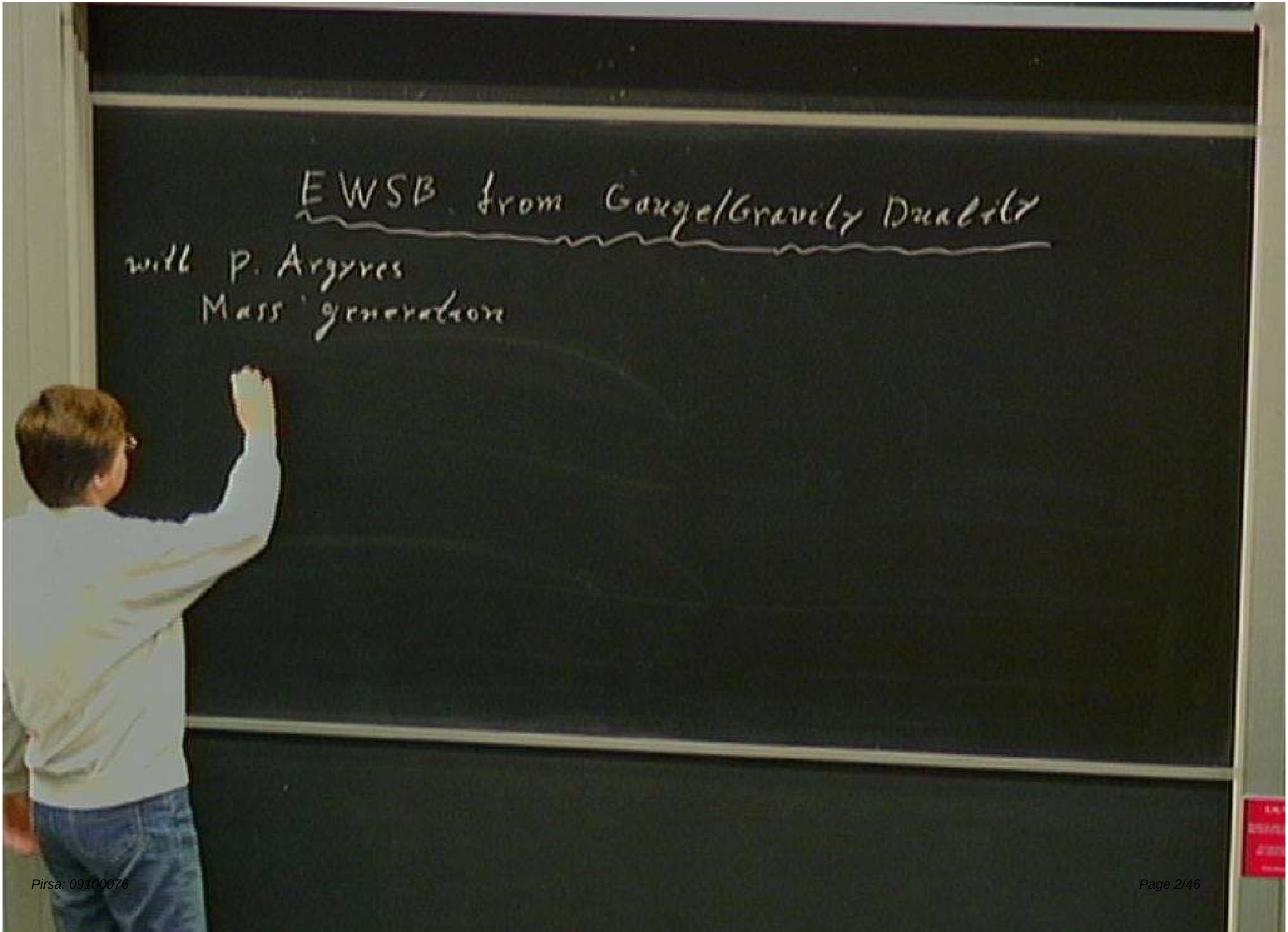
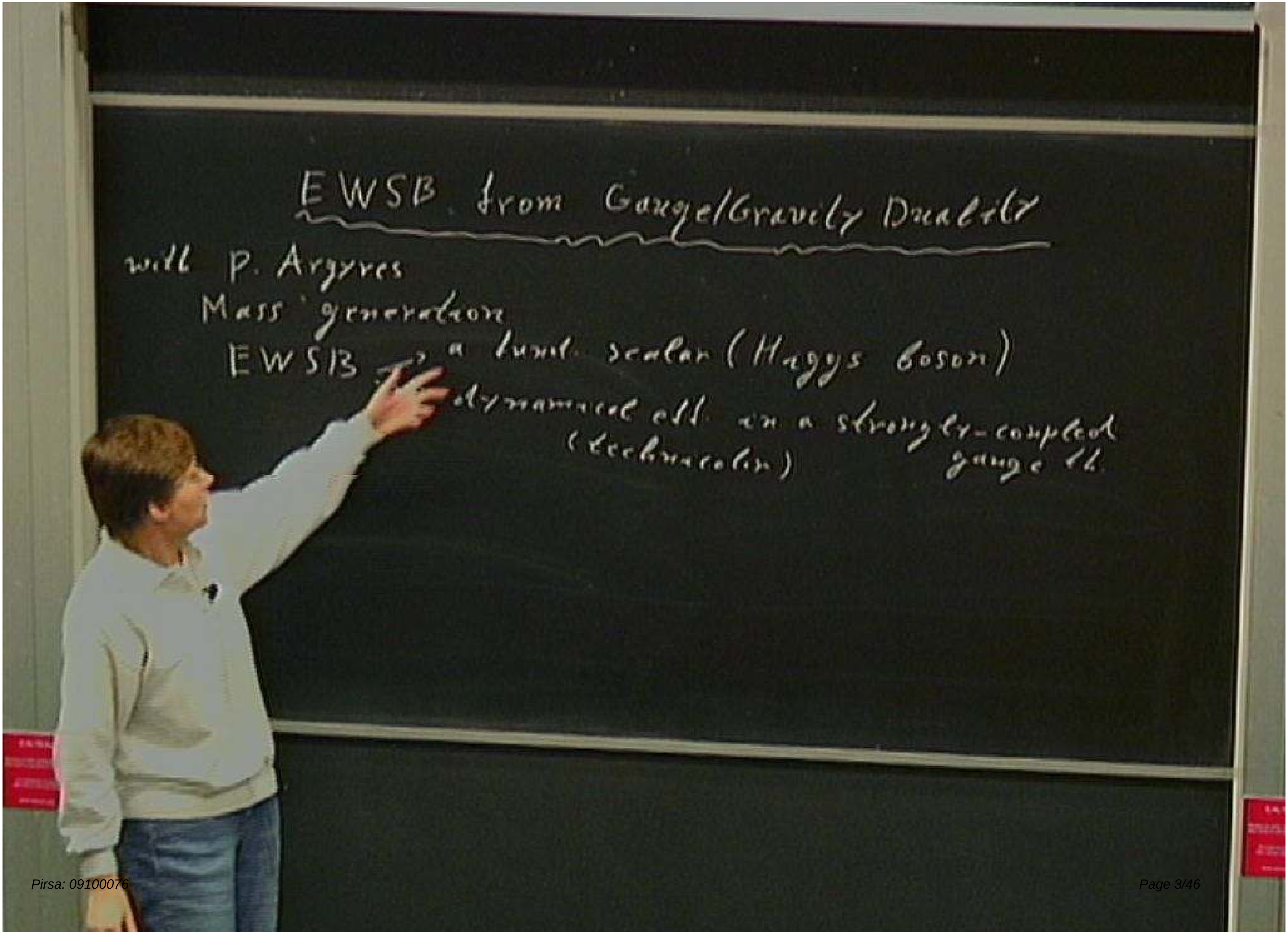
Title: Electroweak Symmetry Breaking from Gauge/Gravity Duality

Date: Oct 27, 2009 11:00 AM

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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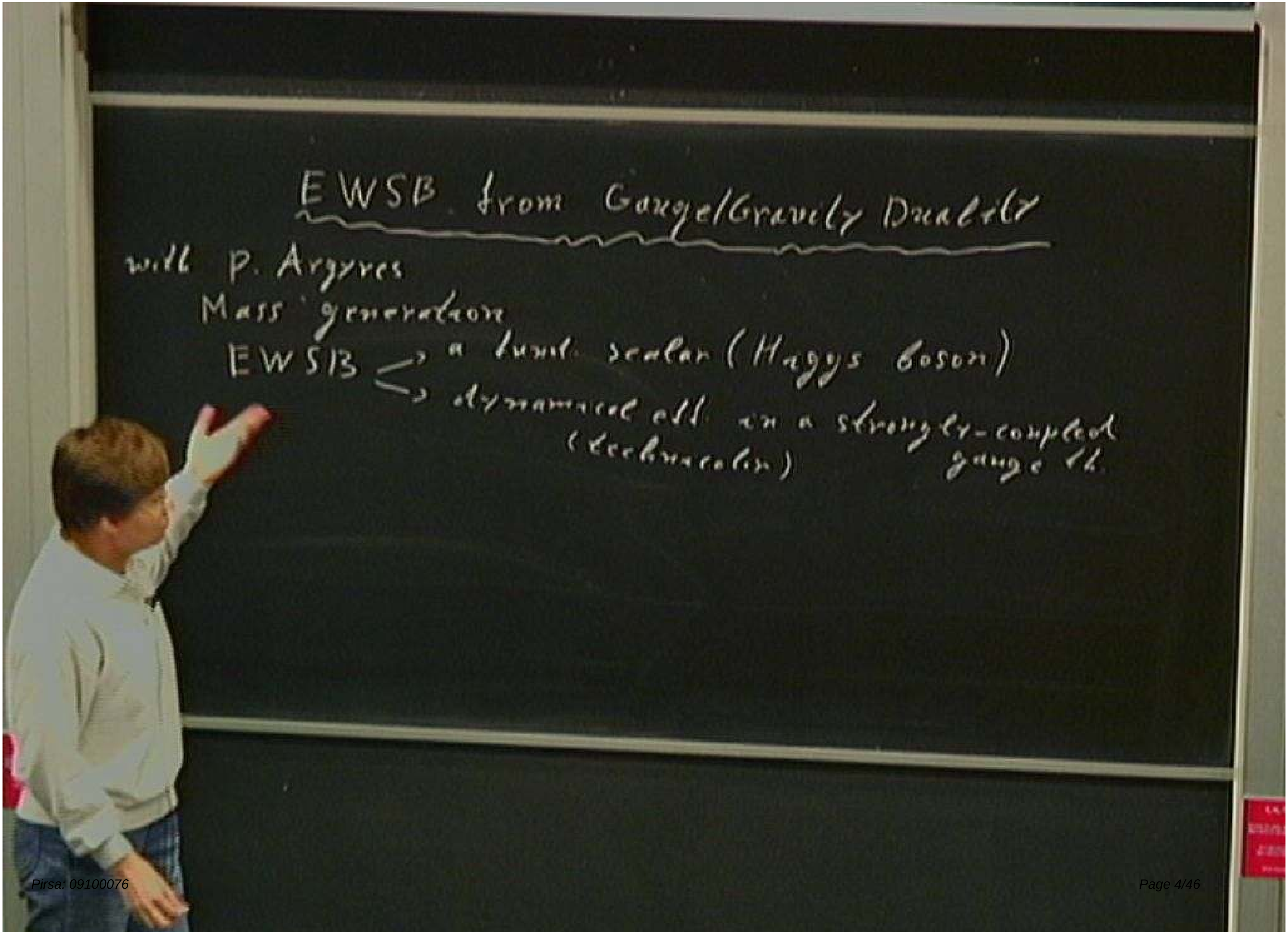
EWSB → a fund. scalar (Higgs boson)
→ dynamical eff. in a strongly-coupled gauge th.
(technicolor)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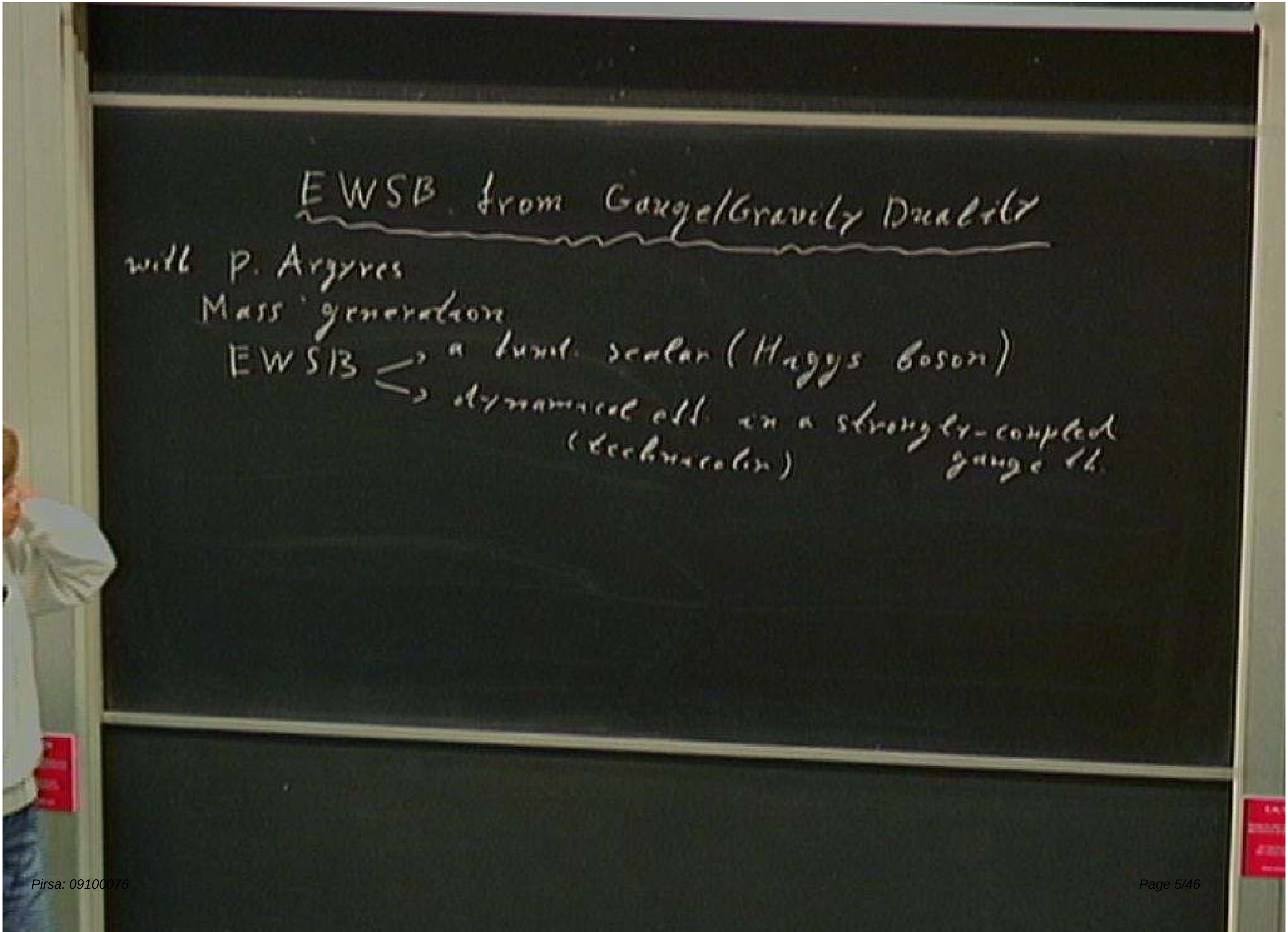
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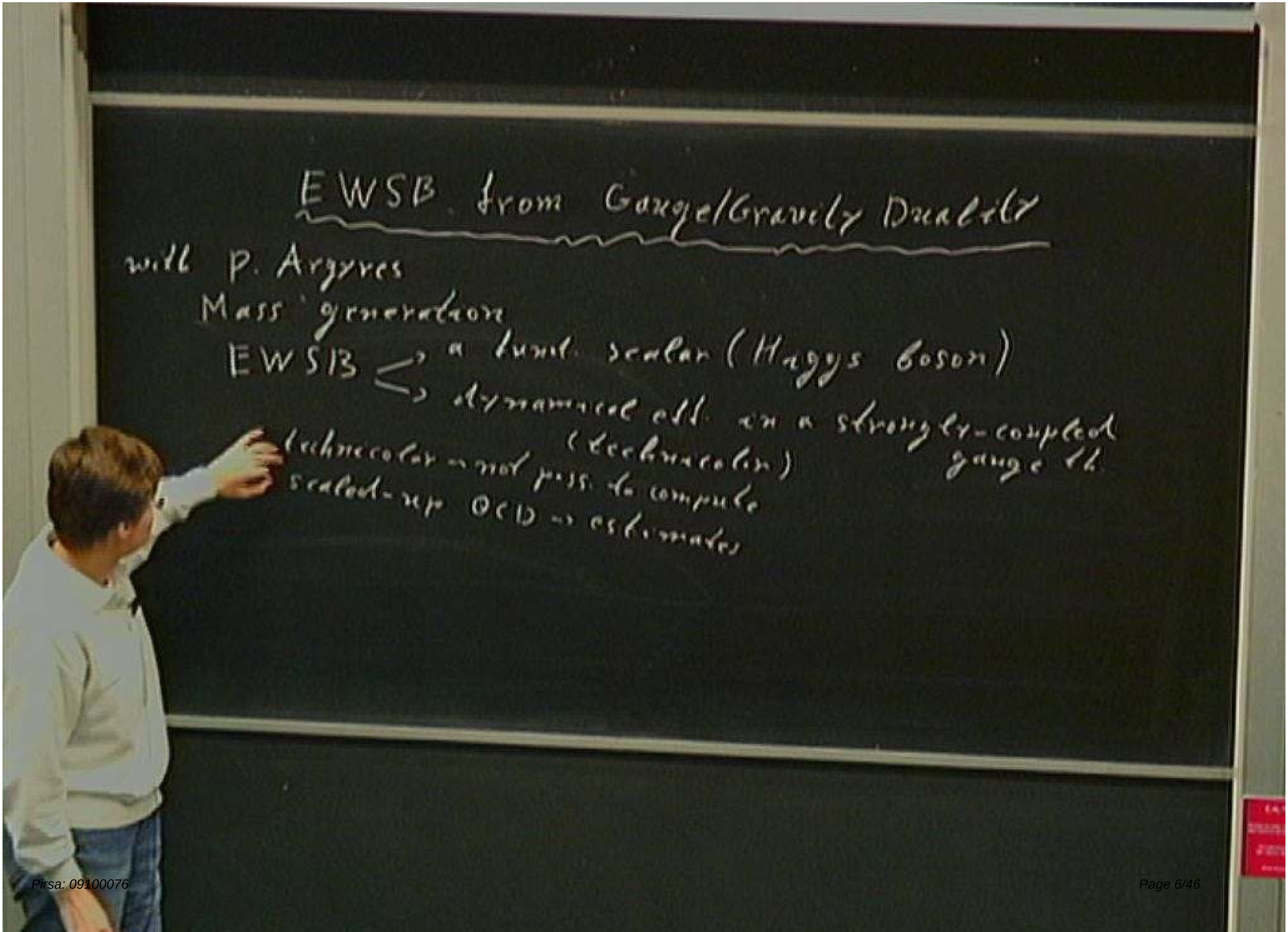
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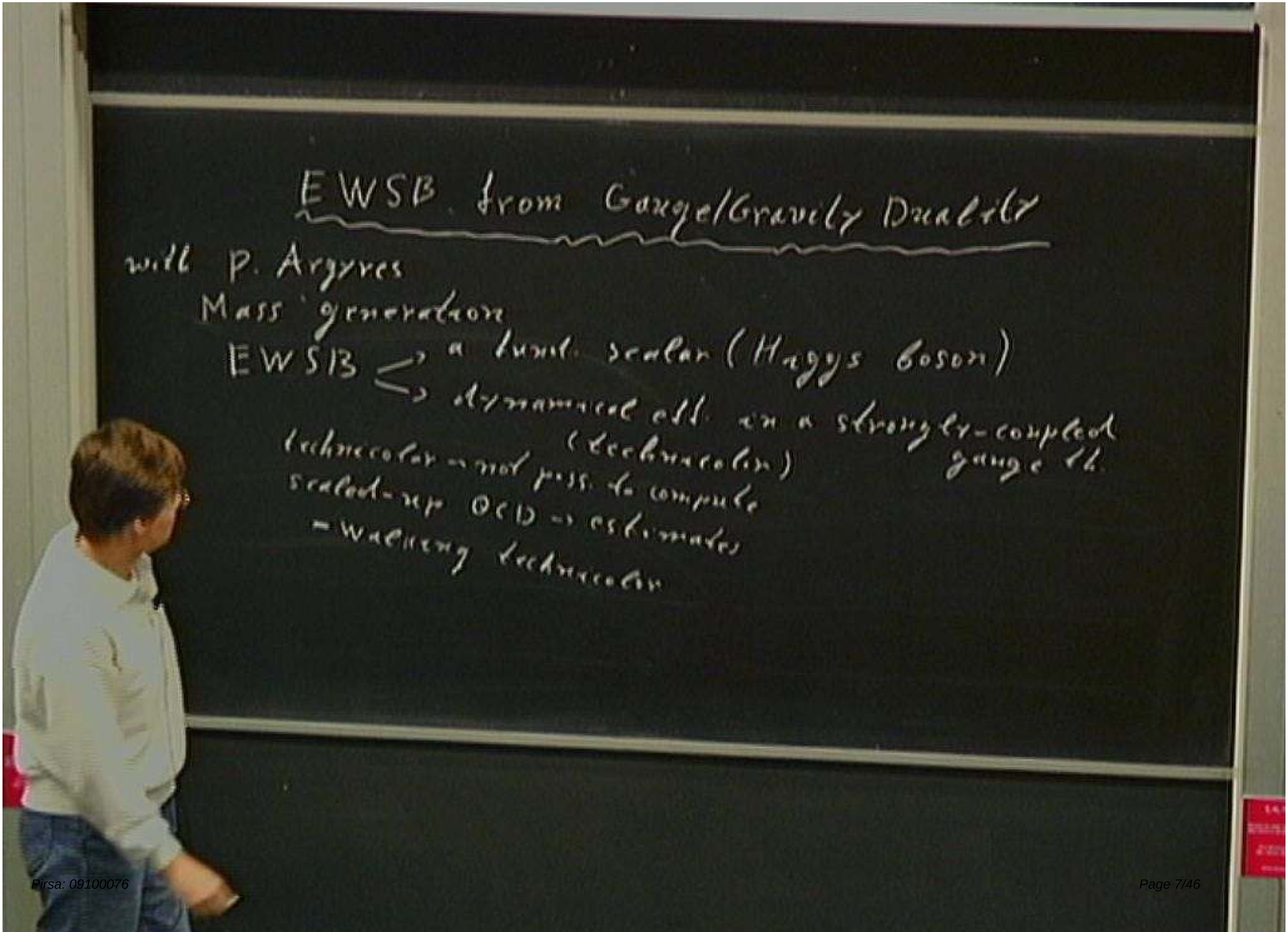
scaled-up QCD → estimates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# EWSB from Gauge/Gravity Duality

with P. Argyres

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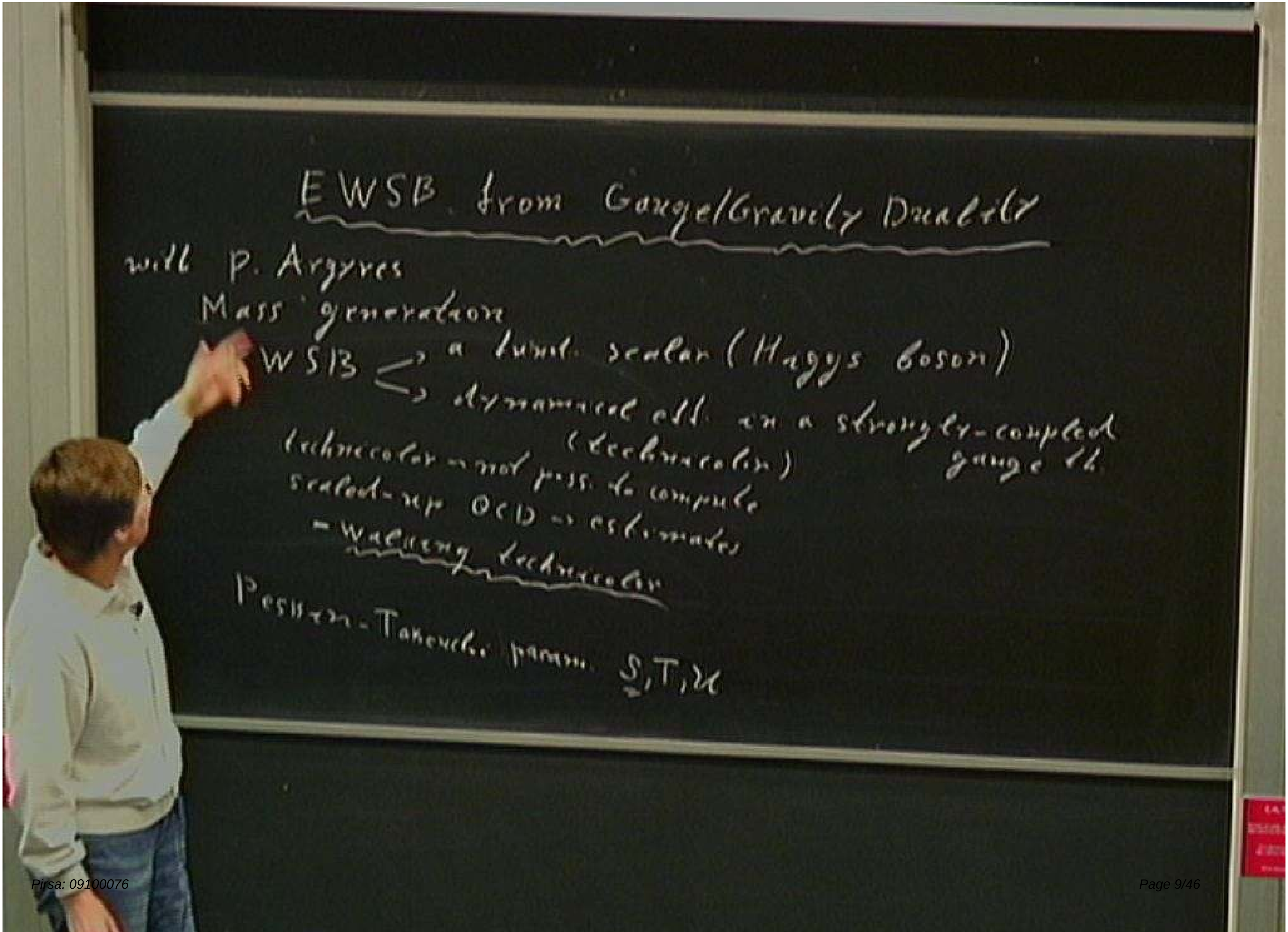
EWSB $\to$ a fund. scalar (Higgs boson)

$\to$ dynamical eff. in a strongly-coupled gauge th. (technicolor)

technicolor $\to$ not poss. to compute

scaled-up QCD $\to$ estimates

- Walking technicolor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Peskin-Takeuchi param. S, T, U

# EWSB from Gauge/Gravity Duality

with P. Argyres

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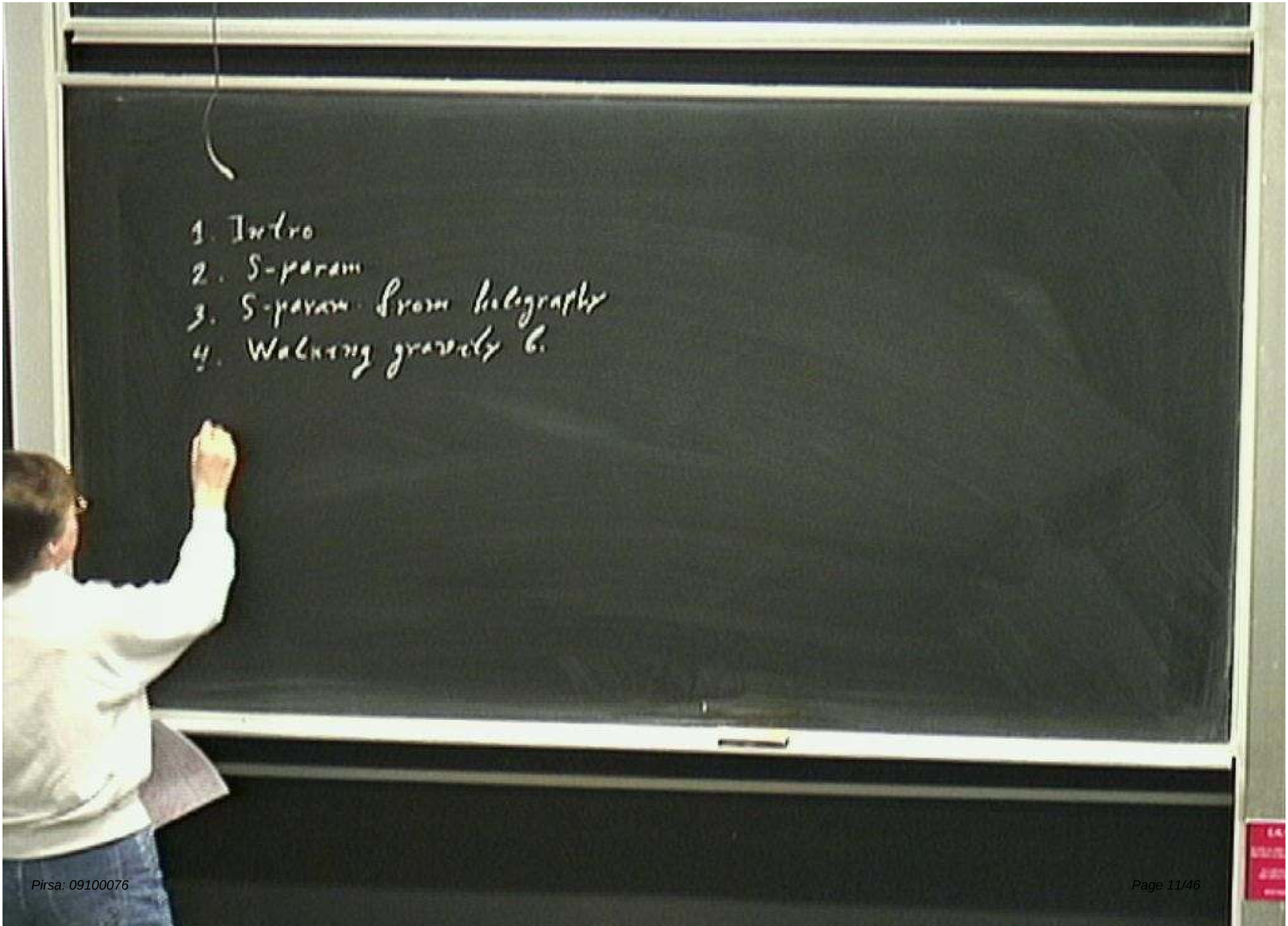
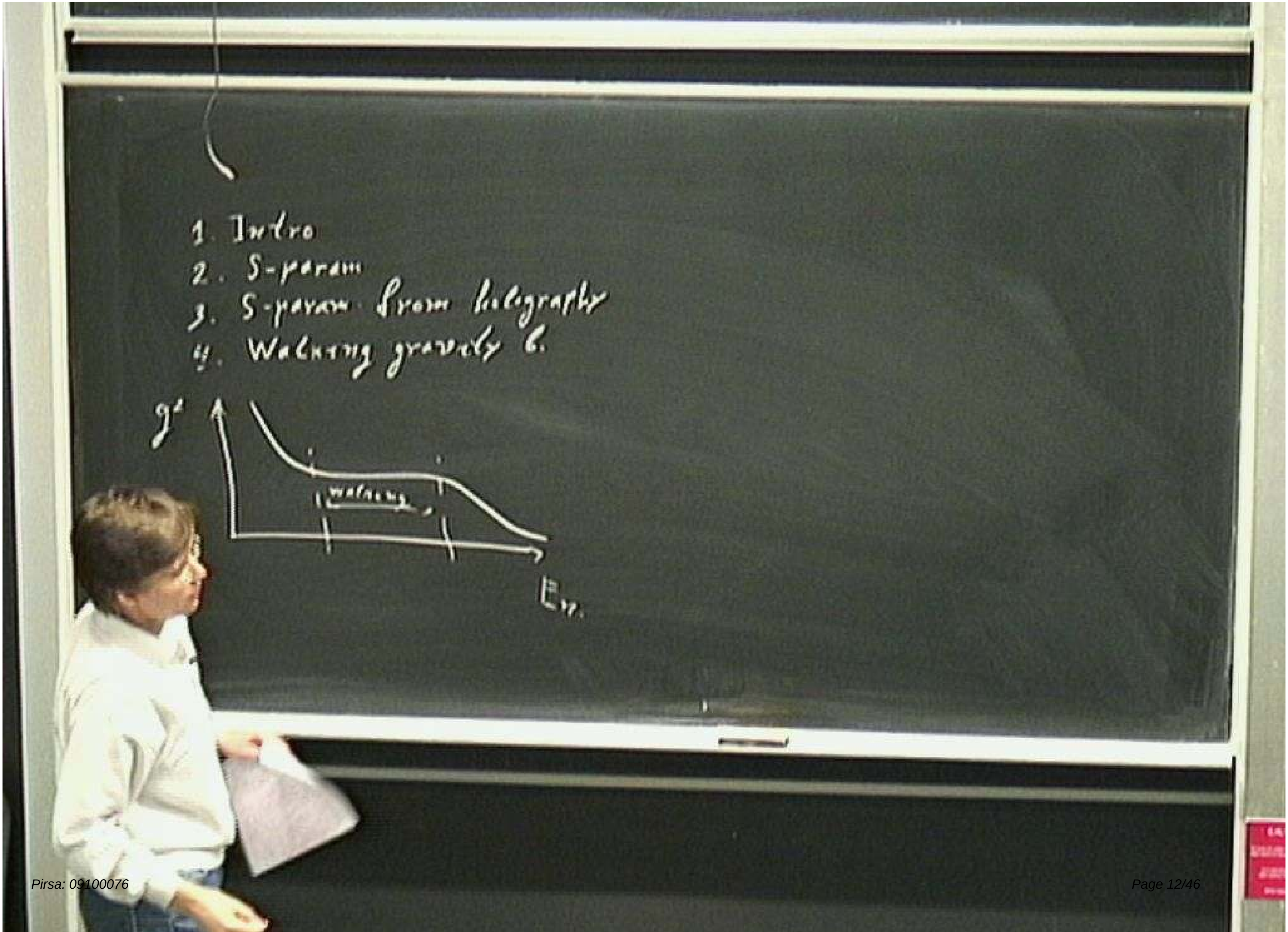
Peskin-Takeuchi param. $S, T, U$


1. Intro
2. S-param
3. S-param from holography
4. Walking gravity 6.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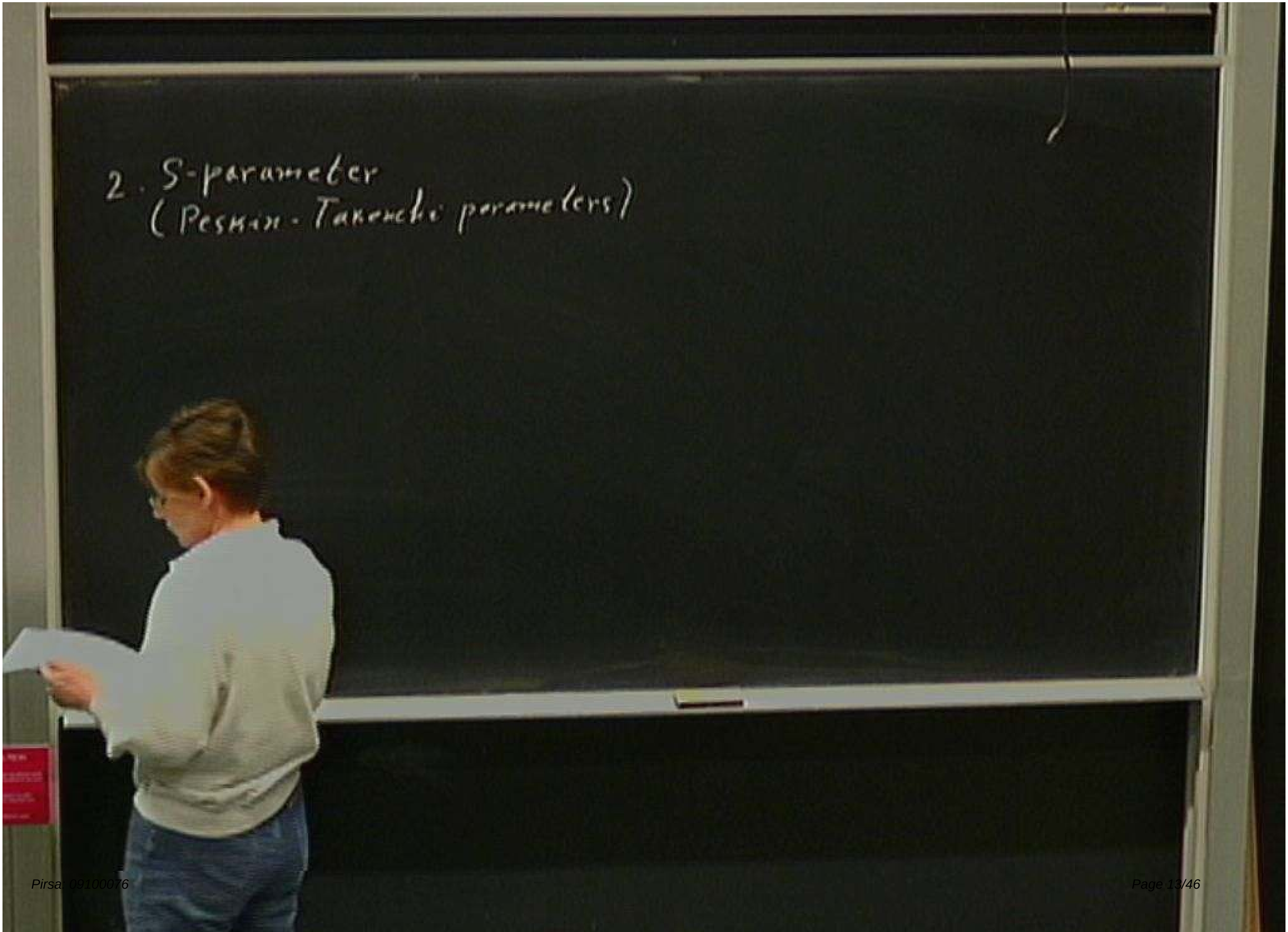
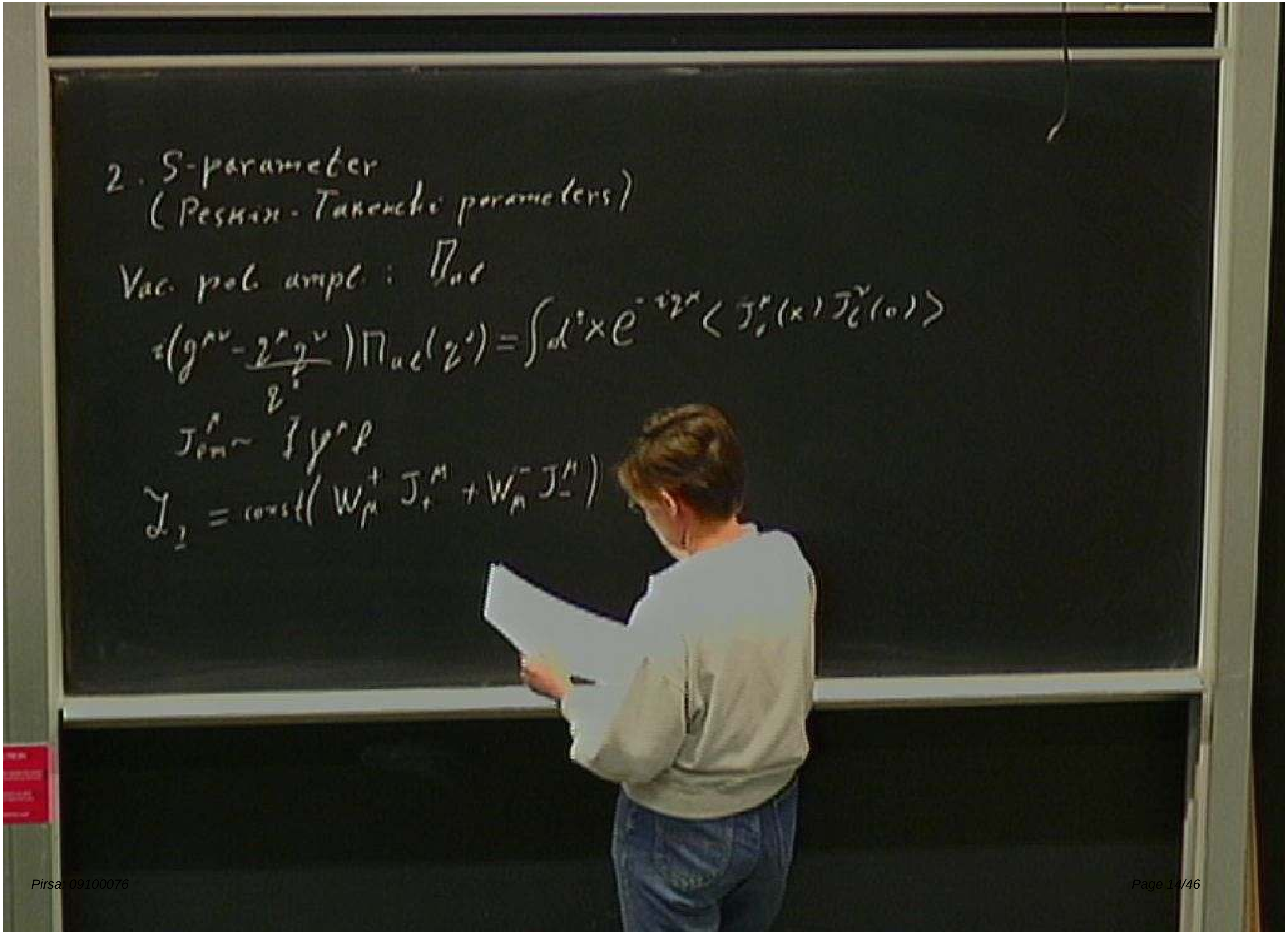
2. S-param
3. S-param from holography
4. Walking gravity b.
$g^2$
walking


2. S-parameter
(Peskin-Takeuchi parameters)


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

2. S-parameter

(Peskin-Takeuchi parameters)

Vac. pol. ampl. : $\Pi_{ab}$

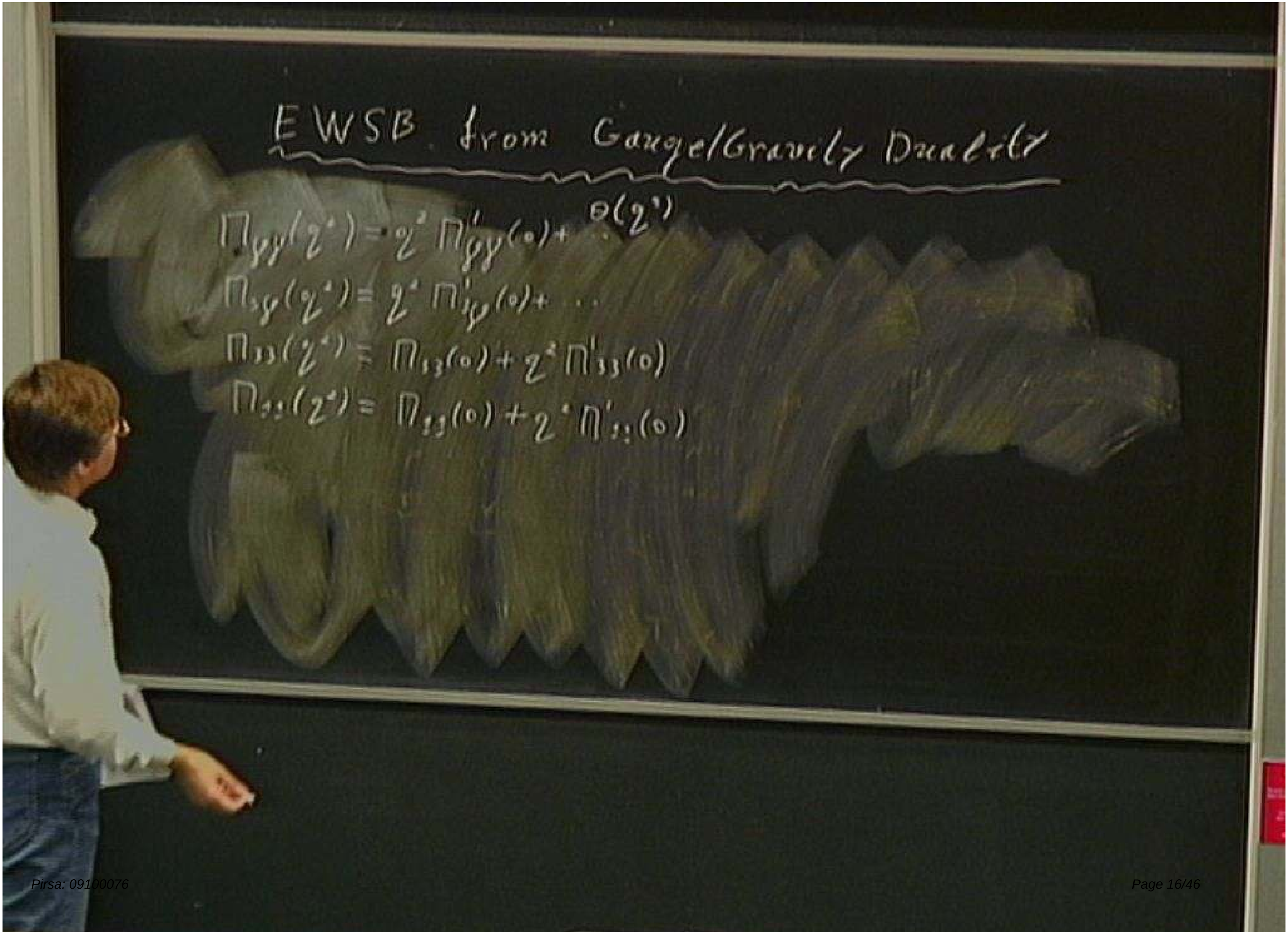
$$i\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right)\Pi_{ab}(q^2) = \int d^4x\, e^{-iqx}\langle J_a^\mu(x)\, J_b^\nu(0)\rangle$$

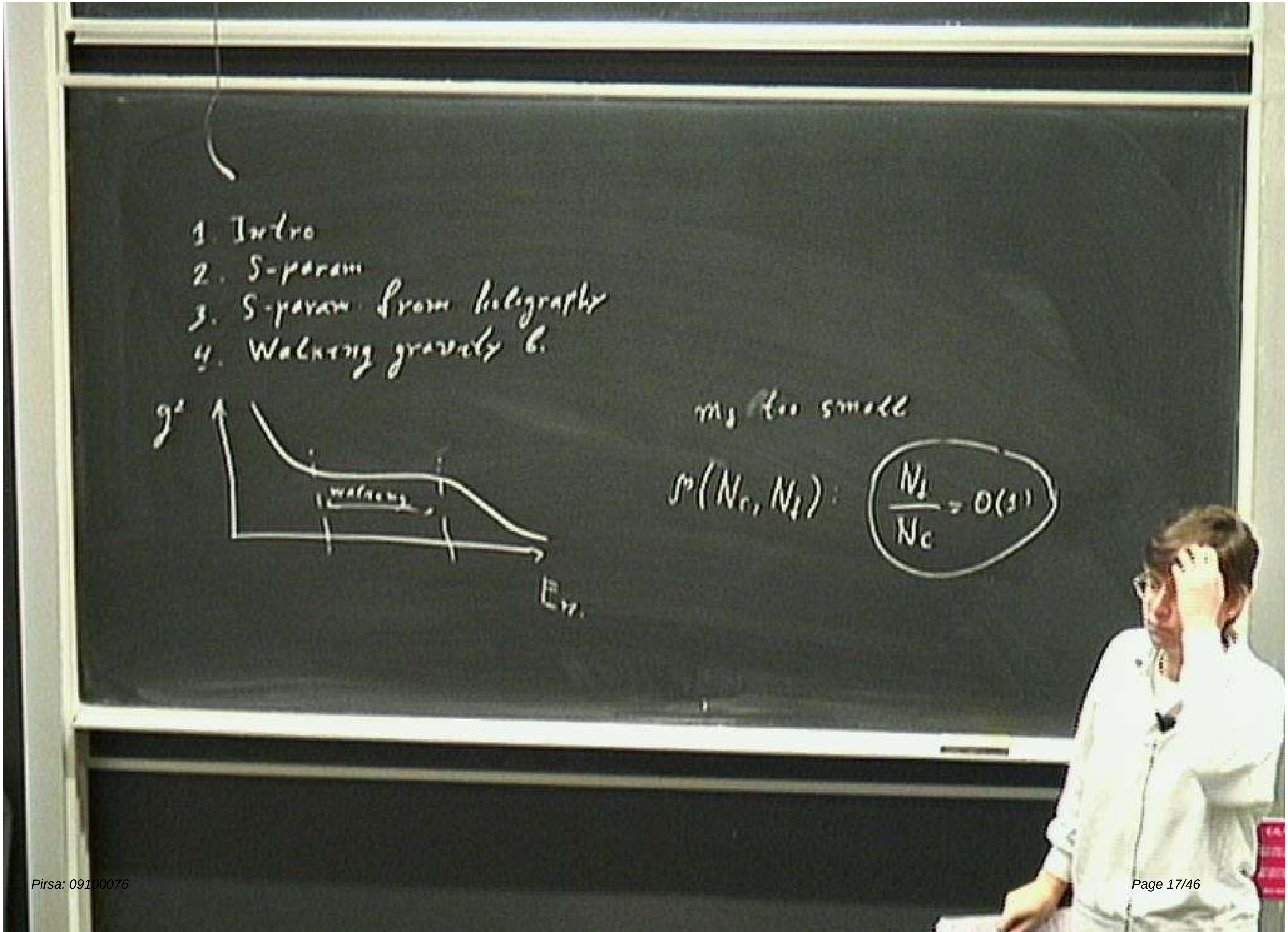
$a, b = 1, 2, 3, Y$

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

$$\mathcal{L}_I = \mathrm{const}\left(W^+_\mu J^\mu_+ + W^-_\mu J^\mu_-\right) + \mathrm{const}'\, Z_\mu\left(J_3^\mu - \sin^2\theta_W J_Y^\mu\right) + eA_\mu J^\mu_Y$$

$E_{cm} \gg m_Z$ : expand in $q^2$ :


EWSB from Gauge/Gravity Duality
$\Pi_{\gamma\gamma}(q^2) = q^2 \Pi'_{\gamma\gamma}(0) + O(q^4)$
$\Pi_{3\gamma}(q^2) = q^2 \Pi'_{3\gamma}(0) + \ldots$
$\Pi_{33}(q^2) = \Pi_{33}(0) + q^2 \Pi'_{33}(0)$
$\Pi_{11}(q^2) = \Pi_{11}(0) + q^2 \Pi'_{11}(0)$


1. Intro
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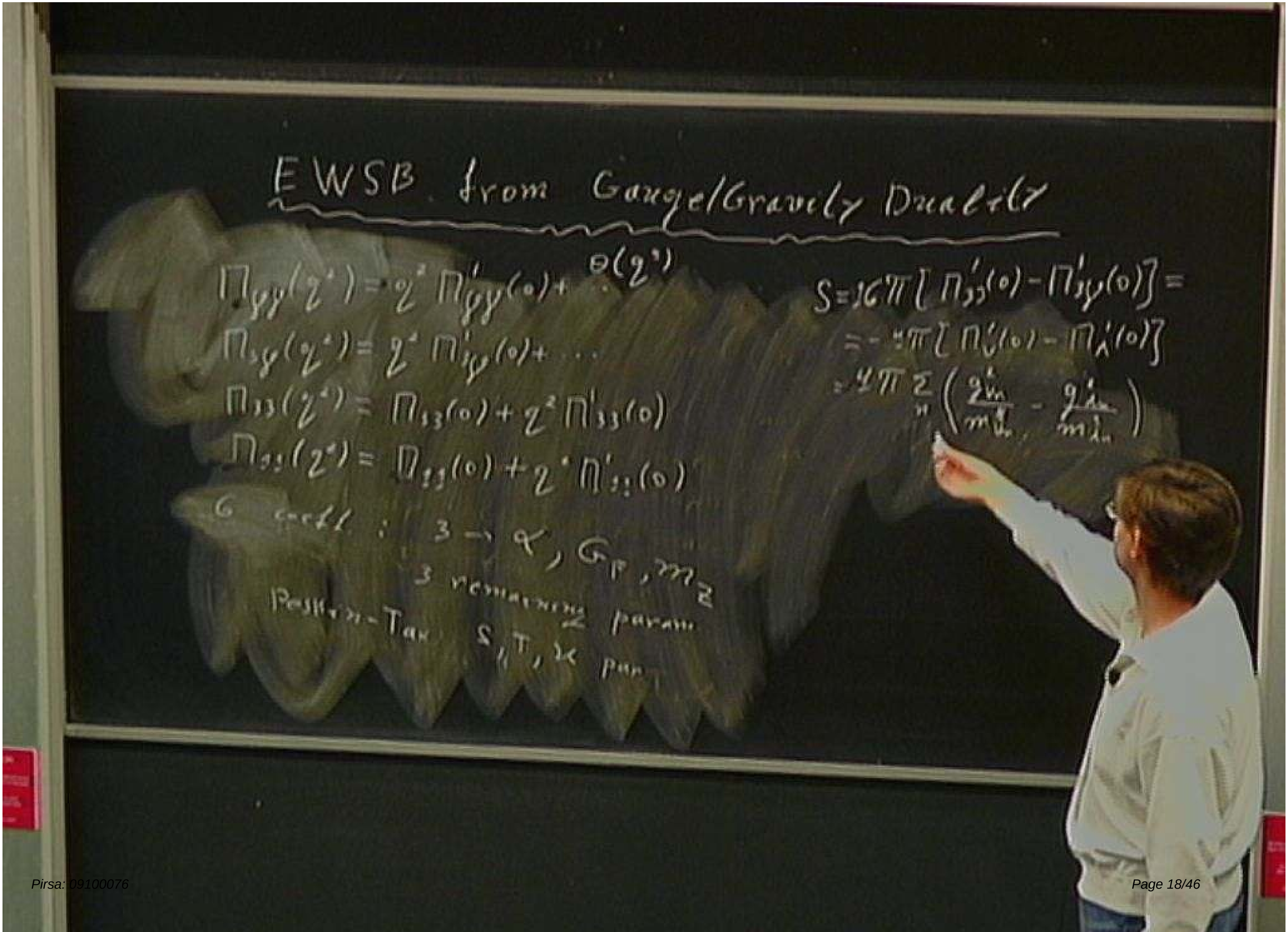
$g^2$
walking
$f(N_c, N_f)$ : $\frac{N_f}{N_c} = O(1)$


EWSB from Gauge/Gravity Duality
$\Pi_{\gamma\gamma}(q^2) = q^2\,\Pi'_{\gamma\gamma}(0) + O(q^4)$
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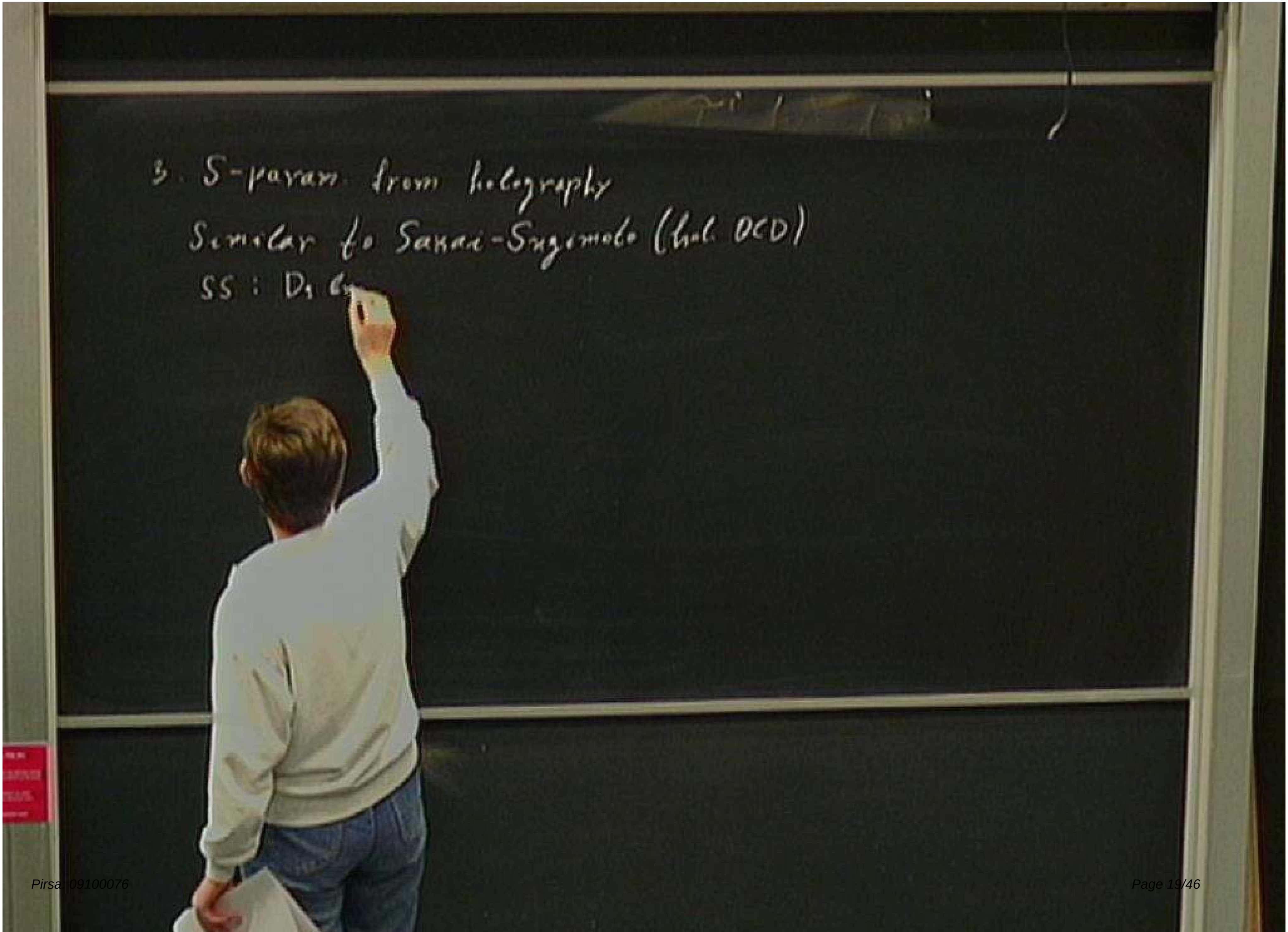
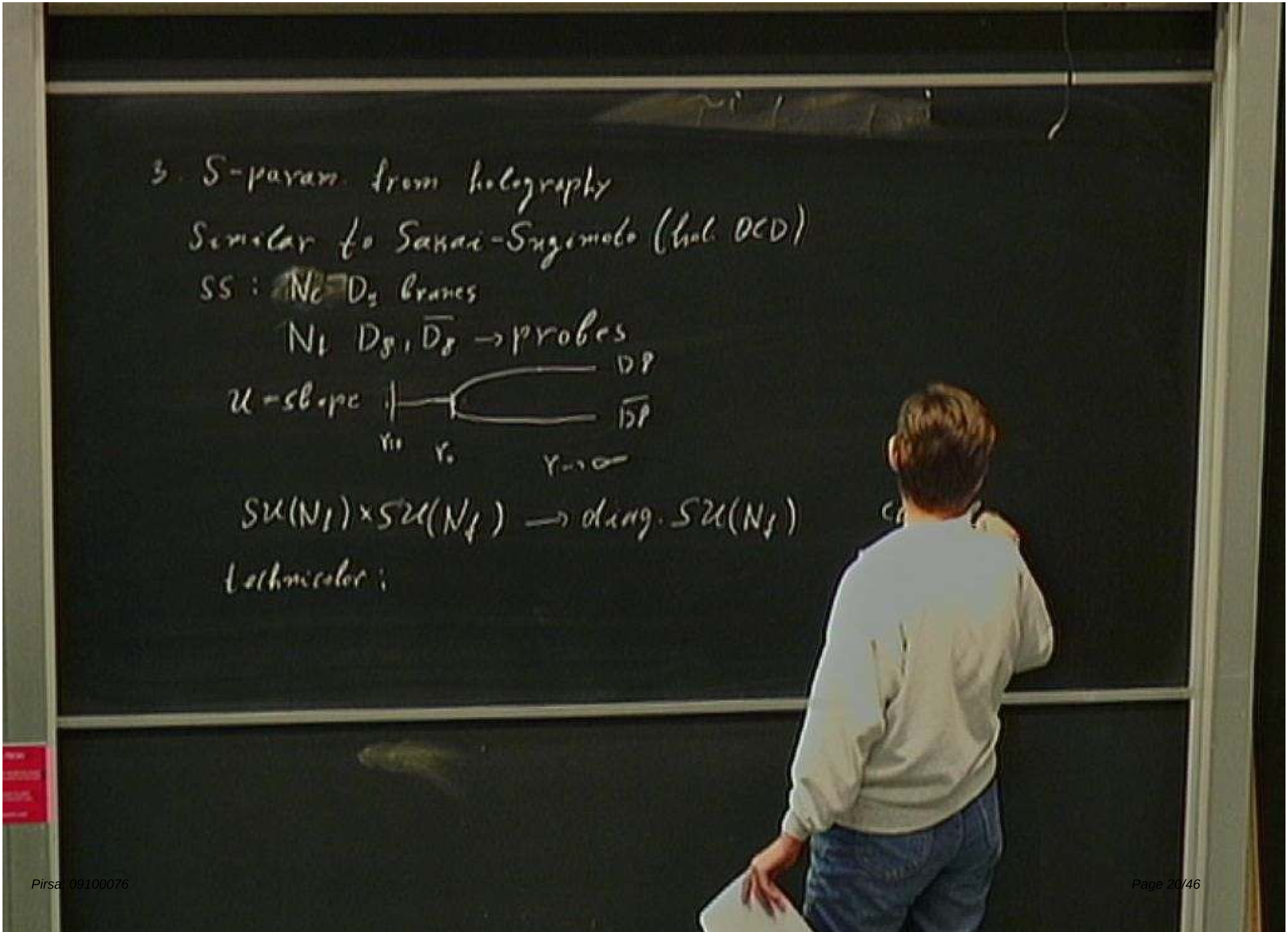
$\Pi_{33}(q^2) = \Pi_{33}(0) + q^2\,\Pi'_{33}(0)$
$\Pi_{11}(q^2) = \Pi_{11}(0) + q^2\,\Pi'_{11}(0)$
6 coeff : 3 → $\alpha, G_F, m_Z$
3 remaining param
Peskin-Takeuchi S, T, U par.
$S = 16\pi[\Pi'_{33}(0) - \Pi'_{3\gamma}(0)] =$
$= -4\pi[\Pi'_V(0) - \Pi'_A(0)]$
$= 4\pi \sum_n \left(\frac{g^2_{Vn}}{m^2_{Vn}} - \frac{g^2_{An}}{m^2_{An}}\right)$


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 : $N_c$ $D_4$ branes
$N_f$ $D_8$, $\overline{D_8}$ → probes
U-shape
D8
$\overline{D8}$
$r_H$
$r_0$
$r \to \infty$
$SU(N_f) \times SU(N_f) \to$ diag. $SU(N_f)$
technicolor :

3. S-param from holography

Similar to Sakai-Sugimoto (hol. QCD)

SS : $N_c$ $D_4$ branes

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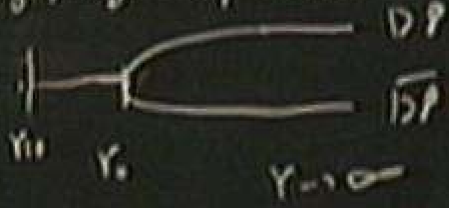
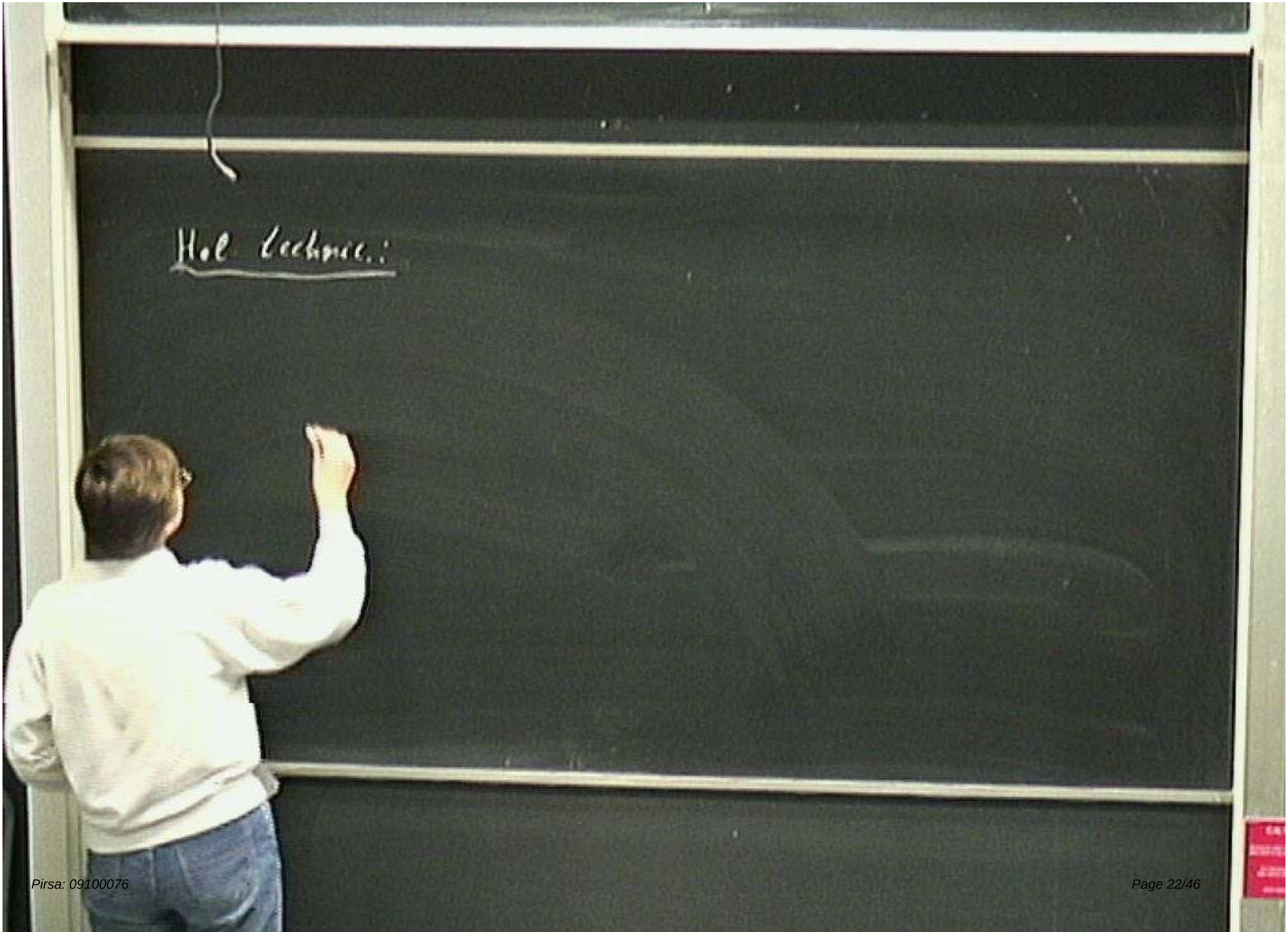
U-shape 

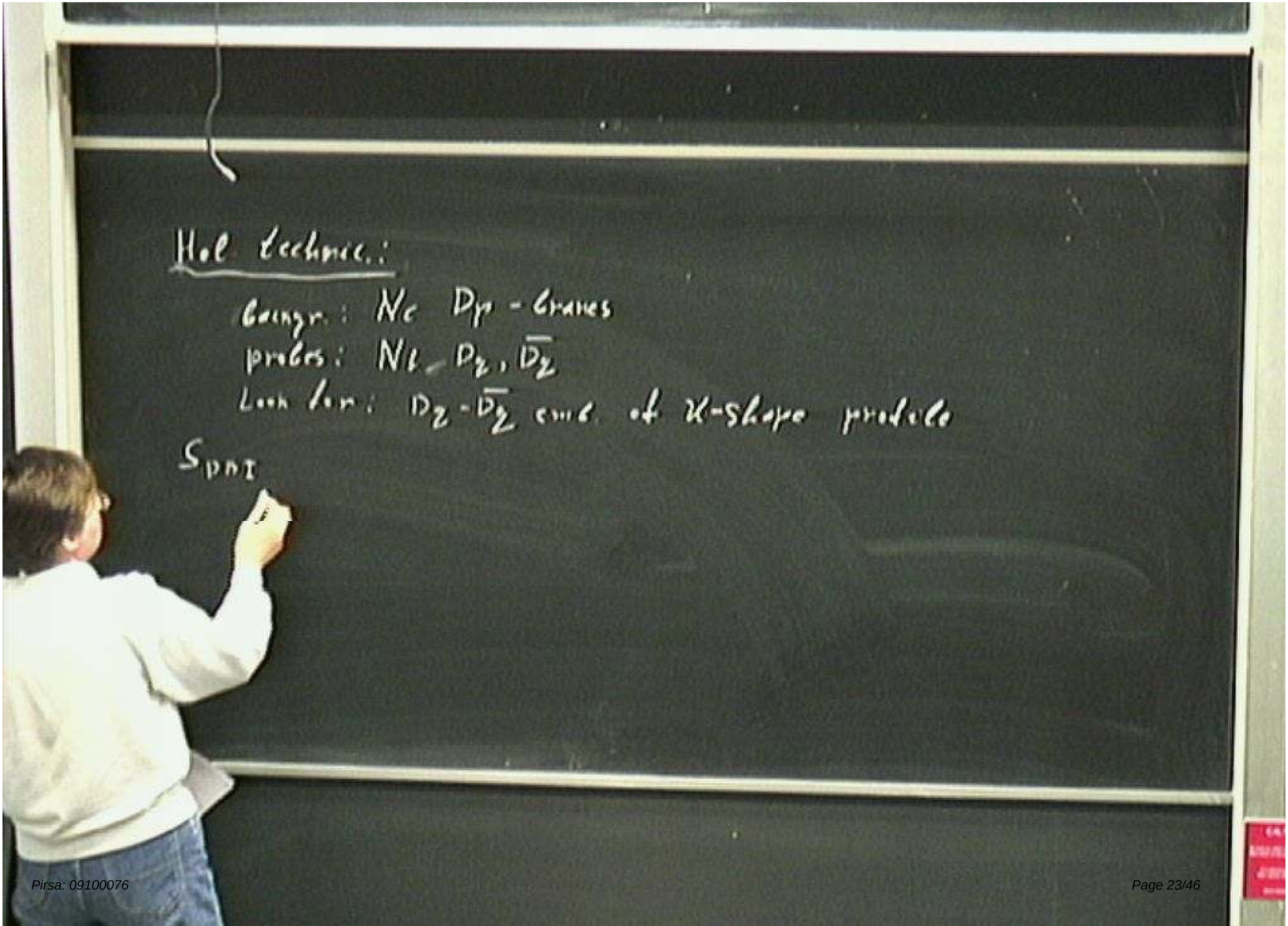


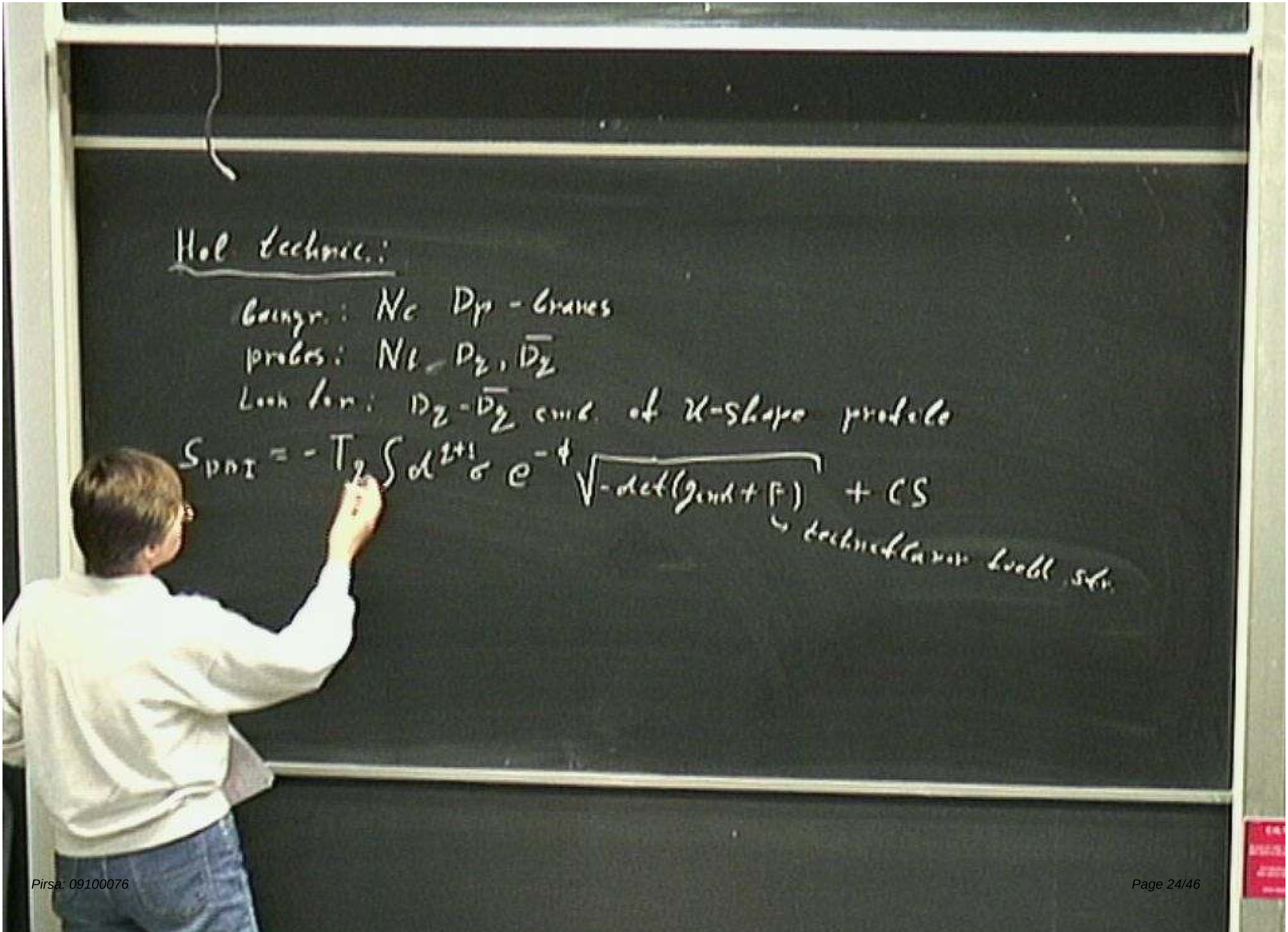
stable, but not susy

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

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


Hol. technique:


Hol. techniq.:
Backgr.: $N_c$ $D_p$ - branes
probes: $N_f$ $D_q$, $\overline{D_q}$
Look for: $D_q$ - $\overline{D_q}$ conn. of U-shape profile
Spin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Look for: $D_q$ - $\overline{D_q}$ conf. of U-shape profile
$S_{DBI} = -T_q \int d^{q+1}\sigma \, e^{-\phi} \sqrt{-\det(g_{ind} + F)} + CS$
↳ technoflavor field str.

Hol technic.:

backgr.: $N_c$ $D_p$ - branes

probes: $N_f$ $D_q$, $\bar{D}_q$

low. lim.: $D_q$ - $\bar{D}_q$ 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.

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

Hol. techn.:

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

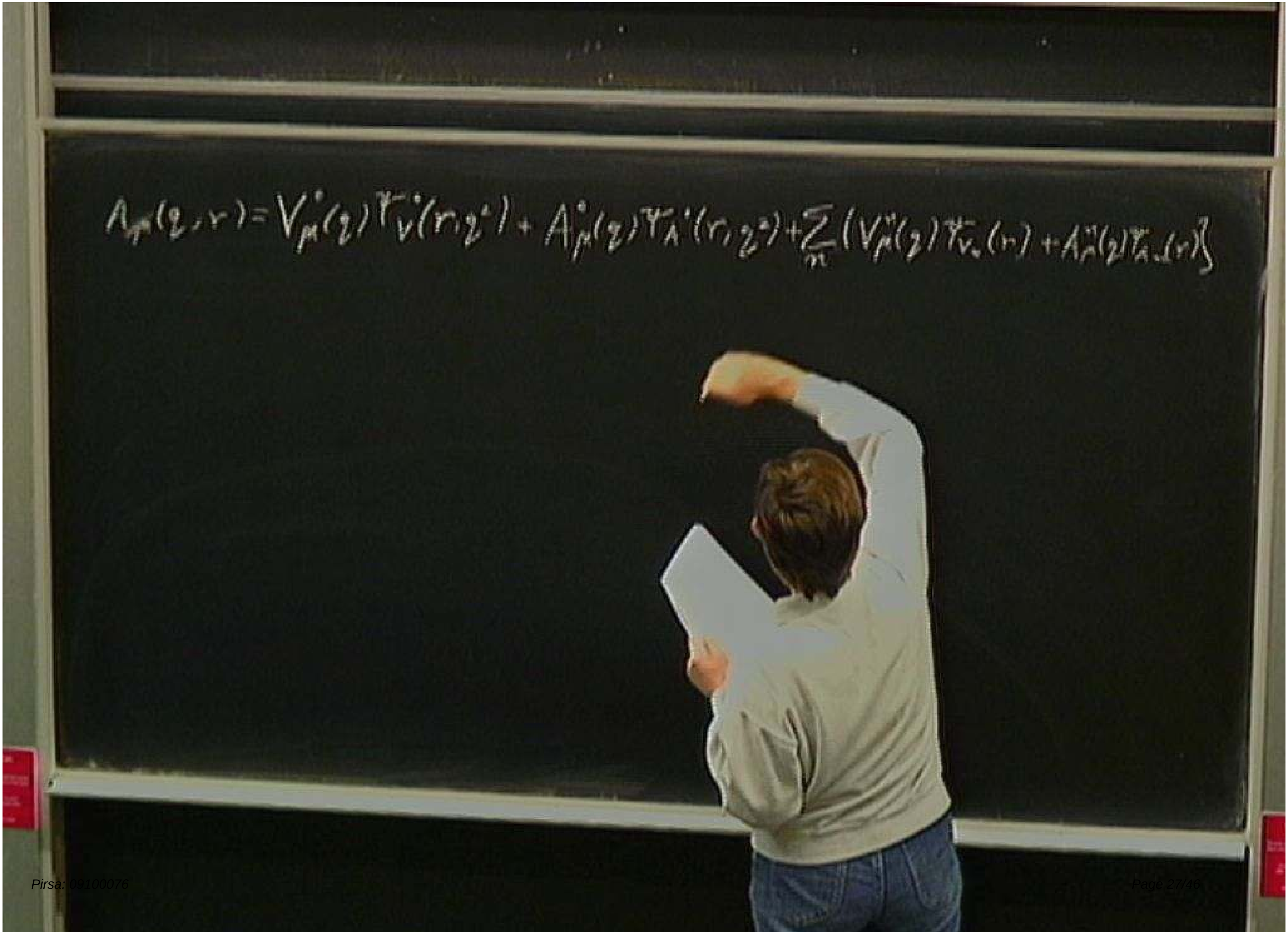
$$S_{DBI} = -T_q \int d^{q+1}\sigma \, e^{-\phi} \sqrt{-\det(g_{ind} + F)} + CS$$

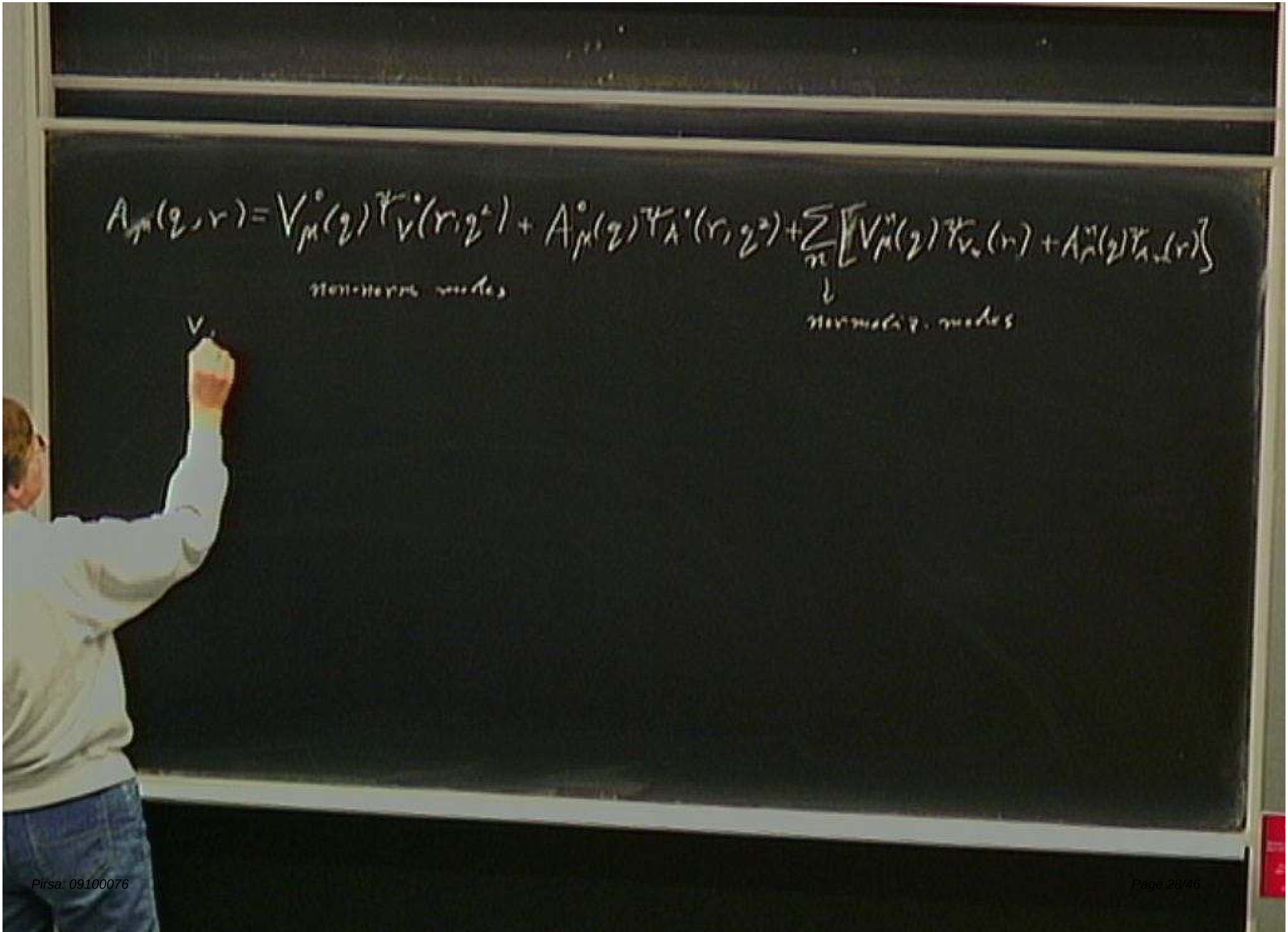
↳ technicolour-like str.

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

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

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


$A_\mu(q,r) = V^0_\mu(q)\Psi^0_V(r,q^2) + A^0_\mu(q)\Psi^0_A(r,q^2) + \sum_n \{V^n_\mu(q)\Psi_{V_n}(r) + A^n_\mu(q)\Psi_{A_n}(r)\}$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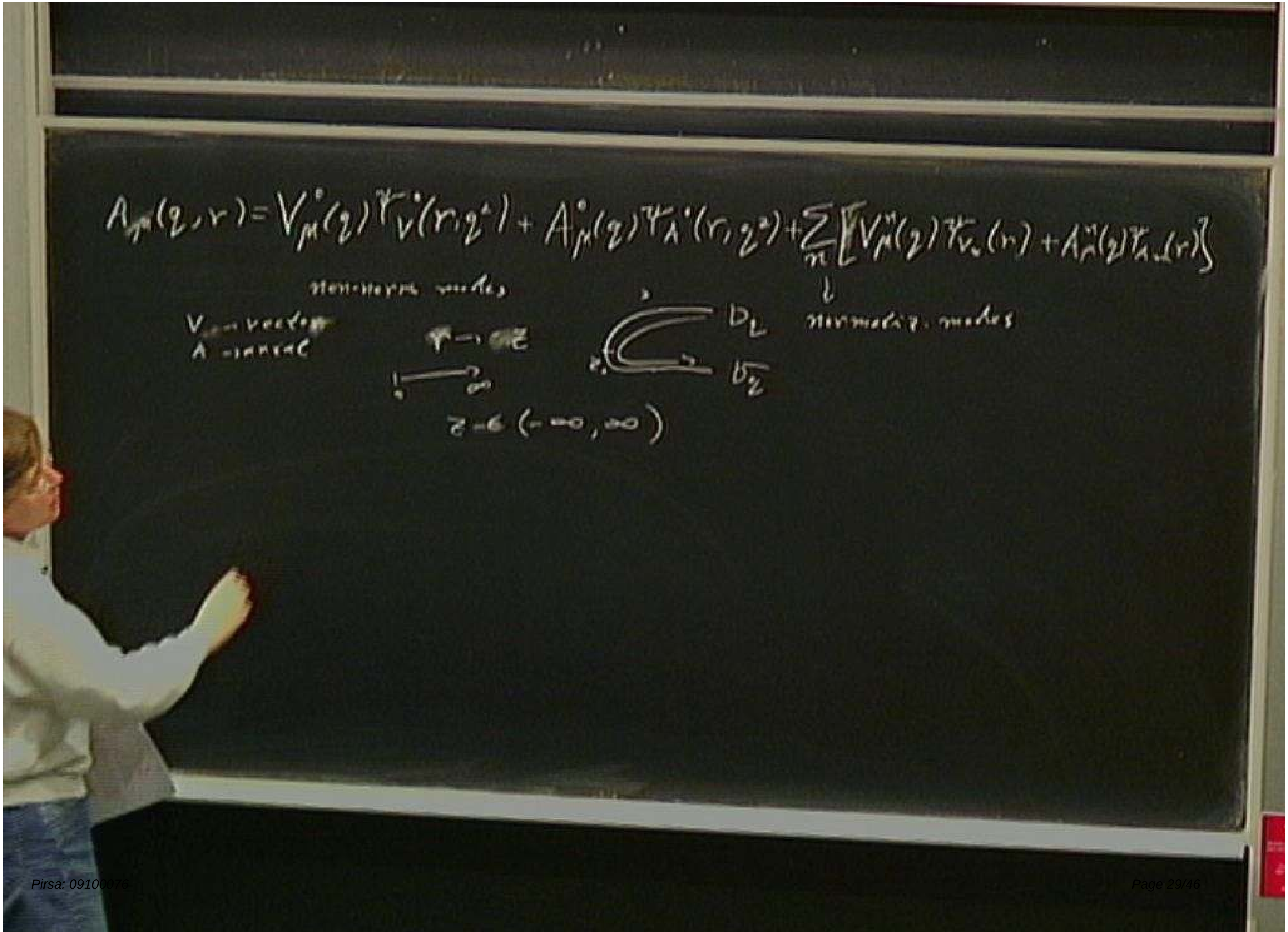
non-norm. modes
normaliz. modes
V,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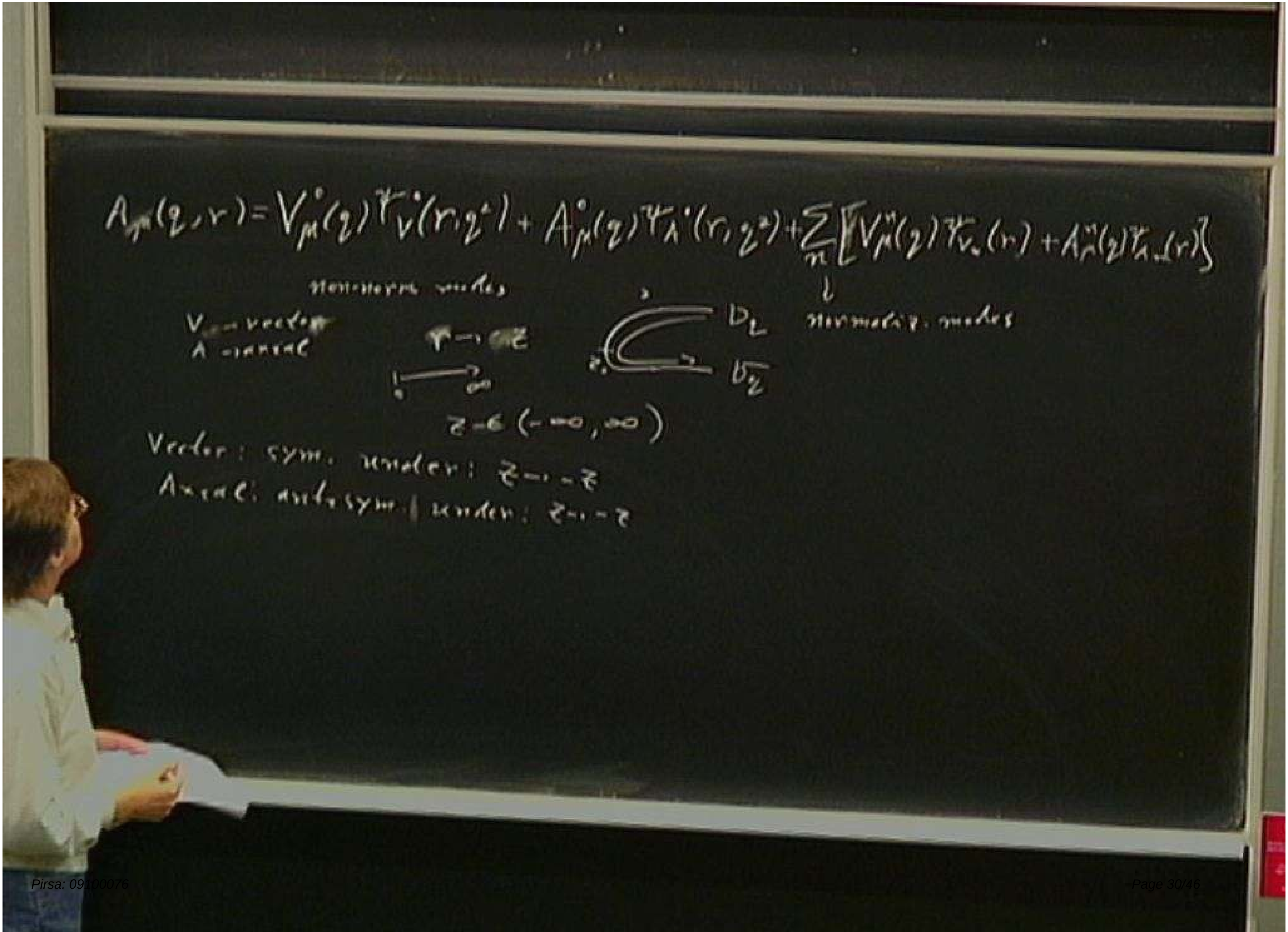
non-norm. modes
normaliz. modes
V – vector
A – axial
$D_L$
$D_R$
$z \in (-\infty, \infty)$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$D_L$
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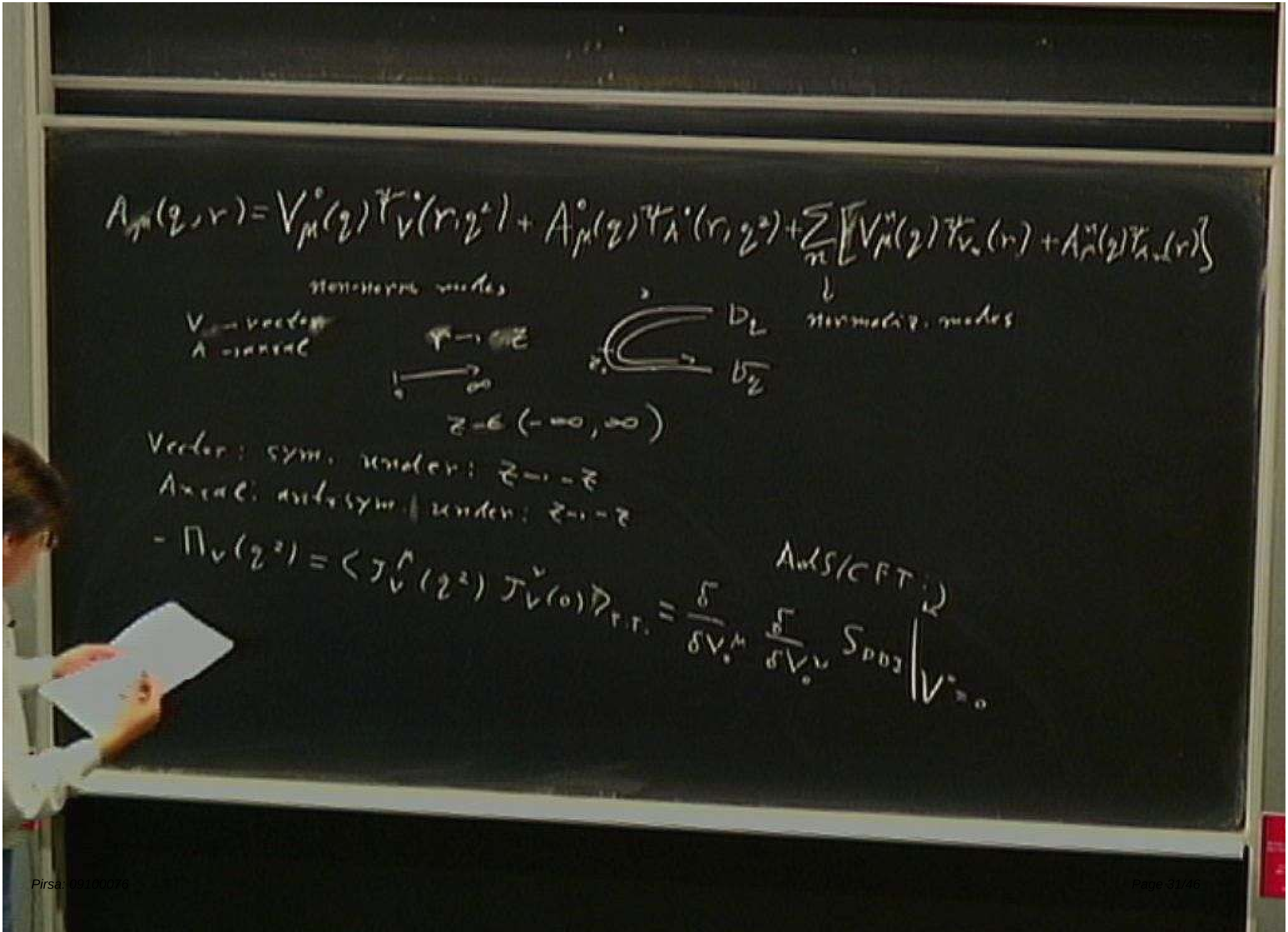
Vector: sym. under: $z \to -z$
Axial: antisym. under: $z \to -z$


A_μ(q,r) = V_μ^0(q) Ψ_V^0(r,q²) + A_μ^0(q) Ψ_A^0(r,q²) + Σ_n [V_μ^n(q) Ψ_{V_n}(r) + A_μ^n(q) Ψ_{A_n}(r)]
non-norm. modes
normaliz. modes
V – vector
A – axial
D_L
D_R
z ∈ (−∞, ∞)
Vector: sym. under: z → −z
Axial: antisym. under: z → −z
AdS/CFT
− Π_V(q²) = <J_V^μ(q²) J_V^ν(0)>_{F.T.} = δ/δV_0^μ δ/δV_0^ν S_{5D}|_{V^0=0}

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

non-norm. modes

normaliz. modes

V → vector

A → axial

$\Psi \to \Xi$

$0 \longrightarrow \infty$


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

Vector: sym. under: $z \to -z$

Axial: antisym. under: $z \to -z$

AdS/CFT:

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

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

non-norm. modes

normaliz. modes

V — vector

A — axial

$r \to z$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$$-\Pi_V(q^2) = \langle J^\mu_V(q^2)\, J^\nu_V(0) \rangle_{F.T.} = \frac{\delta}{\delta V_0^\mu} \frac{\delta}{\delta V_0^\nu} S_{bos} \Big|_{V^0=0}$$

AdS/CFT

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

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

non-norm. modes

normaliz. modes

V → vector
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$r \to z$

$0 \longrightarrow \infty$

$D_L$

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

AdS/CFT

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

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

non-norm. modes

normaliz. modes

V — vector

A — axial

$\psi \to \infty$

$0 \to \infty$


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

Vector: sym. under: $z \to -z$

Axial: antisym. under: $z \to -z$

E.o.M:

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

AdS/CFT

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

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

non-norm. modes

normaliz. modes

V – vector

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$r \to z$

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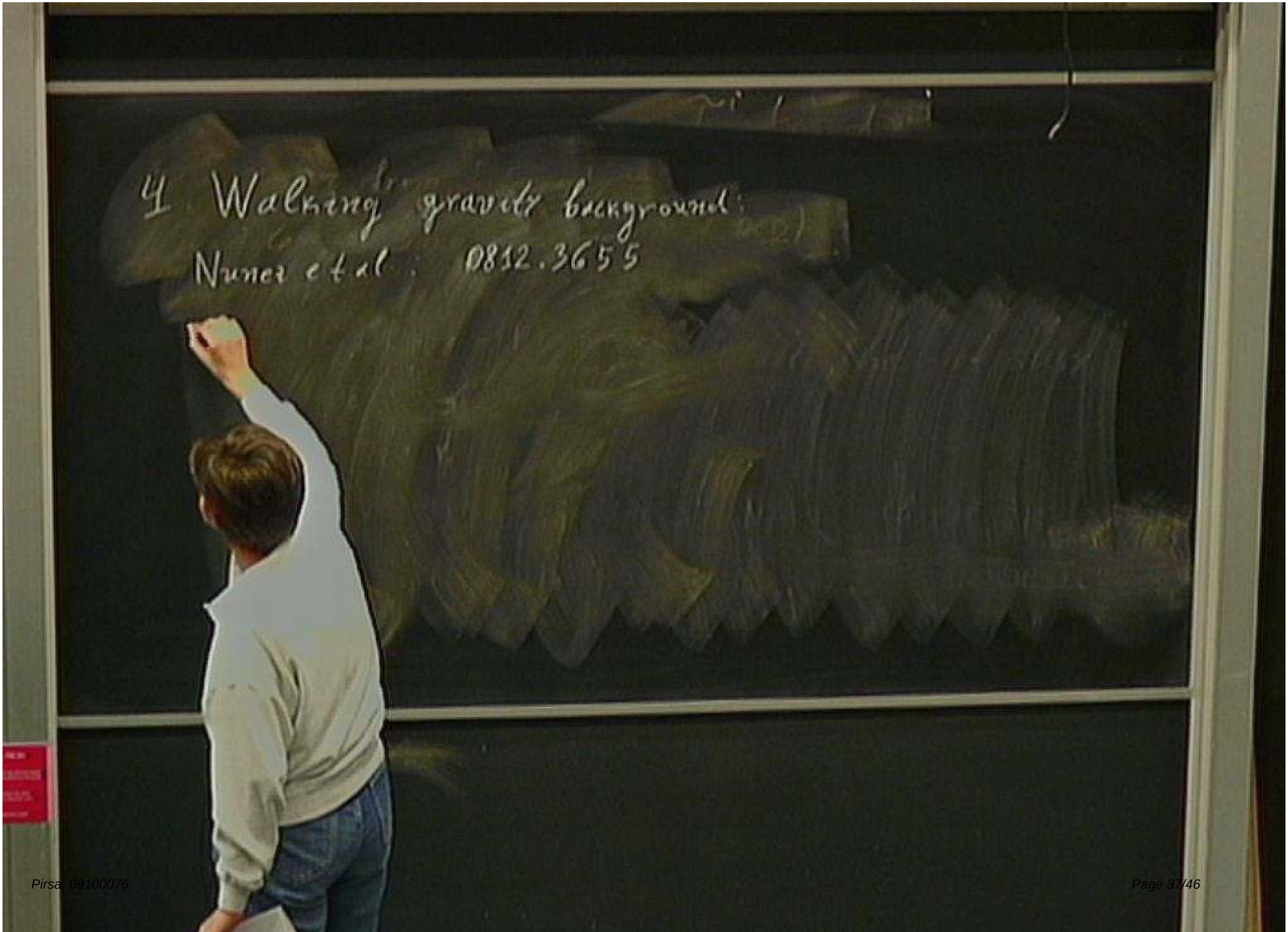
E.M.:

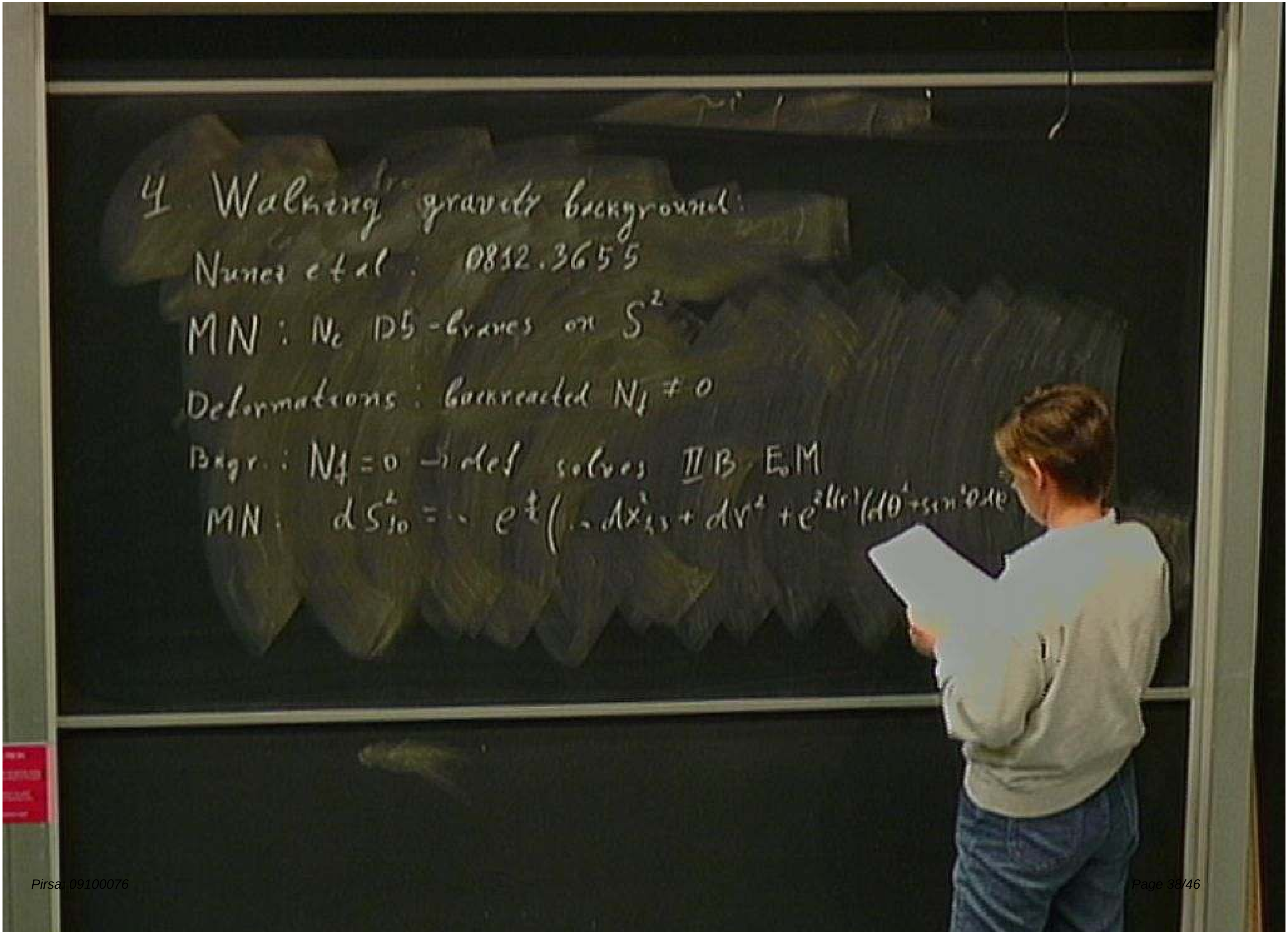
$$\frac{1}{a(r)}\partial_r\left(b(r)\,\partial_r \Psi^0\right) = -q^2\,\Psi^0$$

AdS/CFT:

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

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


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 $N_f \neq 0$
Bkgr.: $N_f = 0 \to$ def. solves IIB EoM
MN: $ds^2_{10} = e^{\phi/2}\left(-dx^2_{1,3} + dr^2 + e^{2h(r)}(d\theta^2 + \sin^2\theta\, d\varphi

4. Walking gravity background:

Nunez et al.: 0812.3655

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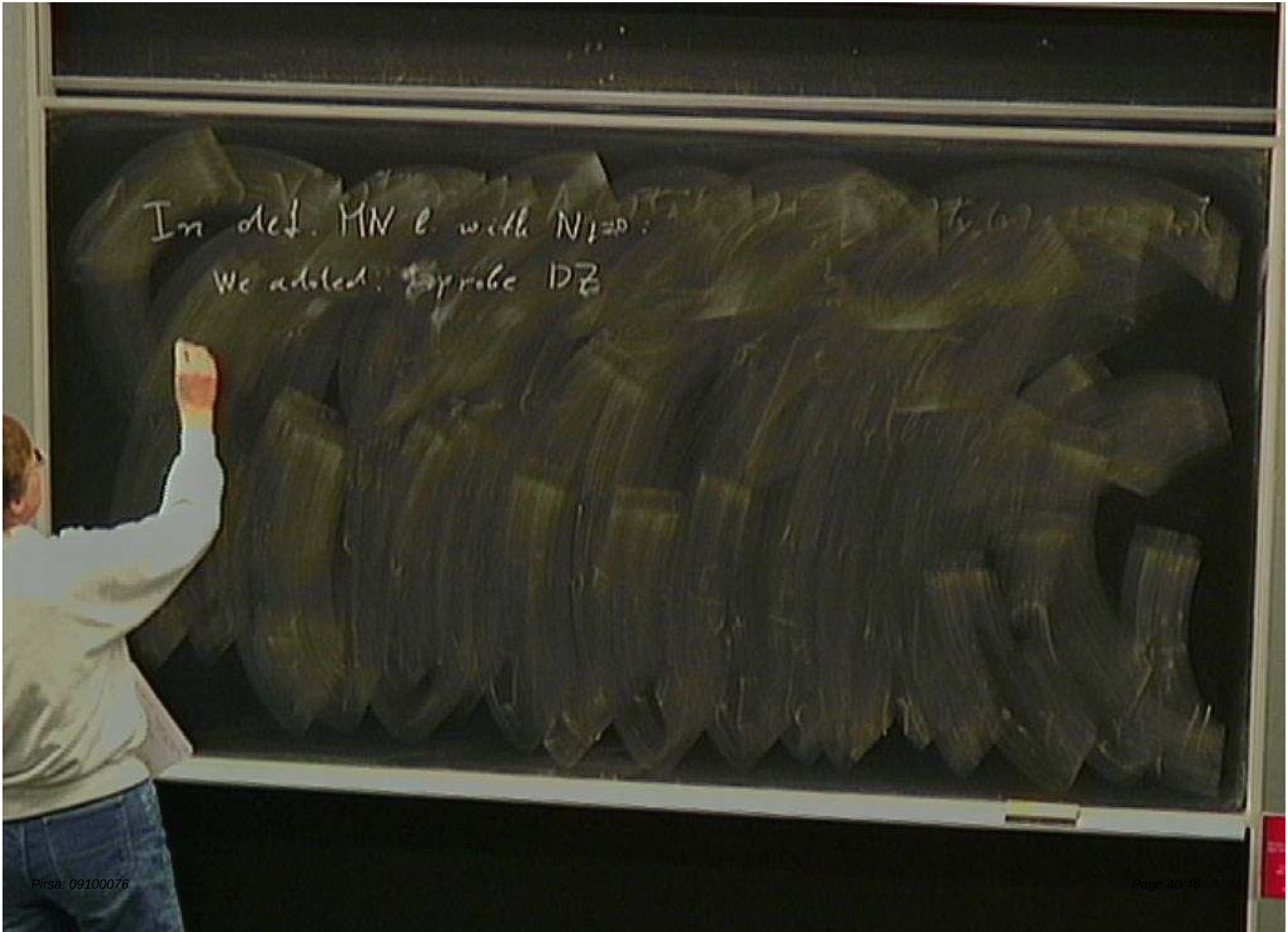
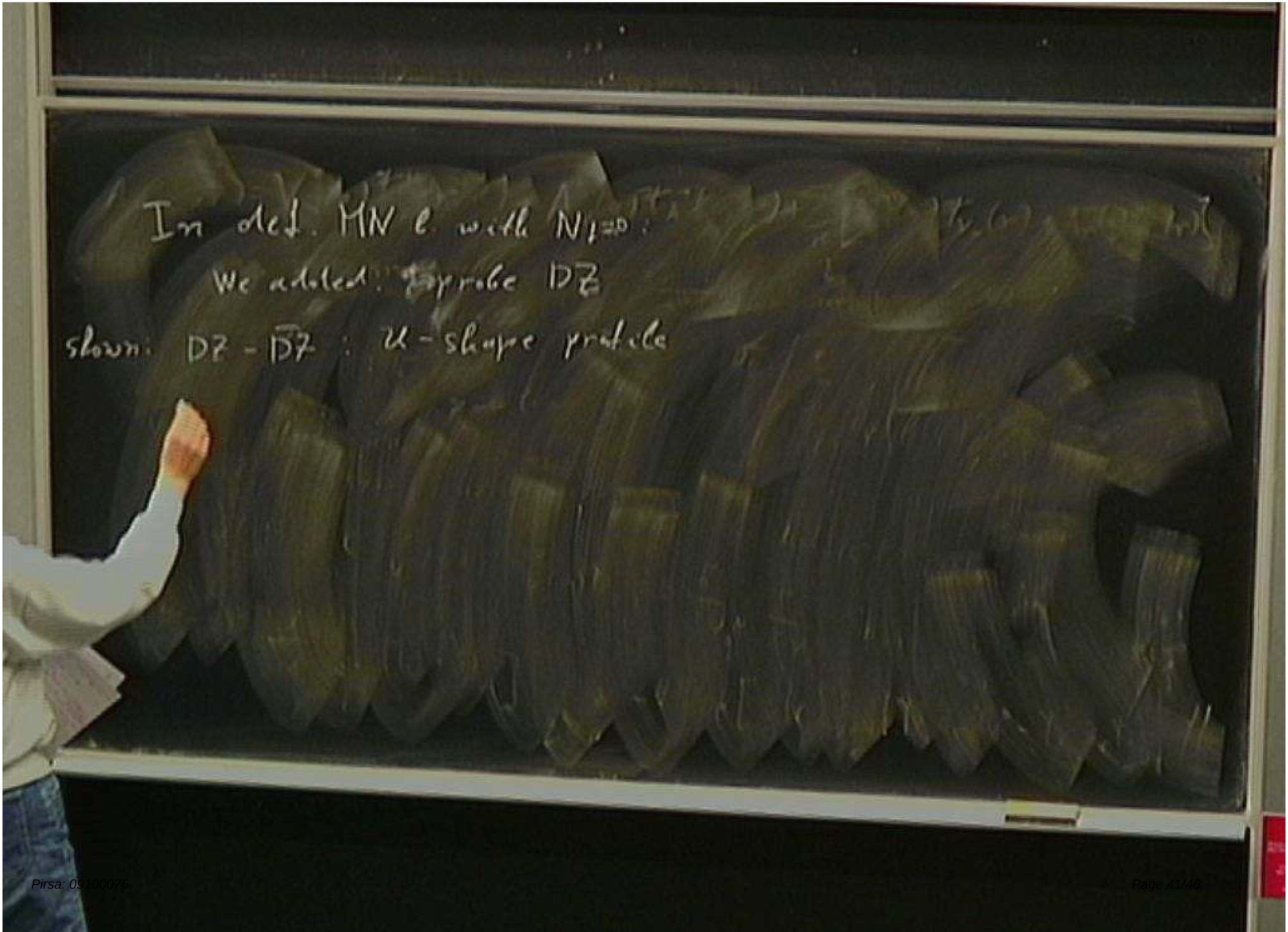
SU(2) left inv. 1-f

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

$$\text{MN}: \quad ds_{10}^2 = e^{\phi(\rho)}\left( -dx_{1,3}^2 + e^{2k(\rho)} d\rho^2 + e^{2h(\rho)}(d\theta^2 + \sin^2\theta\, d\varphi^2) + \frac{1}{4}(\tilde{\omega}_i - A_i)^2 \right)$$

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


In def. MN ℓ with $N_1 = 0$:
We added: probe DZ

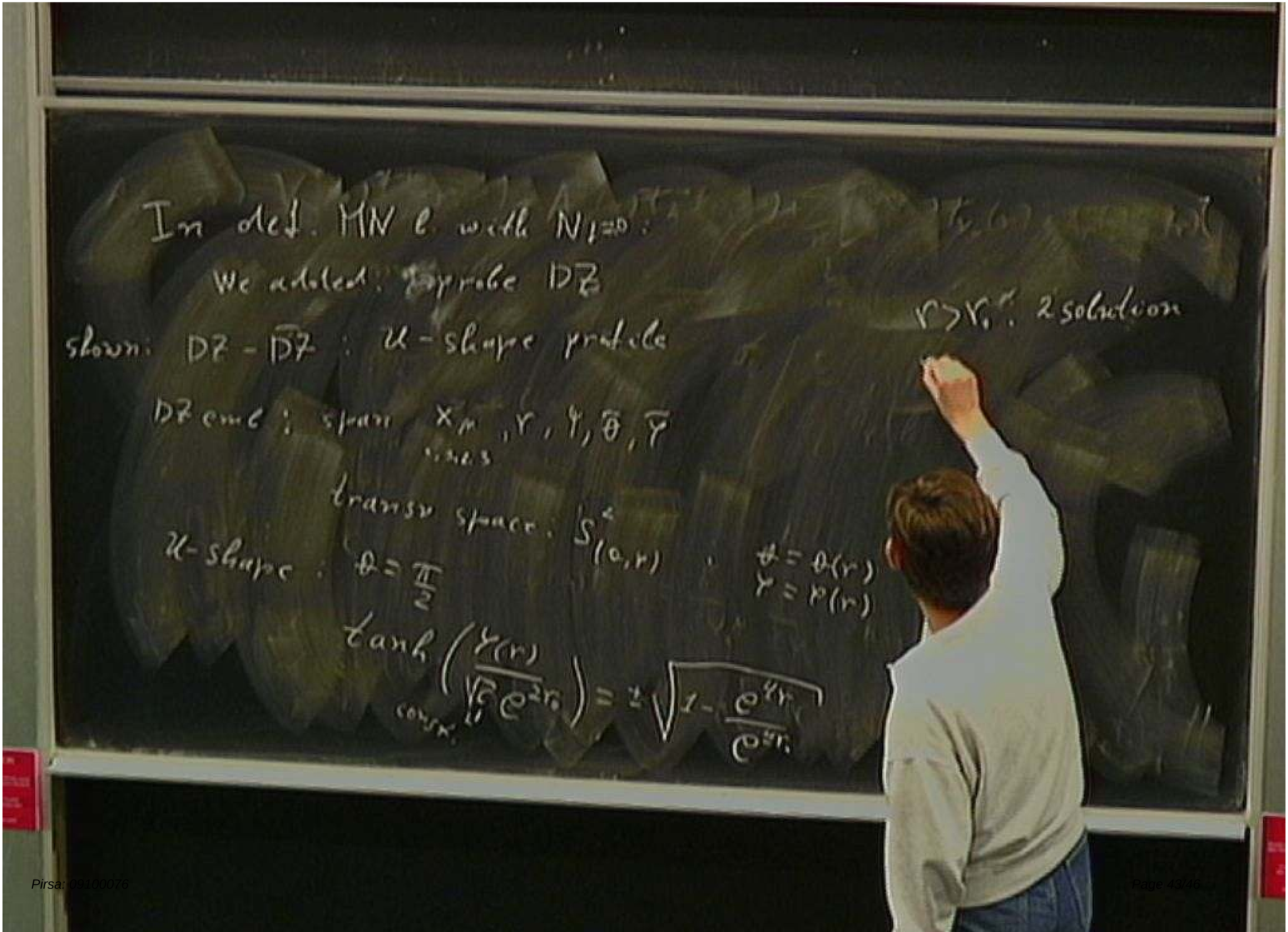

In def. MN ℓ with $N_{1\neq 0}$:
We added: probe DZ
shown: DZ - $\overline{\mathrm{DZ}}$ : U-shape profile

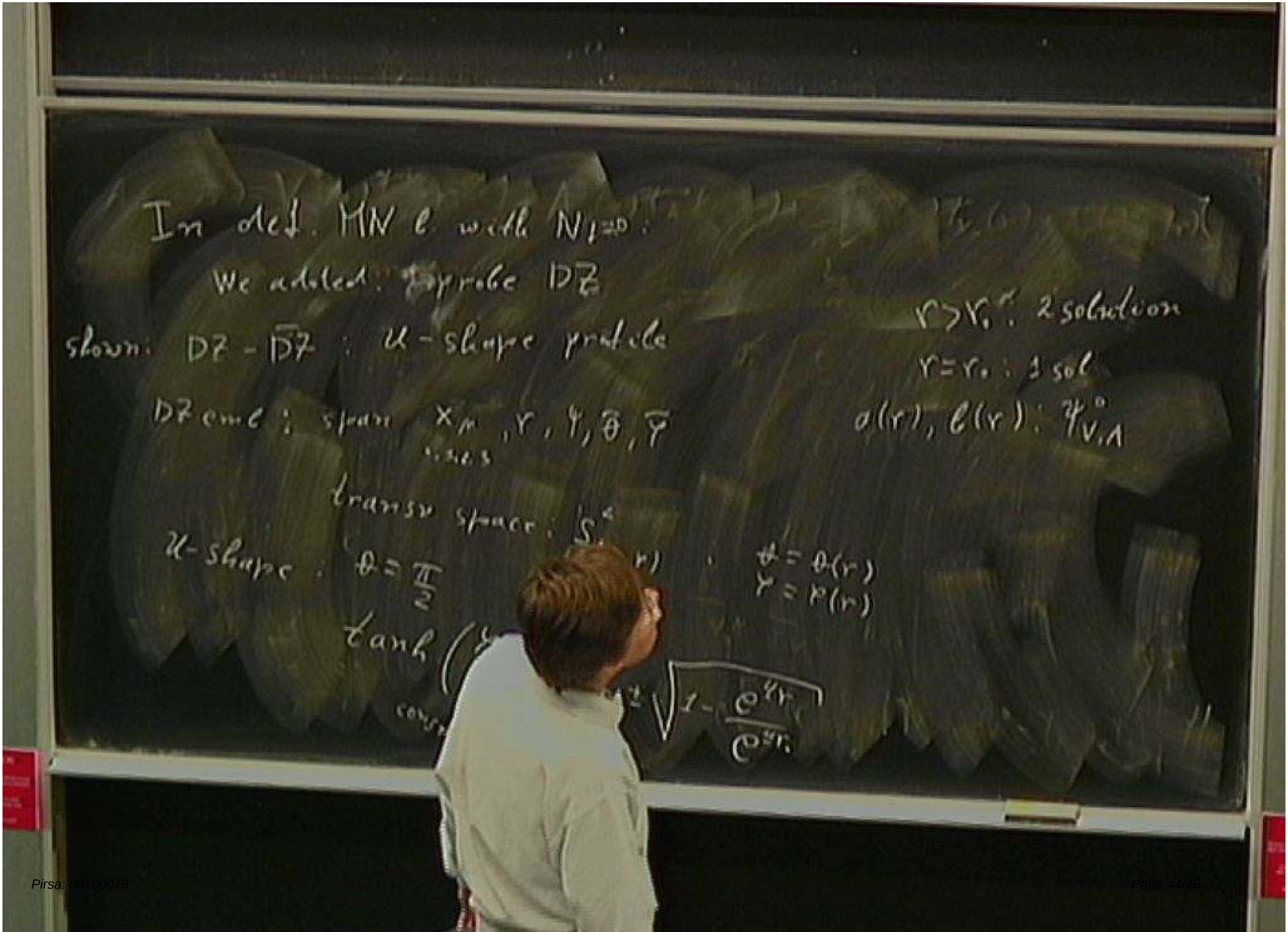
In def. MN l. with $N_{f=0}$:

We added: probe D7

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

D7 emb.: span $x_\mu$, $\mu=0,..,3$


We added: probe D7
shown: D7 - D̄7 : U-shape profile
D7 emb: span
transv space
U-shape
r>r₀: 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
θ = θ(r)
φ = φ(r)
tanh
r > r_0 : 2 solution
r = r_0 : 1 sol
a(r), b(r)

In def. MN $\ell$ with $N_f = 0$:

We added: probe D7

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

D7 emb: span $x_\mu$, $r$, $\psi$, $\tilde{\theta}$, $\tilde{\varphi}$

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

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

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

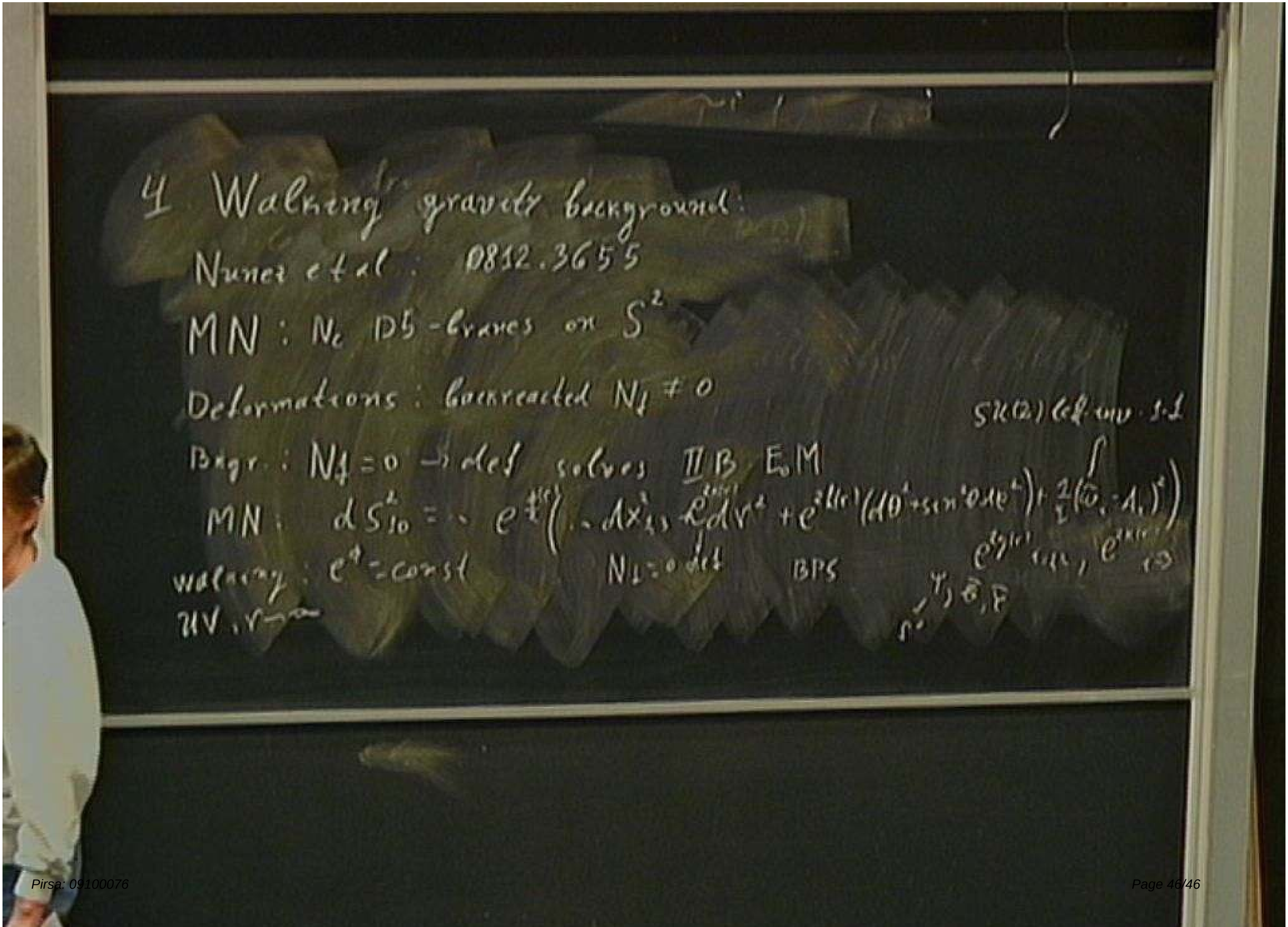
$r > r_0$: 2 solution

$r = r_0$: 1 sol

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

$S = \text{const} \int [b(r) \frac{\partial}{\partial \varphi} (\ldots)]$

$\varphi = 0$
$r = \infty$


4 Walking gravity background:
Nunez et al : 0812.3655
MN : Nc D5-branes on S2
Deformations : backreacted Nf ≠ 0
SU(2) left inv. 1-f
Bkgr : Nf = 0 → def solves IIB EoM
BPS
walking : e^φ = const
UV, r → ∞