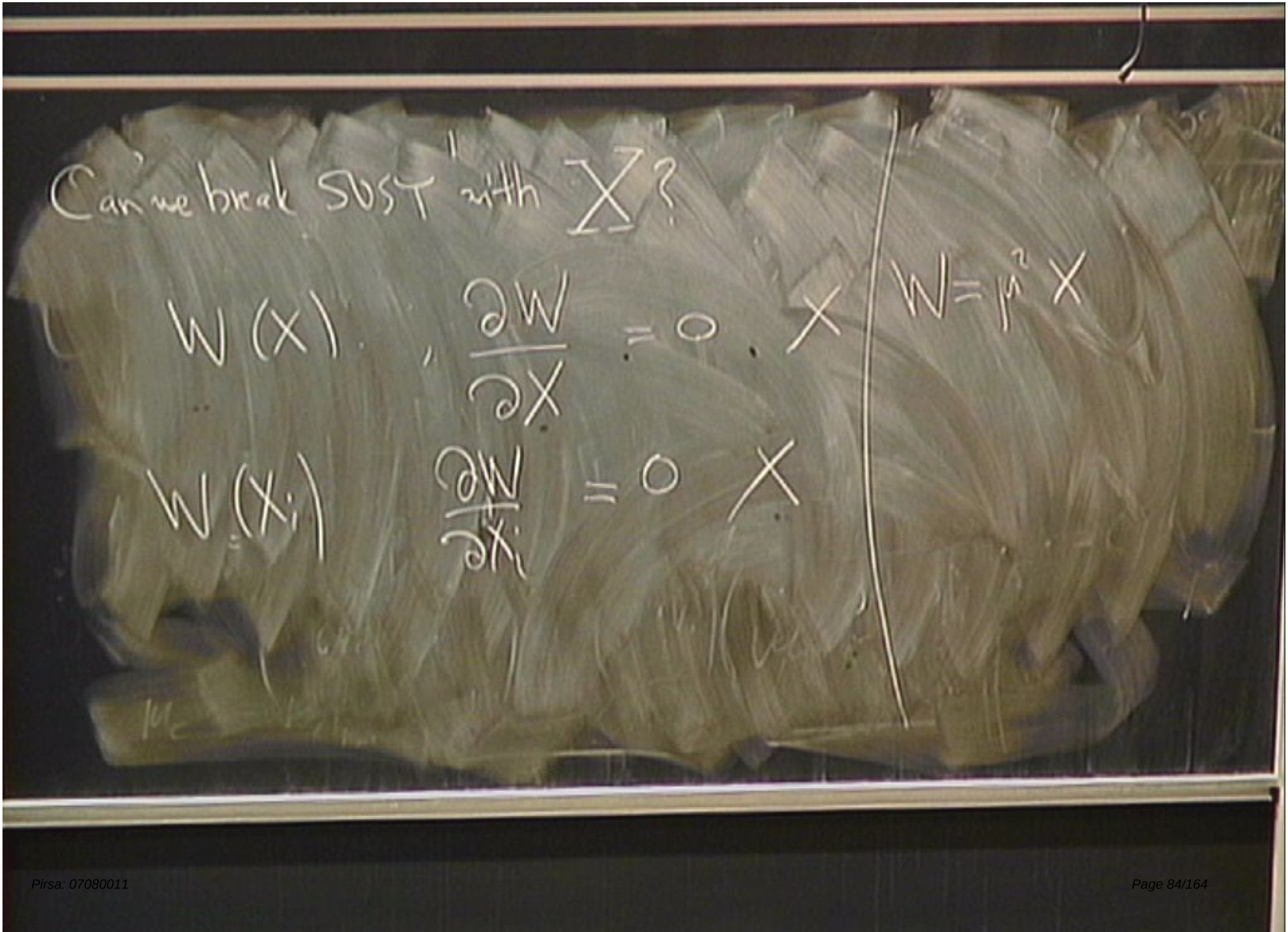

F ≳ (10^10 GeV)^2
m_3/2 ≳ TeV
F << (10^10 GeV)^2
m_3/2 << TeV
think w/ goldstino

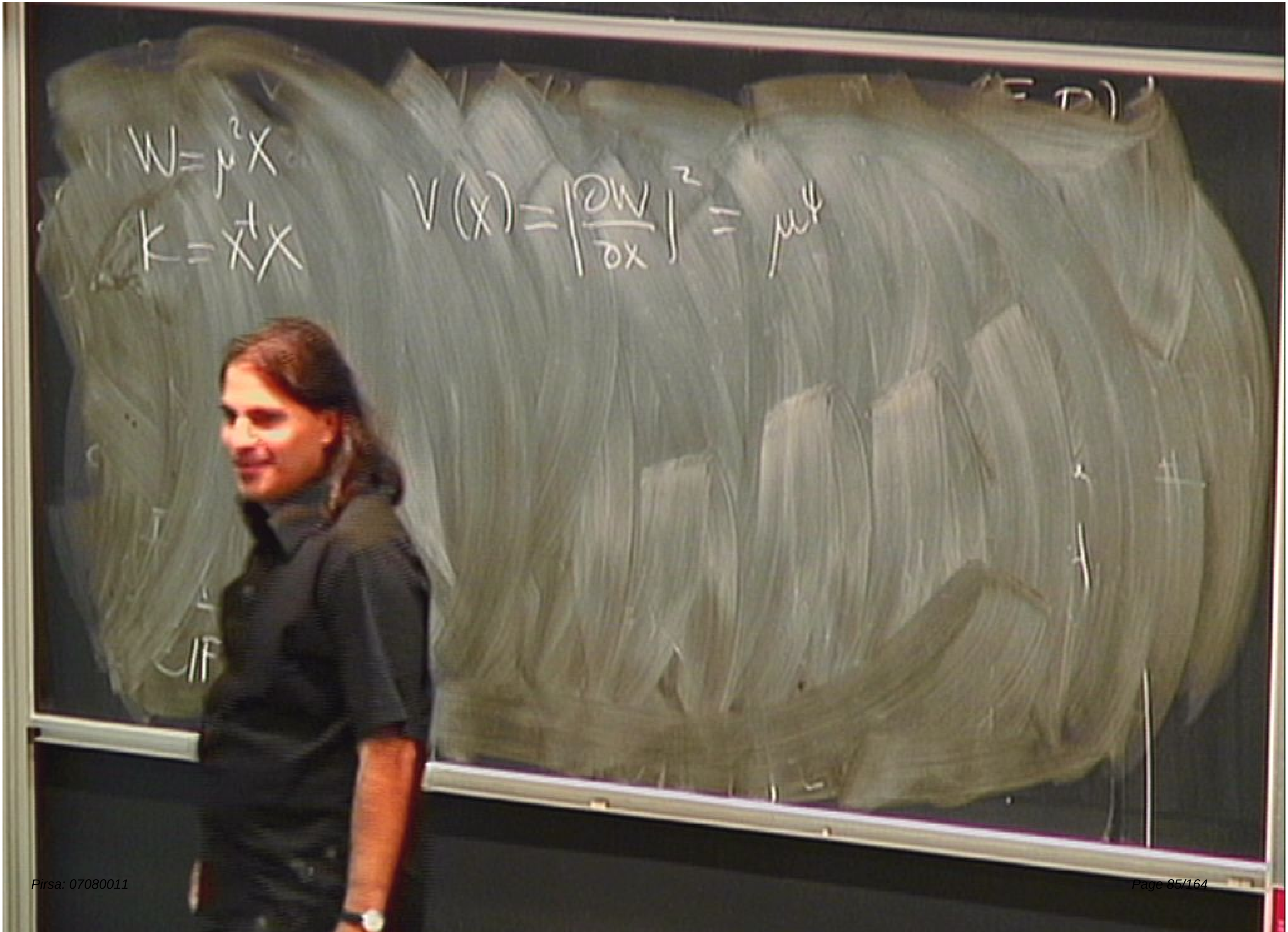

Can we break SUSY with X?

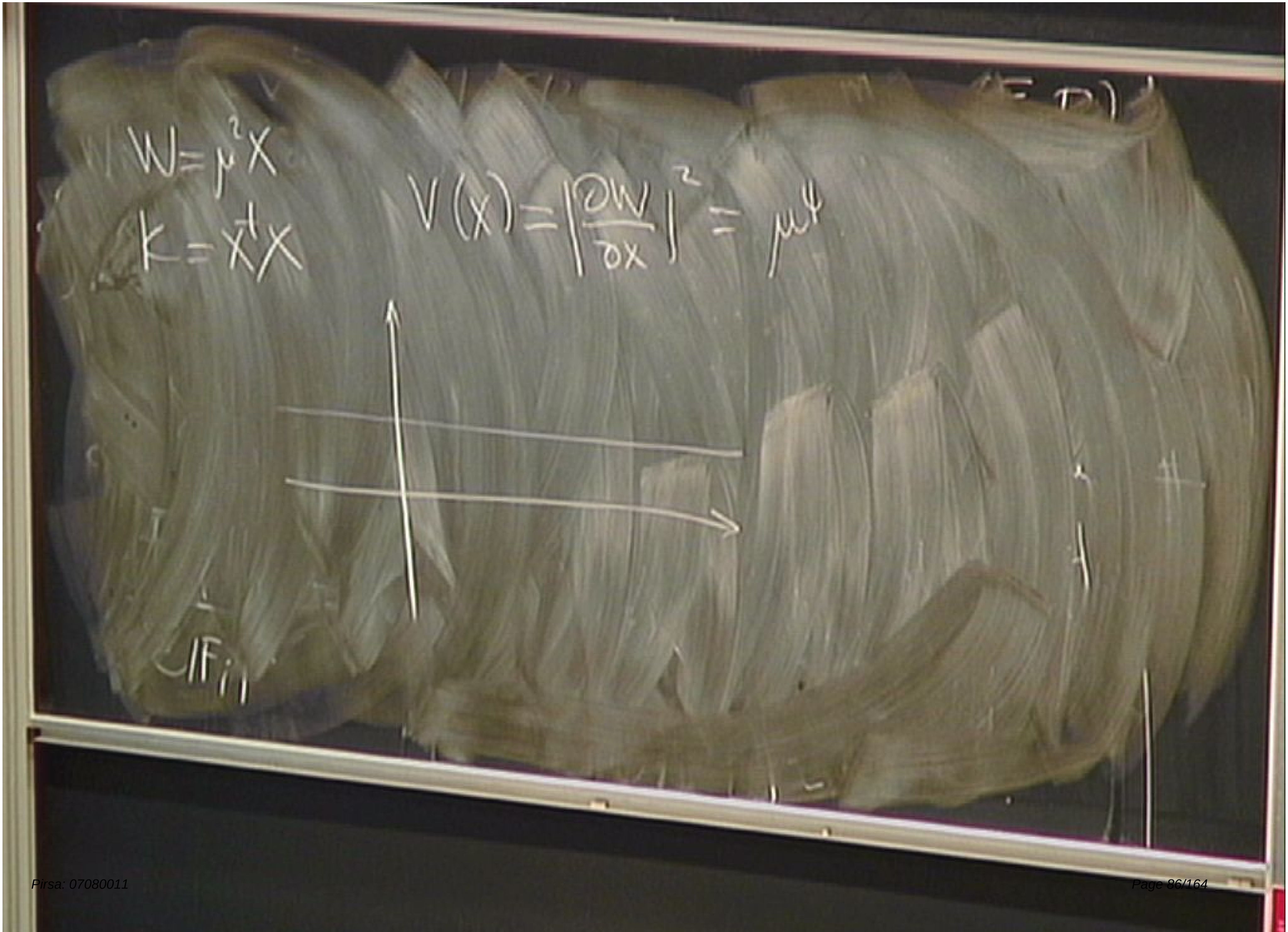
Can we break SUSY with X?

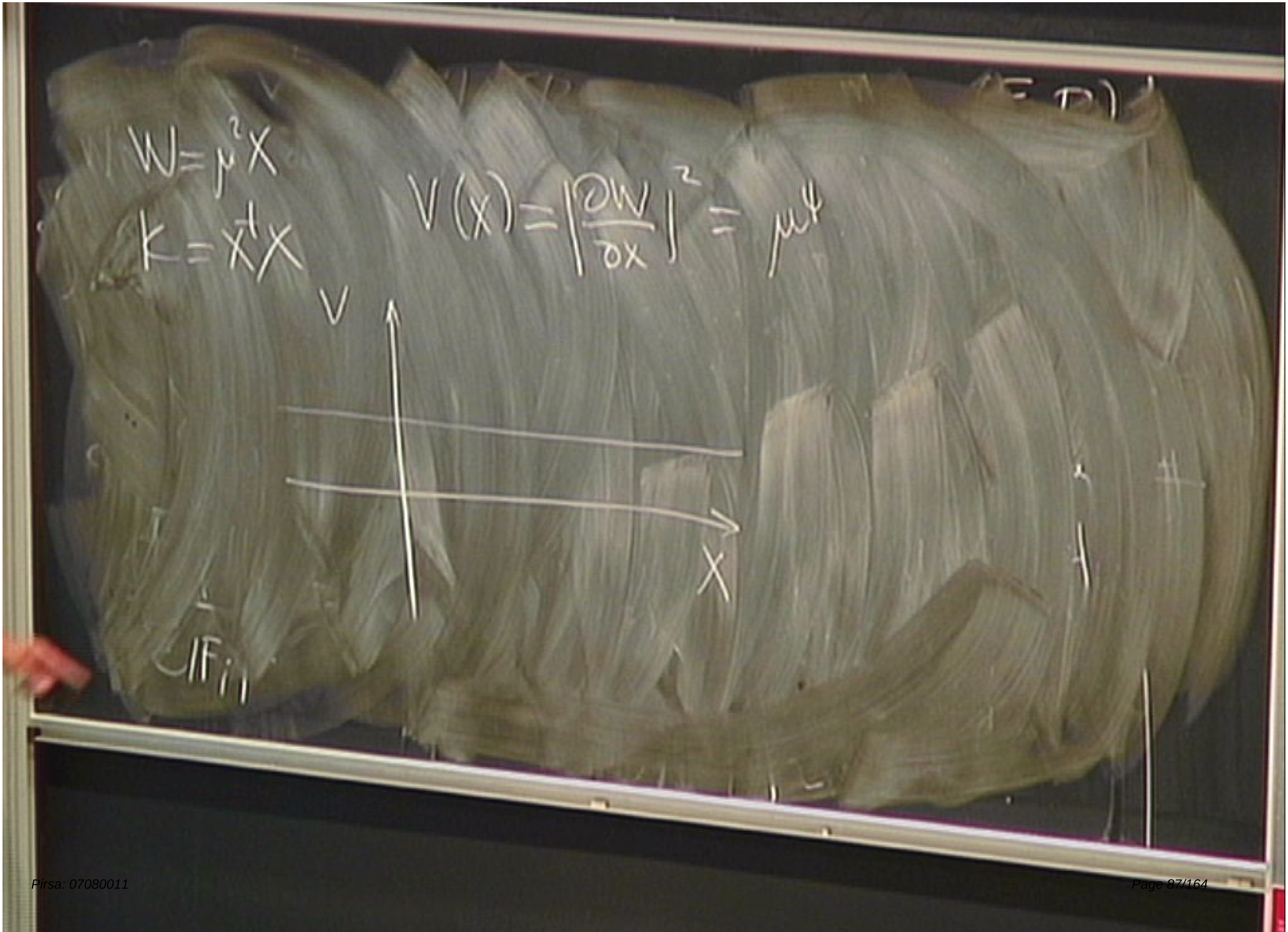
$W(X)$, $\frac{\partial W}{\partial X} = 0$ ✗

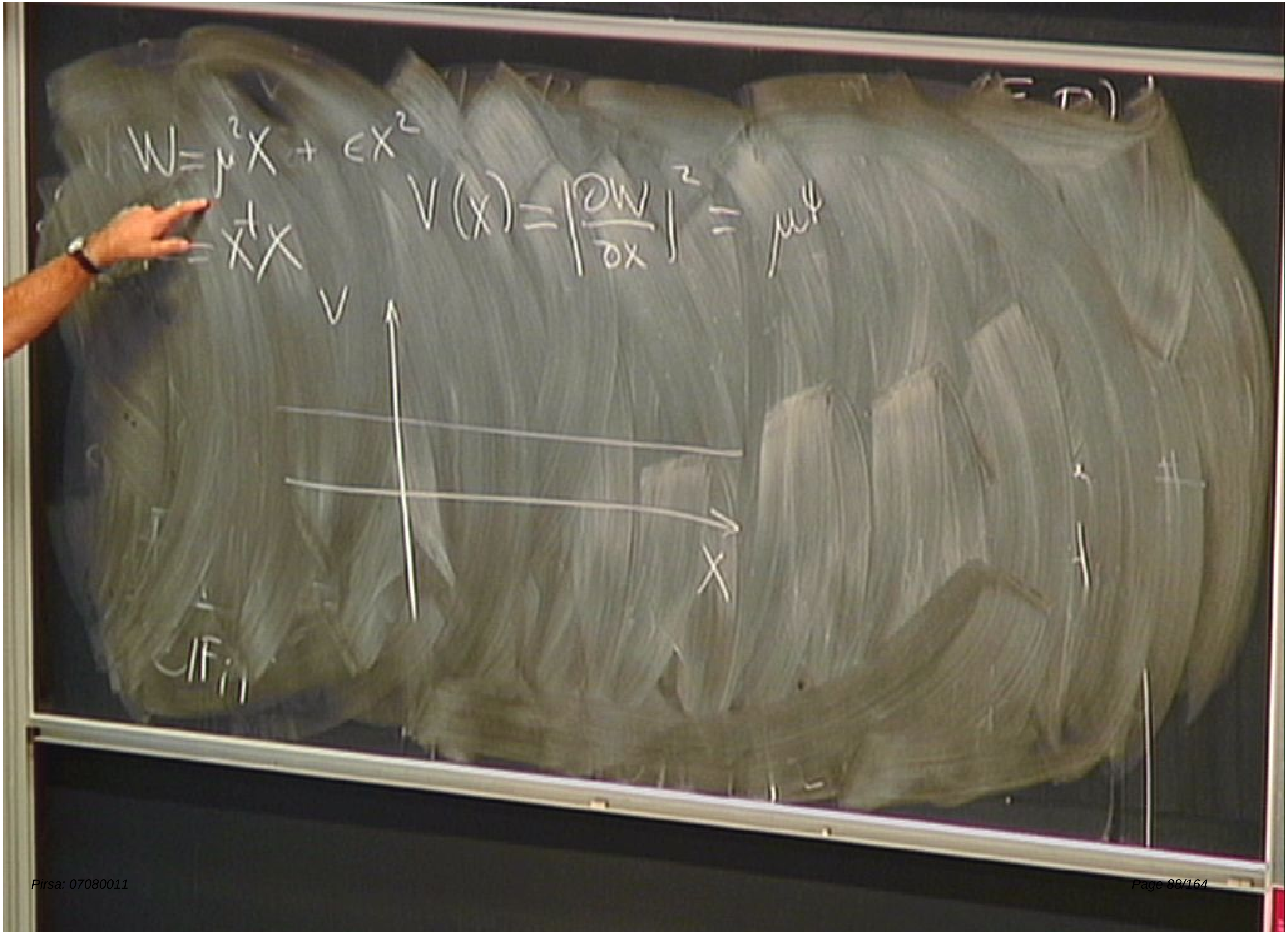

Can we break SUSY with X?
W(X) , ∂W/∂X = 0 ✗
W(X_i) ∂W/∂X_i = 0 ✗

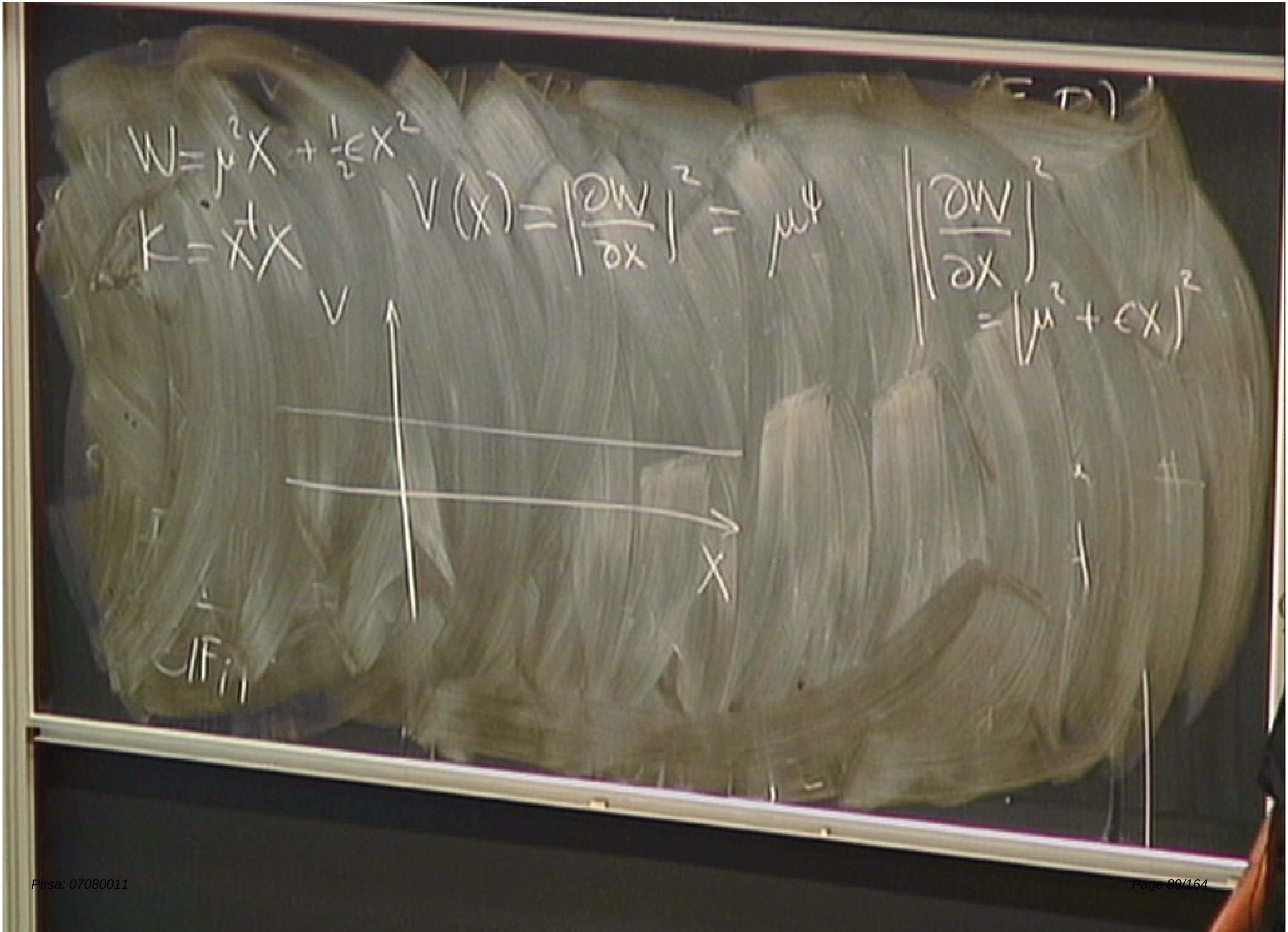

Can we break SUSY with X?
W(X) , ∂W/∂X = 0 . X
W = μ² X
W(Xᵢ) ∂W/∂Xᵢ = 0 X

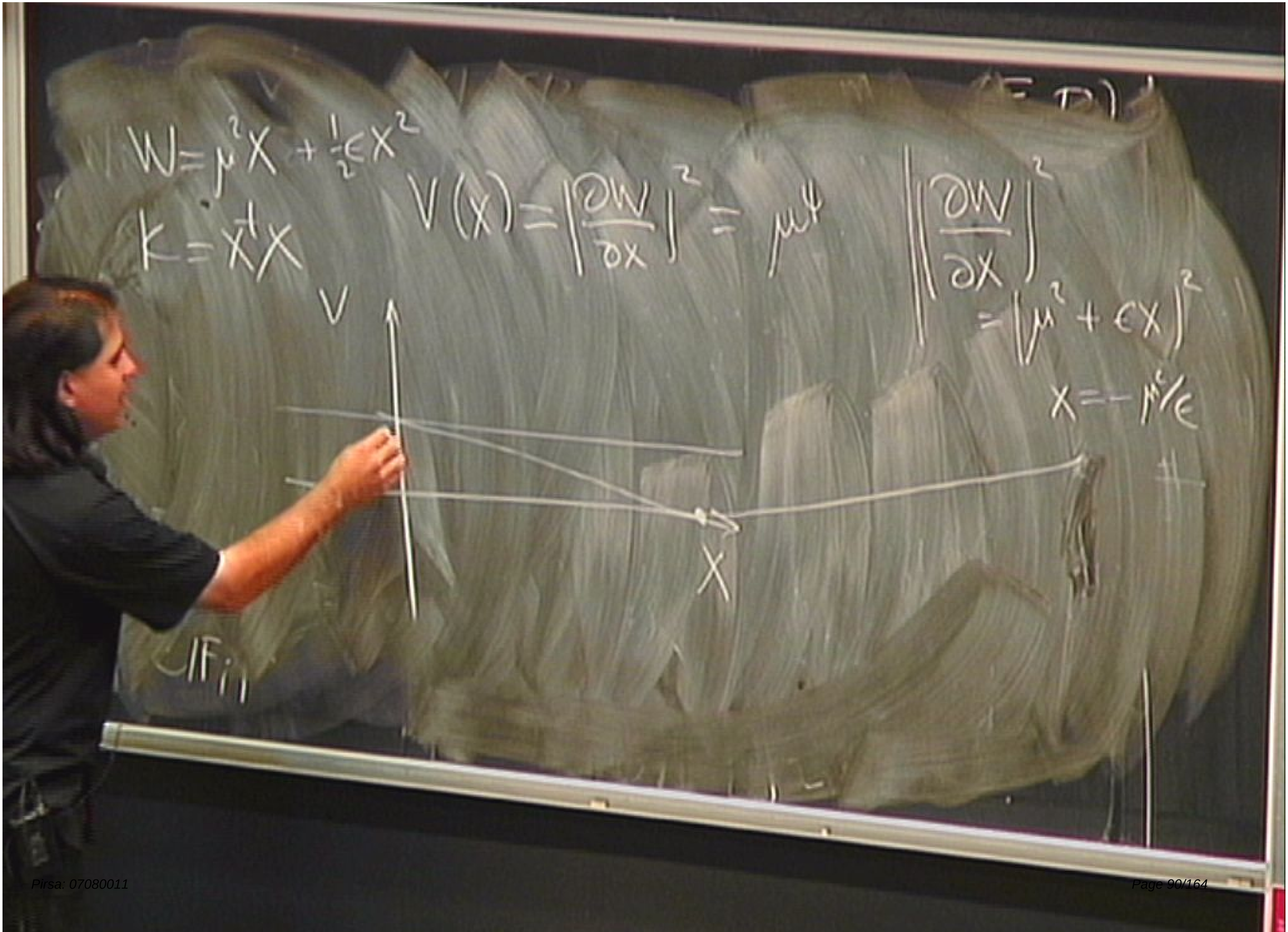

W=μ²X
K=X†X
V(x)=|∂W/∂x|² = μ⁴

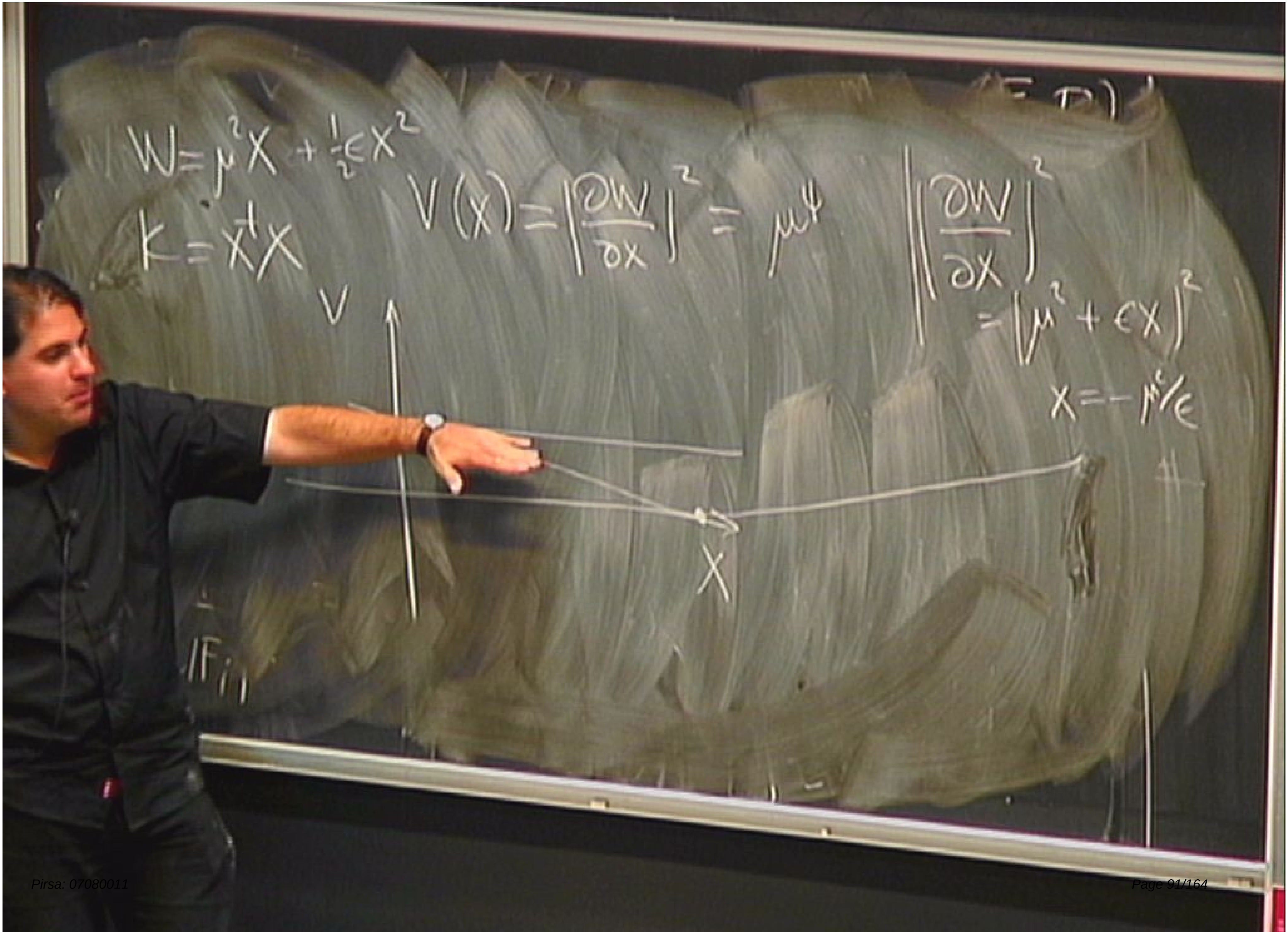

W = μ²X
K = X†X
V(X) = |∂W/∂X|² = μ⁴


W = μ²X
K = X†X
V(X) = |∂W/∂X|² = μ⁴
V
X

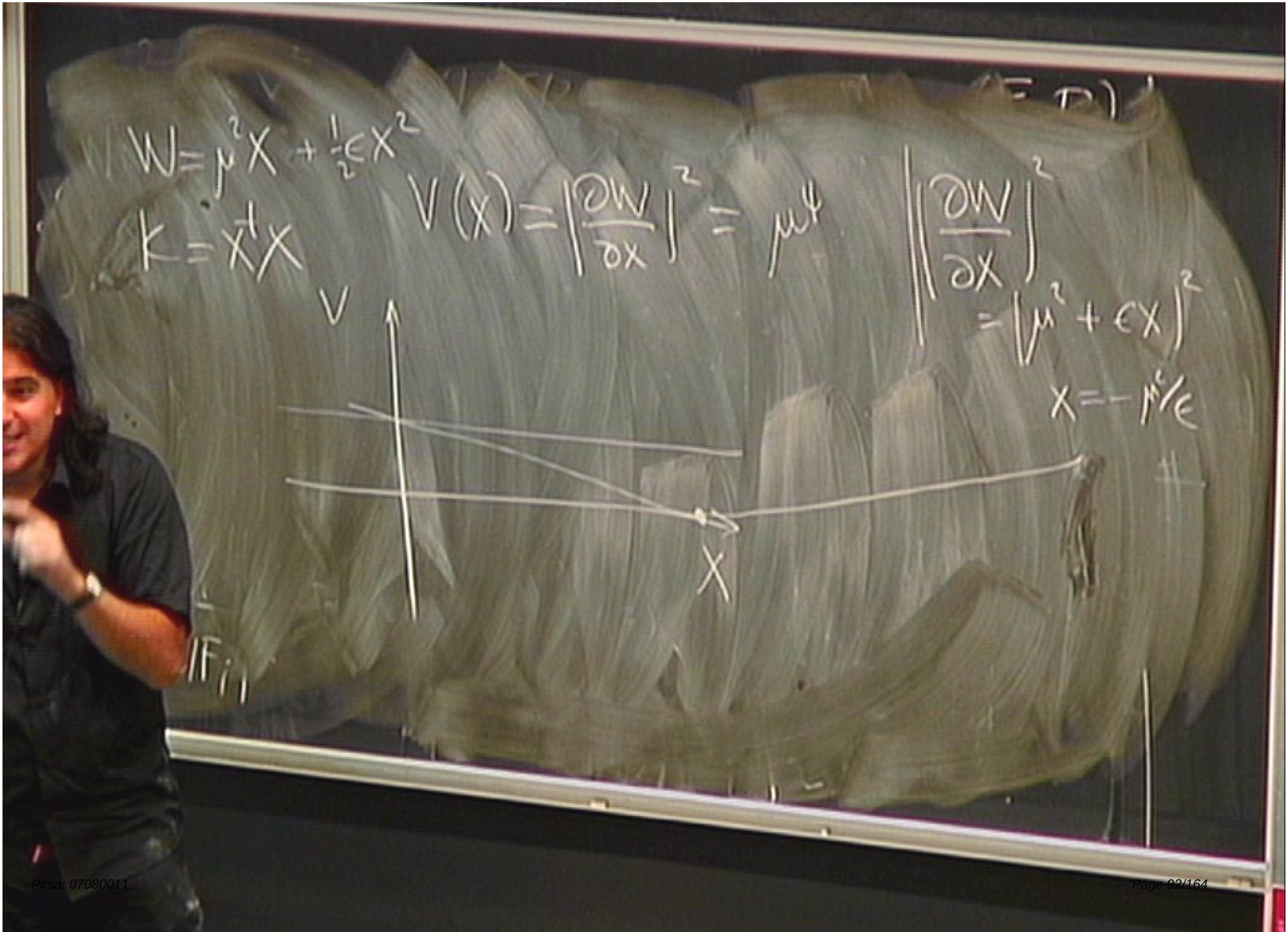

W = μ²X + εX²
V(X) = |∂W/∂X|² = μ⁴
= X†X
V
X

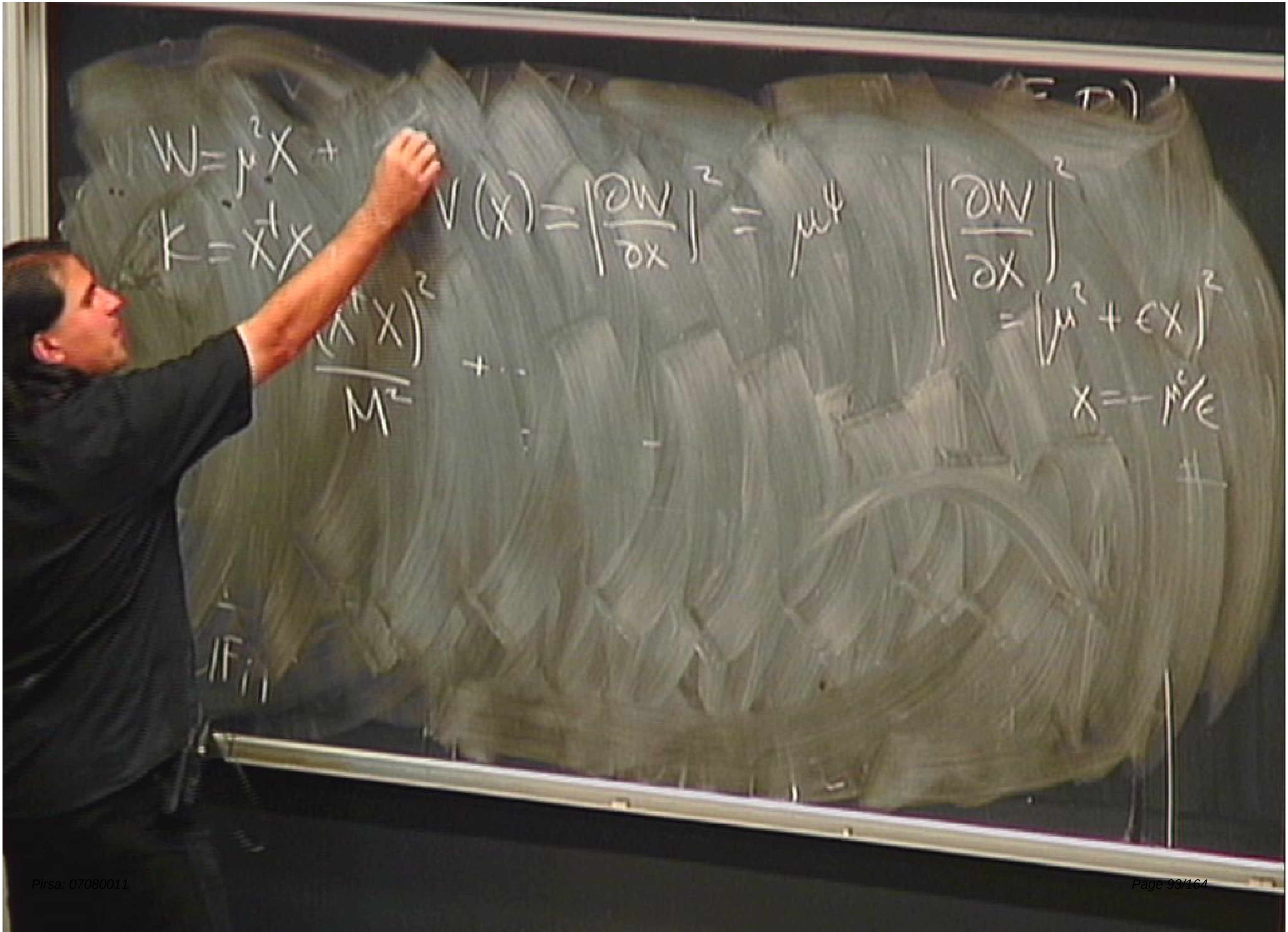

$W = \mu^2 X + \frac{1}{2}\epsilon X^2$
$K = X^\dagger X$
$V(X) = \left|\frac{\partial W}{\partial X}\right|^2 = \mu^4$
$\left|\frac{\partial W}{\partial X}\right|^2 = |\mu^2 + \epsilon X|^2$
V
X


W = μ²X + ½εX²
K = X†X
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|²
= |μ² + εX|²
X = −μ²/ε
V
X



W = μ²X + ½εX²
K = X†X
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|² = |μ² + εX|²
X = −μ²/ε
V
X


W = μ²X + ½εX²
K = X†X
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|²
= |μ² + εX|²
X = −μ²/ε
V
X


W = μ²X +
K = X†X
(X†X)² / M² + ...
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|² = |μ² + εX|²
X = −μ²/ε

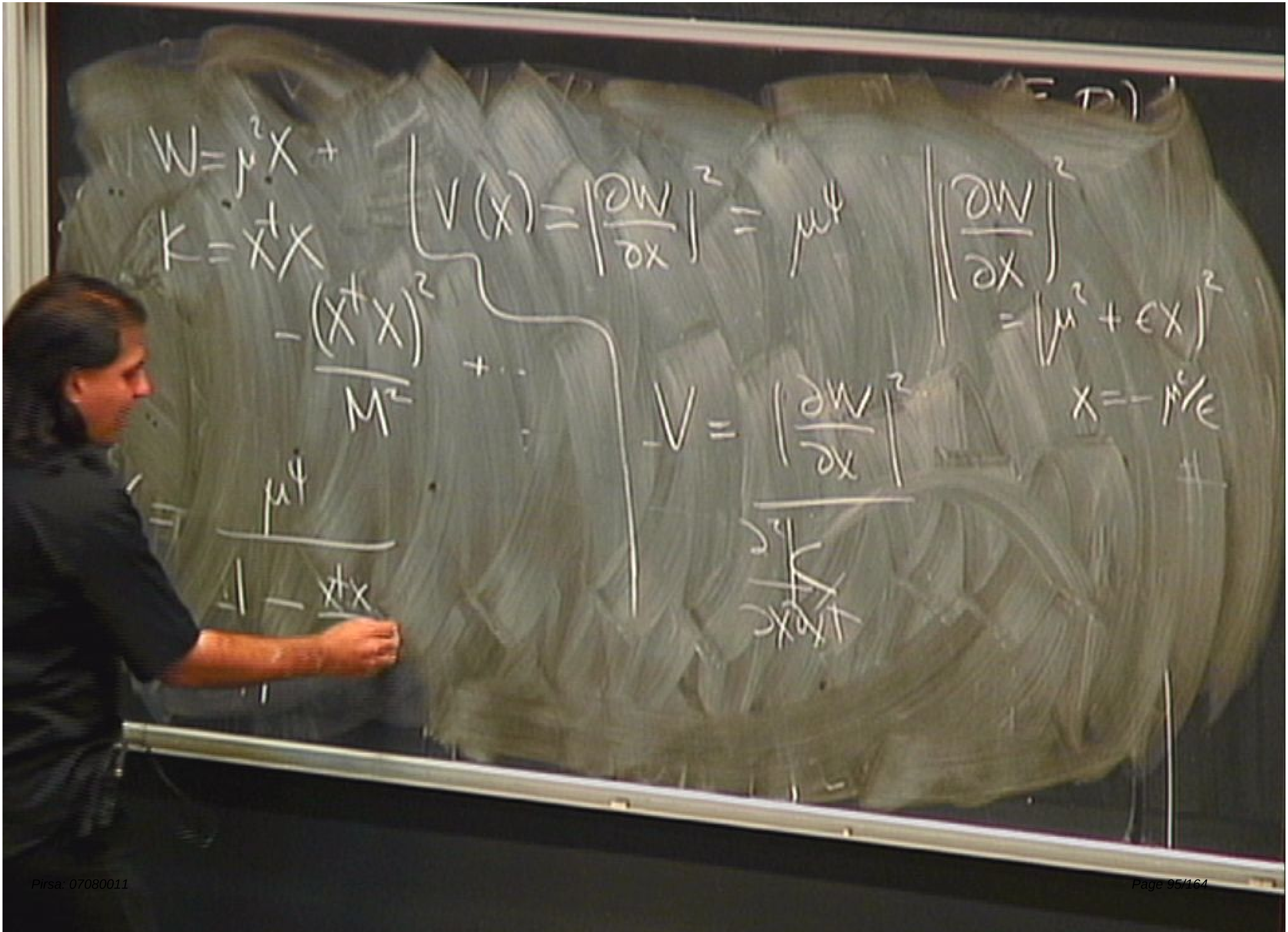
$$W = \mu^2 X + \ldots$$

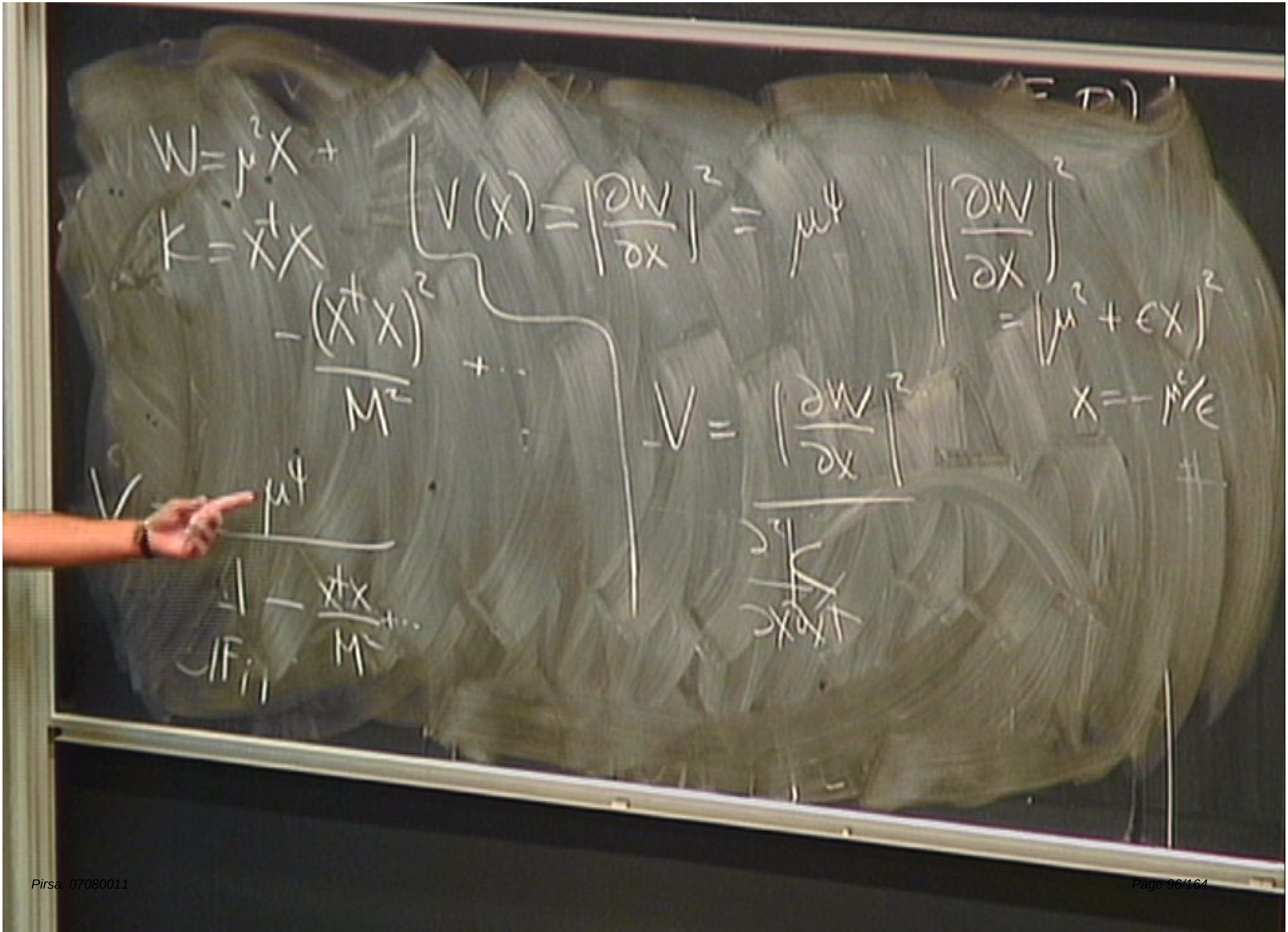
$$K = X^\dagger X - \frac{(X^\dagger X)^2}{M^2} + \ldots$$

$$V(X) = \left|\frac{\partial W}{\partial X}\right|^2 = \mu^4$$

$$\left|\frac{\partial W}{\partial X}\right|^2 = |\mu^2 + \epsilon X|^2$$

$$X = -\mu^2/\epsilon$$


W = μ²X +
K = X†X
− (X†X)² / M² + ...
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|²
= |μ² + εX|²
X = −μ²/ε
V = |∂W/∂X|²
μ⁴
1 − X†X


W = μ²X +
K = X†X − (X†X)²/M² + ...
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|² = |μ² + εX|²
X = −μ²/ε
V = |∂W/∂X|² / (∂²K/∂X∂X†)
V = μ⁴ / (1 − X†X/M² + ...)
|F_i|

$$W = \mu^2 X + \ldots$$

$$K = X^\dagger X - \frac{(X^\dagger X)^2}{M^2} + \ldots$$

$$V(X) = \left|\frac{\partial W}{\partial X}\right|^2 = \mu^4$$

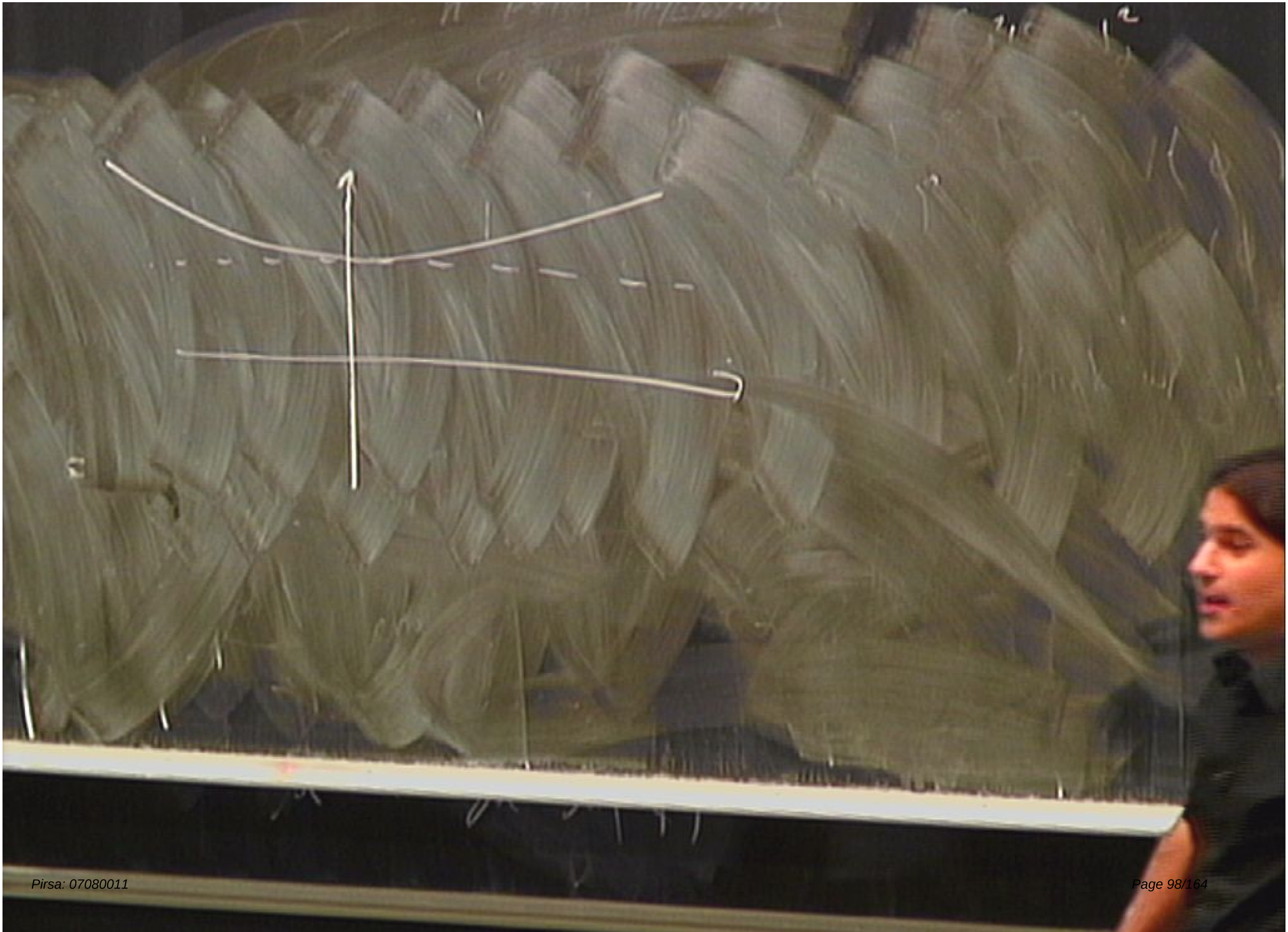
$$\left|\frac{\partial W}{\partial X}\right|^2 = |\mu^2 + \epsilon X|^2$$

$$X = -\mu^2/\epsilon$$

$$V = \frac{\left|\frac{\partial W}{\partial X}\right|^2}{\frac{\partial^2 K}{\partial X \partial X^\dagger}}$$

$$V = \frac{\mu^4}{1 - \frac{X^\dagger X}{M^2} + \ldots} = \mu^4 + \frac{\mu^4}{M^2} X^\dagger X + \ldots$$

$$|F_i|$$



$$W = \mu^2 X + \tfrac{1}{2}\epsilon X^2$$

$$K = X^\dagger X - \frac{(X^\dagger X)^2}{M^2} + \cdots$$

$$V(X) = \left|\frac{\partial W}{\partial X}\right|^2 = \mu^4$$

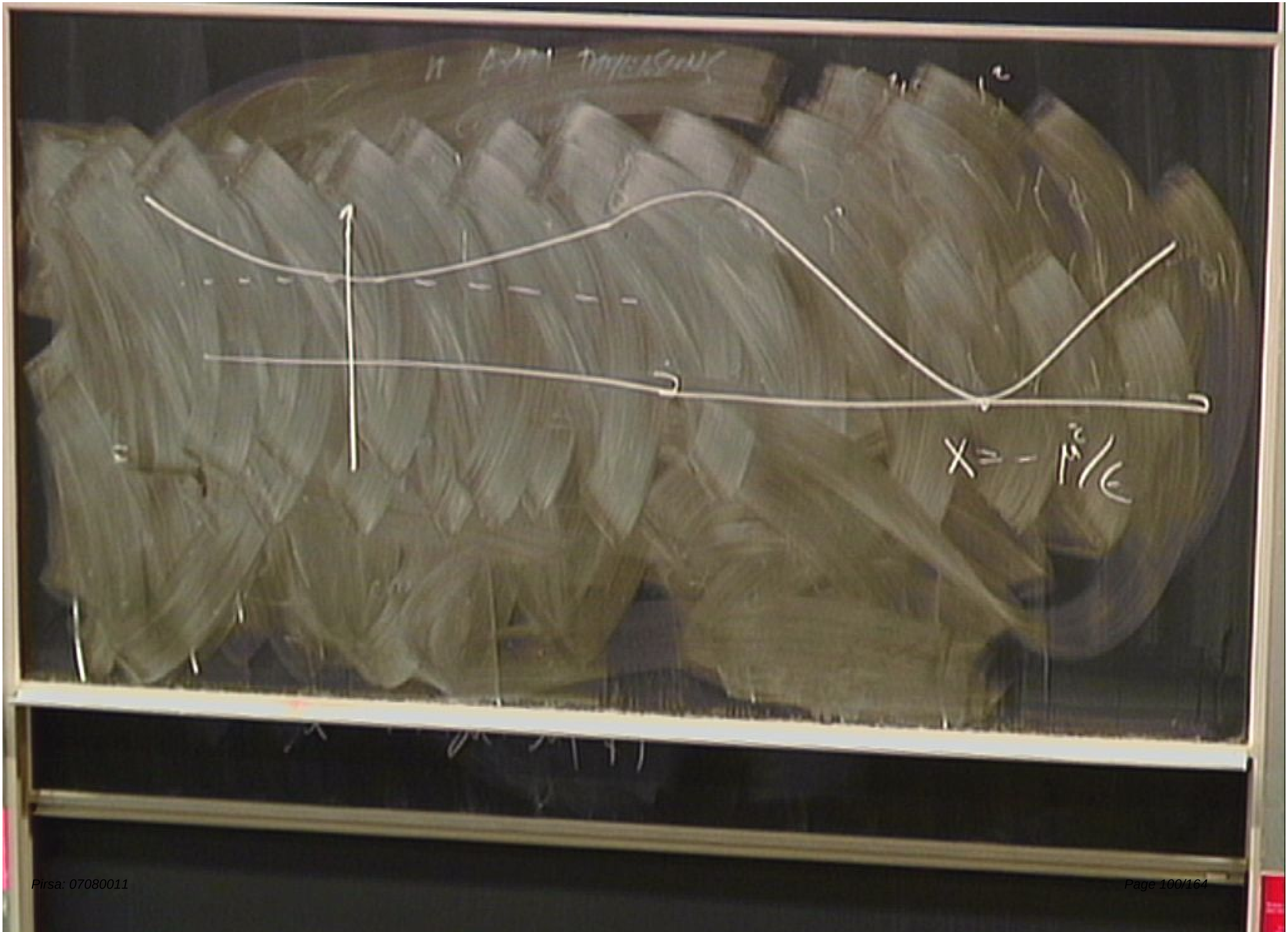
$$\left|\frac{\partial W}{\partial X}\right|^2 = |\mu^2 + \epsilon X|^2$$

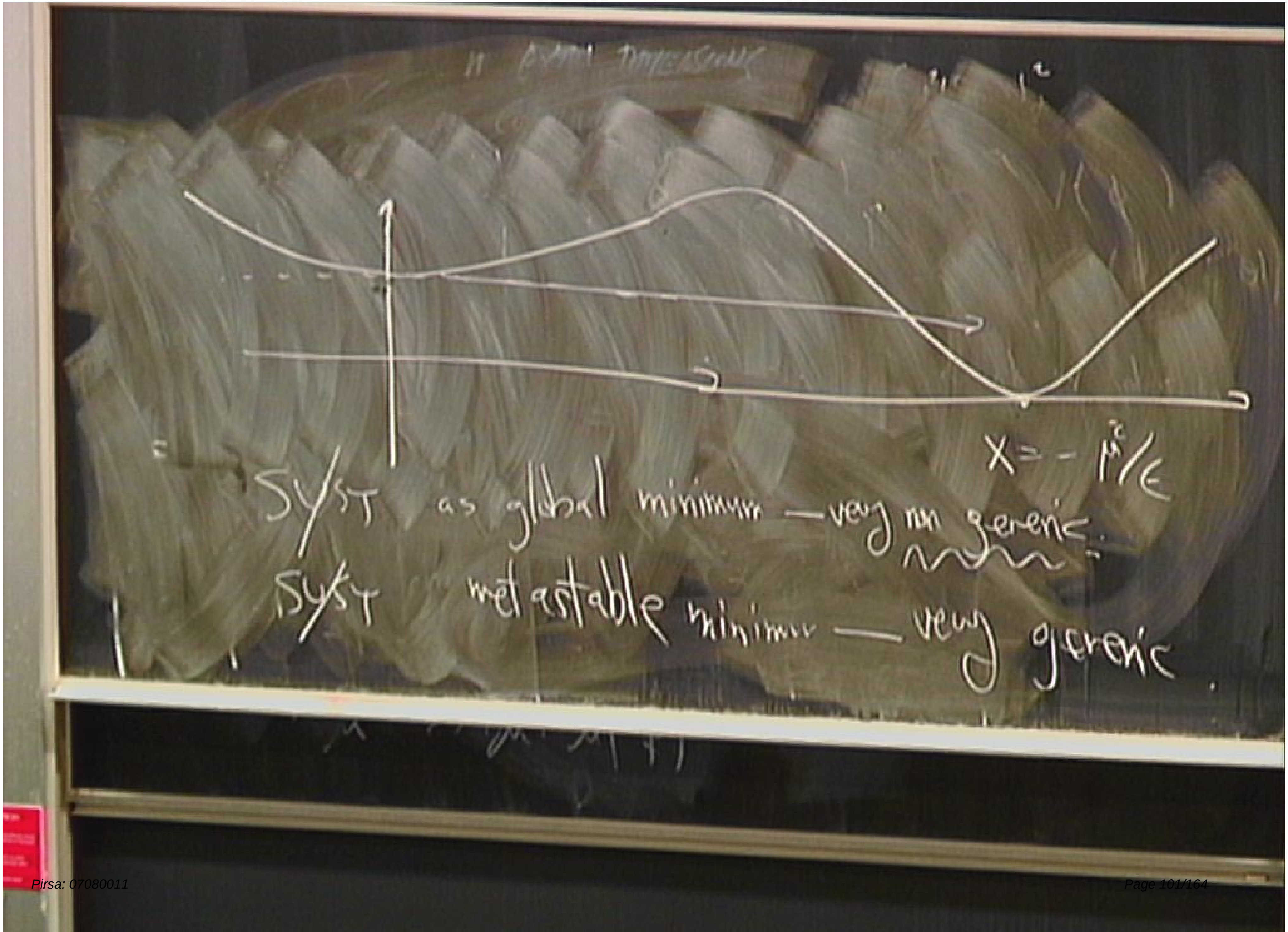
$$X = -\mu^2/\epsilon$$

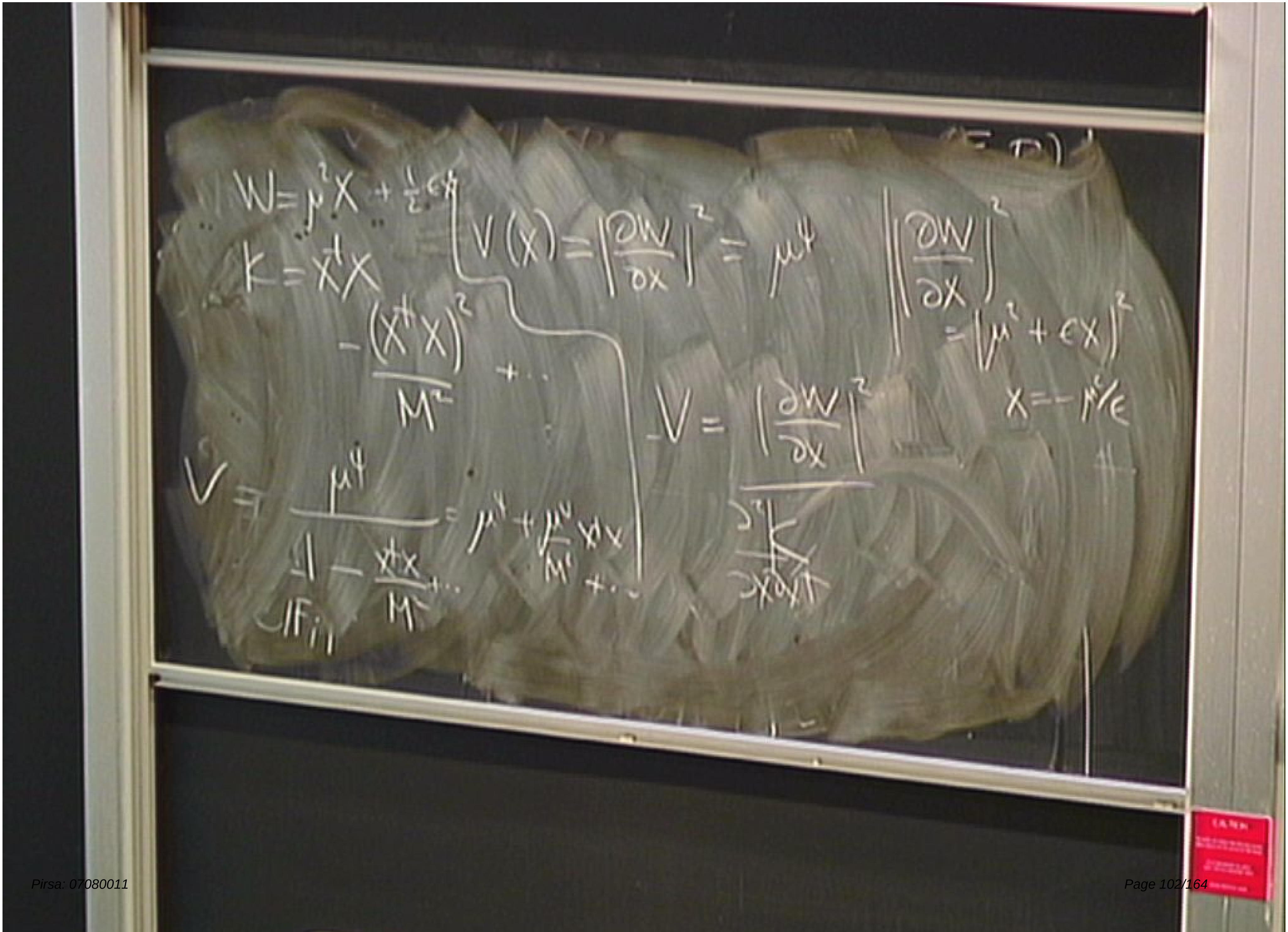
$$V = \frac{\left|\frac{\partial W}{\partial X}\right|^2}{\frac{\partial^2 K}{\partial X \partial X^\dagger}}$$

$$V = \frac{\mu^4}{1 - \frac{X^\dagger X}{M^2} + \cdots} = \mu^4 + \frac{\mu^4}{M^2} X^\dagger X + \cdots$$

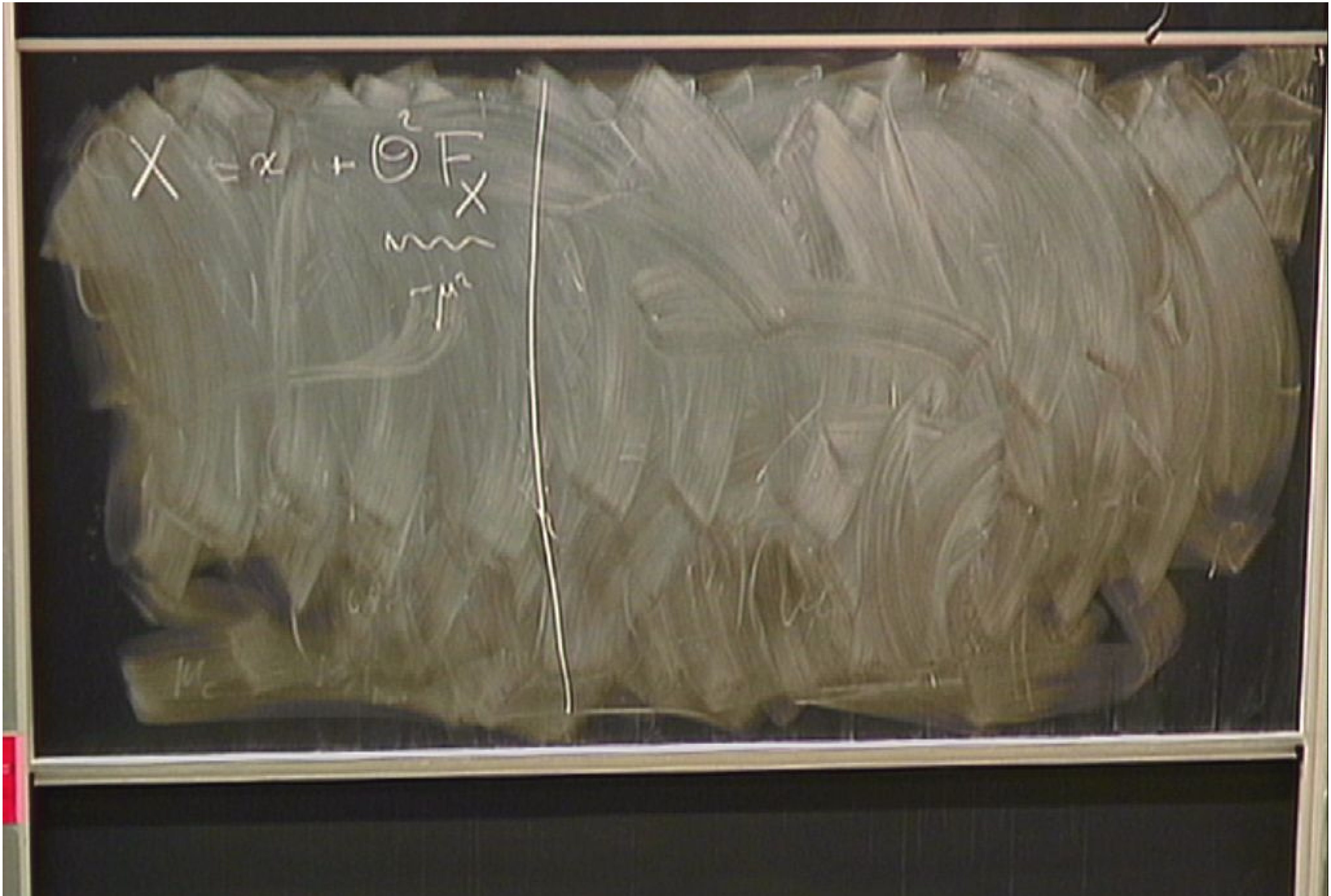
$|F_i|$


X = - μ²/ε

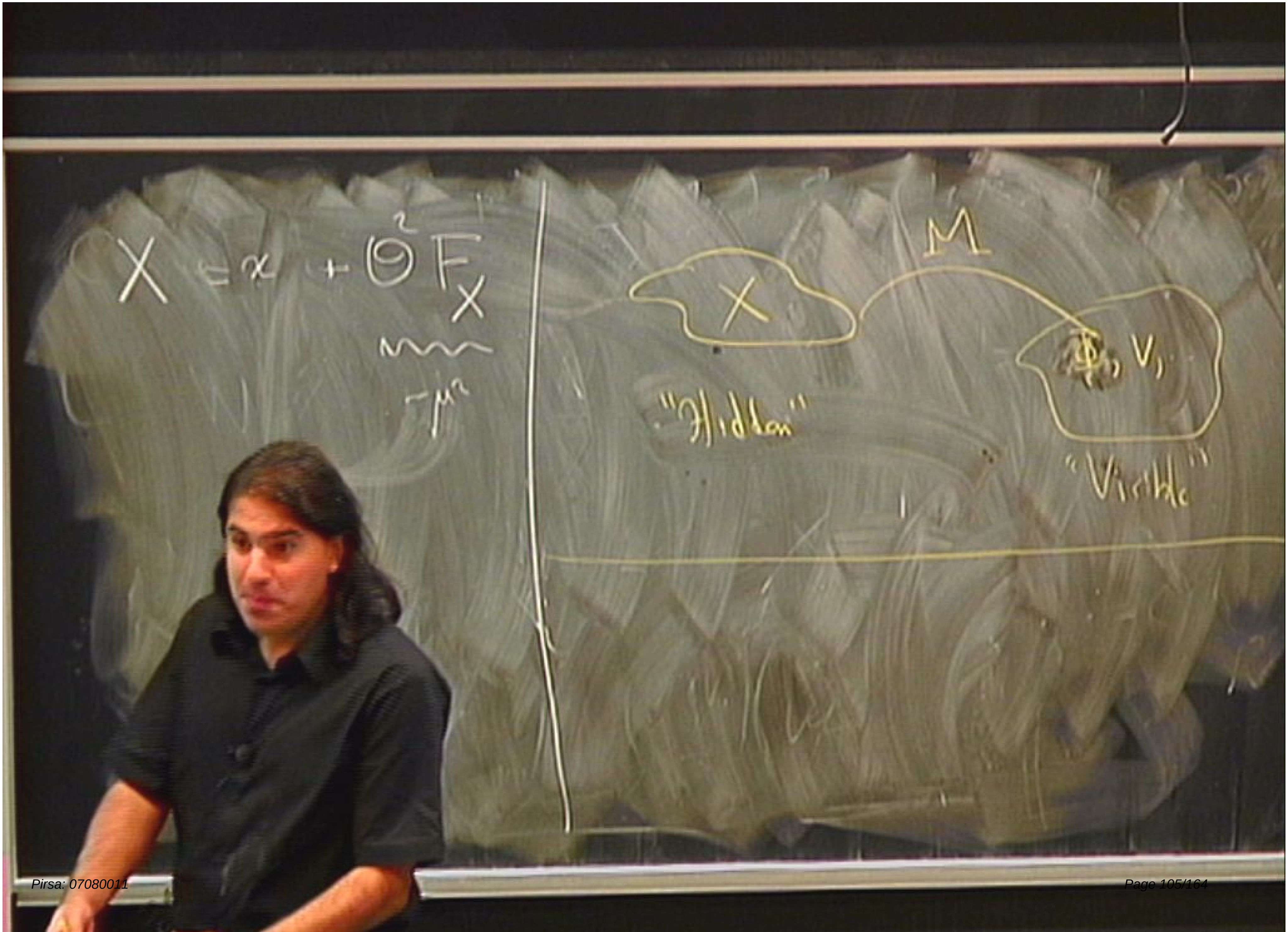

X = - μ²/ε
SUSY as global minimum — very non generic
SUSY metastable minimum — very generic

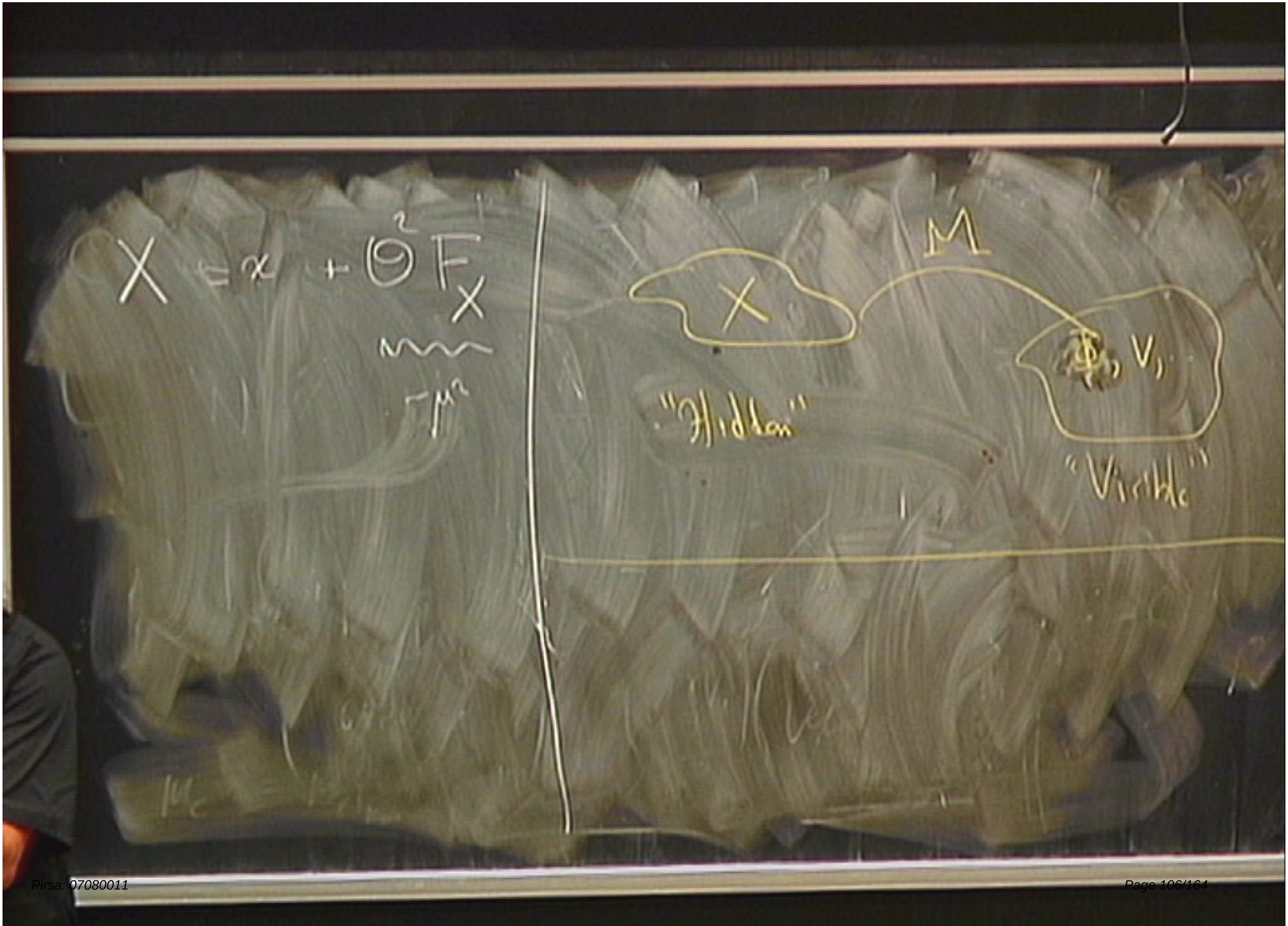


W = μ²X + ½εX²
K = X†X − (X†X)²/M² + …
V(X) = |∂W/∂X|² = μ⁴
|∂W/∂X|² = |μ² + εX|²
X = −μ²/ε
V = |∂W/∂X|²
V = μ⁴ / (1 − X†X/M² + …) = μ⁴ + (μ⁴/M²) X†X + …


X = x + θ² F_X
~ μ²
μ_c


M
X


X = x + θ² F_X
~μ²
M
X
"Hidden"
"Visible"


X = x + θ²F_X
M
X
"Hidden"
Φ, V,
"Visible"

$$\int d^4\theta \, \frac{X^\dagger X}{M^2} \, \varphi^\dagger \varphi$$

$$\frac{X^\dagger}{M} \quad \frac{X}{M}$$

$$X = F_X \theta^2$$

$$\supset \int d^4\theta \, \theta^2 \bar{\theta}^2 \, \frac{|F_X|^2}{M^2} \, \varphi^\dagger \varphi$$

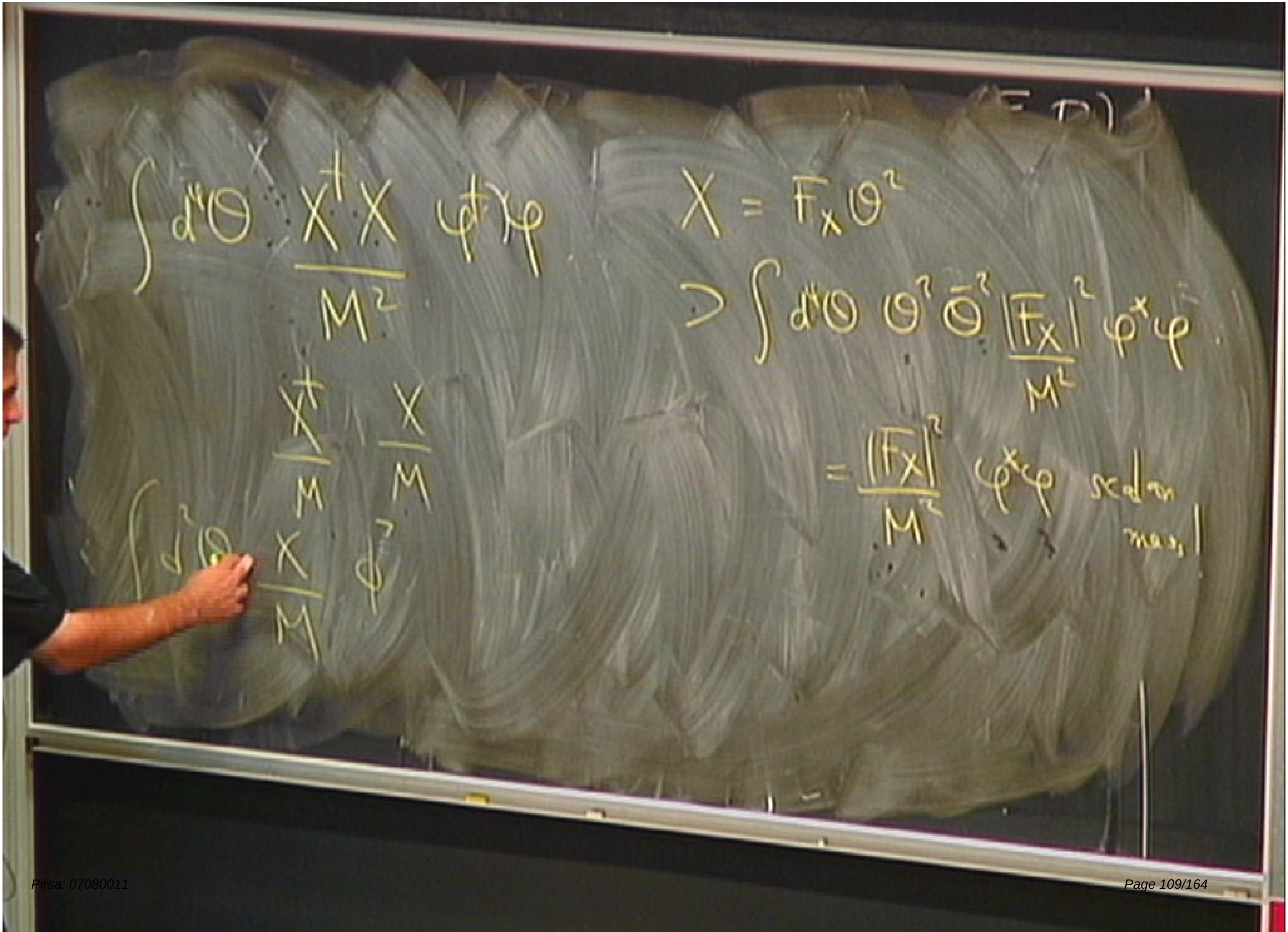
$$\int d^4\theta \, \frac{X^\dagger X}{M^2} \, \varphi^\dagger \varphi$$

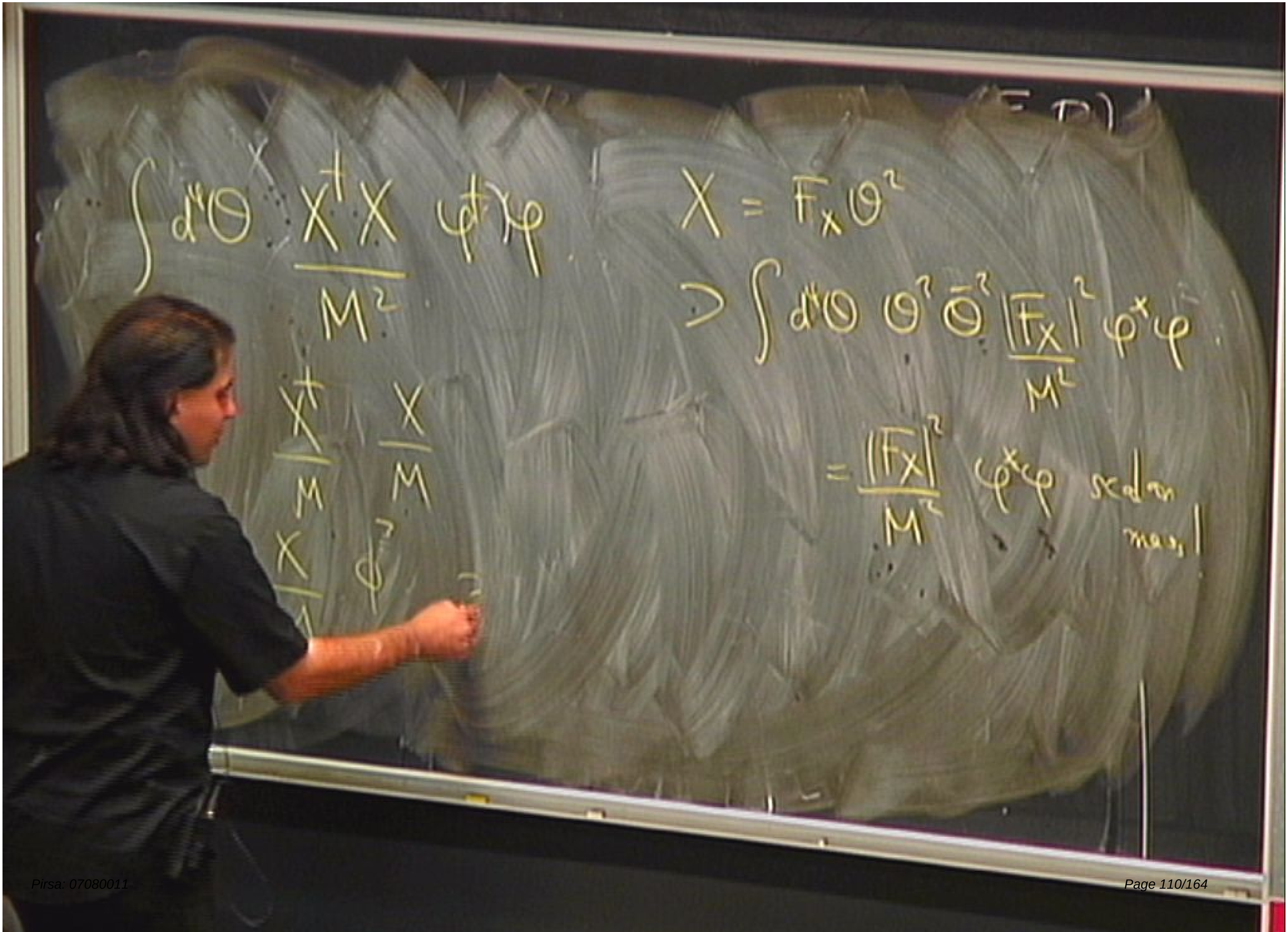
$$\frac{X^\dagger}{M} \quad \frac{X}{M}$$

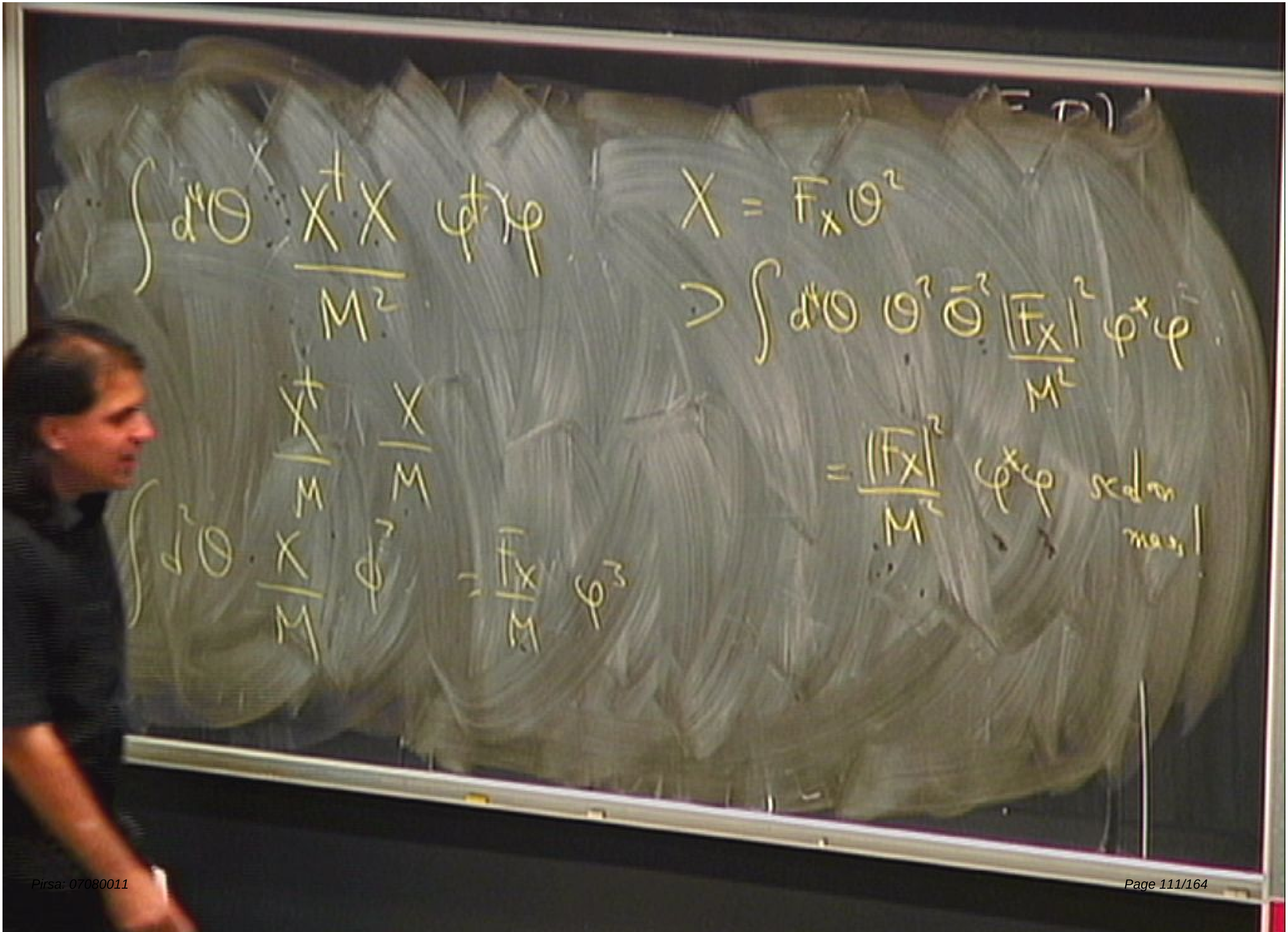
$$X = F_X \theta^2$$

$$\supset \int d^4\theta \, \theta^2 \bar{\theta}^2 \, \frac{|F_X|^2}{M^2} \, \varphi^\dagger \varphi$$

$$= \frac{|F_X|^2}{M^2} \, \varphi^\dagger \varphi$$ scalar mass!


$\int d^4\theta \frac{X^\dagger X}{M^2} \varphi^\dagger\varphi$
$X = F_X \theta^2$
$\supset \int d^4\theta\, \theta^2 \bar\theta^2 \frac{|F_X|^2}{M^2} \varphi^* \varphi$
$\frac{X^\dagger}{M} \quad \frac{X}{M}$
$= \frac{|F_X|^2}{M^2} \varphi^* \varphi$ scalar mass
$\int d^2\theta \frac{X}{M} \phi^2$


$\int d^4\theta \, \frac{X^\dagger X}{M^2} \varphi^\dagger \varphi$
$X = F_X \theta^2$
$\supset \int d^4\theta \, \theta^2 \bar{\theta}^2 \frac{|F_X|^2}{M^2} \varphi^* \varphi$
$= \frac{|F_X|^2}{M^2} \varphi^* \varphi$ scalar mass
$\frac{X^\dagger}{M} \frac{X}{M}$
$\frac{X}{M} \phi^2$


∫d⁴θ X†X/M² φ†φ
X = F_X θ²
⊃ ∫d⁴θ θ² θ̄² |F_X|²/M² φ*φ
X†/M X/M
= |F_X|²/M² φ*φ scalar mass
∫d²θ X/M φ³ = F_X/M φ³

$$\int d^4\theta \, \frac{X^\dagger X}{M^2} \, \varphi^\dagger \varphi$$

$$X = F_X \theta^2$$

$$\supset \int d^4\theta \, \theta^2 \bar{\theta}^2 \, \frac{|F_X|^2}{M^2} \, \varphi^* \varphi$$

$$= \frac{|F_X|^2}{M^2} \, \varphi^* \varphi \quad \text{scalar mass}$$

$$\frac{X^\dagger}{M} \quad \frac{X}{M}$$

$$\int d^2\theta \, \frac{X}{M} \, \phi^3 = \frac{F_X}{M} \, \varphi^3$$

$$\int d^4\theta \, \frac{X^\dagger X}{M^2} \, \varphi^\dagger \varphi \qquad X = F_X \theta^2$$

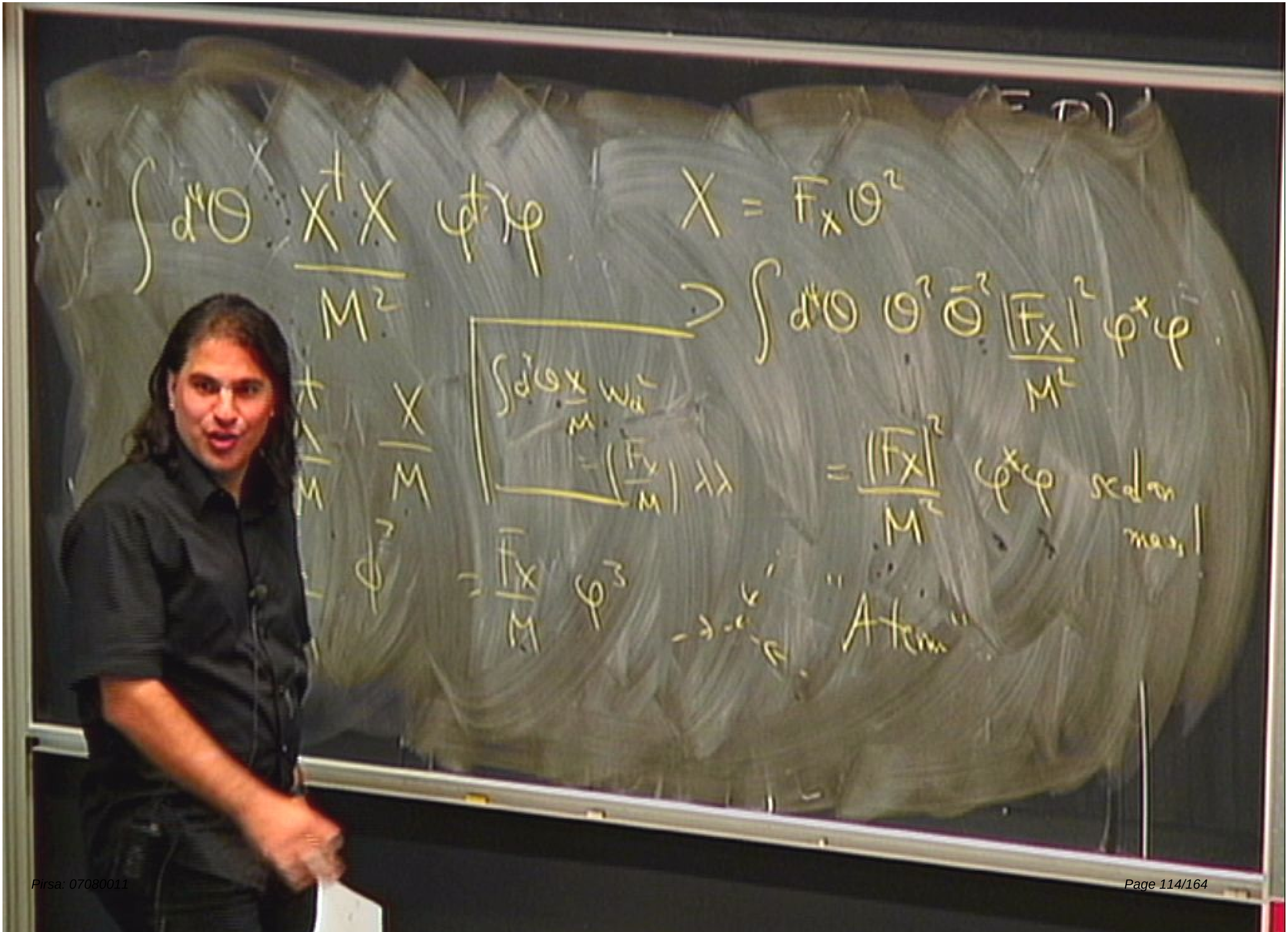
$$\supset \int d^4\theta \, \theta^2 \bar{\theta}^2 \, \frac{|F_X|^2}{M^2} \, \varphi^\dagger \varphi$$

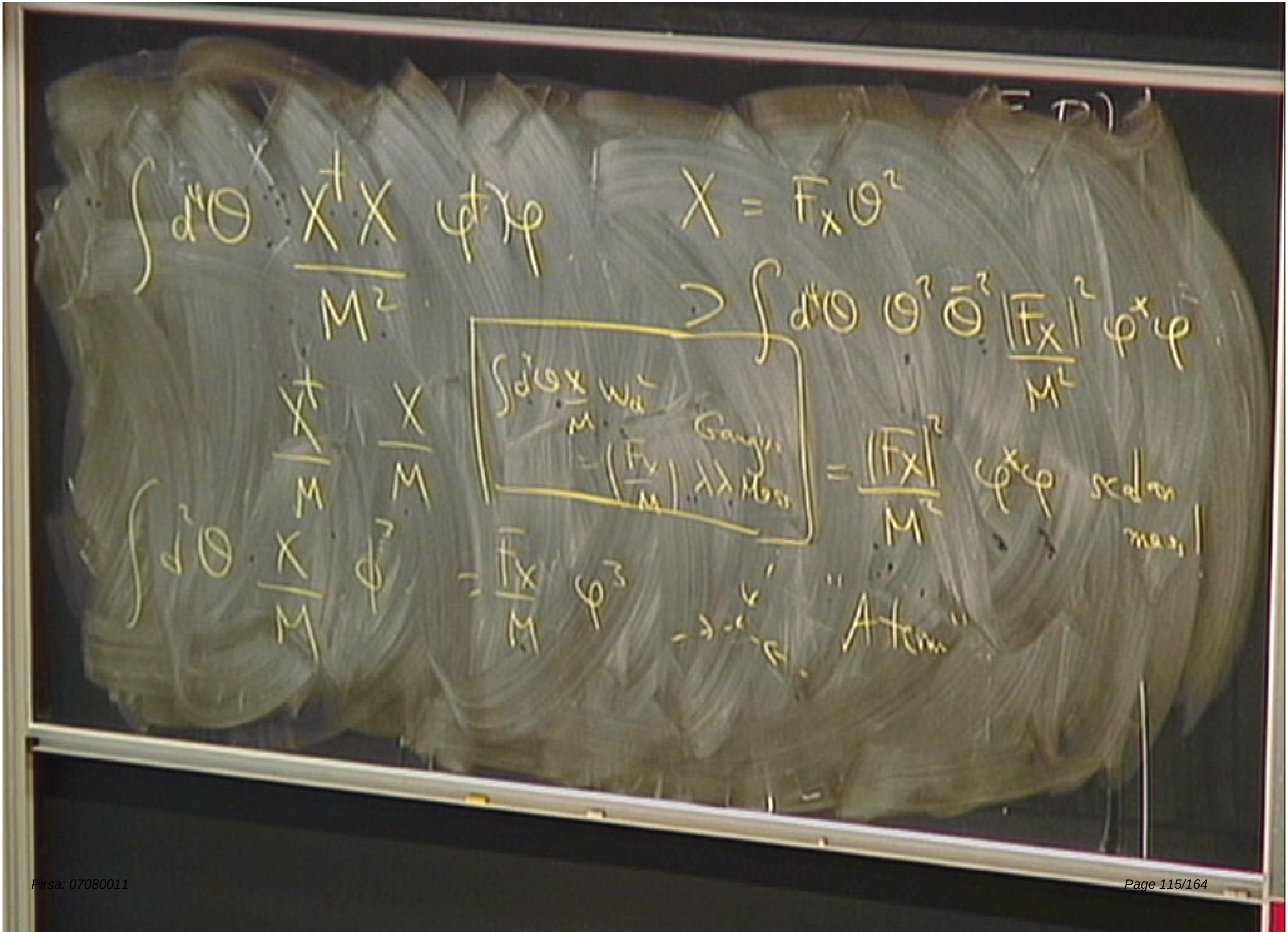
$$= \frac{|F_X|^2}{M^2} \, \varphi^\dagger \varphi \quad \text{scalar mass!}$$

$$\frac{X^\dagger}{M} \qquad \frac{X}{M}$$

$$\int d^2\theta \, \frac{X}{M} \, W_\alpha^2$$

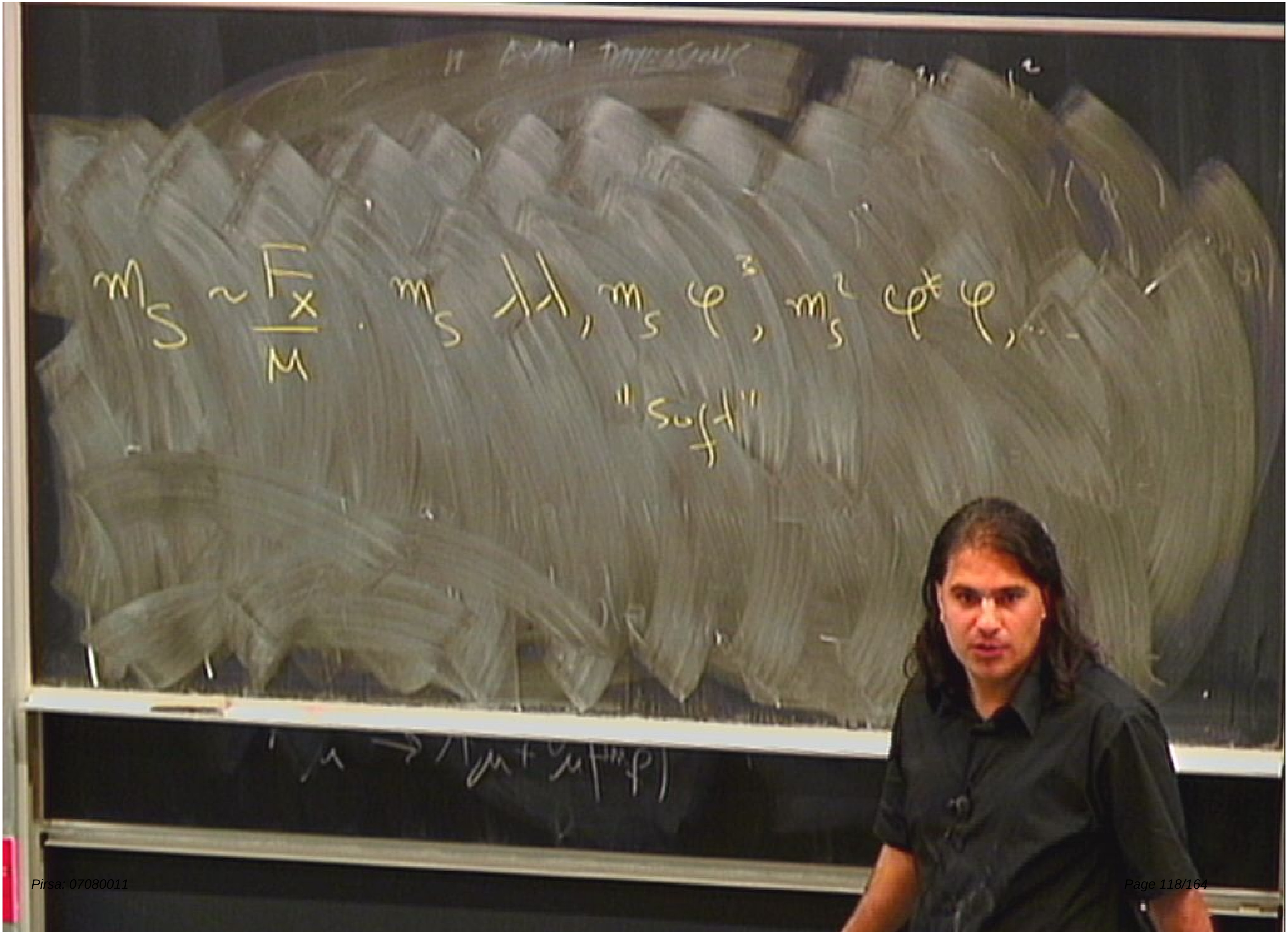
$$\int d^2\theta \, \frac{X}{M} \, \varphi^3 = \frac{F_X}{M} \, \varphi^3 \qquad \text{"A term"}$$


X = F_X θ²
scalar mass
"A term"


∫d⁴θ X†X/M² φ†φ
X = F_X θ²
⊃ ∫d⁴θ θ²θ̄² |F_X|²/M² φ*φ
∫d²θ X/M W_α²
Gaugino
(F_X/M) λλ Mass
X†/M X/M
= |F_X|²/M² φ*φ scalar mass
∫d²θ X/M φ³
= F_X/M φ³
"A term"


m_S ~ F_X / M
λλ
φ³
φ†φ

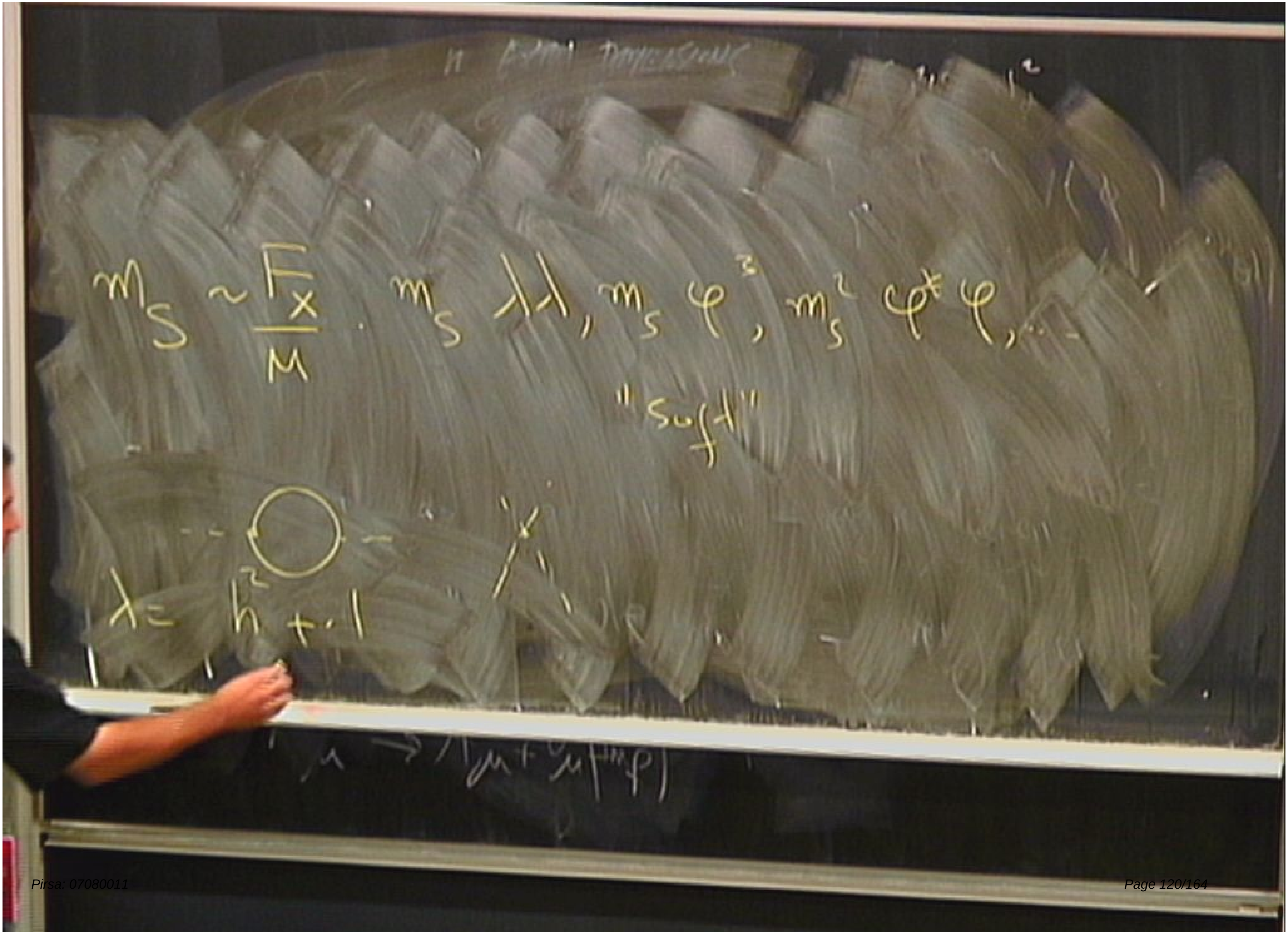
$$m_S \sim \frac{F_X}{M} \cdot \quad m_S \lambda\lambda, \; m_S \varphi^2, \; m_S^2 \varphi^\dagger \varphi, \ldots$$

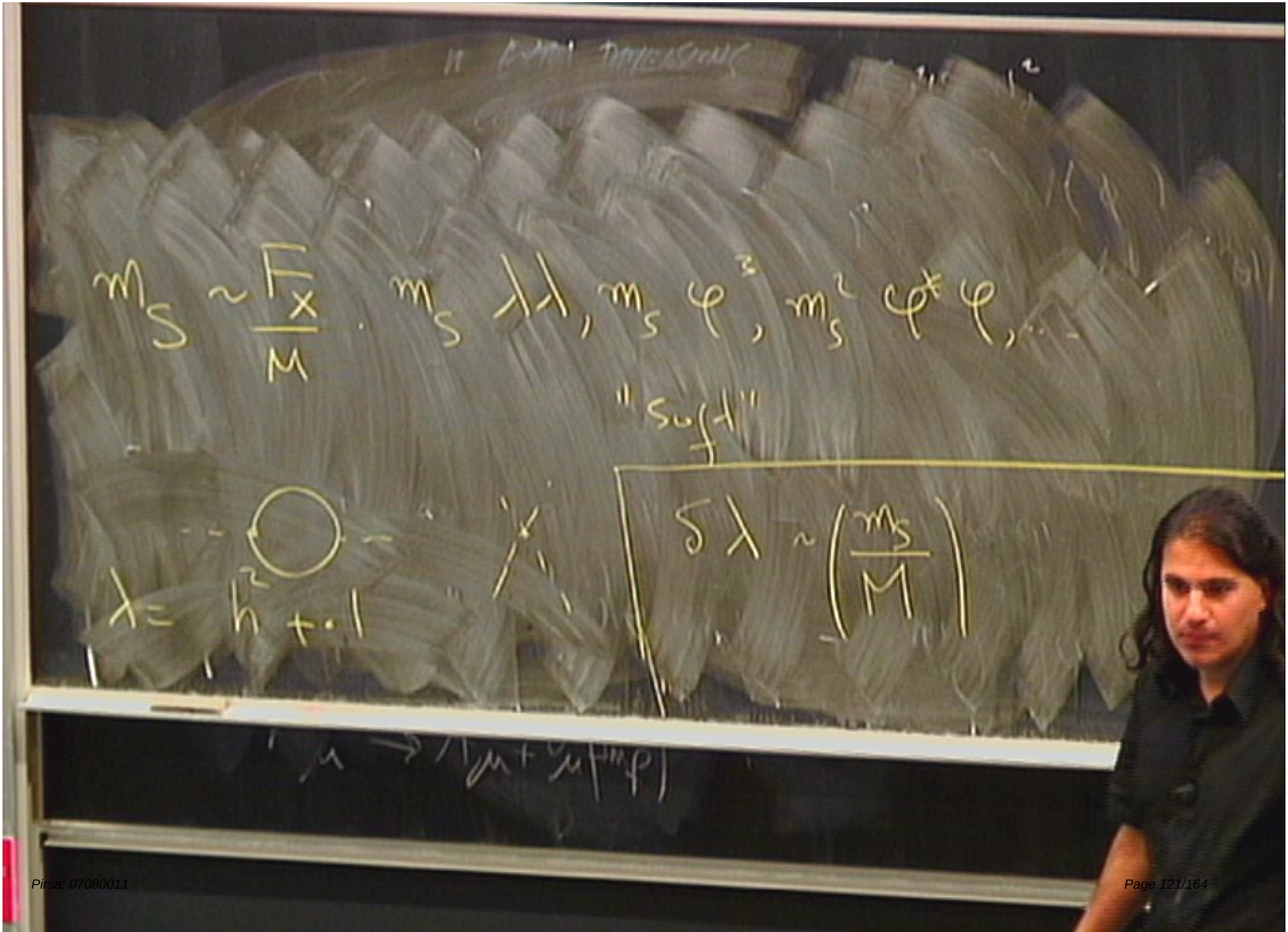

$m_S \sim \frac{F_X}{M}$. $m_S \lambda\lambda$, $m_s \varphi^3$, $m_s^2 \varphi^\dagger \varphi$, ...
"soft"

$$m_S \sim \frac{F_X}{M} : \quad m_S \lambda\lambda, \; m_S \varphi^3, \; m_S^2 \varphi^\dagger \varphi, \ldots$$

"soft"

$\lambda = h^2$


m_S ~ F_X / M
m_S λλ, m_s φ³, m_s² φ† φ, ...
"soft"
λ = h² + 1

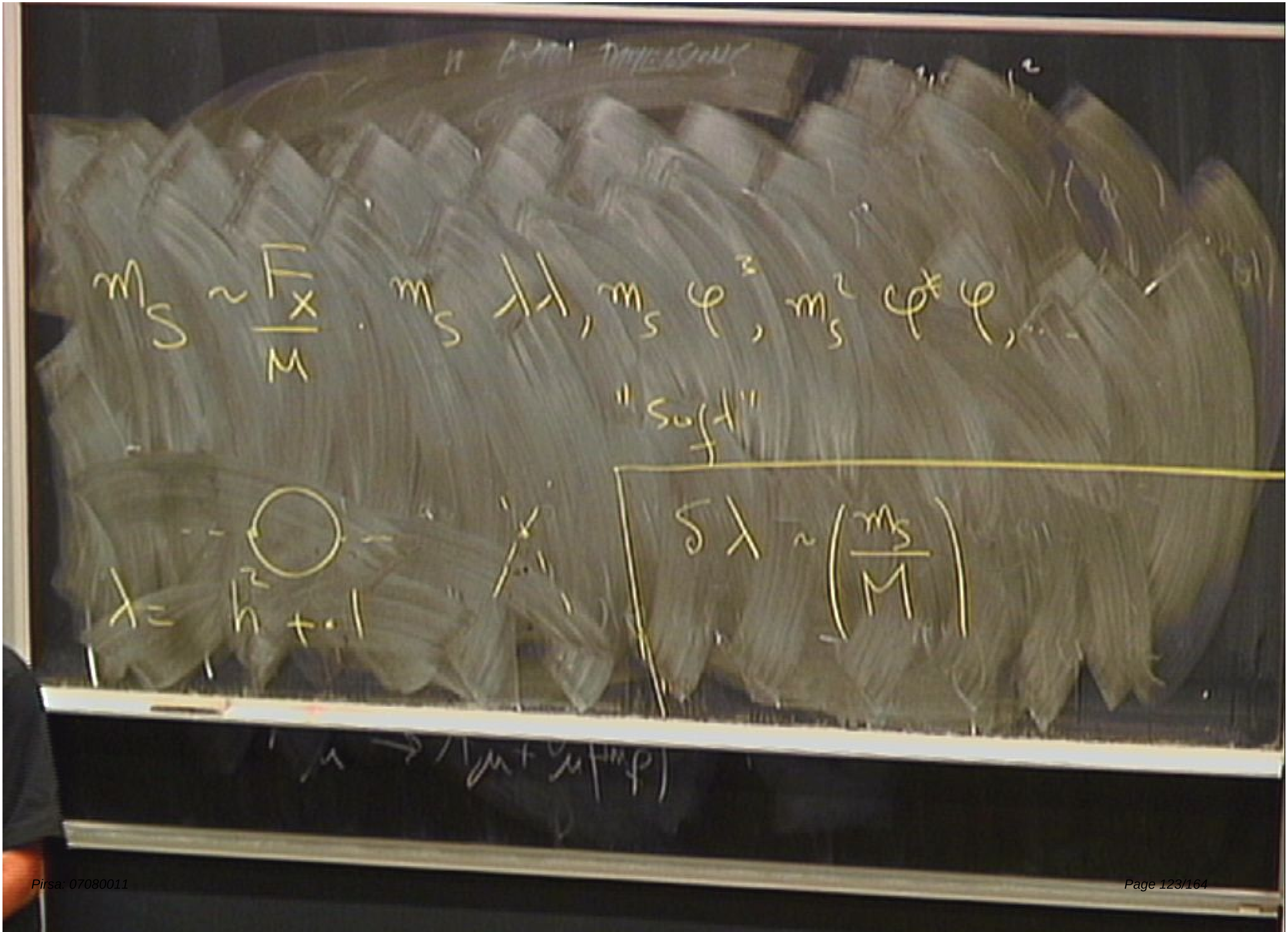

$m_S \sim \frac{F_X}{M}$
$m_S \lambda\lambda, m_s \varphi^3, m_s^2 \varphi^\dagger \varphi, \ldots$
"soft"
$\delta\lambda \sim \left(\frac{m_s}{M}\right)$
$\lambda = h^2 + \ldots$

$$m_S \sim \frac{F_X}{M} : \quad m_S \lambda\lambda, \; m_S \varphi^3, \; m_S^2 \varphi^\dagger \varphi, \ldots$$

"soft"

$$\lambda = h^2 + \ldots$$

$$\delta\lambda \sim \left(\frac{m_S}{M}\right)$$

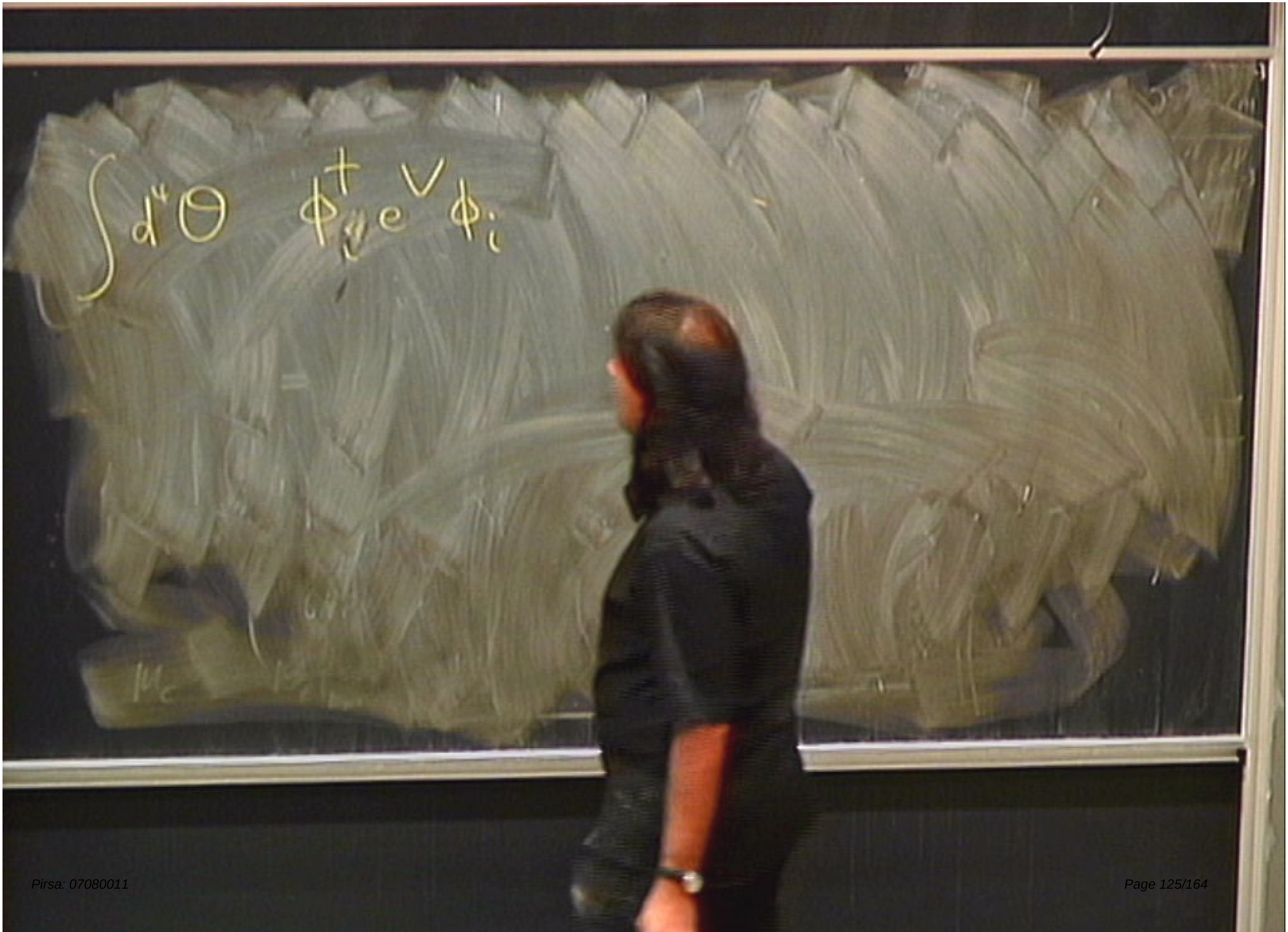

m_S ~ F_X / M : m_S λλ, m_S φ^3, m_S^2 φ†φ, ...
"soft"
δλ ~ (m_S / M)
λ = h^2 + ...

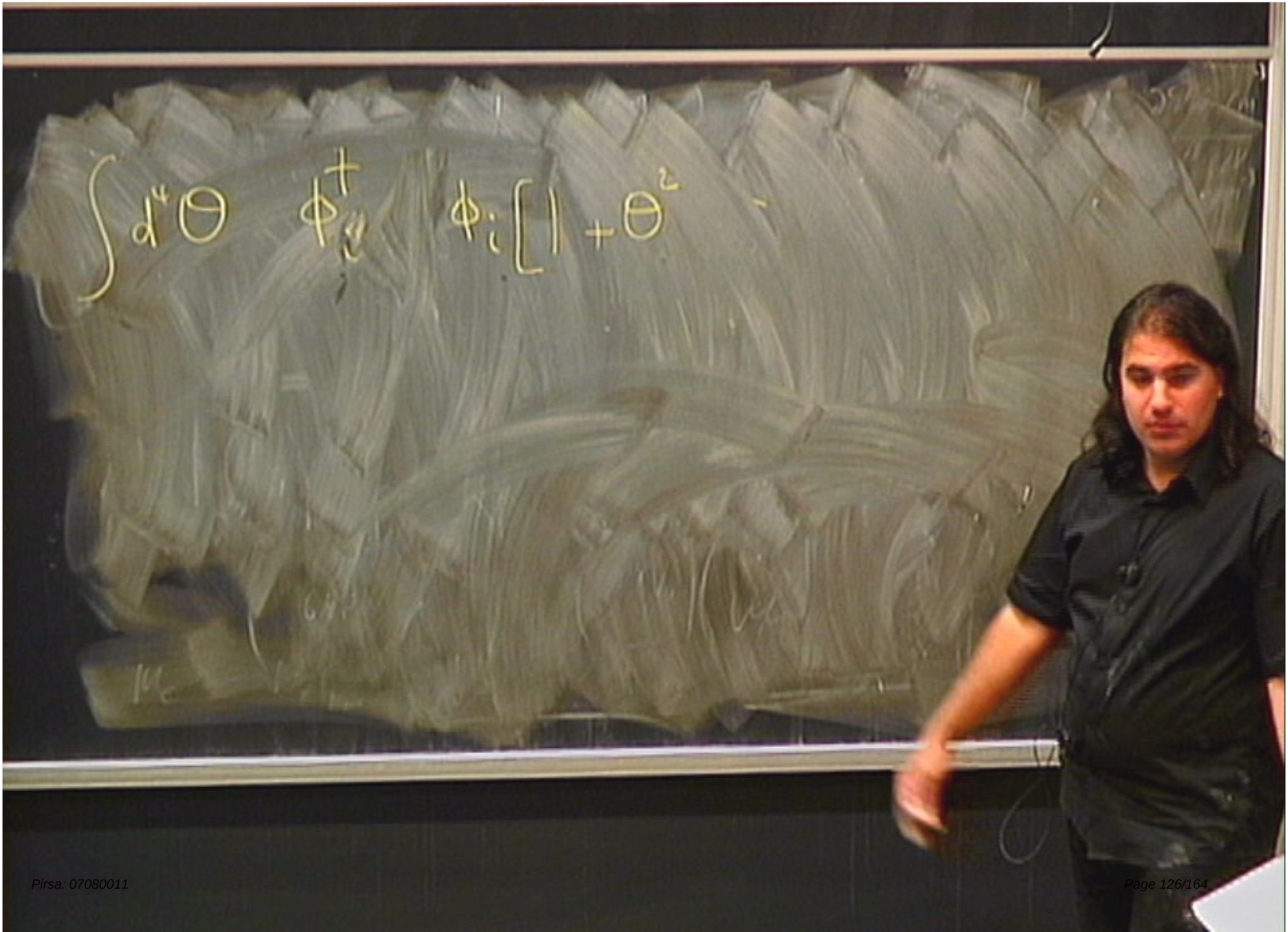
$$m_S \sim \frac{F_X}{M} \; : \; m_S \lambda\lambda, \; m_S \varphi^3, \; m_S^2 \varphi^\dagger \varphi, \ldots$$

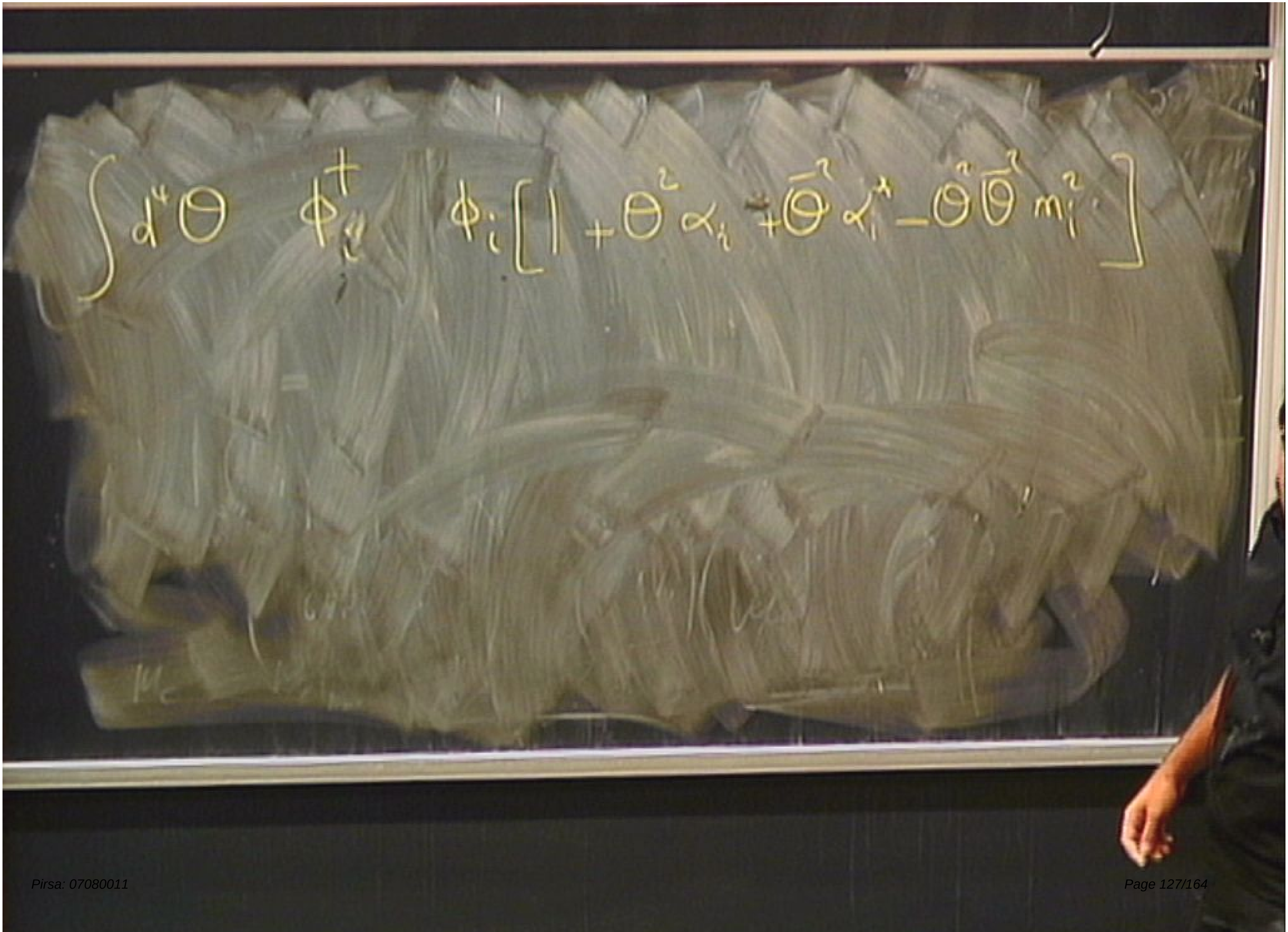
"soft"

$$\lambda = h^2 + \ldots$$

$$\delta\lambda \sim \left(\frac{m_S}{M}\right)$$

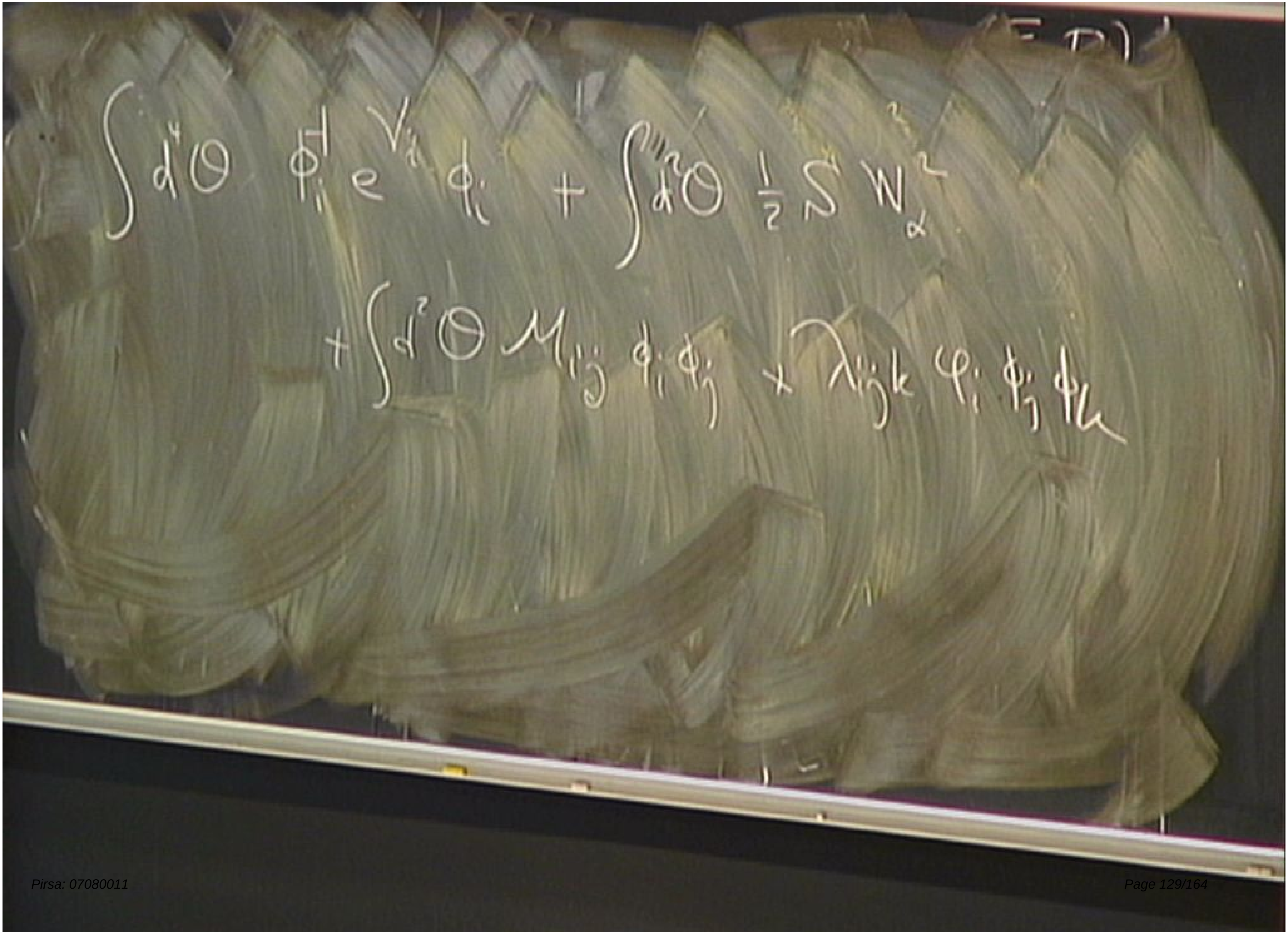

$\int d^4\theta \; \phi_i^\dagger e^V \phi_i$


∫d⁴θ φ†ᵢ φᵢ [1 + θ²


$\int d^4\theta \; \phi_i^\dagger \; \phi_i \left[1 + \theta^2 \alpha_i + \bar{\theta}^2 \alpha_i^* - \theta^2 \bar{\theta}^2 m_i^2 \right]$

$$\int d^4\theta \; \phi_i^\dagger \phi_i \left[1 + \theta^2 \alpha_i + \bar{\theta}^2 \alpha_i^* - \theta^2 \bar{\theta}^2 m_i^2 \right]$$

$$+ \int d^2\theta \left(\frac{1}{g^2} + \theta^2 \frac{m_\lambda}{g^2} \right) W_\alpha^2 + \int d^2\theta \left(m_{ij} \phi_i \phi_j (1 + \theta^2 b_{ij}) + \lambda_{ijk} \phi_i \phi_j \phi_k (1 + \theta^2 a_{ijk}) \right) + \ldots$$


$\int d^4\theta \; \phi_i^\dagger e^{V_i} \phi_i + \int d^2\theta \; \frac{1}{2} S \, W_\alpha^2$
$+ \int d^2\theta \; \mu_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$

$$\int d^4\theta \; \phi_i^\dagger Z_i \phi_i + \int d^2\theta \; \frac{1}{2} S W_\alpha^2$$

$$+ \int d^2\theta \; M_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$$

$$\int d^4\theta\ \phi_i^\dagger Z_i \phi_i + \int d^2\theta\ \frac{1}{2} S\, W_\alpha^2$$

$$+ \int d^2\theta\ \mu_{ij}\, \phi_i \phi_j + \lambda_{ijk}\, \phi_i \phi_j \phi_k$$

$$Z_i = e^{V_i}$$

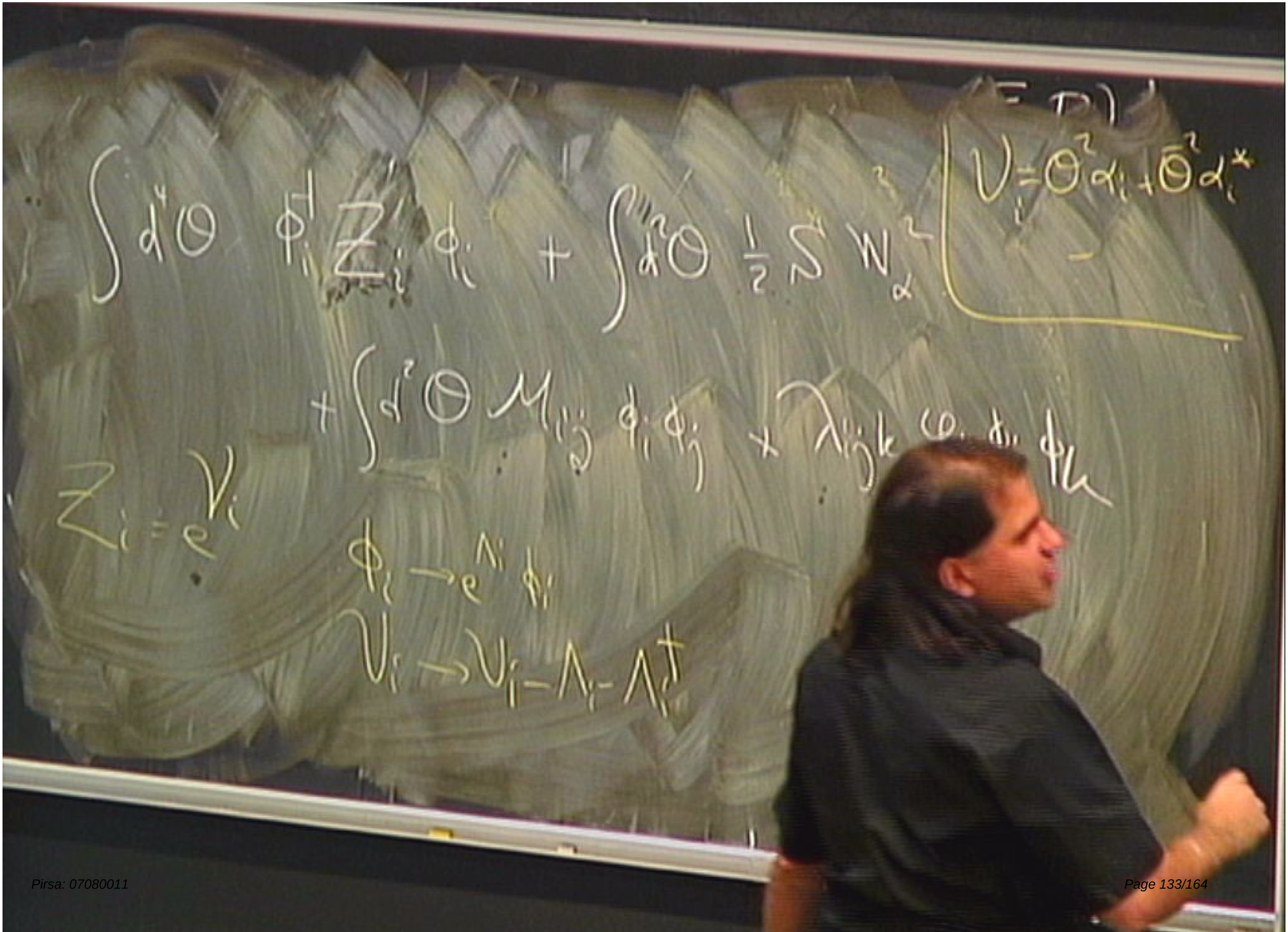
$$\int d^4\theta \; \phi_i^\dagger Z_i \phi_i + \int d^2\theta \; \tfrac{1}{2} S \, W_\alpha^2$$

$$+ \int d^2\theta \; \mu_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$$

$$Z_i = e^{V_i}$$

$$\phi_i \to e^{\Lambda_i} \phi_i$$

$$V_i \to V_i - \Lambda_i - \Lambda_i^\dagger$$


$\int d^4\theta \; \phi_i^\dagger Z_i \phi_i + \int d^2\theta \; \frac{1}{2} S \, W_\alpha^2$
$V_i = \theta^2 \alpha_i + \bar{\theta}^2 \alpha_i^*$
$+ \int d^2\theta \; M_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$
$Z_i = e^{V_i}$
$\phi_i \to e^{\Lambda_i} \phi_i$
$V_i \to V_i - \Lambda_i - \Lambda_i^\dagger$

$$\int d^4\theta \; \phi_i^\dagger Z_i \phi_i + \int d^2\theta \; \frac{1}{2} S \, W_\alpha^2$$

$$V_i = \theta^2 \alpha_i + \bar{\theta}^2 \alpha_i^* - \theta^2 \bar{\theta}^2 m_i^2$$

$$+ \int d^2\theta \; \mu_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$$

$$Z_i = e^{V_i}$$

$$\phi_i \to e^{\Lambda_i} \phi_i$$

$$V_i \to V_i - \Lambda_i - \Lambda_i^\dagger$$

$$\int d^4\theta \; \phi_i^\dagger Z_i \phi_i + \int d^2\theta \; \tfrac{1}{2} S \, W_\alpha^2$$

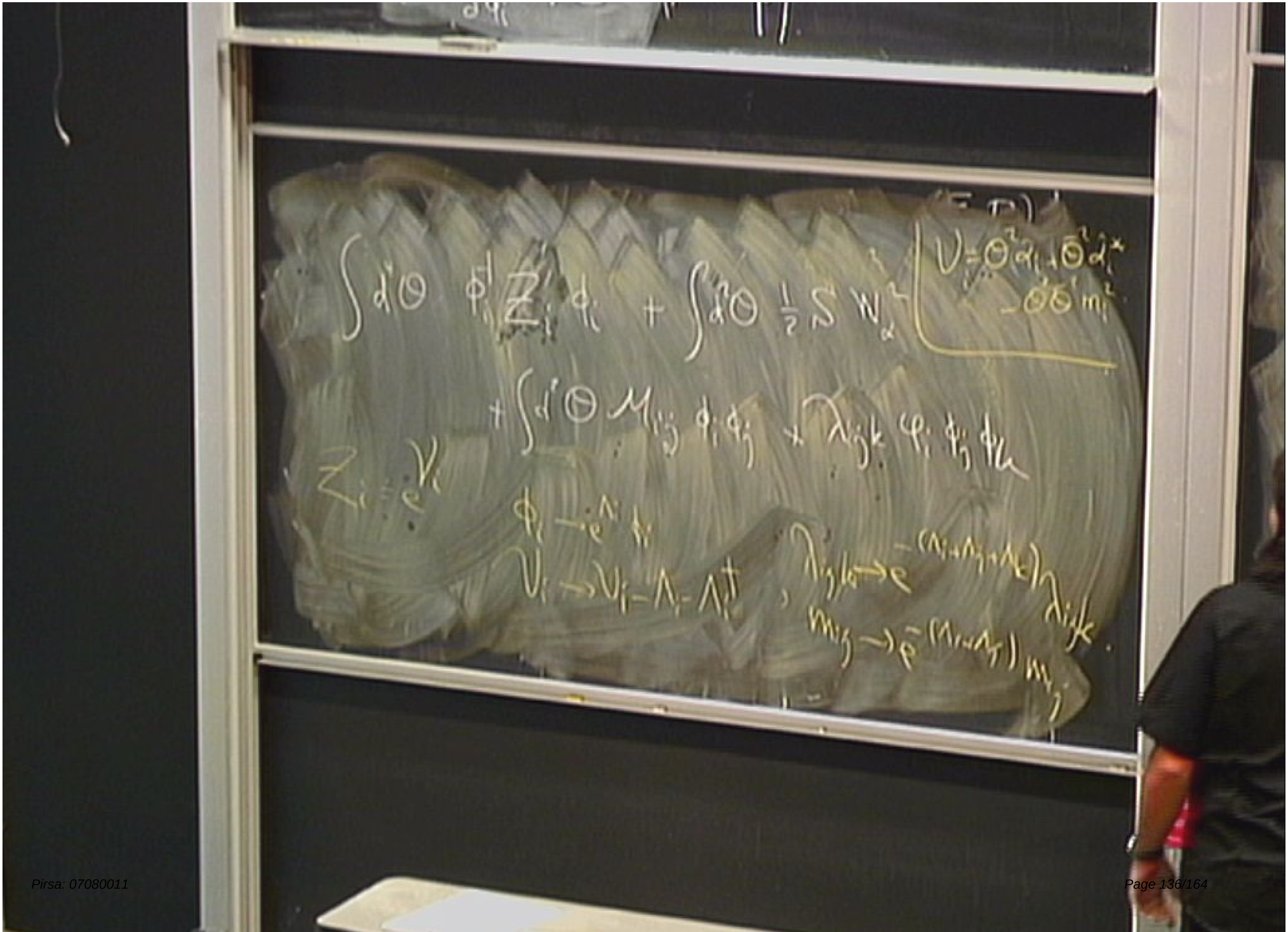
$$+ \int d^2\theta \; \mu_{ij} \phi_i \phi_j + \lambda_{ijk} \phi_i \phi_j \phi_k$$

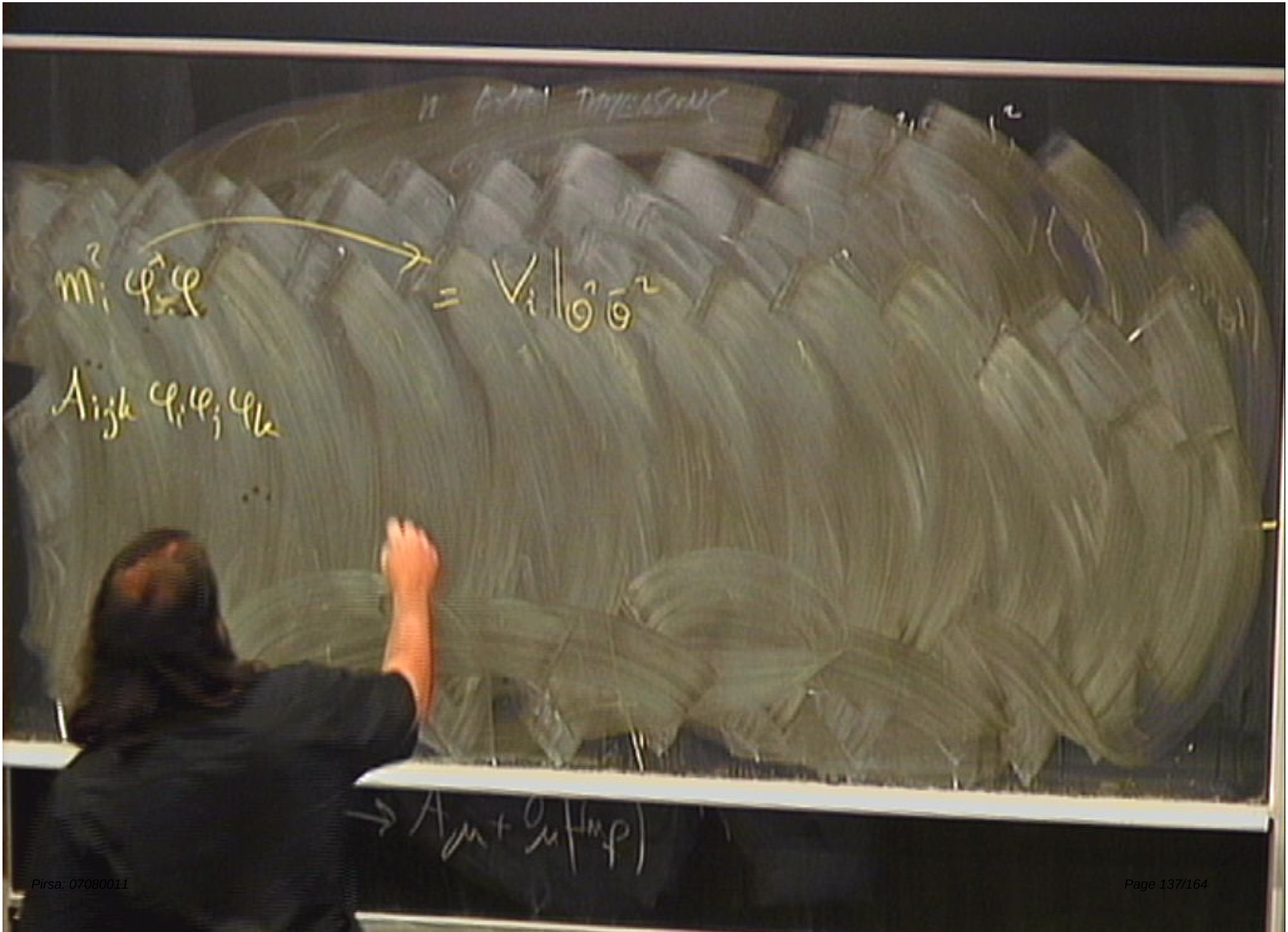
$$V_i = \theta^2 \alpha_i + \bar\theta^2 \alpha_i^* - \theta^2 \bar\theta^2 m_i^2$$

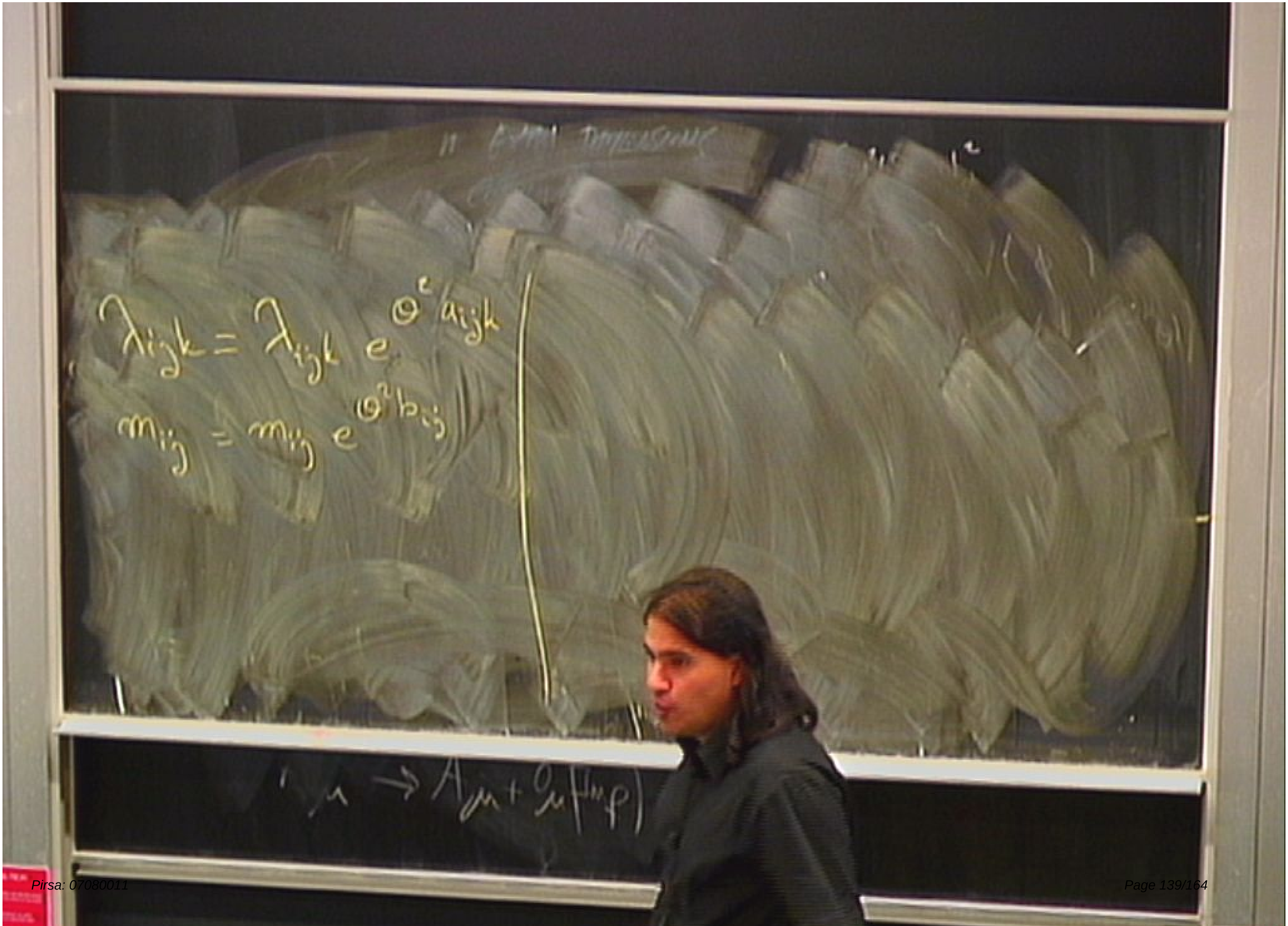
$$Z_i = e^{V_i}$$

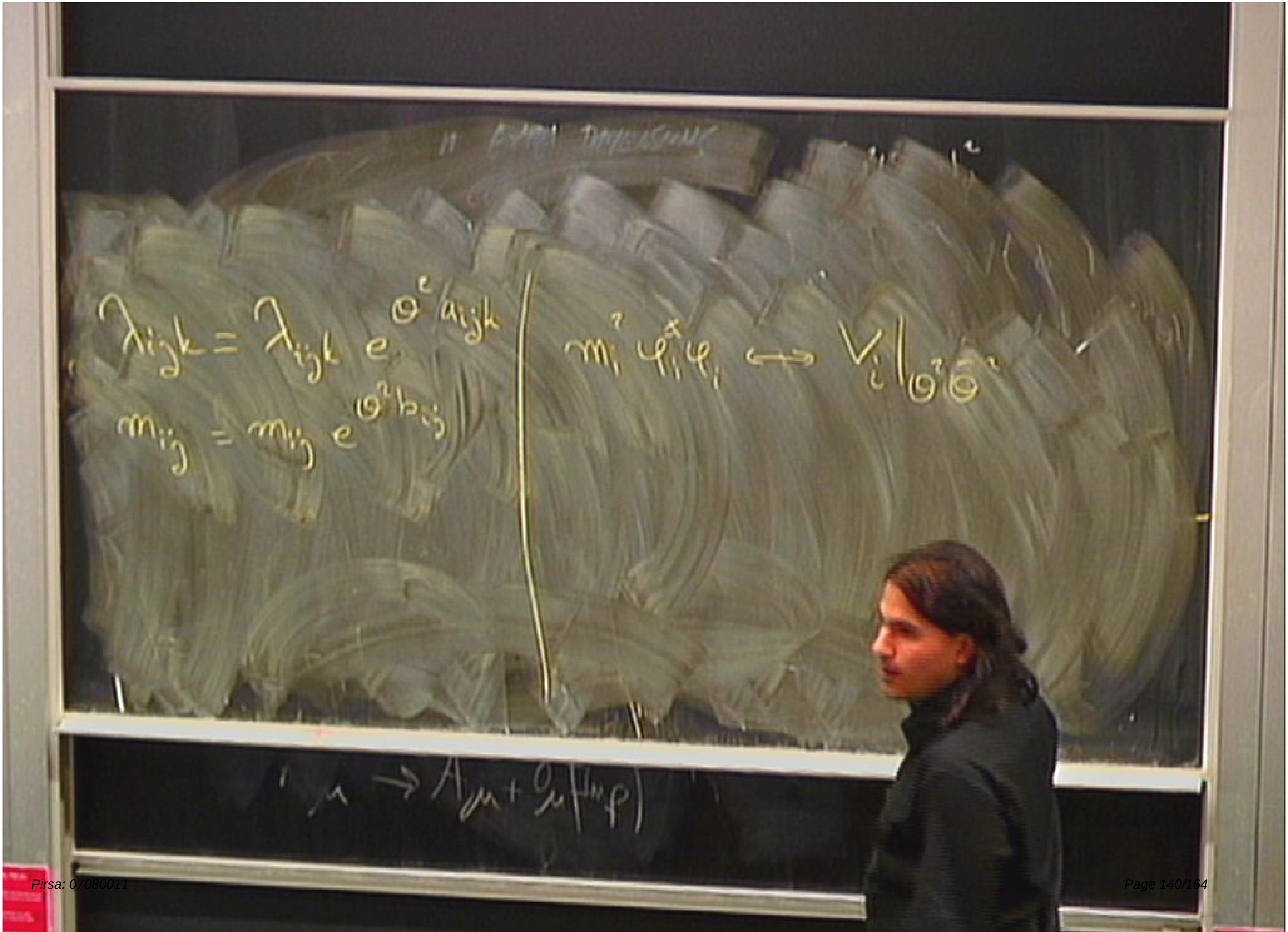
$$\phi_i \to e^{\Lambda_i} \phi_i$$

$$V_i \to V_i - \Lambda_i - \Lambda_i^\dagger \,, \quad \lambda_{ijk} \to e^{-(\Lambda_i + \Lambda_j + \Lambda_k)} \lambda_{ijk} .$$


∫d⁴θ φᵢ† Zᵢ φᵢ + ∫d²θ ½ S W_α²
V = θ²αᵢ + θ̄²αᵢ* − θθ̄ mᵢ²
+ ∫d²θ μᵢⱼ φᵢ φⱼ + λᵢⱼₖ φᵢ φⱼ φₖ
Zᵢ = e^Vᵢ
φᵢ → e^Λᵢ φᵢ
Vᵢ → Vᵢ − Λᵢ − Λᵢ†
λᵢⱼₖ → e^−(Λᵢ+Λⱼ+Λₖ) λᵢⱼₖ
mᵢⱼ → e^−(Λᵢ+Λⱼ) mᵢⱼ




λijk = λijk e^(Θ² aijk)
mij = mij e^(Θ² bij)
Aμ → Aμ + ∂μ(Im ρ)


$\lambda_{ijk} = \lambda_{ijk}\, e^{\theta^2 a_{ijk}}$
$m_{ij} = m_{ij}\, e^{\theta^2 b_{ij}}$
$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i|_{\theta^2\bar{\theta}^2}$

$$\lambda_{ijk} = \lambda_{ijk}\, e^{\Theta^2 a_{ijk}}$$

$$m_{ij} = m_{ij}\, e^{\Theta^2 b_{ij}}$$

$$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i\big|_{\Theta^2\bar{\Theta}^2} = m_i^2$$

$$\lambda_{ijk} A_{ijk}\, \varphi_i \varphi_j \varphi_k \qquad A_{ijk} = a_{ijk}$$

$$A_\mu \to A_\mu + \partial_\mu (\operatorname{Im} \rho)$$

$$\lambda_{ijk} = \lambda_{ijk}\, e^{\Theta^2 a_{ijk}}$$

$$m_{ij} = m_{ij}\, e^{\Theta^2 b_{ij}}$$

$$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i \big|_{\Theta^2 \bar{\Theta}^2} = m_i^2$$

$$\lambda_{ijk} A_{ijk} \varphi_i \varphi_j \varphi_k \qquad A_{ijk} = a_{ijk} + \alpha_i + \alpha_j + \alpha_k$$

$$A_\mu \rightarrow A_\mu + \partial_\mu(\mathrm{Im}\,\rho)$$

$$\lambda_{ijk} = \lambda_{ijk}\, e^{\theta^2 a_{ijk}}$$

$$m_{ij} = m_{ij}\, e^{\theta^2 b_{ij}}$$

$$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i\big|_{\theta^2\bar{\theta}^2} = m_i^2$$

$$\lambda_{ijk} A_{ijk} \varphi_i \varphi_j \varphi_k \qquad A_{ijk} = a_{ijk} + \alpha_i + \alpha_j + \alpha_k$$

$$B_{ij} m_{ij} \varphi_i \varphi_j \qquad B_{ij} = b_{ij} + \alpha_i + \alpha_j$$

$$A_\mu \rightarrow A_\mu + \partial_\mu(\mathrm{Im}\,\rho)$$

$$\lambda_{ijk} = \lambda_{ijk}\, e^{\Theta^2 a_{ijk}}$$

$$m_{ij} = m_{ij}\, e^{\Theta^2 b_{ij}}$$

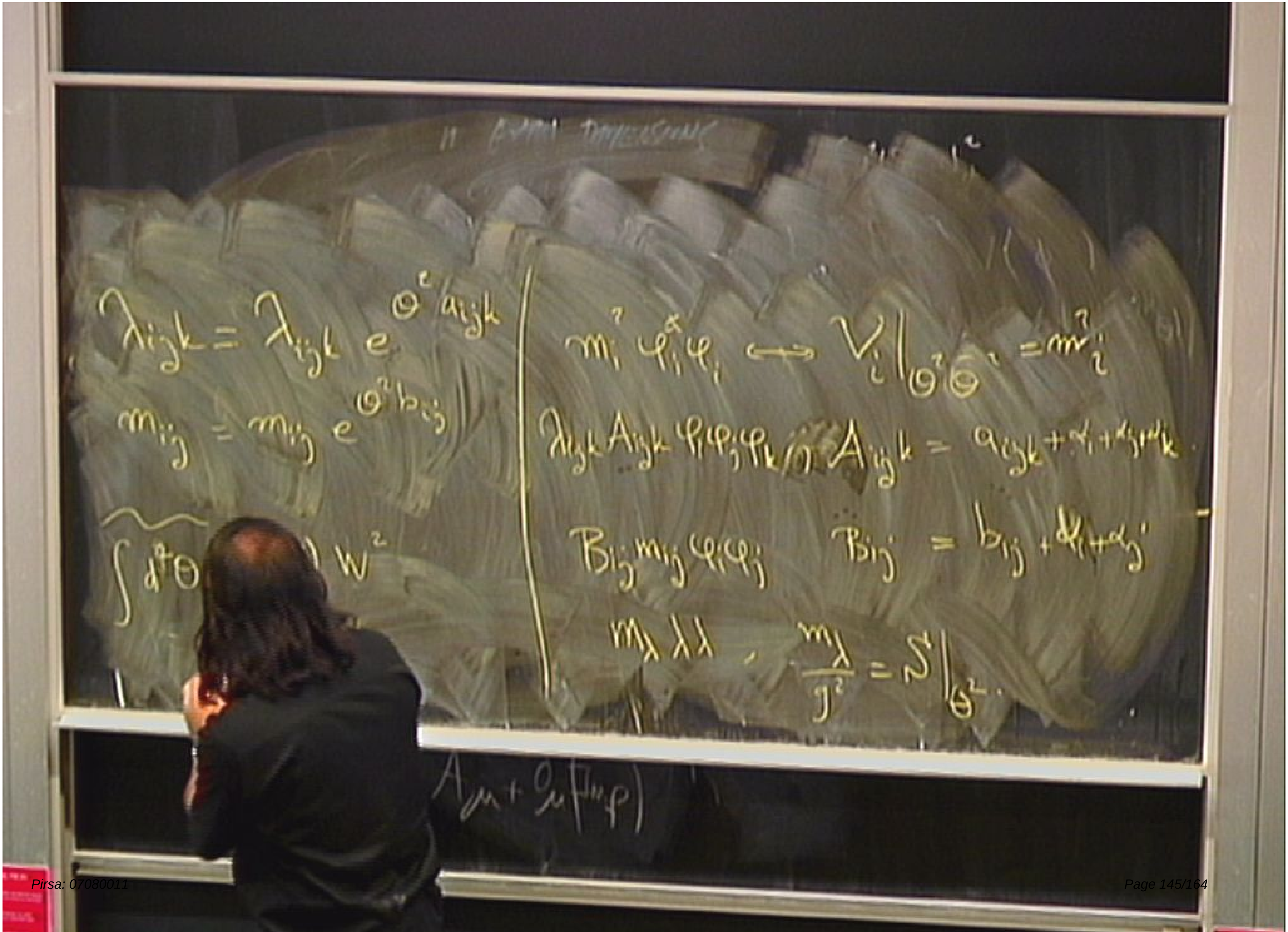
$$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i\big|_{\Theta^2\bar{\Theta}^2} = m_i^2$$

$$\lambda_{ijk} A_{ijk} \varphi_i \varphi_j \varphi_k \qquad A_{ijk} = a_{ijk} + \alpha_i + \alpha_j + \alpha_k$$

$$B_{ij} m_{ij} \varphi_i \varphi_j \qquad B_{ij} = b_{ij} + \alpha_i + \alpha_j$$

$$m_\lambda \lambda\lambda \,, \quad \frac{m_\lambda}{g^2} = S\big|_{\Theta^2}.$$

$$A_\mu \to A_\mu + \partial_\mu (\mathrm{Im}\,\rho)$$


λijk = λijk e θ² aijk
mij = mij e θ² bij
∫ d⁴θ W²
m²i φ*i φi ⟷ Vi |θ²θ̄² = m²i
λijk Aijk φi φj φk   Aijk = aijk + αi + αj + αk
Bij mij φi φj   Bij = bij + αi + αj
mλ λλ ,   mλ / g² = S |θ²

$$\lambda_{ijk} = \lambda_{ijk}\, e^{\theta^2 a_{ijk}}$$

$$m_{ij} = m_{ij}\, e^{\theta^2 b_{ij}}$$

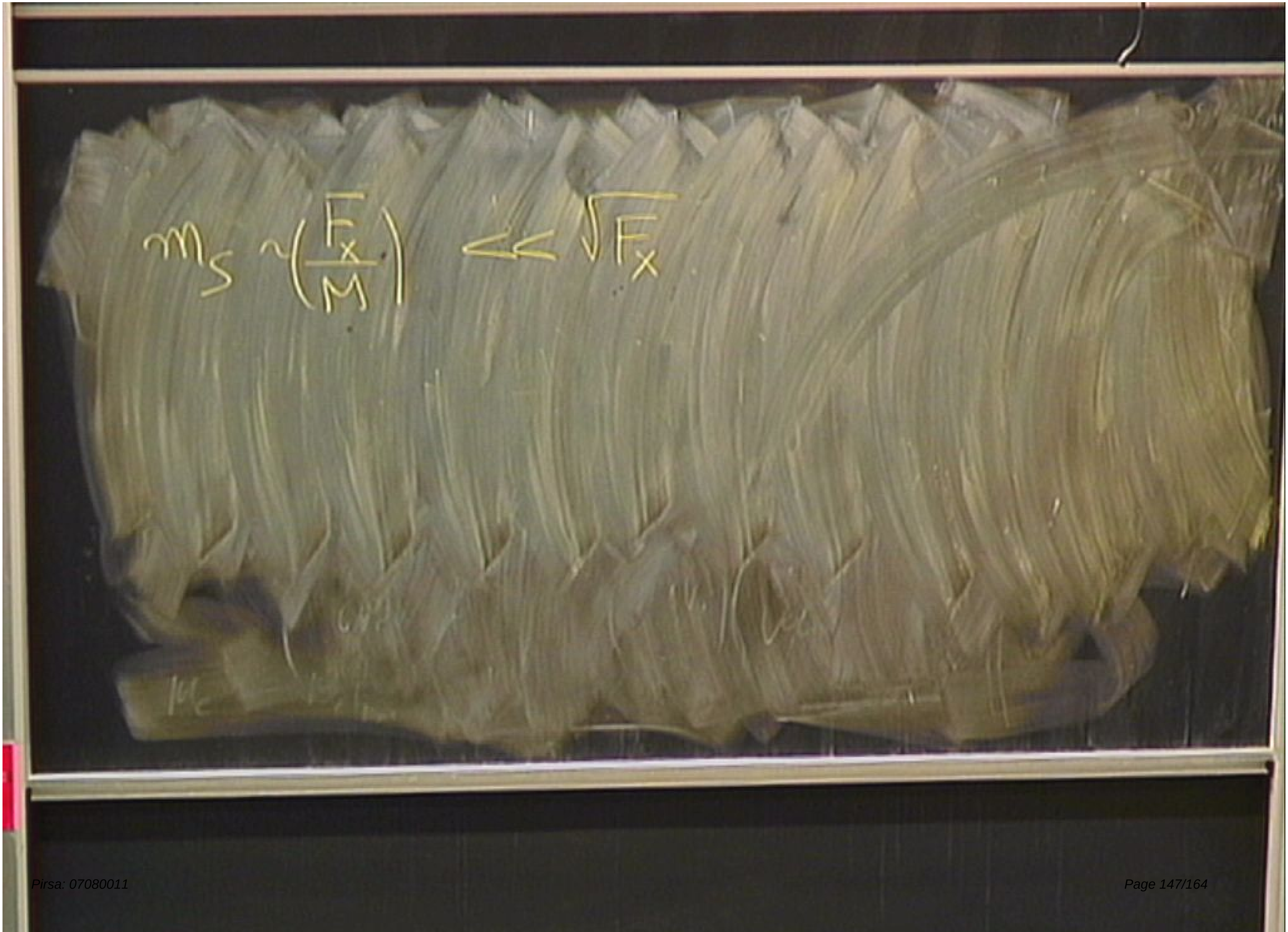
$$m_i^2 \varphi_i^\dagger \varphi_i \longleftrightarrow V_i\big|_{\theta^2\bar\theta^2} = m_i^2$$

$$\lambda_{ijk} A_{ijk} \varphi_i \varphi_j \varphi_k \qquad A_{ijk} = a_{ijk} + \alpha_i + \alpha_j + \alpha_k$$

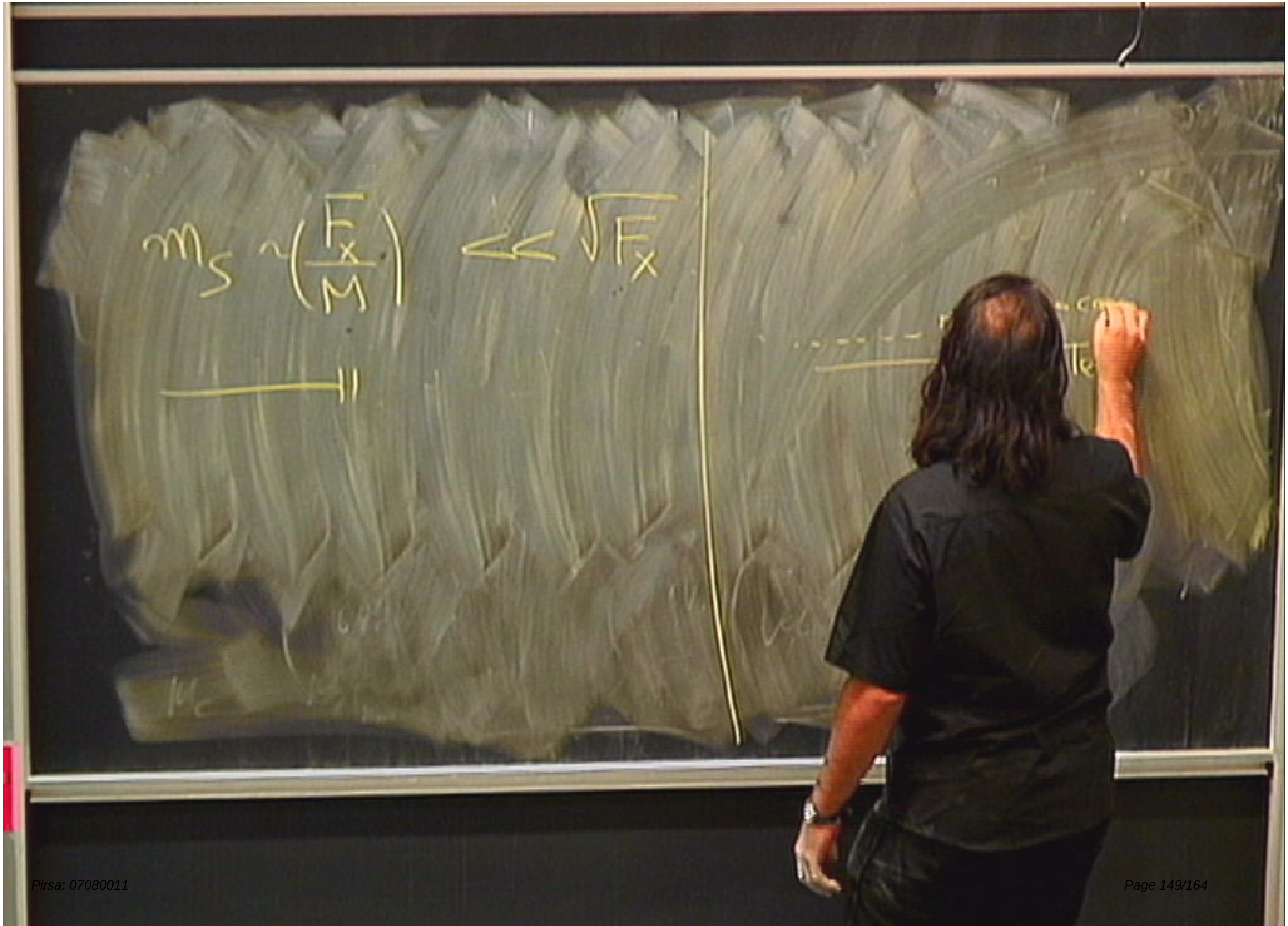
$$B_{ij} m_{ij} \varphi_i \varphi_j \qquad B_{ij} = b_{ij} + \alpha_i + \alpha_j$$

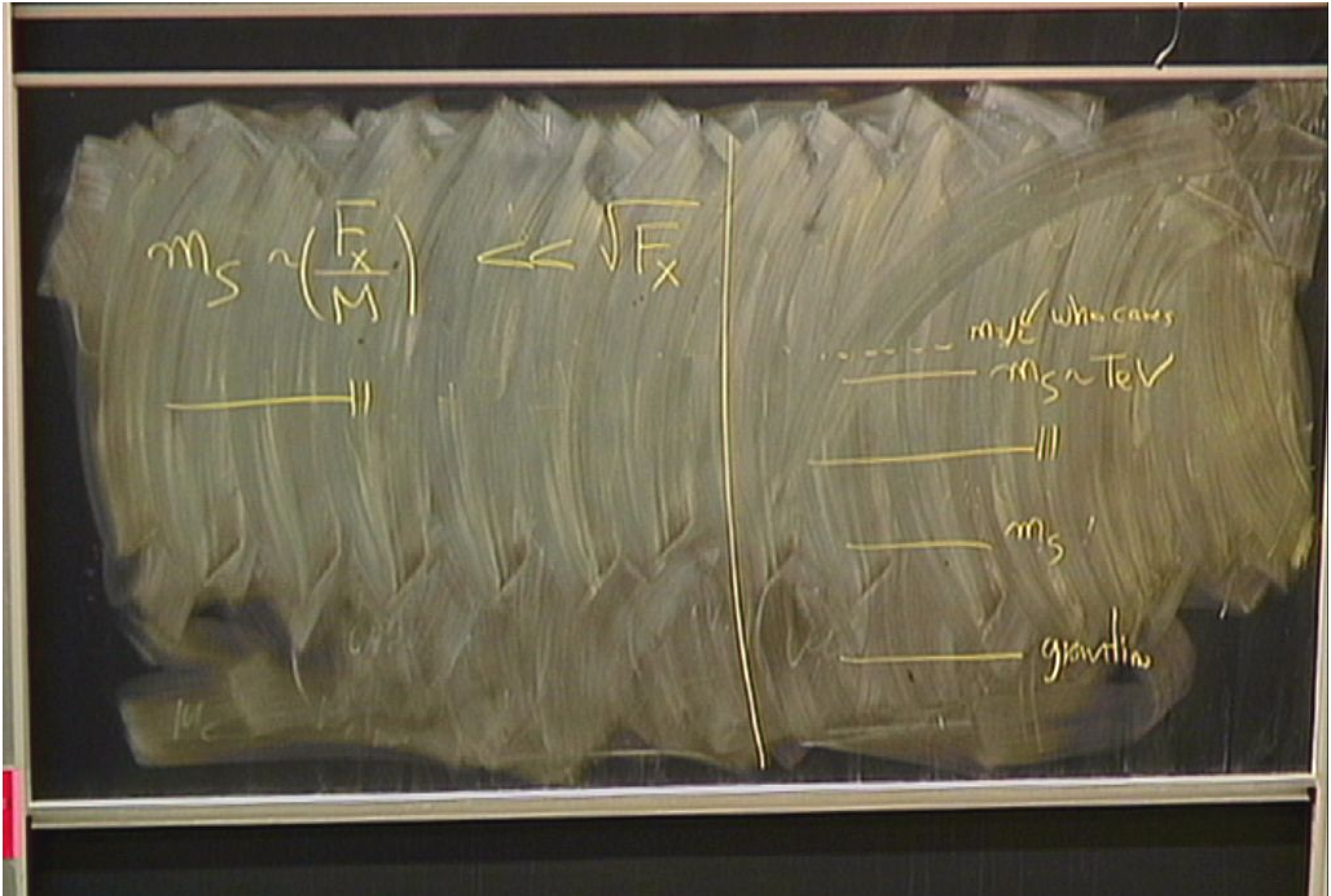
$$m_\lambda \lambda\lambda \;, \quad \frac{m_\lambda}{g^2} = S\big|_{\theta^2}$$

$$A_\mu \to A_\mu + \partial_\mu (\operatorname{Im} \rho)$$

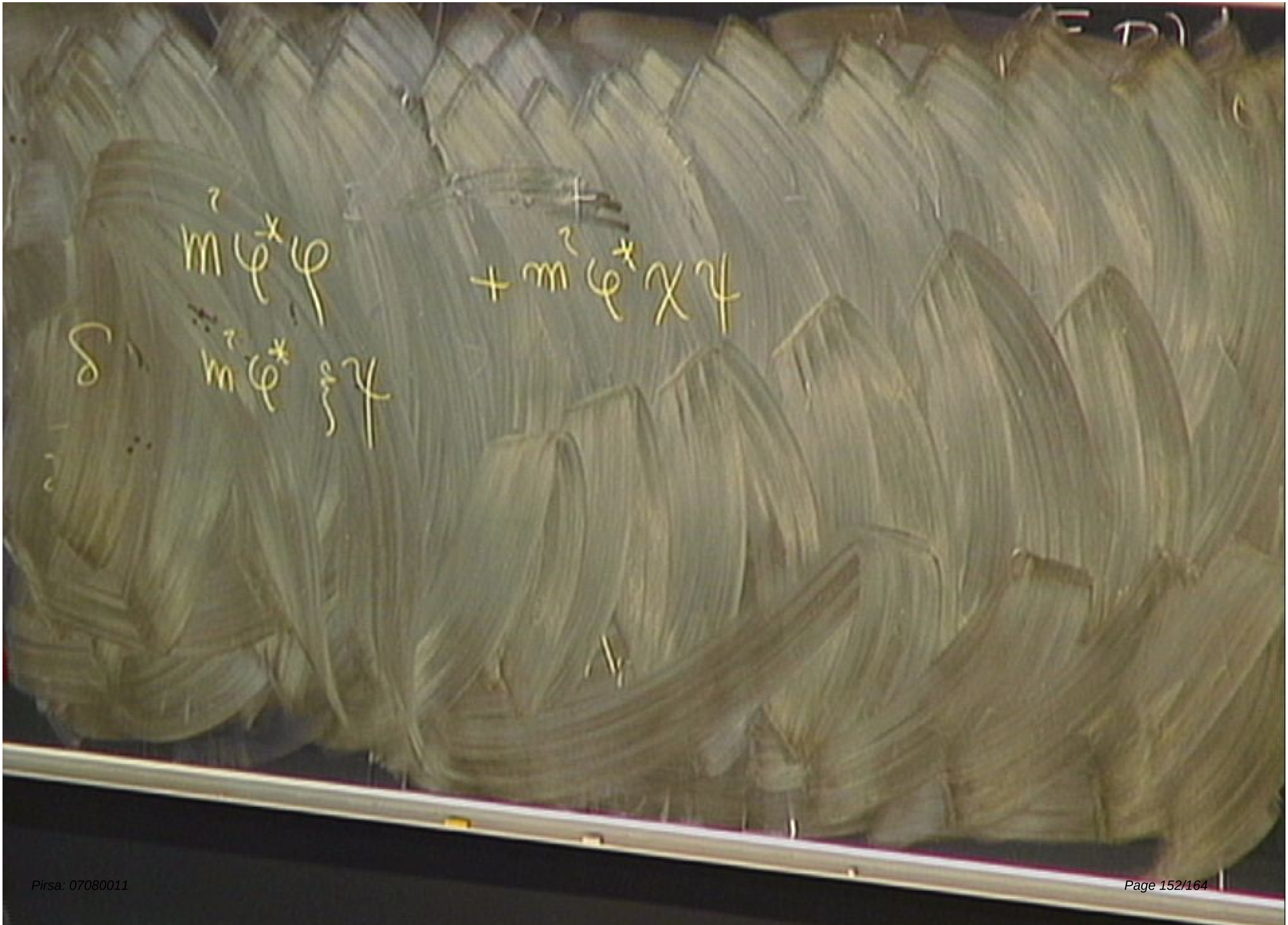

$m_S \sim \left(\frac{F_X}{M}\right) << \sqrt{F_X}$

$$m_S \sim \left(\frac{F_X}{M}\right) \ll \sqrt{F_X}$$

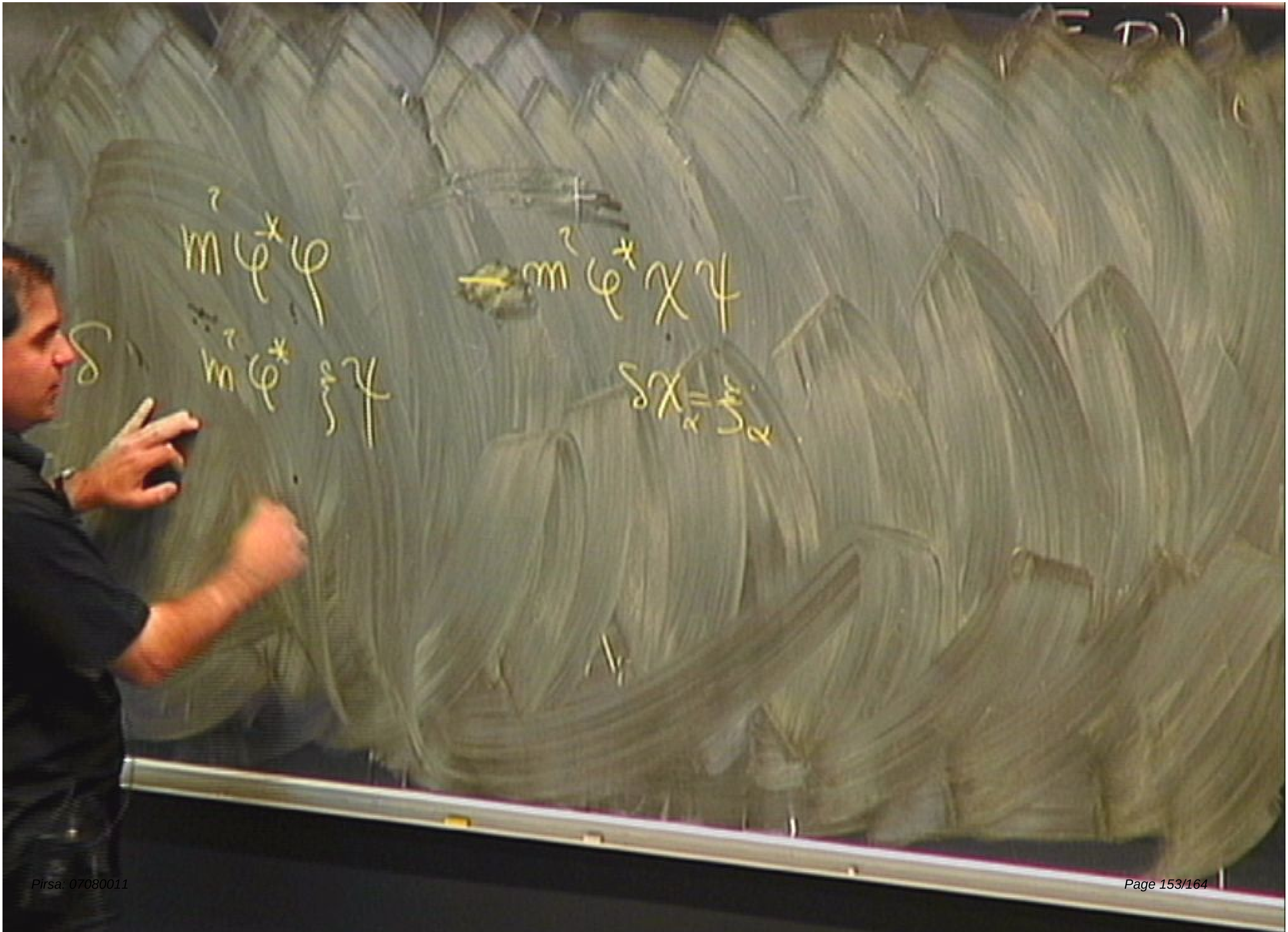

$m_S \sim \left(\frac{F_X}{M}\right) \ll \sqrt{F_X}$

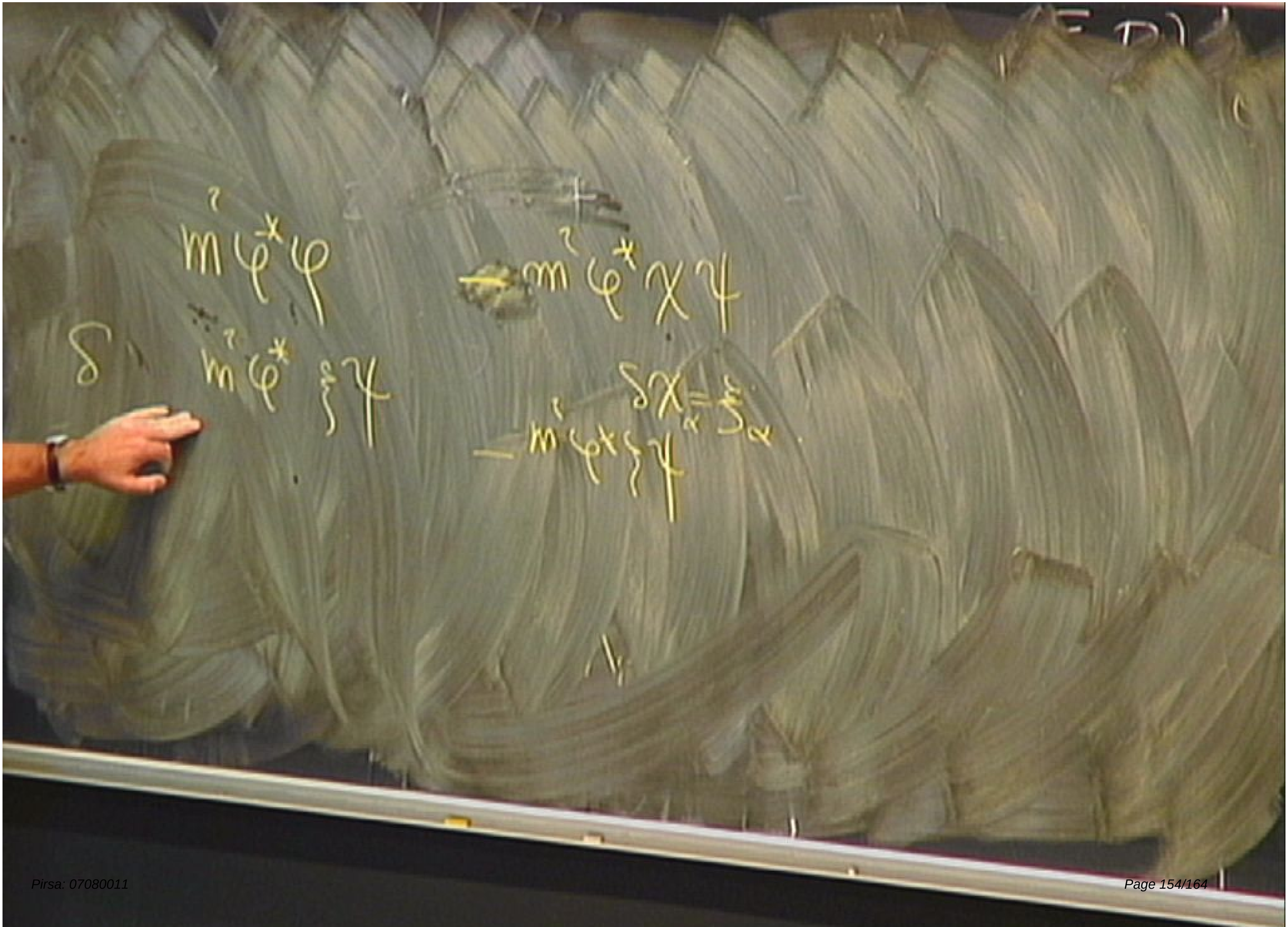

$m_S \sim \left(\frac{F_X}{M}\right) \ll \sqrt{F_X}$
$m_{3/2}$ who cares
$m_S \sim$ TeV
m_S'
gravitino

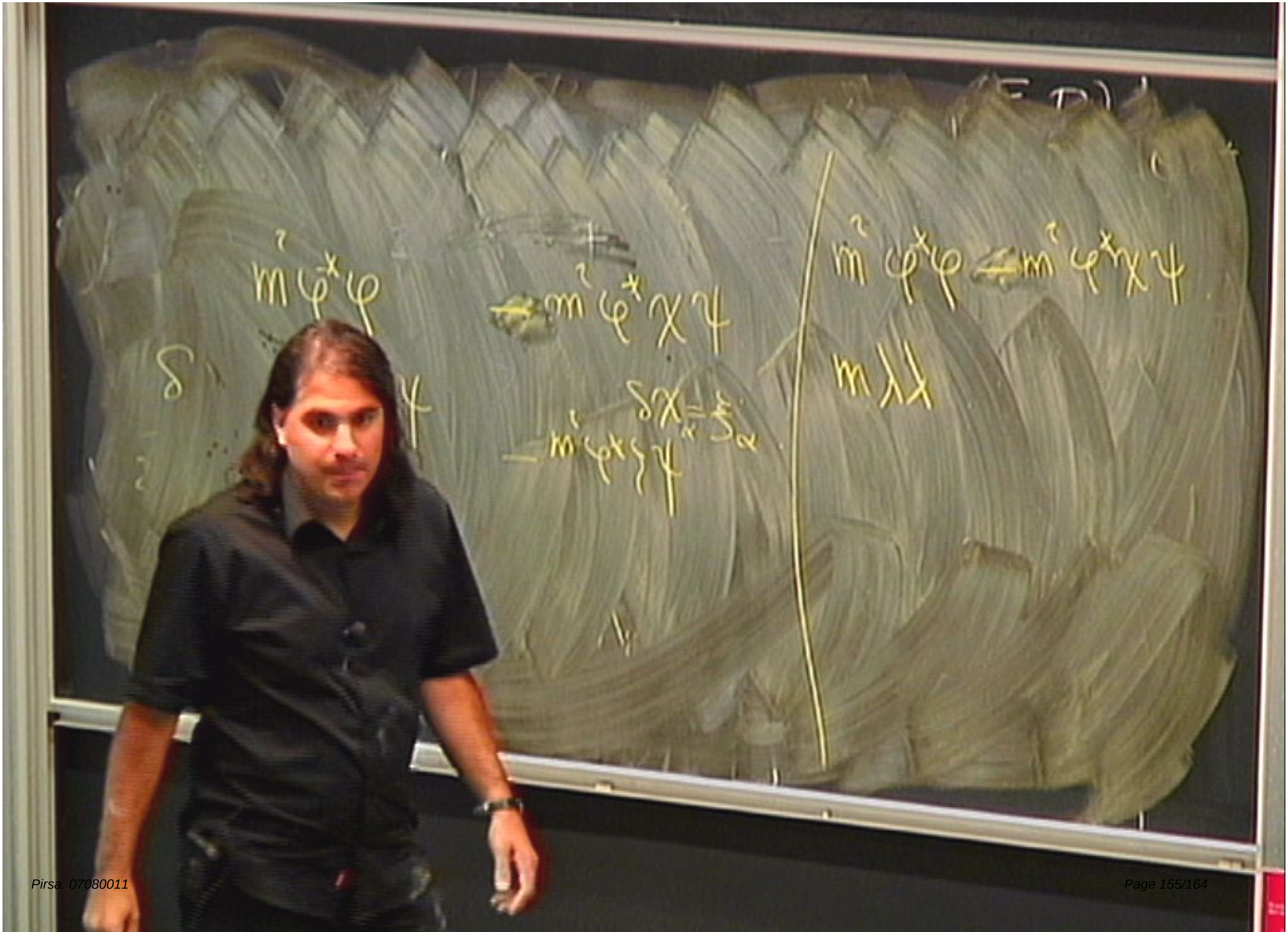

$m^2 \varphi^* \varphi$



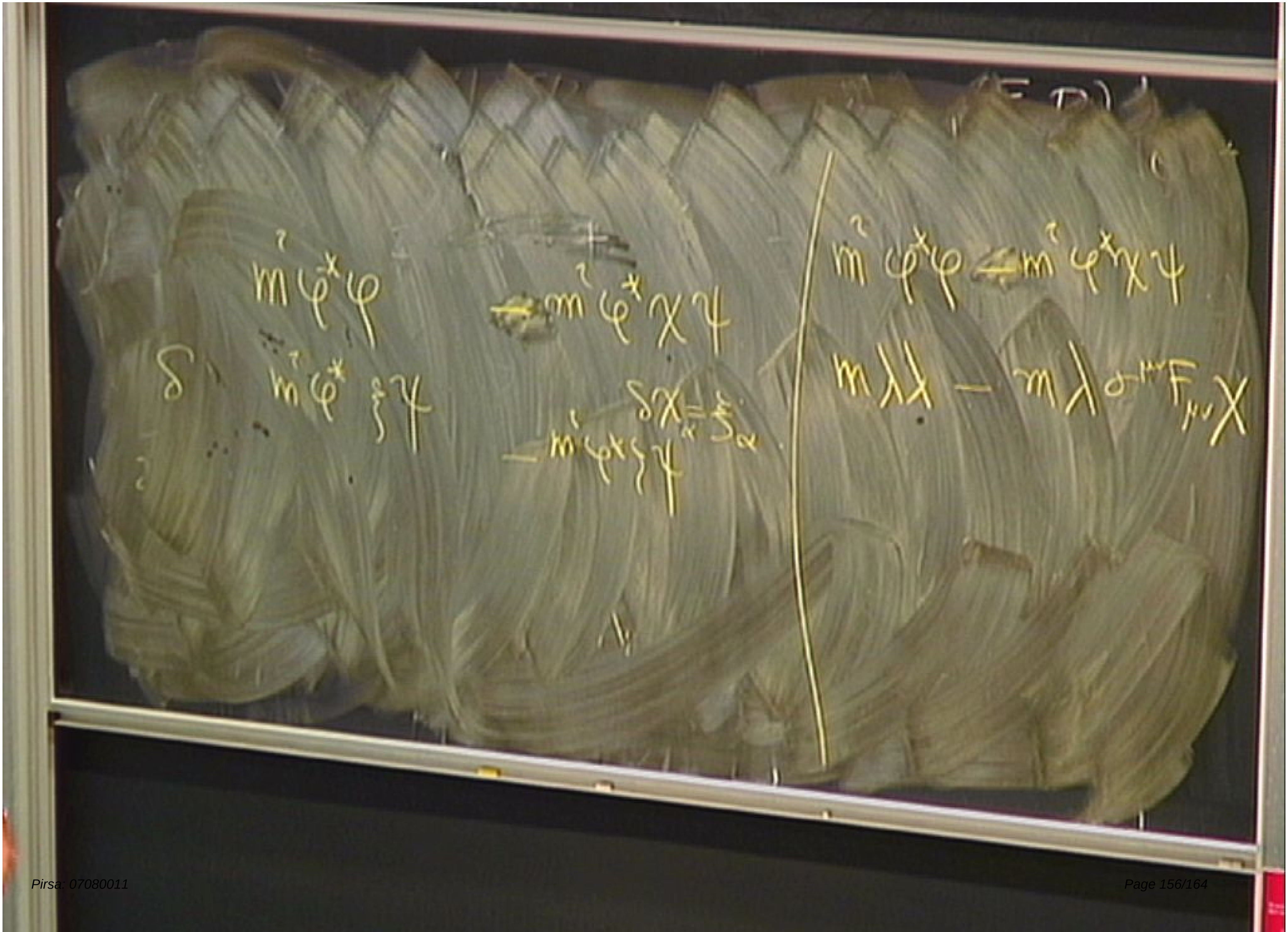
$m^2 \varphi^* \varphi$
$+ m^2 \varphi^* \chi \psi$
δ
$m^2 \varphi^* \xi \psi$

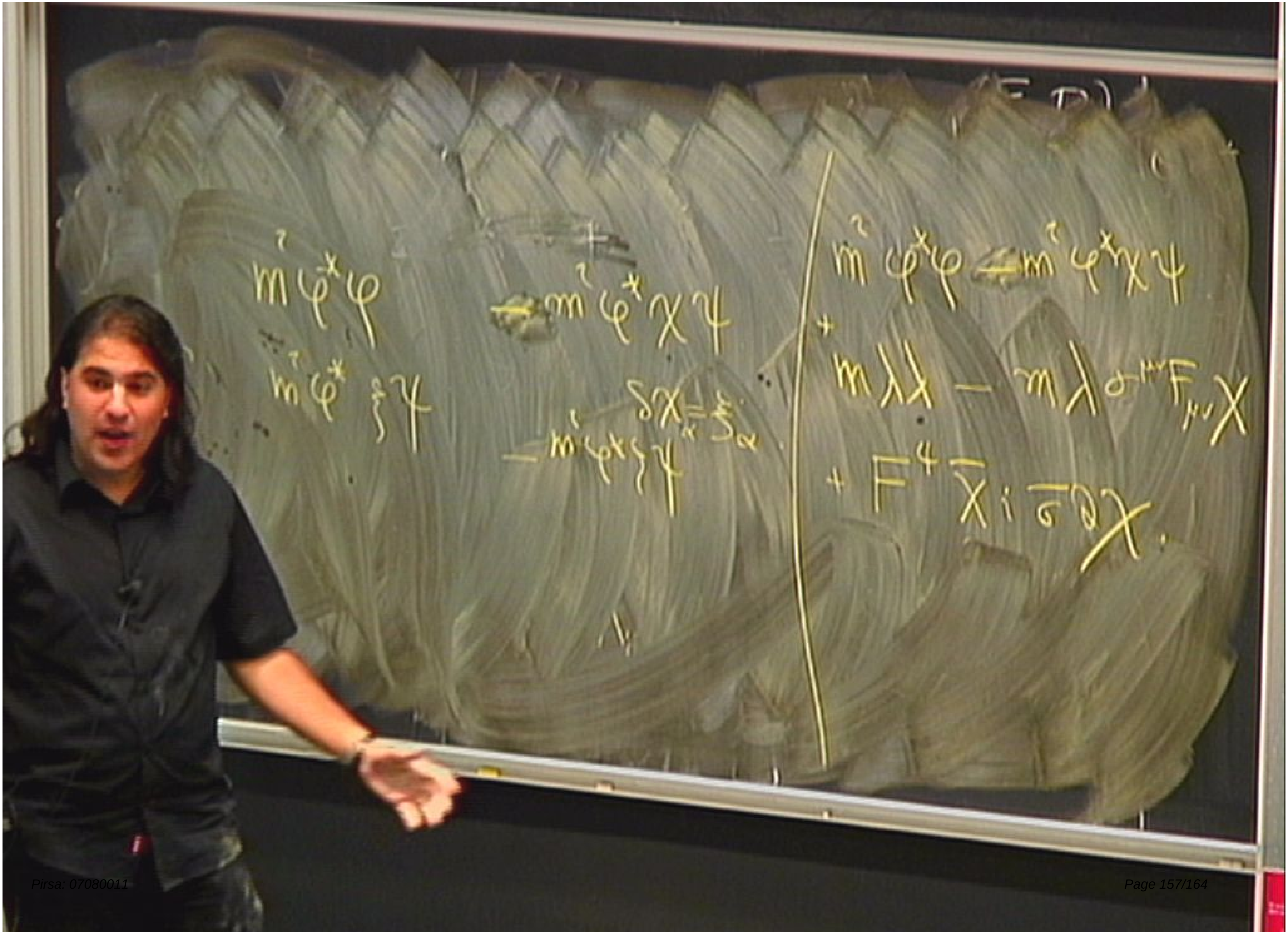

m² φ* φ
m² φ* χ ψ
δ
m² φ* ξ ψ
δχ_α = ξ_α

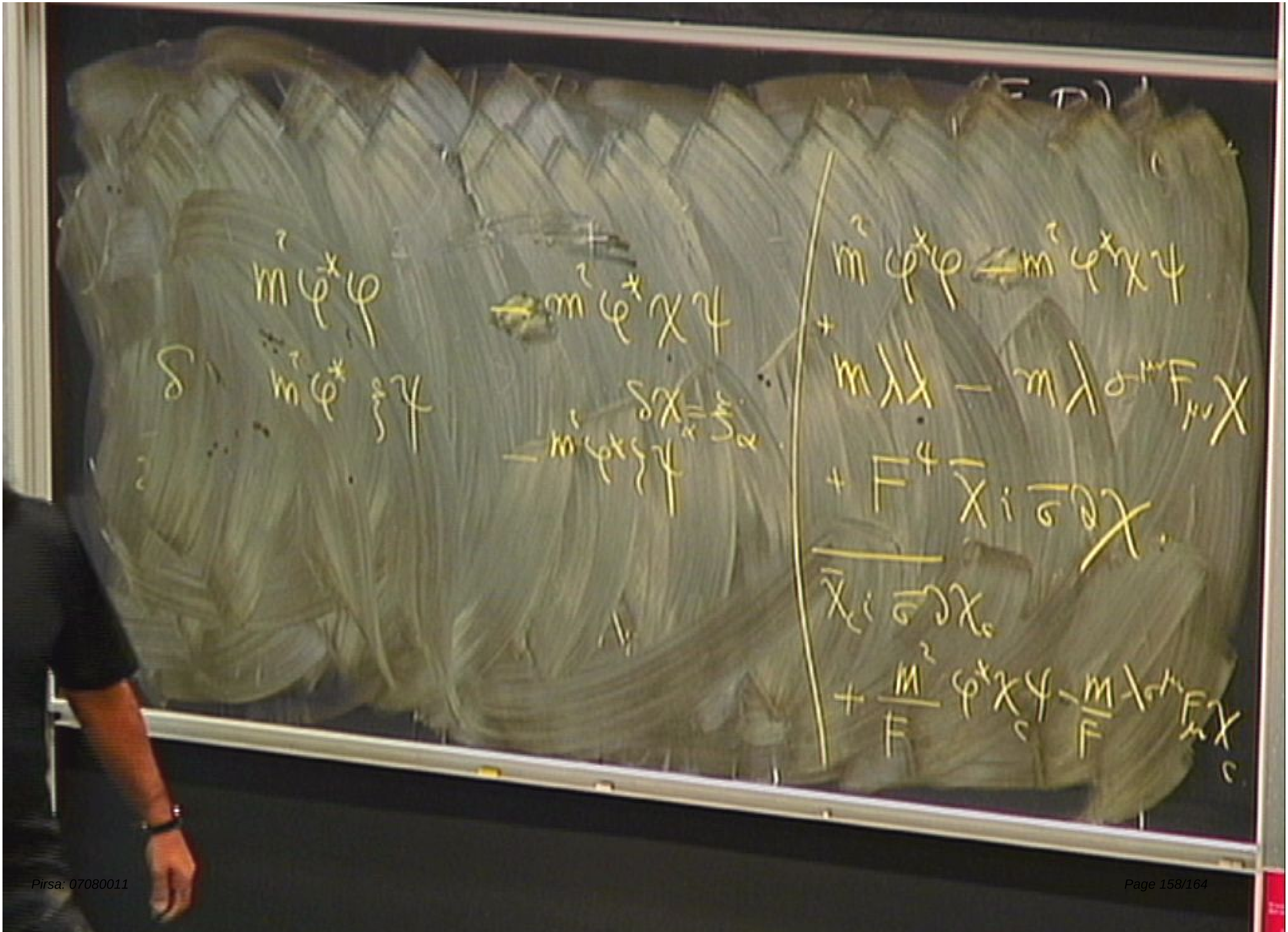

$m^2 \varphi^* \varphi$
$m^2 \varphi^* \chi \psi$
δ
$m^2 \varphi^* \xi \psi$
$\delta \chi = \xi^\alpha \xi_\alpha$
$- m^2 \varphi^* \xi \psi$

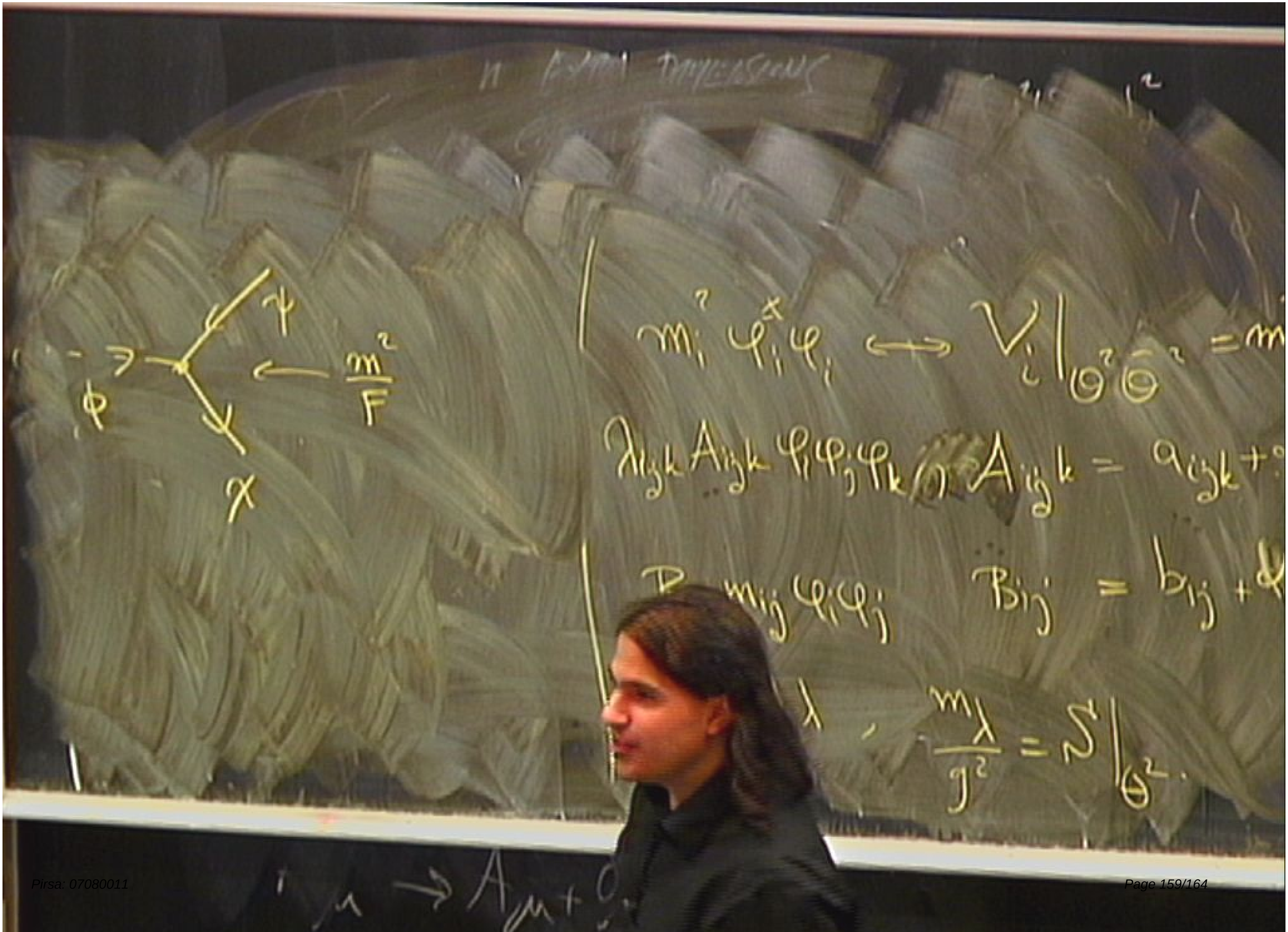


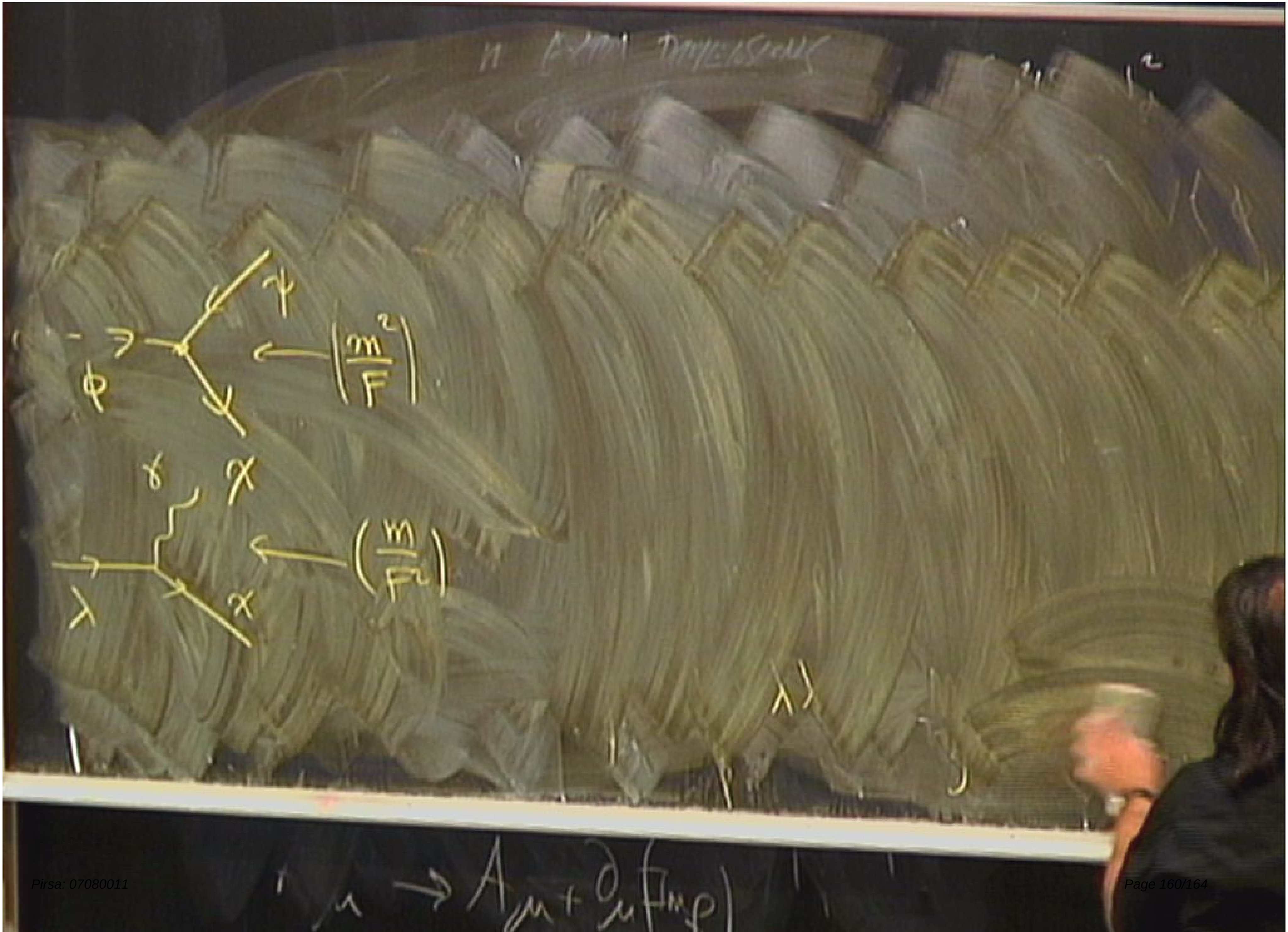
m²φ*φ ← m²φ*χψ
m²φ*φ ← m²φ*χψ
mλλ

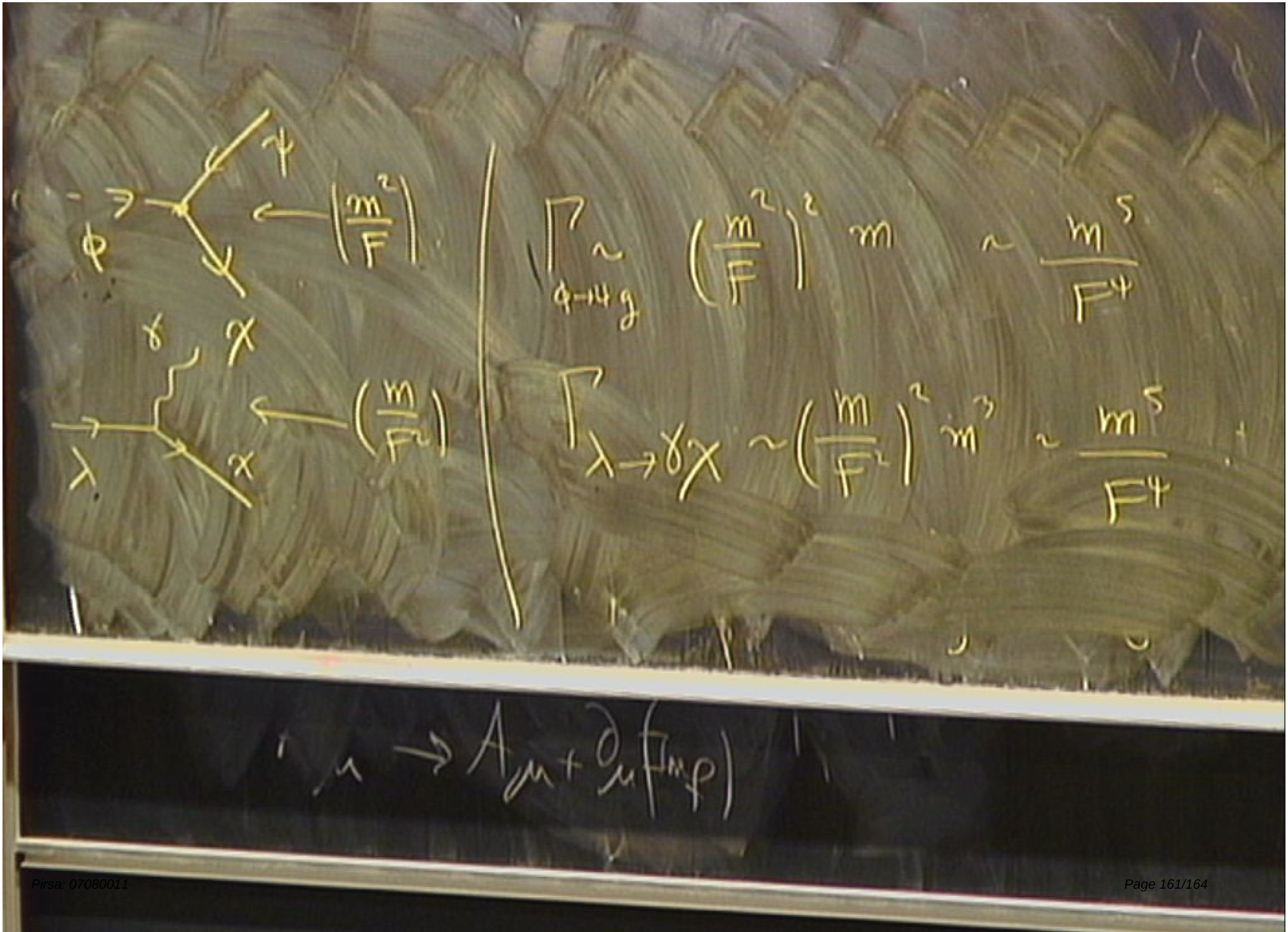

m²φ*φ
→ m²φ*χψ
δ m²φ* ξψ
δχ = ξ_α
− m²φ*ξψ
m²φ*φ → m²φ*χψ
mλλ − mλσ^{μν}F_{μν}χ


m²φ*φ
m²φ*χψ
m²φ*ξψ
δχ = ξ
m²φ*φ + m²φ*χψ
+ mλλ − mλσ^{μν}F_{μν}χ
+ F⁴ χ̄ iσ̄∂χ

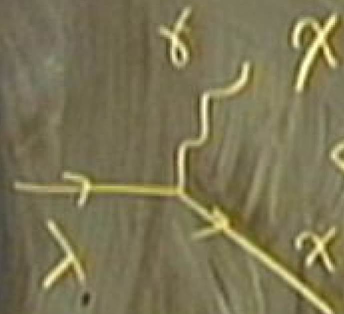

m² φ* φ ← m² φ* χ ψ
δ m² φ* ξ ψ
δχ = ξ_α
− m² φ* ξ ψ
m² φ* φ ← m² φ* χ ψ
+ m λ λ − m λ σ^{μν} F_{μν} χ
+ F⁴ − χ̄ i σ̄ ∂ χ
χ̄_c i σ̄ ∂ χ_c
+ M²/F φ* χ_c ψ − M/F λ σ^{μν} F_{μν} χ_c


m²/F
Bij = bij +
mλ/g² = S|θ².


ψ
φ
m²/F
γ
χ
λ


φ
ψ
g
(m²/F)
Γ_{φ→ψg} ~ (m²/F)² m ~ m⁵/F⁴
γ
χ
λ
(m/F²)
Γ_{λ→γχ} ~ (m/F²)² m³ ~ m⁵/F⁴
A_μ → A_μ + ∂_μ(Im φ)

$\longleftarrow \left(\frac{m^2}{F}\right)$

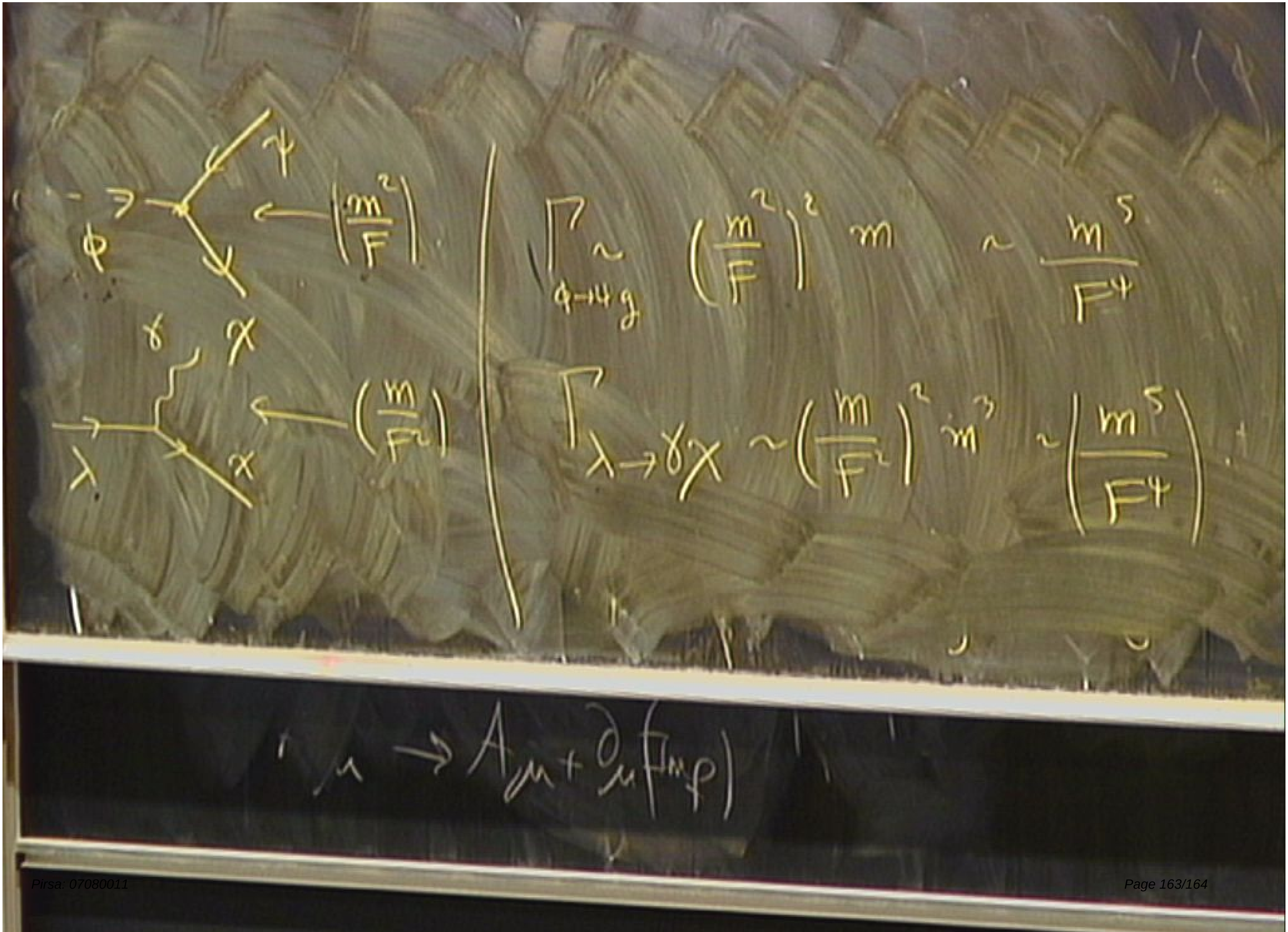


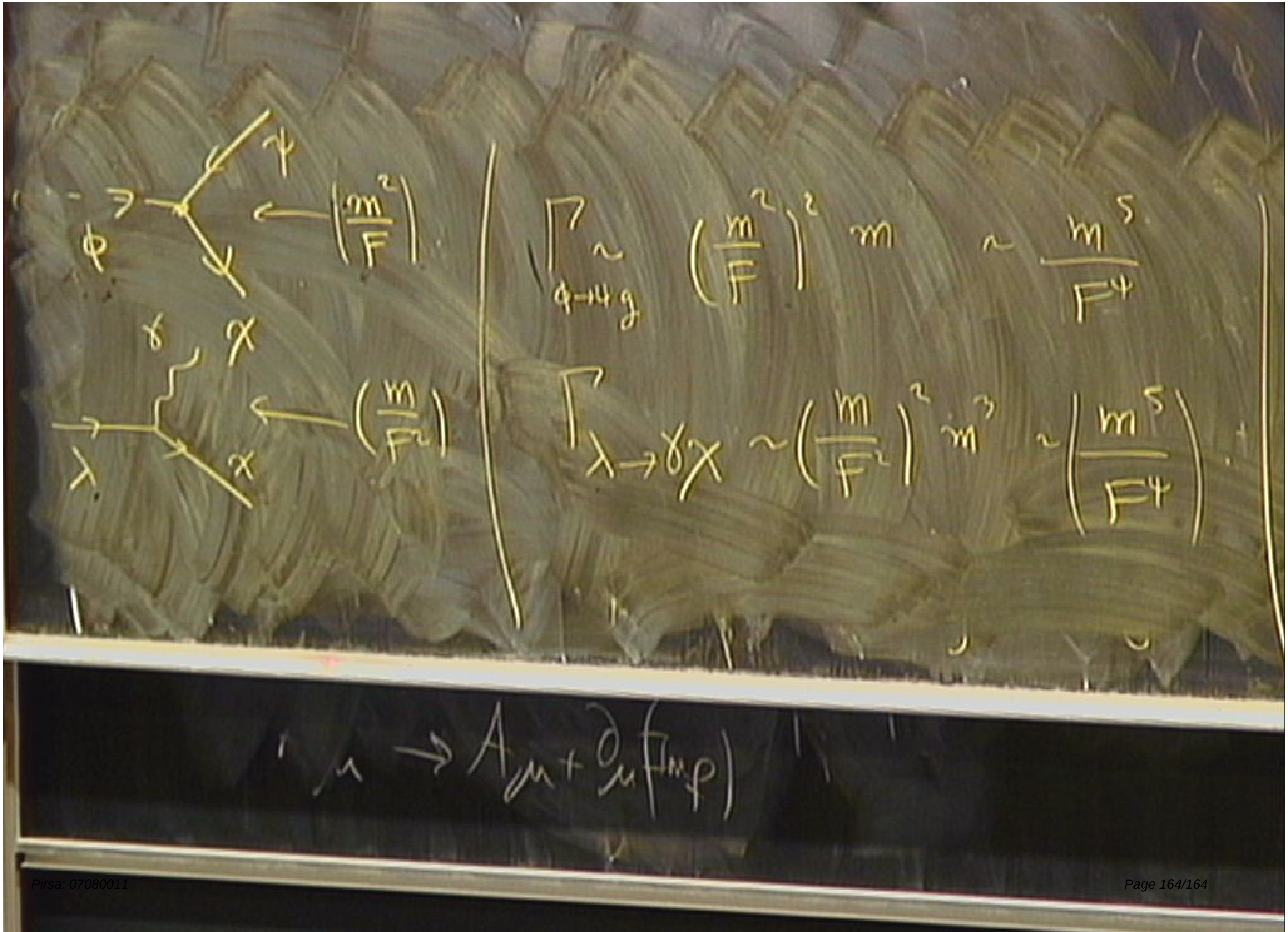
$\longleftarrow \left(\frac{m}{F^2}\right)$

$$\Gamma_{\phi\to\psi\psi} \sim \left(\frac{m^2}{F}\right)^2 m \sim \frac{m^5}{F^4}$$

$$\Gamma_{\lambda\to\gamma\chi} \sim \left(\frac{m}{F^2}\right)^2 m^3 \sim \left(\frac{m^5}{F^4}\right)$$

$$A_\mu \to A_\mu + \partial_\mu (\mathrm{Im}\,\phi)$$


(m²/F)
(m/F²)
Γ φ→4g ~ (m²/F)² m ~ m⁵/F⁴
Γ λ→γχ ~ (m/F²)² m³ ~ (m⁵/F⁴)
→ A_μ + ∂_μ(Im φ)


(m²/F)
(m/F²)
Γ φ→ψg ~ (m²/F)² m ~ m⁵/F⁴
Γ λ→γχ ~ (m/F²)² m³ ~ (m⁵/F⁴)
A_μ → A_μ + ∂_μ(Im φ)