Title: Electroweak Symmetry Breaking from Gauge/Gravity Duality

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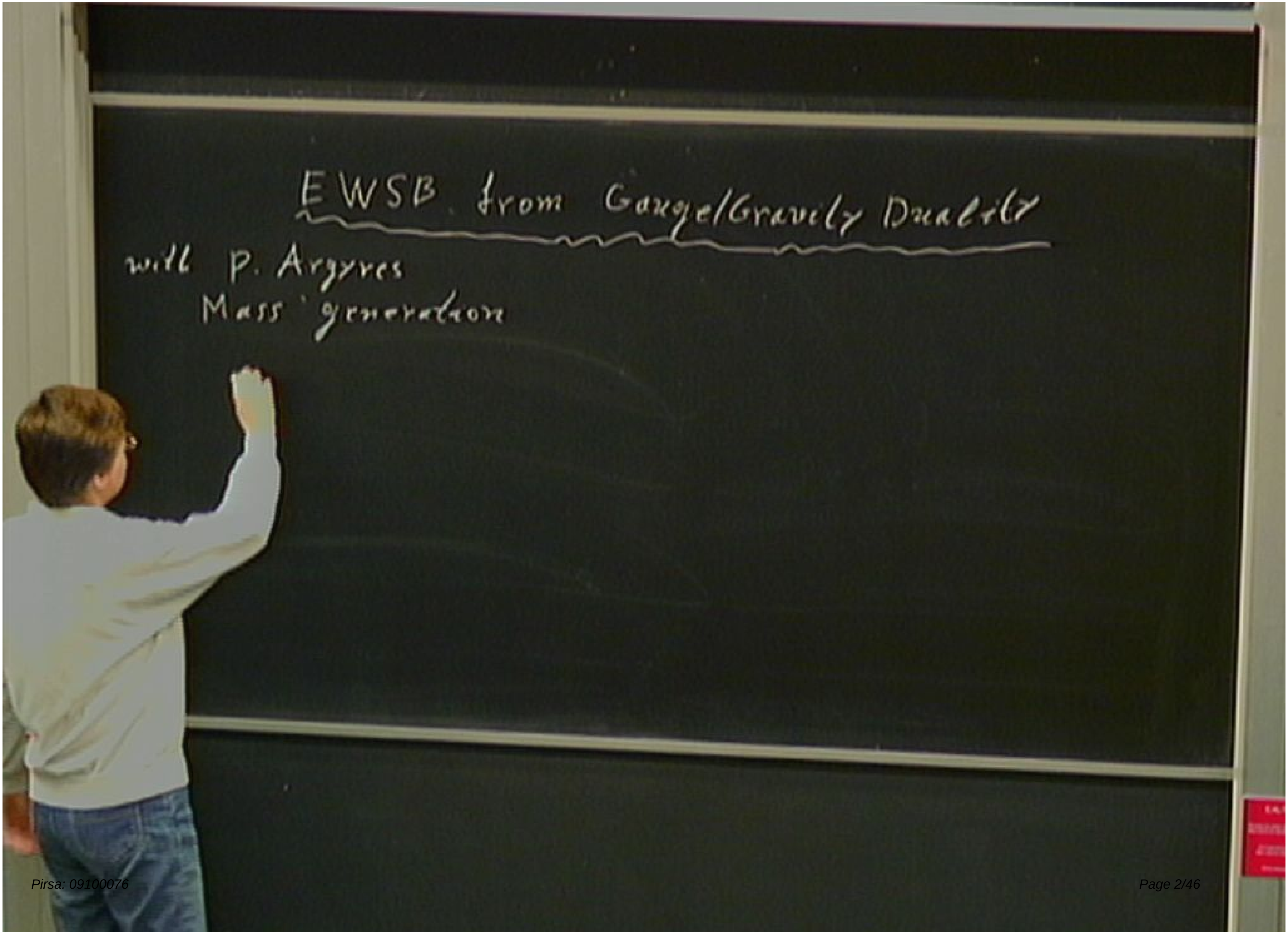
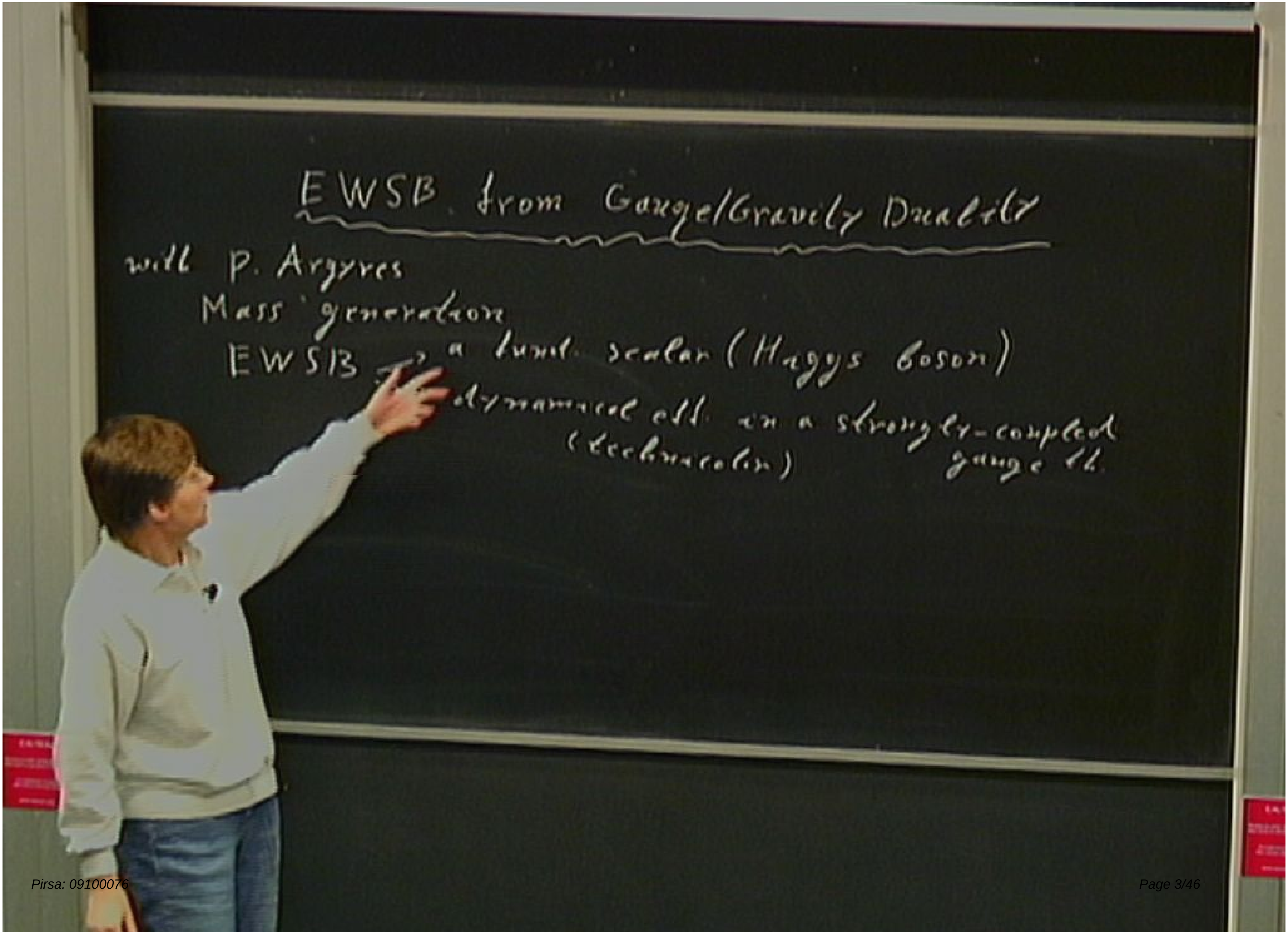
URL: http://pirsa.org/09100076

Abstract: We utilize the tools of the gauge/gravity correspondence in order to investigate electroweak symmetry breaking (EWSB). For quite some time now, a walking technicolor sector has been viewed by phenomenologists as a very promising alternative to the Higgs boson. Unfortunately however, no precise computations have been possible since in the technicolor gauge theory EWSB is due to strong-coupling dynamics. Using recent developments in the gauge/gravity duality, we construct a gravity dual of a walking technicolor model and aim to compute the Peskin-Takeuchi S-parameter, which is an observable that can distinguish between a Higgs and a technicolor sector.


EWSB from Gauge/Gravity Duality
with P. Argyres
Mass generation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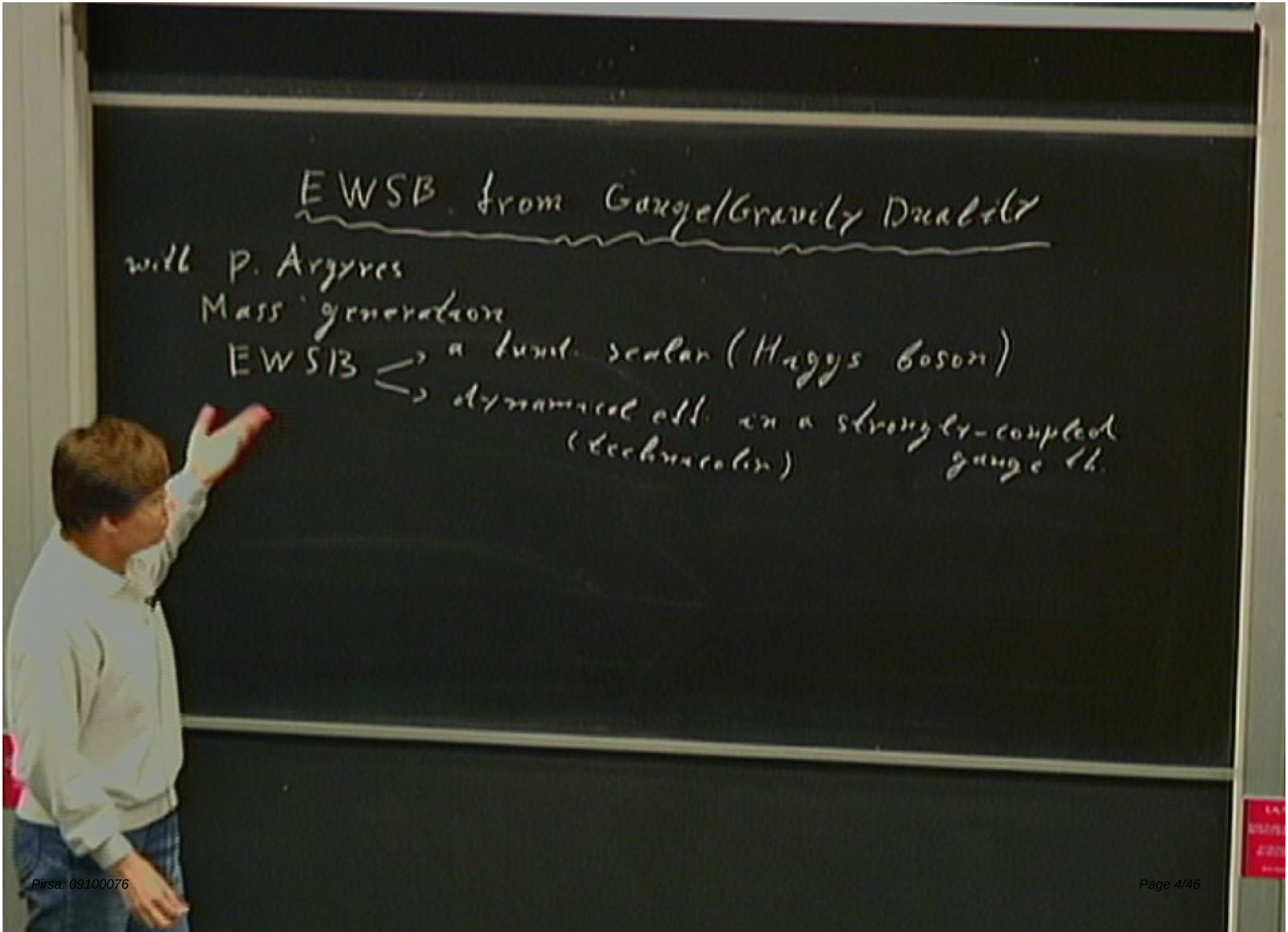
EWSB → a fund. scalar (Higgs boson)
→ dynamical eff. in a strongly-coupled gauge th.
(technicolor)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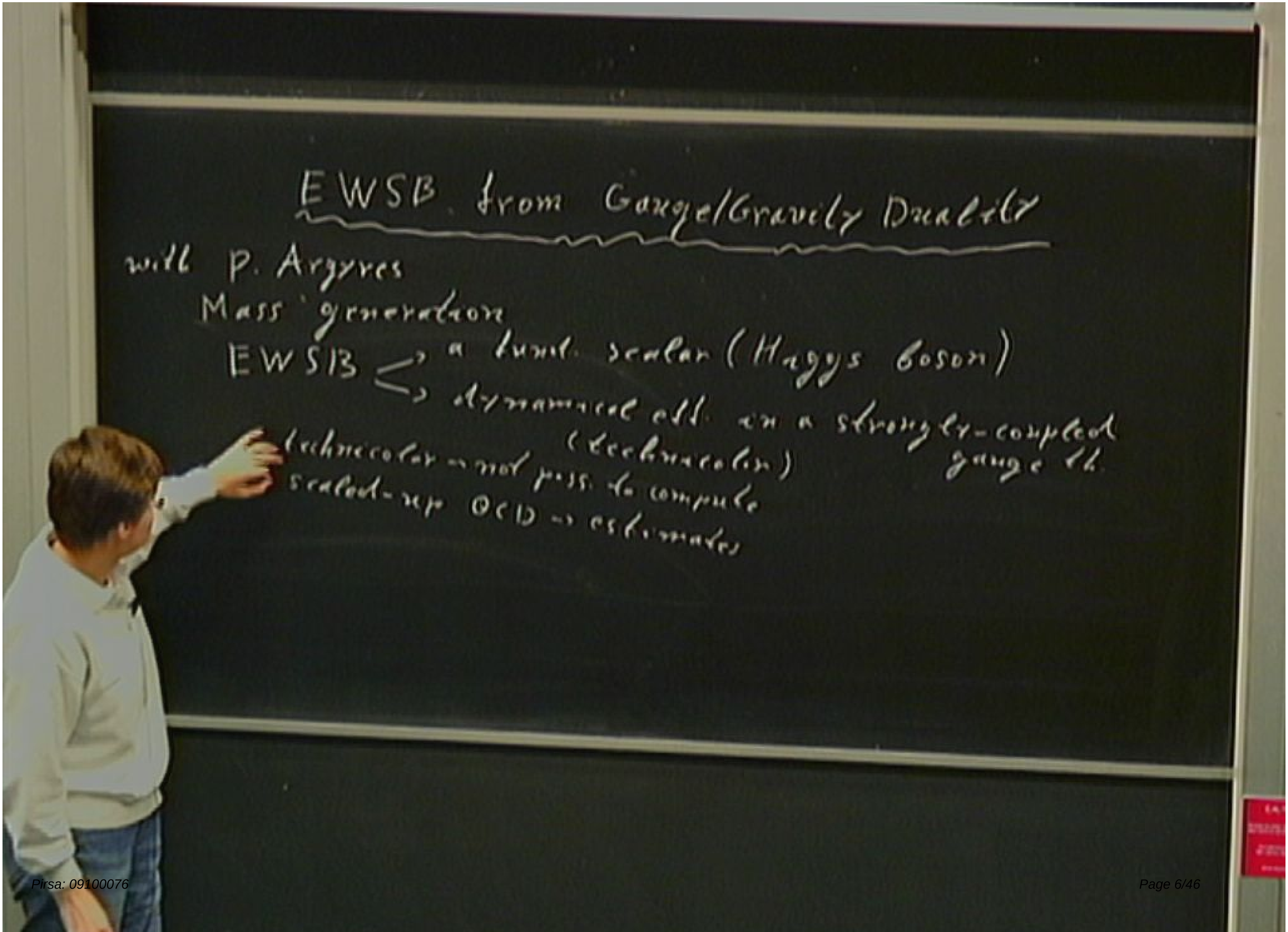
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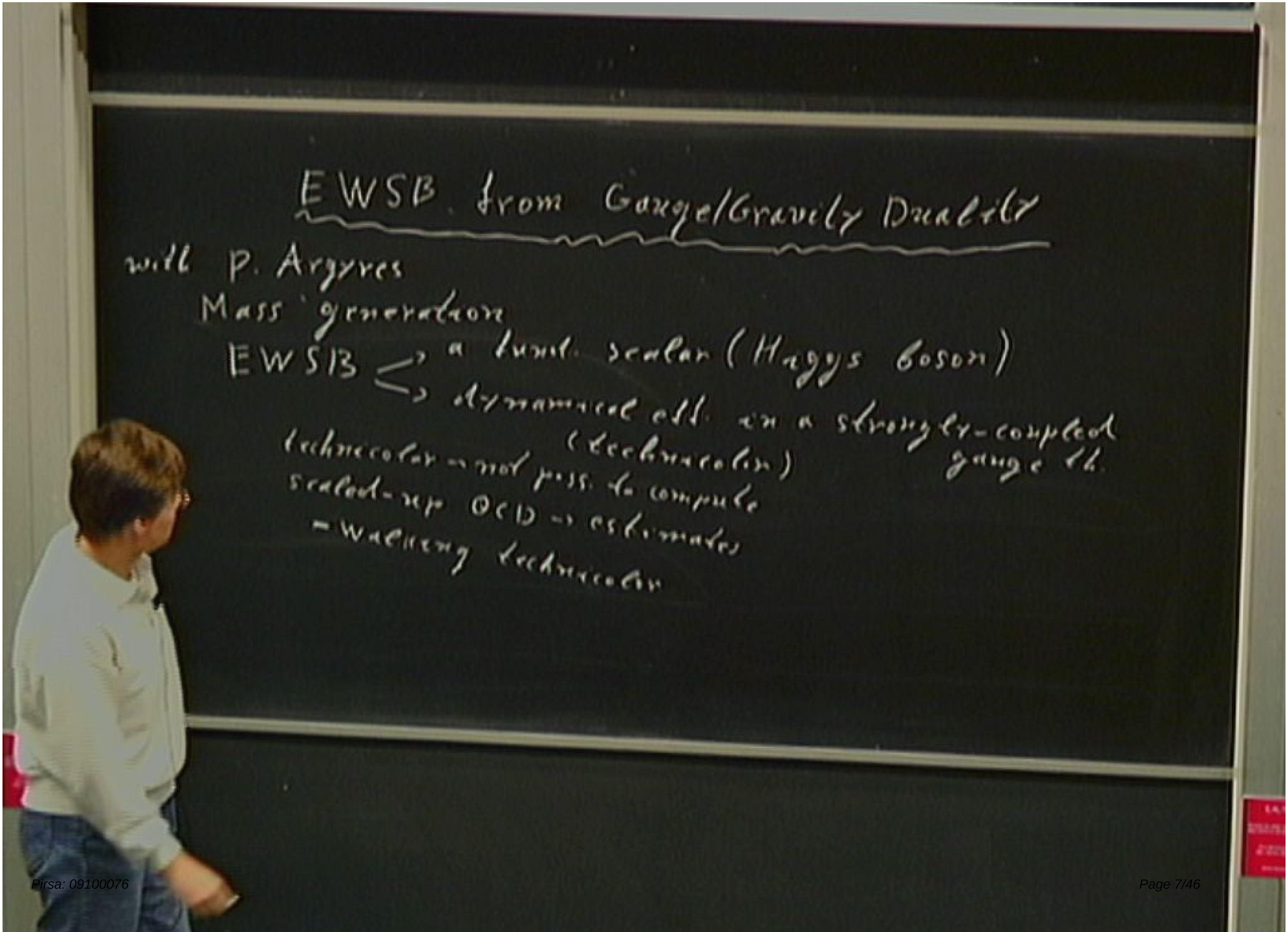
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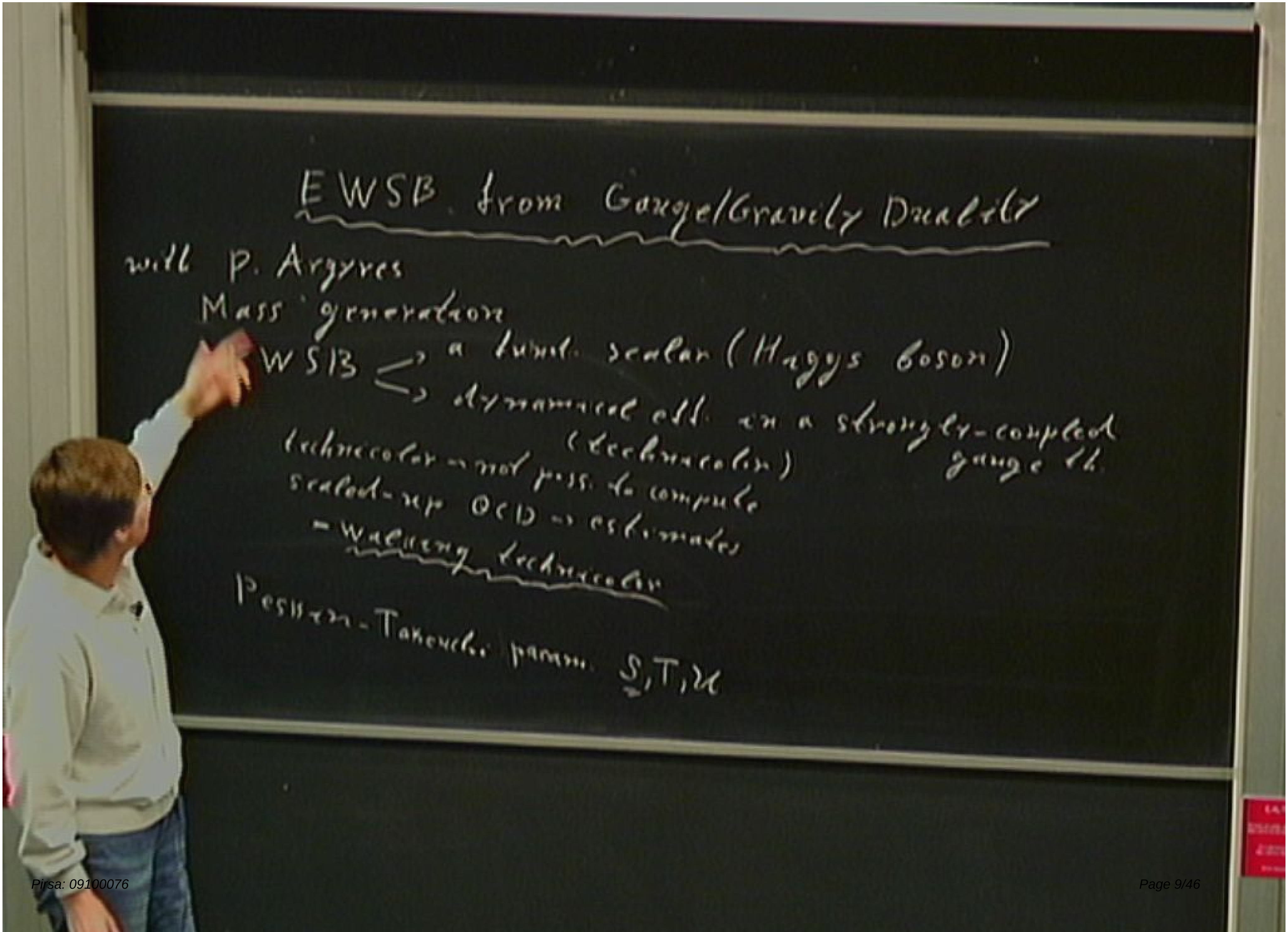
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Peskin-Takeuchi param. S, T, U

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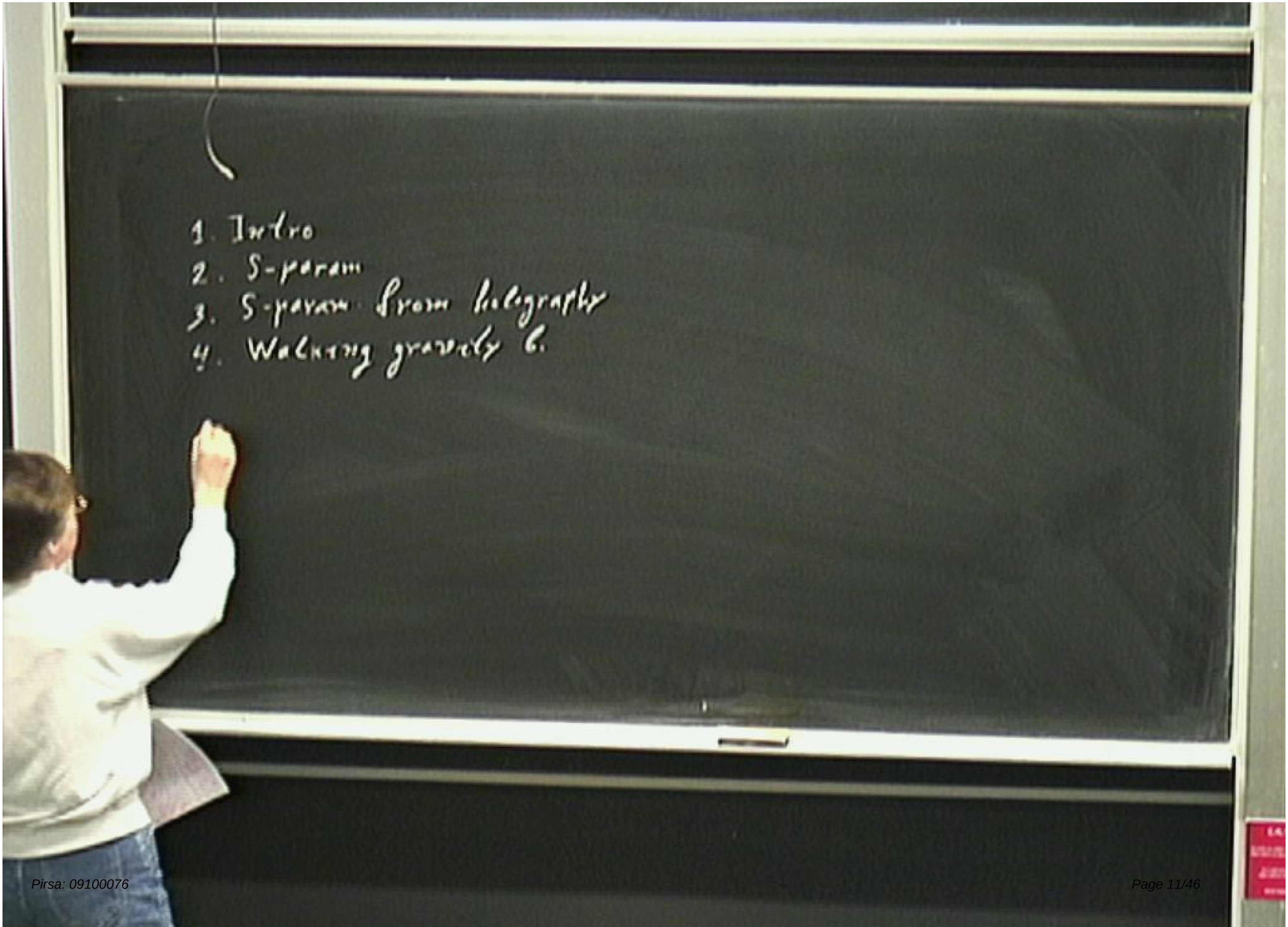
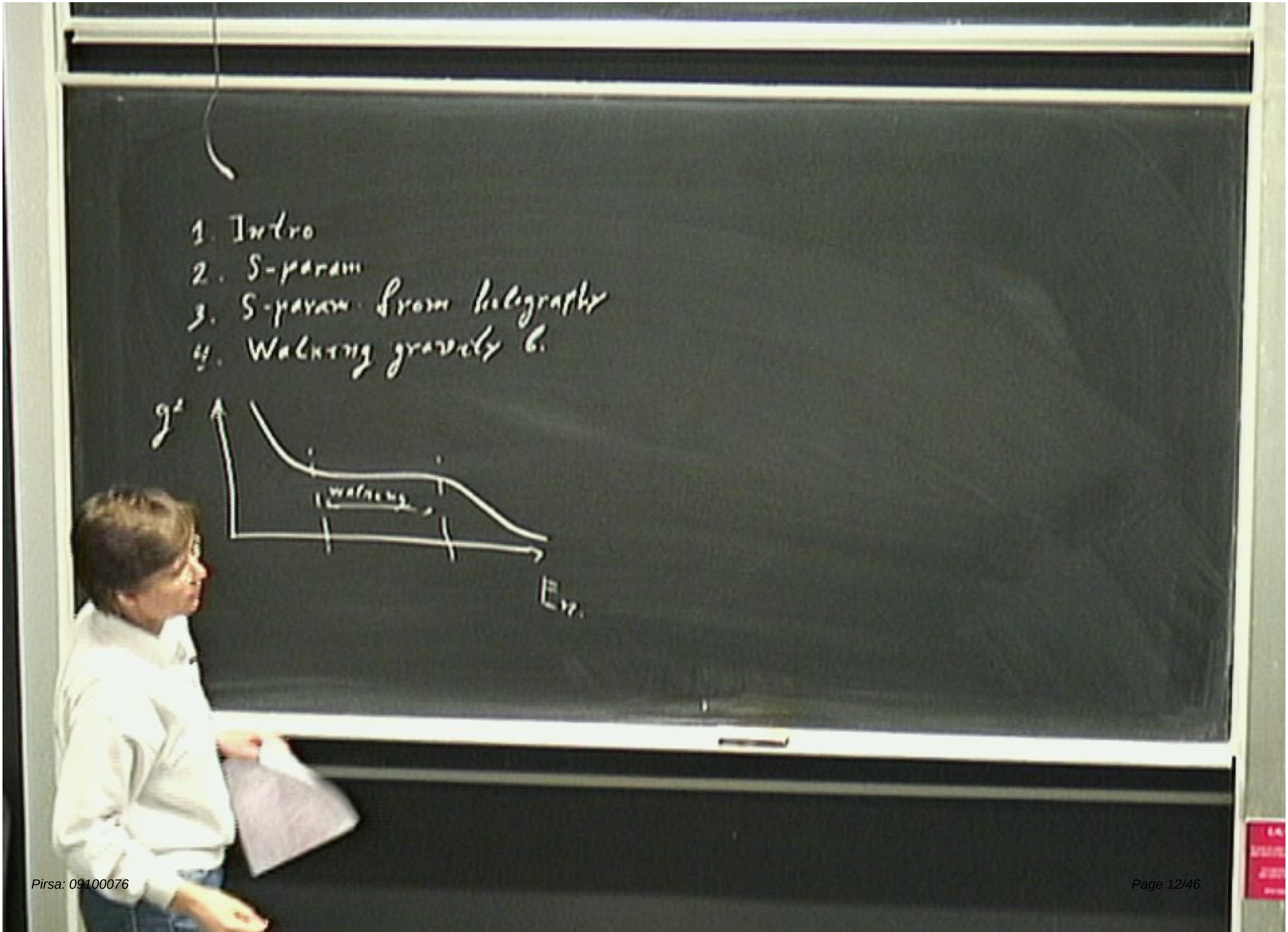

1. Intro
2. S-param
3. S-param from holography
4. Walking gravity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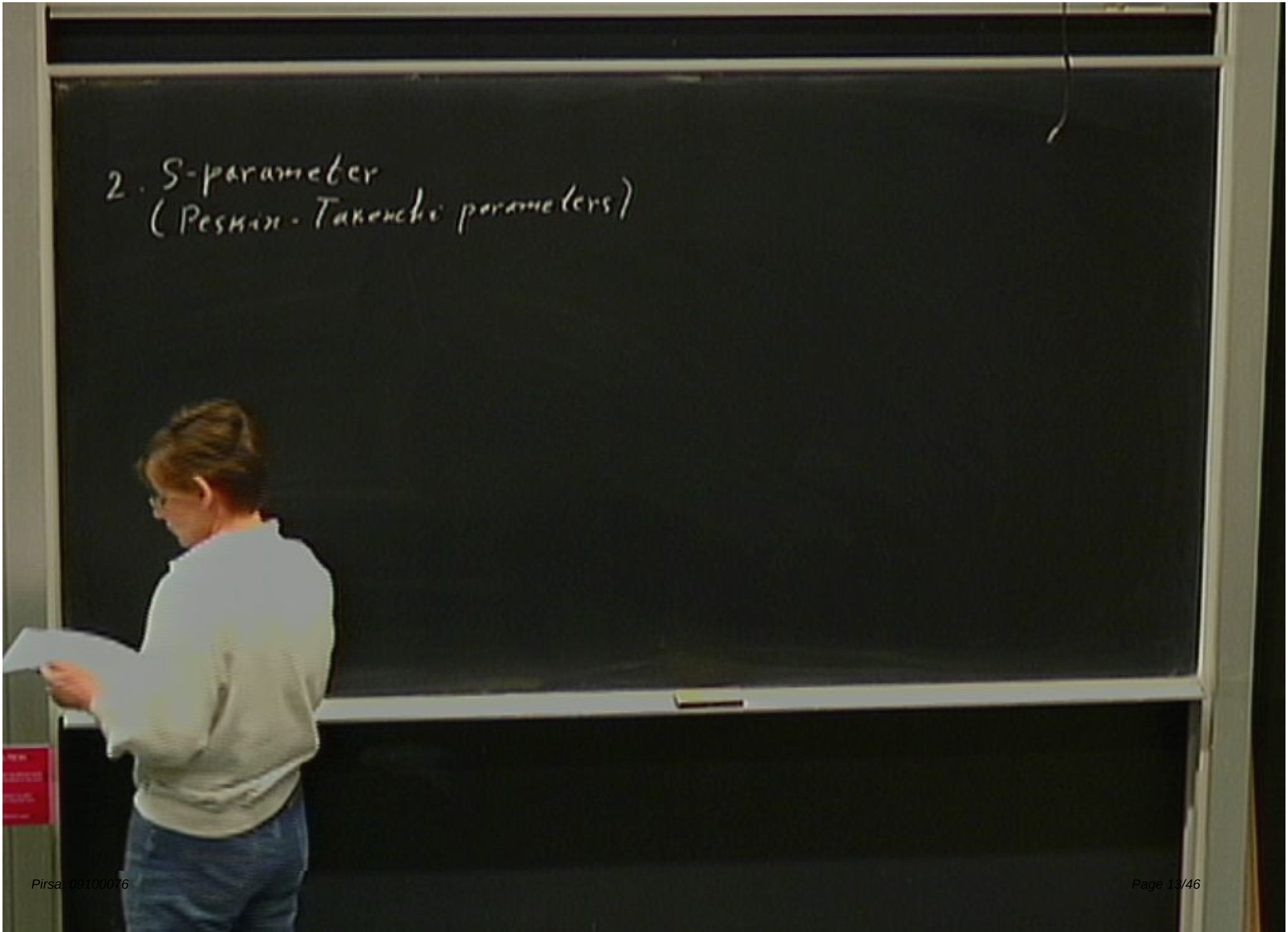
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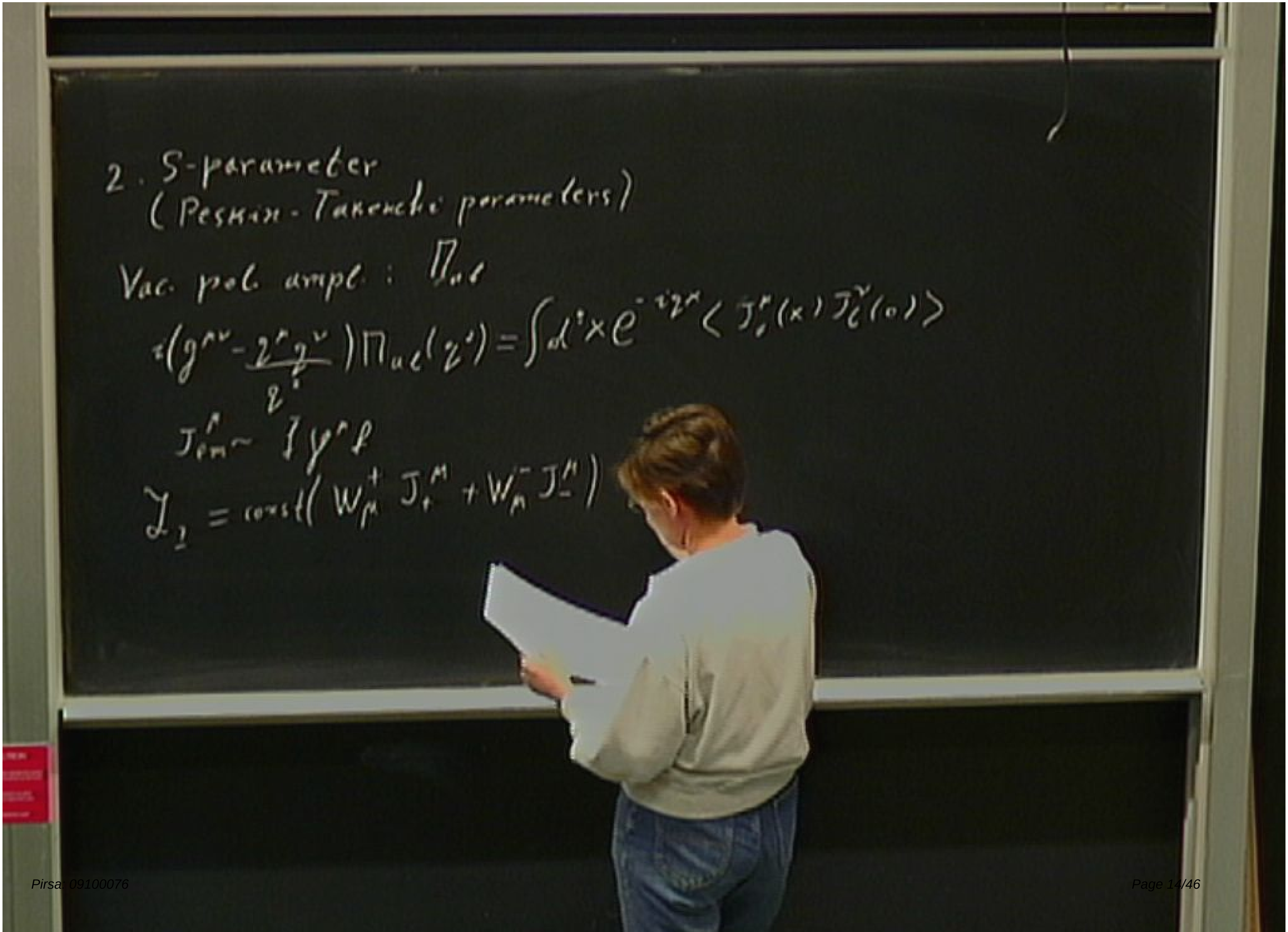
(Peskin-Takeuchi parameters)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(Peskin-Takeuchi parameters)
Vac. pol. ampl. : Π_{ab}
$i(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2})\Pi_{ab}(q^2) = \int d^4x\, e^{-iqx} \langle J_a^\mu(x) J_b^\nu(0) \rangle$
$J^\mu_{em} \sim \bar{f}\gamma^\mu f$
$\mathcal{L}_I = \text{const}(W^+_\mu J^\mu_+ + W^-_\mu J^\mu_-)$

2. S-parameter
(Peskin - Takeuchi parameters)

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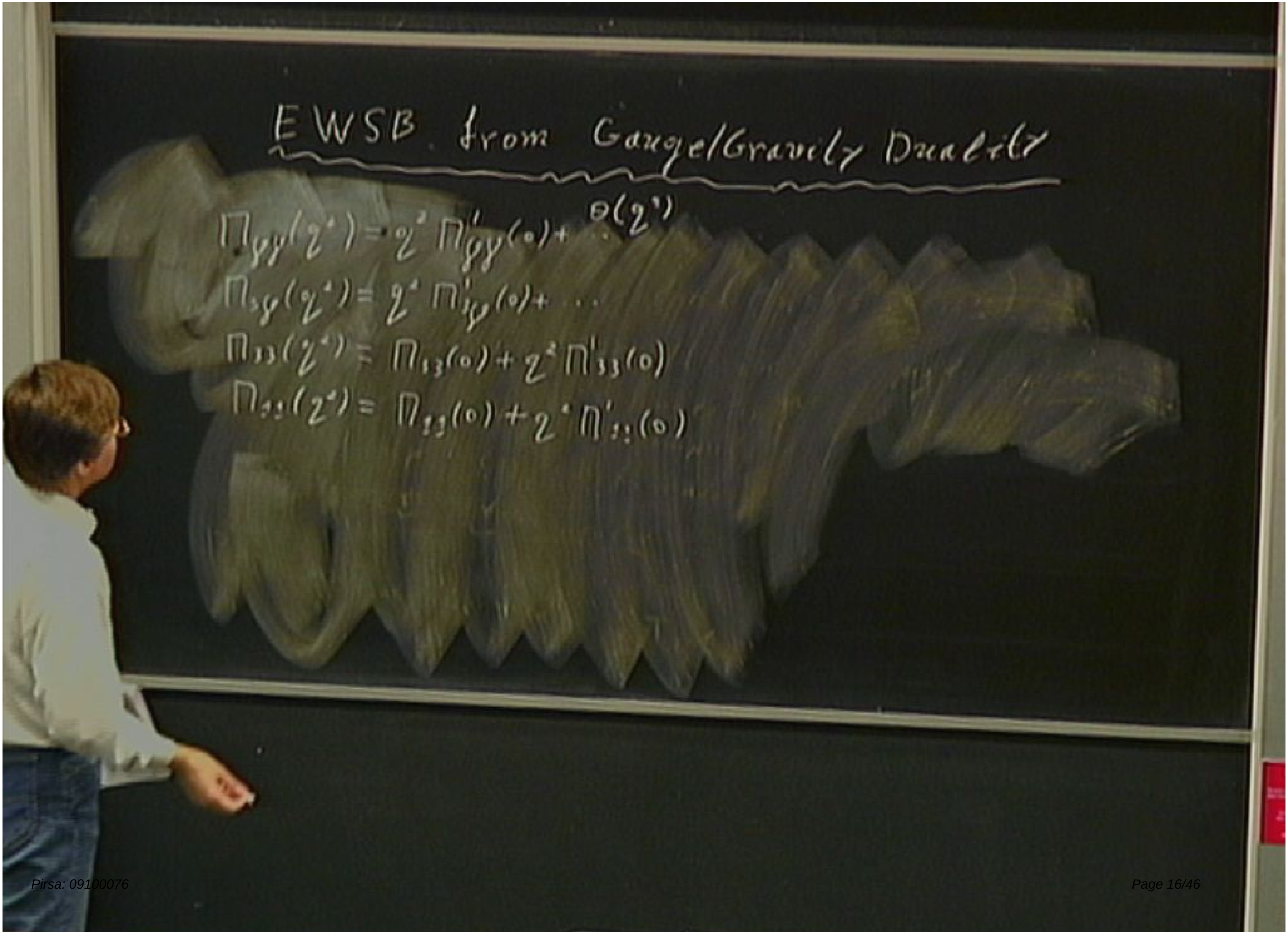
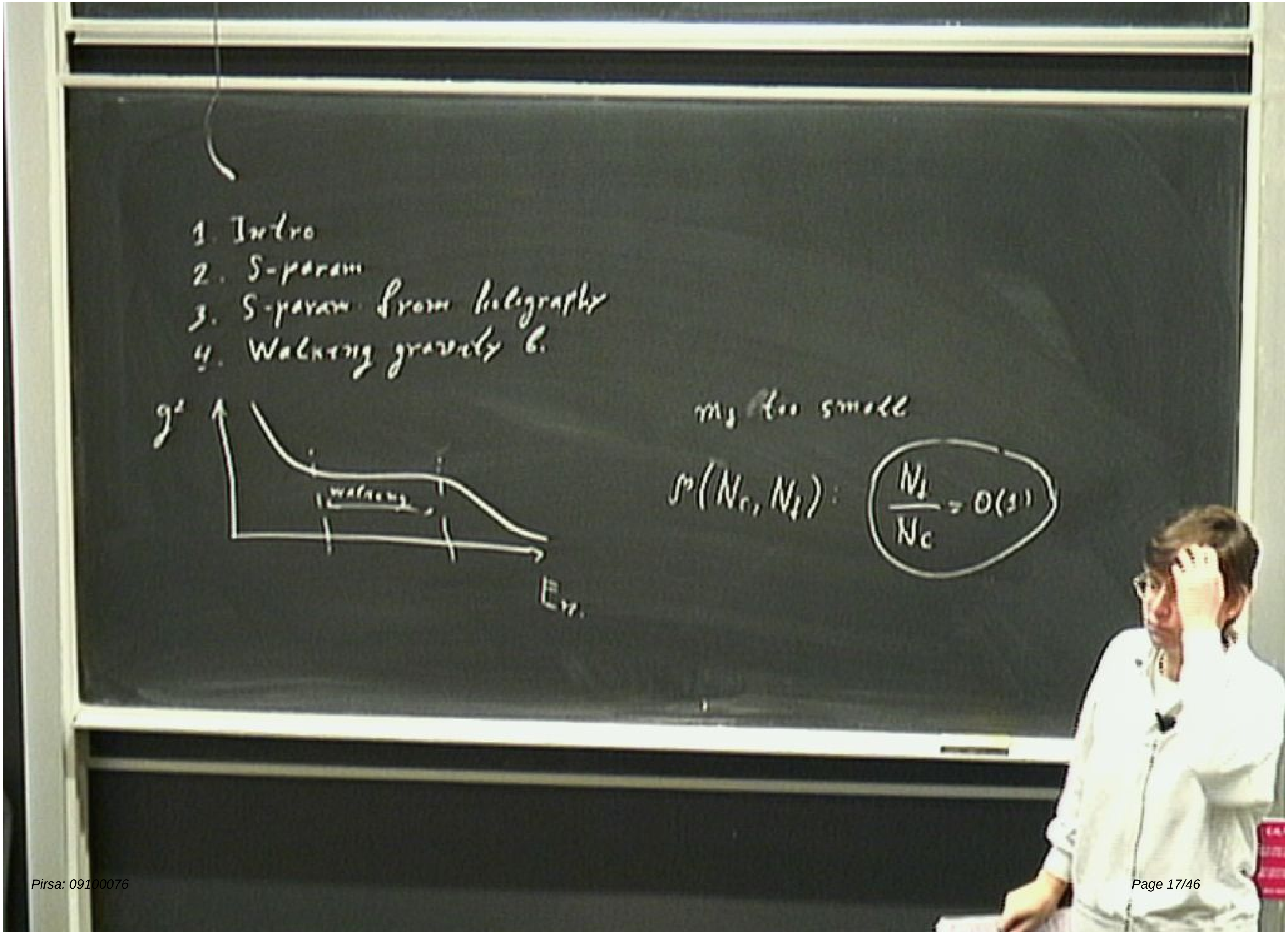
$a, b = 1, 2, 3, Y$

$J^\mu_{em} \sim \bar{\ell}\gamma^\mu \ell$ EW: $SU(2) \times U(1)$

$$\mathcal{L}_I = \text{const}\left(W^+_\mu J^\mu_+ + W^-_\mu J^\mu_-\right) + \text{const}' Z_\mu\left(J^\mu_3 - \sin^2\theta_W J^\mu_Y\right) + eA_\mu J^\mu_Y$$

$E_n \gg m_Z$: expand in q^2 :


EWSB from Gauge/Gravity Duality
$\Pi_{\gamma\gamma}(q^2) = q^2\,\Pi'_{\gamma\gamma}(0) + O(q^4)$
$\Pi_{3\gamma}(q^2) = q^2\,\Pi'_{3\gamma}(0) + \ldots$
$\Pi_{33}(q^2) = \Pi_{33}(0) + q^2\,\Pi'_{33}(0)$
$\Pi_{11}(q^2) = \Pi_{11}(0) + q^2\,\Pi'_{11}(0)$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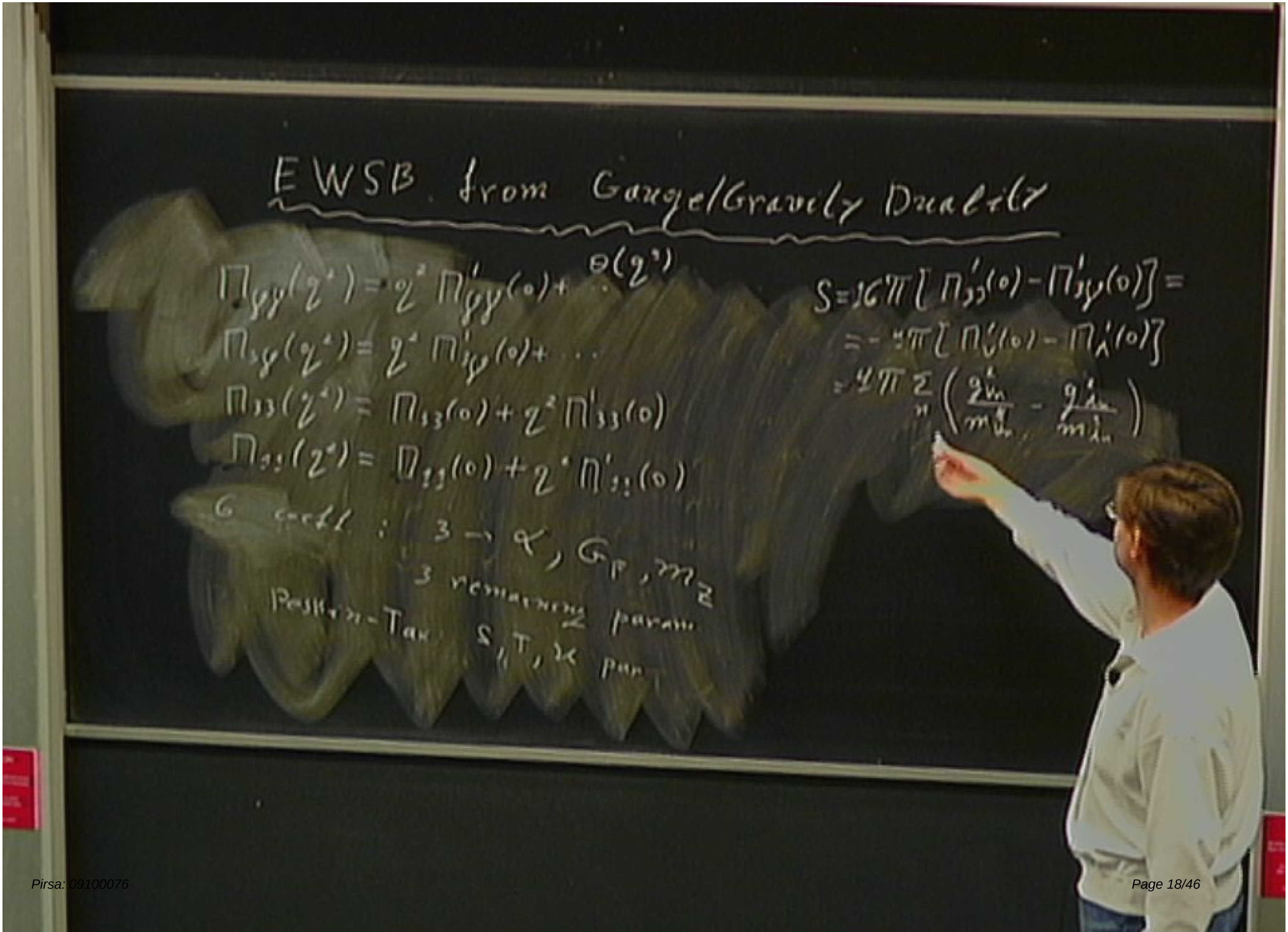
walking
$N_f / N_c = O(1)$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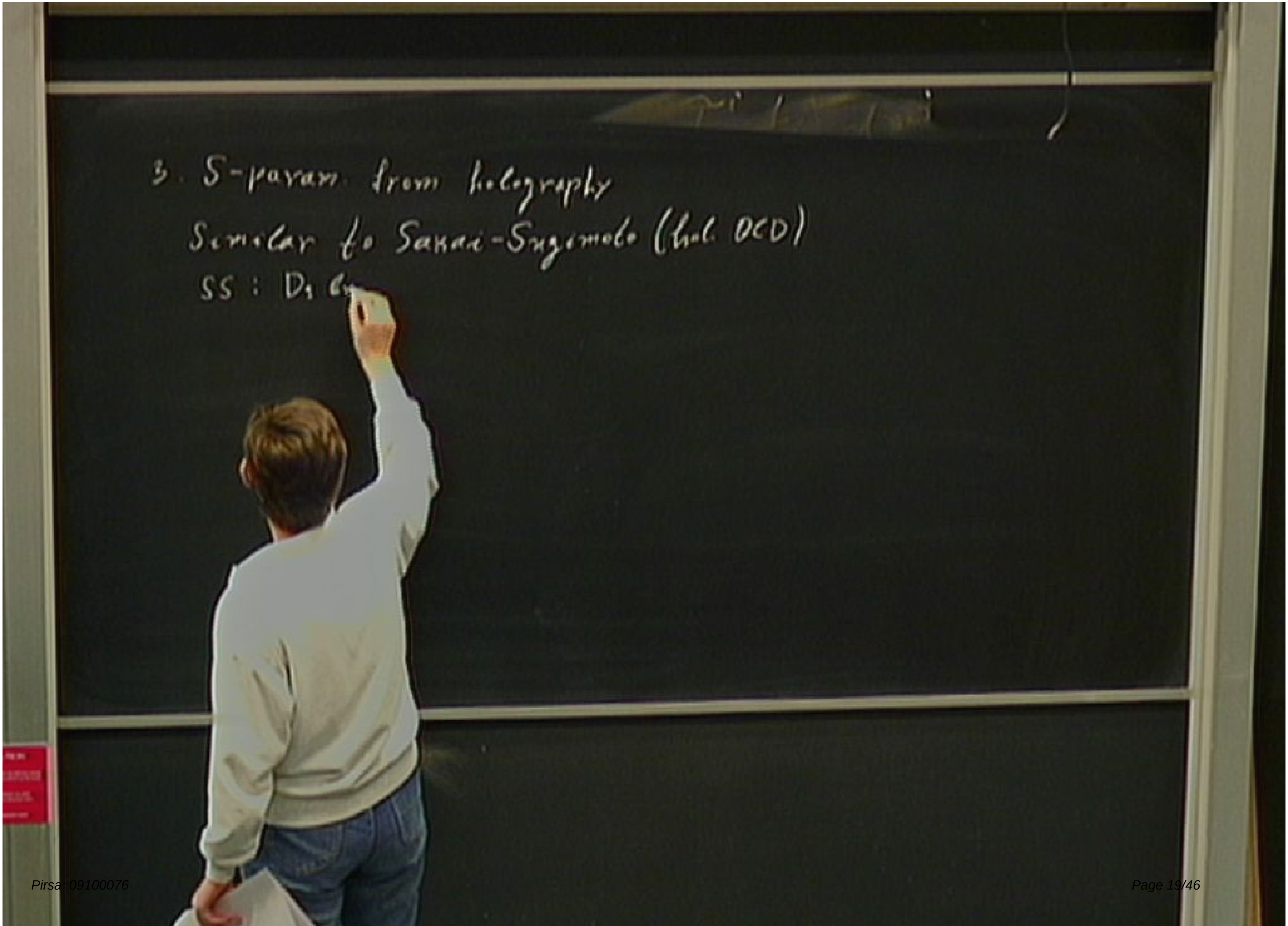
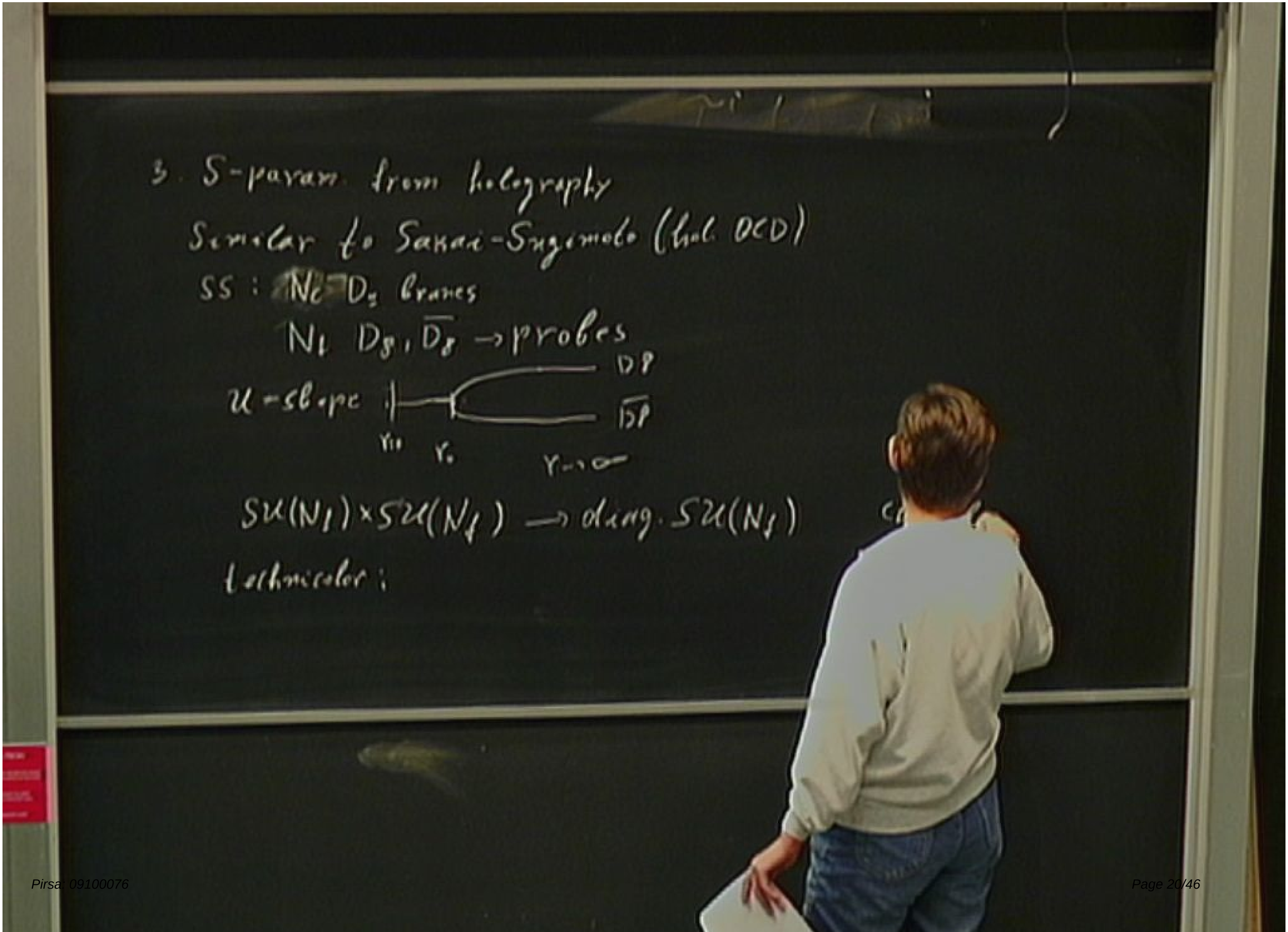
$\Pi_{33}(q^2) = \Pi_{33}(0) + q^2\,\Pi'_{33}(0)$
$\Pi_{11}(q^2) = \Pi_{11}(0) + q^2\,\Pi'_{11}(0)$
6 coeff : 3 → α, G_F, m_Z
3 remaining param
Peskin-Tak S, T, U par
$S = 16\pi\,[\Pi'_{33}(0) - \Pi'_{3\gamma}(0)] =$
$= -4\pi\,[\Pi'_V(0) - \Pi'_A(0)]$
$= 4\pi \sum_n \left(\frac{g^2_{V_n}}{m^2_{V_n}} - \frac{g^2_{A_n}}{m^2_{A_n}} \right)$


3. S-param. from holography
Similar to Sakai-Sugimoto (hol. QCD)
SS : D4

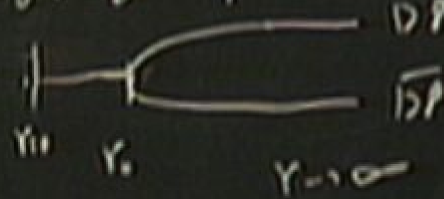

3. S-param from holography
Similar to Sakai-Sugimoto (hol. QCD)
SS : Nc D4 branes
Nf D8, D8 → probes
U-shape
D8
D8
r0
r → ∞
SU(Nf) × SU(Nf) → diag. SU(Nf)
technicolor :

3. S-param from holography

Similar to Sakai-Sugimoto (hol. QCD)

SS : N_c D_4 branes

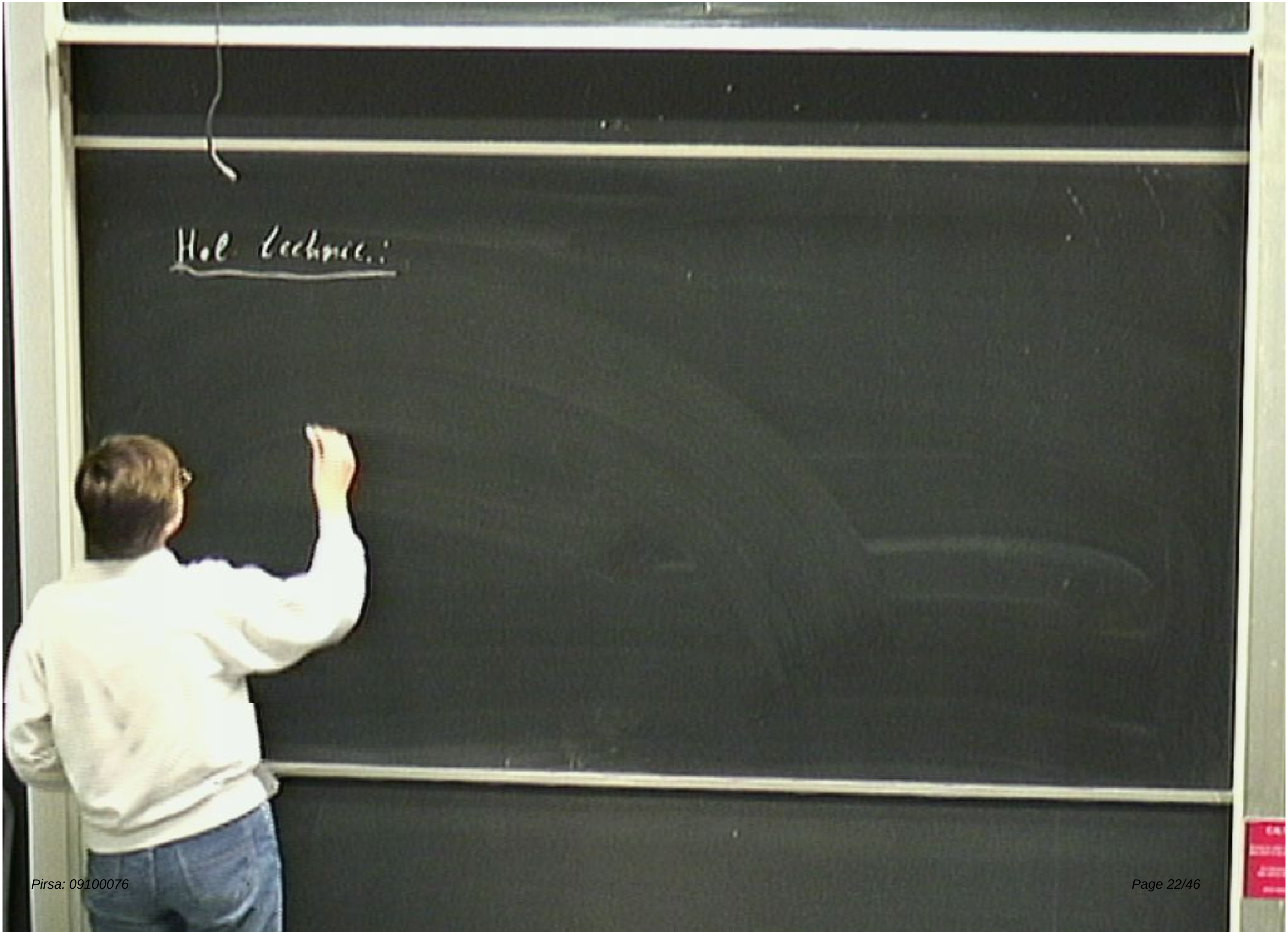
N_f $D_8, \overline{D_8}$ $\to$ probes

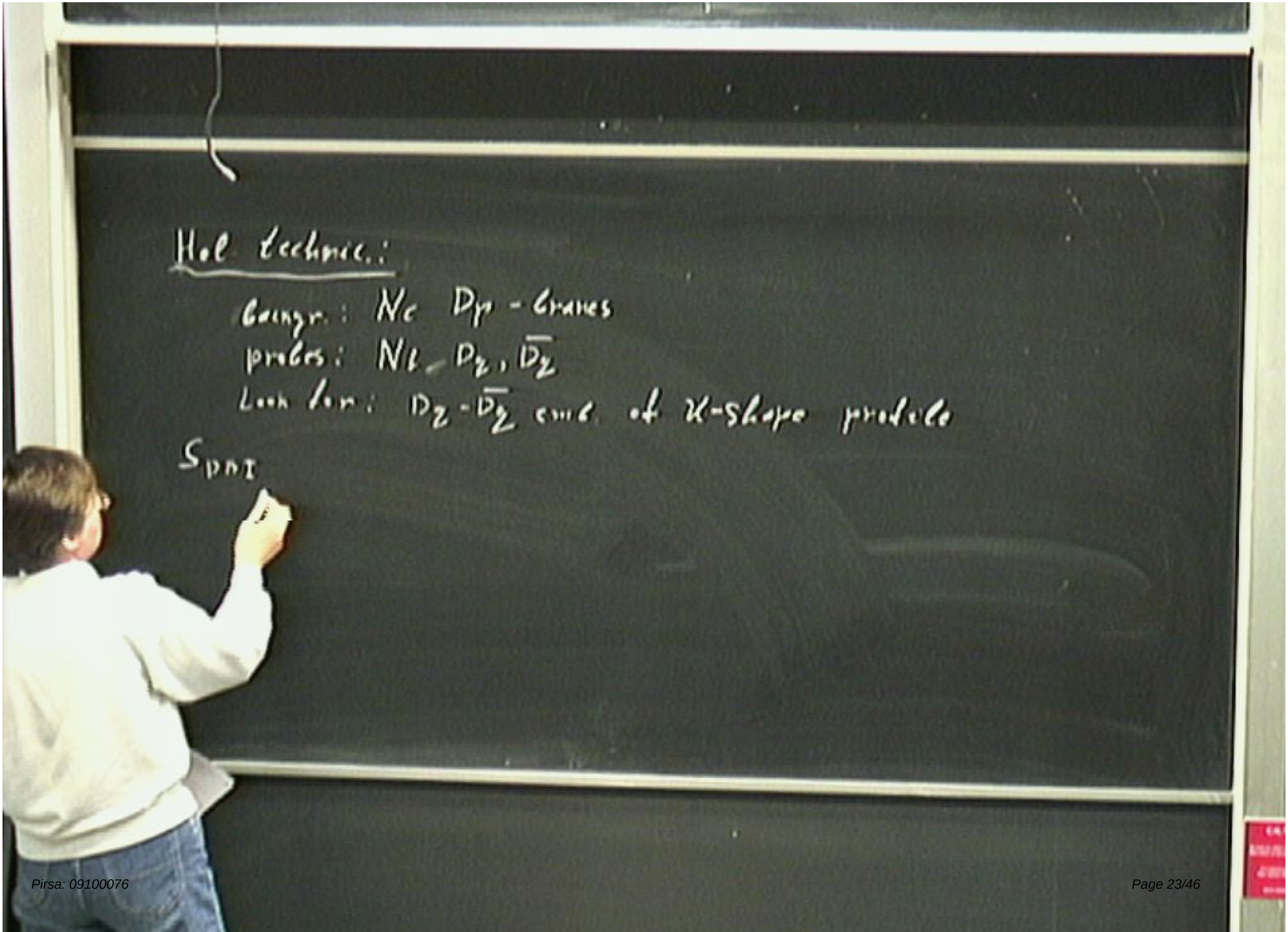
U-shape 

Stable, but not susy

$SU(N_f)\times SU(N_f) \longrightarrow$ diag. $SU(N_f)$ chiral SB

technicolor: chiral SB $\longrightarrow$ EWSB due to $SU(2)\times U(1) \subset SU(N_f)$


Hol technic.:


Hol technic.:
Backgr.: N_c D_p-branes
probes: N_f D_q, $\overline{D_q}$
Look for: D_q-$\overline{D_q}$ conf. of U-shape profile
Spin

Hol. technic.:

backgr.: N_c Dp - branes

probes: N_f Dq, $\overline{Dq}$

Low. lim.: Dq - $\overline{Dq}$ conn. of U-shape profile

$$S_{DBI} = -T_q \int d^{q+1}\sigma \, e^{-\phi} \sqrt{-\det(g_{ind} + F)} + CS$$

↳ technoflavor field str.

Hol. technic.:

Backgr.: N_c Dp-branes

probes: N_f D_q, $\overline{D_q}$

Look for: D_q-$\overline{D_q}$ conf. of U-shape profile

$$S_{DBI} = -T_q \int d^{q+1}\sigma \, e^{-\phi} \sqrt{-\det(g_{ind} + F)} + CS$$

$$\overset{YM}{\approx} -\frac{\tilde{T}_q}{4} \int d^4x \, dr \left[a(r) F_{\mu\nu} F^{\mu\nu} + 2\, b(r) F_{\mu r} F^{\mu}{}_{r} \right]$$

↳ technoflavor field str.

Hol technic.:

backgr.: N_c D_p - branes

probes: N_f D_q, $\overline{D_q}$

Look for: D_q - $\overline{D_q}$ conf. of U-shape profile

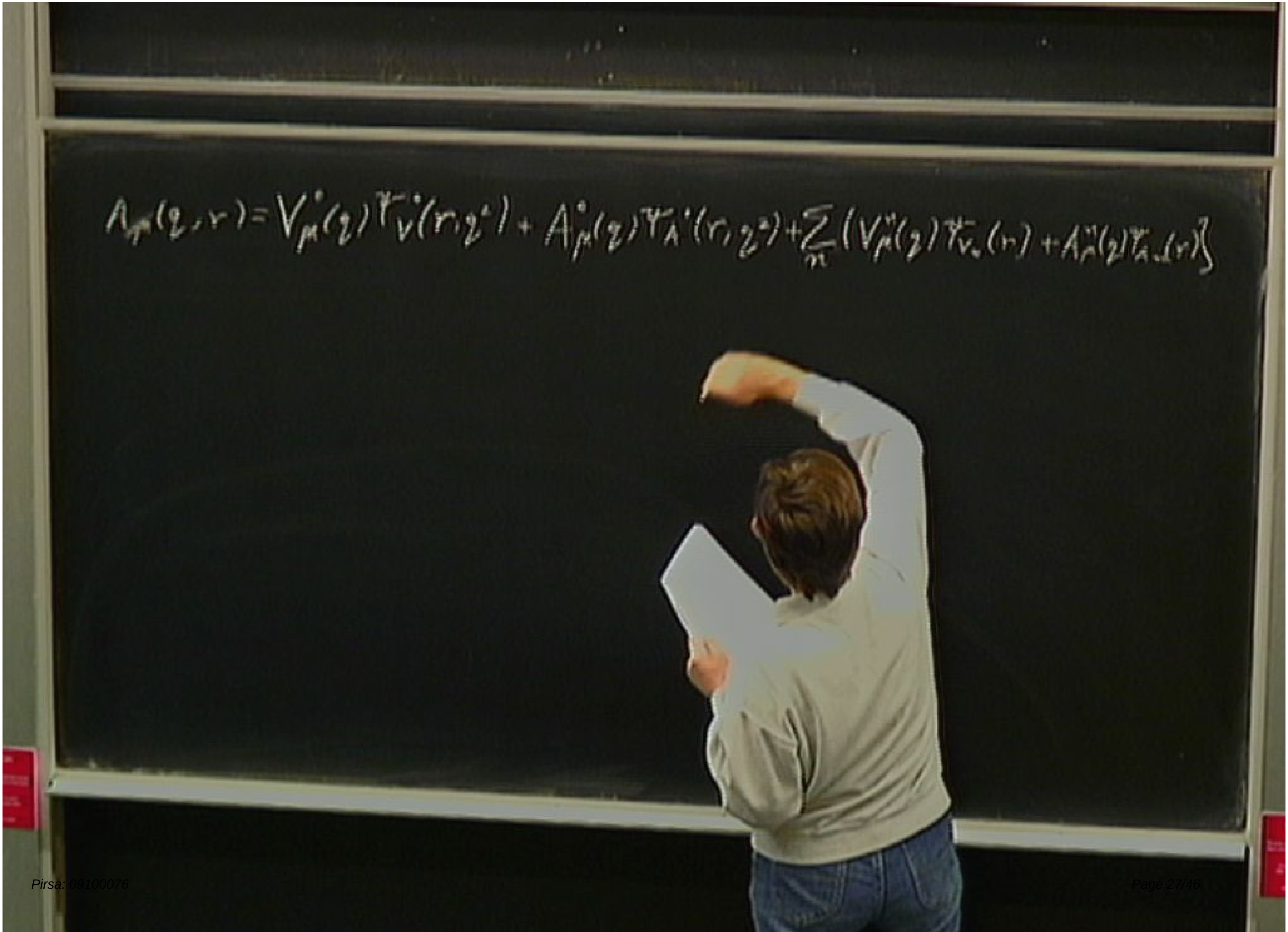
$$S_{DBI} = -T_q \int d^{q+1}\sigma\, e^{-\phi} \sqrt{-\det(g_{ind} + F)} + CS$$

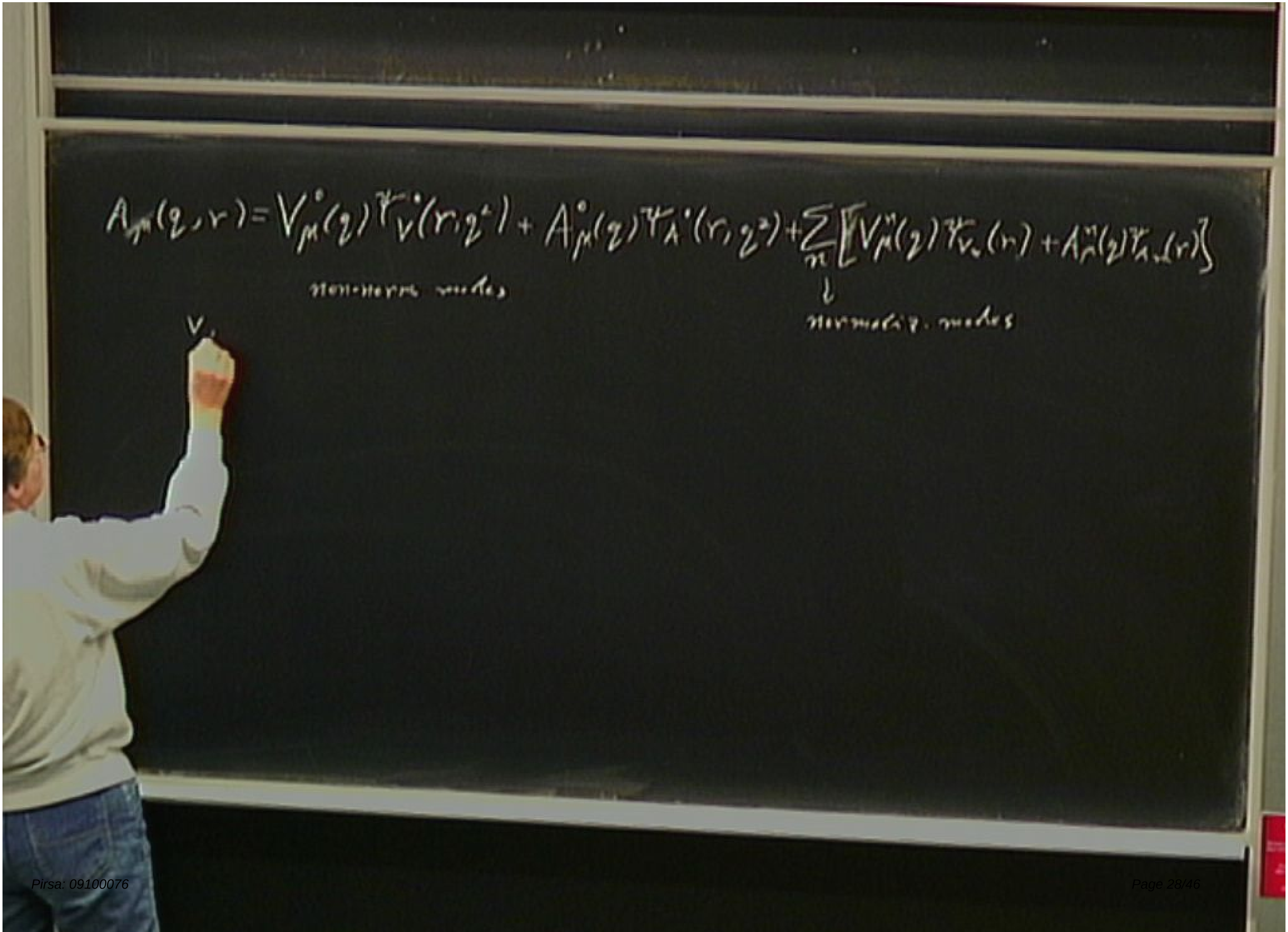
$\hookrightarrow$ technoflavor backl. str.

$$\overset{YM}{\underset{\downarrow}{=}} -\frac{\pi_p}{4} \int d^2x\, dr \left[a(r) F_{\mu\nu} F^{\mu\nu} + 2\, b(r) F_{\mu r} F^{\mu}{}_{r} \right]$$

E.M.: $a(r)\partial^\mu F_{\mu\nu} + \partial^\mu (b(r) F_{\mu r}) = 0$

$$\partial^\mu F_{\mu\nu} = 0$$


$A_\mu(q,r) = V_\mu^0(q)\,\Psi_V^0(r,q^2) + A_\mu^0(q)\,\Psi_A^0(r,q^2) + \sum_n \{V_\mu^n(q)\,\Psi_{V_n}(r) + A_\mu^n(q)\,\Psi_{A_n}(r)\}$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non-norm. modes
normaliz. modes
V

$$A_\mu(q,r) = V^0_\mu(q)\,\Psi^0_V(r,q^2) + A^0_\mu(q)\,\Psi^0_A(r,q^2) + \sum_n \left[V^n_\mu(q)\,\Psi_{V_n}(r) + A^n_\mu(q)\,\Psi_{A_n}(r) \right]$$

non-norm. modes

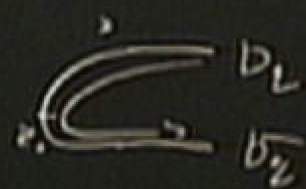
normaliz. modes

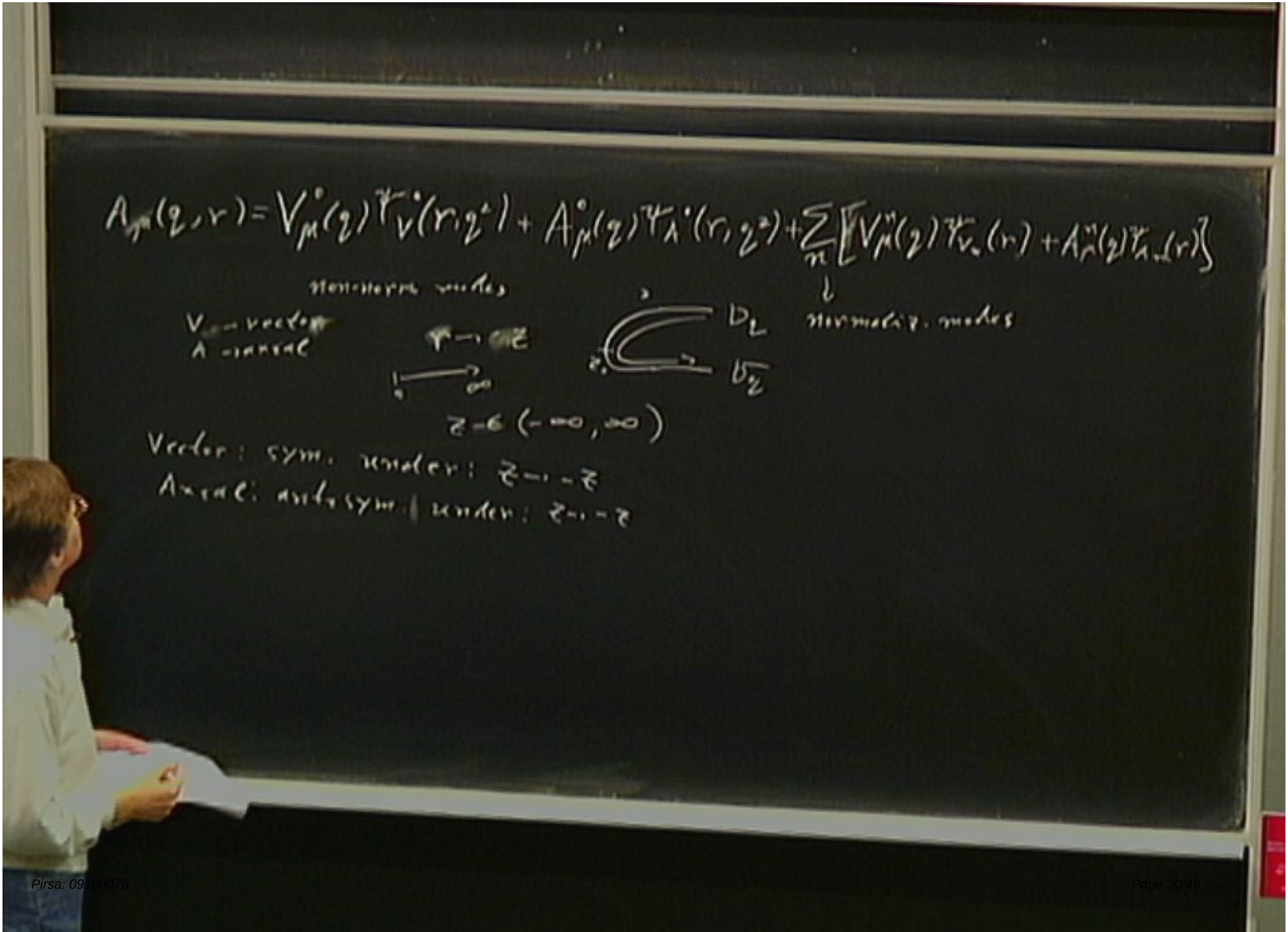
V — vector
A — axial

$r \to z$

$0 \longrightarrow \infty$

$z \in (-\infty, \infty)$





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$r \to z$
D_L
$D_{\bar{L}}$
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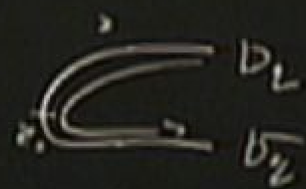

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AdS/CFT

$$-\Pi_V(q^2) = \langle J^\mu_V(q^2)\, J^\nu_V(0) \rangle_{F.T.} = \frac{\delta}{\delta V^\mu_0} \frac{\delta}{\delta V^\nu_0} S_{D3} \Big|_{V^0 = 0}$$

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$$A_\mu(q,r) = V^0_\mu(q)\,\psi^0_V(r,q^2) + A^0_\mu(q)\,\psi^0_A(r,q^2) + \sum_n \left[V^n_\mu(q)\,\psi_{V_n}(r) + A^n_\mu(q)\,\psi_{A_n}(r) \right]$$

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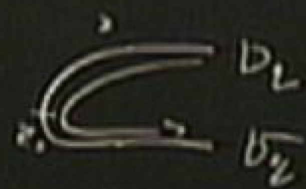

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$$S = -4\pi \frac{d}{dq^2}\left[\Pi_V - \Pi_A\right]\Big|_{q^2=0} = -4\pi K_r \left[\ell(r) \frac{\partial}{\partial q^2} \left(\psi^0_V \partial_r \psi^0_V - \psi^0_A \partial_r \psi^0_A \right) \right] \Big|$$

$$A_\mu(q,r) = V^0_\mu(q)\,\psi^0_V(r,q^2) + A^0_\mu(q)\,\psi^0_A(r,q^2) + \sum_n \left[V^n_\mu(q)\,\psi_{V_n}(r) + A^n_\mu(q)\,\psi_{A_n}(r) \right]$$

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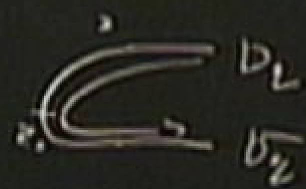

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AdS/CFT

$$S = -4\pi \frac{d}{dq^2}\left[\Pi_V - \Pi_A\right]\Big|_{q^2=0} = -4\pi\kappa_r \left[C(r) \frac{\partial}{\partial q^2} \left(\psi^0_V \partial_r \psi^0_V - \psi^0_A \partial_r \psi^0_A \right) \right]\Big|_{q^2=0,\ r=\infty}$$

$$A_\mu(q,r) = V_\mu^0(q)\,\Psi_V^0(r,q^2) + A_\mu^0(q)\,\Psi_A^0(r,q^2) + \sum_n \left[V_\mu^n(q)\,\Psi_{V_n}(r) + A_\mu^n(q)\,\Psi_{A_n}(r)\right]$$

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E.M.:

$$\frac{1}{a(r)}\partial_r\left(b(r)\,\partial_r \Psi^0\right) = -q^2\,\Psi^0$$

AdS/CFT

$$-\Pi_V(q^2) = \langle J_V^\mu(q^2)\, J_V^\nu(0)\rangle_{F.T.} = \frac{\delta}{\delta V_0^\mu}\frac{\delta}{\delta V_0^\nu} S_{bdy}\Big|_{V^0=0}$$

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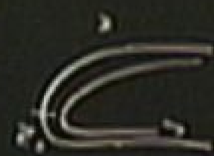

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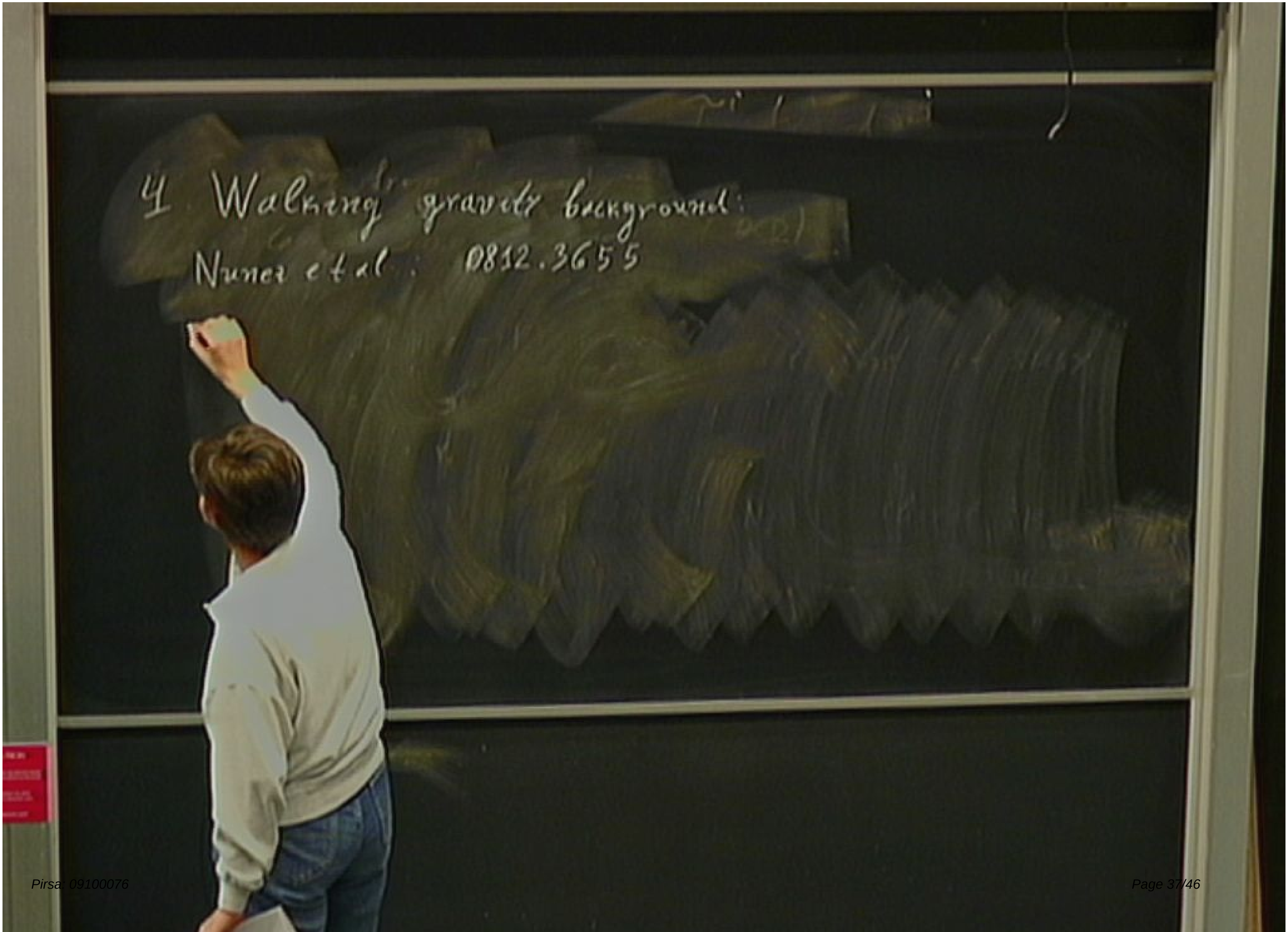
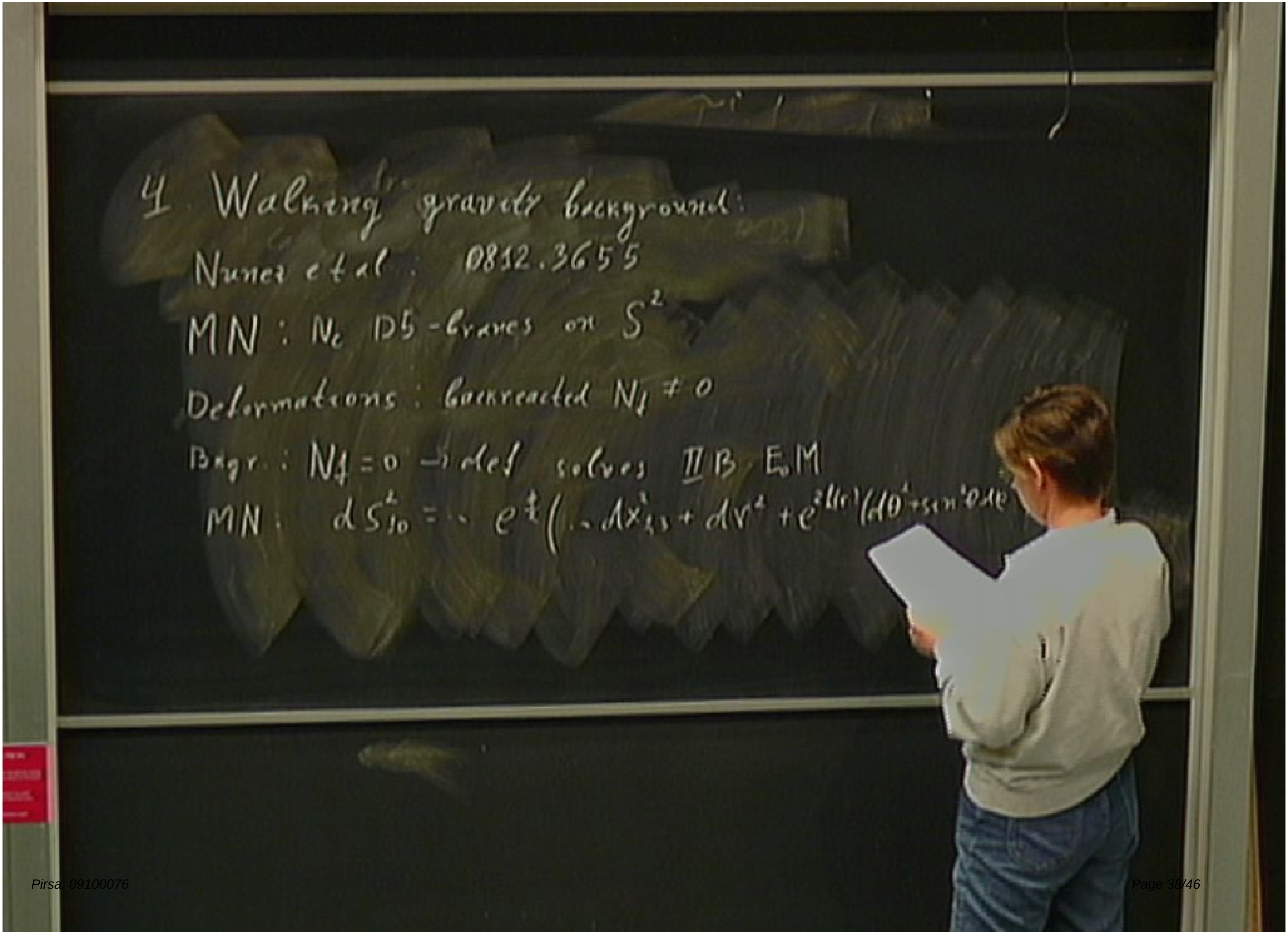
$$S = -4\pi \frac{d}{dq^2}\left[\Pi_V - \Pi_A\right]\Big|_{q^2=0} = -4\pi K_r \left[b(r)\,\frac{\partial}{\partial q^2}\left(\Psi^0_V\,\partial_r \Psi^0_V - \Psi^0_A\,\partial_r \Psi^0_A\right)\right]\Big|_{\substack{q^2=0 \\ r=\infty}}$$


4 Walking gravity background:
Nunez et al: 0812.3655


4. Walking gravity background:
Nunez et al: 0812.3655
MN: N_c D5-branes on S^2
Deformations: backreacted N_f ≠ 0
Bkgr.: N_f = 0 → def solves IIB EoM
MN: ds^2_10 = e^{φ/2}(- dx^2_{1,3} + dr^2 + e^{2h(r)}(dθ^2+sin^2θ dφ^2)

4 Walking gravity background:

Nunez et al : 0812.3655

MN : N_c D5-branes on S^2

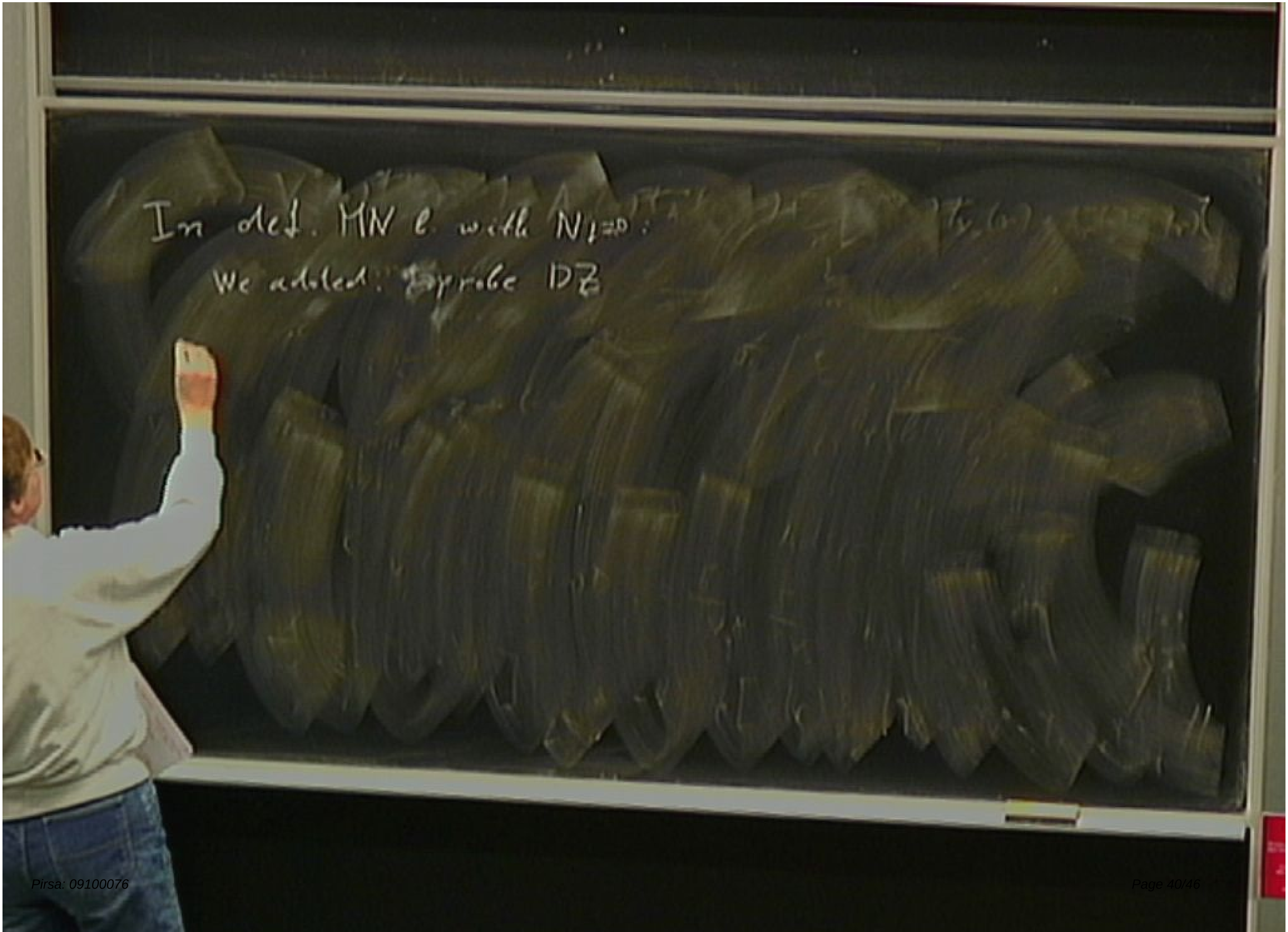
Deformations : backreacted $N_f \neq 0$

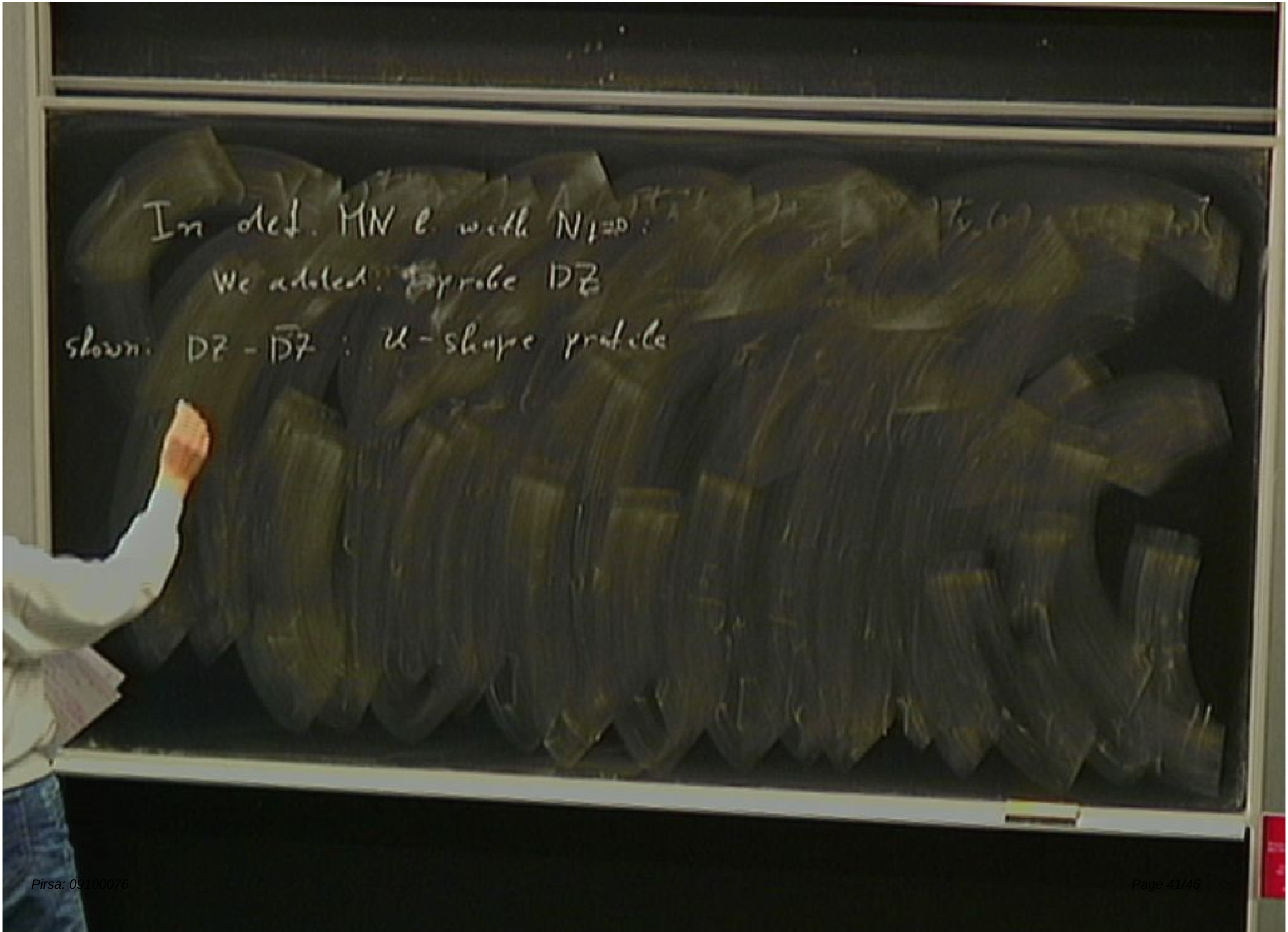
SU(2) left inv. 1-f

Bkgr. : $N_f = 0 \to$ def solves IIB EoM

$$MN : \quad ds^2_{10} = e^{\phi(r)} \left(dx^2_{1,3} + e^{2k(r)} dr^2 + e^{2h(r)} (d\theta^2 + \sin^2\theta \, d\varphi^2) + \frac{1}{4}(\tilde{\omega}_i - A_i)^2 \right)$$

$N_f = 0$ def   BPS $e^{g(r)}$, $e^{2k(r)}$


In def. MN l. with N₁=0:
We added: probe DZ

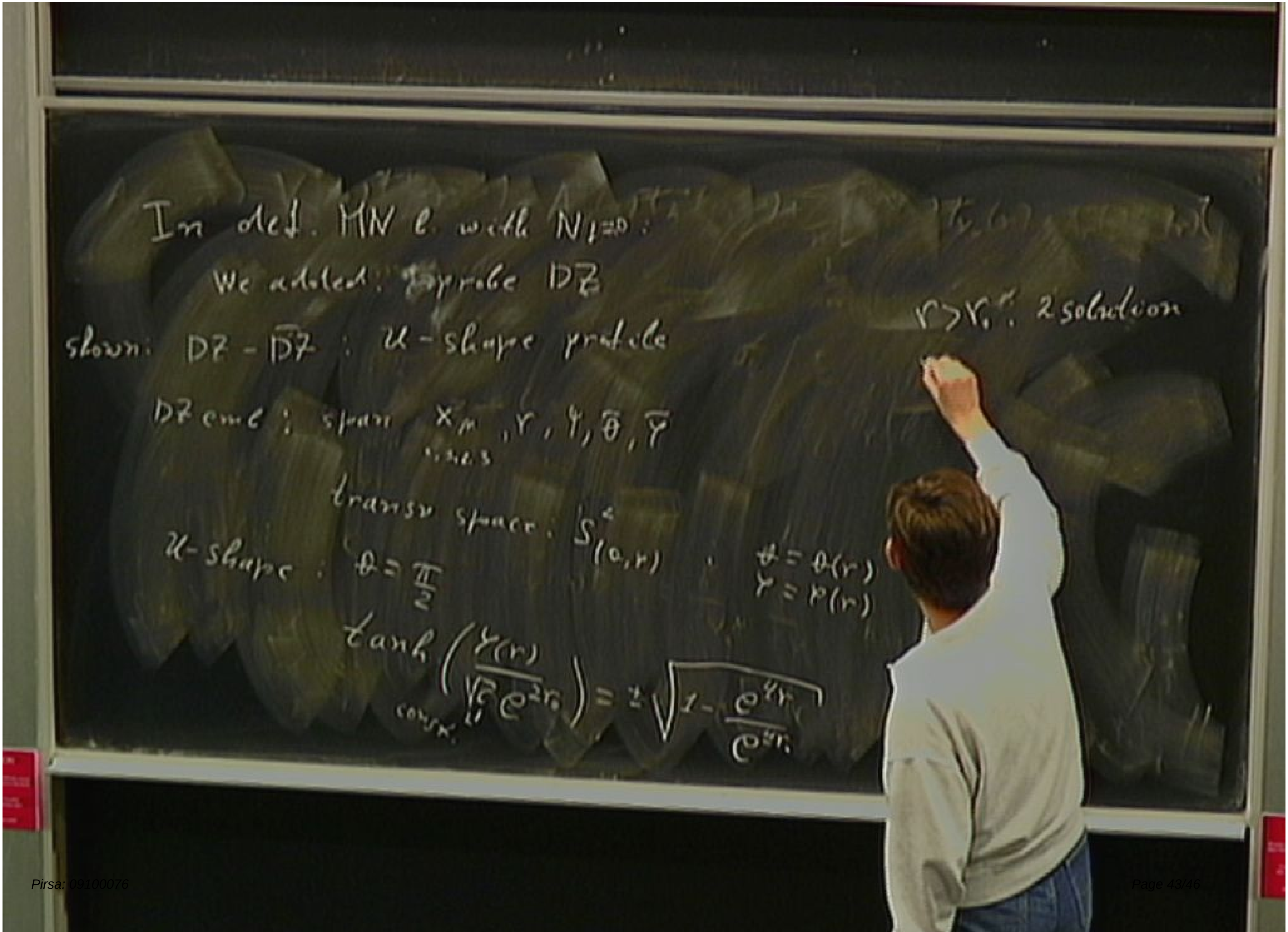

In def. MN e with N₁=0:
We added: probe DZ
shown: DZ - D̄Z : U-shape profile

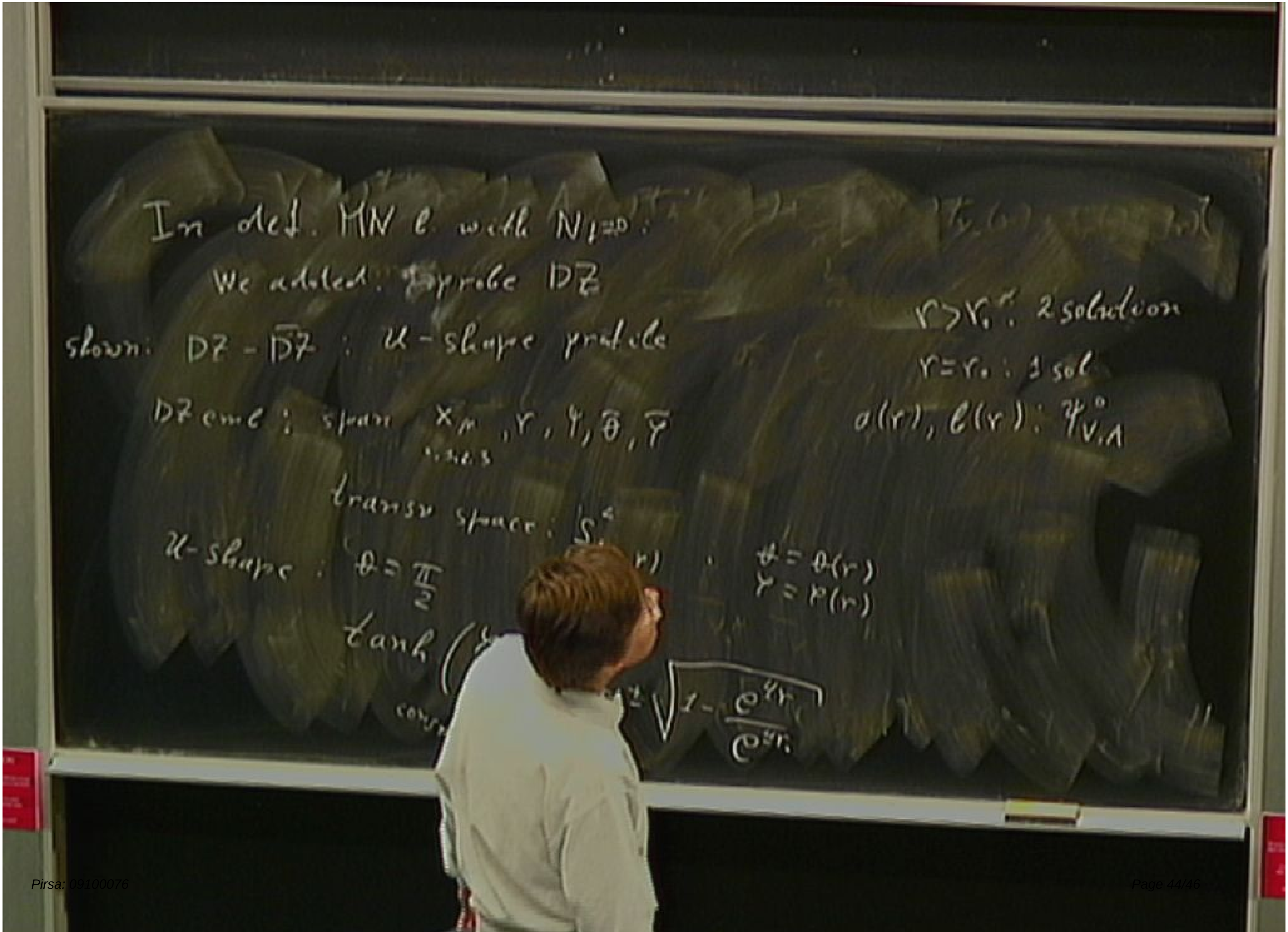
In def. MN l. with $N_1 \neq 0$:

We added: probe DZ

shown: DZ − $\overline{\text{DZ}}$: U-shape profile

DZ emb: span x_μ, $\mu \neq 3$


In def. MN b. with N_f≠0:
We added: probe D7
shown: D7 - D̄7 : U-shape profile
D7 emb: span x_μ (μ=0,1,2,3), r, ψ, θ̃, φ̃
transv space: S^2_(θ,r) : θ = θ(r), φ = φ(r)
U-shape: θ = π/2
tanh(φ(r) / (√2 e^{2r_0})) = ± √(1 - e^{4r_0}/e^{4r})
const.
r > r_0: 2 solution


In def. MN b. with N_f ≠ 0 :
We added: probe D7
shown: D7 - D̄7 : U-shape profile
D7 emb : span x_μ , r , ψ , θ̃ , φ̃
transv space : S^2
U-shape : θ = π/2
tanh
r > r_0 : 2 solution
r = r_0 : 1 sol
a(r), b(r) : ψ^0_{V,A}
θ = θ(r)
φ = φ(r)

In def. MN b. with $N_f = 0$:

We added: probe D7

shown: D7 - $\overline{D7}$: U-shape profile

D7 emb: span x_μ, r, ψ, $\tilde{\theta}$, $\tilde{\varphi}$

$\mu = 0,1,2,3$

transv space: $S^2_{(\theta, r)}$: $\theta = \theta(r)$, $\varphi = \varphi(r)$

U-shape: $\theta = \frac{\pi}{2}$

$$\tanh\left(\frac{\varphi(r)}{\sqrt{2}\,e^{2r_0}}\right) = \pm\sqrt{1 - \frac{e^{4r_0}}{e^{4r}}}$$

const.

$r > r_0$: 2 solution

$r = r_0$: 1 sol

$a(r)$, $b(r)$: $\psi^0_{V,A}$

$S = \text{const}\left[b(r)\frac{\partial}{\partial z}\left(\ldots\right)\right]$

$z = 0$

$r = \infty$

4 Walking gravity background:

Nunez et al : 0812.3655

MN : N_c D5-branes on S^2

Deformations : backreacted $N_f \neq 0$

Bkgr. : $N_f = 0 \to$ def solves IIB EoM

SU(2) left-inv. 1-f.

$$MN: \quad ds^2_{10} = \cdot\, e^{\frac{\phi(r)}{2}}\left(-dx^2_{1,3} + e^{2k(r)} dr^2 + e^{2h(r)}(d\theta^2 + \sin^2\theta\, d\varphi^2) + \frac{1}{2}(\tilde{\omega}_i - A_i)^2\right)$$

walking : $e^{\phi} = \mathrm{const}$ $\quad$ $N_f = 0$ def $\quad$ BPS $\quad$ $e^{2g(r)}$, $e^{2k(r)}$

UV, $r \to \infty$ $\quad$ $\Psi, \vec{B}, F$