Title: Alternative Worldsheet Gauges and Closed-String Tachyon Condensation

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Abstract: Alternative gauge choices for worldsheet supersymmetry can elucidate dynamical phenomena obscured in the usual superconformal guage. In the particular example of the tachyonic E_8 heterotic string, we use a judicious gauge choice to show that the process of closed-string tachyon condensation can be understood in terms of a worldsheet super-Higgs effect. The worldsheet gravitino assimilates the goldstino and becomes a dynamical propagating field. Conformal, but not superconformal, invariance is maintained throughout.

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C. Keeler, UC Berkeley

December 7, 2007

based on 0709.3296, and 0709.2162, with P. Hořava

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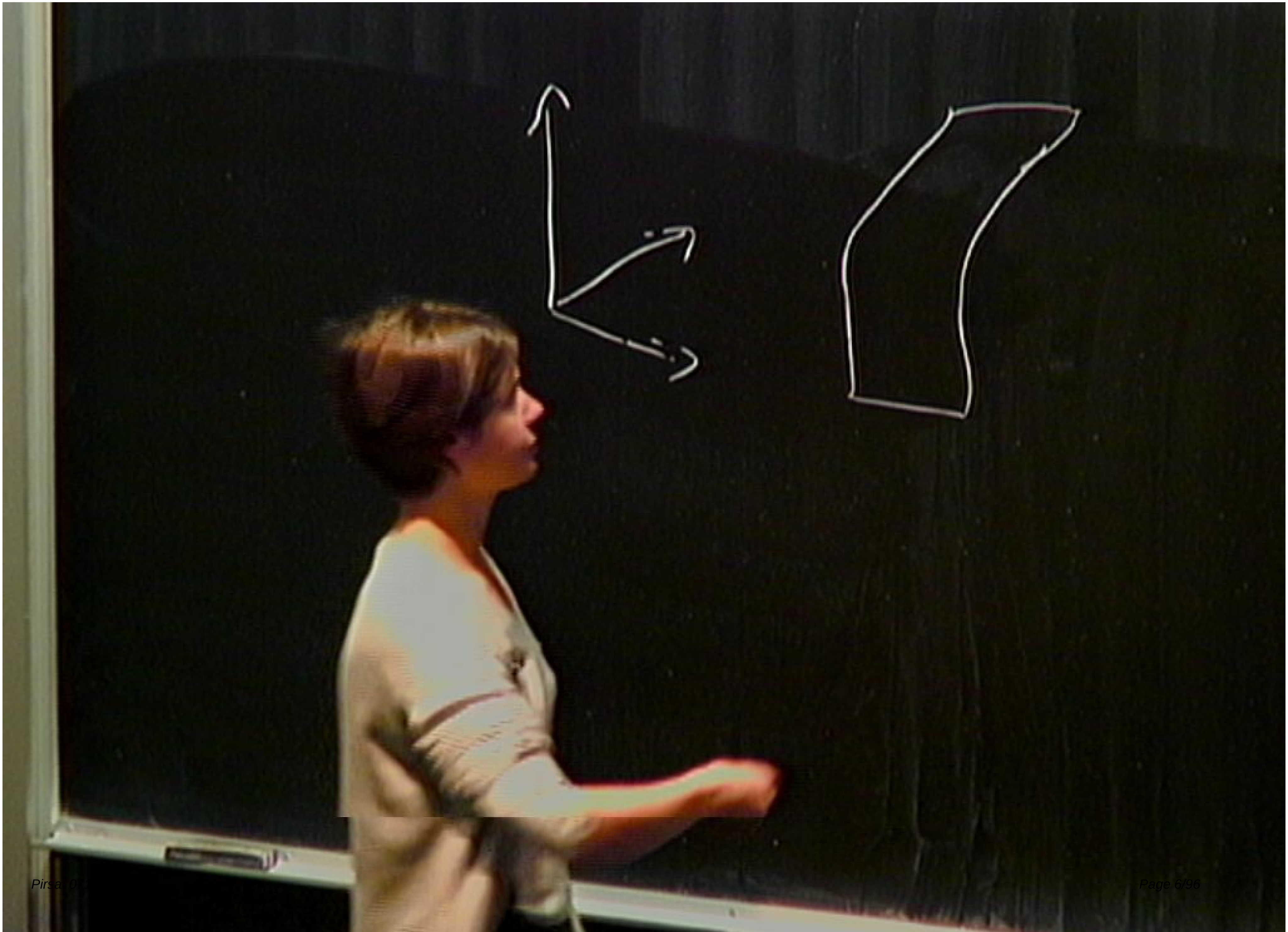
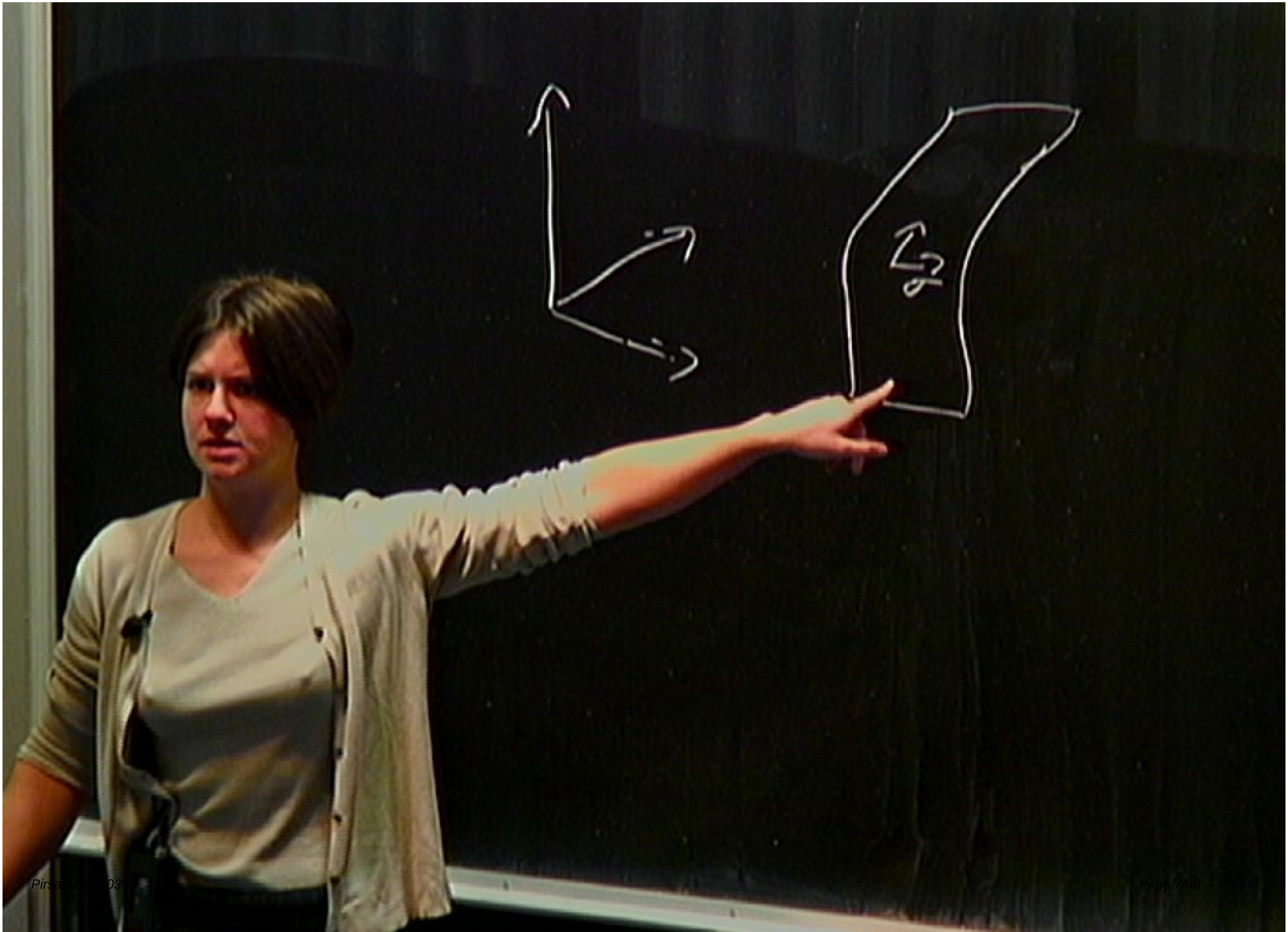
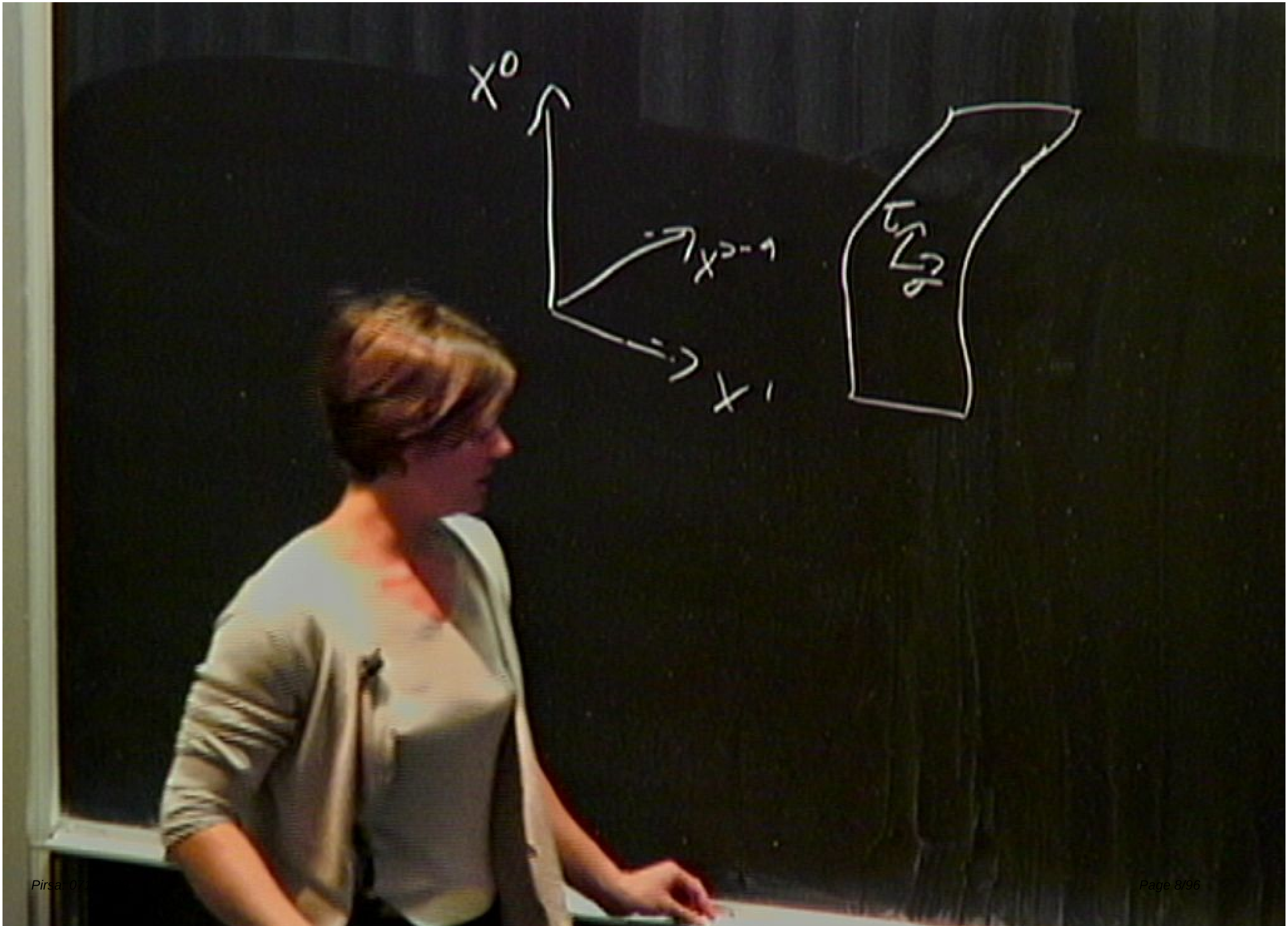
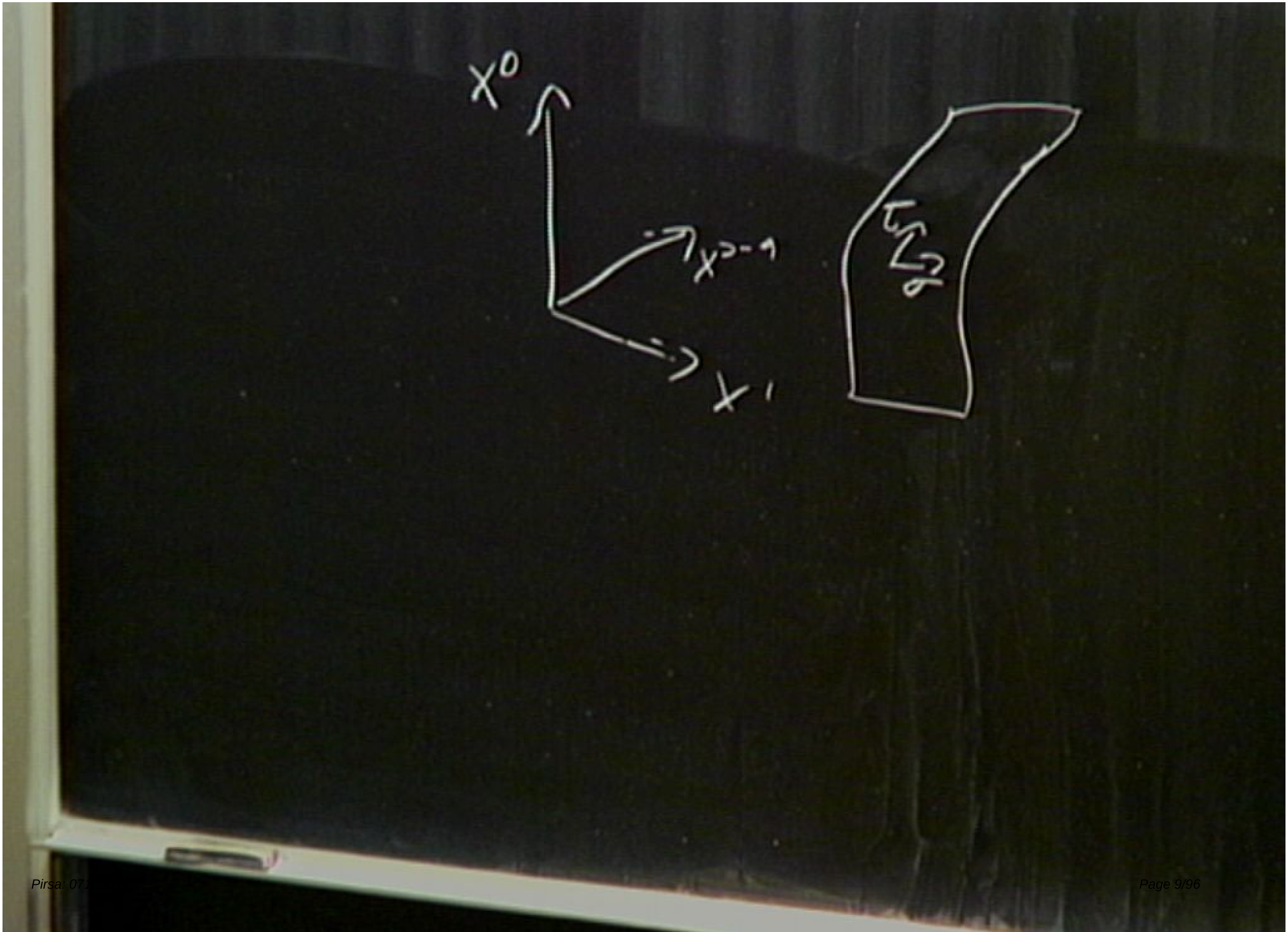
Perturbative Strings: Worldsheet vs. Spacetime

On the worldsheet, σ,τ are coordinates; X_0 through X_9 are fields.
The bosonic worldsheet action is






x^0
x^{D-1}
x^1
τ
σ


X^0
$X^{2 \cdots 9}$
X^1
τ
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In the spacetime effective action, x_0 through x_9 are coordinates, while G, ϕ, and $H_{\mu\nu\lambda}$ are fields:

$$S \approx \int d^D x\sqrt{-G}e^{-2\phi}\left[R_D + 4\nabla_\mu\phi\nabla^\mu\phi - \frac{1}{12}H_{\mu\nu\lambda}H^{\mu\nu\lambda} + \mathcal{O}(\alpha')\right]$$

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From now on we'll work on the worldsheet, perturbing around a flat background.

What is a tachyon?

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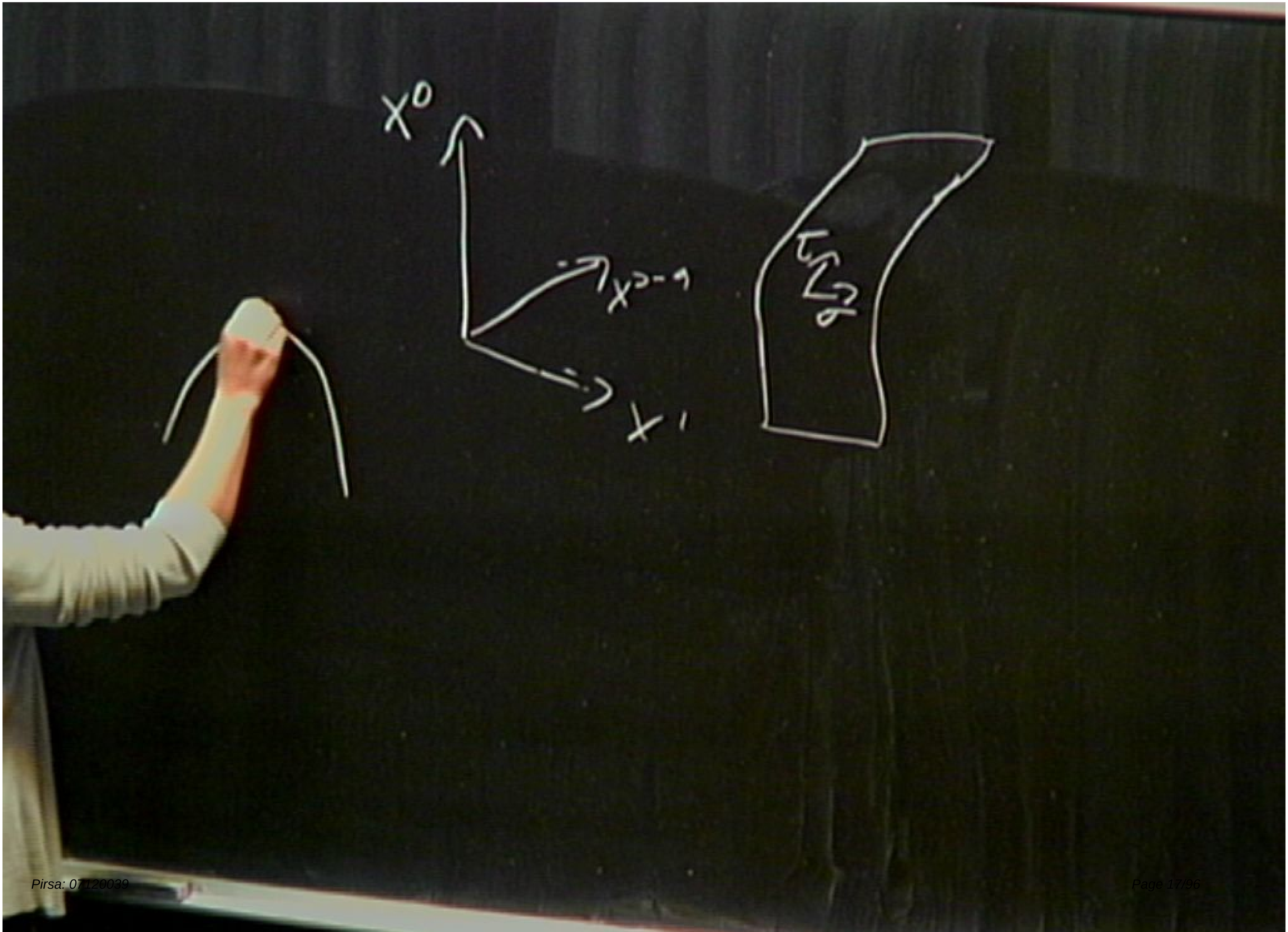

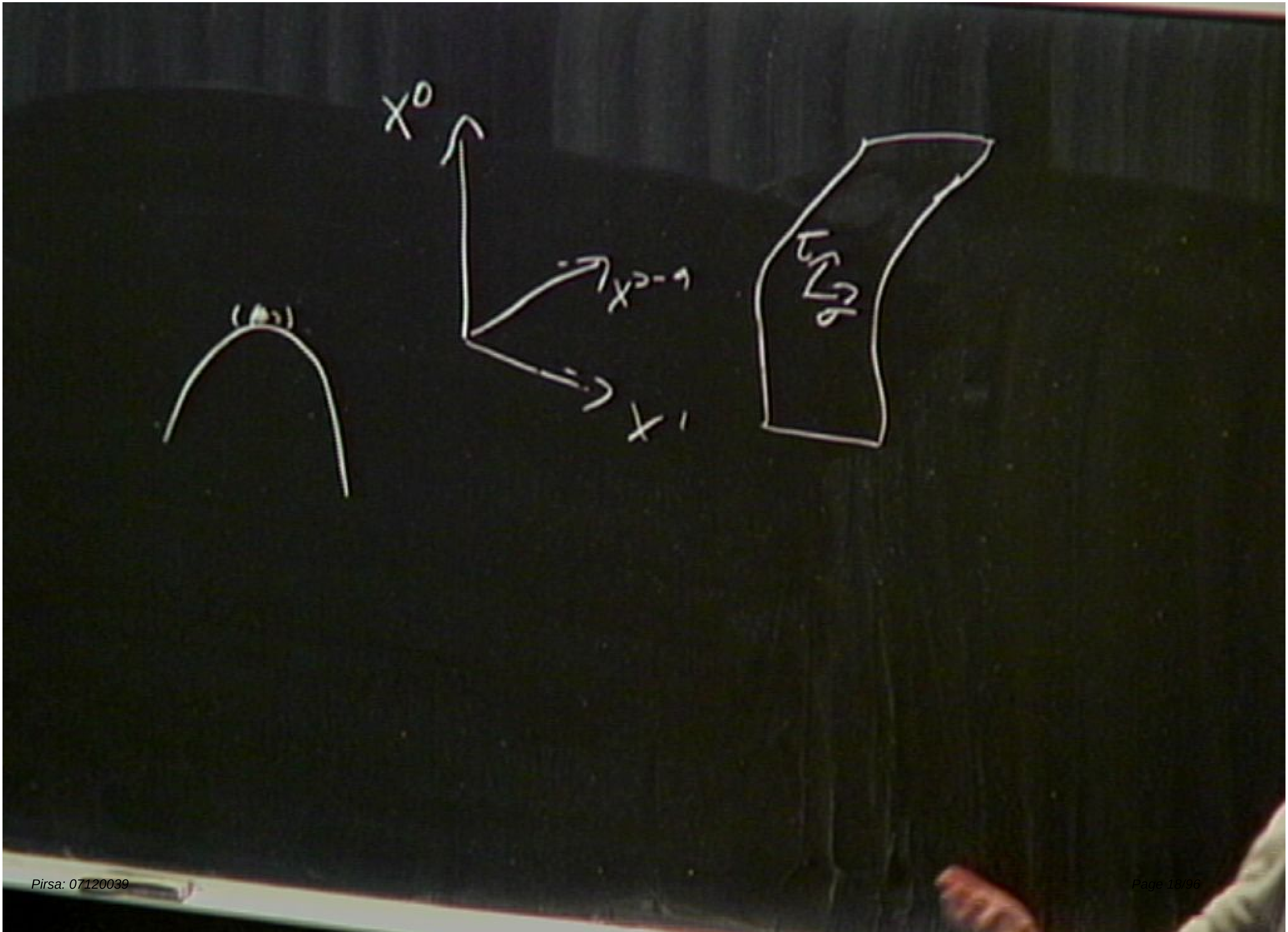
X⁰
X¹
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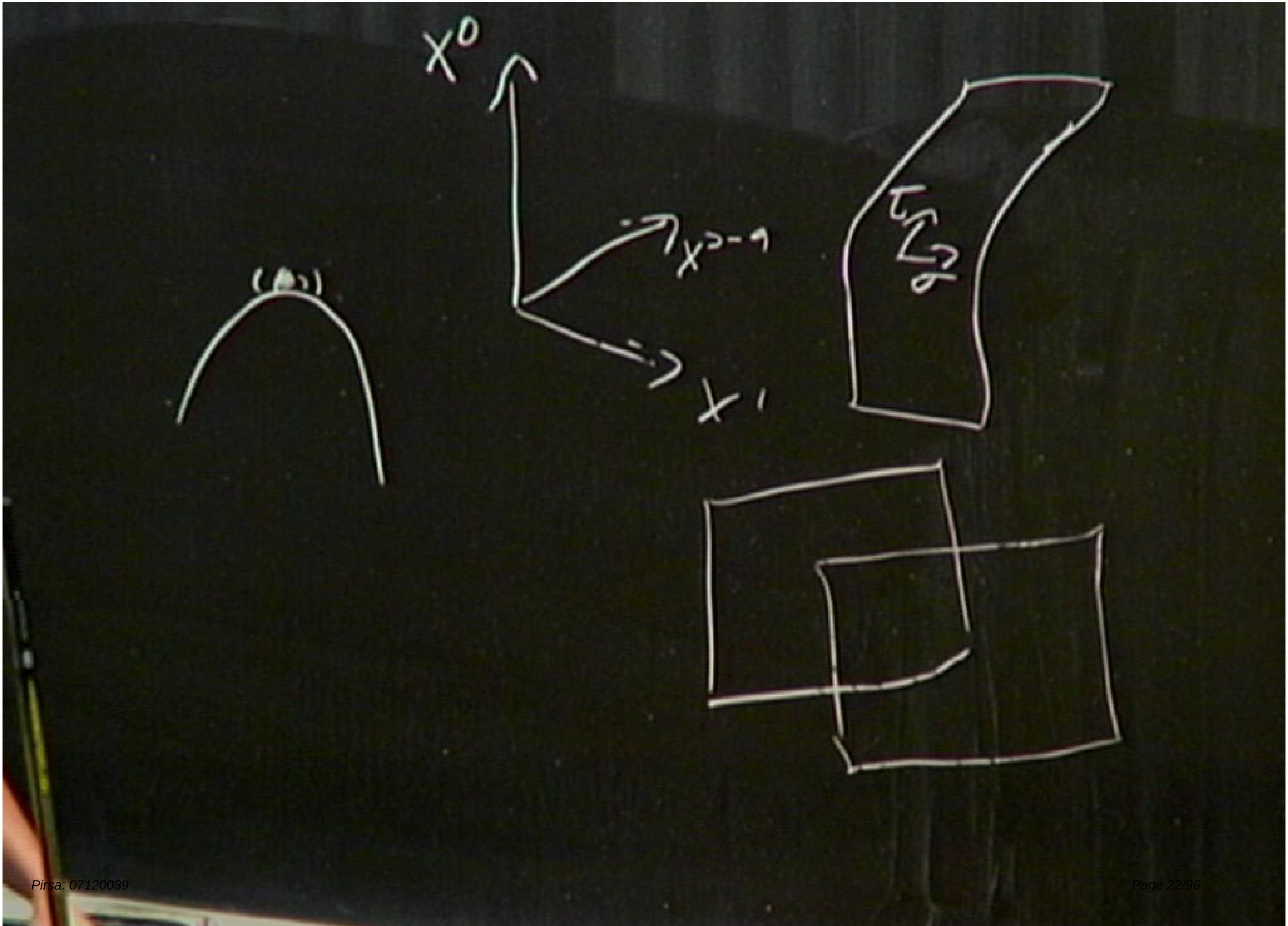
X0
X1

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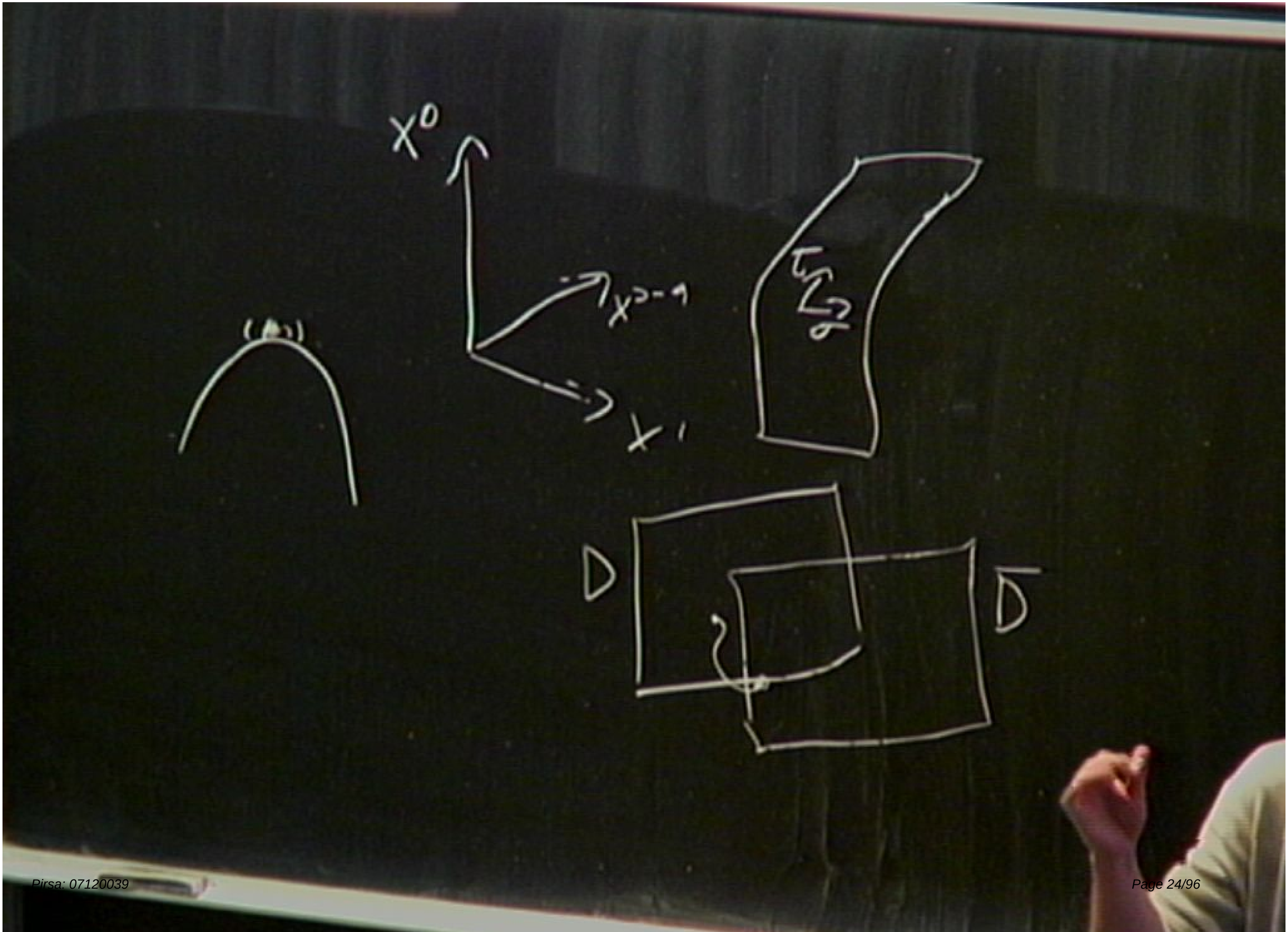

X^0
X^{D-1}
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D
$\bar{D}$

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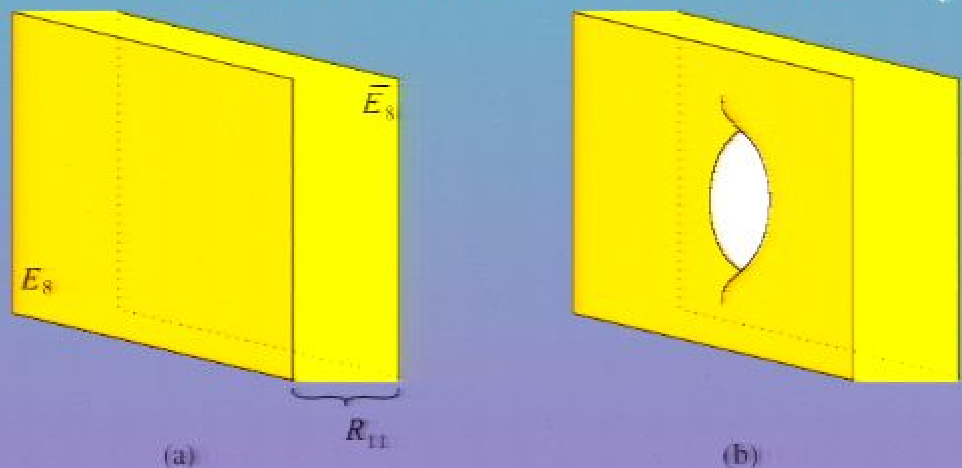
Both Casimir force and instanton (as in figure) are present.



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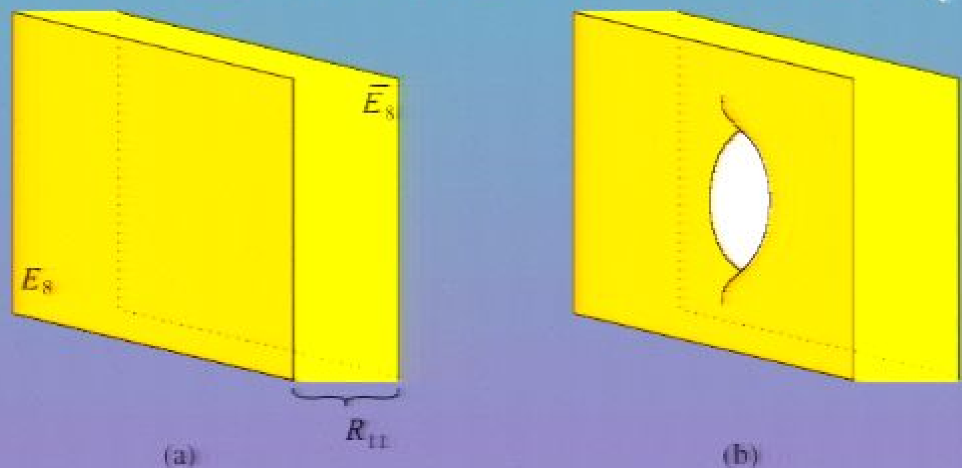

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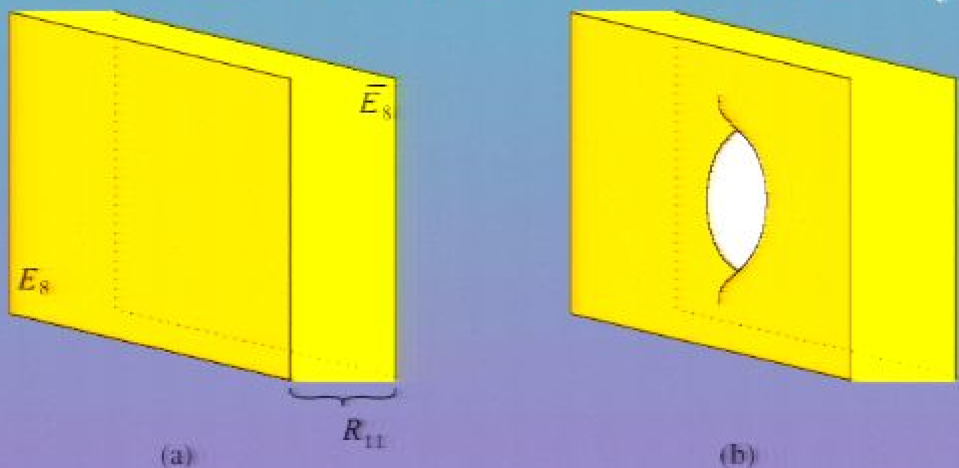

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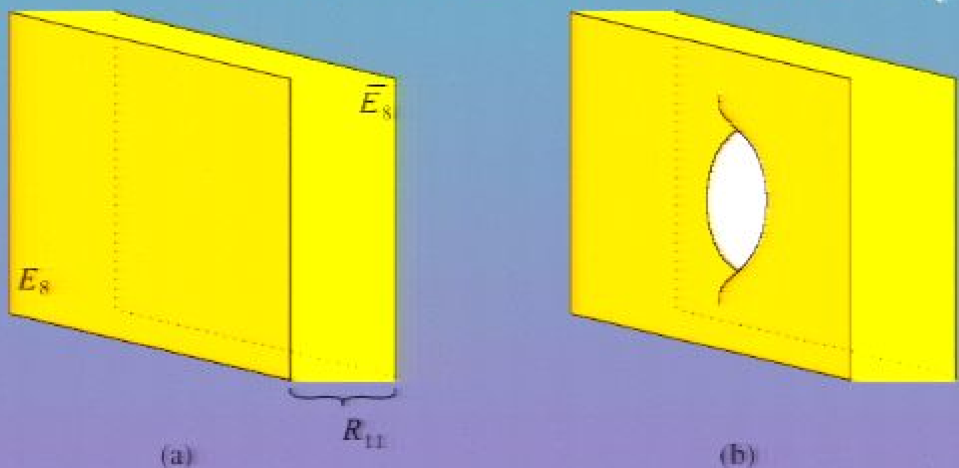

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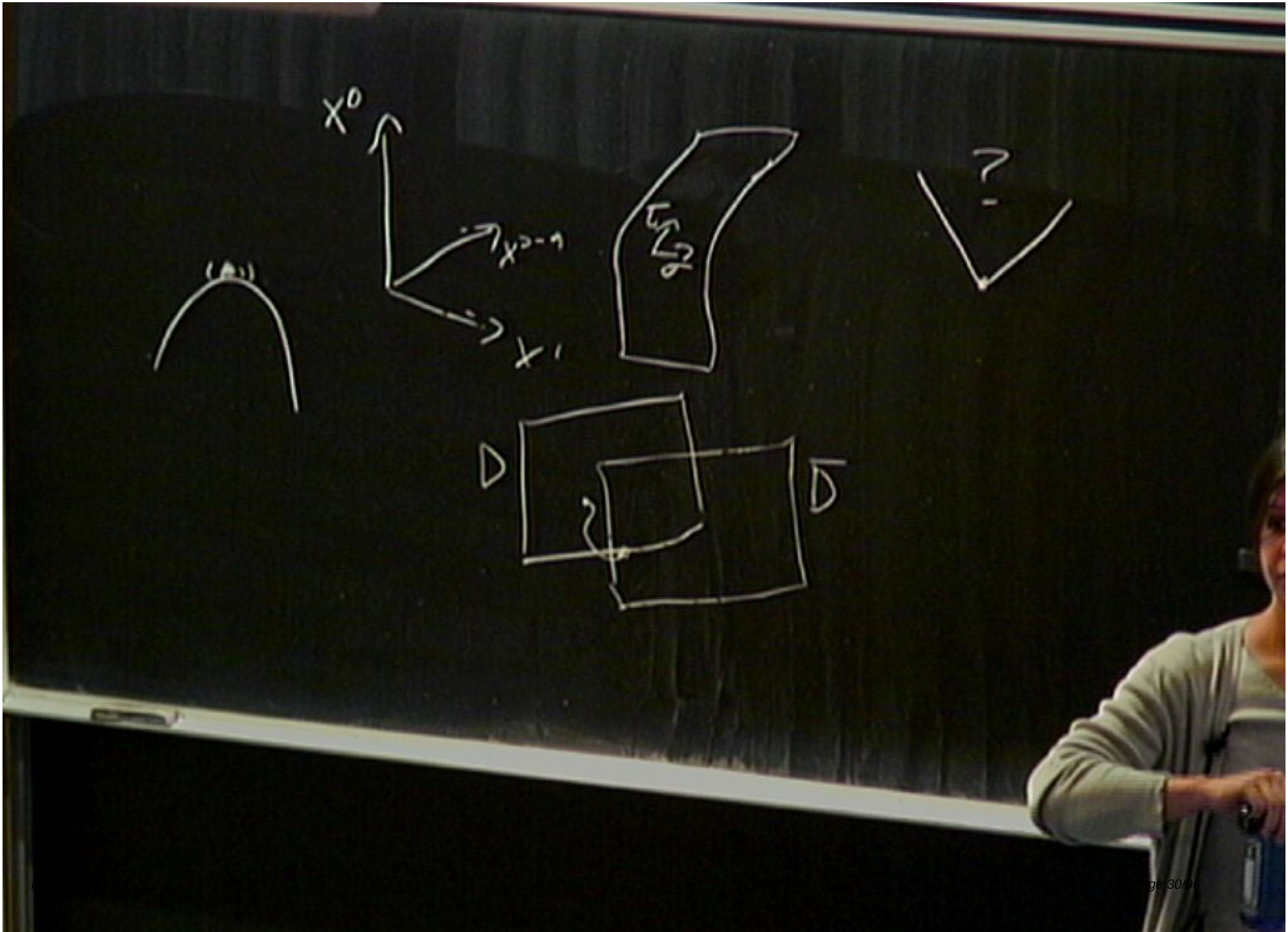
X^0
X^{D-1}
X^1
?
D
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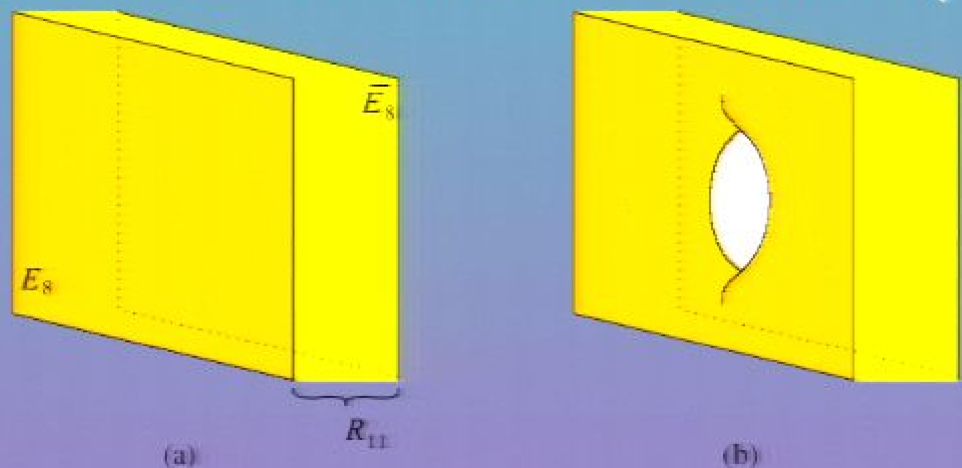

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The E_8 Heterotic String: Beyond the Looking-Glass?

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- Current algebra is E_8 at level two, consistent with brane-antibrane higgsing of $U(N) \times U(N)$ to diagonal level two $U(N)$.
- E_8 heterotic string tachyon is a singlet under the gauge symmetry.
- Massless fermion spectrum is nonchiral (as in brane-antibrane)
- Both E_8 heterotic string and $E_8 \times \overline{E_8}$ M-theory can be built from standard supersymmetric cases by a $\mathbb{Z}_2$ orbifold

Free fermion description of E_8 string

$$S_0 = -\frac{1}{4\pi\alpha'}\int d^2\sigma\, e[\eta_{\mu\nu}(h^{mn}\partial_m X^\mu \partial_n X^\nu + i\psi^\mu\gamma^m\partial_m\psi^\nu$$
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Superconformal Gauge

Gauge fix $\chi = 0$ and h^{mn} to be unit metric. Fadeev-Popov procedure produces ghosts bc and $\beta\gamma$. The central charges (measure of quantum conformal anomaly) add to 0:

Field	c_L	c_R
X^+, X^-, X^i	10	10
linear dilaton	0	0
bc ghosts	-26	-26
ψ^i	0	4
ψ^+, ψ^-	0	1
β, γ ghosts	0	11
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Common to pick light cone gauge $X^+ = \tau$ as extra condition.

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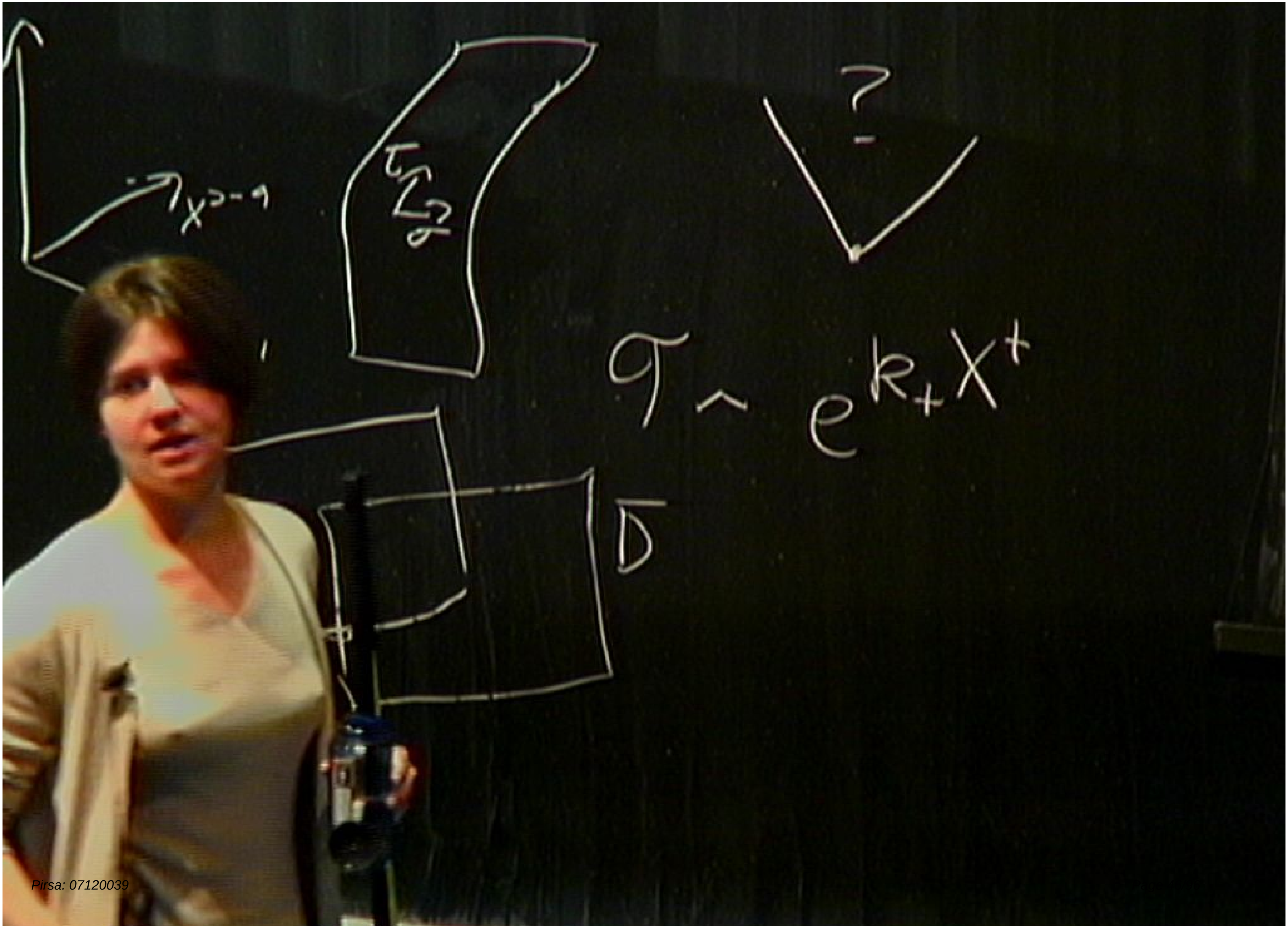
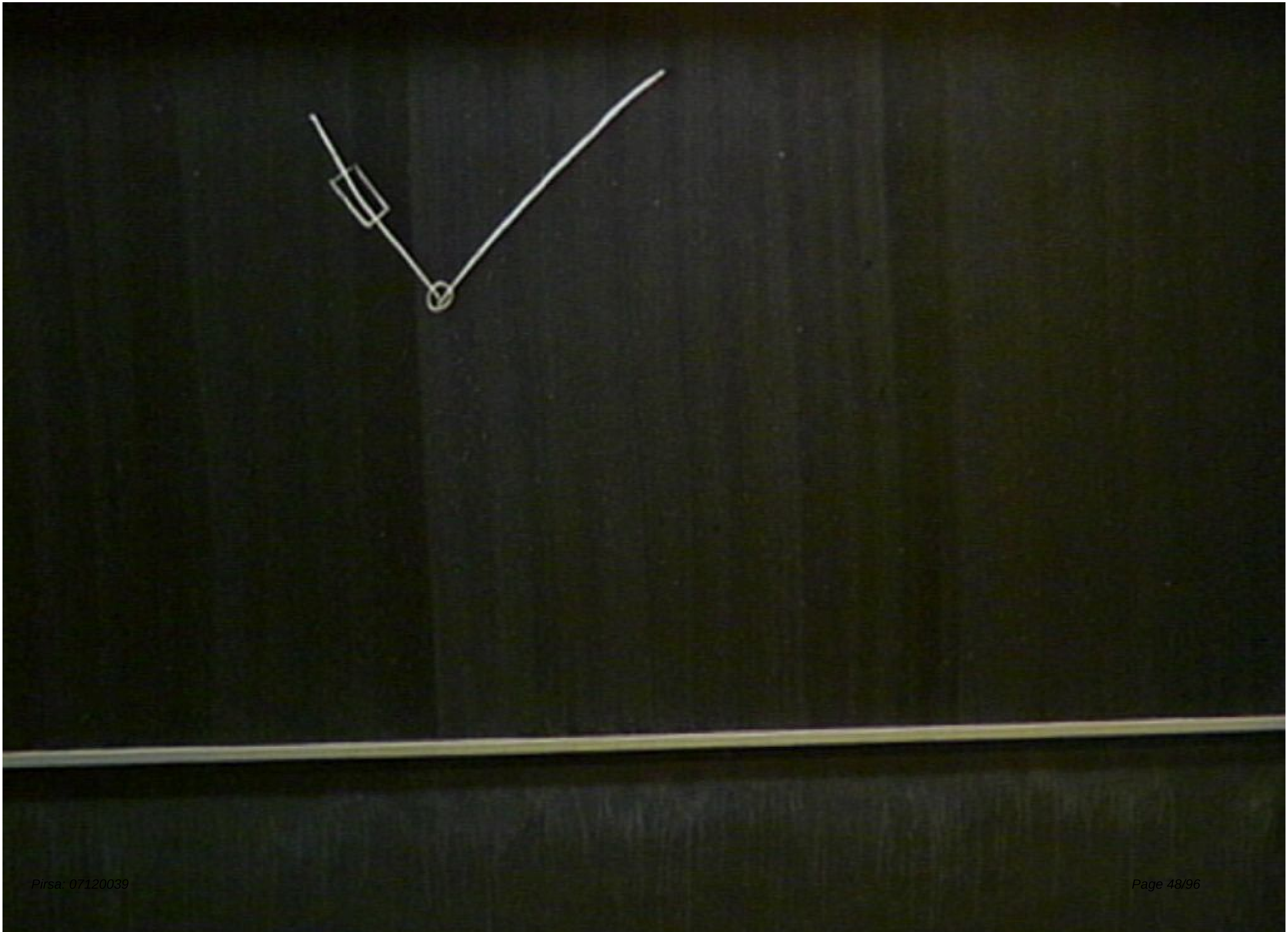


X^{2-9}
?
$\sigma \sim e^{k_+ X^+}$
D
Pirsa: 07120039



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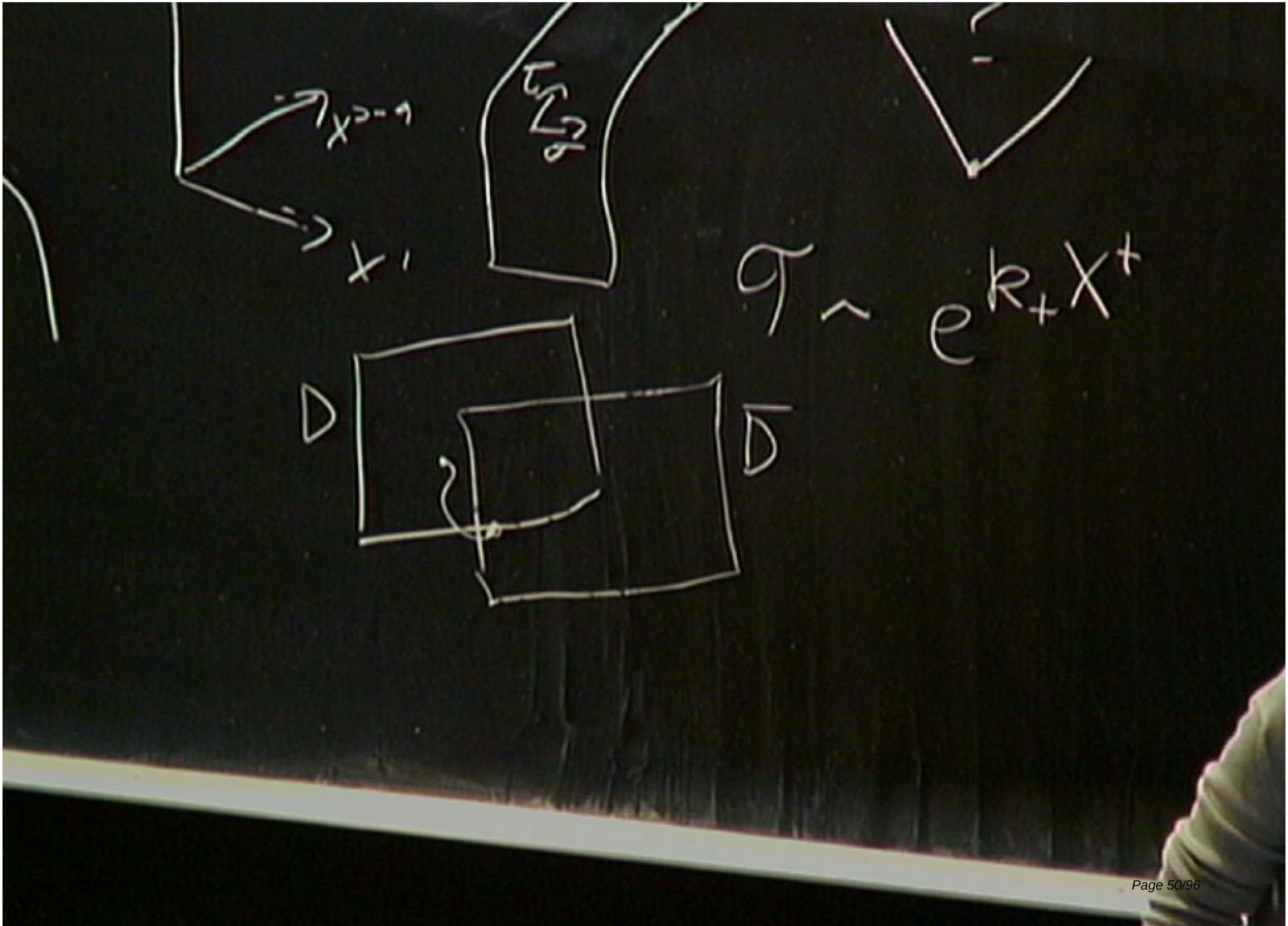
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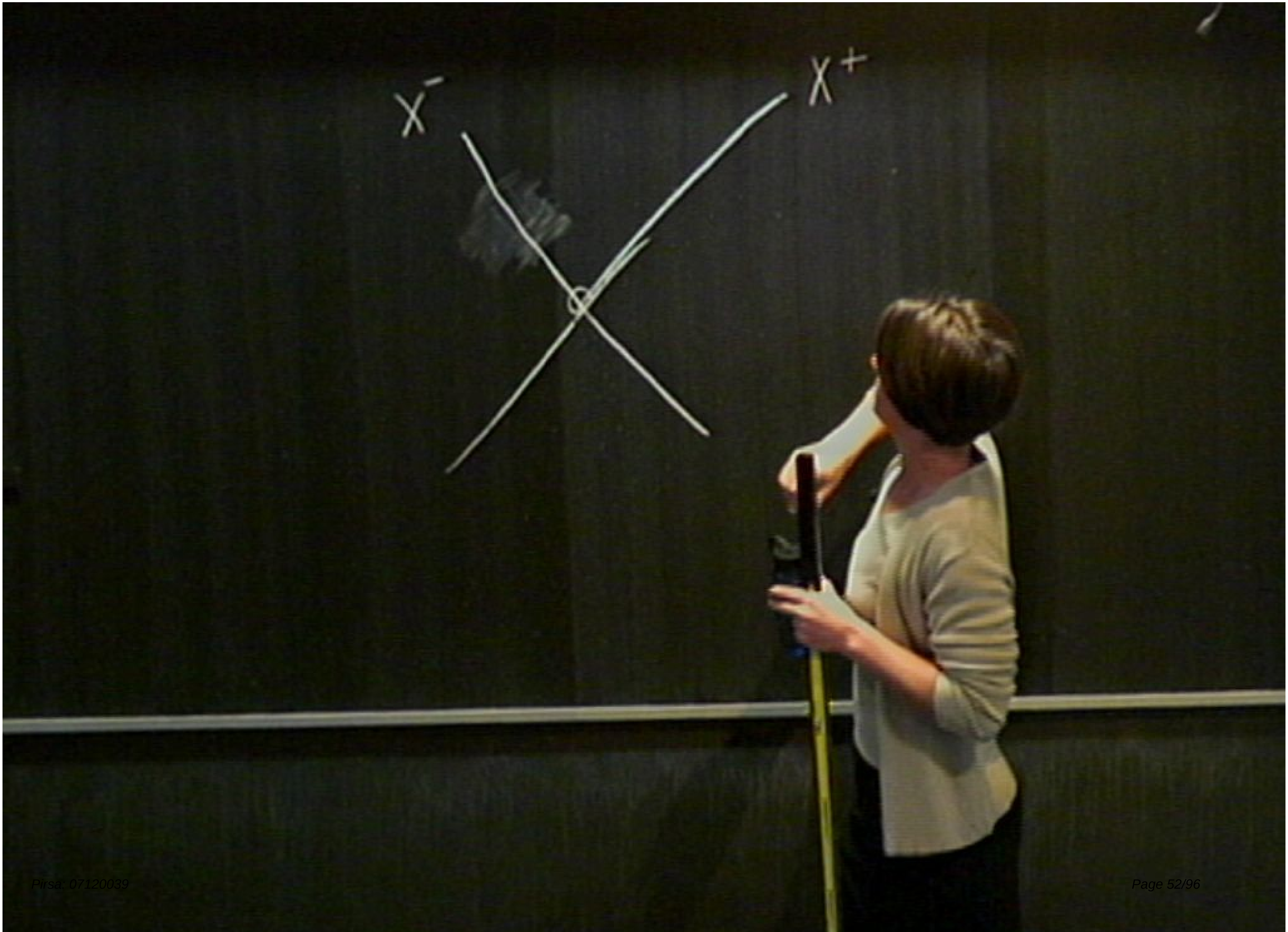
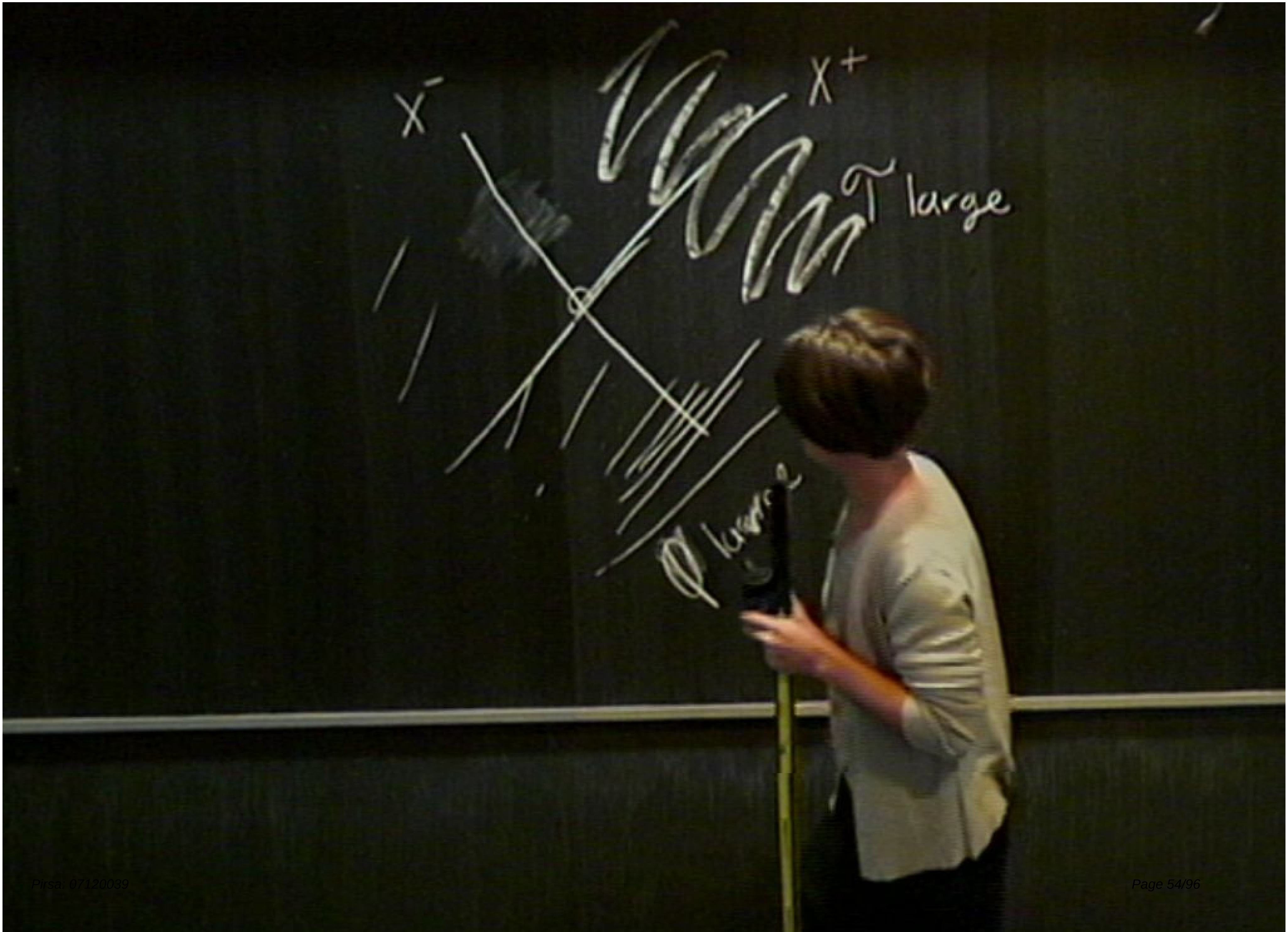
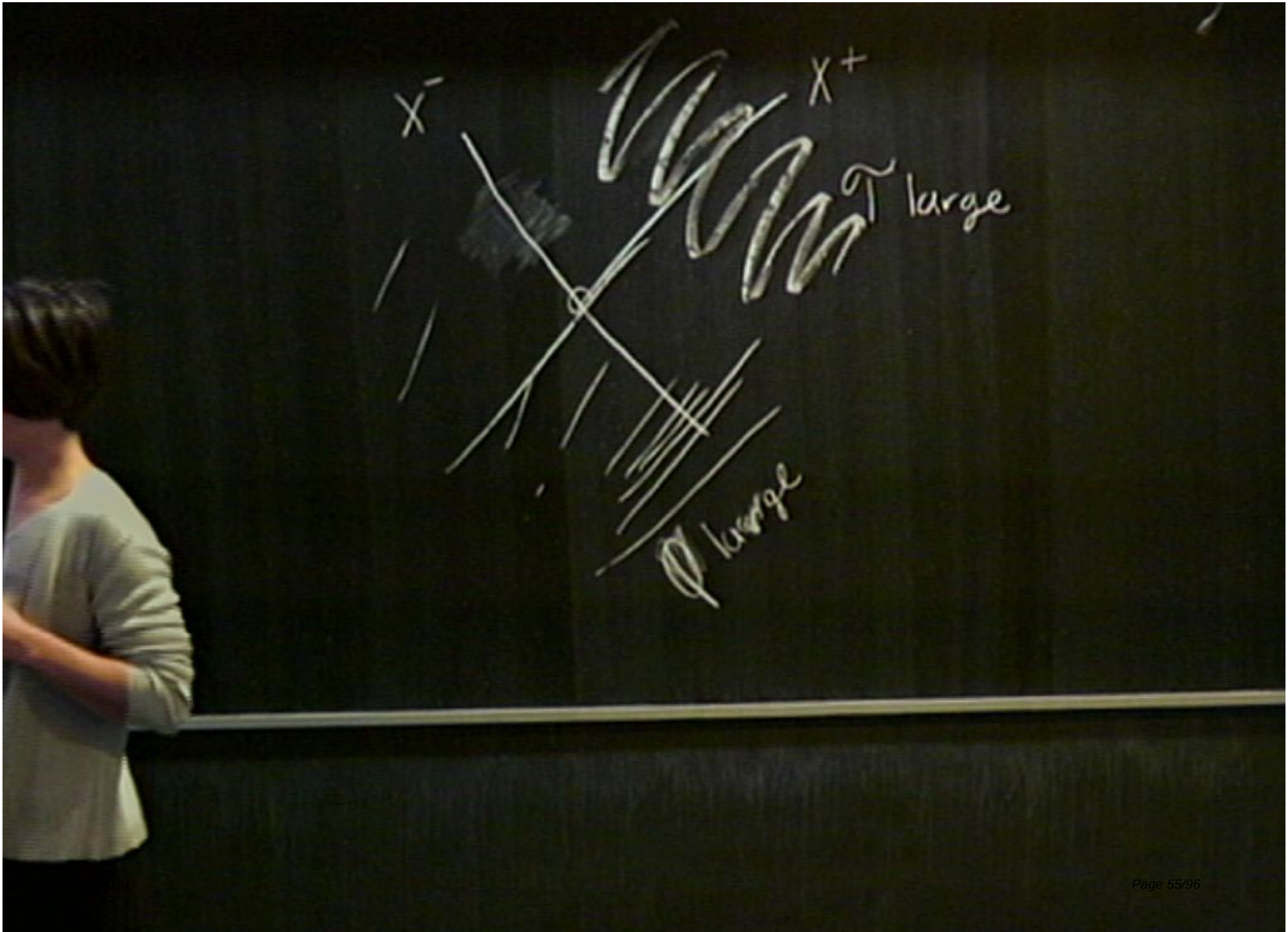


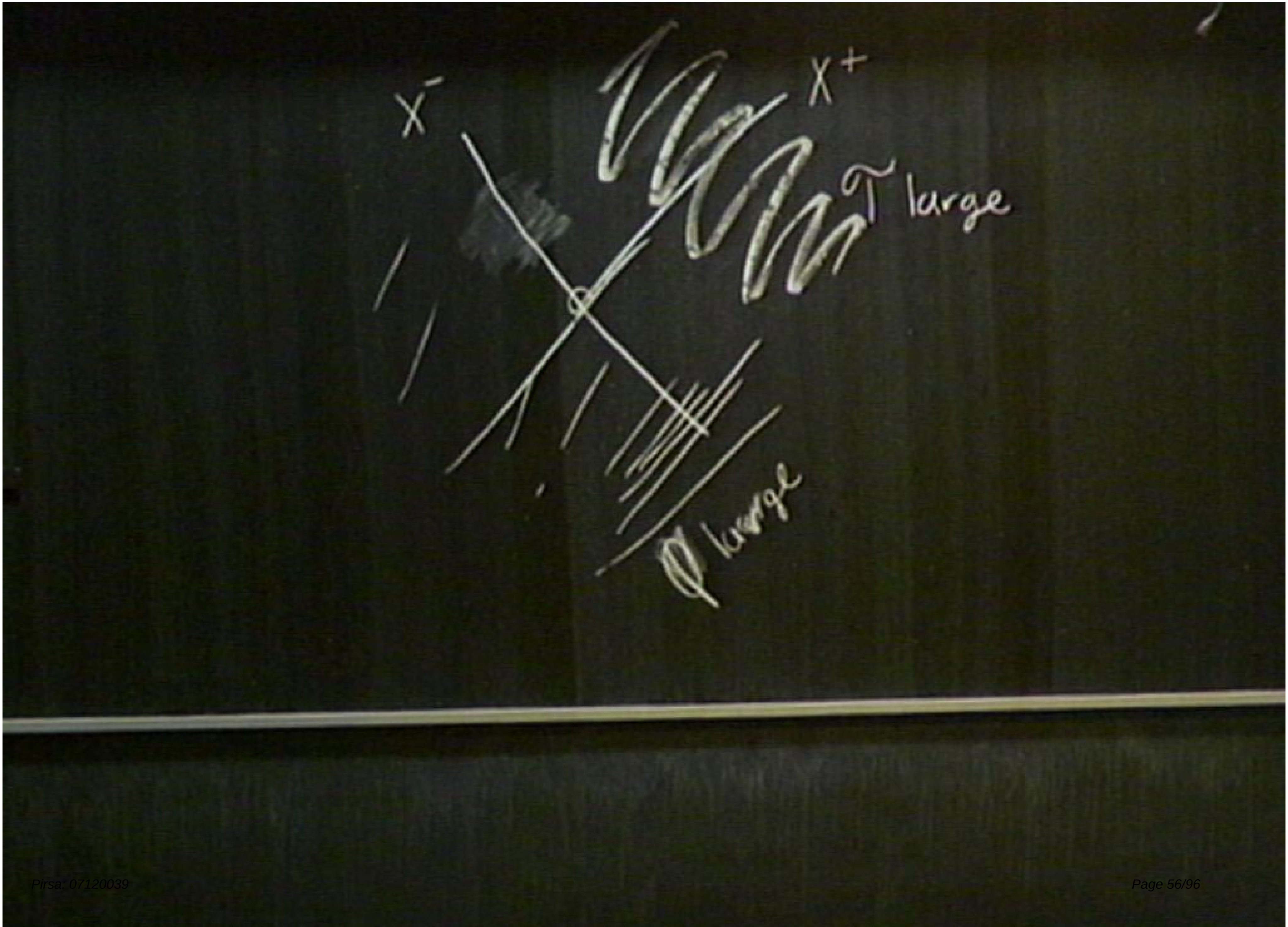
x^-
x^+


x⁻
x⁺
large



x^-
x^+
$\tilde{\phi}$ large
ϕ large


x^-
x^+
large
large



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To maintain supersymmetry of this action we change $\delta\psi^\mu$ to
$\delta\psi^\mu = \gamma^m\partial_m X^\mu\epsilon + \alpha' V^\mu\gamma^m D_m\epsilon.$

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Conformal invariance in higher orders of μ requires both k_μ and V_μ to be null. We choose k_+ and V_-, and find $V_- k_+ = -\frac{1}{2\alpha'}$.

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We are interested in tachyon condensates whose profile $\mathcal{T}(X) \sim \exp(k_\mu X^\mu)$ for some constant k_μ.

We wish to add only marginal deformations; marginality requires $-k^2 + 2V \cdot k = \frac{2}{\alpha'}$.

Conformal invariance in higher orders of μ requires both k_μ and V_μ to be null. We choose k_+ and V_-, and find $V_- k_+ = -\frac{1}{2\alpha'}$.

Thus the new terms in our action are

$$S_W = \frac{\mu}{\pi\alpha'} \int d^2\sigma \left(F - ik_+\lambda_+\psi_-^+\right) \exp(k_+X^+).$$

The Full Action (in Conformal Gauge)

$$S = \frac{1}{\pi\alpha'}\int d^2\sigma^{\pm}\,\big(\partial_+ X^i \partial_- X^i + \tfrac{i}{2}\psi^i_- \partial_+ \psi^i_- - \partial_+ X^+ \partial_- X^-$$

$$-\tfrac{i}{2}\psi^+_- \partial_+ \psi^-_- - \tfrac{i}{2}\lambda_+ \partial_- \lambda_+ - \mu^2 \exp(2k_+ X^+)$$

$$-i\kappa\chi_{++}\psi^i_- \partial_- X^i + \tfrac{i}{2}\kappa\chi_{++}\psi^+_- \partial_- X^- + \tfrac{i}{2}\kappa\chi_{++}\psi^-_- \partial_- X^+$$

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$$+\,i\kappa\alpha' V_- \chi_{++}\partial_- \psi_-^- - i\mu k_+ \lambda_+ \psi_-^+ \exp(k_+ X^+)\Big)\,.$$

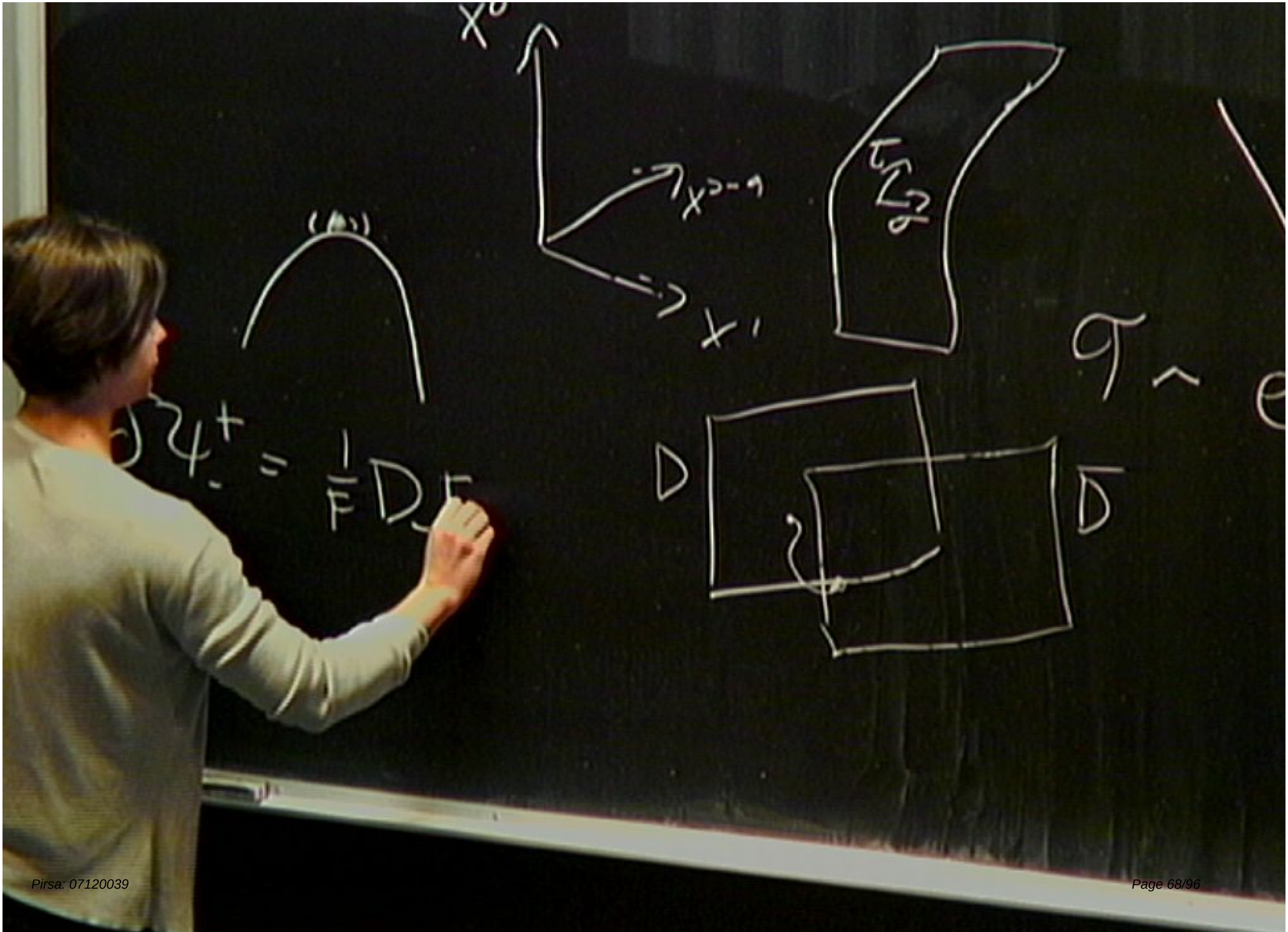
- All F_A have been integrated out. For the superpartner of the lone fermion, we find $F = 2\mu\exp(k_+ X^+)$.
- All other F_A are 0; all other λ_A have been replaced by their current algebra equivalent.

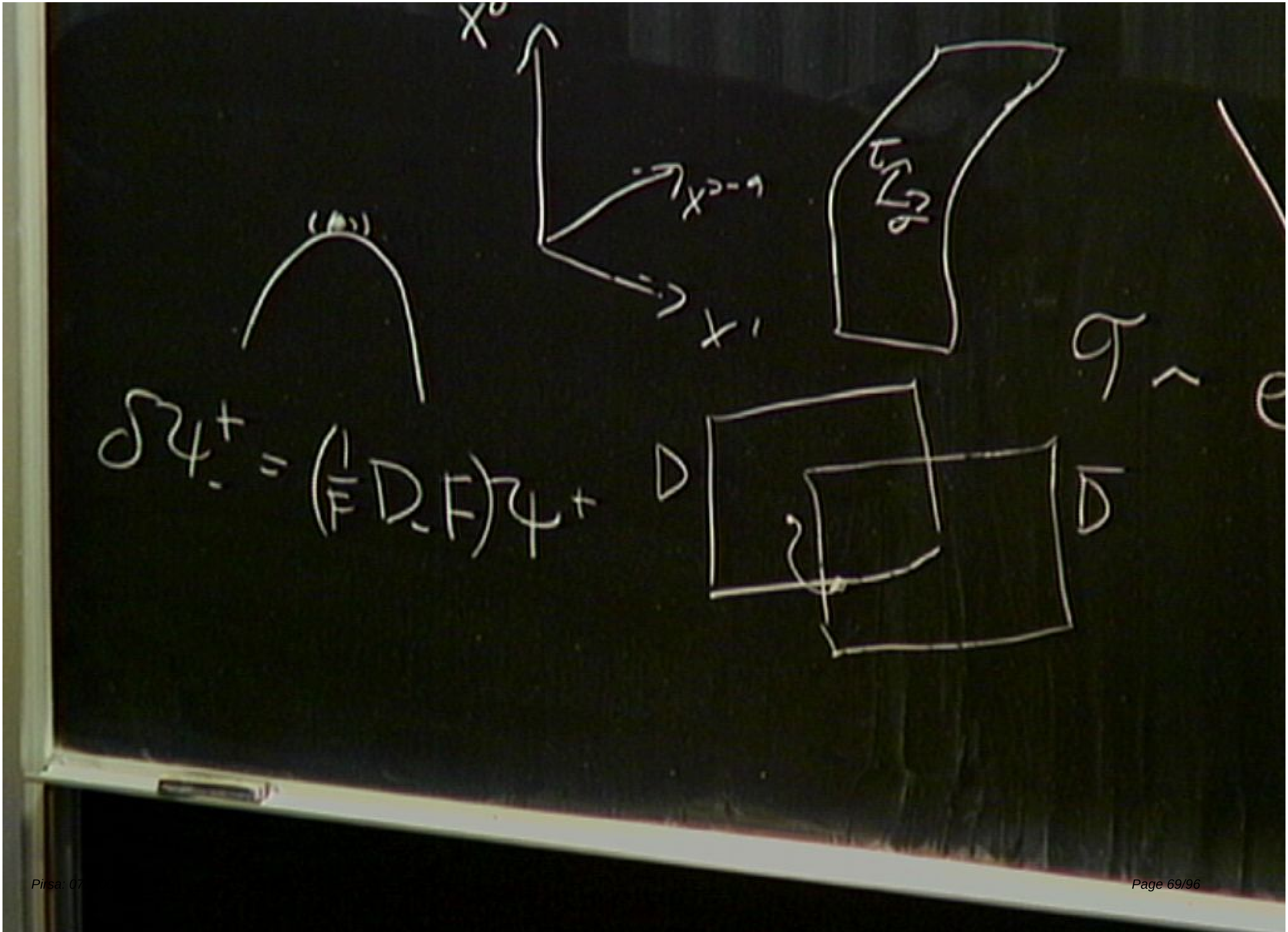
Supersymmetry Transformations

The full set of SUSY transformations, in conformal gauge, are

$$\begin{aligned} \delta X^\mu &= i\epsilon_+\psi^\mu_-, & \delta\psi^\mu_- = -2\partial_- X^\mu\epsilon_+ + 4\alpha' V^\mu D_-\epsilon_+, \\ \delta\lambda^A_+ &= F^A\epsilon_+, & \delta F^A = -2i\epsilon_+\partial_-\lambda^A_+, \\ \delta e_{+-} &= -2i\kappa\epsilon_+\chi_{++}, & \delta\chi_{++} = \frac{2}{\kappa}\partial_+\epsilon_+. \end{aligned}$$

[redacted]




x^0
x^1
D
$\bar{D}$

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Note that the transformation of λ_+/F looks like that for a goldstino.

Picking a new gauge

We will always stick to conformal gauge. However we must also pick a fermionic gauge fixing. Normally we set $\chi = 0$; but as we expect our gravitino to become propagating, this seems unwise.

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Thus, we will choose

$$\psi_-^+ = 0.$$

$\psi^+_- = 0$ Gauge

The action in this gauge simplifies to

$$\frac{1}{\pi\alpha'}\int d^2\sigma^{\pm}\left(\partial_+X^i\partial_-X^i + \frac{i}{2}\psi^i_-\partial_+\psi^i_- - \partial_+X^+\partial_-X^- + \frac{i}{2}\lambda_+\partial_-\lambda_+ \right.$$
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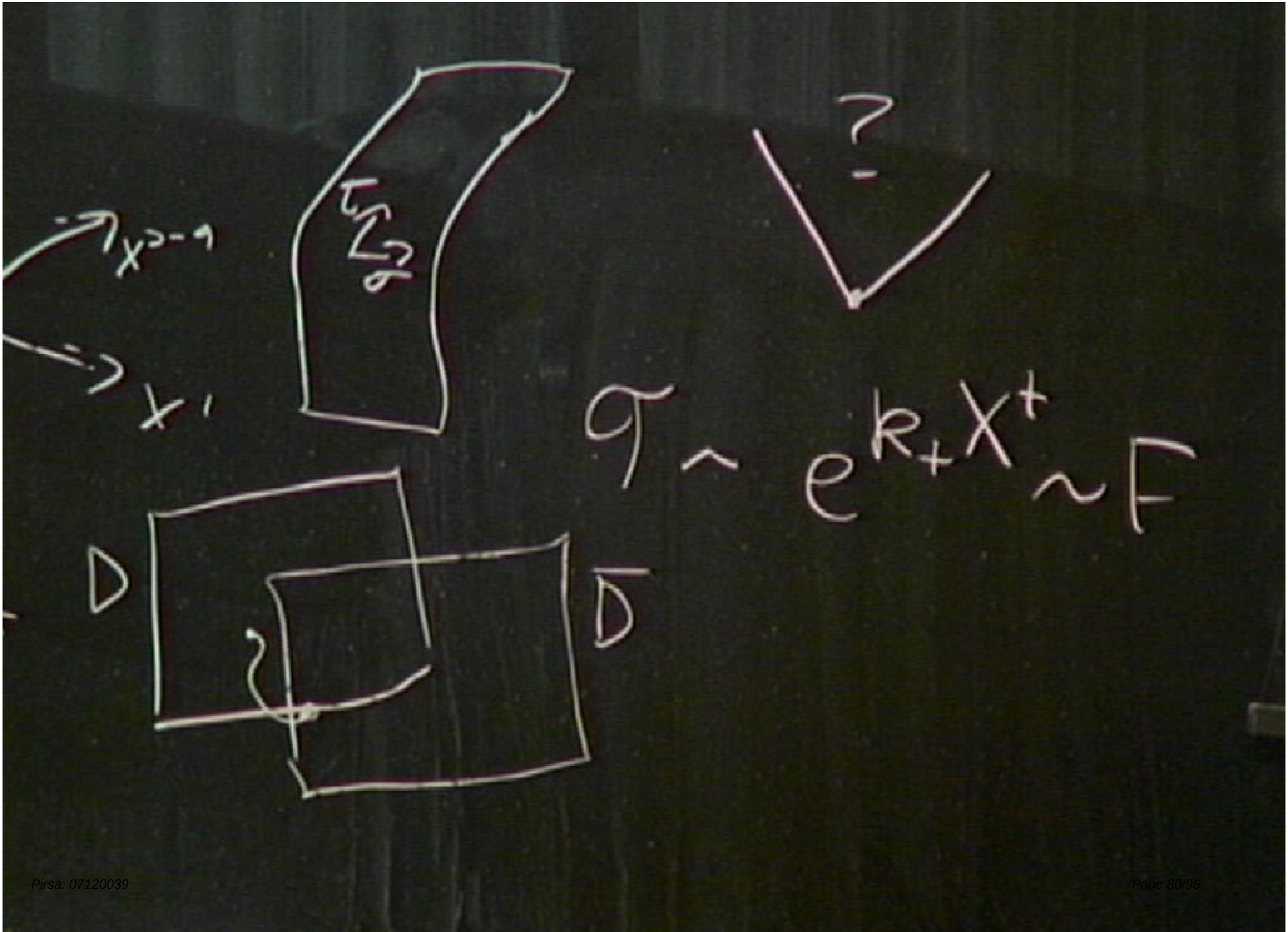
We can further simplify by rescaling

$$\widetilde{\chi}_{++} = F\chi_{++}, \qquad \widetilde{\psi}_-^- = \frac{\psi_-^-}{F}.$$


X^{1}
D
$\bar{D}$
$\sigma \sim e^{k_+ X^+} \sim F$

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Proper Rescaling

Rescaling χ_{++} and ψ_-^- by X^+ dependent terms introduces another subtle Jacobian:

$$\widetilde{J} = \exp\left\{-\frac{i}{4\pi\alpha'}\int d^2\sigma\hat{e}\left(\alpha' k_+^2 \hat{h}^{mn}\partial_m X^+ \partial_n X^+ + \alpha' k_+ X^+ R\right)\right\}.$$

Notice the $\partial X^+ \partial X^+$ term here precisely cancels the effect from $J_{\psi_-^+\epsilon}$.

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The linear dilaton shift

This term is easily seen to be a contribution to the linear dilaton; here we are in Euclidean signature initially:

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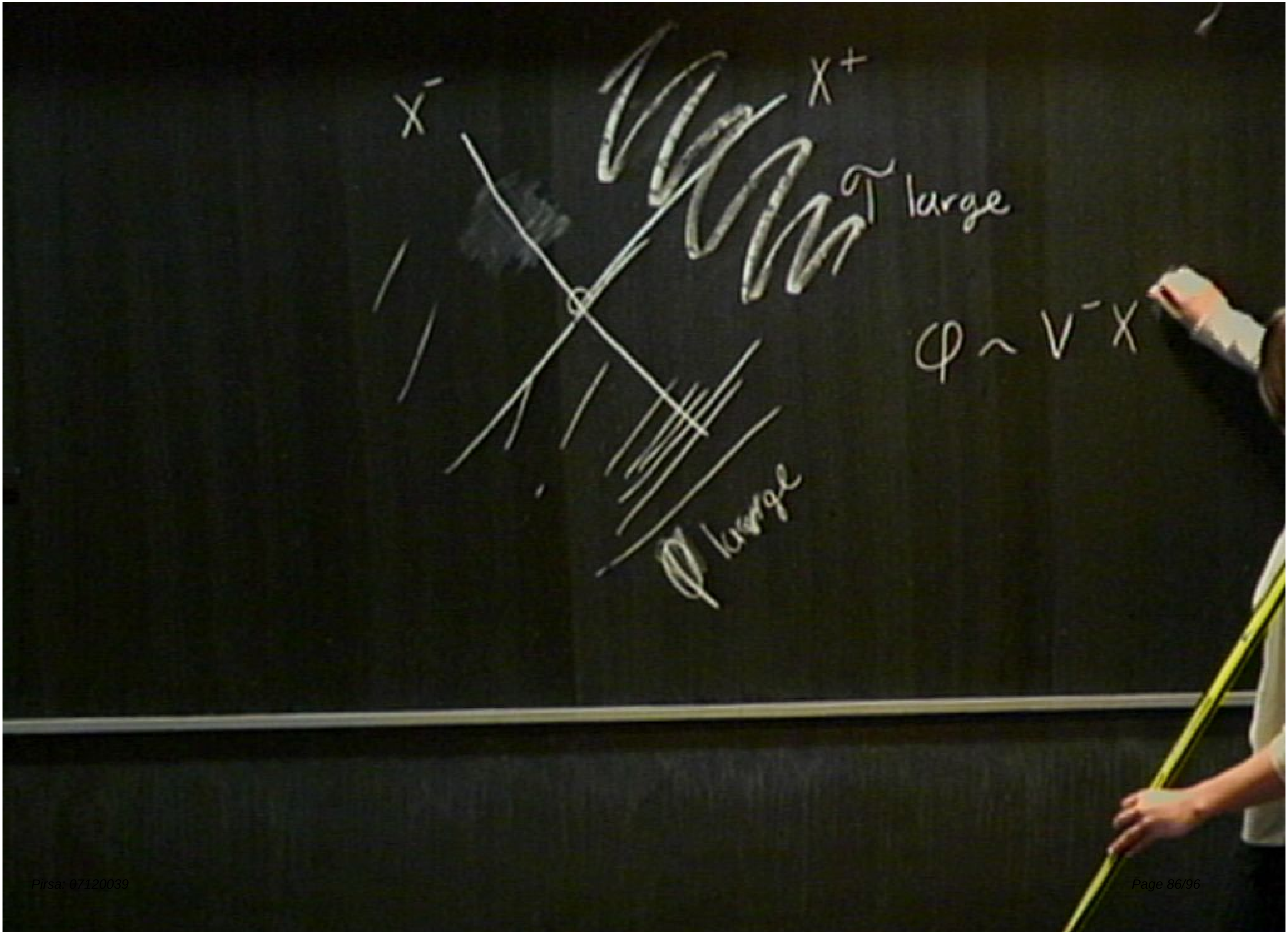
Now we use the expression $eR = -2\delta^{mn}\partial_m\partial_n\phi$ for the worldsheet scalar curvature in conformal gauge, to get

$$\Delta S_E = \frac{1}{4\pi}\int d^2\sigma\, e\, k_+ X^+ R.$$

Rotating back to Minkowski signature:

$$\Delta S = -\frac{1}{4\pi}\int d^2\sigma\, e\, k_+ X^+ R.$$

which represents a shift in the dilaton by $V_+ = k_+$; our new central charge is thus $c_{dil} = 6\alpha' V^2 = 12$.



x^-
x^+
$\tilde{\varphi}$ large
$\varphi \sim V^- x$
φ large

Overall central charge

Superconformal gauge

Field	c_L	c_R
X^+, X^-, X^i	10	10
linear dilaton	0	0
bc ghosts	-26	-26
ψ^i	0	4
ψ^+, ψ^-	0	1
β, γ ghosts	0	11
λ_+	$1/2$	0
$(E_8)_2$	$31/2$	0

The alternative gauge

Field	c_L	c_R
X^+, X^-, X^i	10	10
linear dilaton	12	12
bc ghosts	-26	-26
ψ^i	0	4
$\widetilde{\chi}$, $\widetilde{\psi}^-$	-11	0
$\widetilde{\beta}$, $\widetilde{\gamma}$ ghosts	-1	0
λ_+	$1/2$	0
$(E_8)_2$	$31/2$	0

Analysis at large X^+

We have, as clearly visible in the $\psi_-^+ = 0$ gauge:

- Shifted linear dilaton
- propagating free spin $3/2$ gravitino system $\chi\psi^-$
- large potential term $\mu^2 \exp(2k_+ X^+)$ which expels d.o.f's from condensed region
- late time SUSY is restored under $\widetilde{\epsilon}_+ = F\epsilon_+$:

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Conclusions

- Found a good gauge in which to view tachyon condensation

Future Directions

- Application of new gauges to other systems

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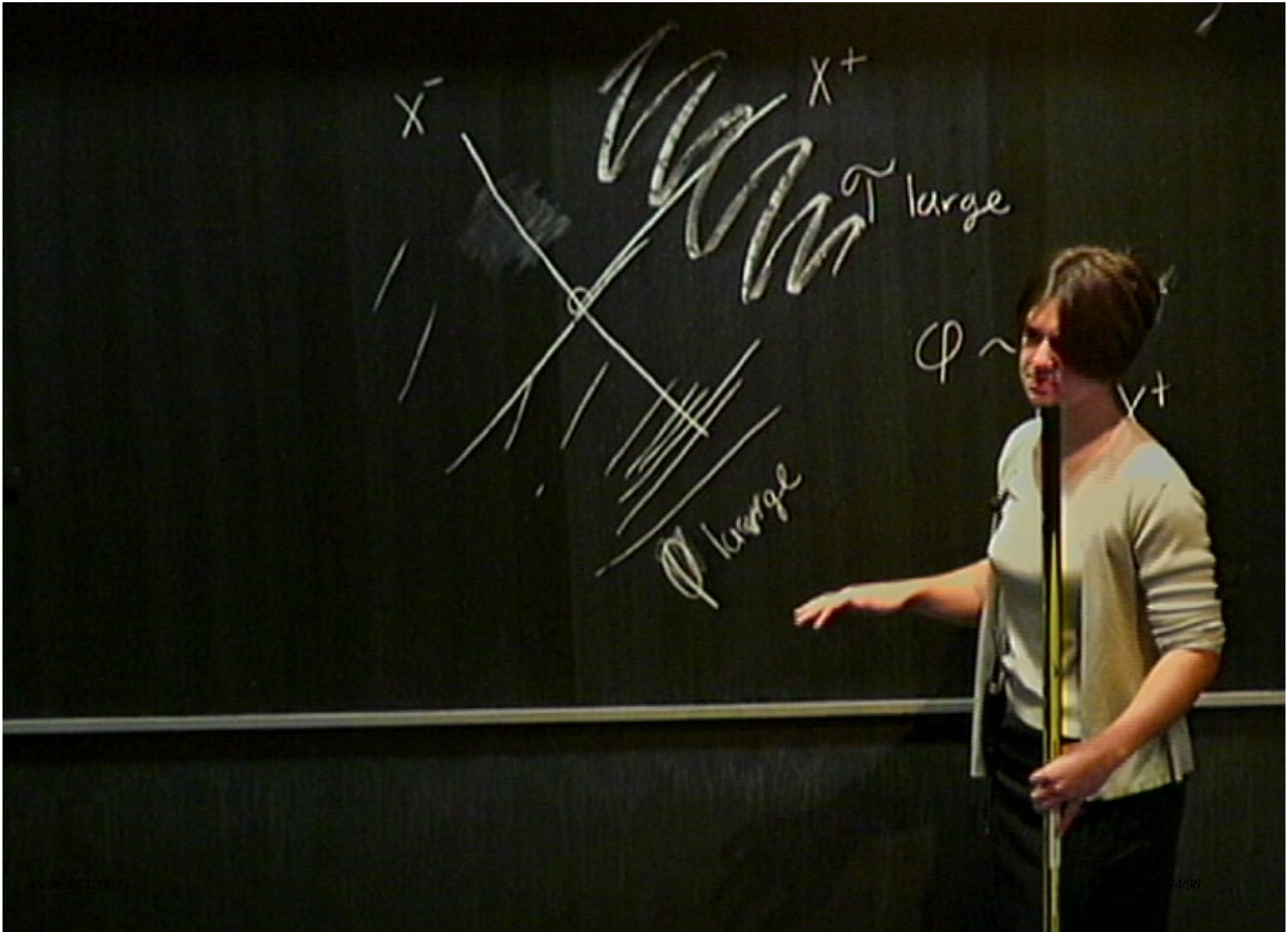
x⁻
x⁺
large
φ large
φ ~
x⁺

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- Towards non-equilibrium string theory