Title: Introduction to the Bosonic String 9B

Date: Mar 20, 2009 12:00 PM

URL: http://pirsa.org/09030016

Abstract: This course provides a thorough introduction to the bosonic string based on the Polyakov path integral and conformal field theory. We introduce central ideas of string theory, the tools of conformal field theory, the Polyakov path integral, and the covariant quantization of the string. We discuss string interactions and cover the tree-level and one loop amplitudes. More advanced topics such as T-duality and D-branes will be taught as part of the course. The course is geared for M.Sc. and Ph.D. students enrolled in Collaborative Ph.D. Program in Theoretical Physics. Required previous course work: Quantum Field Theory (AM516 or equivalent). The course evaluation will be based on regular problem sets that will be handed in during the term. The primary text is the book: 'String theory. Vol. 1: An introduction to the bosonic string. J. Polchinski (Santa Barbara, KITP) . 1998. 402pp. Cambridge, UK: Univ. Pr. (1998) 402 p.' All interested students should contact Alex Buchel at abuchel@uwo.ca as soon as possible.

Why do we want $c = 0$?

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$\Leftrightarrow$ anomaly free Weyl symmetry

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Symmetry in QFT.

global

local or gauge symmetry

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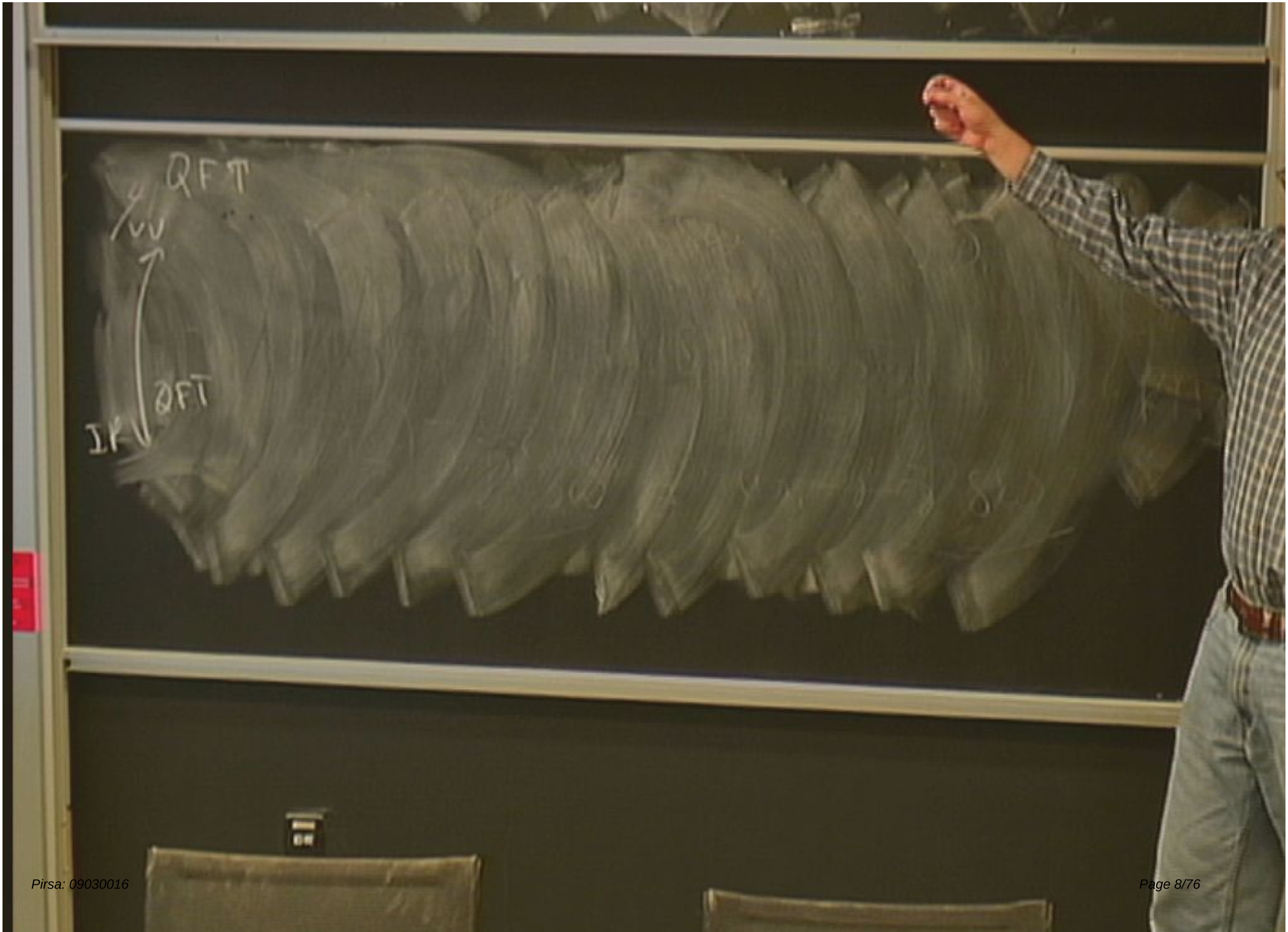
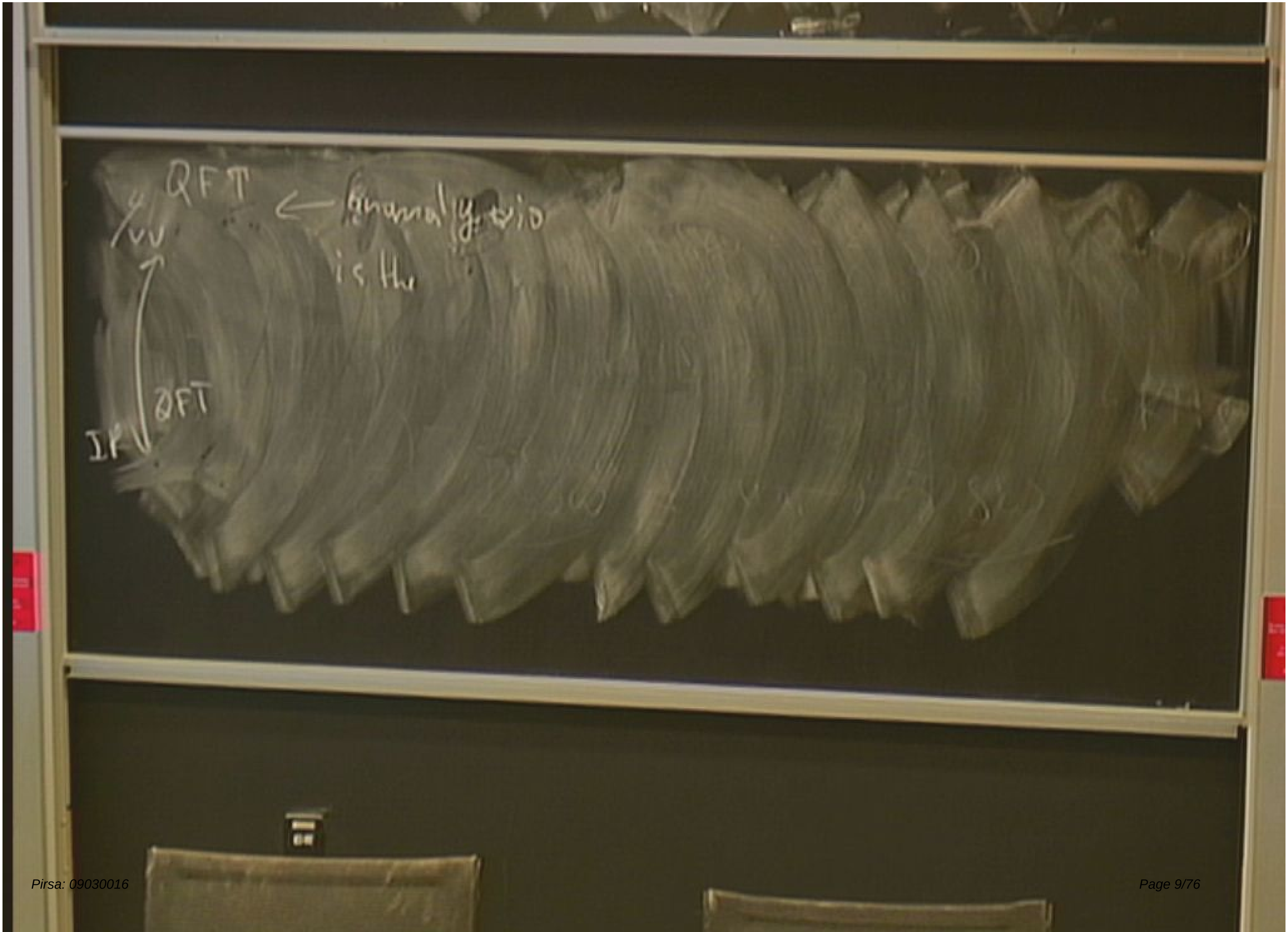
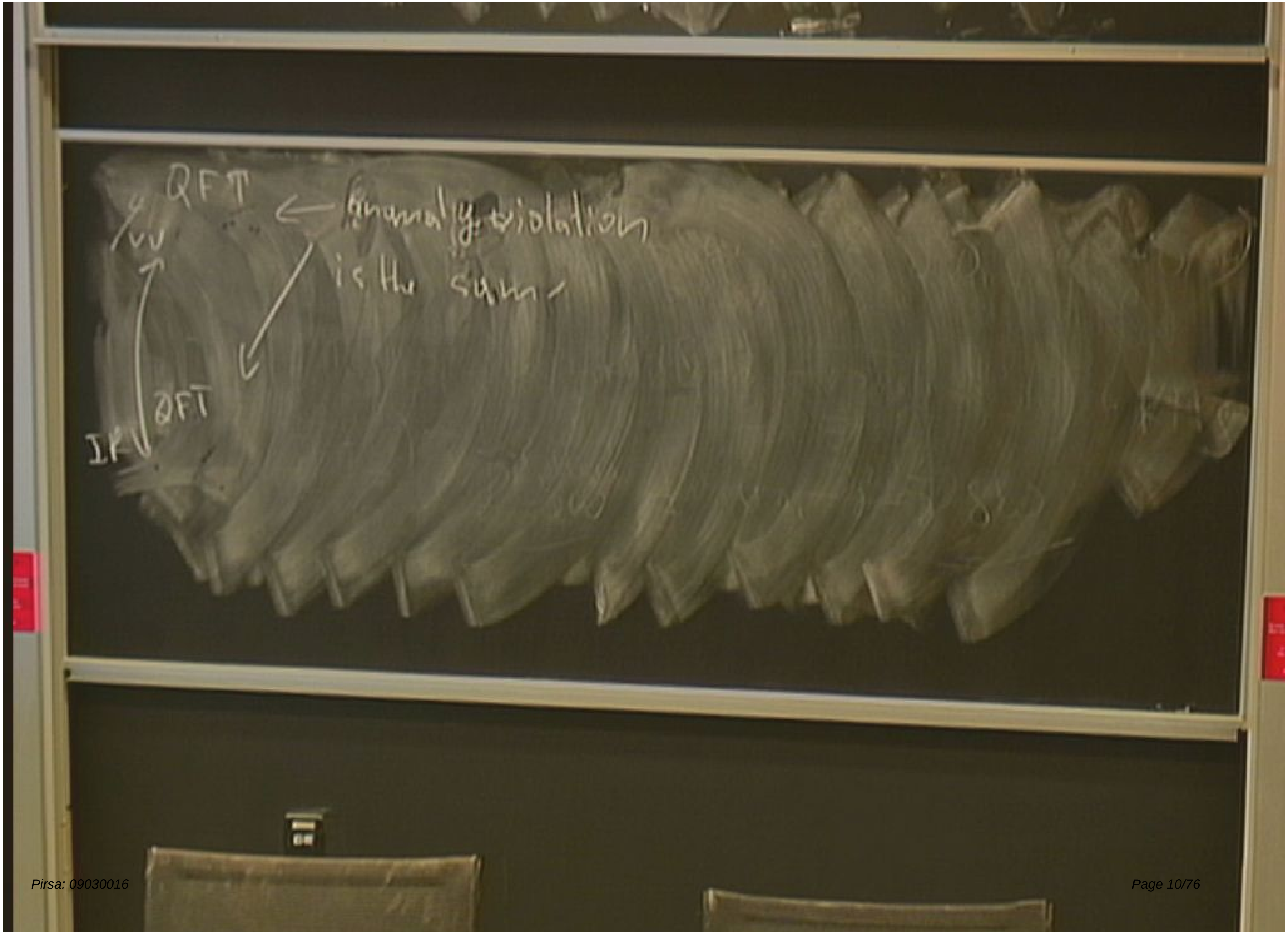
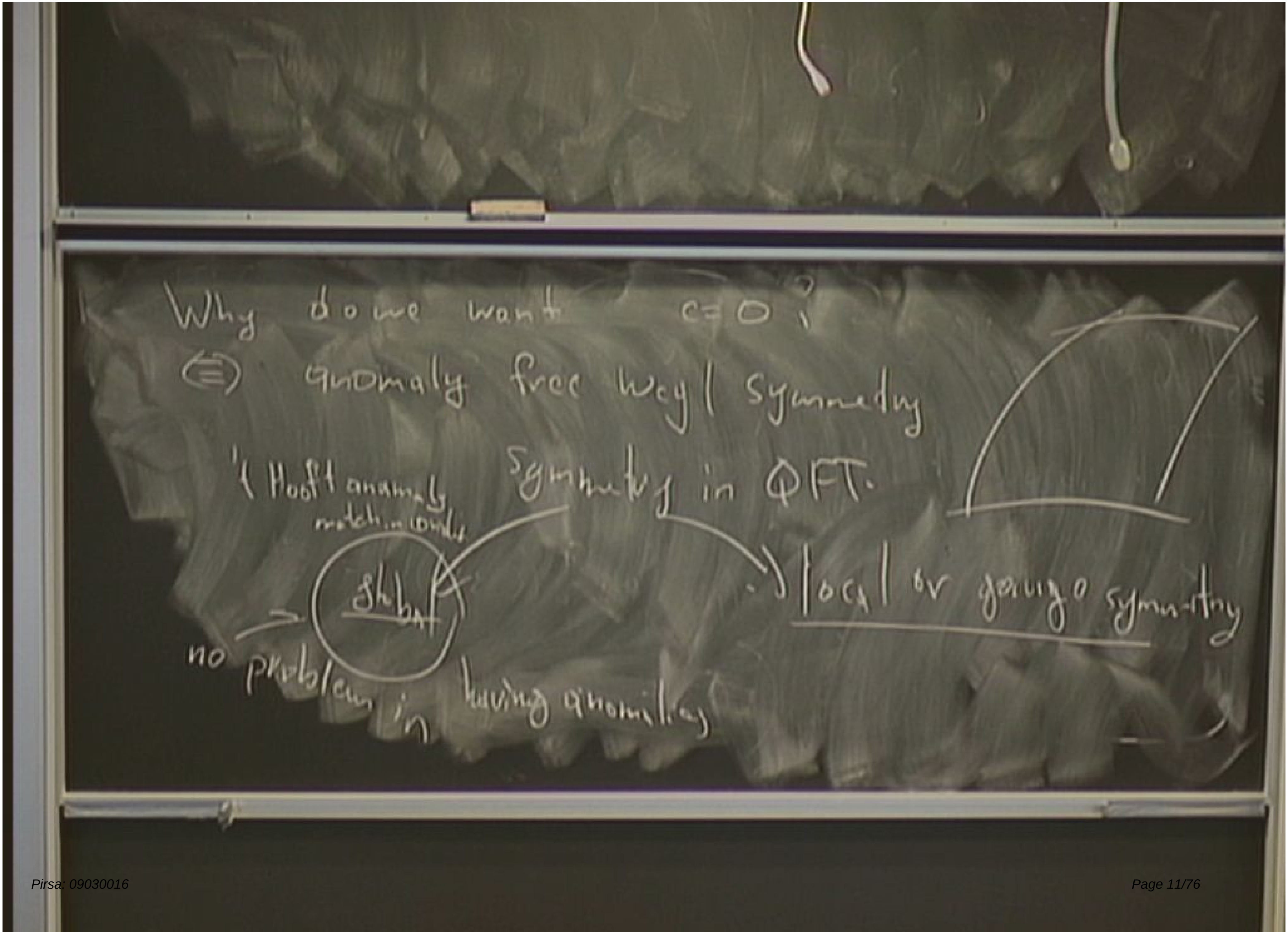

QFT
QFT
IR


QFT
UV
is the
QFT
IR


QFT
UV
anomaly violation
is the same
QFT
IR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Why do we want $c=0$? Physical conf = $\frac{\text{Total Conf}}{\text{Gauge sym}}$

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Symmetry in QFT.

't Hooft anomaly matching condition

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local or gauge symmetry

can never be anomalous !

no problem in having anomalies

can never be anomalous !

In Polyakov string Weyl transf $\equiv$ gauge ("real")

no problem in having anomalies

can never be anomalous !

In Polyakov string Weyl transf $\equiv$ gauge ("local")

$\Rightarrow$ What will happen if Weyl is not gauge anymore?

$$Z = \int \frac{[dX]}{\text{diff} \times \text{Weyl}} e^{-S_X}$$

no problem in having anomalies

can never be anomalous!

In Polyakov string Weyl transf $\equiv$ gauge ("local")

$\Rightarrow$ What will happen if Weyl is not gauge anymore?

$$\underset{c \neq 0}{Z \neq} \int \underbrace{[dX]}_{\text{diff} \times \text{Weyl}} e^{-S_X}$$

no problem in having anomalies

can never be anomalous!

In Polyakov string Weyl transf $\in$ gauge ("local")

$\Rightarrow$ What will happen if Weyl is not gauge anymore?

$$Z \neq \int \underbrace{[dX]}_{\text{diffeo}} [dg] e^{-S_X}$$

$C \neq 0$

no problem in having anomalies

can never be anomalous !

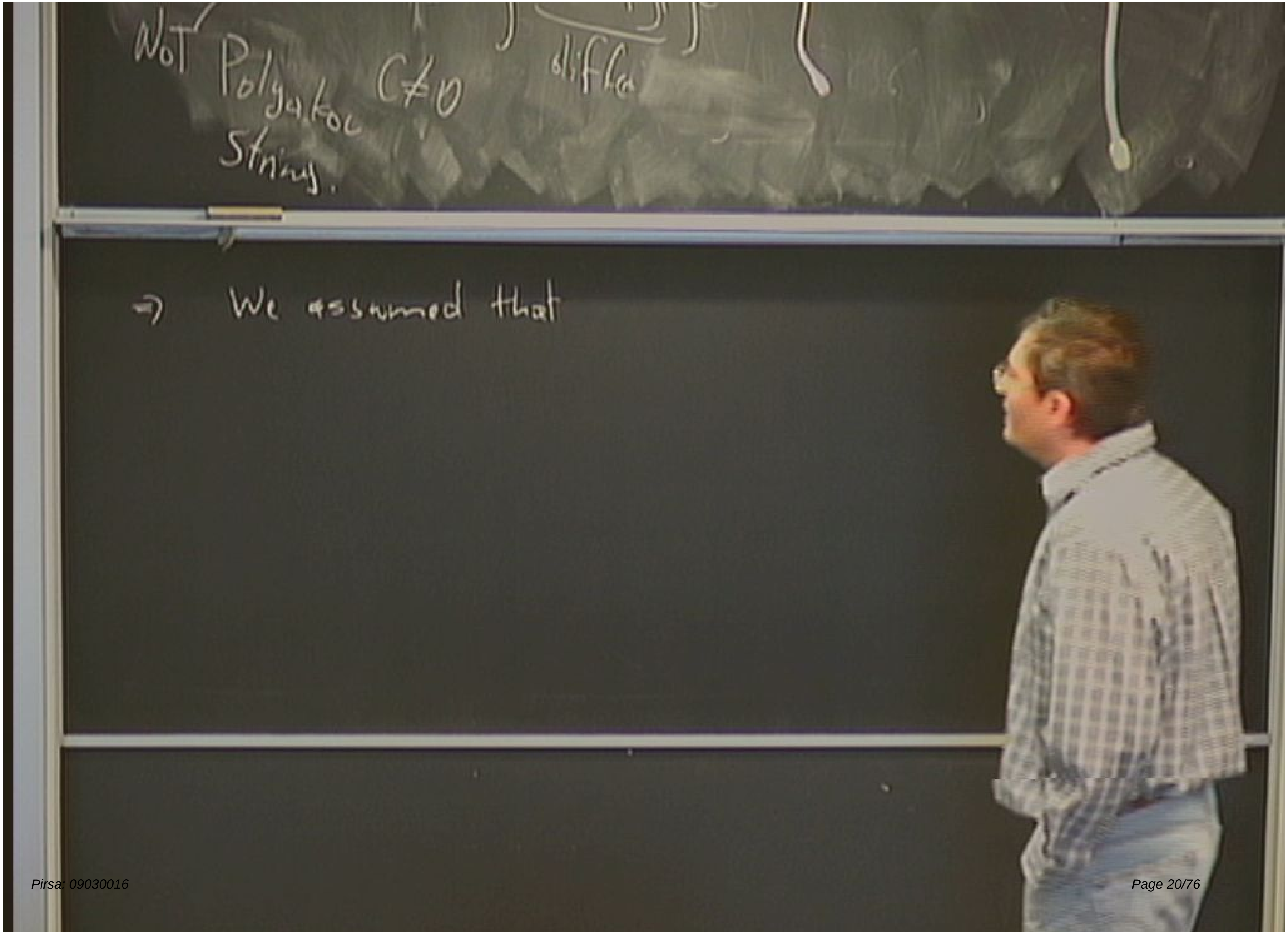
symmetry

In Polyakov string Weyl transf $\equiv$ gauge ("local")

$\Rightarrow$ What will happen if Weyl is not gauge anymore?

$$Z \neq \int \underbrace{[dX][dg]}_{\text{diff}} e^{-S_X}$$

NOT Polyakov string. $C \neq 0$


NoT Polyakov String.
C≠0
differ
⇒ We assumed that

NOT Polyakov string. $C \neq 0$ diff[illegible]

$\Rightarrow$ We assumed that in $\mathbb{R}^{D-1,1}$!!

NOT Polyakov $C \neq 0$ diff

string.

$\Rightarrow$ We assumed that in $\mathbb{R}^{D-1,1}$!

$\hookrightarrow$ Study strings in curved space-time.

NoT Polyakov string.

$c \neq 0$

diff

$\Rightarrow$ We assumed that in $R^{D-1,1}$!

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must Be weyl inv. in curved space-time!

NOT Polyakov $C \neq 0$ diff
String.

$\Rightarrow$ We assumed that in $R^{D-1,1}$!

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$\hookrightarrow$ Weyl inv on a string world-sheet

NOT Polyakov string. $C \neq 0$ differ

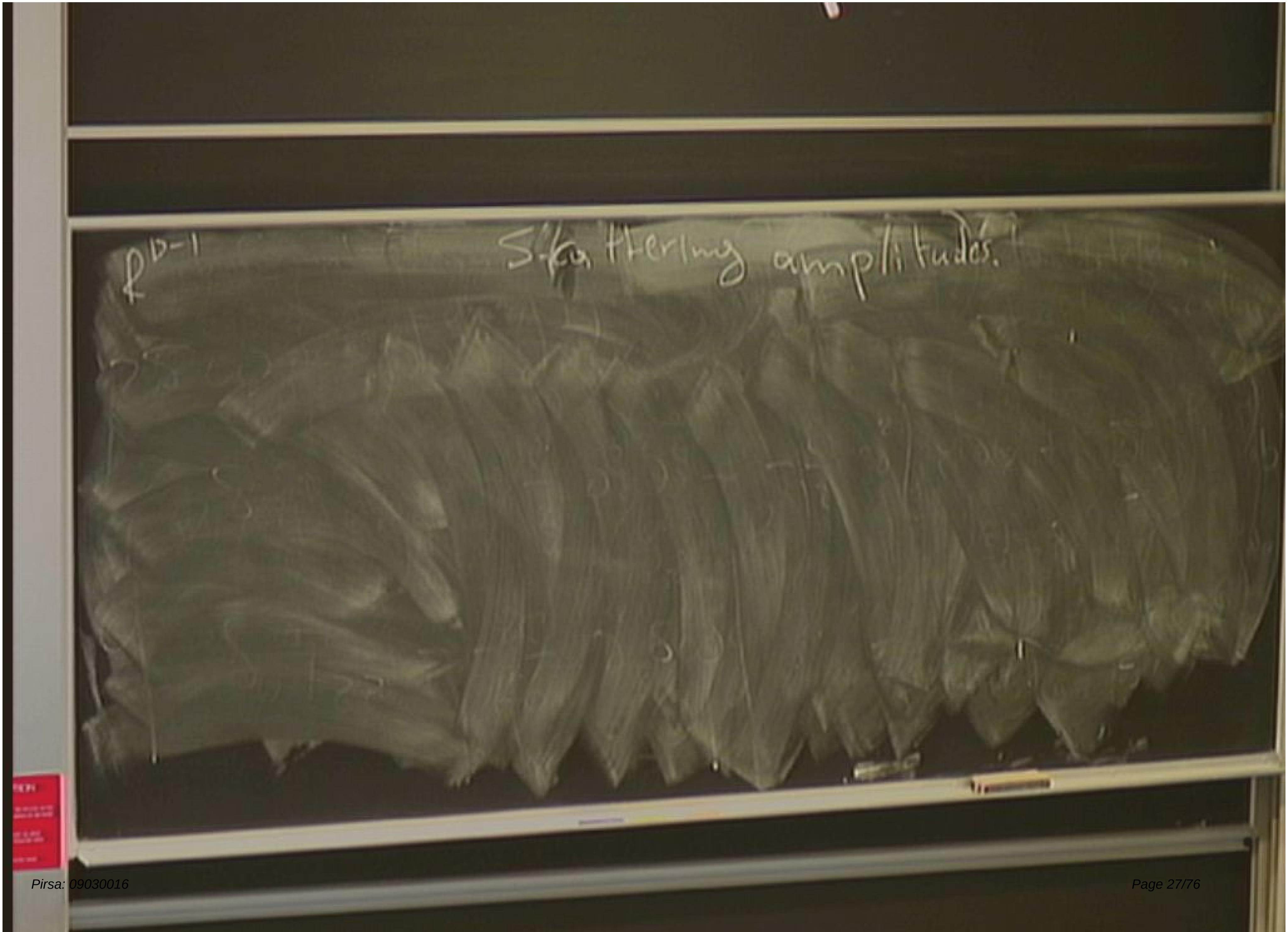
$\Rightarrow$ We assumed that in $\mathbb{R}^{D-1,1}$!

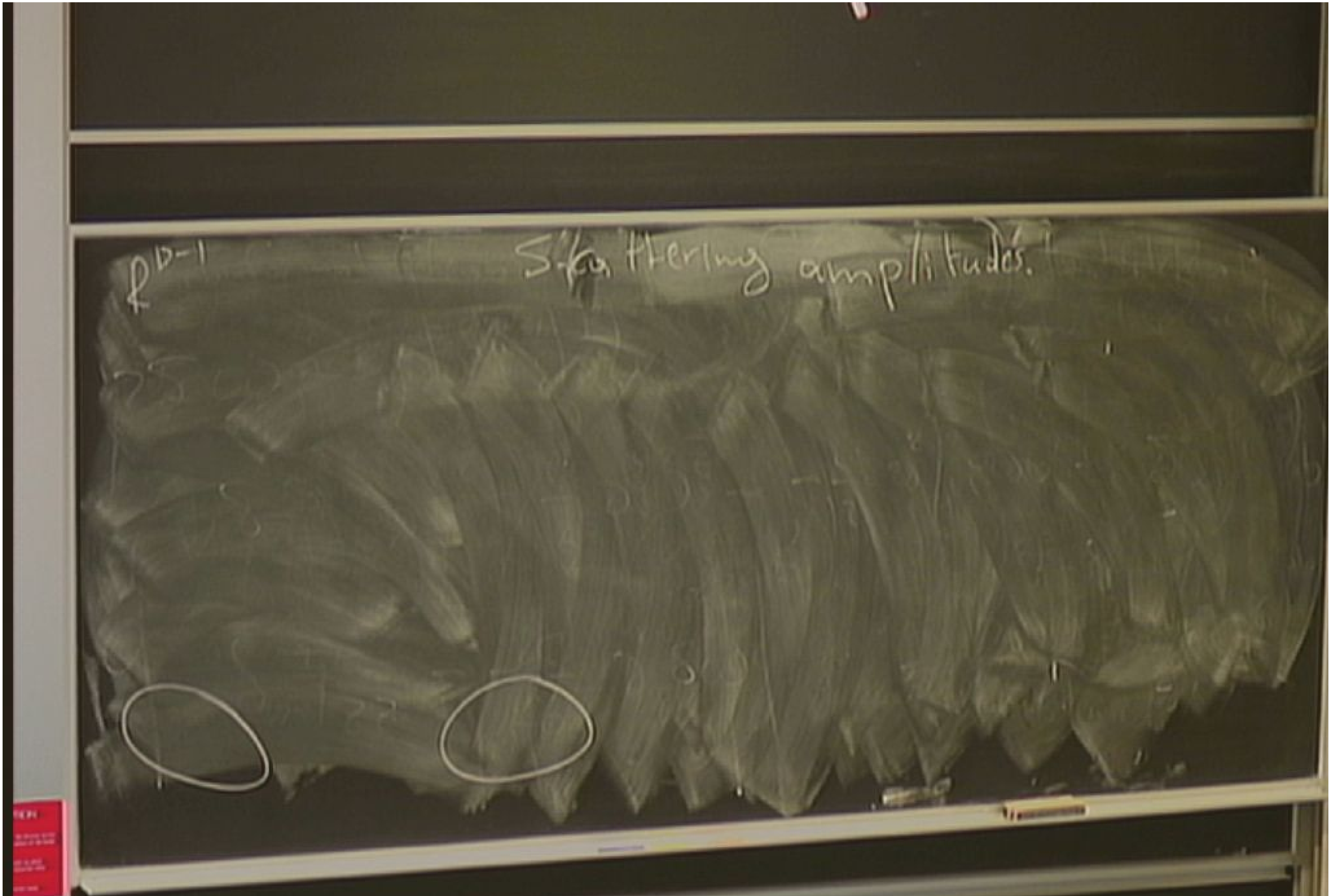
$\hookrightarrow$ Study strings in curved space-time.

must Be Weyl inv. in curved space-time!

$\hookrightarrow$ Weyl inv on a string world-sheet $\Longrightarrow$ Einstein gravity in D dim

Scattering amplitudes.


R^{D-1}
Scattering amplitudes.


R^{D-1}
Scattering amplitudes.

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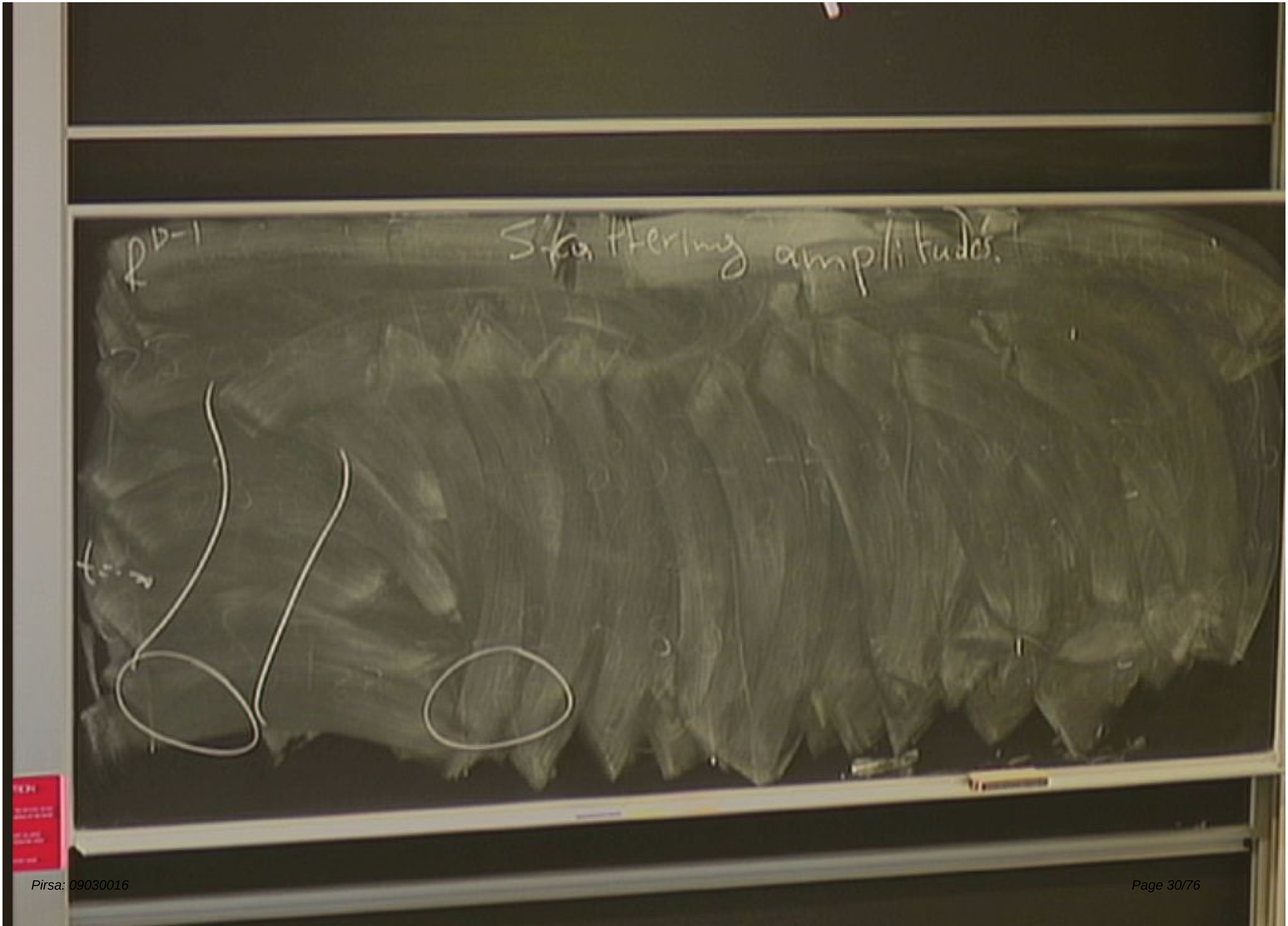
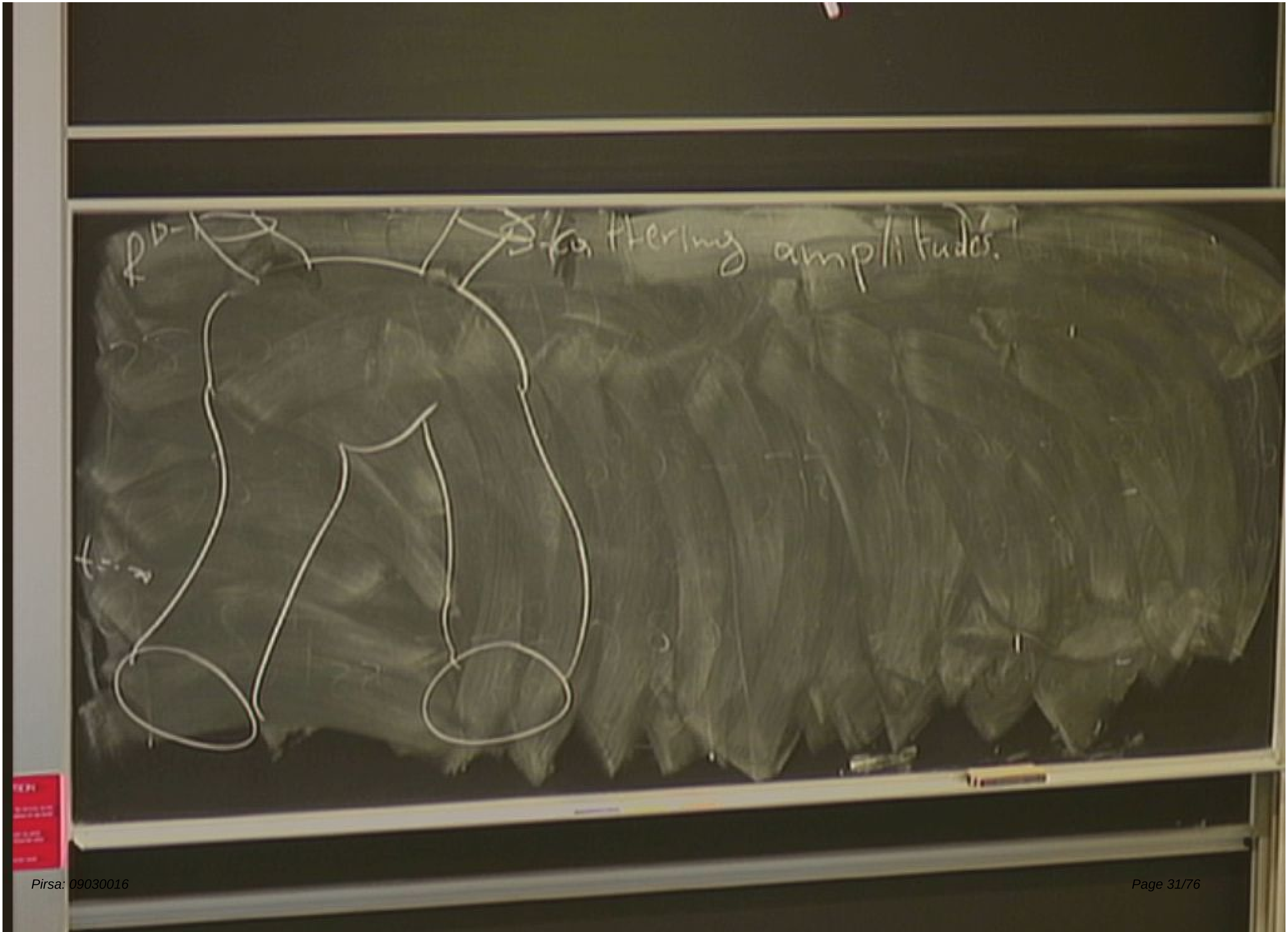
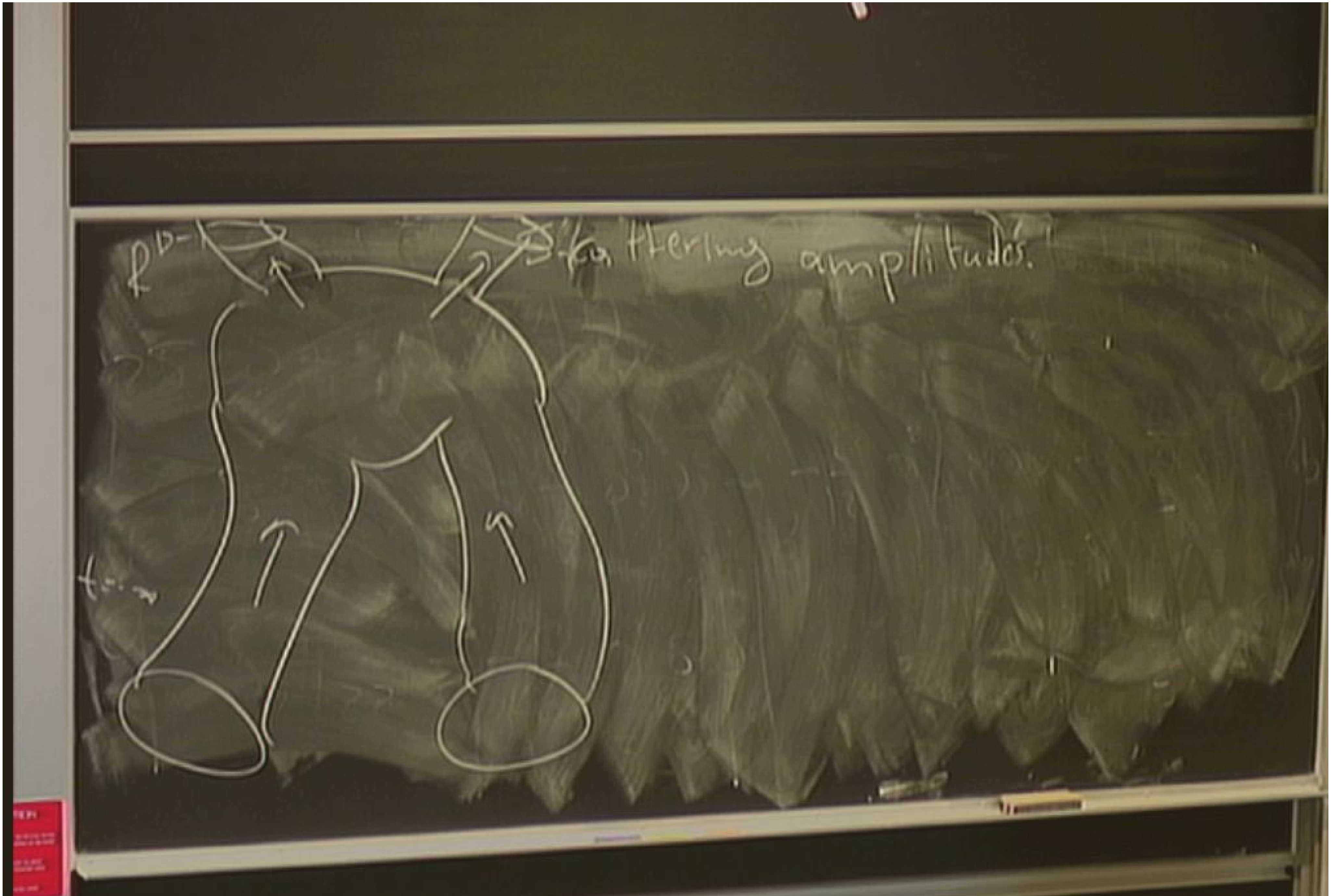
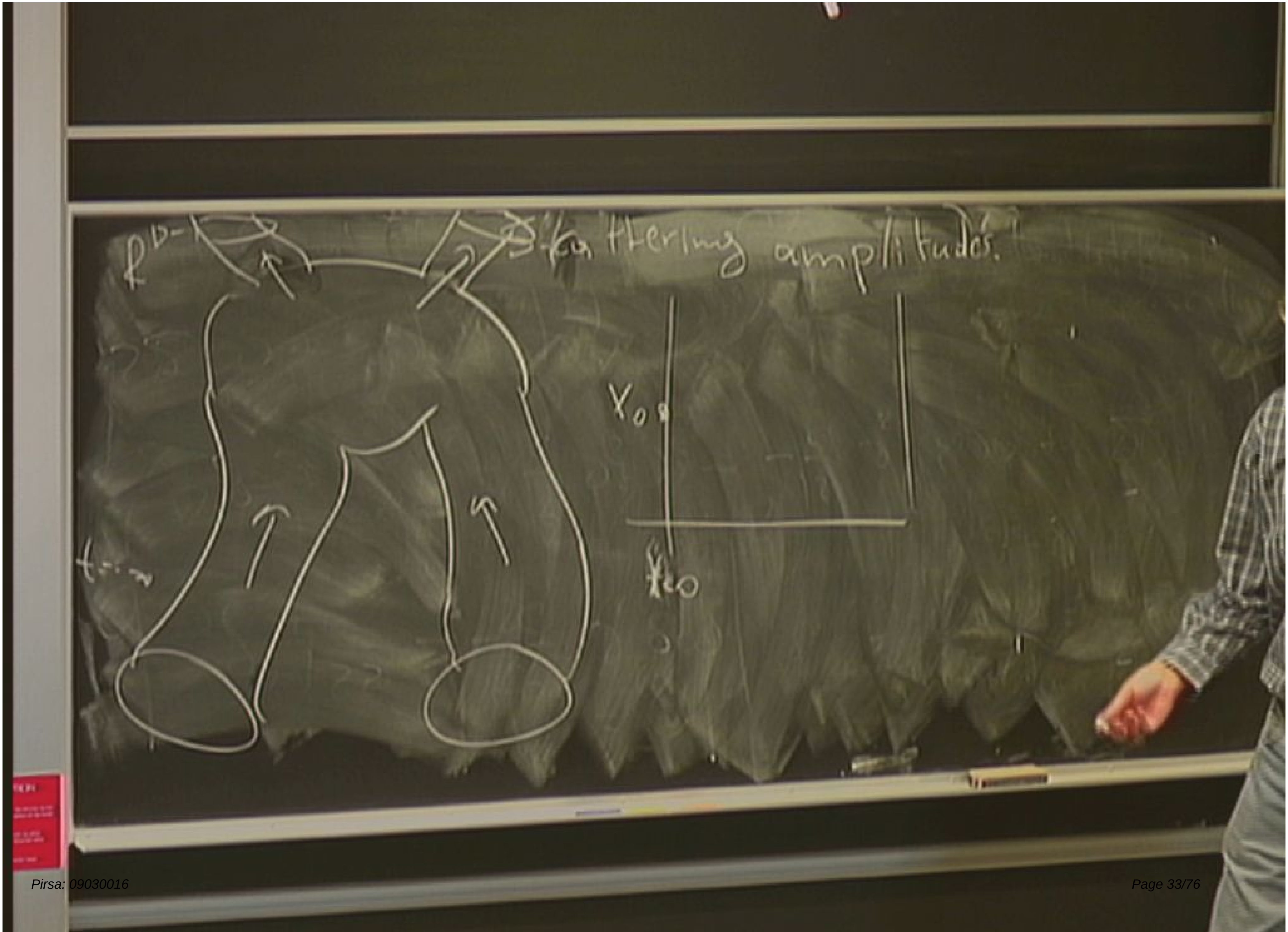
Scattering amplitudes.

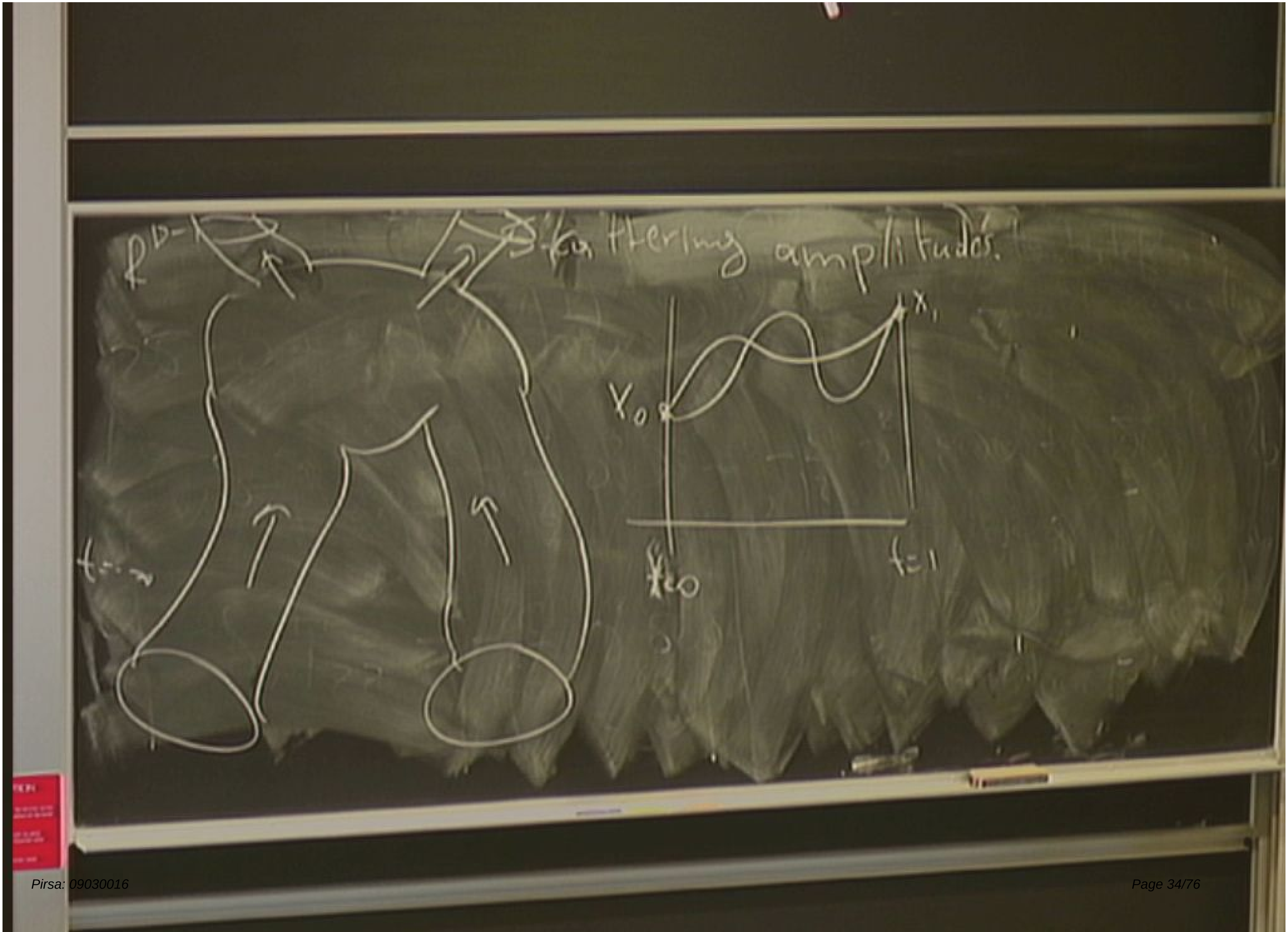
$t = -\infty$

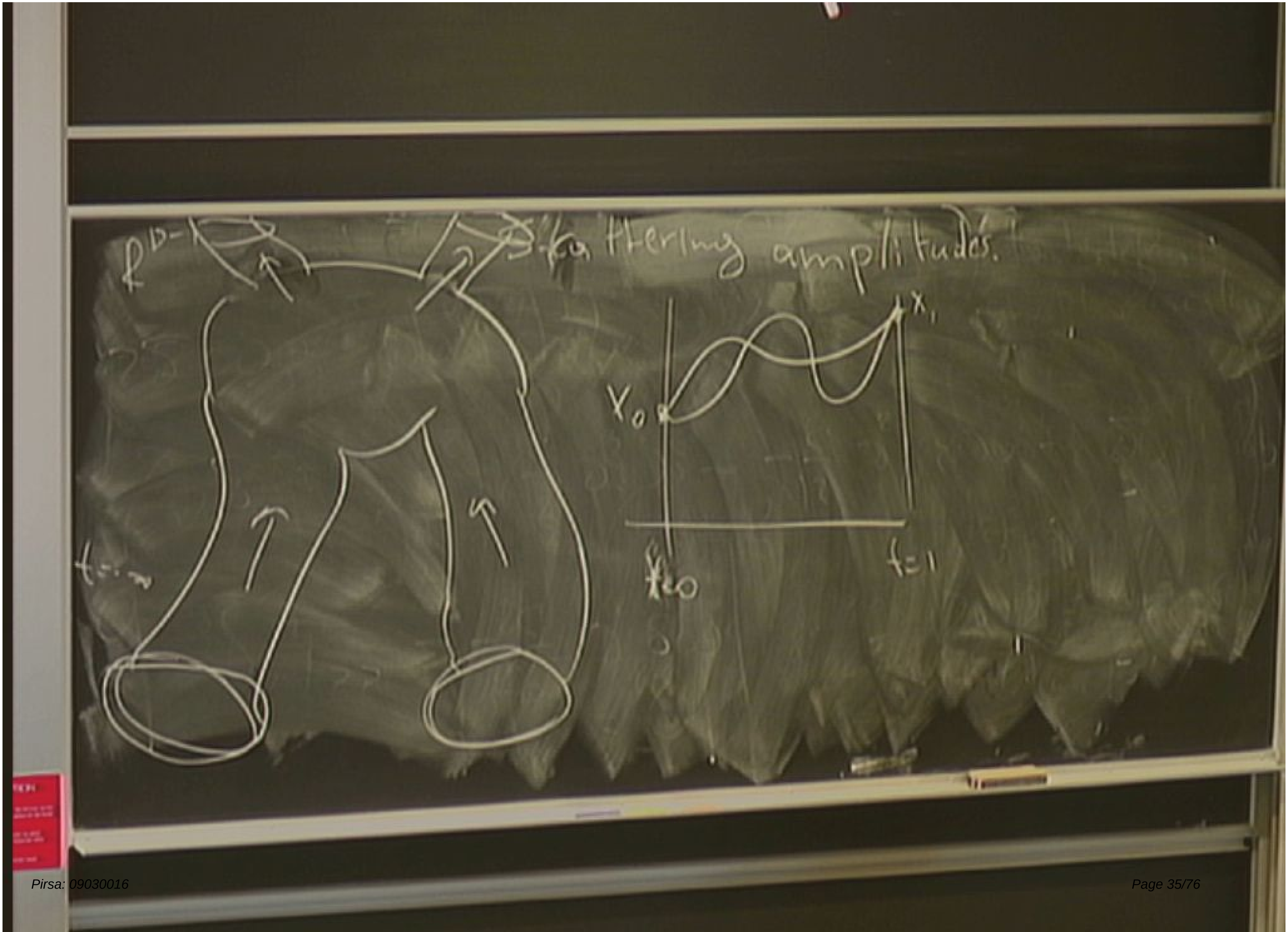

Scattering amplitudes.

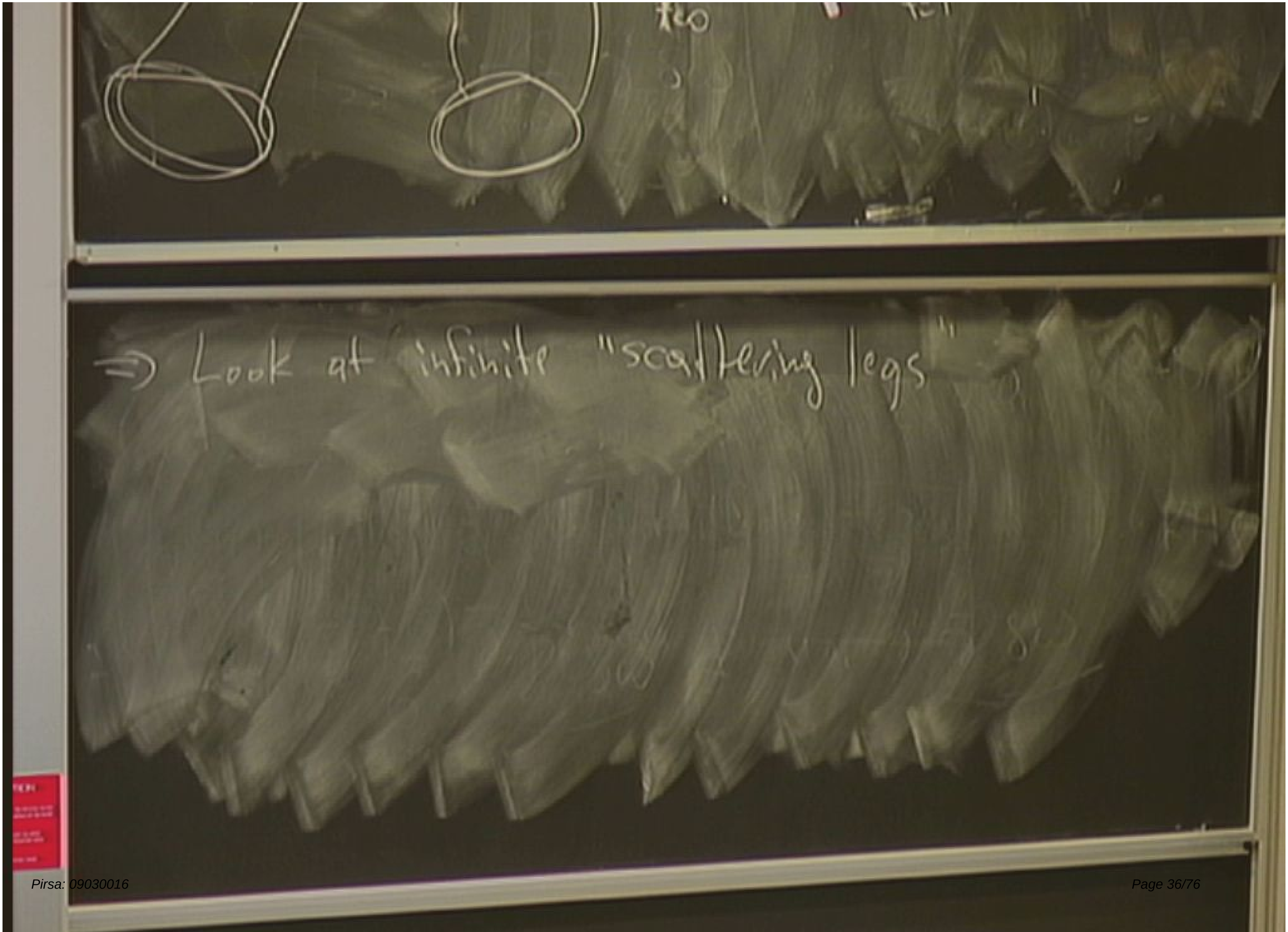

Scattering amplitudes

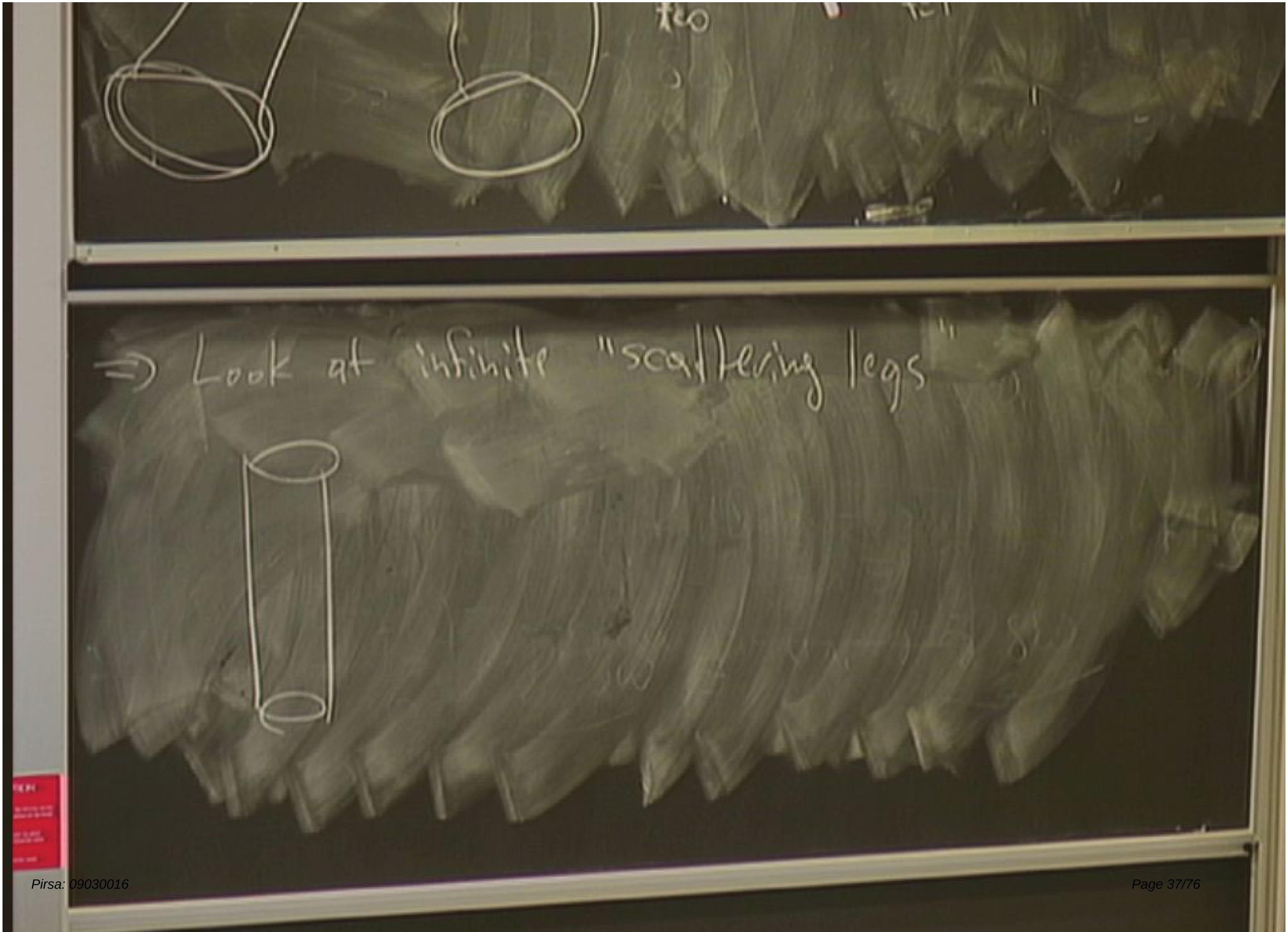

Scattering amplitudes:


Scattering amplitudes.


Scattering amplitudes.
x_1
x_0
$t=0$
$t=1$


Scattering amplitudes
x_0
x_1
t=0
t=1


⇒ Look at infinite "scattering legs"


⇒ Look at infinite "scattering legs"

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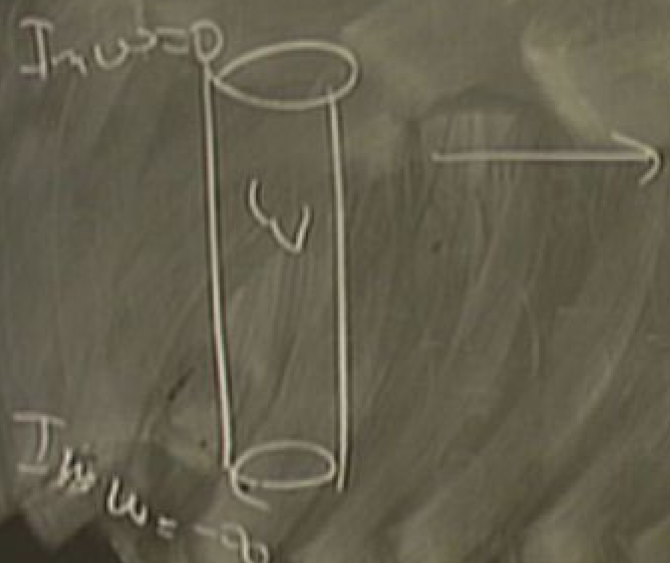
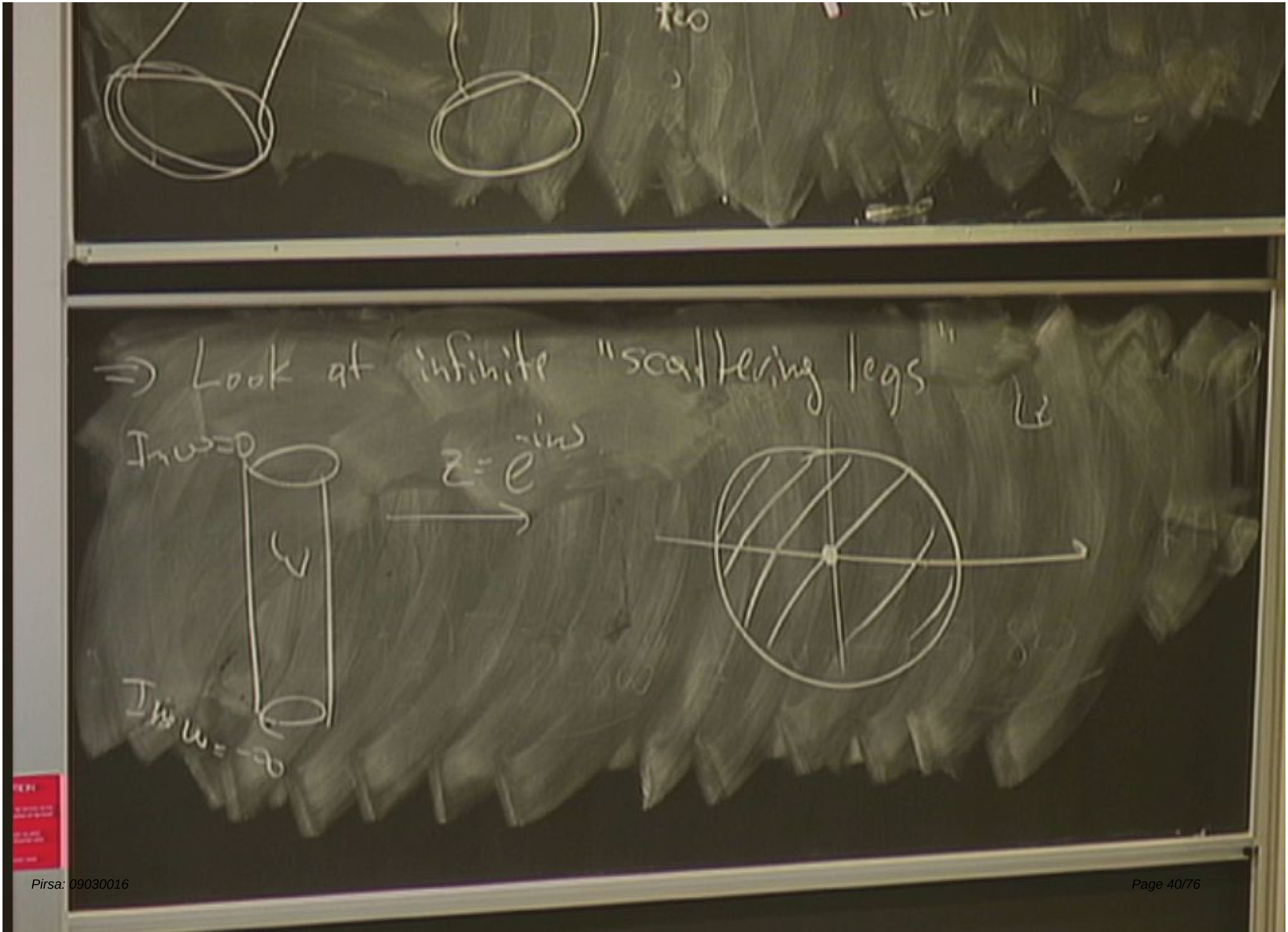
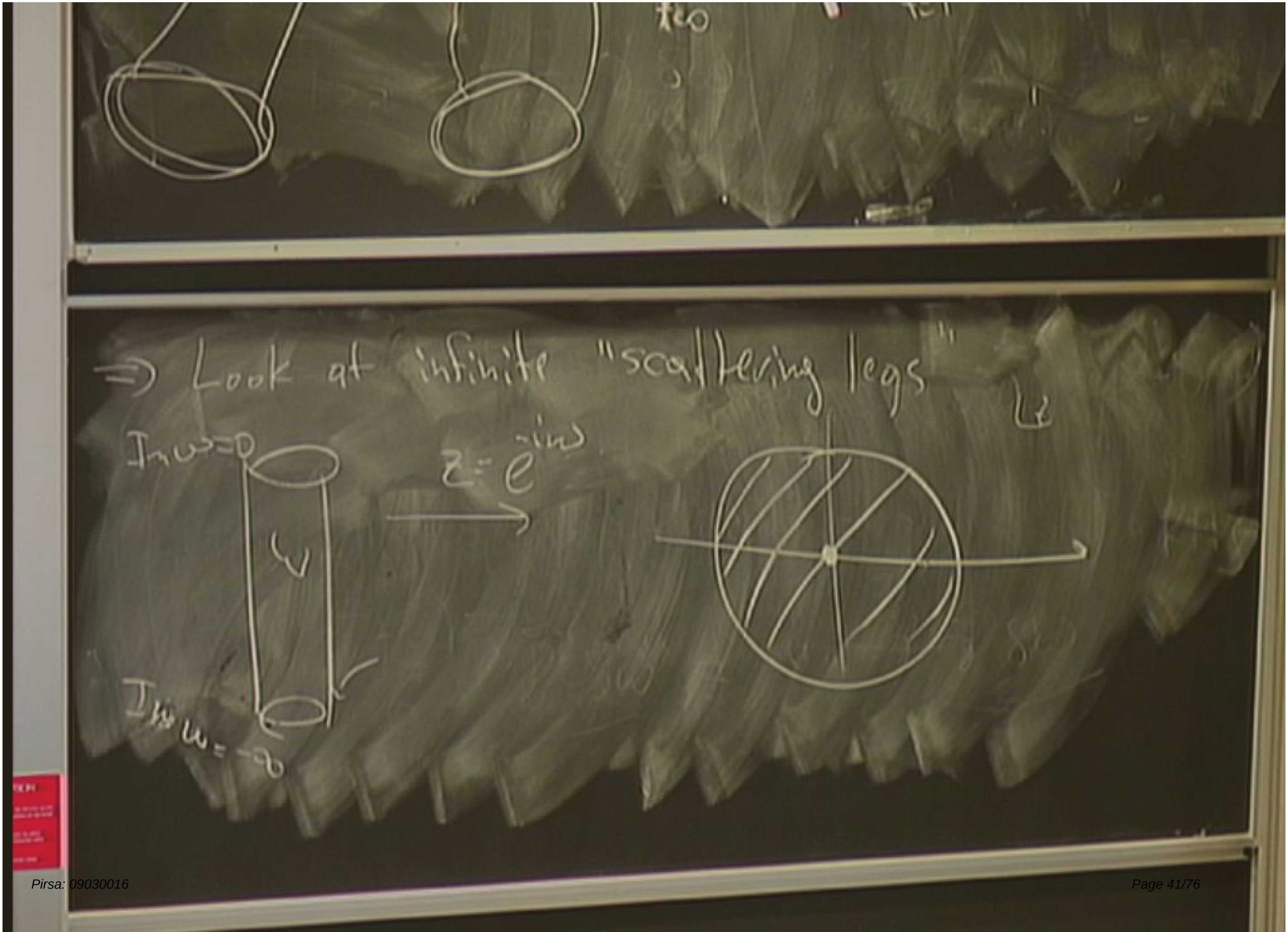
Thus

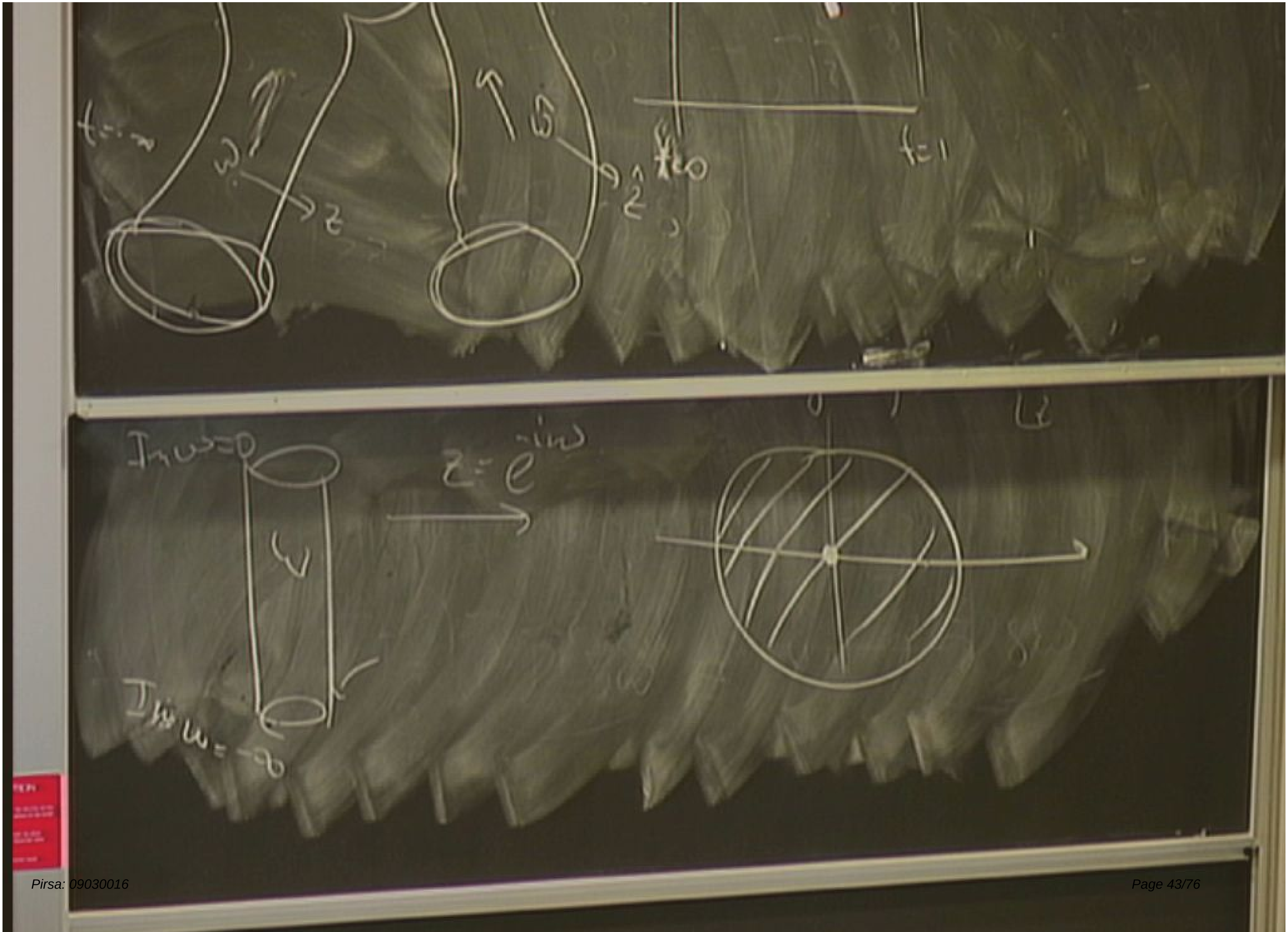
$\Rightarrow$ Look at infinite "scattering legs"

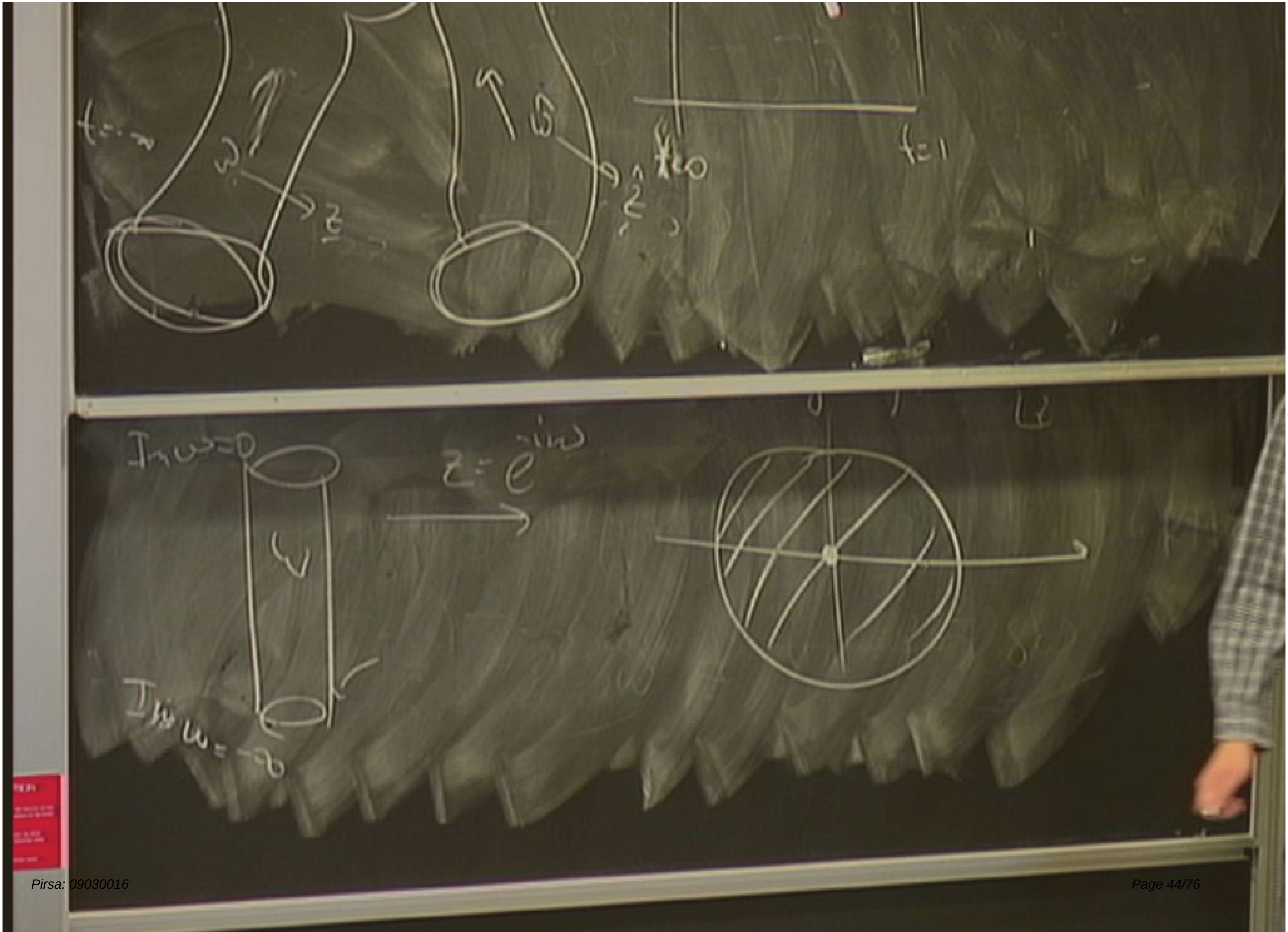


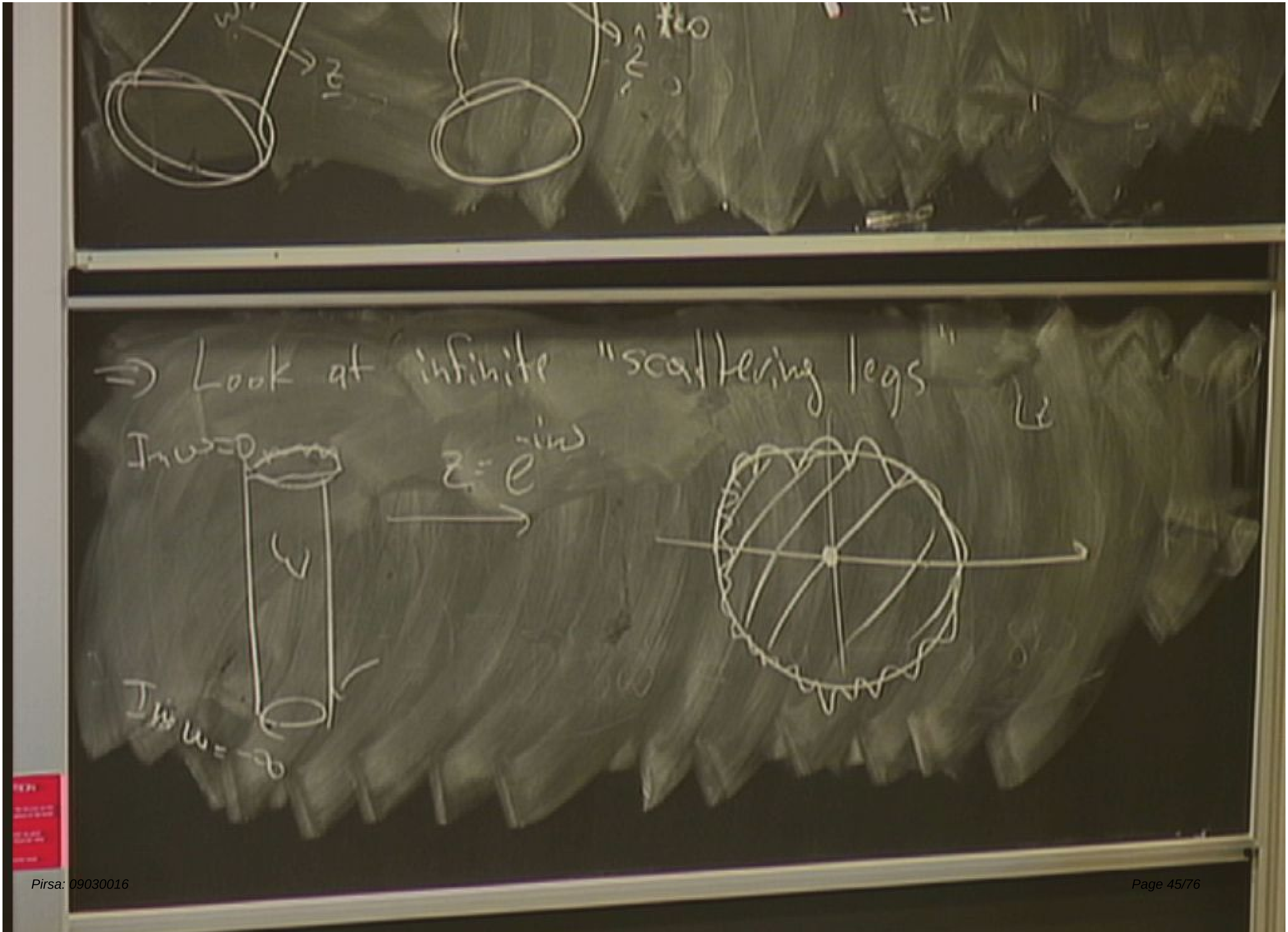

⇒ Look at infinite "scattering legs"
Im w = 0
$z = e^{-iw}$
w
Im w = -∞


⇒ Look at infinite "scattering legs"
Im ω=0
z = e^{-iω}
ω
Im ω = -∞


t=0
t=1
Im w=0
z = e^{-iw}
w
Im w = -∞


t=1
Im w=0
z=e^{-iw}
w
Im w=-∞


t=-∞
w
z
ŵ
ẑ
t=0
t=1
Im w=0
z = e^{-iw}
w
Im w=-∞


⇒ Look at infinite "scattering legs"
Im w = 0
z = e^{-iw}
w
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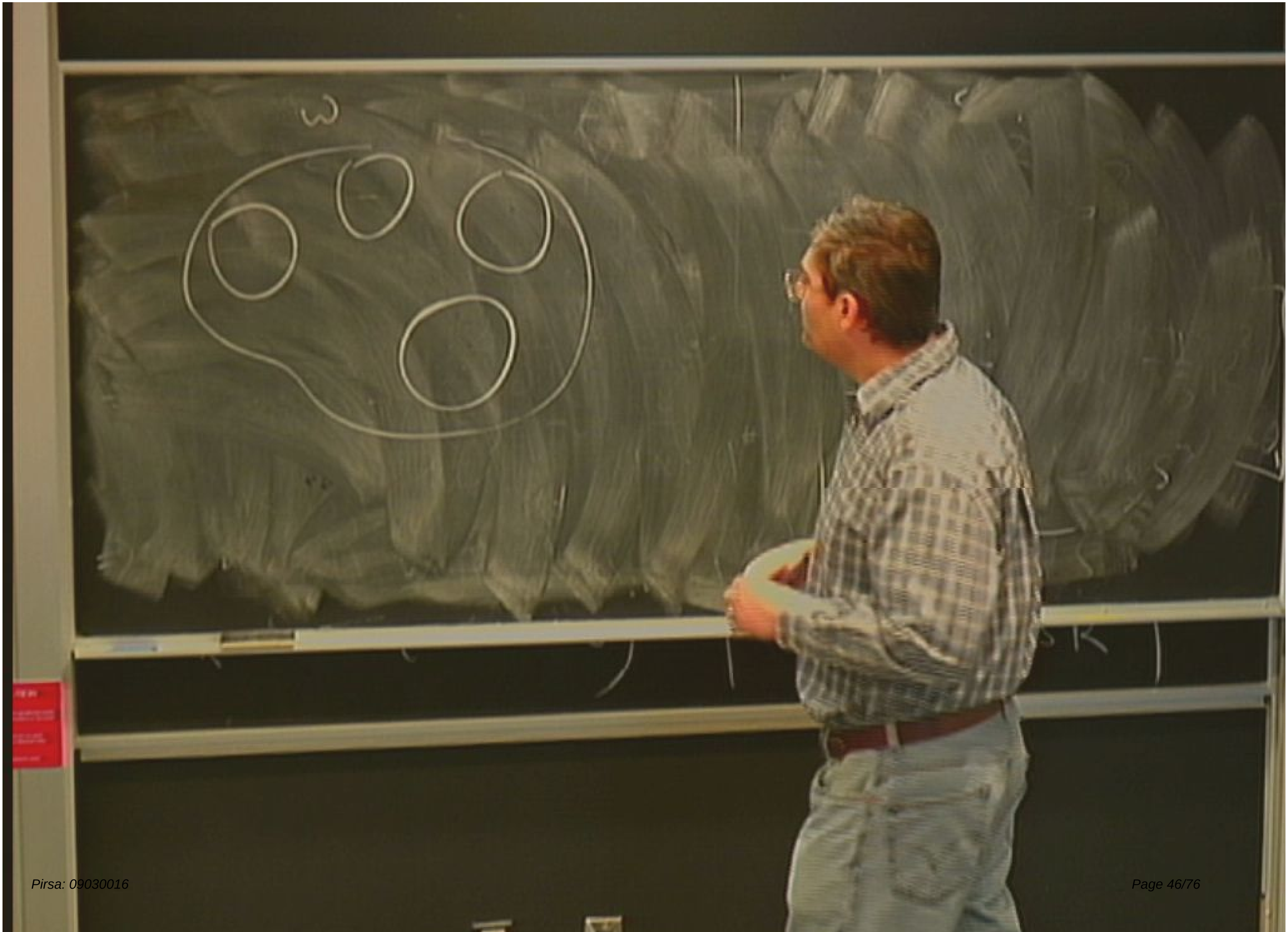
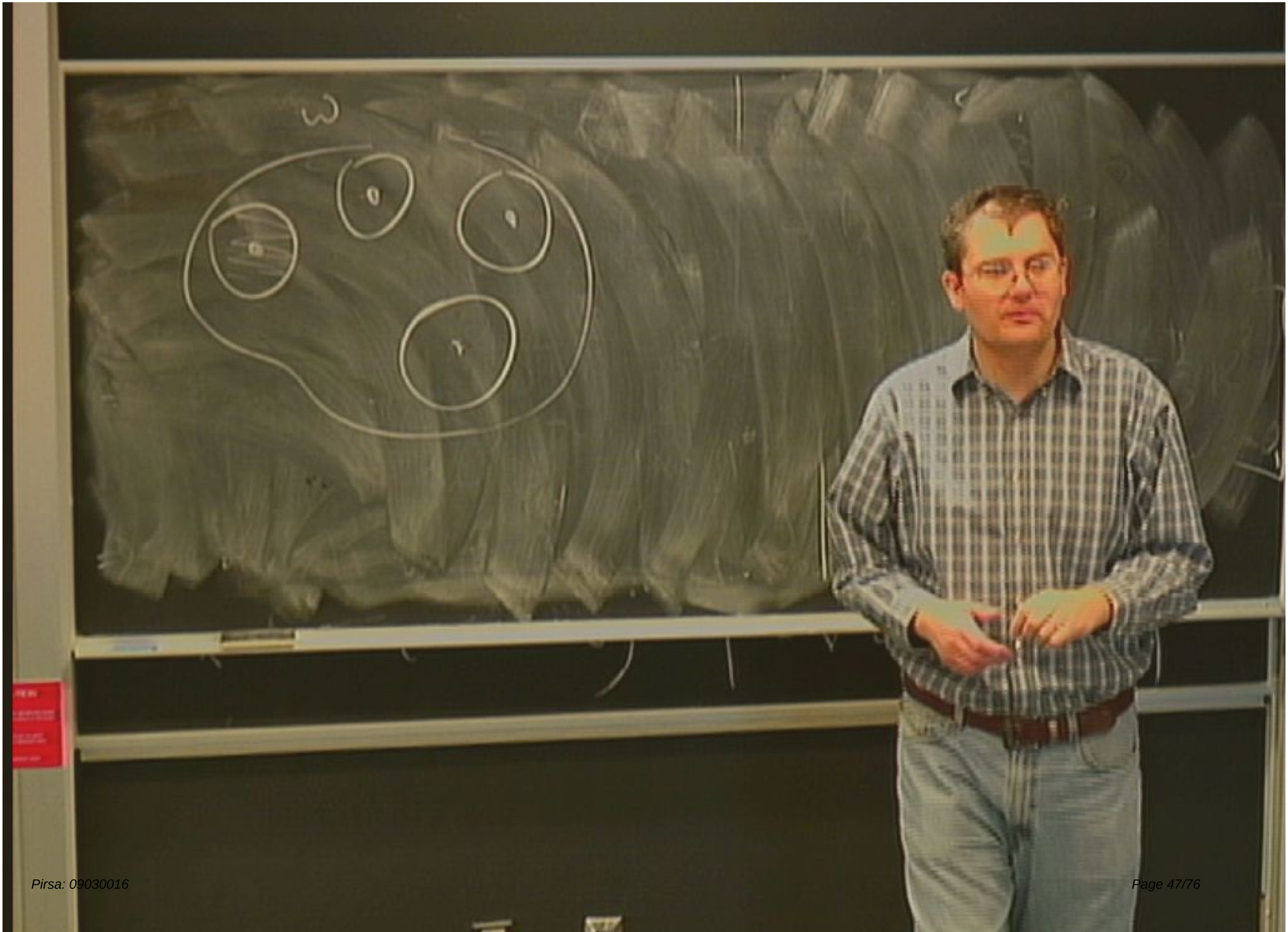
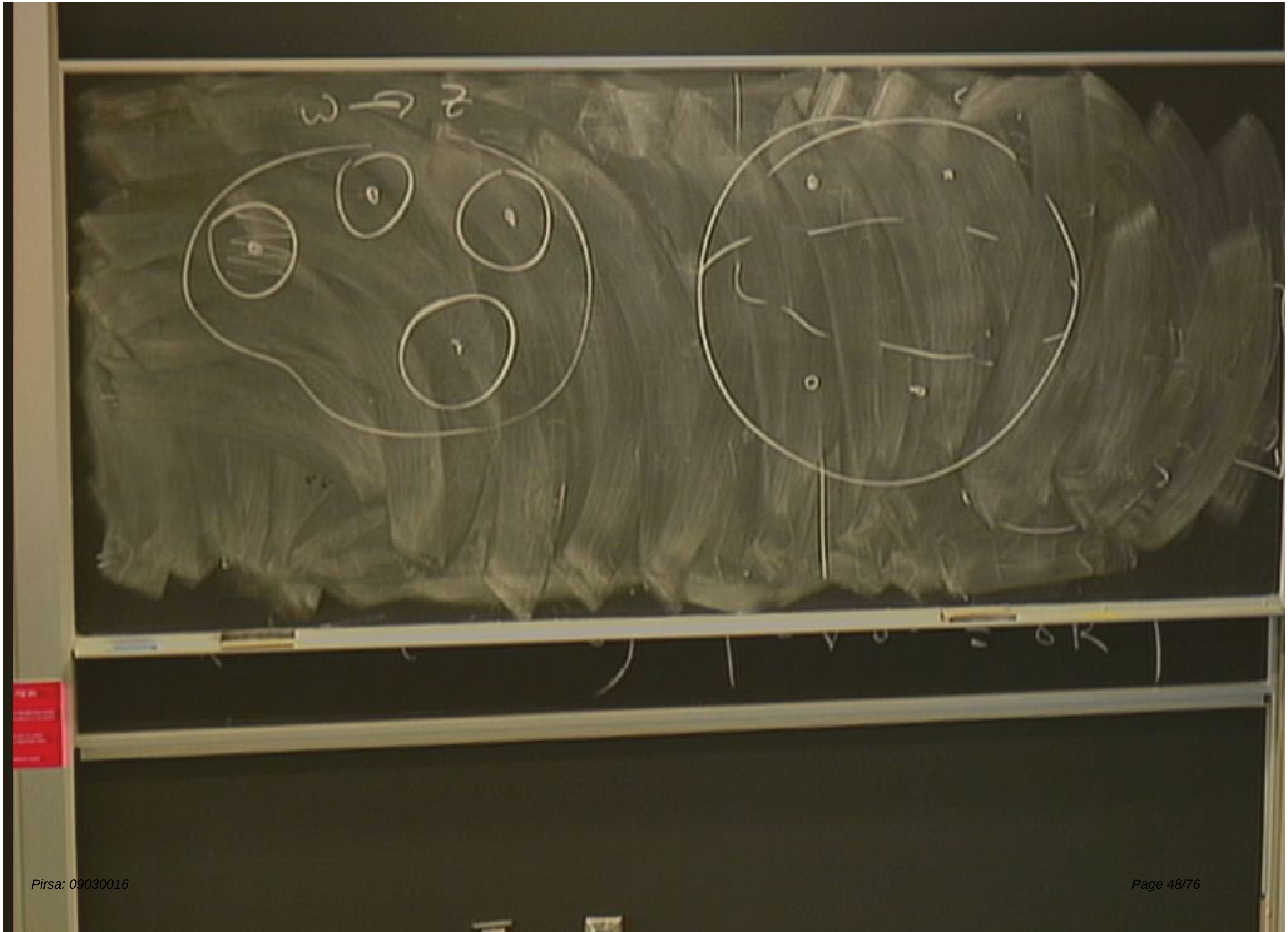
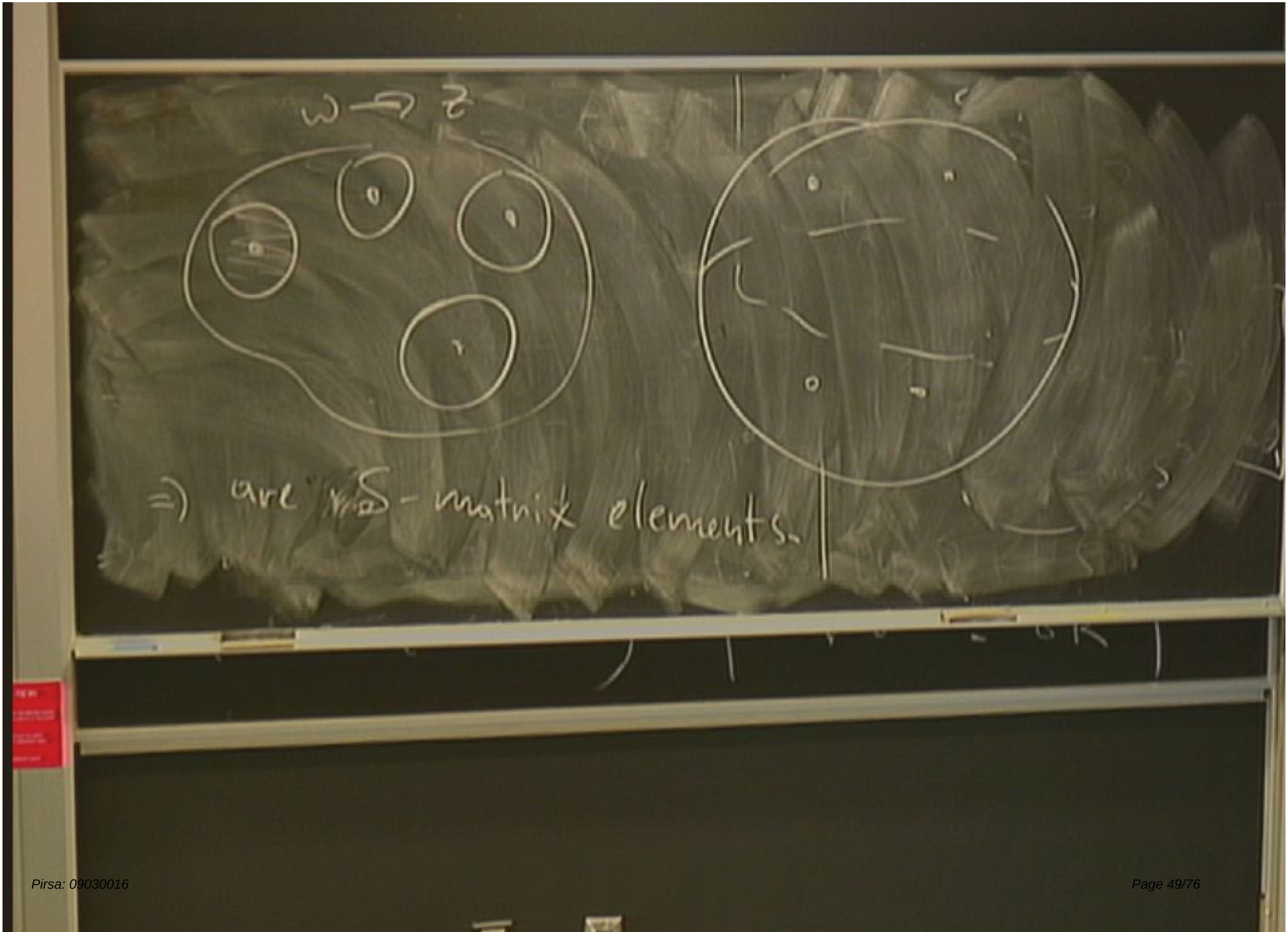
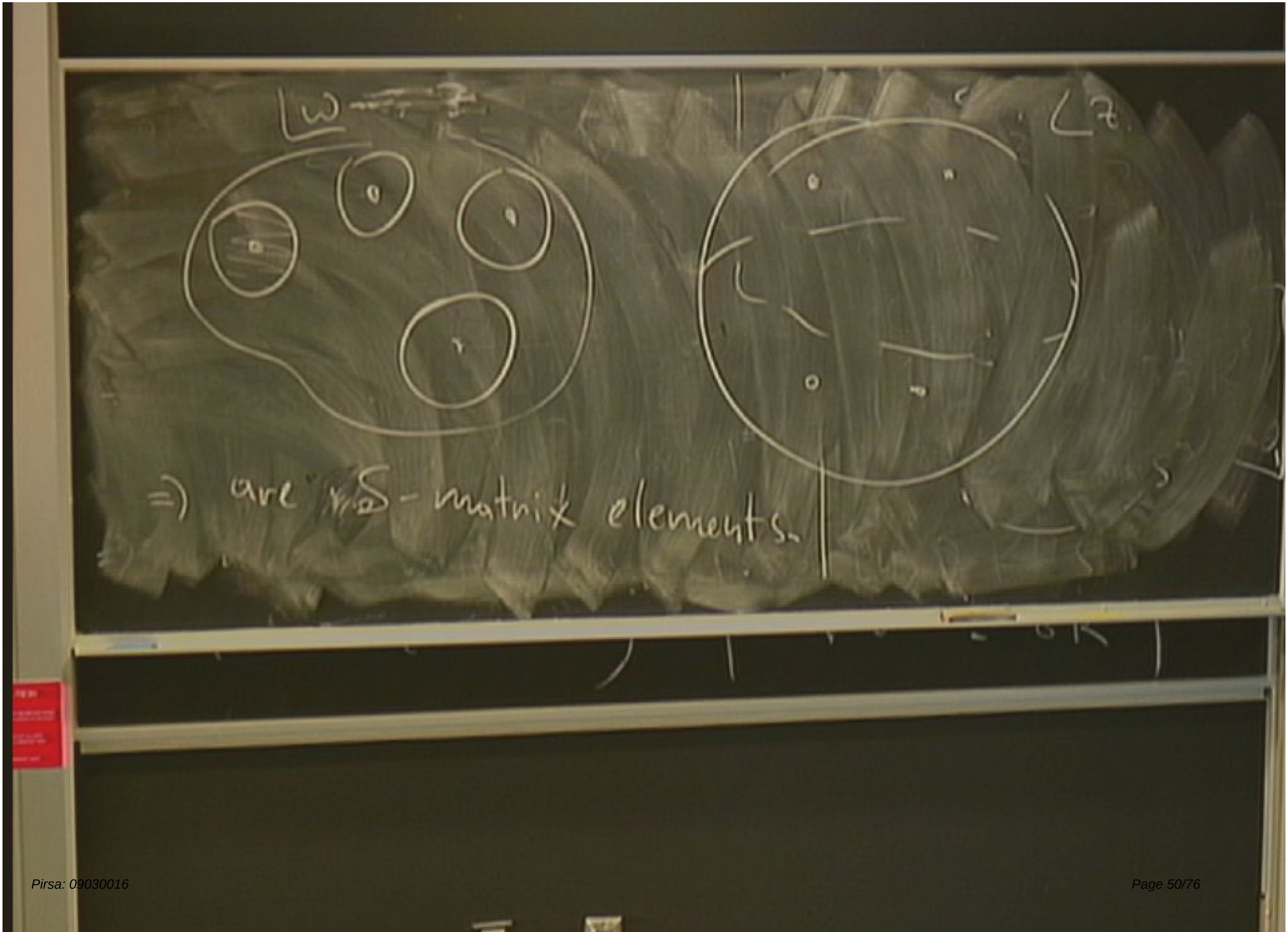




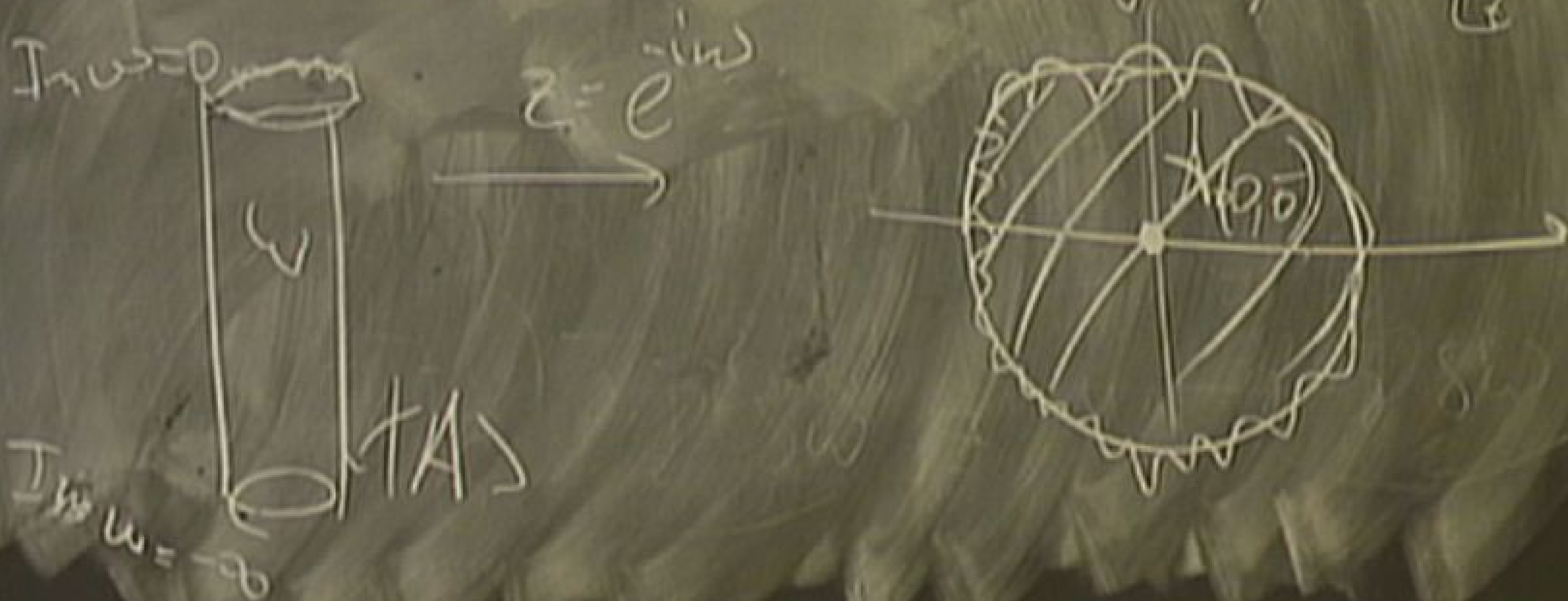


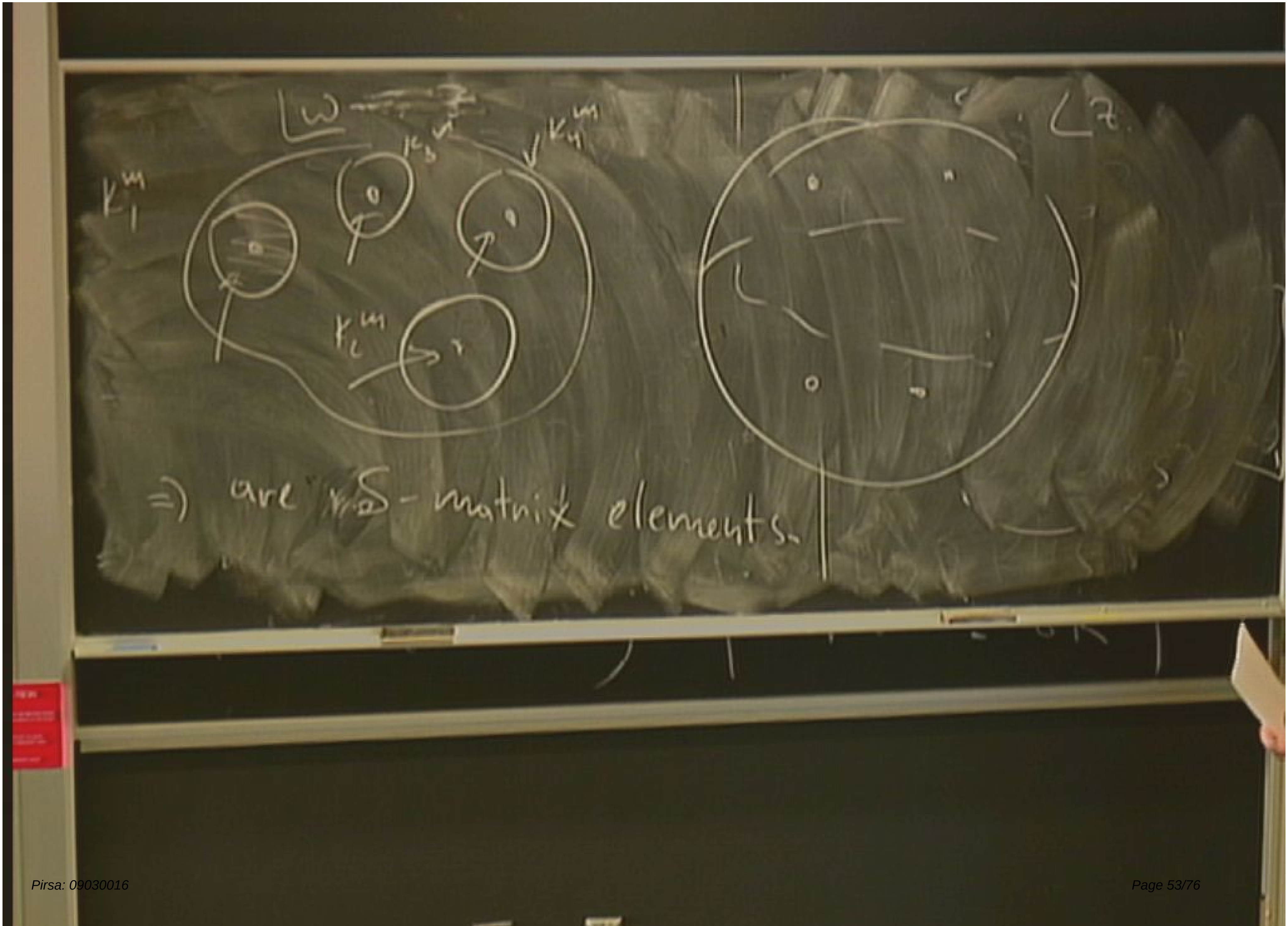

w → z
⇒ are S-matrix elements.


Lw
$\Rightarrow$ are S-matrix elements.


Lw
=) are S-matrix elemen

$\Rightarrow$ Look at infinite "scattering legs"

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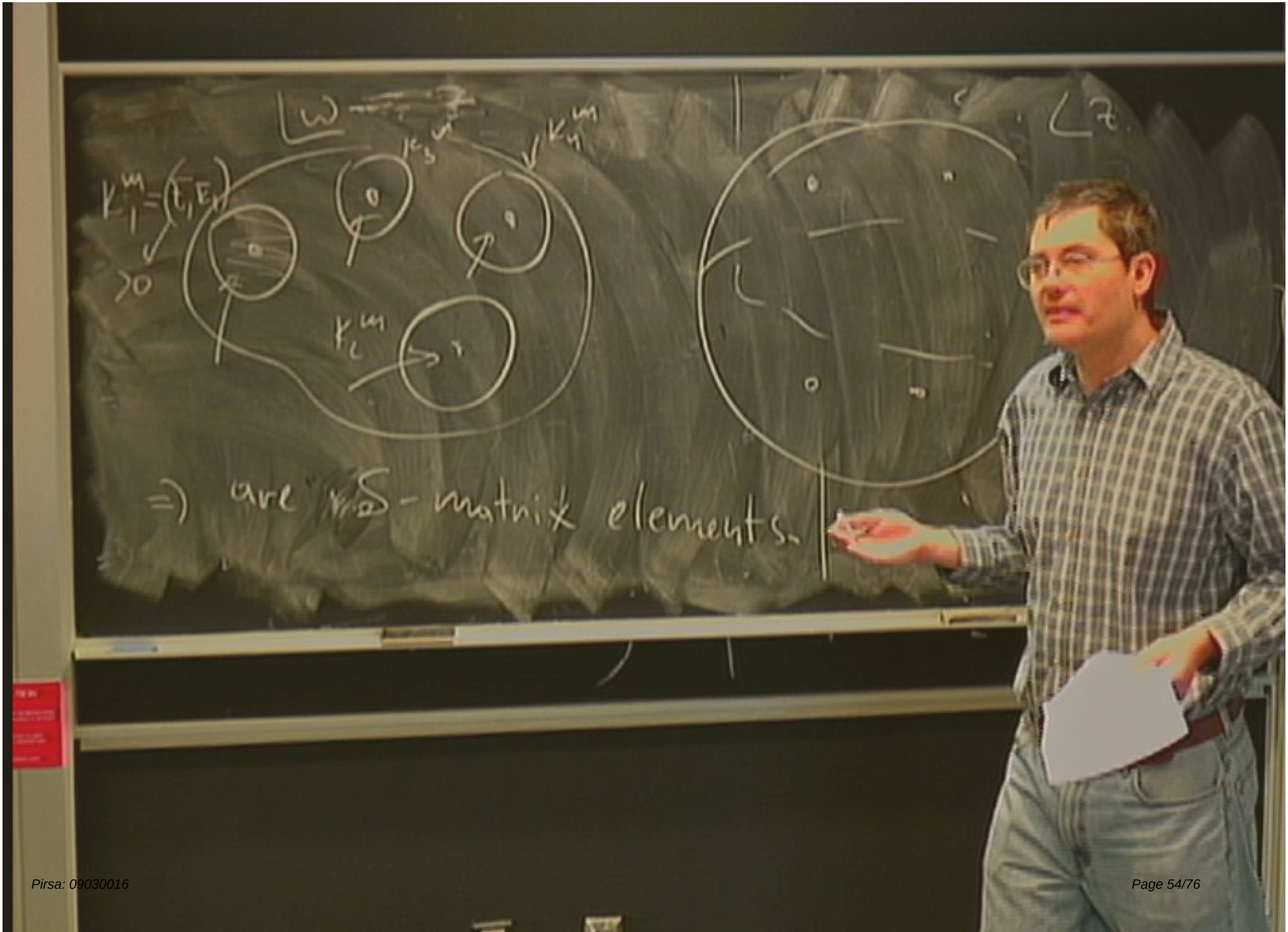
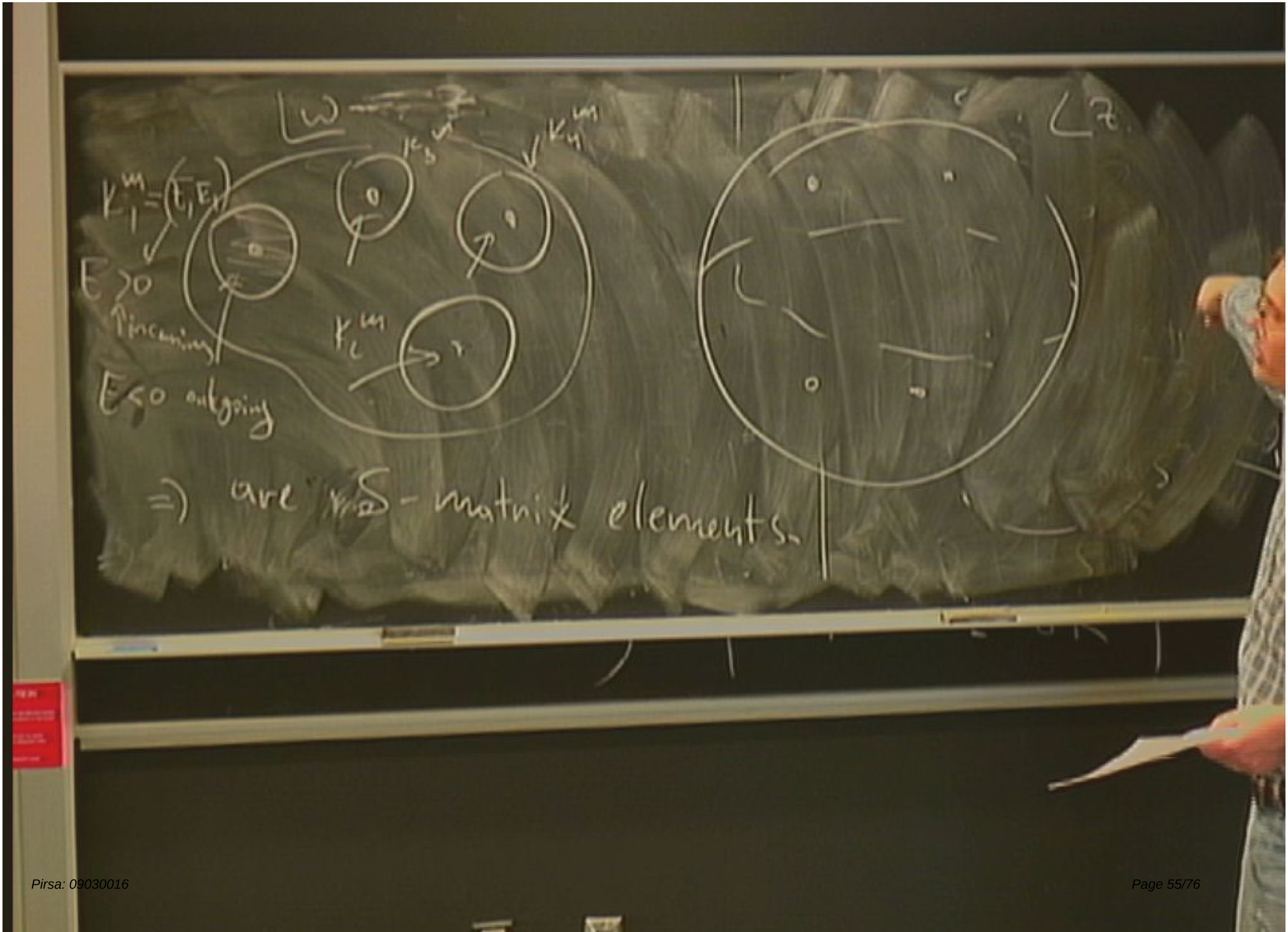
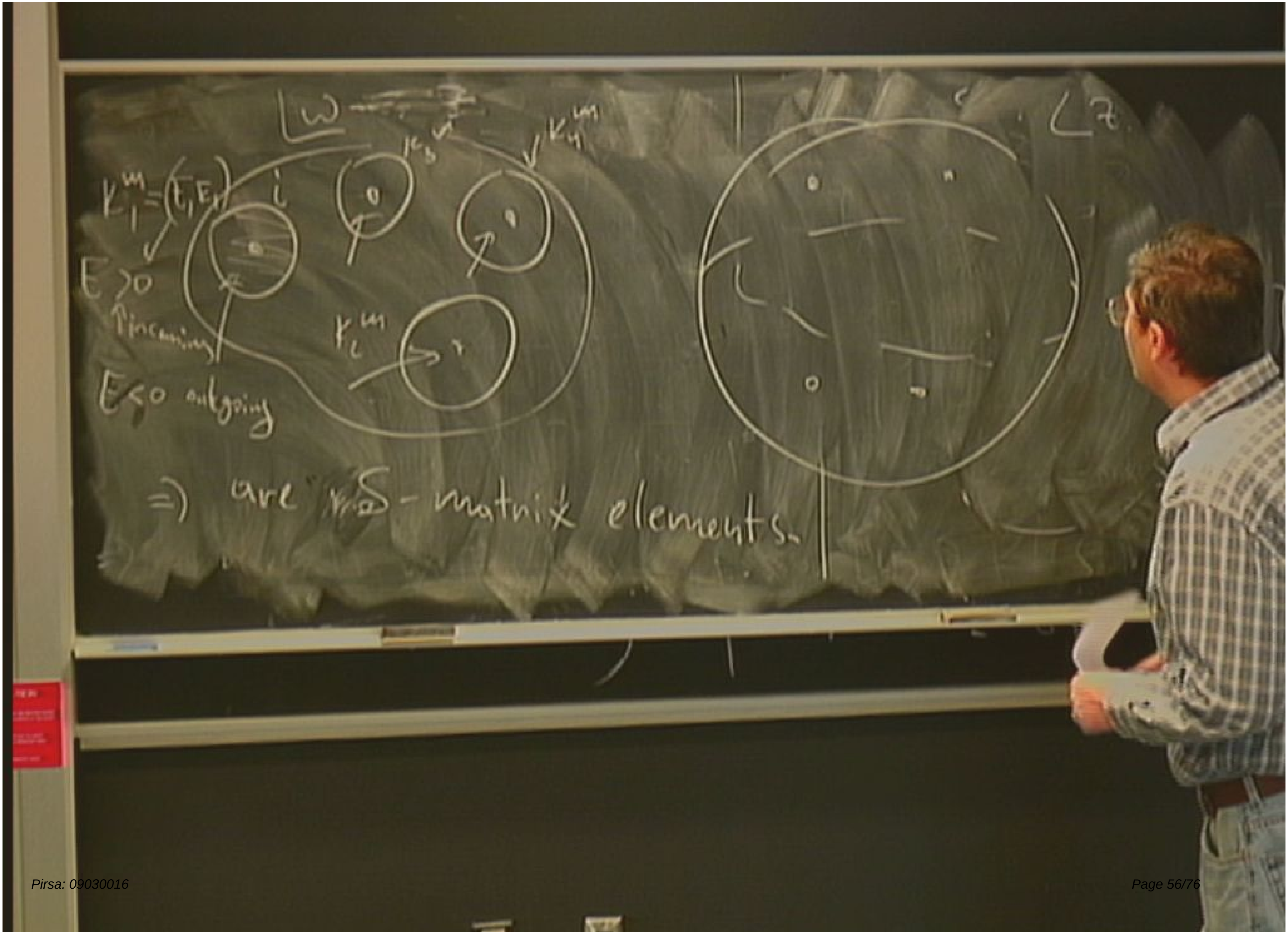
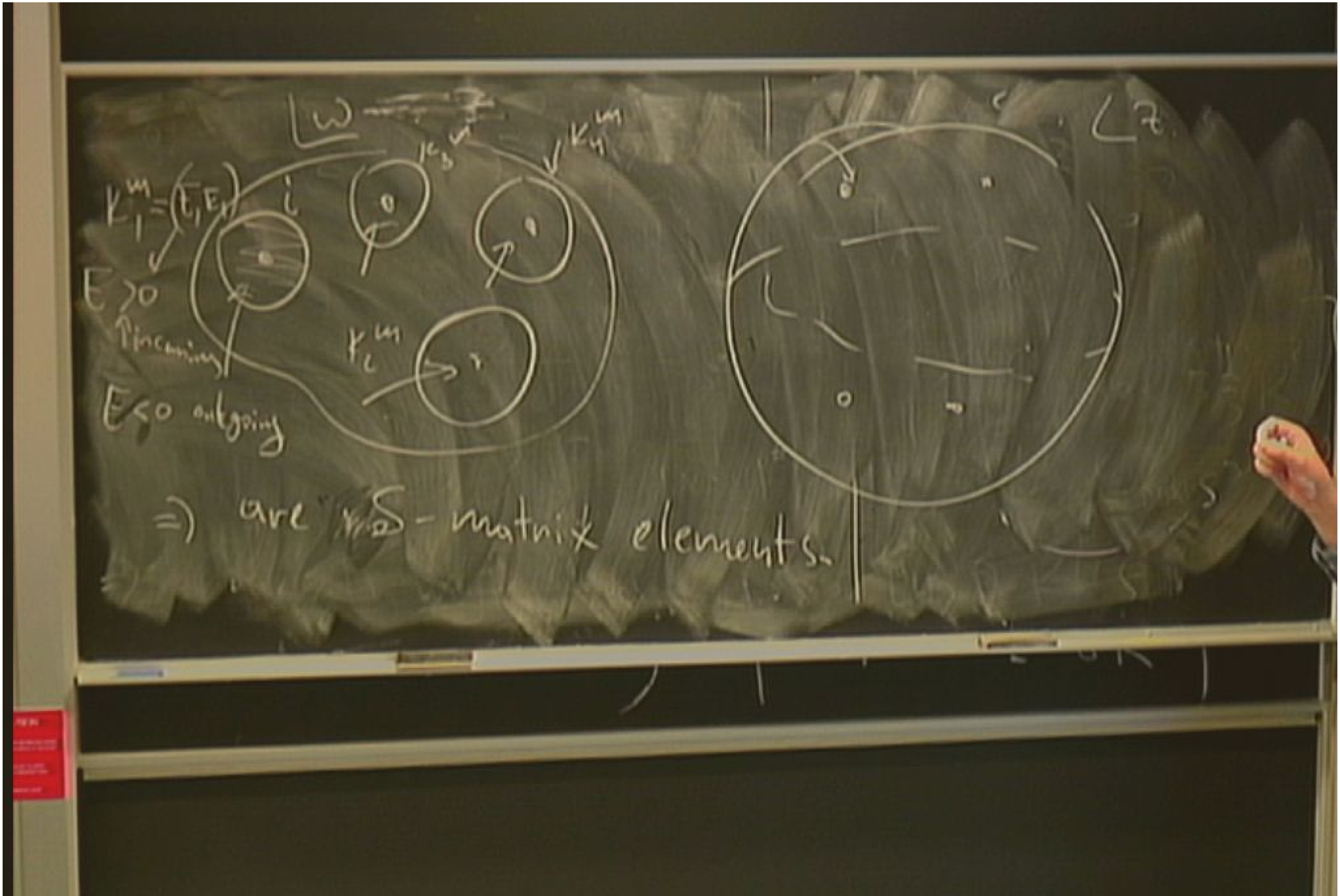
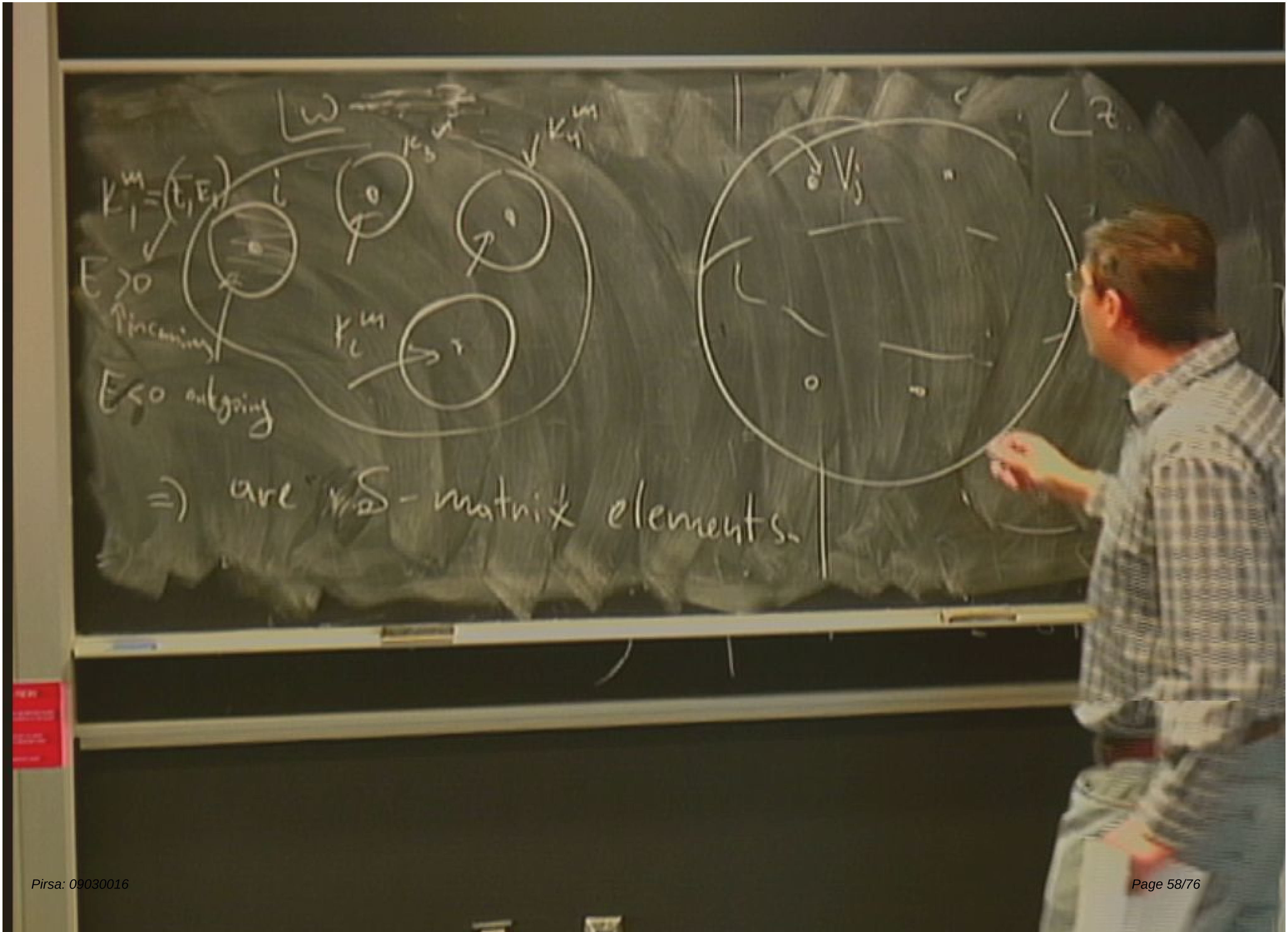

$K_1^{in} = (t_1, E_1)$
>0
K_3^{in}
K_4^{in}
K_L^{in}
⇒ are S-matrix elements.

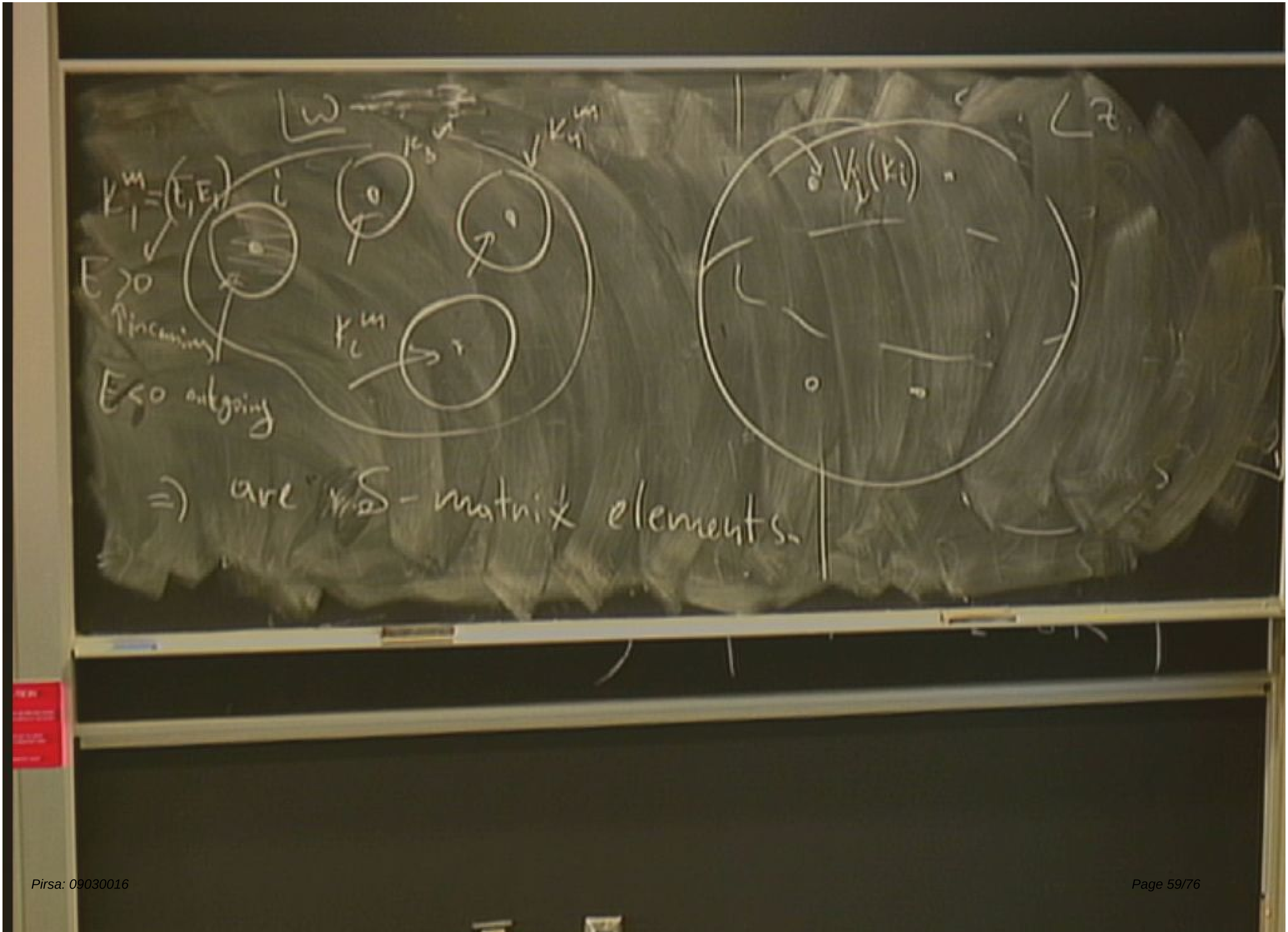


$k_1^{in} = (t_1, E_1)$
$E > 0$
incoming
$E < 0$ outgoing
k_3^{in}
k_4^{in}
k_i^{in}
⇒ are S-matrix elements.


E>0 incoming
E<0 outgoing
are S-matrix elements.


Lω
k_1^in = (t_1, E_1)
E > 0
incoming
E < 0 outgoing
k_2^in
k_3^in
k_4^in
⇒ are S-matrix elements.


LW
K_1^in = (t_1, E_1)
K_i^in
E > 0 incoming
E < 0 outgoing
V_j
⇒ are S-matrix elements.


$k_1^{in} = (t_1, E_1)$
$E > 0$ incoming
$E < 0$ outgoing
k_3^{in}
k_4^{in}
k_L^{in}
$V_L(k_i)$
⇒ are S-matrix elements.

...x elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

...ix elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

$S_{j_1 \cdots j_n}$

... elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-iw}$

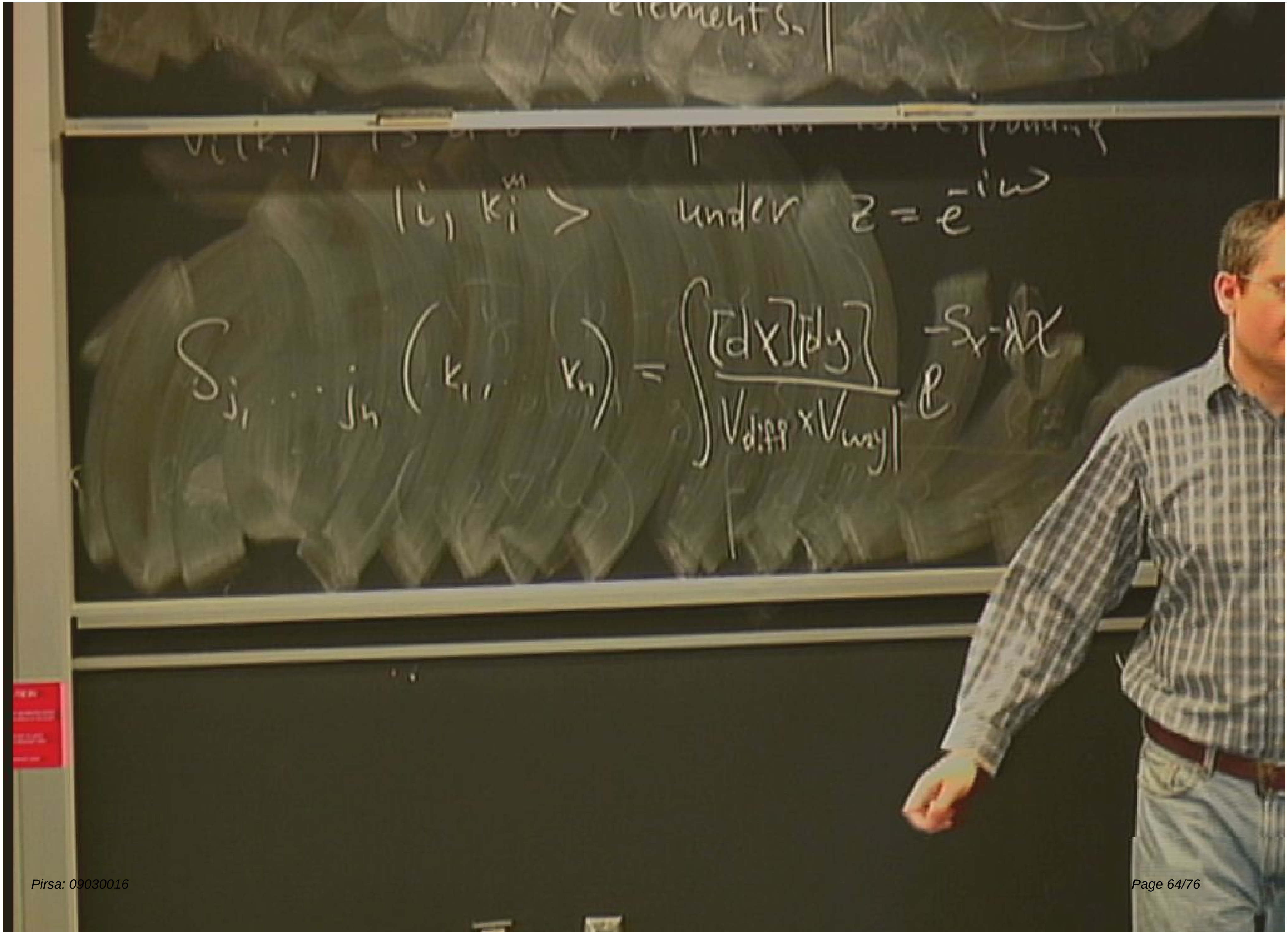
$$S_{j_1 \cdots j_n}(k_1, \ldots k_n) =$$

...matrix elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-iw}$

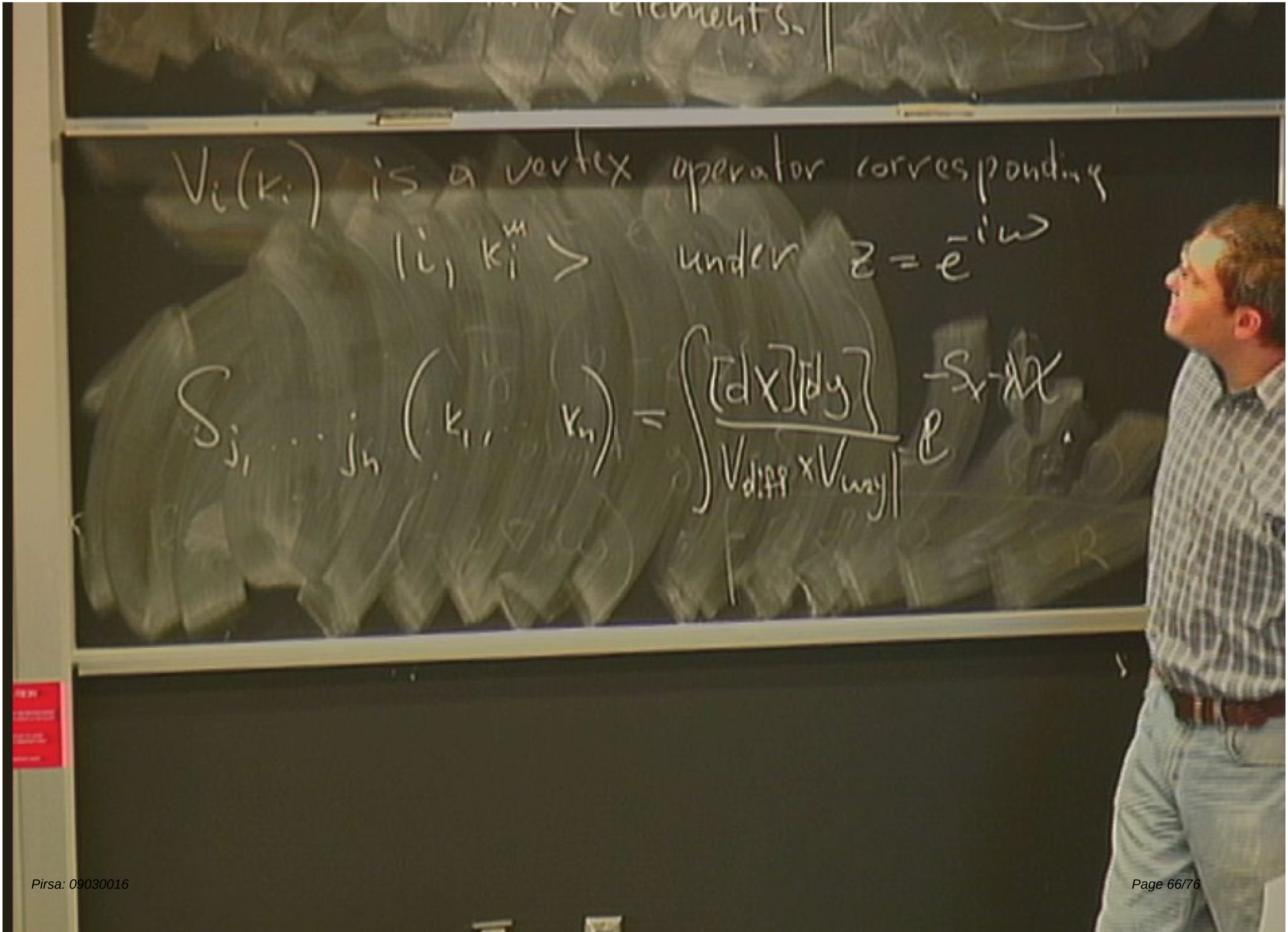
$$S_{j_1 \dots j_n}(k_1, \dots k_n) = \int [dx][dy]$$


|i, k_i^m > under z = e^{-iw}
S_{j_1 ... j_n} (k_1, ... k_n) = ∫ [dx][dy] / |V_diff × V_wey| e^{-S_T - λχ}

...x elements.

$V_i(k_i)$ is a vertex operator corresponding
$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

$$S_{j_1 \ldots j_n}(k_1, \ldots k_n) = \int \frac{[dx][dy]}{|V_{diff} \times V_{wey}|} e^{-S_r - \lambda\chi}$$


Vi(ki) is a vertex operator corresponding
|i, ki^m > under z = e^{-iw}
Sj1 ... jn (k1, ... kn) = ∫ [dX][dy] / |Vdiff x Vweyl| e^{-Sx-λχ}

matrix elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

$$S_{j_1 \dots j_n}(k_1, \dots k_n) = \int \frac{[dX][dy]}{|V_{diff} \times V_{weyl}|} e^{-S_r - \lambda\chi}$$

... ix elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

$$S_{j_1 \dots j_n}(k_1, \dots k_n) = \int \frac{[dx][dy]}{V_{diff} \times V_{w\!z\!y}} e^{-S_x - \lambda\chi} \cdot \int d^2\sigma_i$$

...x elements.

$V_i(k_i)$ is a vertex operator corresponding

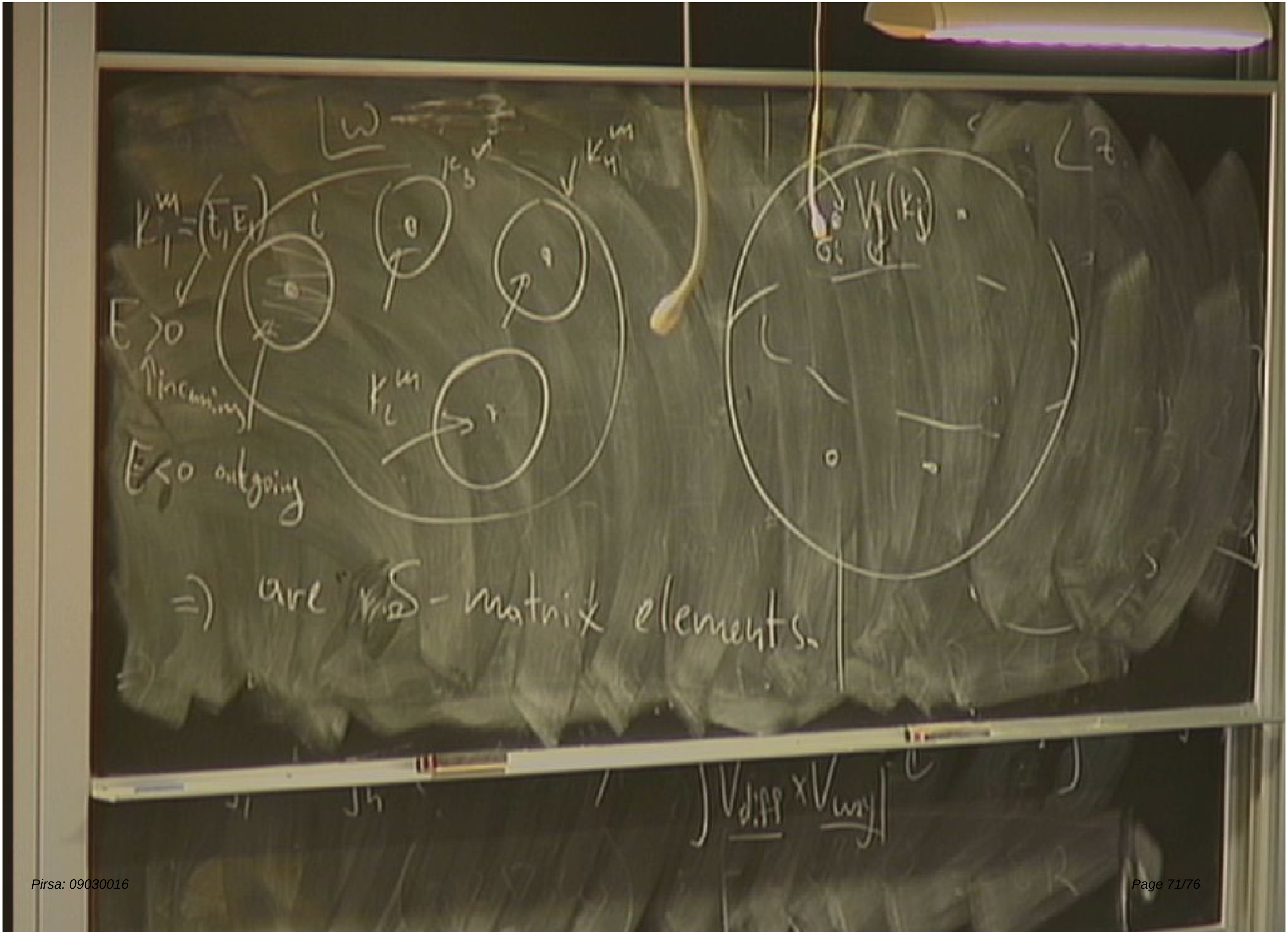
$|i, k_i^m\rangle$ under $z = e^{-iw}$

$$S_{j_1 \cdots j_n}(k_1, \ldots, k_n) = \int \frac{[dX][dg]}{V_{\underline{diff}} \times V_{\underline{weyl}}} e^{-S_X - \lambda\chi} \cdot \int d^2\sigma_i \sqrt{g}(\sigma_i)$$

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-i\omega}$

$$S_{j_1 \cdots j_n}(k_1, \ldots k_n) = \int \frac{[dX][dy]}{|V_{\text{diff}} \times V_{\text{weyl}}|} e^{-S_X - \lambda\chi} \cdot \int d^2\sigma_i \sqrt{g(\sigma_i)}\, V_j(k_i; \sigma_i)$$


LW
K1in = (t1, E1)
i
K3in
K4in
E > 0 incoming
E < 0 outgoing
K2in
⇒ are S-matrix elements.
LZ
Vj(kj)
∫ Vdiff × Vweyl

matrix elements.

$V_i(k_i)$ is a vertex operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-iw}$

$$S_{j_1 \ldots j_n}(k_1, \ldots k_n) = \int \frac{[dx][dy]}{V_{diff} \times V_{wey}} e^{-S_r - \lambda\chi} \prod_j \int d^2\sigma_j \sqrt{g(\sigma_j)}\, V_j(k_j, \sigma_j)$$

... matrix elements.

$V_i(k_i)$ is a ... operator corresponding

$|i, k_i^m\rangle$ under $z = e^{-iw}$

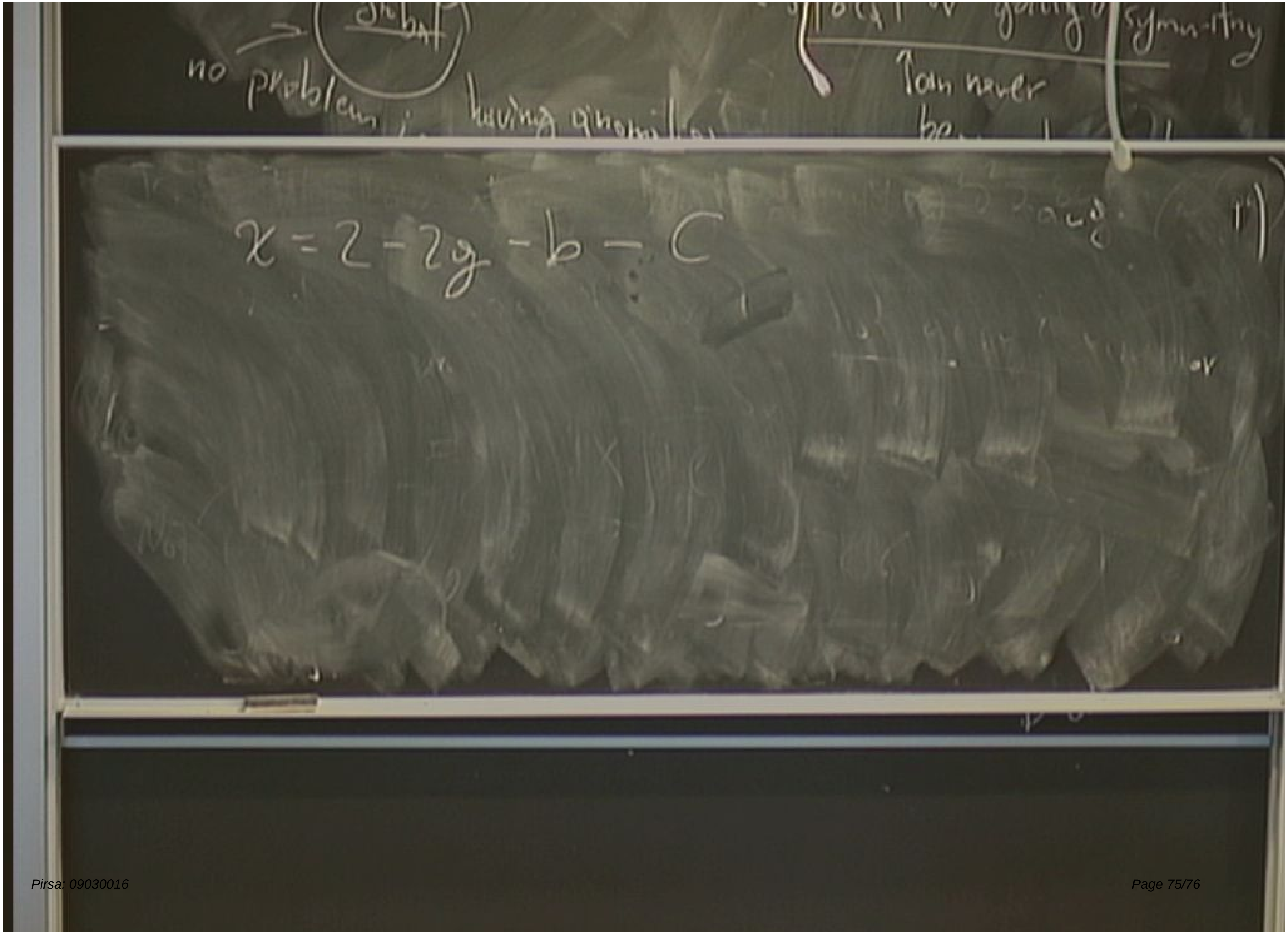
$$S_{j_1 \ldots j_n}(k_1, \ldots k_n) = \int \frac{[dx][dy]}{[V_{diff} \times V_{weyl}]} e^{-S_r - \lambda\chi} \prod_j \int d^2\sigma_j \sqrt{g(\sigma_j)}\, V_j(k_j;\sigma_j)$$

symmetry

no problem in having anomaly

can never be

$x =$


symmetry
no problem
can never
x = 2 − 2g − b − c

no problem having

symmetry

can never be

$$x = 2 - 2g - b - c$$