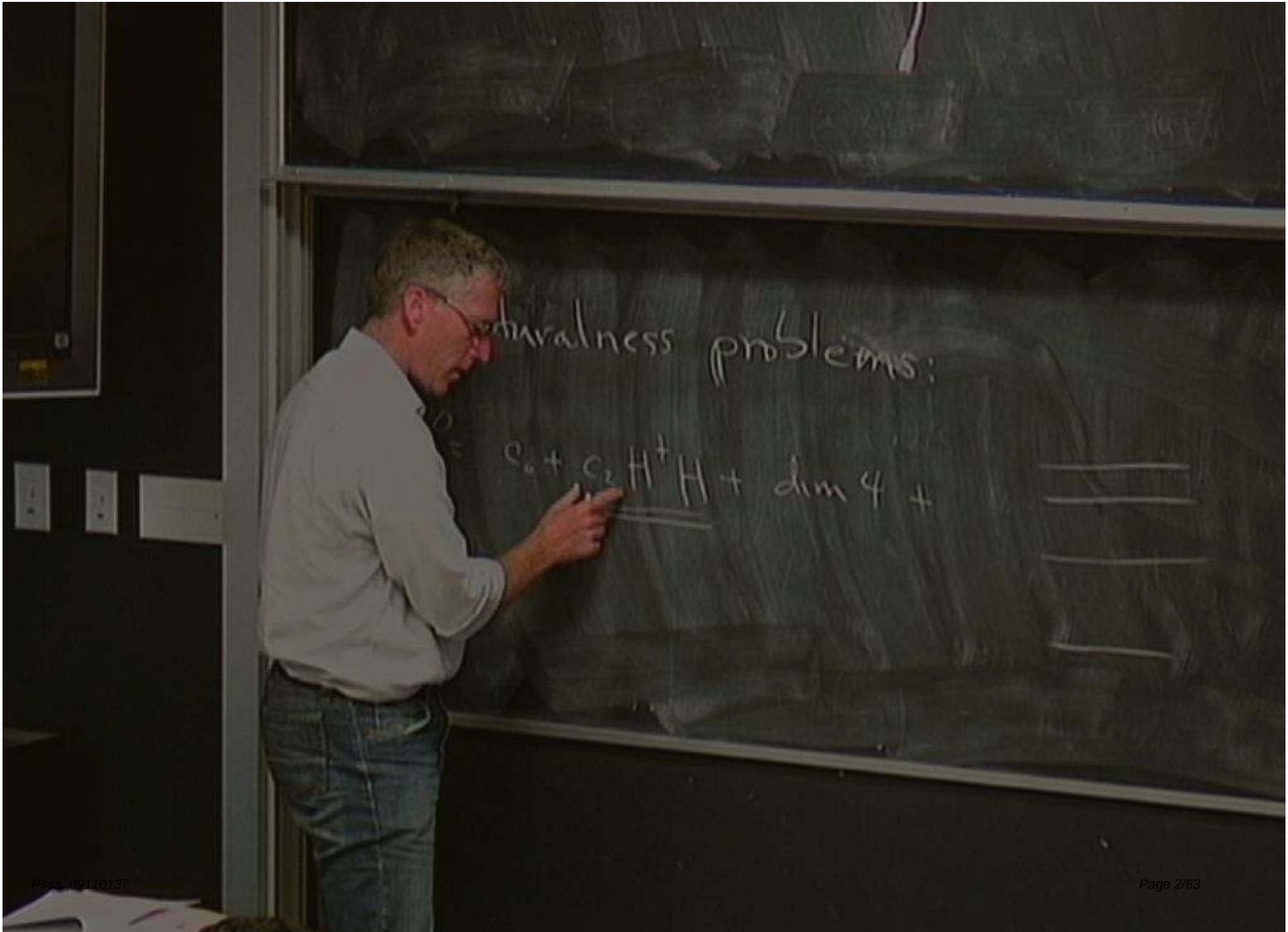
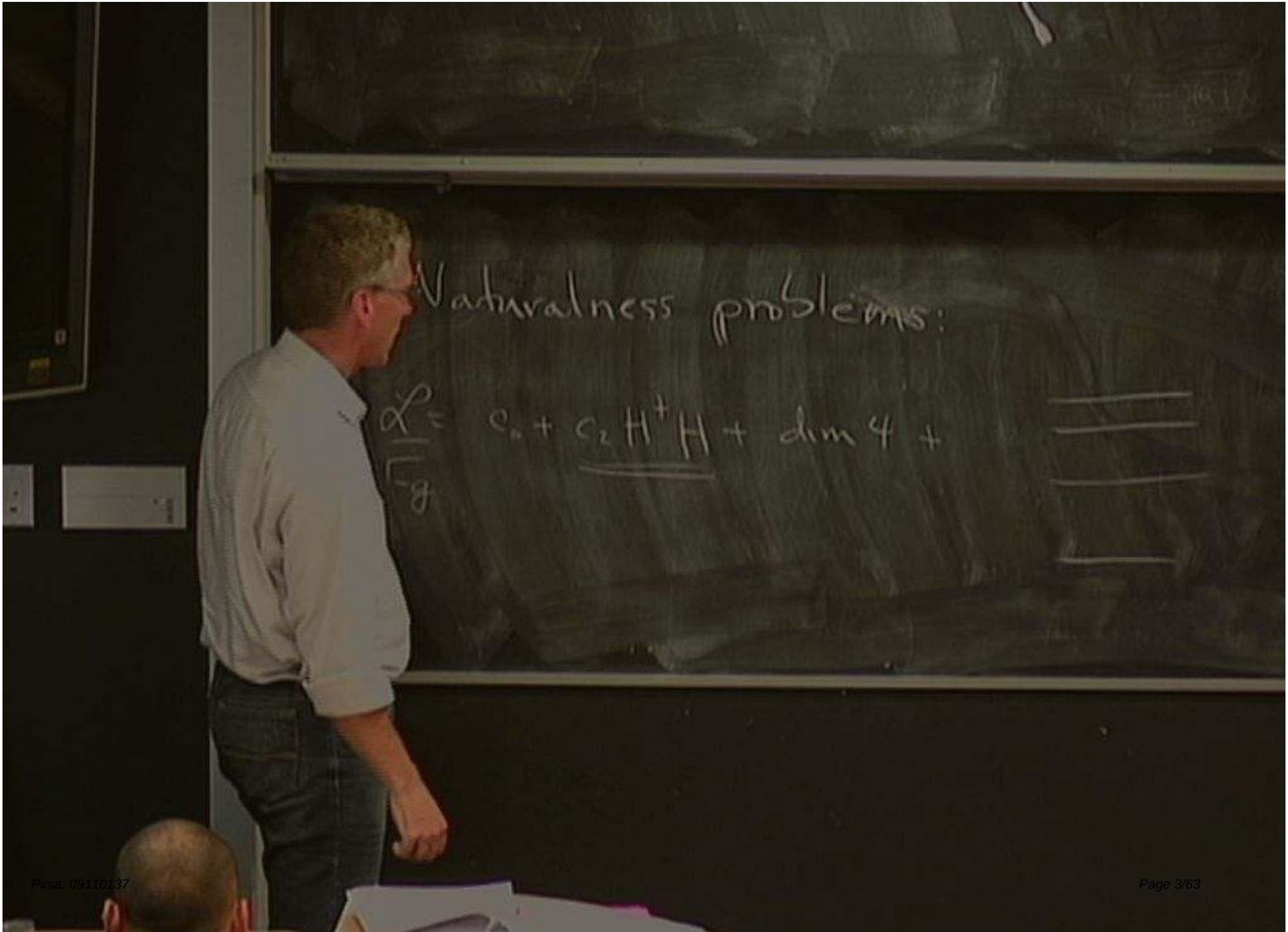
Title: Introduction to Effective Field Theory - Lecture 9C

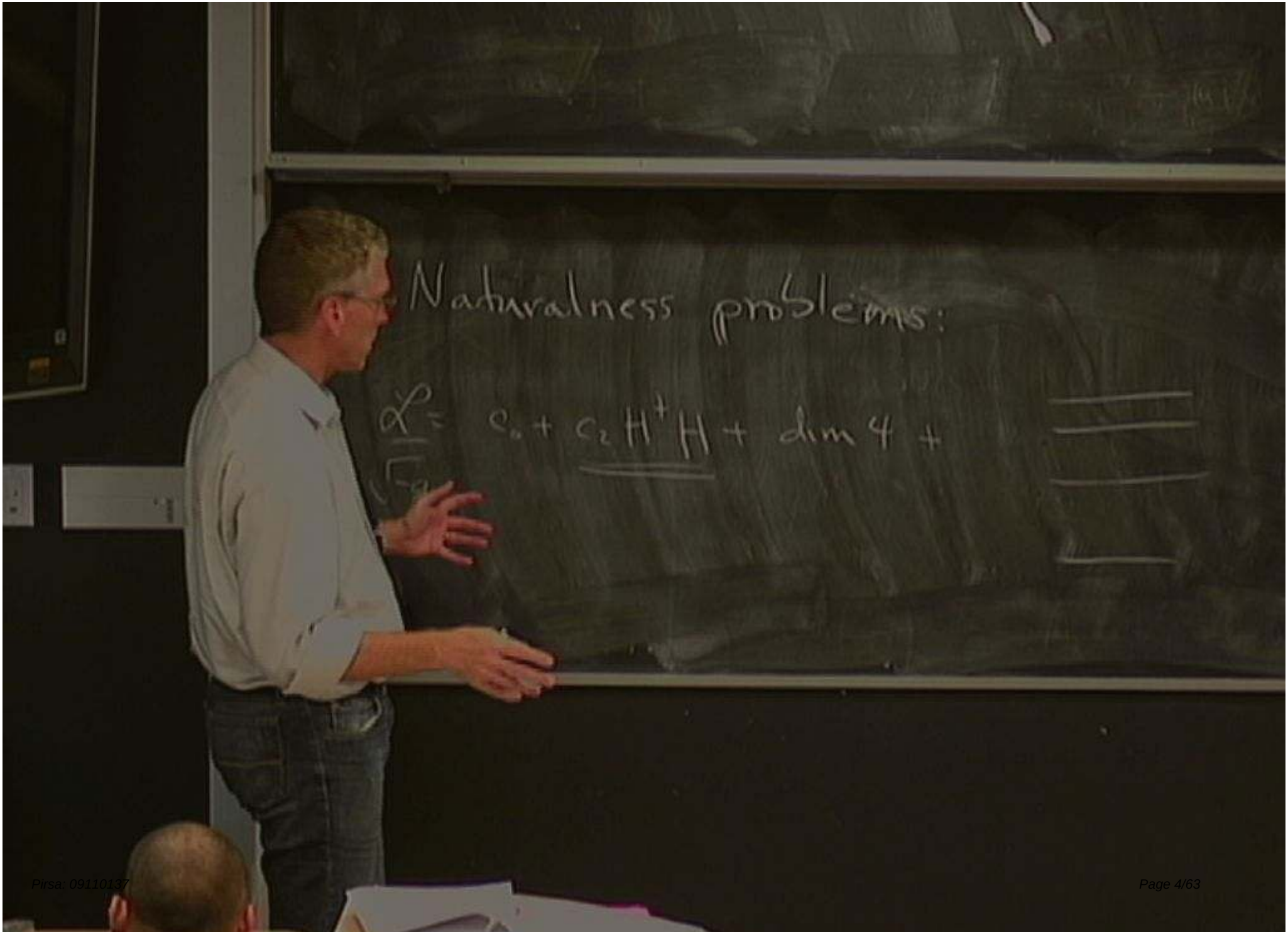
Date: Nov 18, 2009 03:30 PM

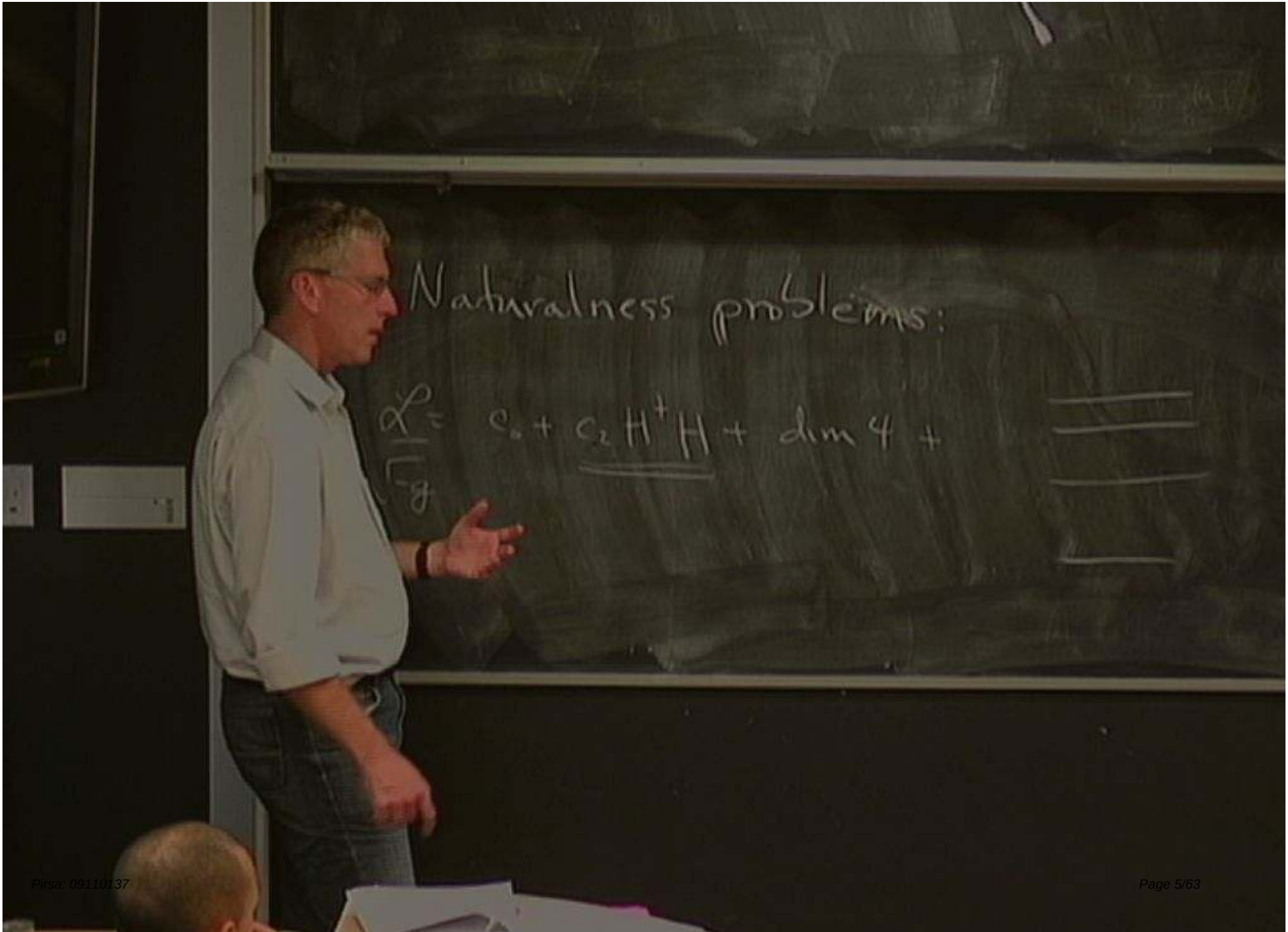
URL: http://pirsa.org/09110137

Abstract:


turalness problems:
$c_0 + c_2 H^\dagger H + \dim 4 +$


Naturalness problems:
$\mathcal{L} = c_0 + c_2 H^\dagger H + \dim 4 +$


Naturalness problems:
$\mathcal{L} = c_0 + c_2 H^\dagger H + \dim 4 +$

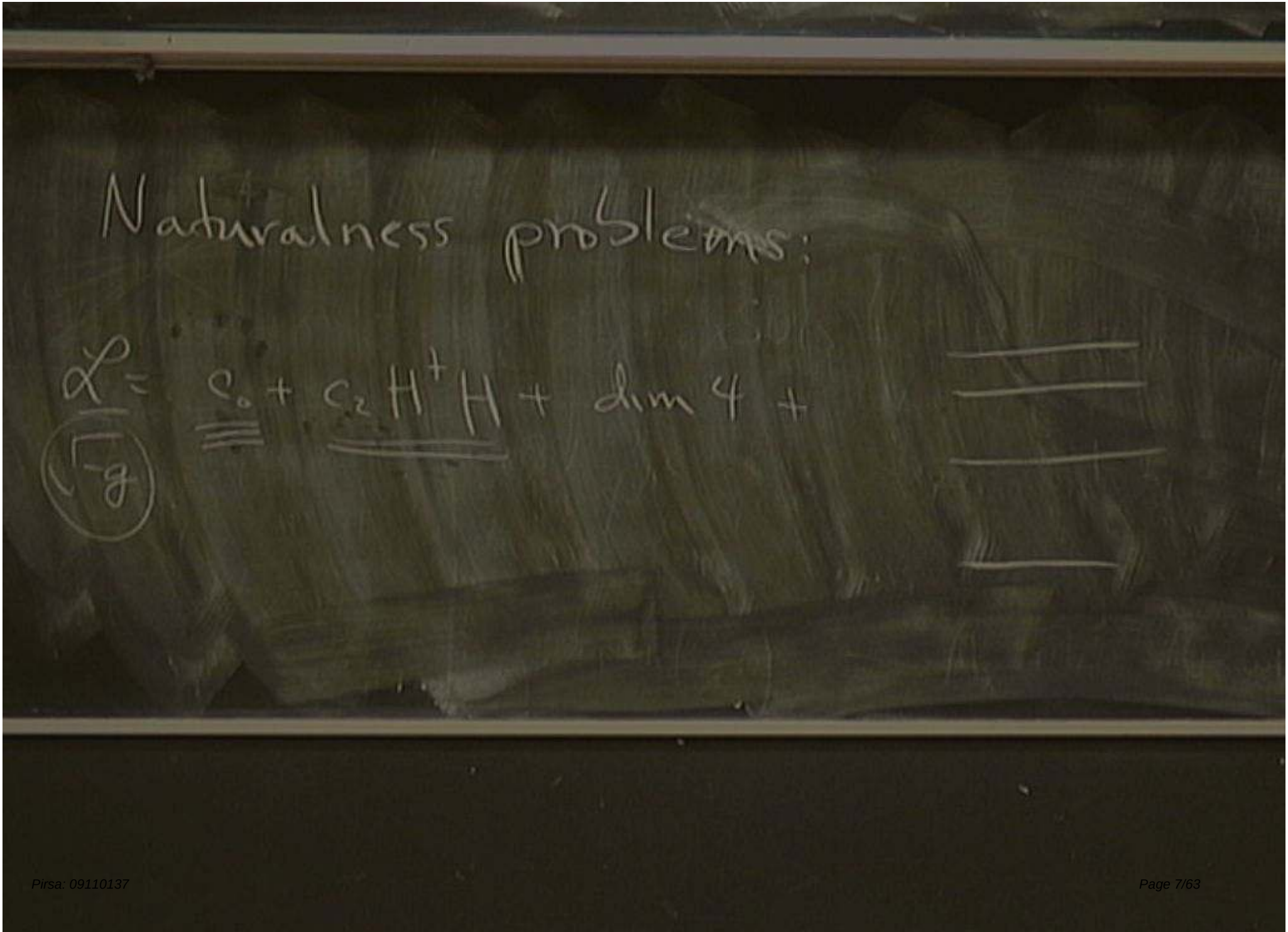

Naturalness problems:
$\mathcal{L} = c_0 + c_2 H^\dagger H + \dim 4 +$

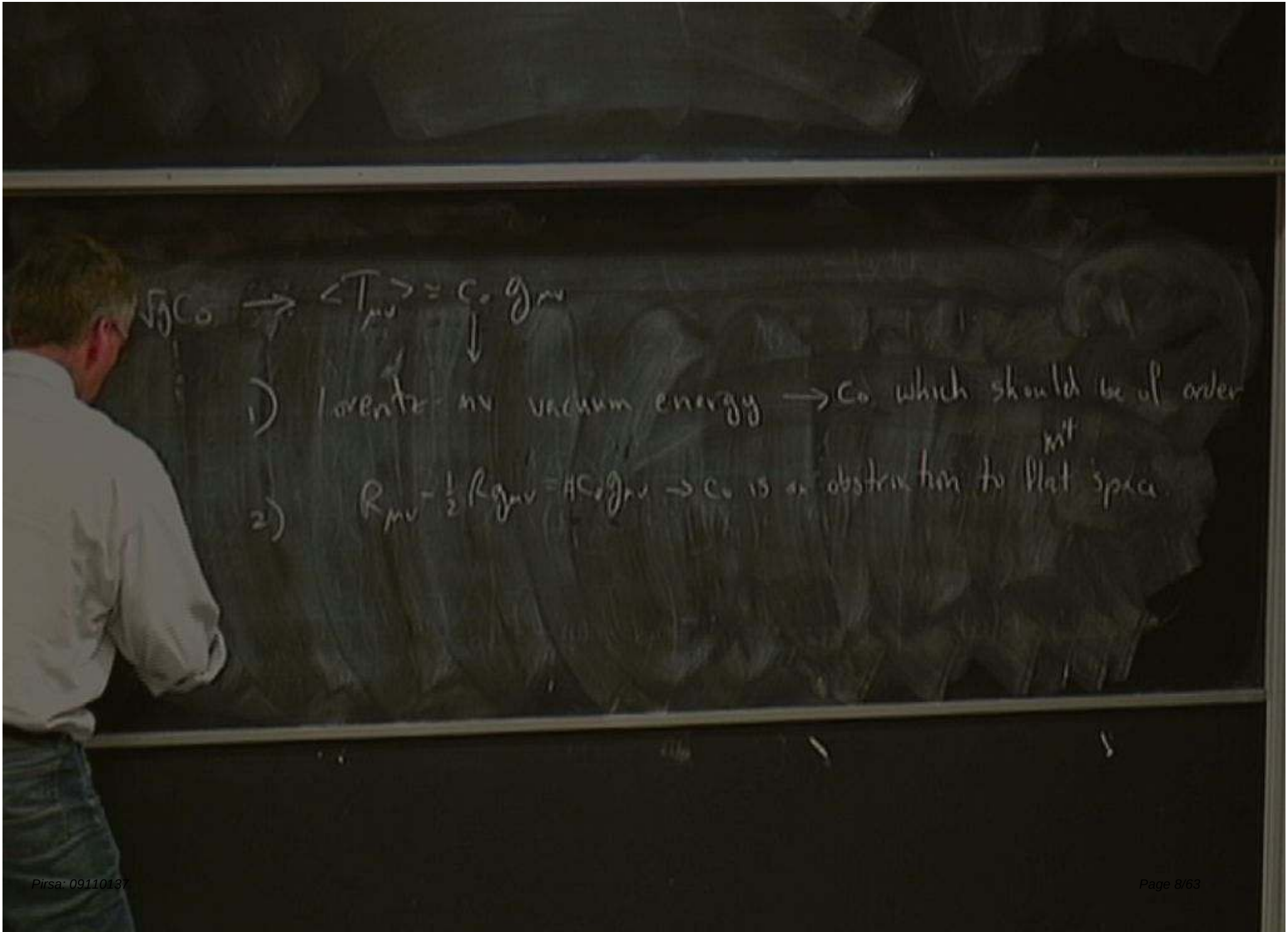
$C_{2\,exp} \simeq (100\ GeV)^2$ particles of mass M contribute $\sim M^2$

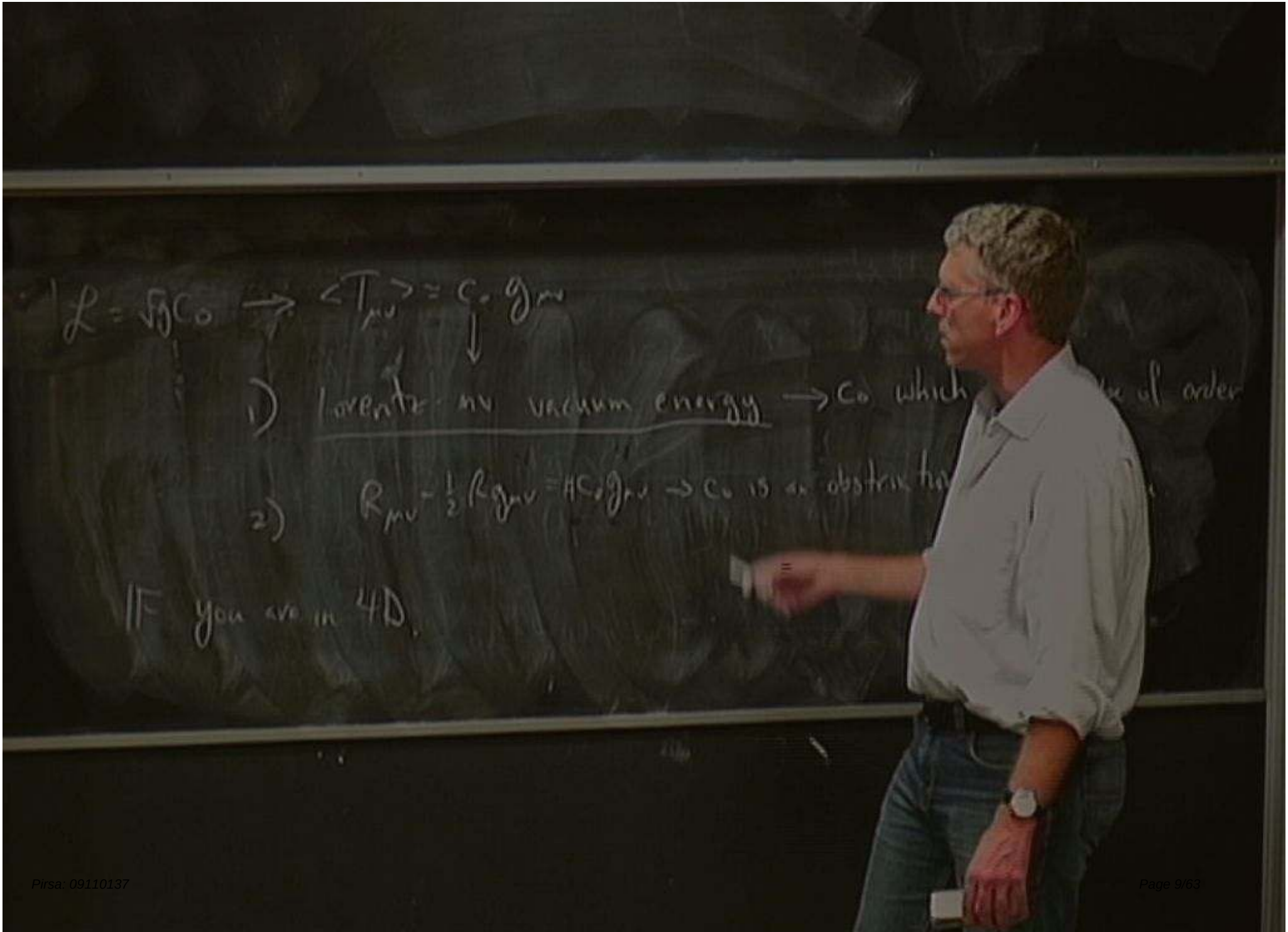
$C_{0\,exp} \sim (10^{-2}\ eV)^4 \simeq$ ~~M^4~~ " " " " M " " $\underline{M^4}$

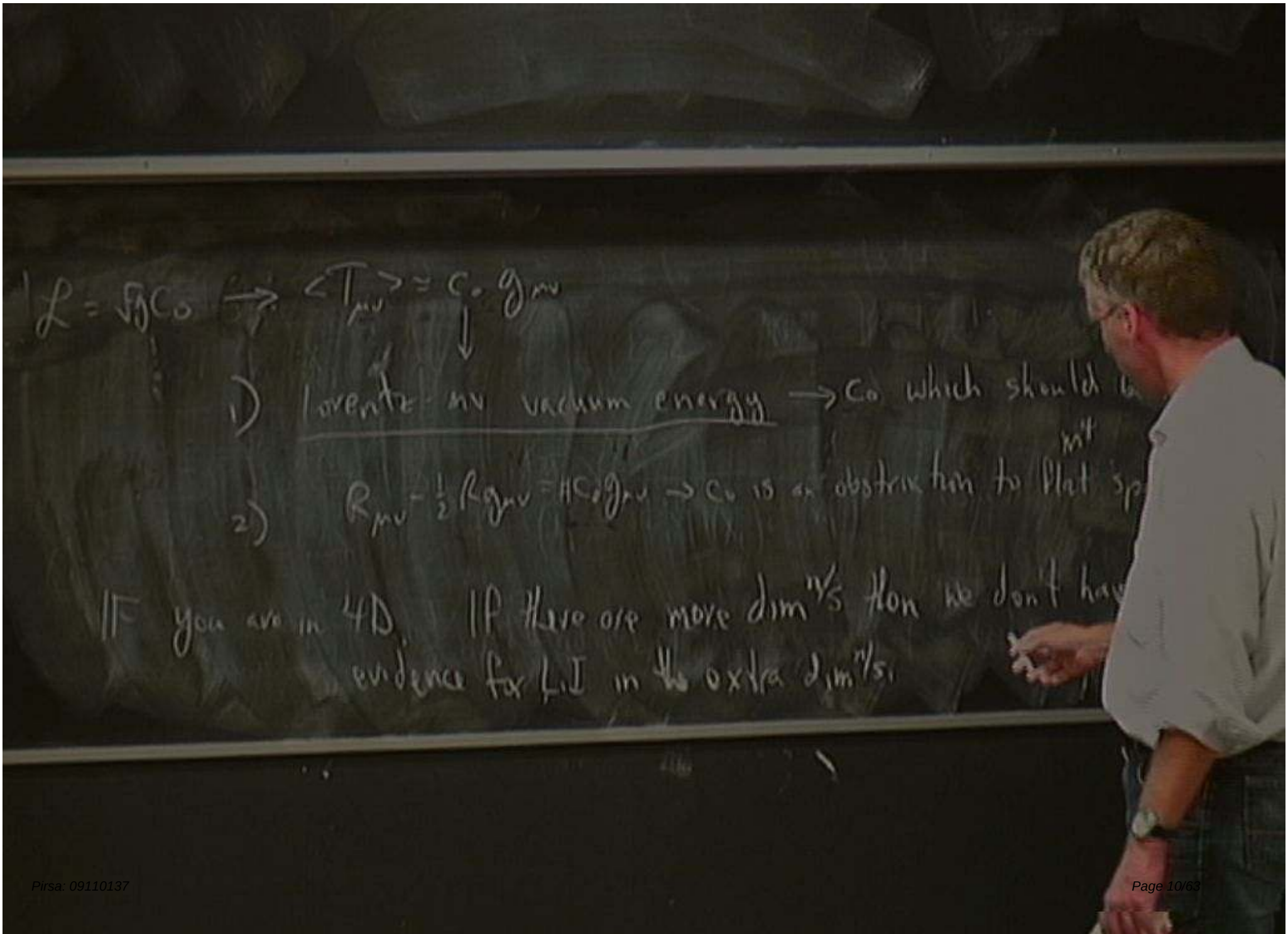
$m_e^4 \sim (10^6\ eV)^4$

even the electron gives 10^{32} time too large a result.


Naturalness problems:
$\mathcal{L} = c_0 + c_2 H^\dagger H + \dim 4 +$
$\sqrt{-g}$


$\sqrt{}C_0 \rightarrow \langle T_{\mu\nu} \rangle = C_0 g_{\mu\nu}$
1) Lorentz inv vacuum energy $\rightarrow C_0$ which should be of order M^4
2) $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi C_0 g_{\mu\nu} \rightarrow C_0$ is an obstruction to flat space


$\mathcal{L} = \sqrt{g} C_0 \rightarrow \langle T_{\mu\nu} \rangle = C_0 g_{\mu\nu}$
1) Lorentz inv vacuum energy $\rightarrow C_0$ which
2) $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G C_0 g_{\mu\nu} \rightarrow C_0$ is
IF you are in 4D.

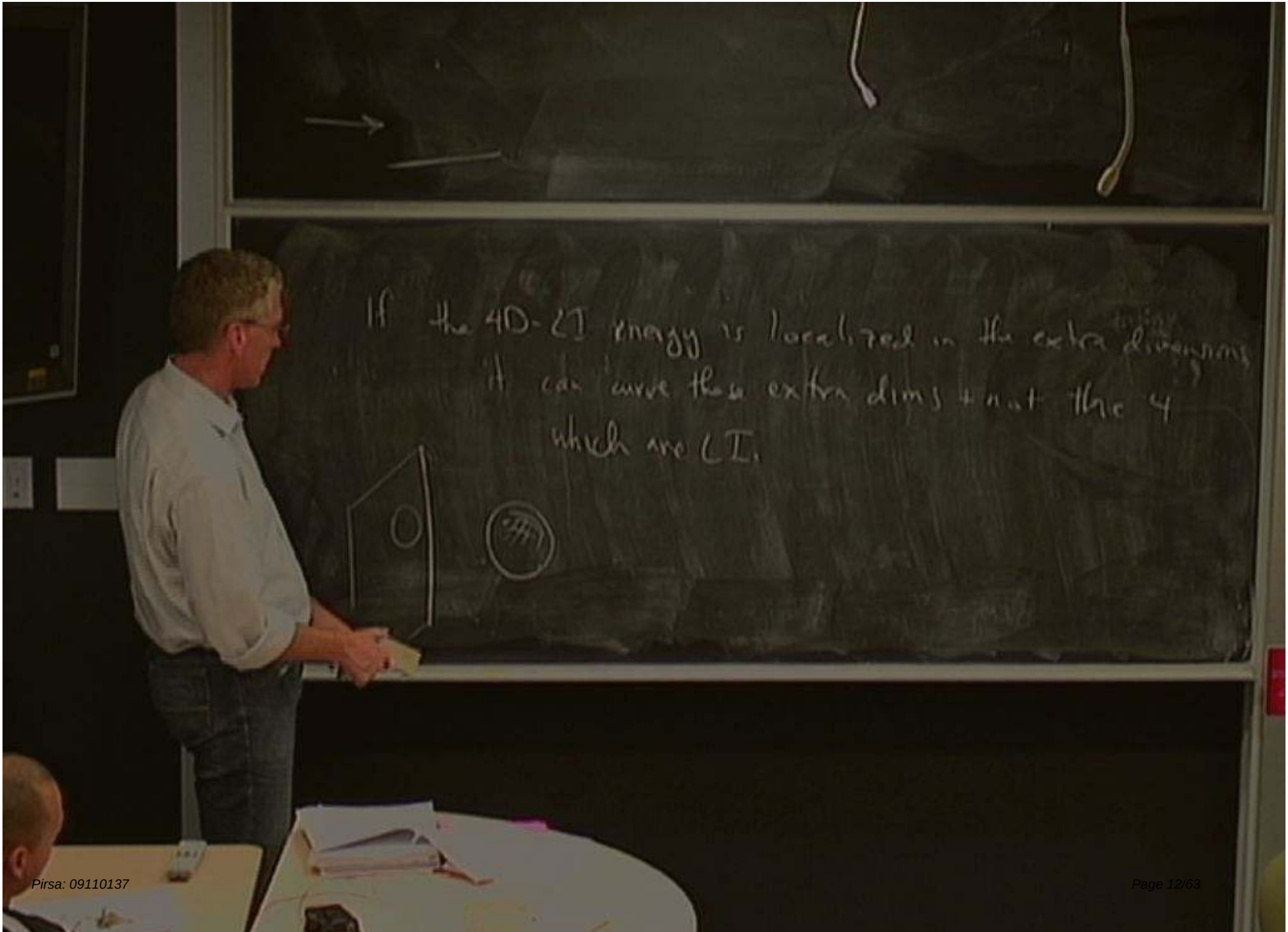

$\mathcal{L} = \sqrt{g}\, c_0 \rightarrow \langle T_{\mu\nu} \rangle \simeq c_0\, g_{\mu\nu}$
1) Lorentz inv vacuum energy → c_0 which should b
2) $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \pi c_0 g_{\mu\nu}$ → c_0 is an obstruction to flat sp
IF you are in 4D. If there are more dim^{n}s then we don't hav
evidence for L.I in the extra dim^{n}s.

$\mathcal{L} = \sqrt{g} C_0 \rightarrow \langle T_{\mu\nu} \rangle = C_0 \cdot g_{\mu\nu}$

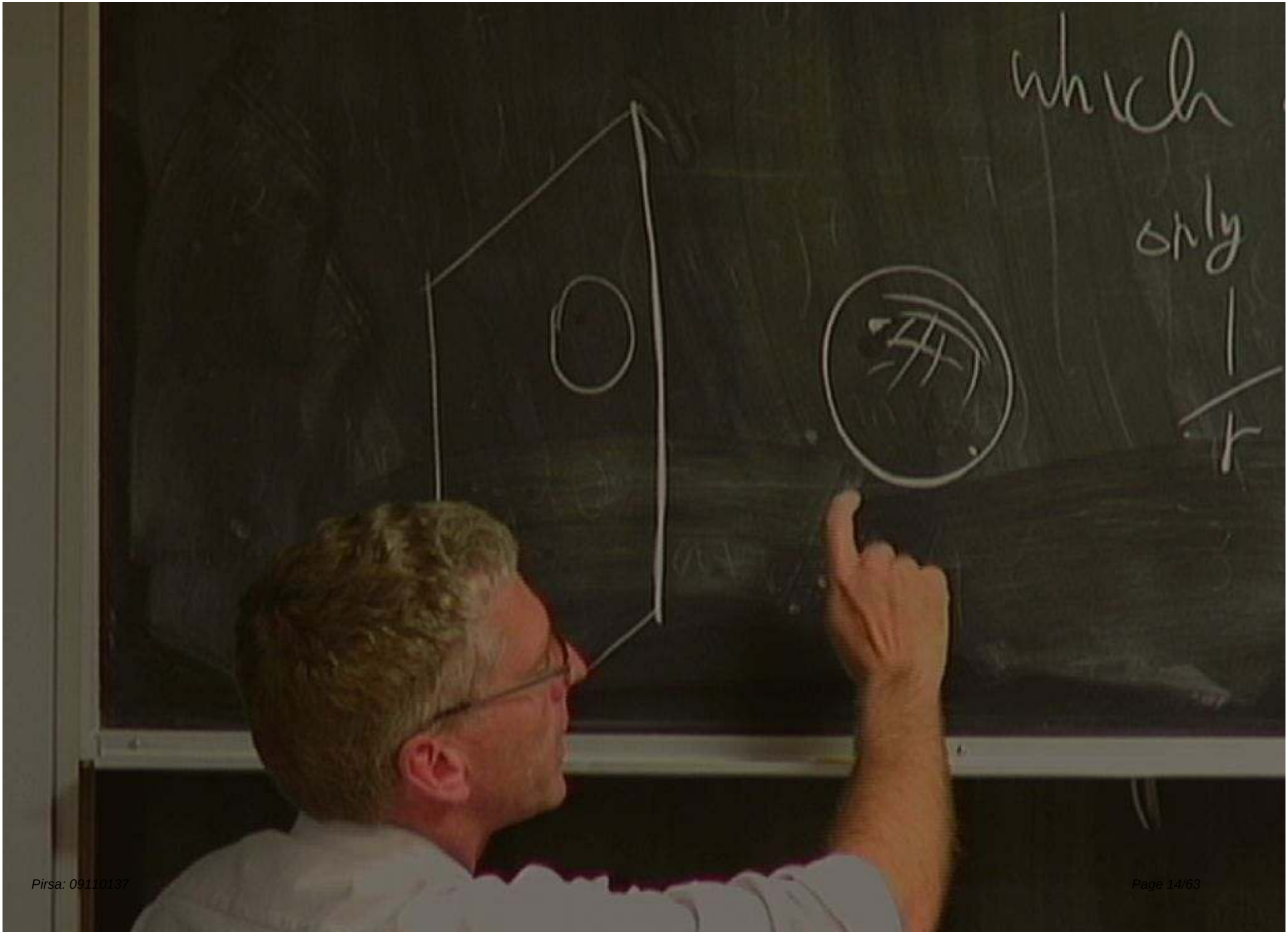
1) Lorentz inv vacuum energy $\rightarrow C_0$ which should be of order M^4

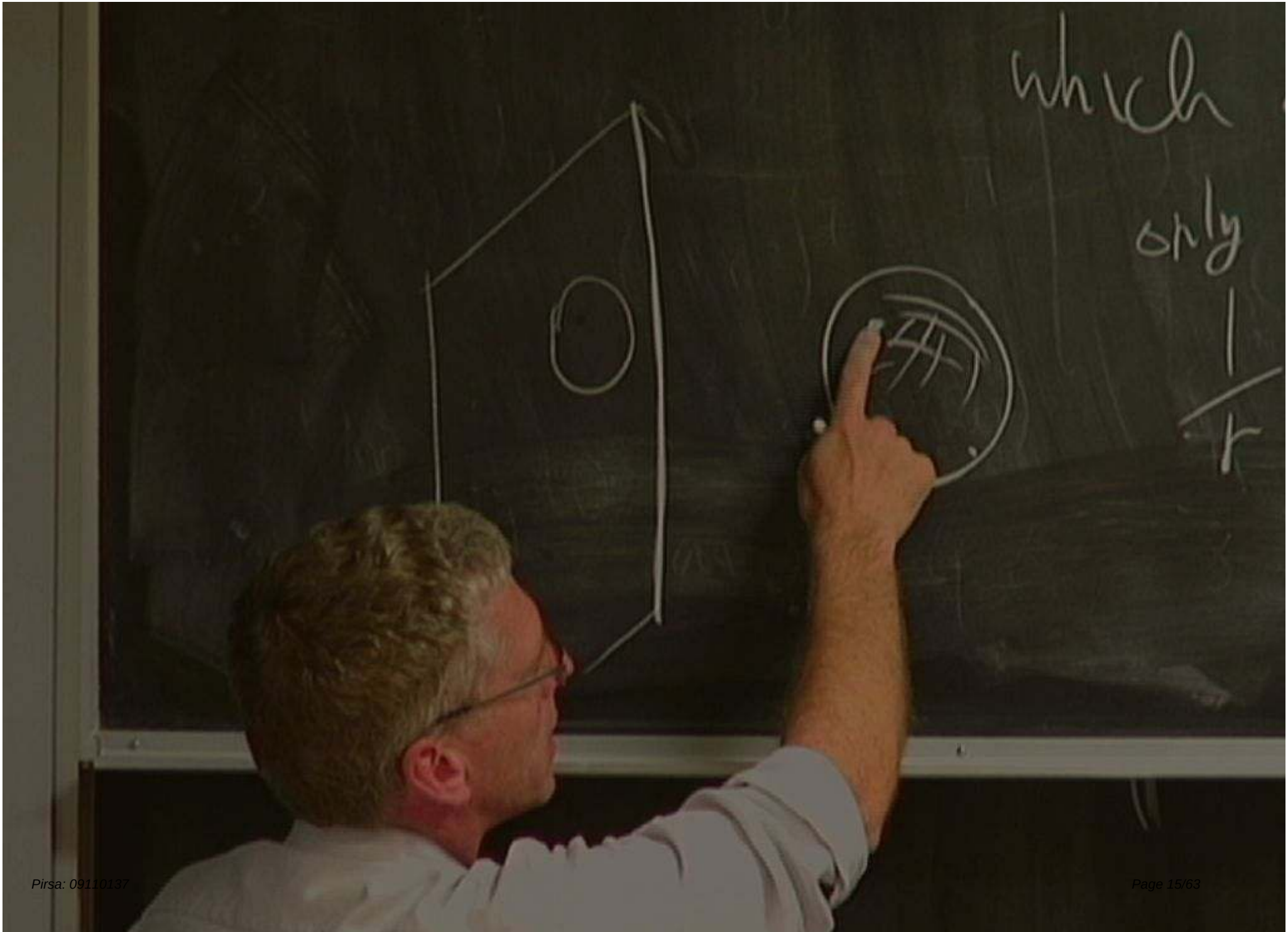
2) $R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi C_0 g_{\mu\nu} \rightarrow C_0$ is an obstruction to flat space

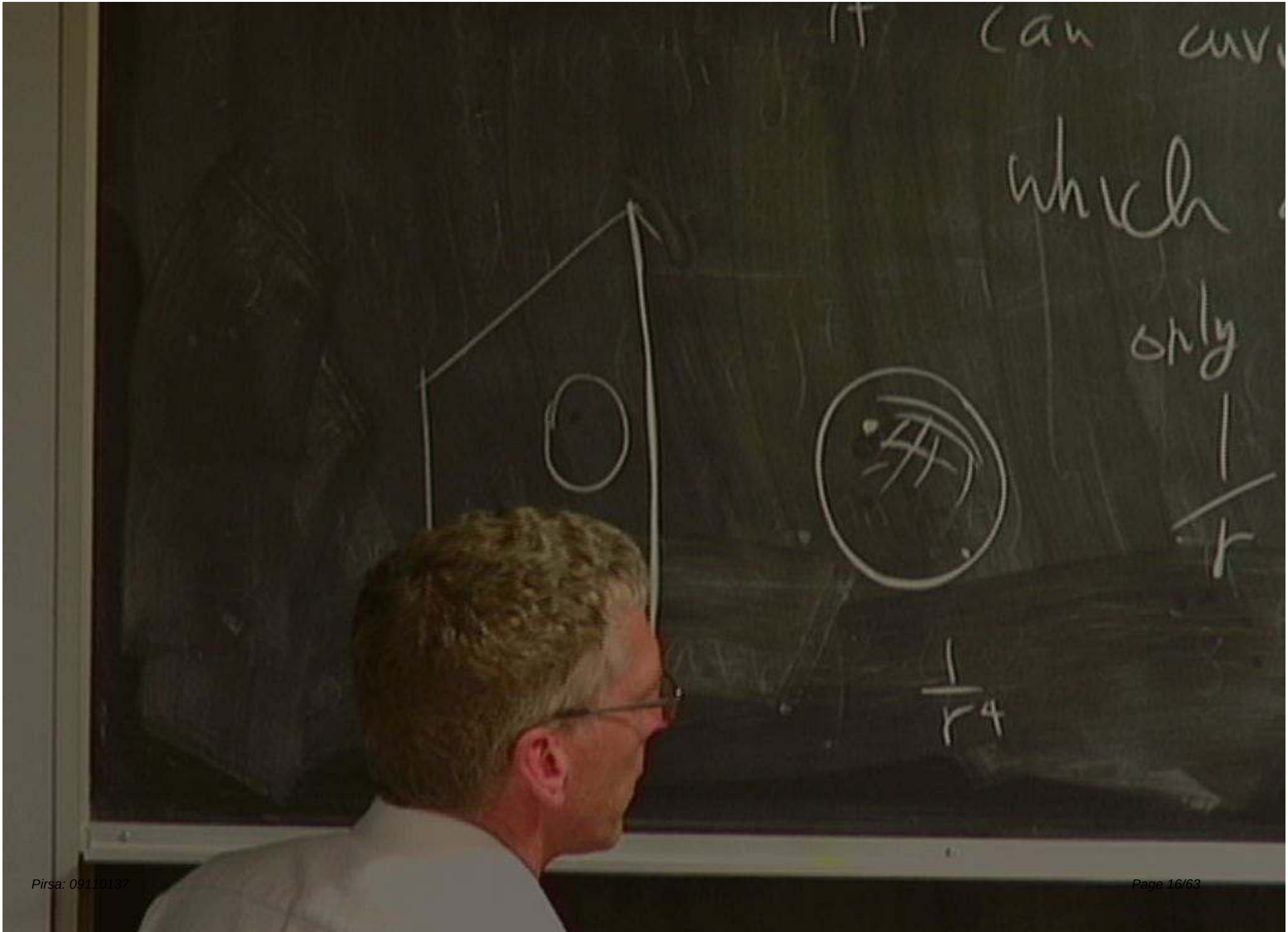
IF you are in 4D. If there are more dim's than we don't have any evidence for L.I in the extra dim's.

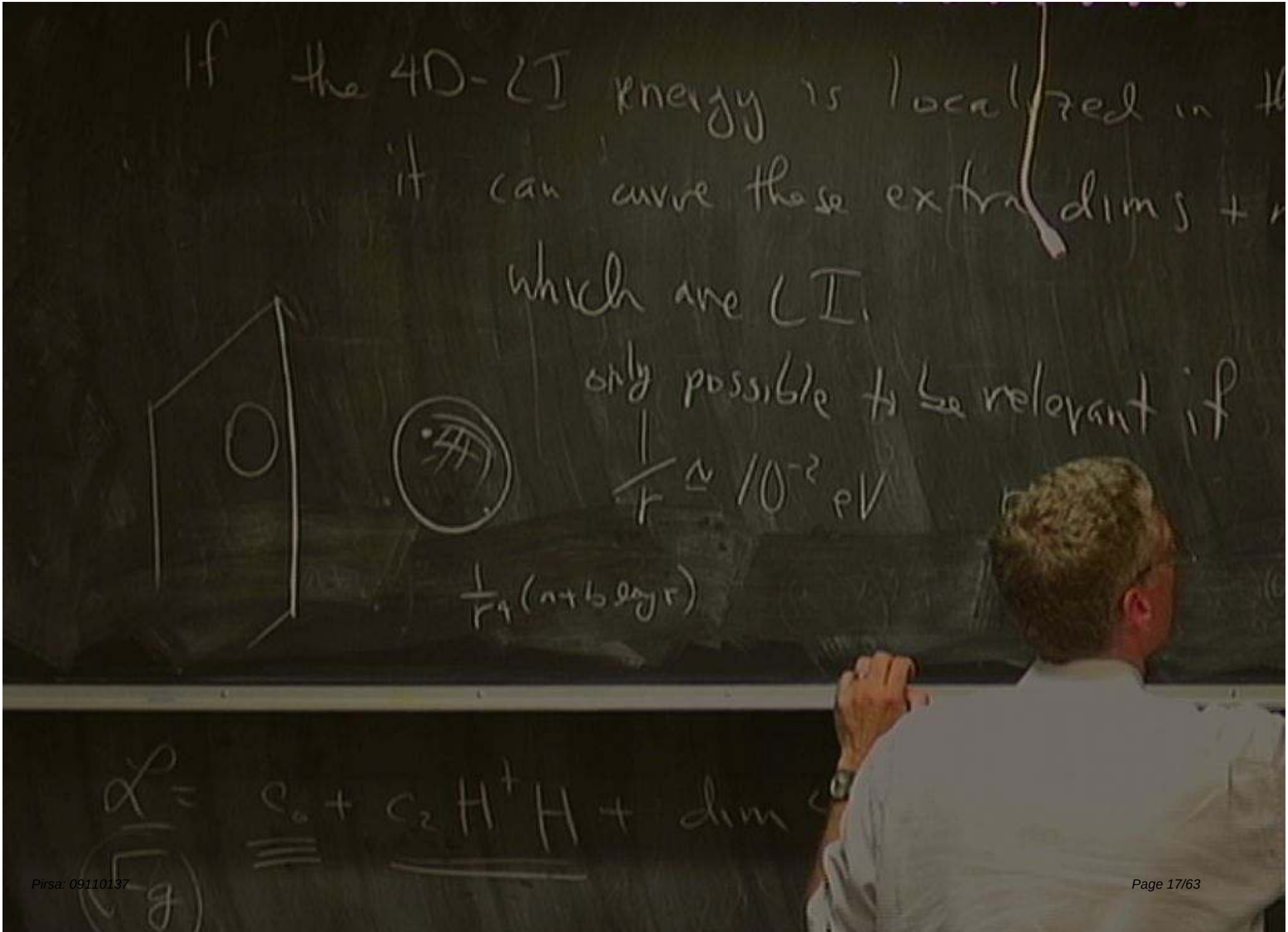

If the 4D-CJ energy is localized in the extra dimensions
it can curve these extra dims but not the 4
which are CI.

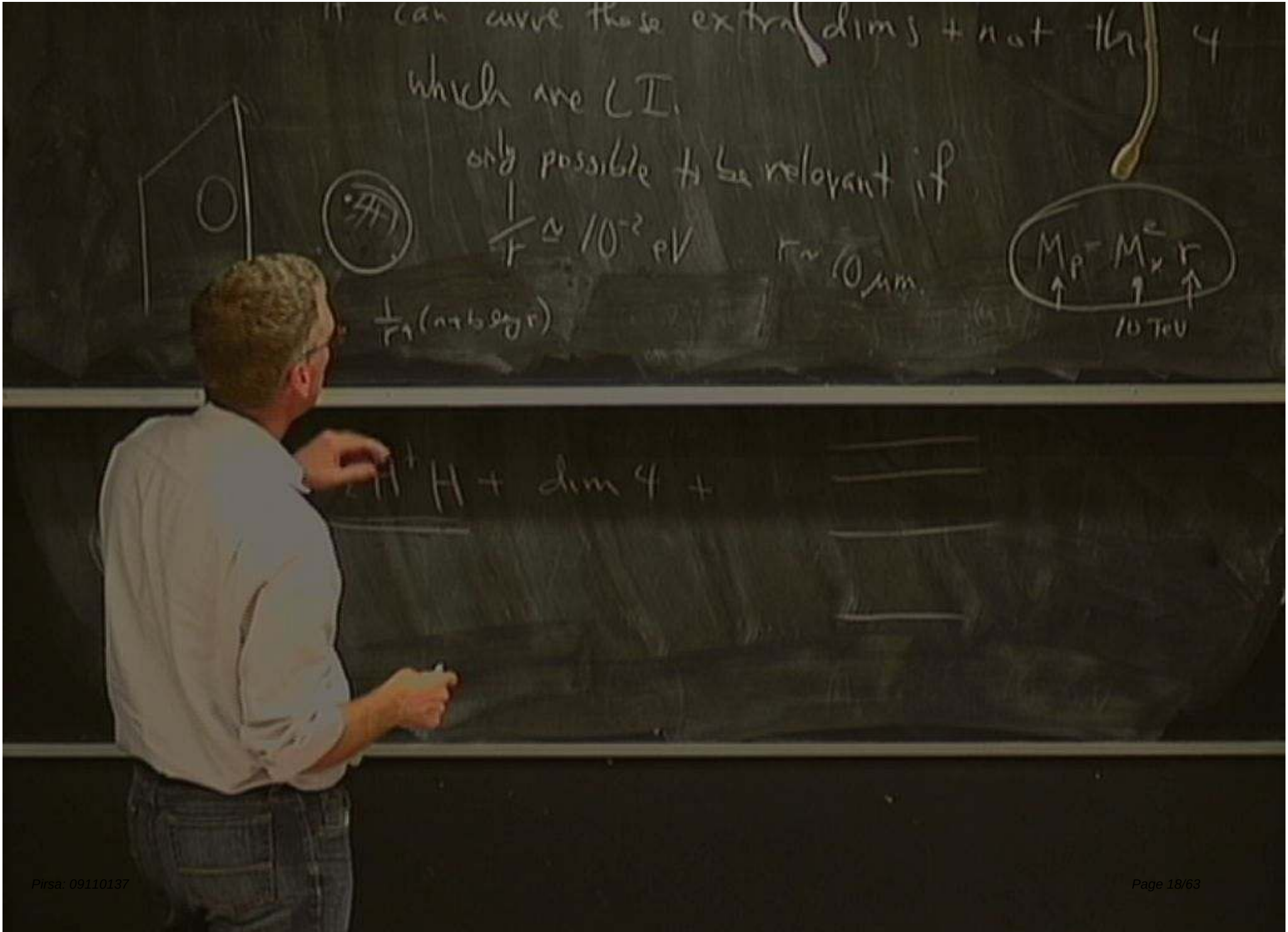
If the 4D-LI energy is localized in the extra dimensions, it can curve these extra dims + not the 4 which are LI.

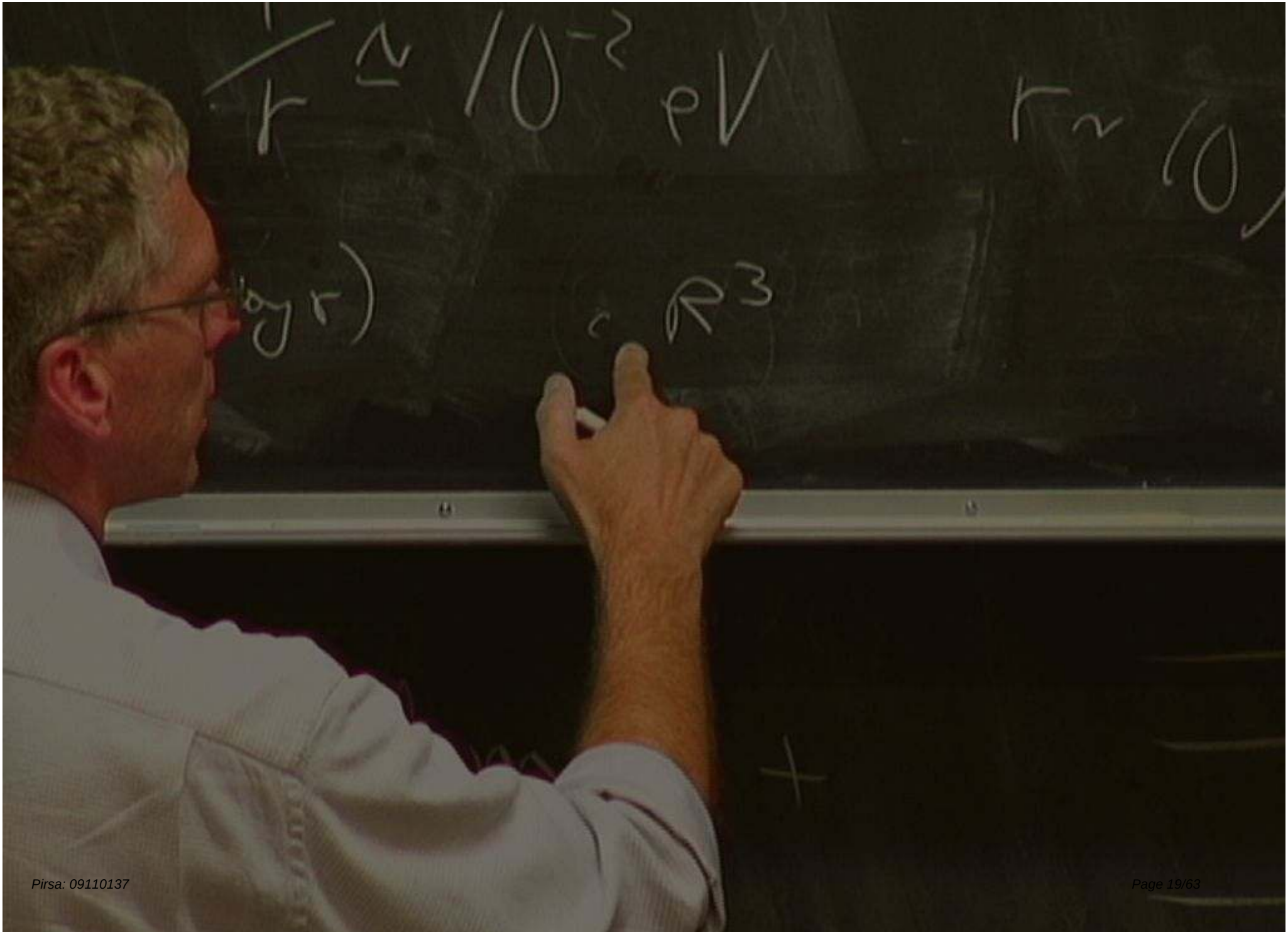

which
only

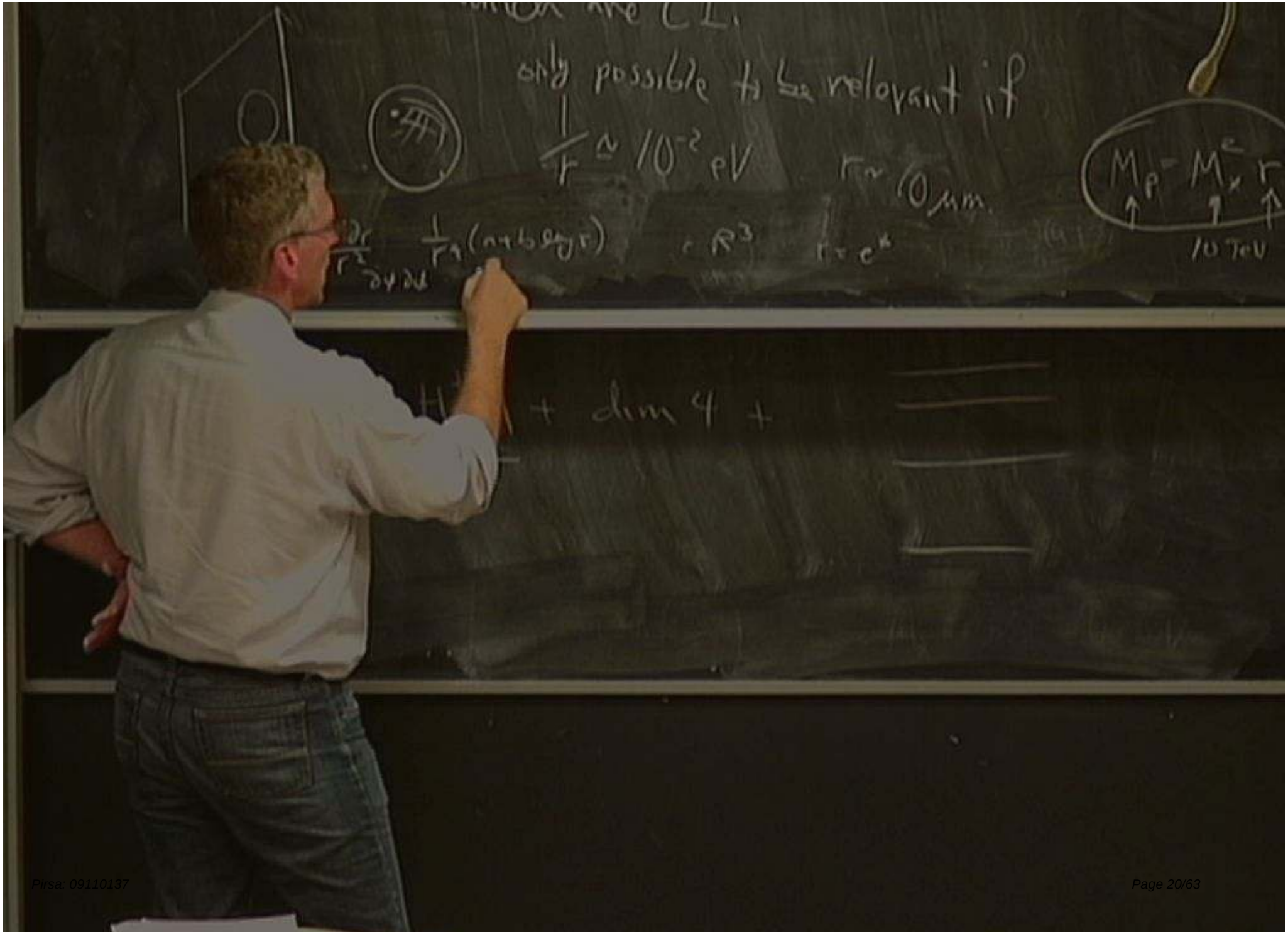

which
only
1
r

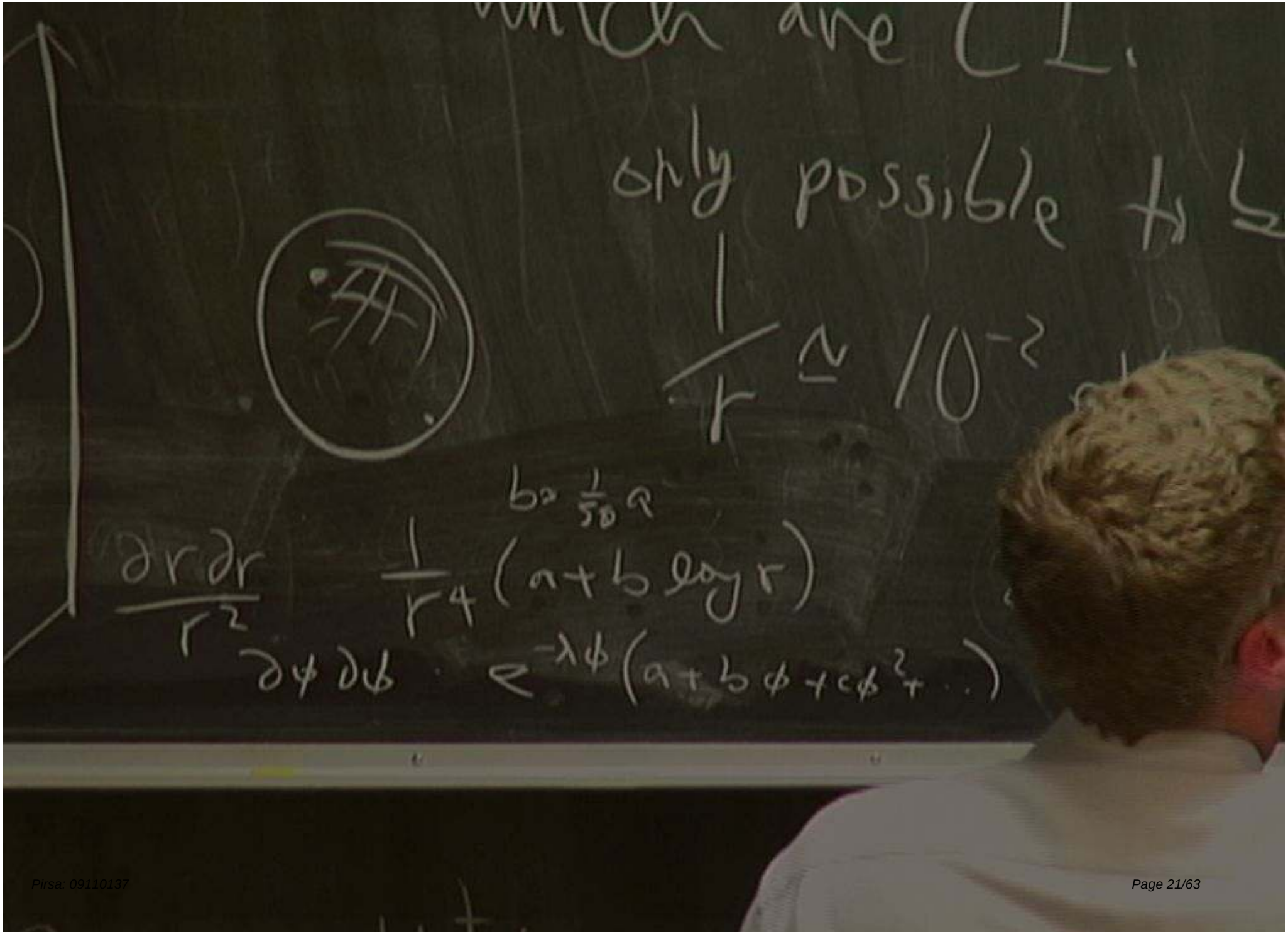

It can curv
which
only
1
r
1
r4

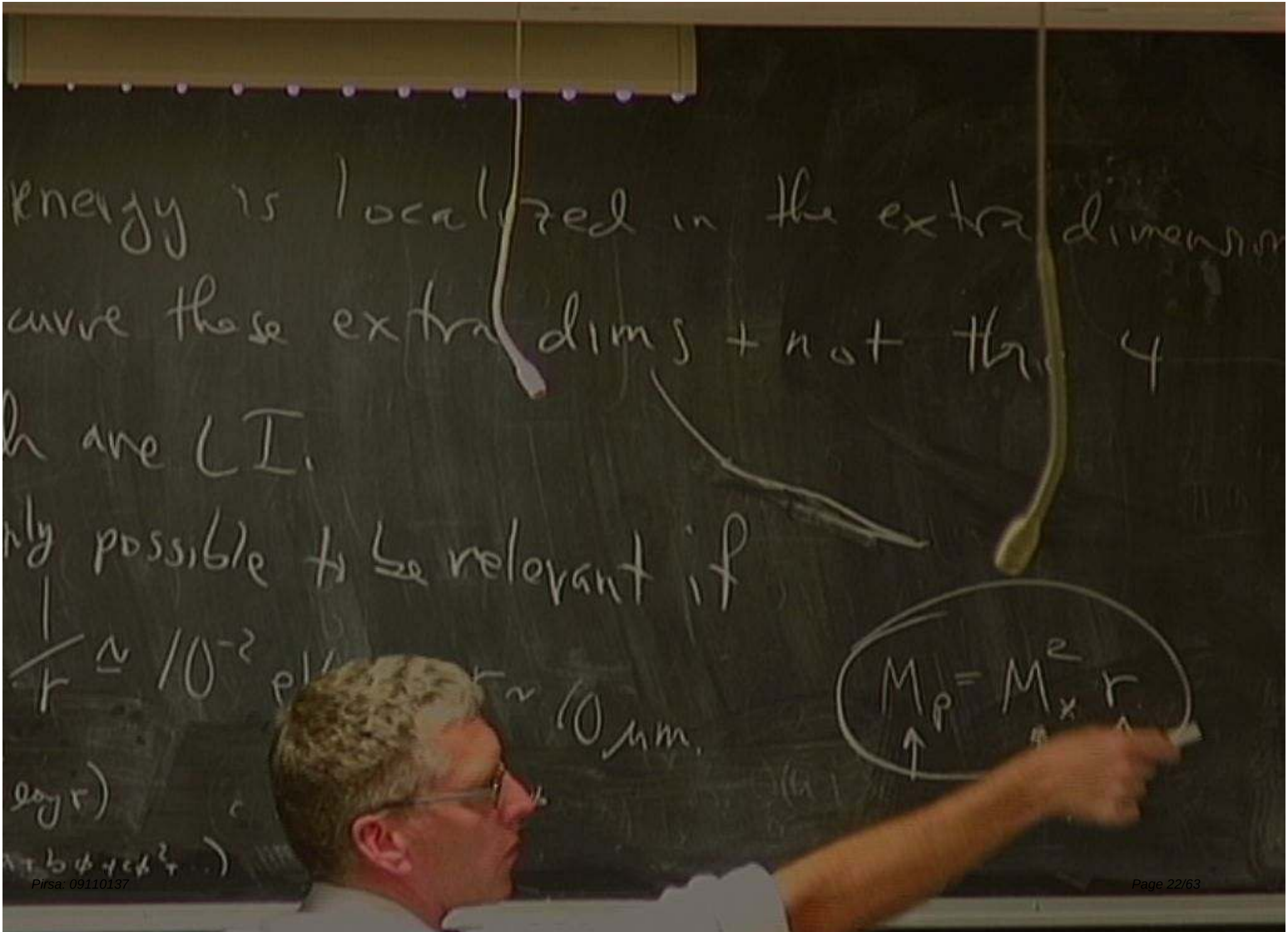

If the 4D-CI energy is localized in
it can curve those extra dims +
which are CI.
only possible to be relevant if
$\frac{1}{r} \simeq 10^{-2}$ eV
$\frac{1}{r^4}(n + b \log r)$
$\mathcal{L} = c_0 + c_2 H^+ H +$ dim
$\sqrt{-g}$


can curve these extra dims + not the 4
which are LI.
only possible to be relevant if
1/r ≃ 10^-2 eV
r ~ 10 μm
M_p = M_*^2 r
10 TeV
H^† H + dim 4 +


$\frac{1}{r} \simeq 10^{-2}$ eV
R^3


only possible to be relevant if
$\frac{1}{r} \simeq 10^{-2}$ eV
$r \sim 10$ mm
$M_P = M_* r$
10 TeV
+ dim 4 +


which are CL.
only possible th
$\frac{1}{r} \sim 10^{-2}$
$b \sim \frac{1}{50} a$
$\frac{\partial r \partial r}{r^2}$
$\frac{1}{r^4}(a + b \log r)$
$\partial\phi\,\partial b$
$e^{-\lambda\phi}(a + b\phi + c\phi^2 + \ldots)$


energy is localized in the extra dimensions
curve these extra dims + not the 4
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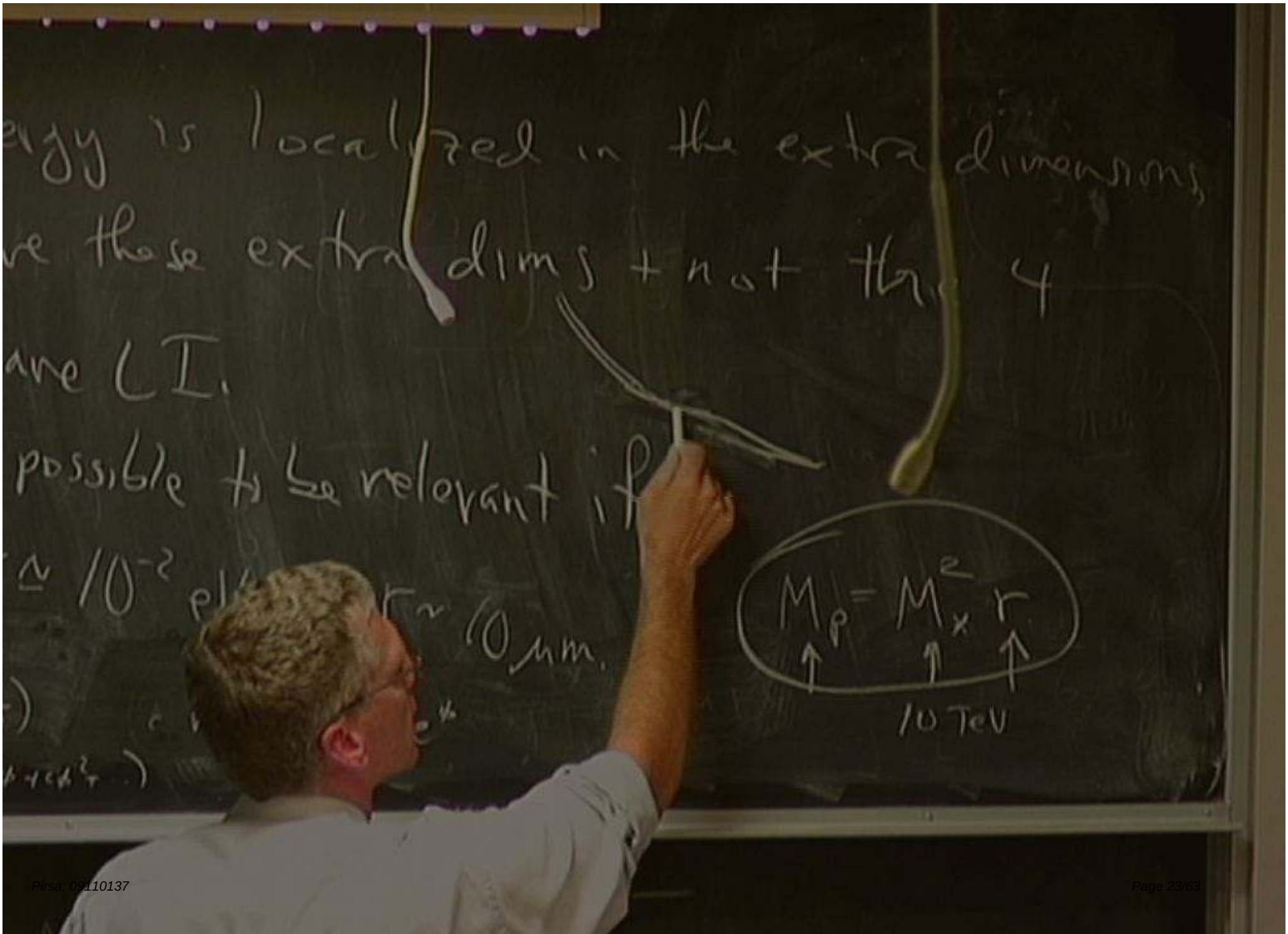
nly possible to be relevant if
$M_P = M_* r$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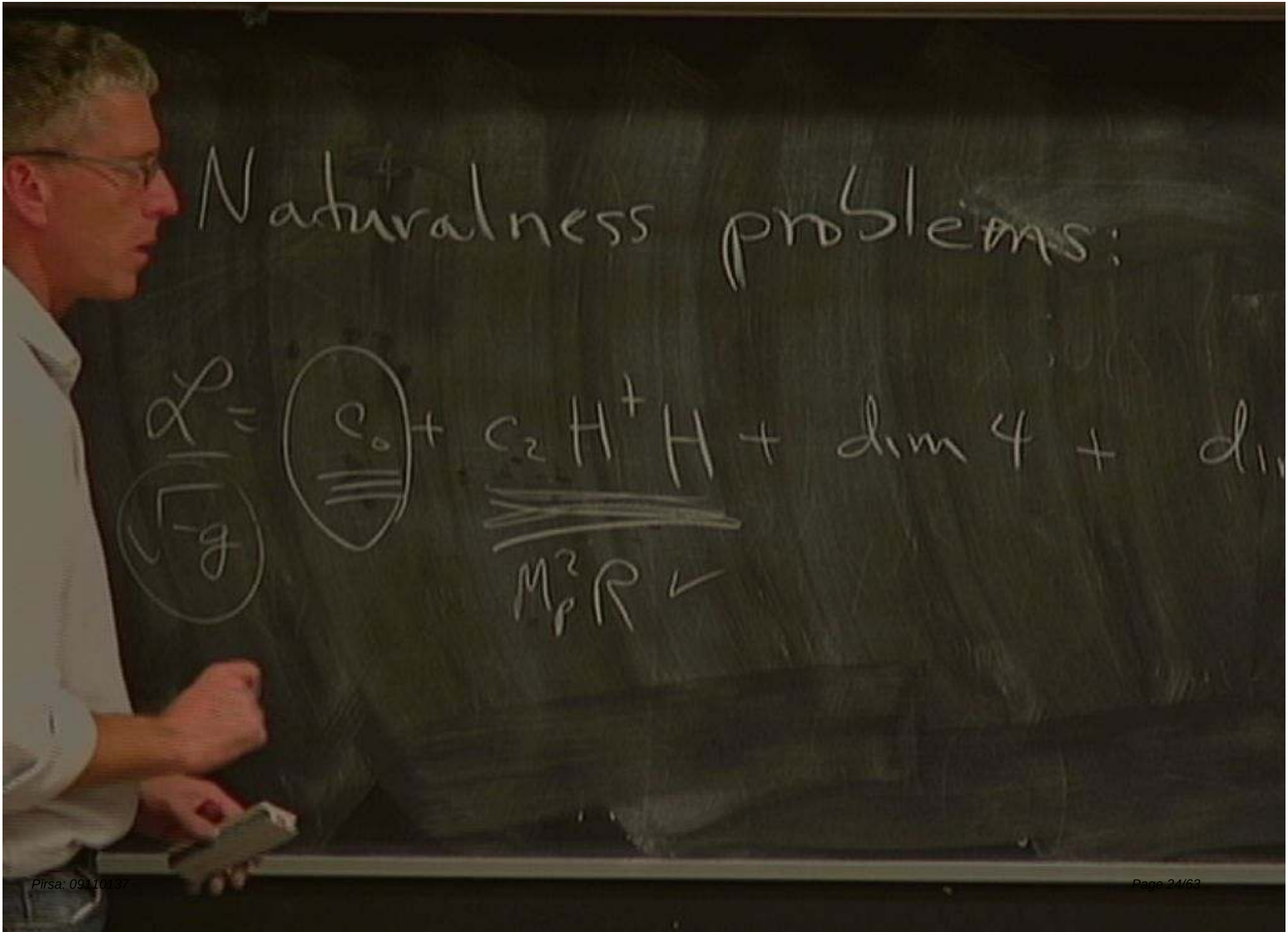
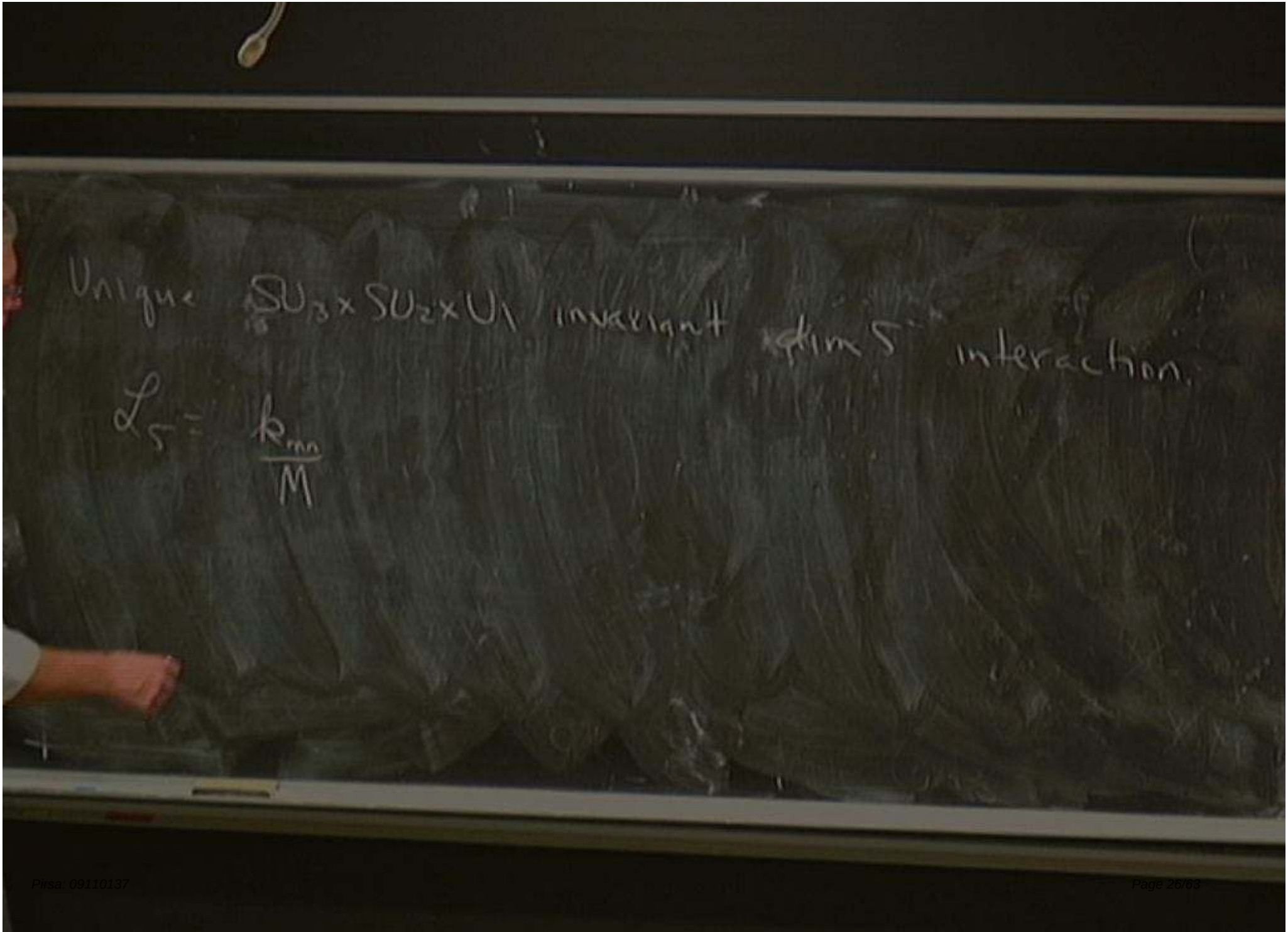
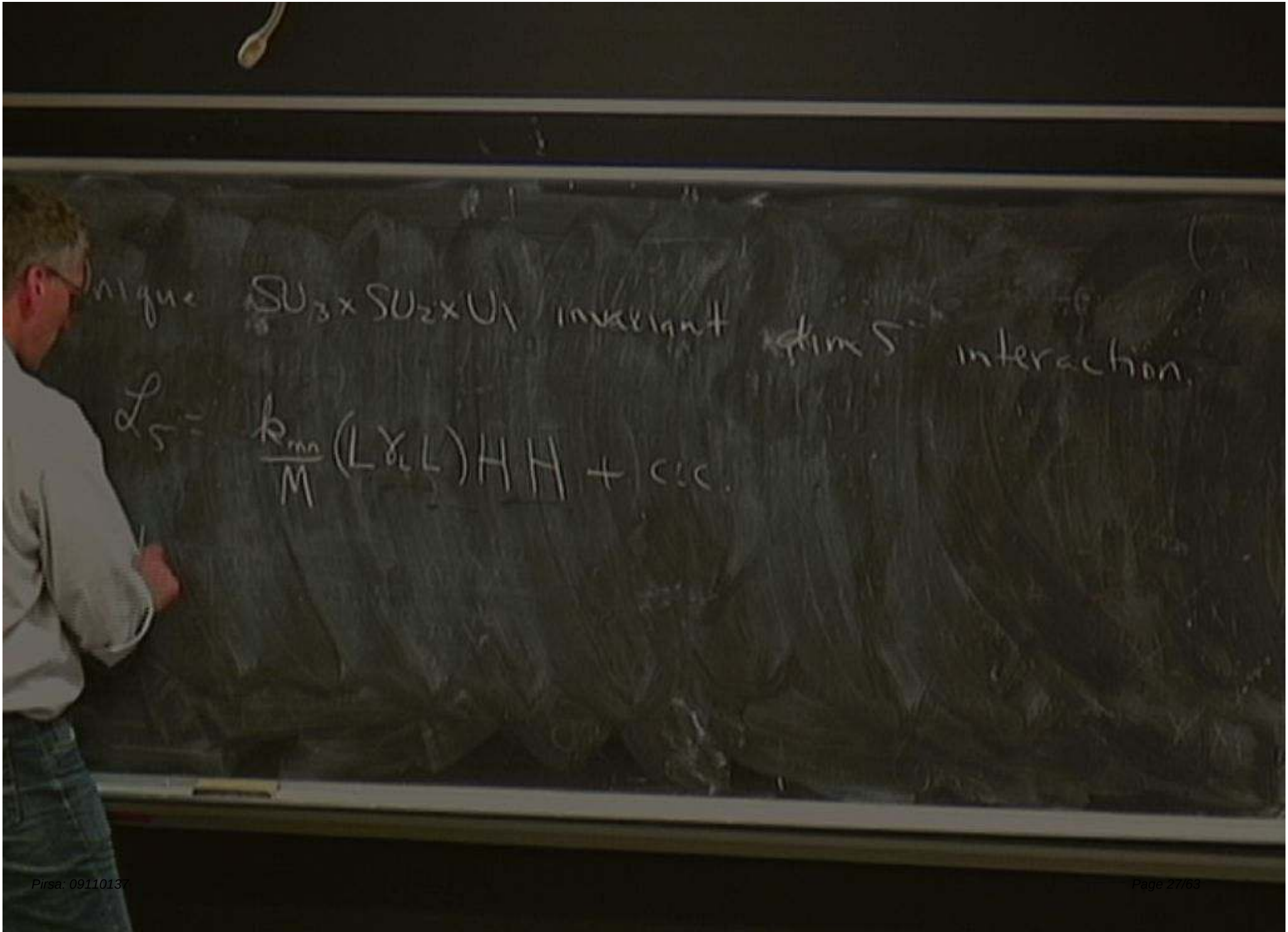
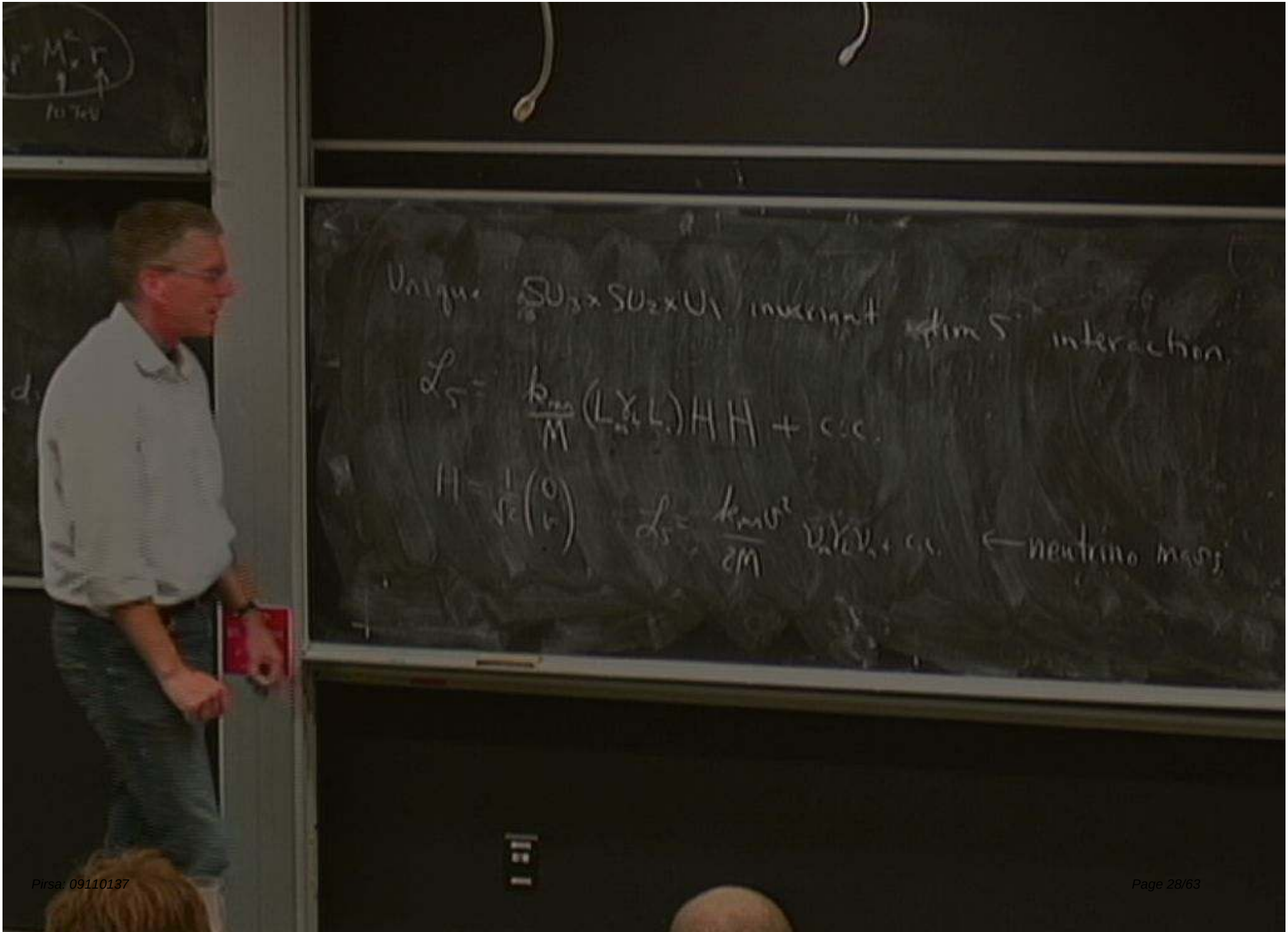
possible to be relevant if
$M_P = M_* r$
10 TeV


Naturalness problems:
$\mathcal{L} = c_0 + c_2 H^\dagger H + \dim 4 + \dim$
$M_P^2 R$

Unique $SU_3 \times SU_2 \times U_1$ invariant $\times$ dim 5 interaction.


Unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.
$\mathcal{L}_5 = \frac{k_{mn}}{M}$

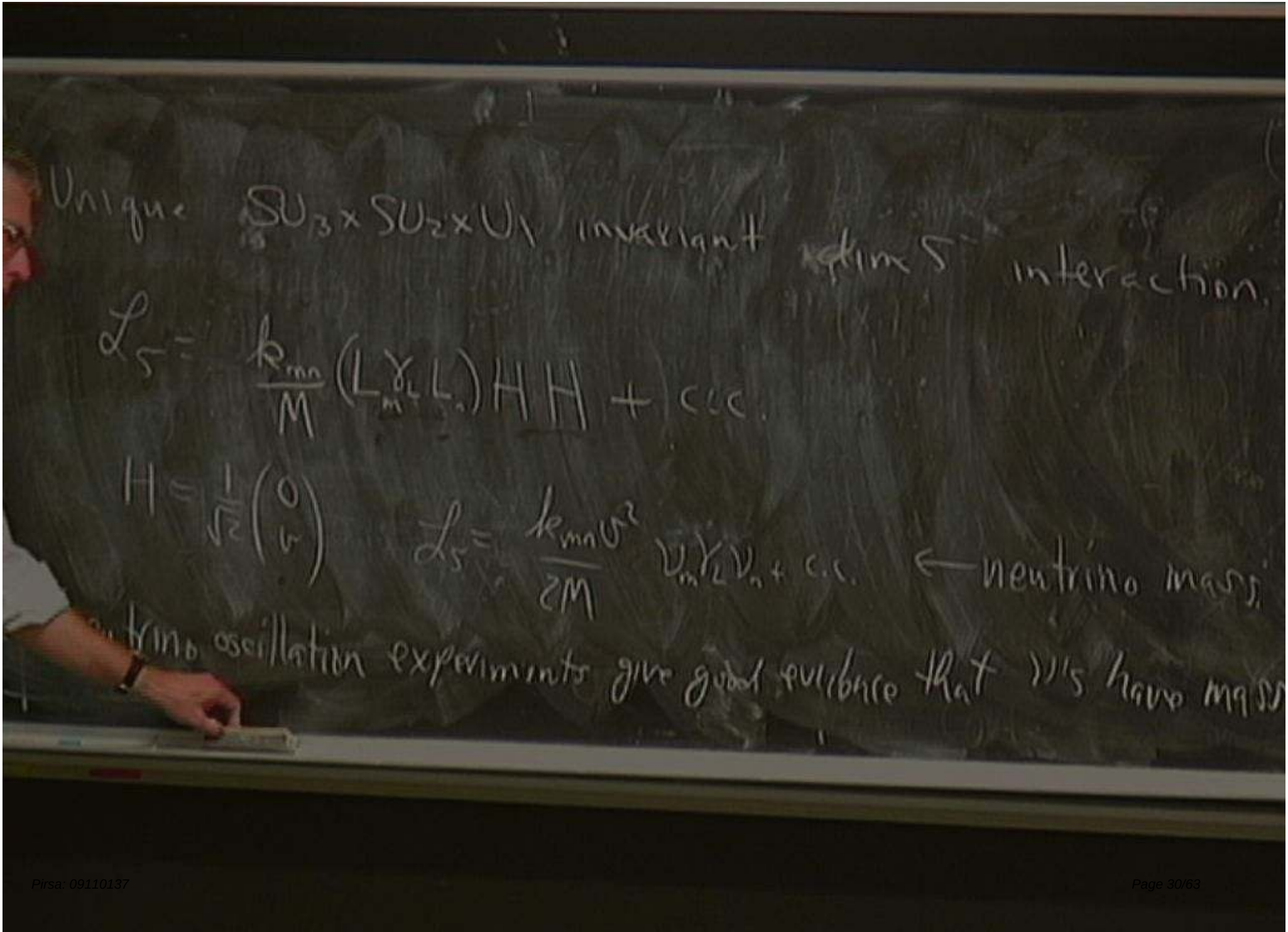

unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.
$\mathcal{L}_5 = \frac{k_{mn}}{M}(L\gamma_L L)HH + c.c.$


Unique SU3 × SU2 × U1 invariant dim 5 interaction.
← neutrino mass

Unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.

$$\mathcal{L}_5 = \frac{k_{mn}}{M} (L_m^T \gamma_2 L_n) H H + \text{c.c.}$$

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \nu_m^T \gamma_2 \nu_n + \text{c.c.} \leftarrow \text{neutrino mass}$$


Unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.
$\mathcal{L}_5 = \frac{k_{mn}}{M}(L_m \gamma_L L_n) H H + c.c.$
$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$
$\mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \nu_m \gamma_L \nu_n + c.c.$ ← neutrino mass
trino oscillation experiments give good evidence that ν's have mass

Unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.

$$\mathcal{L}_5 = \frac{k_{mn}}{M}(L_m^T \gamma_2 L_n) H H + \text{c.c.}$$

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \nu_m \gamma_2 \nu_n + \text{c.c.} \leftarrow \text{neutrino mass}$$

Neutrino oscillation experiments give good evidence that ν's have mass

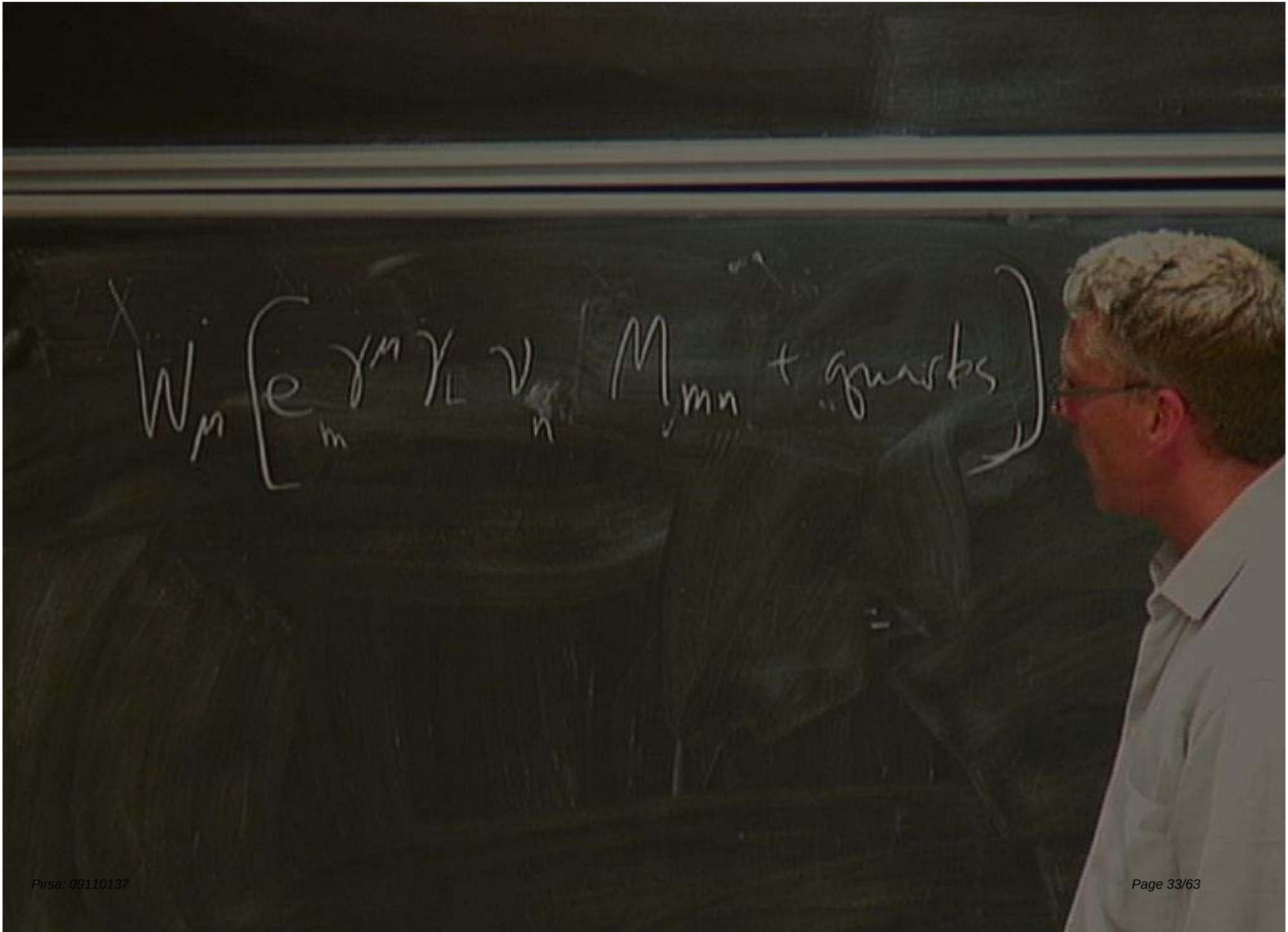
Unique $SU_3 \times SU_2 \times U_1$ invariant dim 5 interaction.

$$\mathcal{L}_5 = \frac{k_{mn}}{M}(L_m^T \gamma_2 L_n) H H + \text{c.c.}$$

$$\nu_L = \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \nu_m \gamma_2 \nu_n + \text{c.c.} \leftarrow \text{neutrino mass}$$

neutrino oscillation experiments give good evidence that ν's have masses


$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n M_{mn} + \text{quarks} \right]$

$$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$$

$$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$$

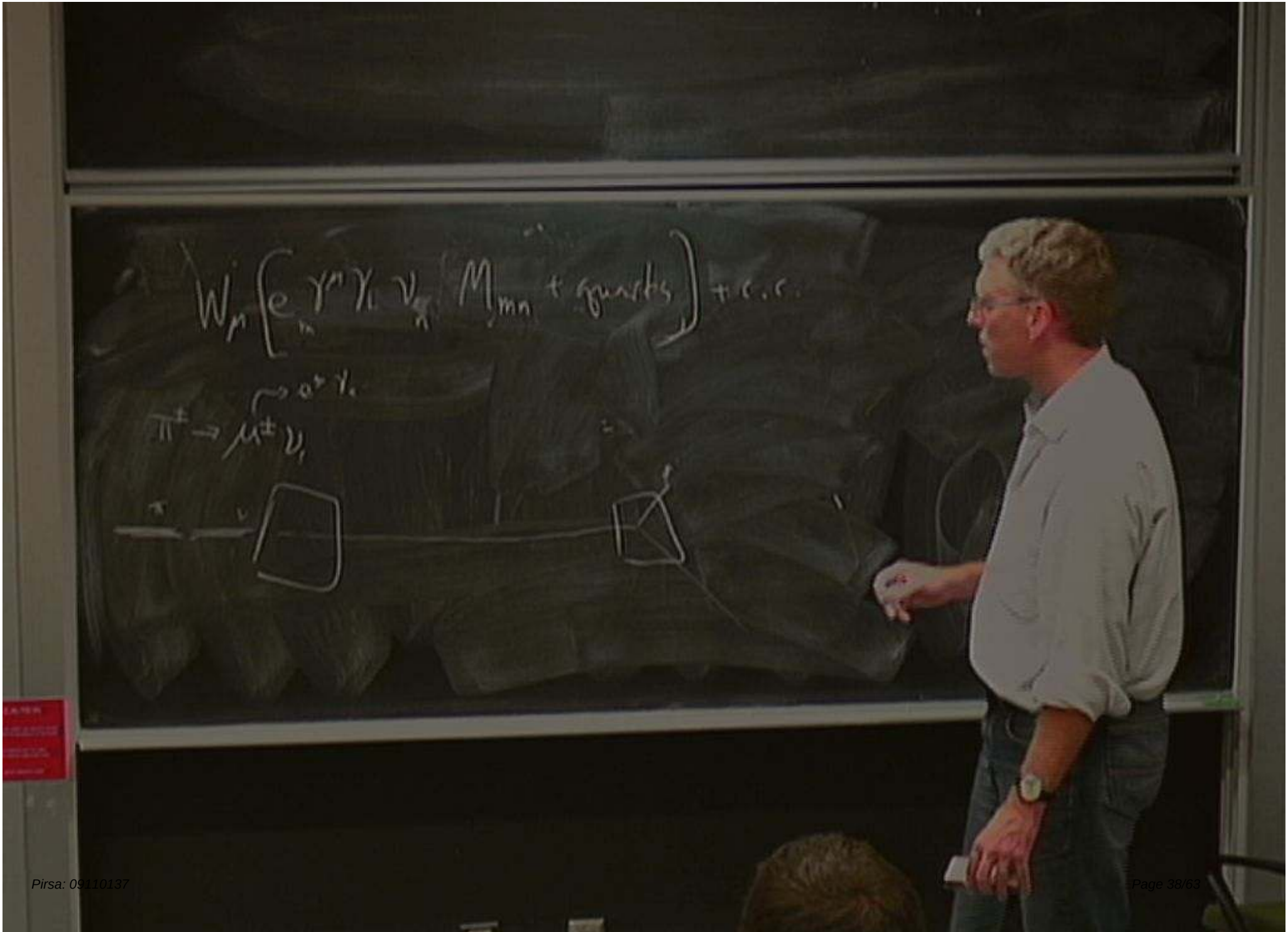
$\pi^\pm \to \mu^\pm \nu$

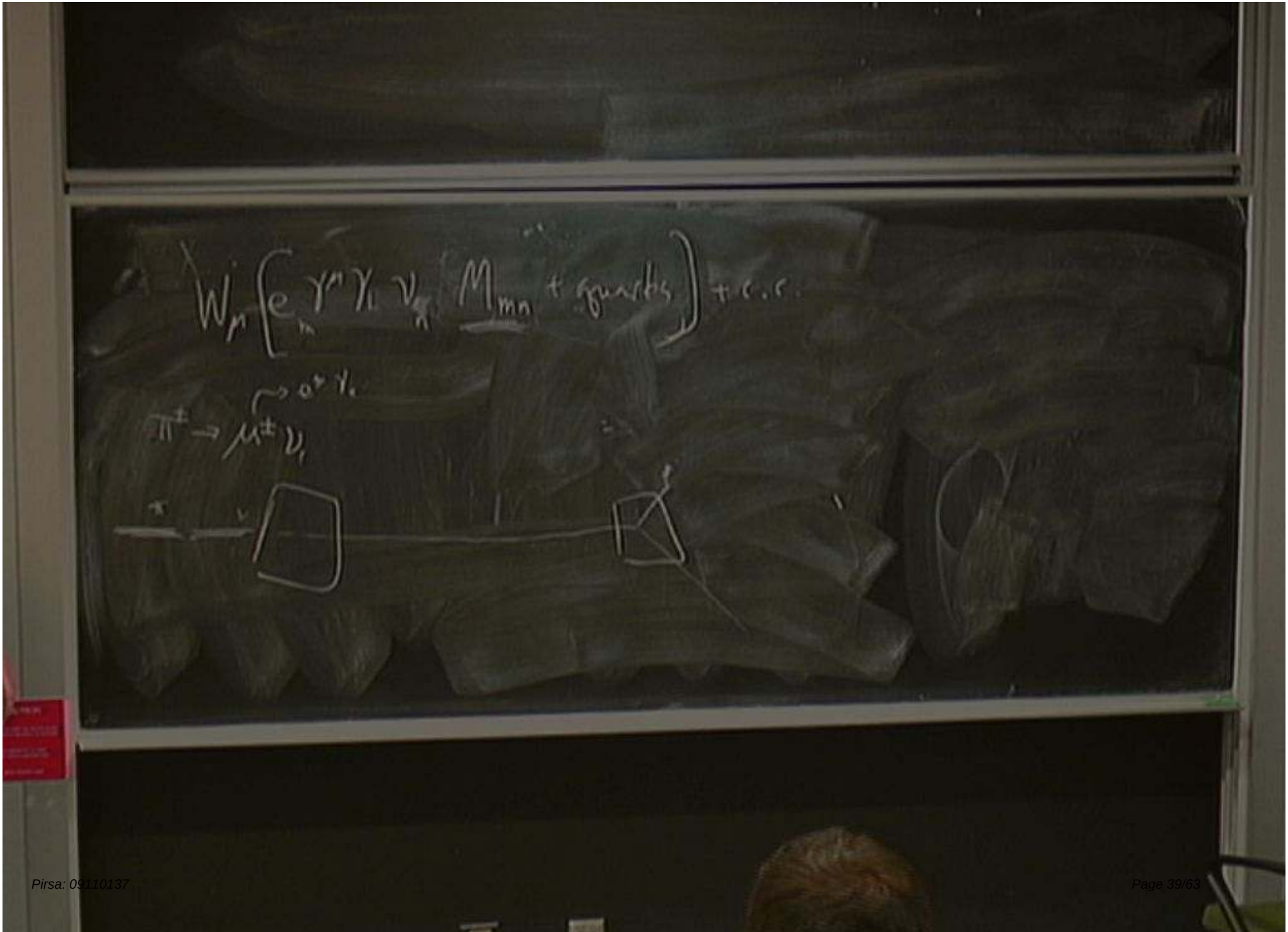
$$W_\mu \left[e_m \gamma^m \gamma_L \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$$

$\pi^\pm \to \mu^\pm \nu$ =

$$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$$

$\pi^\pm \to \mu^\pm \nu_\mu$


$W_\mu \left[e_m \gamma^\mu \gamma_5 \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$
$\pi^\pm \to \mu^\pm \nu_\mu$


$W_\mu \left[e_m \gamma^\mu \gamma_5 \nu_n M_{mn} + \text{quarks} \right] + \text{c.c.}$
$\pi^\pm \to \mu^\pm \nu_\mu$

$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \; M_{mn} + \text{quarks} \right] +$

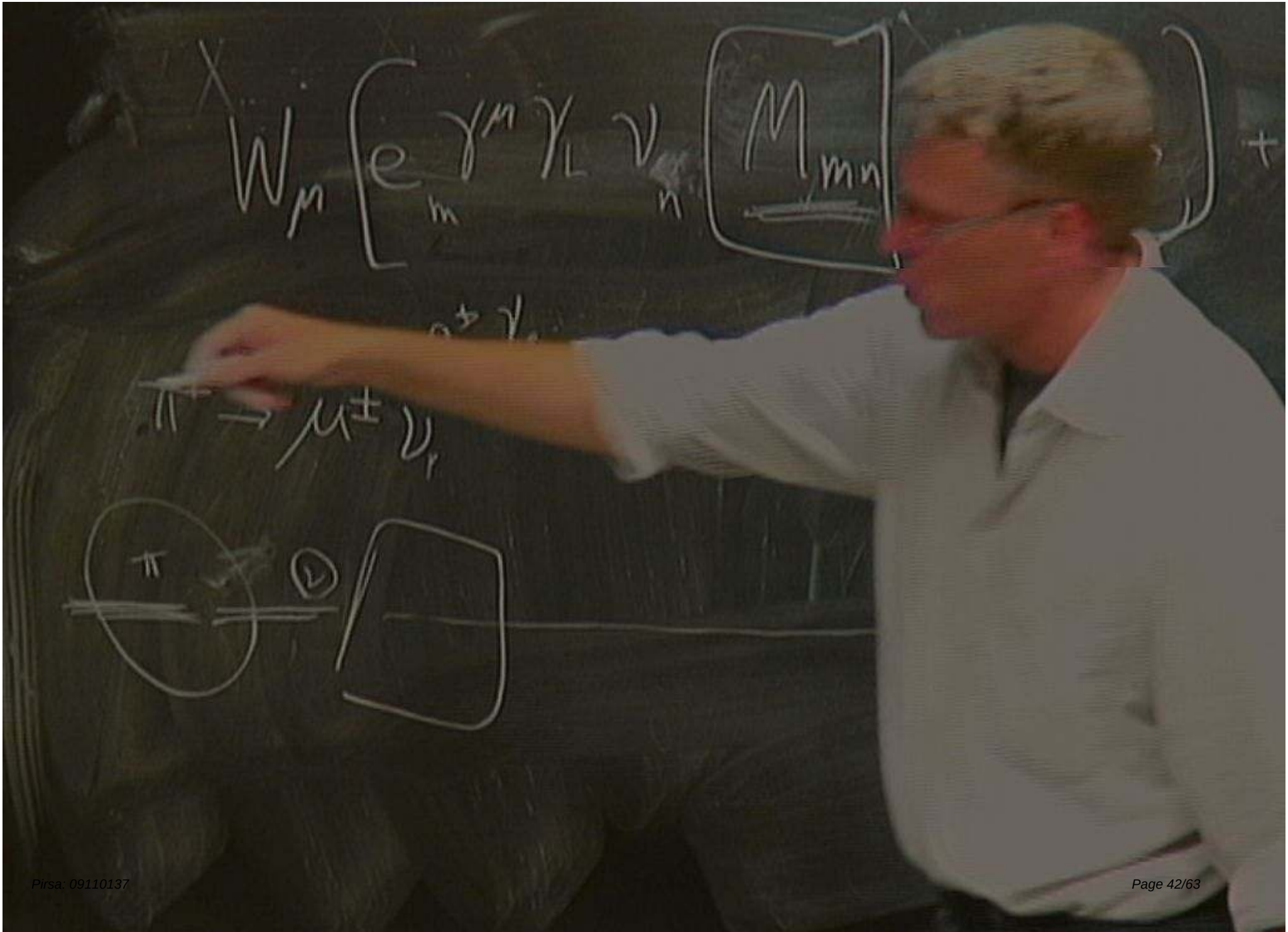
$\hookrightarrow e^\pm \nu_e$

$\pi^\pm \to \mu^\pm \nu_\mu$

$$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n M_{mn} + \text{quarks} \right] +$$

$\hookrightarrow e^\pm \nu_e$

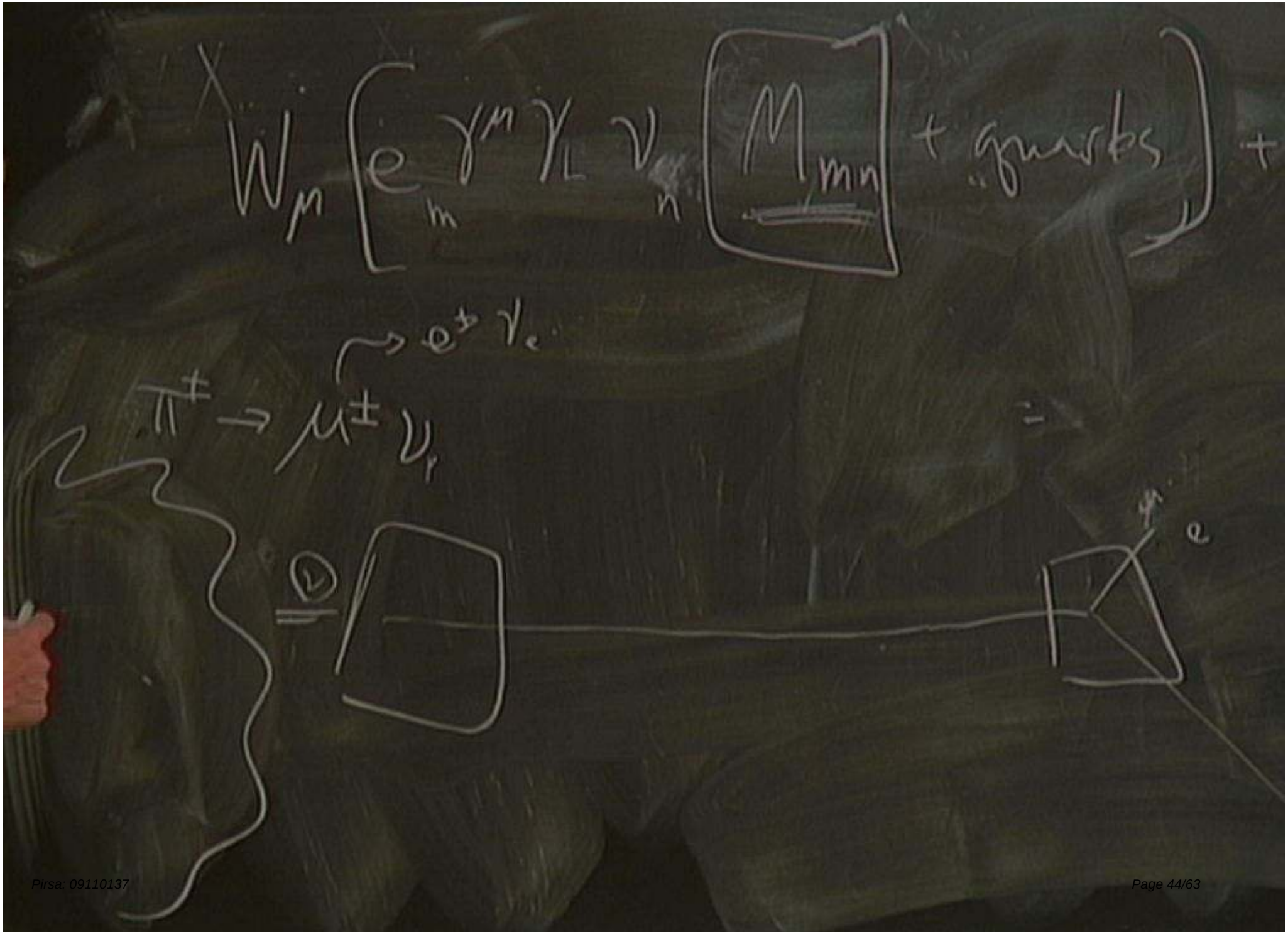
$\pi^\pm \to \mu^\pm \nu_\mu$

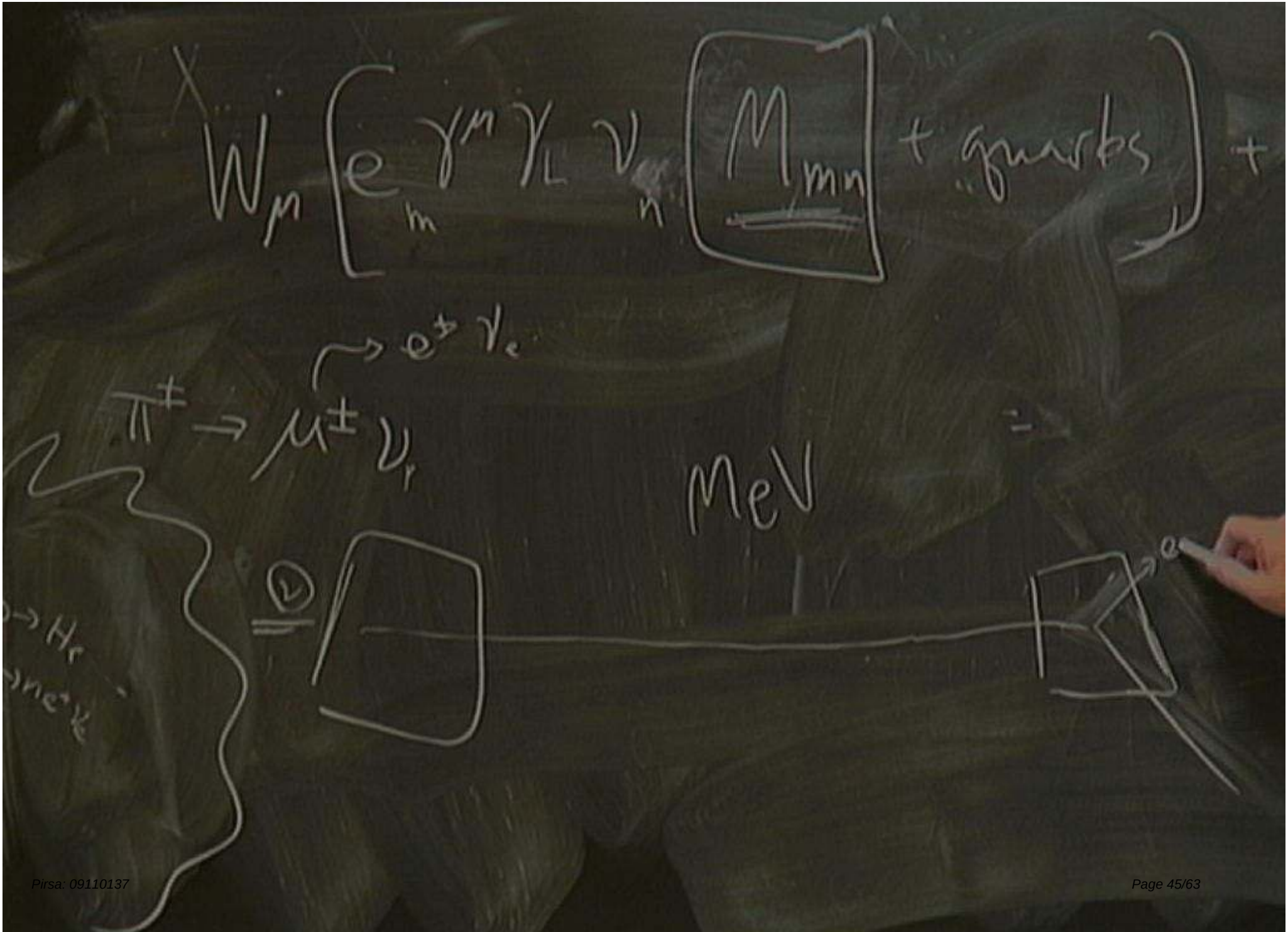

W_μ
$e_m \gamma^\mu \gamma_L \nu_n$
M_{mn}
$\pi^- \to \mu^\pm \nu_\mu$
π
ν

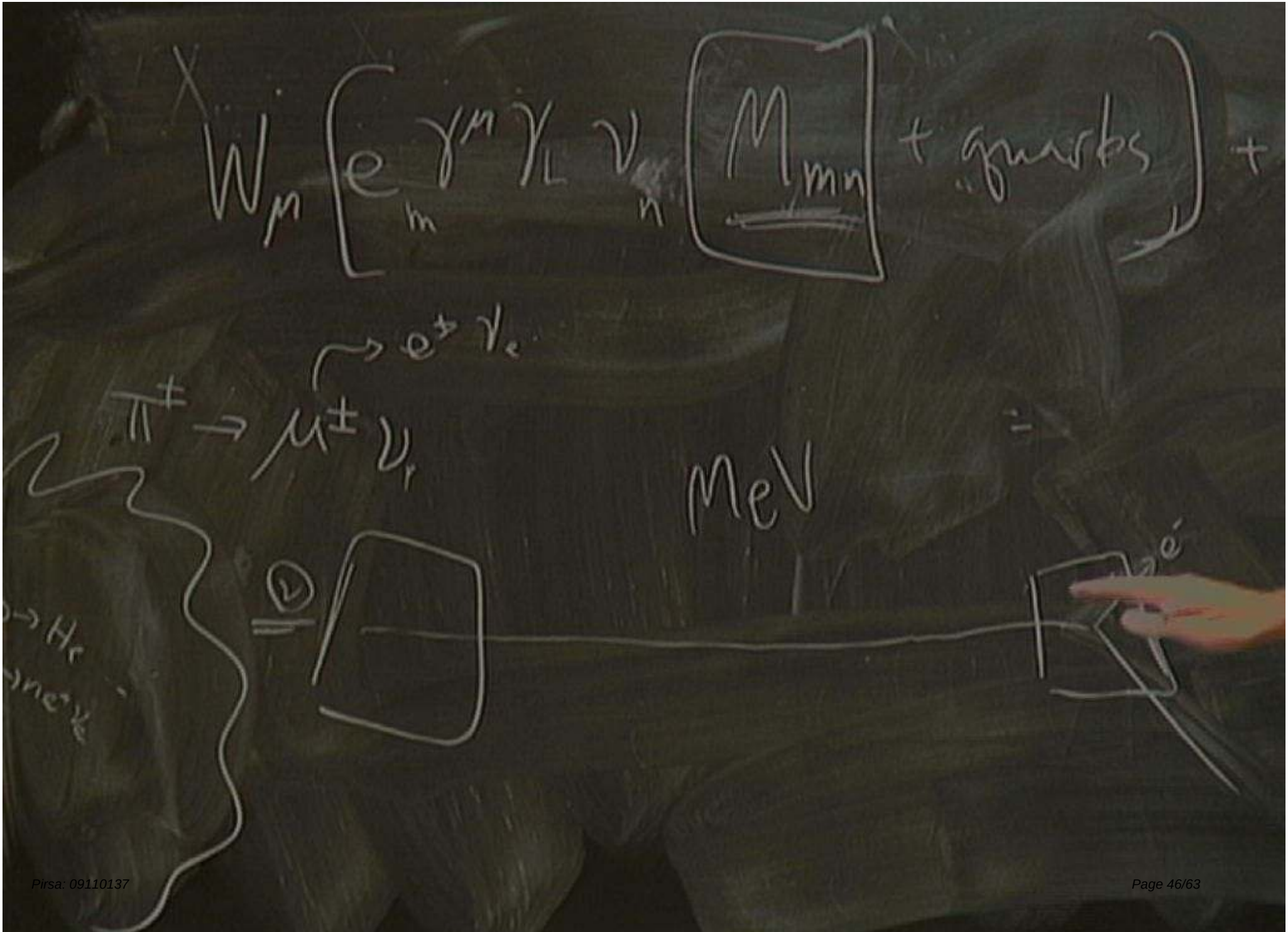
$$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \boxed{M_{mn}} + \text{quarks} \right] +$$

$\hookrightarrow e^\pm \nu_e$

$\pi^\pm \to \mu^\pm \nu_\mu$


$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \boxed{M_{mn}} + \text{quarks} \right] +$
$\hookrightarrow e^\pm \nu_e$
$\pi^\pm \to \mu^\pm \nu_\mu$
ν
e


$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \boxed{M_{mn}} + \text{quarks} \right] +$
$\to e^\pm \nu_e$
$\pi^\pm \to \mu^\pm \nu_\mu$
MeV
$\to H_e$
$\to n e^+ \nu_e$

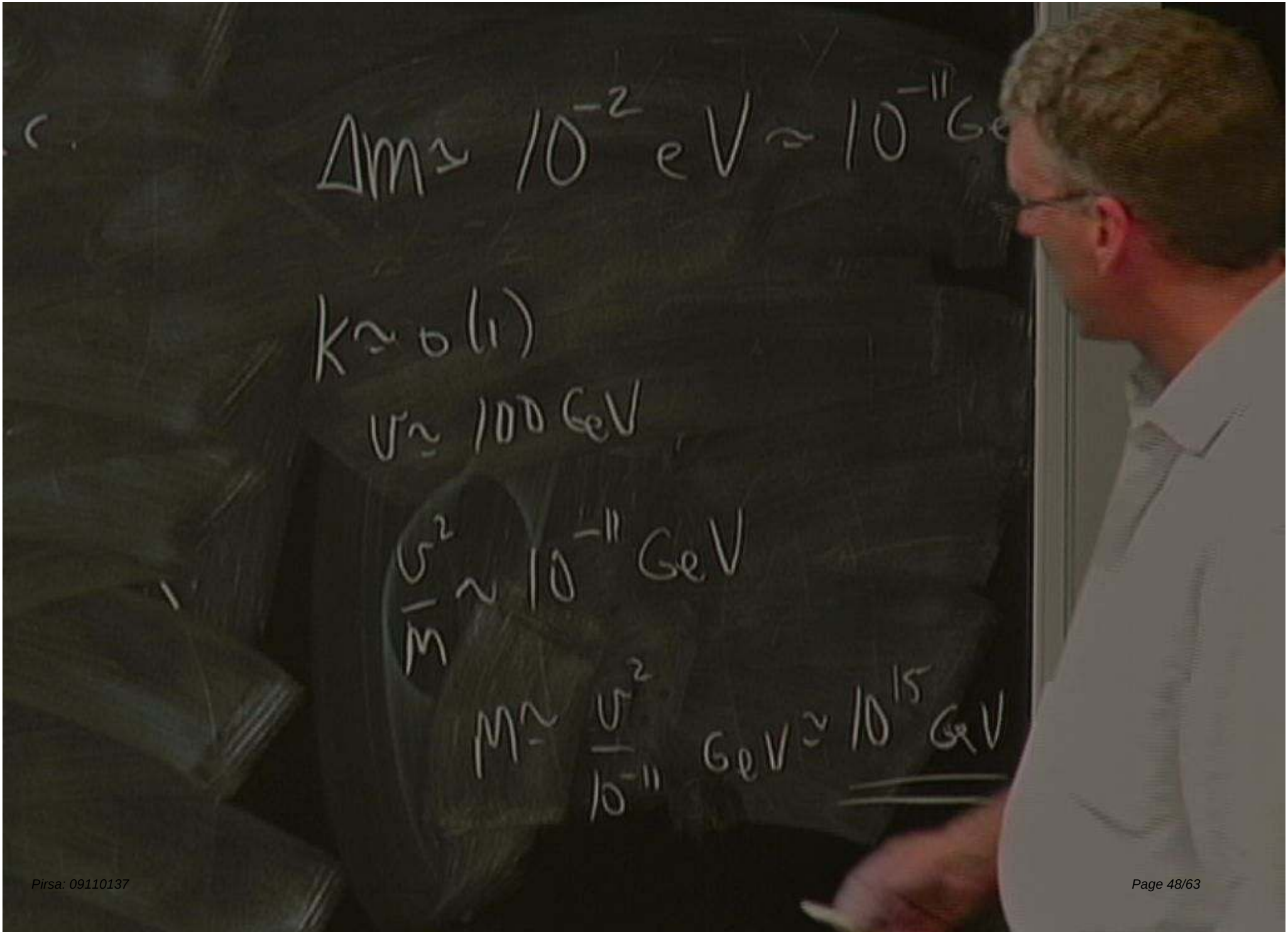

$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \boxed{M_{mn}} + \text{quarks} \right] +$
$\hookrightarrow e^\pm \nu_e$
$\pi^\pm \to \mu^\pm \nu_\mu$
MeV
ν
e^-

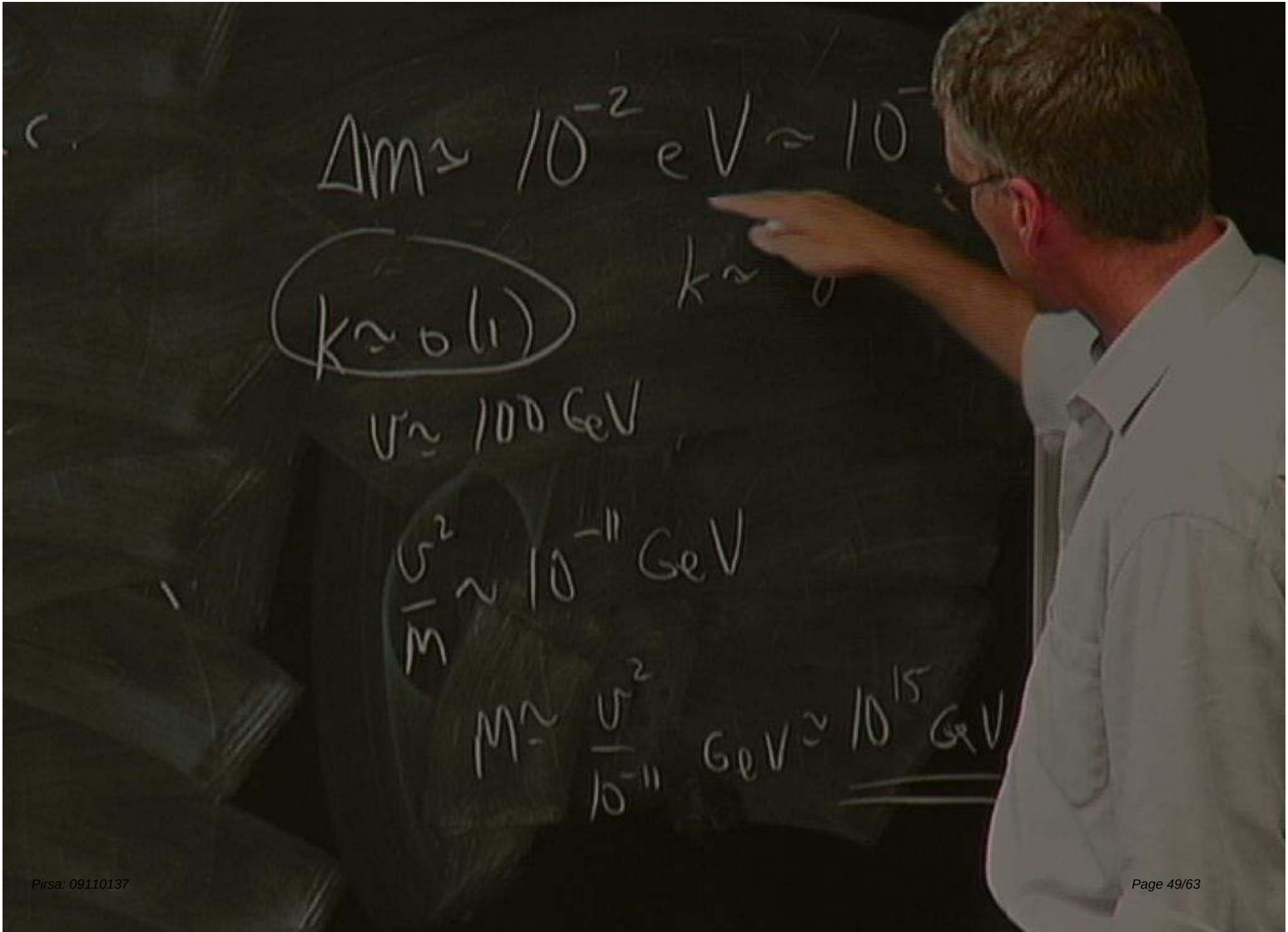
$W_\mu \left[e_m \gamma^\mu \gamma_L \nu_n \boxed{M_{mn}} + \text{quarks} \right] + c.$

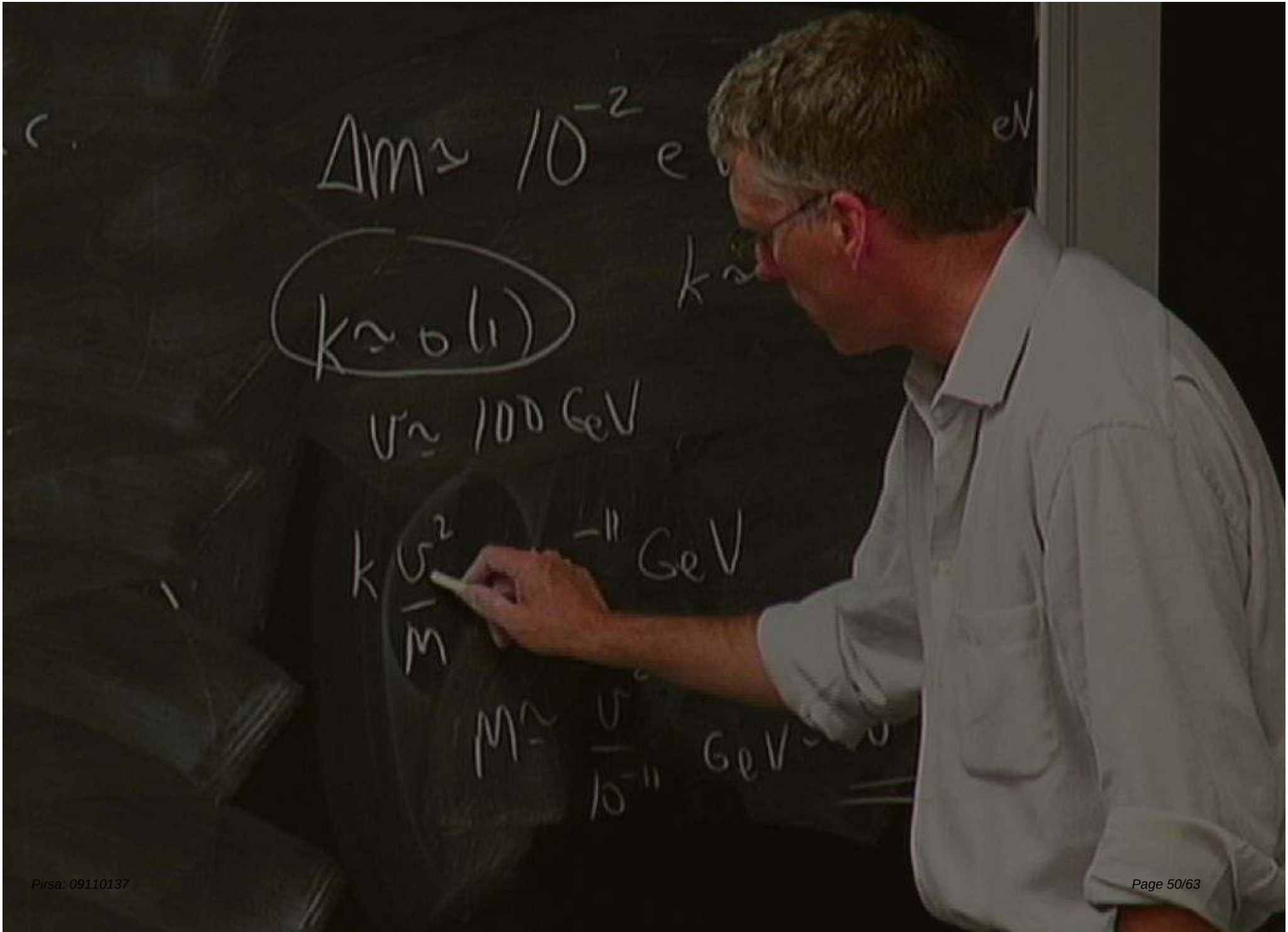
$\hookrightarrow e^\pm \nu_e \nu_\mu$

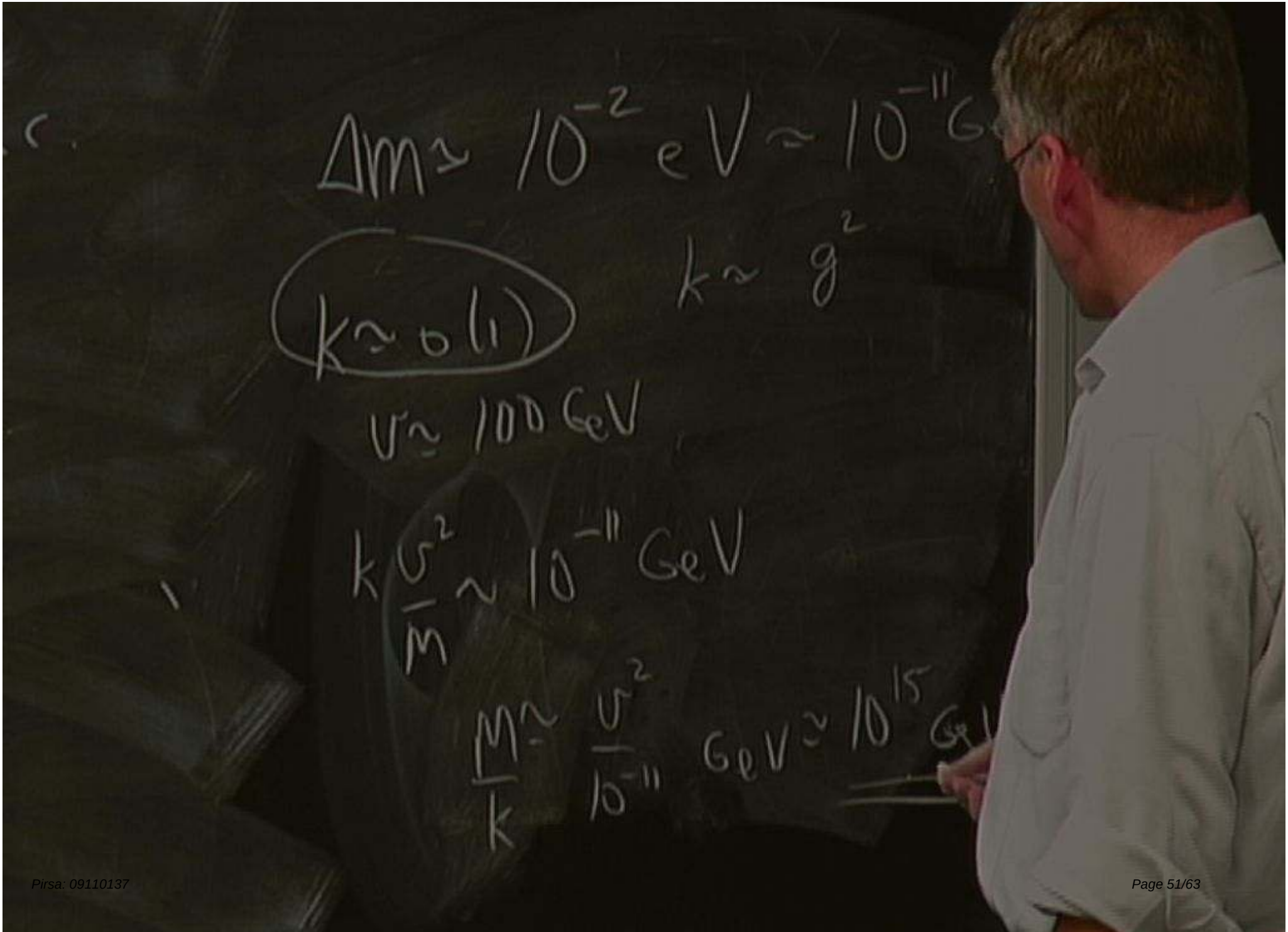
$\pi^\pm \to \mu^\pm \nu_\mu$

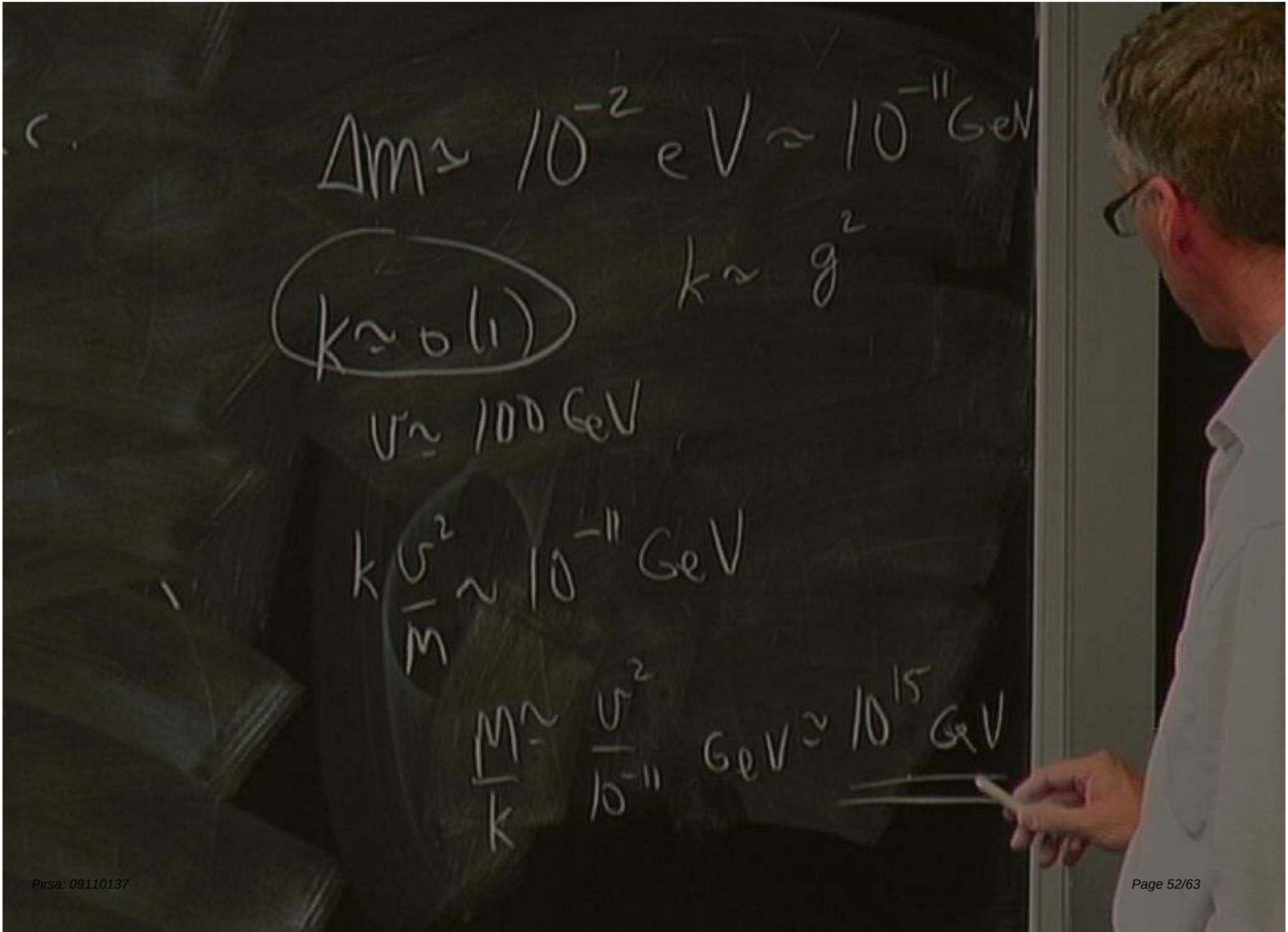
MeV


$\Delta m \simeq 10^{-2}$ eV $\simeq 10^{-11}$ Ge
$k \simeq o(1)$
$v \simeq 100$ GeV
$\frac{v^2}{M} \simeq 10^{-11}$ GeV
$M \simeq \frac{v^2}{10^{-11}}$ GeV $\simeq 10^{15}$ GeV


$\Delta m \sim 10^{-2}$ eV
$k \sim O(1)$
$v \sim 100$ GeV
$\frac{v^2}{M} \sim 10^{-11}$ GeV
$M \sim \frac{v^2}{10^{-11}}$ GeV $\sim 10^{15}$ GeV


$\Delta m \sim 10^{-2}$ eV
$k \sim O(1)$
$v \sim 100$ GeV
$k \frac{v^2}{M} \sim 10^{-11}$ GeV
$M \sim \frac{v}{10^{-11}}$ GeV


$\Delta m \sim 10^{-2}\ eV \sim 10^{-11}$
$k \sim g^2$
$k \sim o(1)$
$v \sim 100\ GeV$
$k\frac{v^2}{M} \sim 10^{-11}\ GeV$
$\frac{M}{k} \sim \frac{v^2}{10^{-11}}\ GeV \sim 10^{15}$


$\Delta m \sim 10^{-2}\ eV \sim 10^{-11}\ GeV$
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$k \simeq O(1)$
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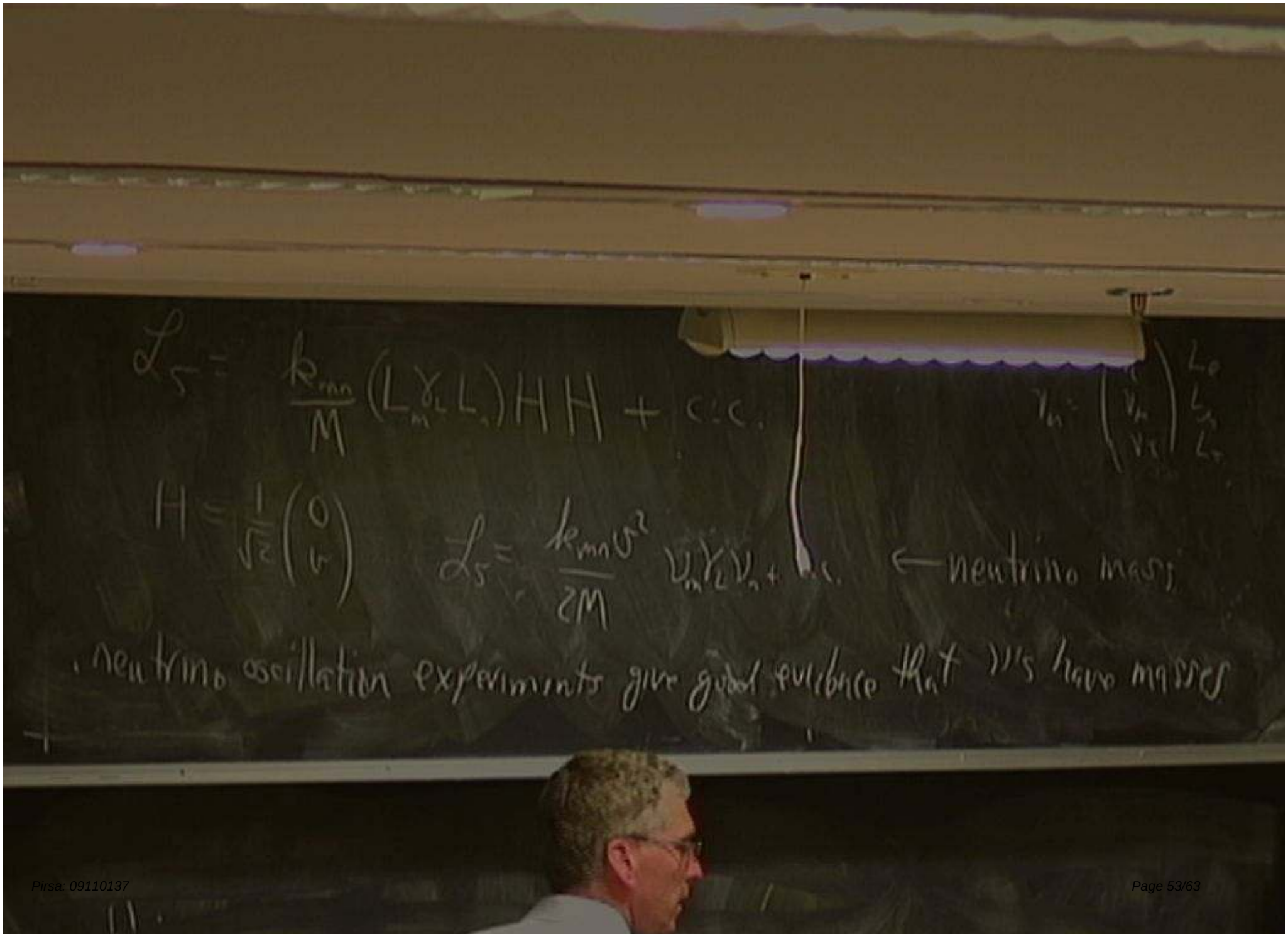

$\mathcal{L}_5 = \frac{k_{mn}}{M}(L_m \gamma_L L_n) H H + c.c.$
$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$
$\mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \nu_m \gamma_L \nu_n + c.c.$
← neutrino mass
neutrino oscillation experiments give good evidence that ν's have masses

$$\mathcal{L}_5 = \frac{k_{mn}}{M}(L_m \gamma_L L_n) H H + c.c.$$

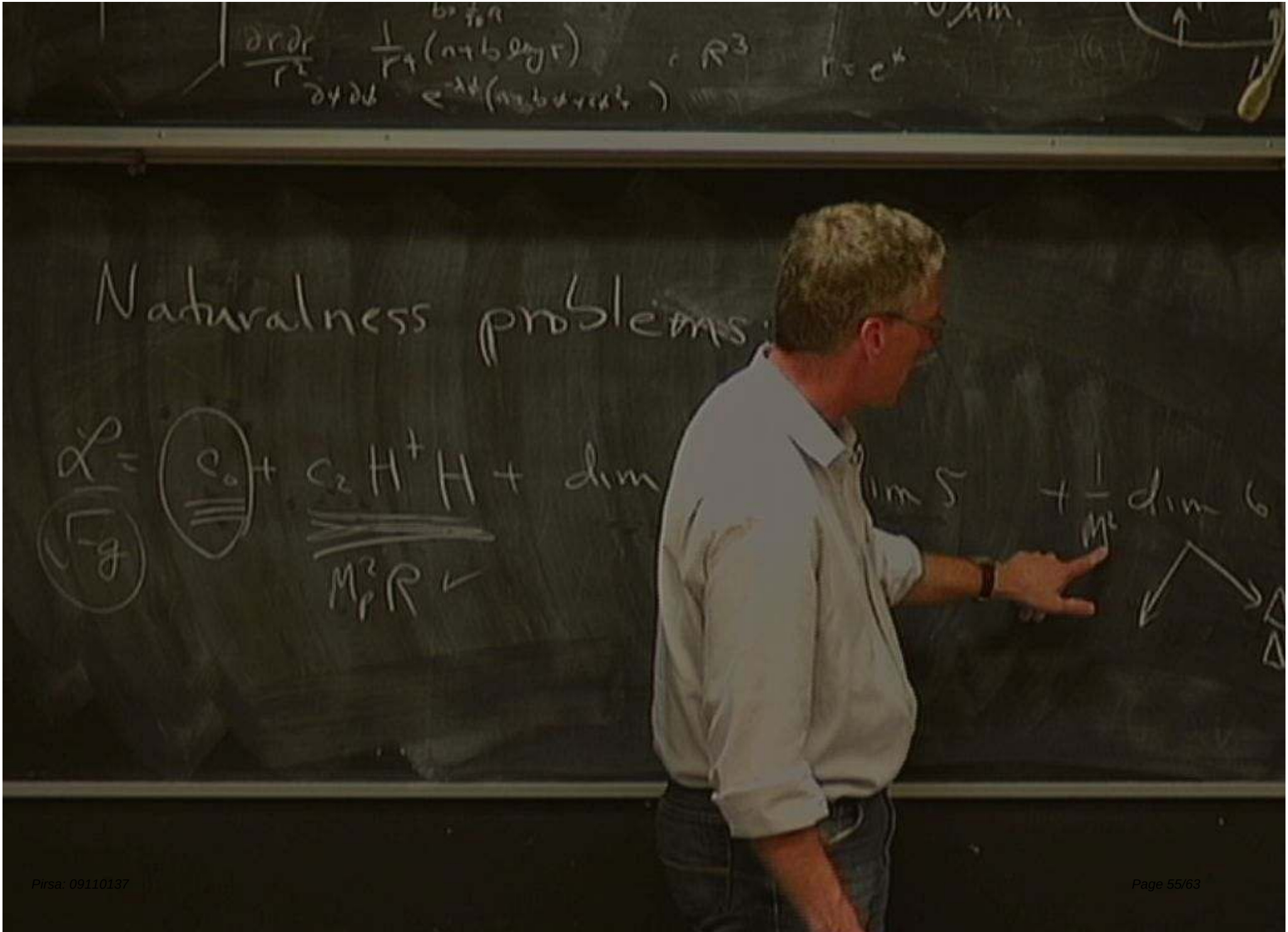
$$\nu_m = \begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} \begin{matrix} L_e \\ L_\mu \\ L_\tau \end{matrix}$$

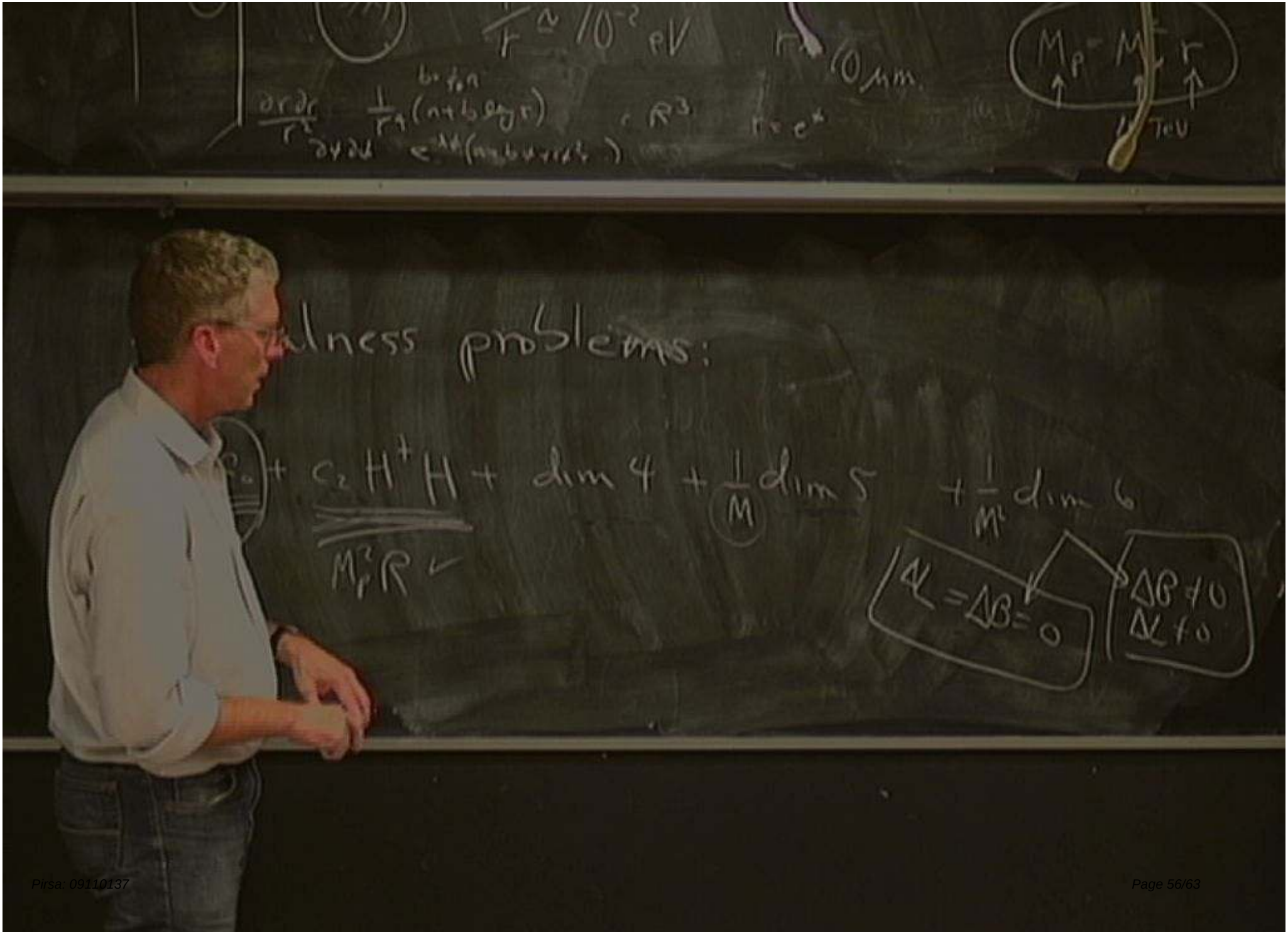
$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}$$

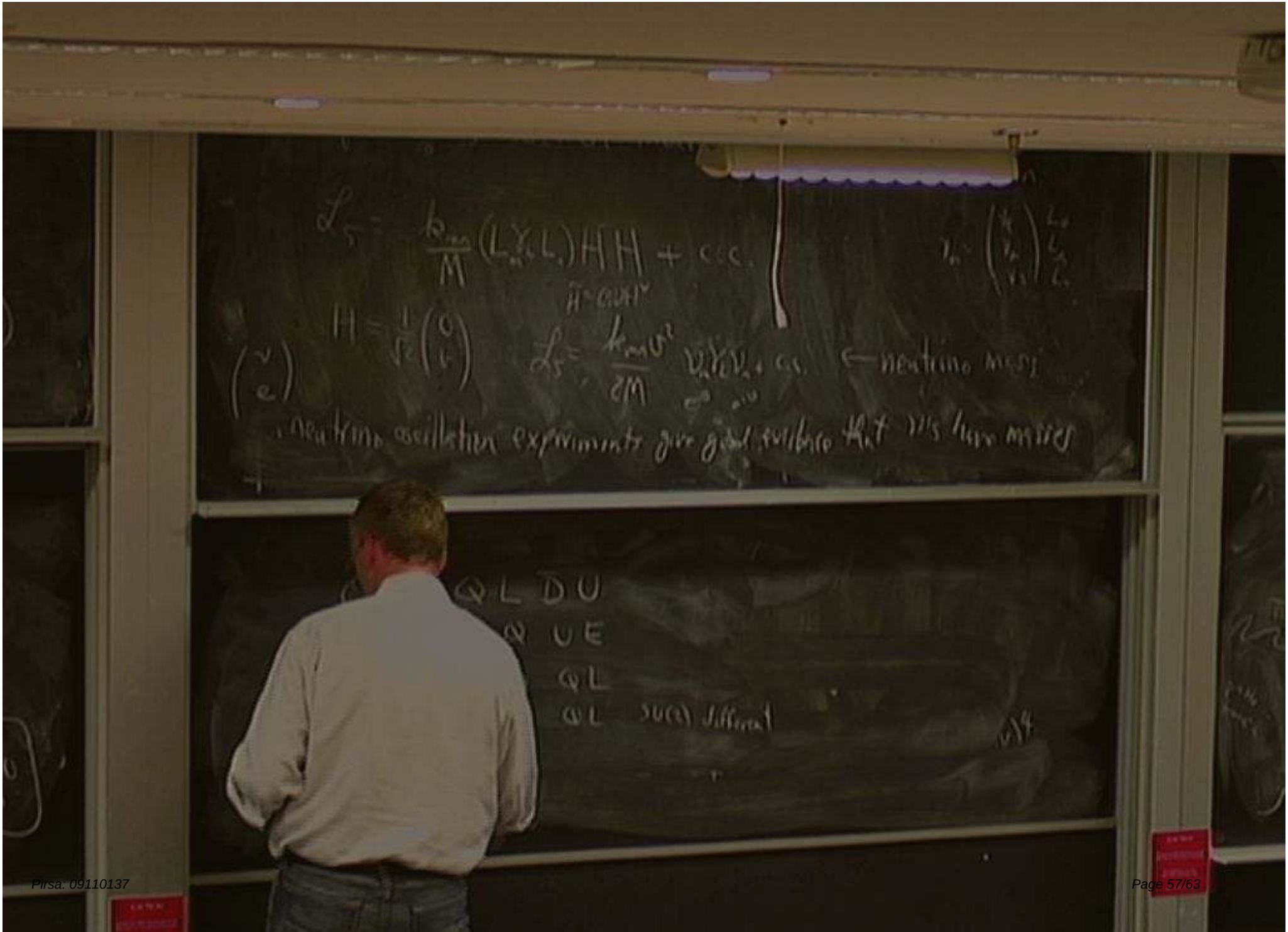
$$\begin{pmatrix} \nu \\ e \end{pmatrix}$$

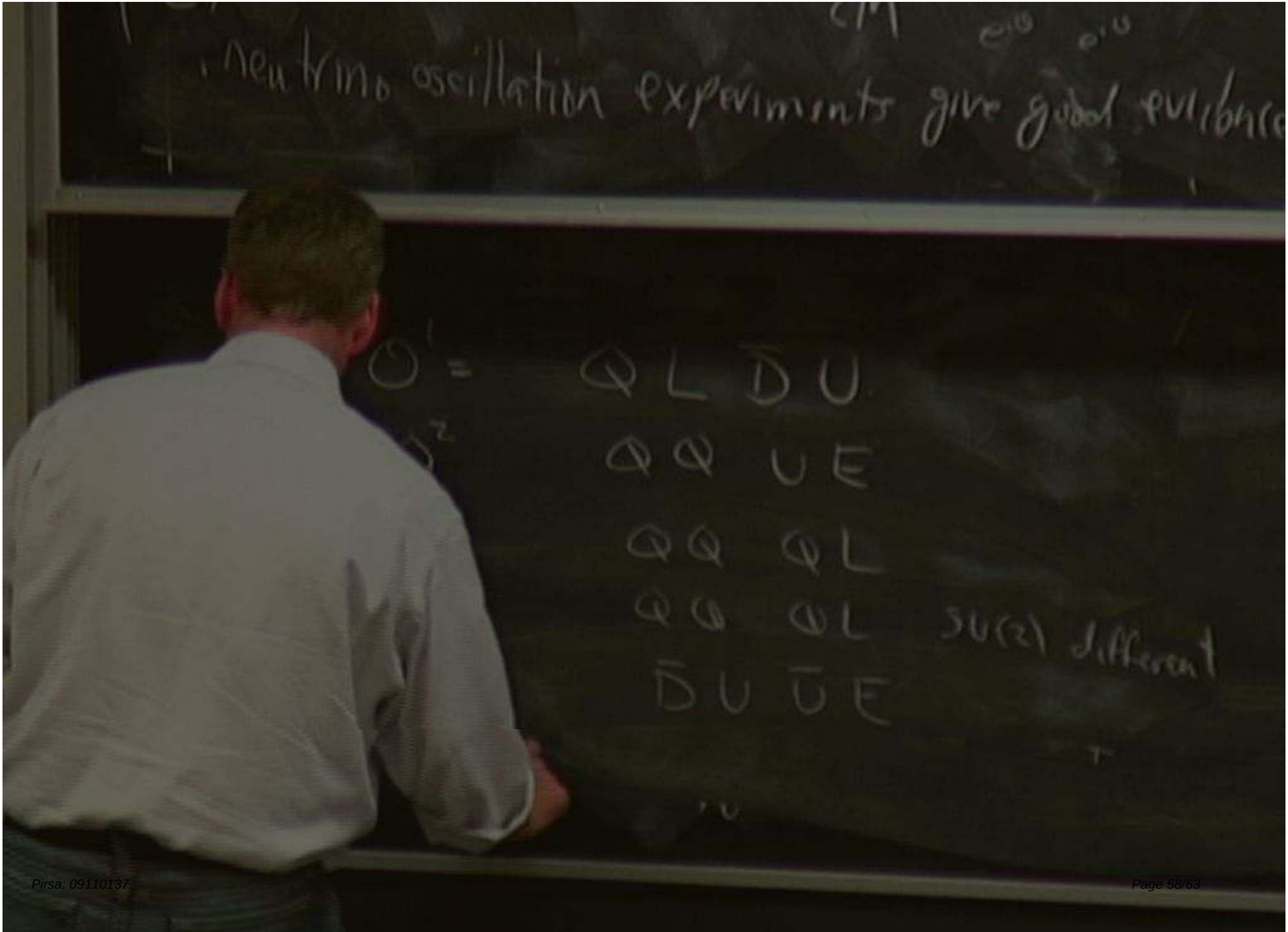
$$\mathcal{L}_5 = \frac{k_{mn} v^2}{2M} \underset{e^{i\theta}}{\nu_m} \gamma_L \underset{e^{i\theta}}{\nu_n} + c.c. \quad \leftarrow \text{neutrino mass}$$

neutrino oscillation experiments give good evidence that ν's have masses


Naturalness problems:


dness problems:
$c_2 H^\dagger H$ + dim 4 + $\frac{1}{M}$ dim 5 + $\frac{1}{M^2}$ dim 6
$M_P^2 R$
$\Delta L = \Delta B = 0$
$\Delta B \neq 0$
$\Delta L \neq 0$


← neutrino mass
neutrino oscillation experiments give good evidence that ν's have masses
QLDU
QUE
QL
QL SU(2) different


neutrino oscillation experiments give good evidence
SU(2) different

neutrino oscillation experiments give good evidence

$O^1 = QLD\bar{U}$

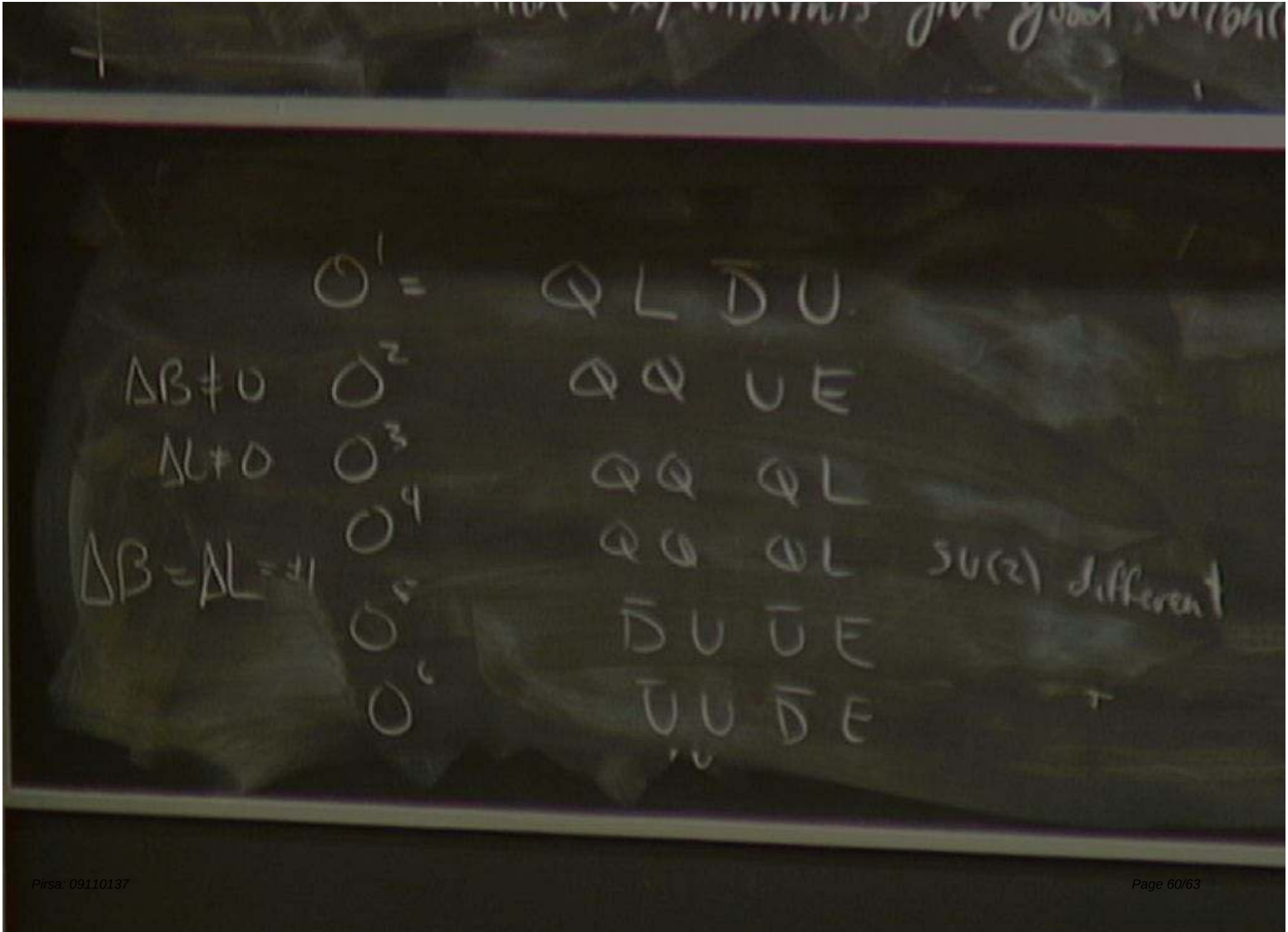
$O^2 = QQU\bar{E}$

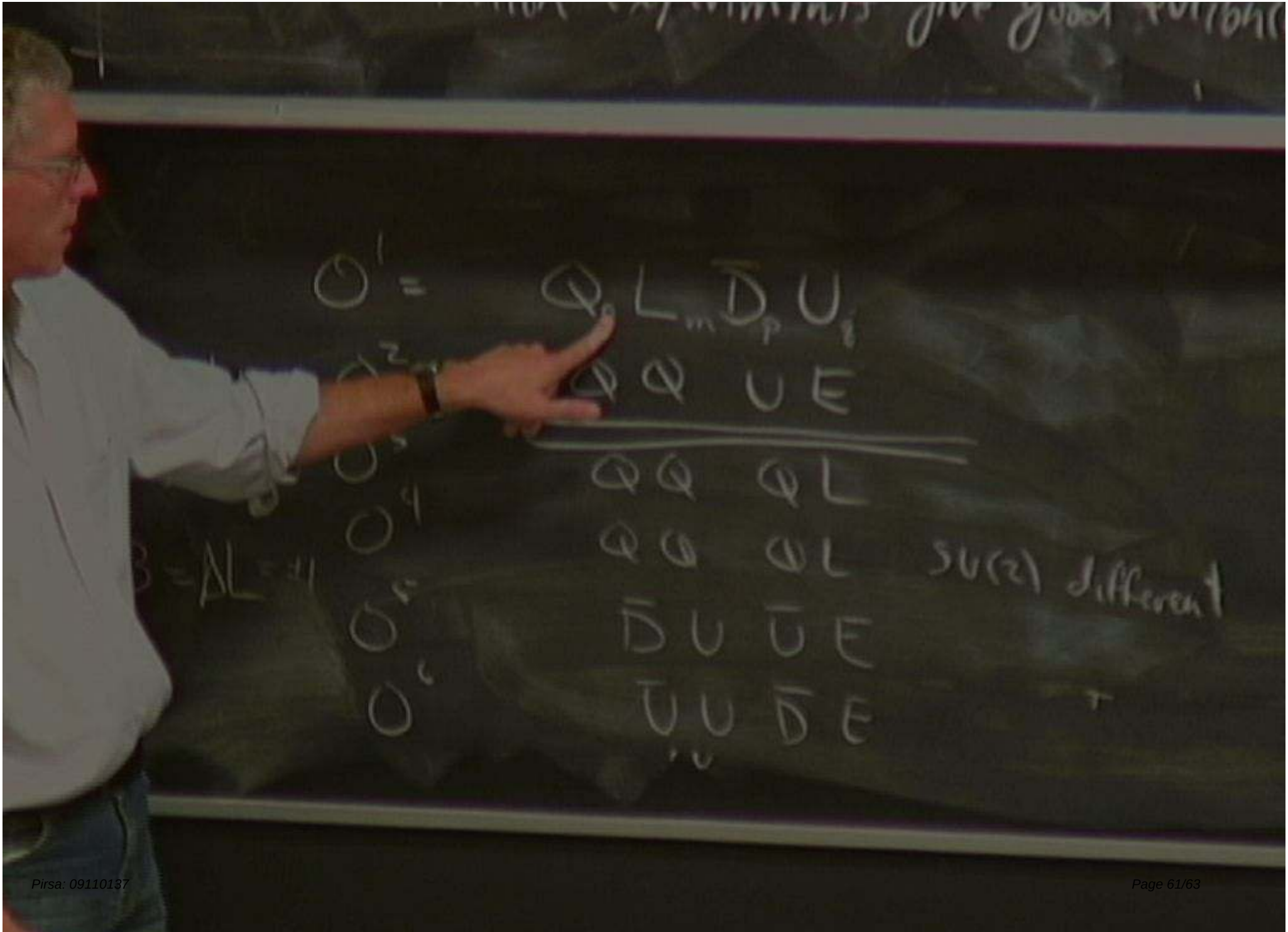
$O^3 = QQQL$

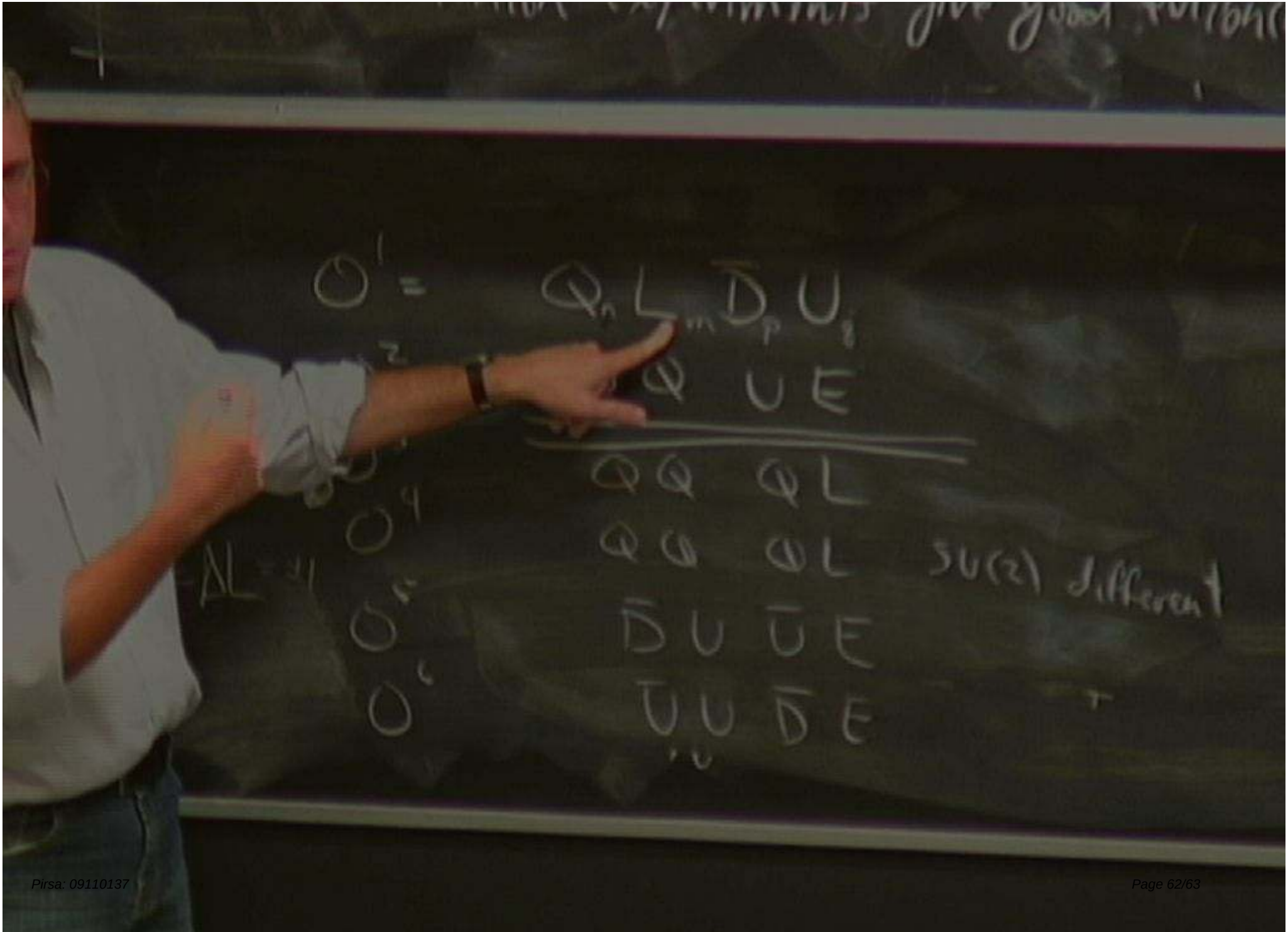
$O^4 = QQQL$ SU(2) different

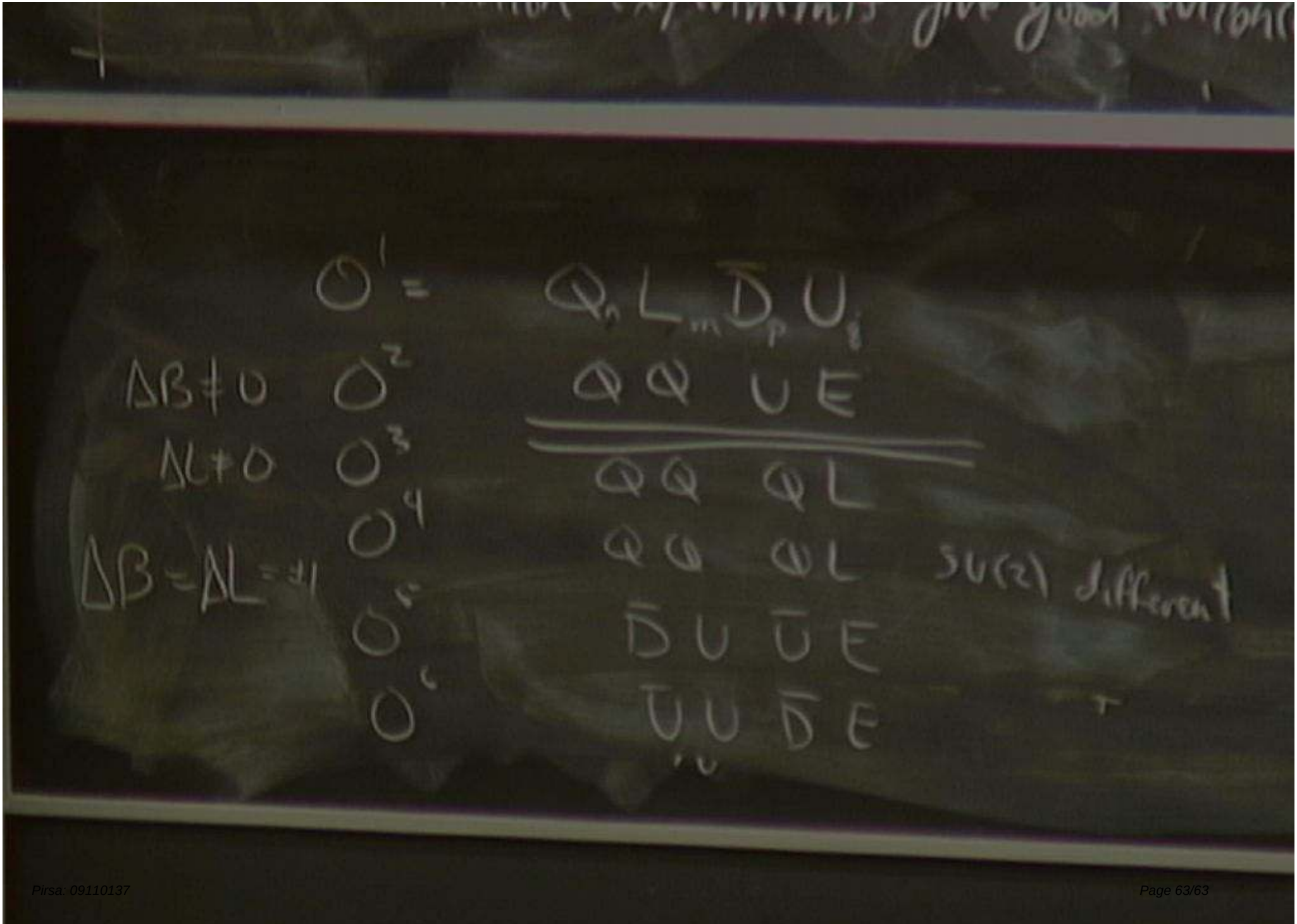
$O^5 = \bar{D}U\bar{U}\bar{E}$

$O^6 = \bar{U}U\bar{D}E$


$O^1 = QLD\bar{U}$
$\Delta B \neq 0$ O^2 $QQU\bar{E}$
$\Delta L \neq 0$ O^3 $QQQ\bar{L}$
O^4 $QQ\bar{Q}\bar{L}$
$\Delta B = \Delta L = 1$ O^5 $\bar{D}U\bar{U}\bar{E}$
O^6 $\bar{U}U\bar{D}\bar{E}$
SU(2) different


O¹ = Q L_m D̄_p U_q
Q Q U E
Q Q Q L
Q Q Q L
SU(2) different
D̄ U Ū E
Ū U D̄ E
B = ΔL = ±1


O' = Q_n L_m D̄_p U_q
Q U E
QQ QL
QQ QL SU(2) different
D̄ U Ū E
Ū U D̄ E


$O^1 = Q_n L_m \bar{D}_p U_q$
$\Delta B \neq 0$ O^2 $Q Q U E$
$\Delta L \neq 0$ O^3
O^4 $Q Q Q L$
$\Delta B = \Delta L = 1$ O^5 $Q Q Q L$ SU(2) different
O^6 $\bar{D} U \bar{U} E$
O^7 $\bar{U} U \bar{D} E$