

Title: Graduate Course on Standard Model & Quantum Field Theory - 16B

Date: Mar 28, 2007 03:30 PM

URL: <http://pirsa.org/07030046>

Abstract: Graduate Course on Standard Model & Quantum Field Theory

Can you tell experimentally if L is broken?

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Yes: $\beta\beta$ decay would im

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Yes: $0\nu\beta\beta$ decay would imply L broken.

Can you tell experimentally

Yes: $0\nu\beta\beta$ decay would imply

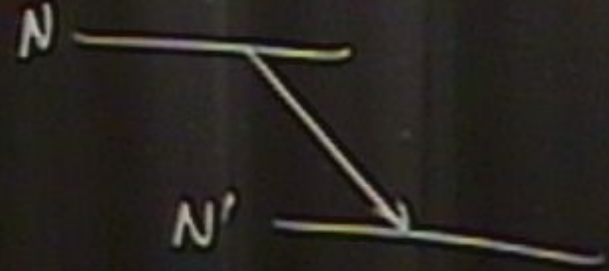
β decay

Can you tell experimentally if L is broken

Yes: $0\nu\beta\beta$ decay would imply L broken.

β decay

$$N \rightarrow N' e^- \bar{\nu}_e$$



Yes: $0\nu\beta\beta$ decay would imply

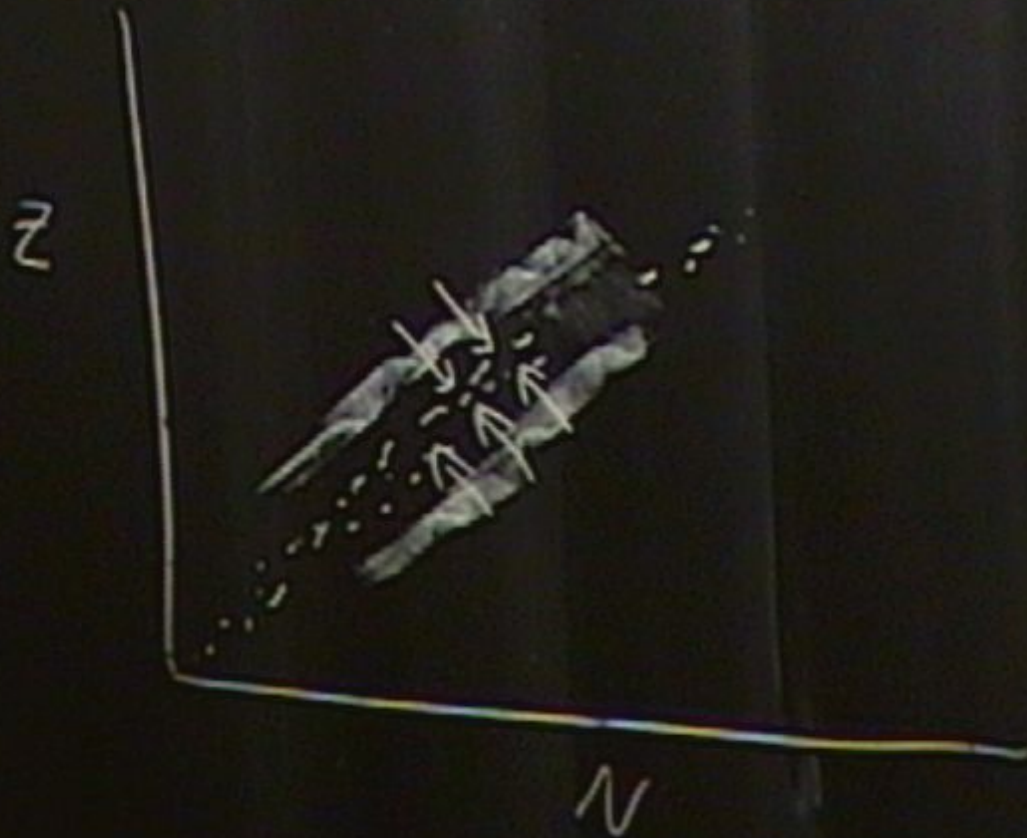
β decay $N \rightarrow N' e^- \bar{\nu}_e$ $N -$

z

N

Yes: $0\nu\beta\beta$ decay would imply

β decay $N \rightarrow N' e^- \bar{\nu}_e$ $N -$



Yes: $0\nu\beta\beta$ decay

 β decay

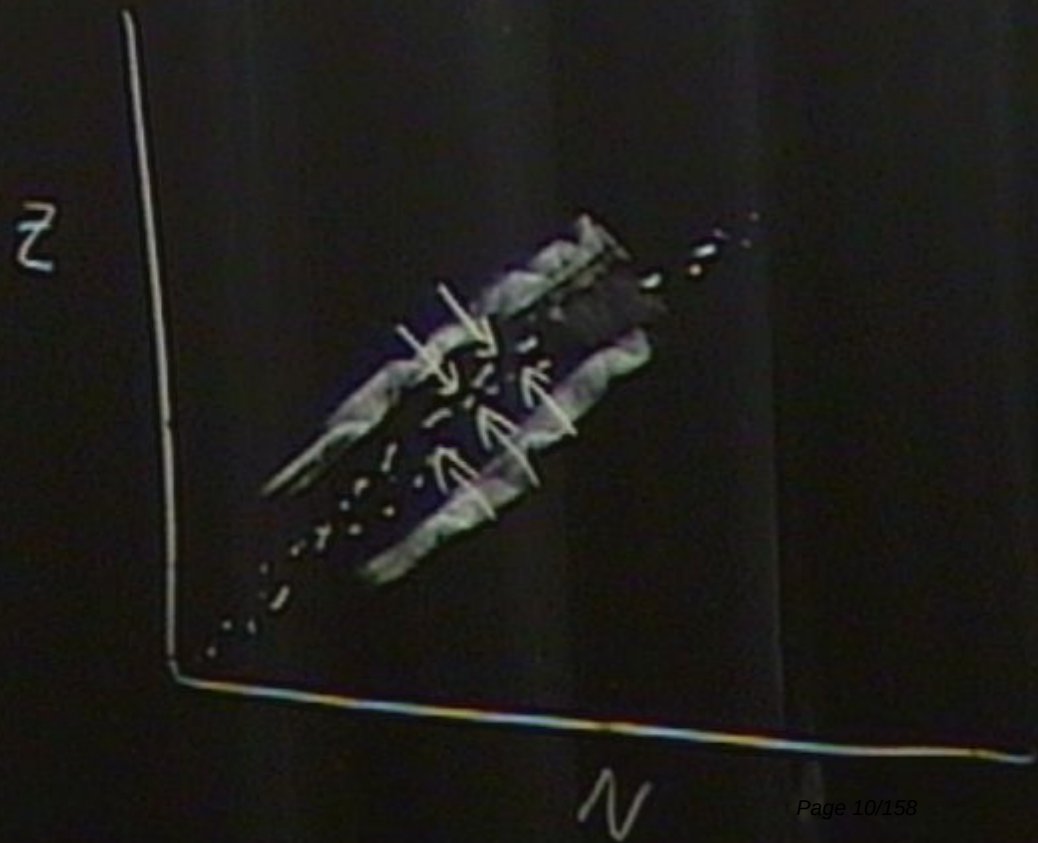
$N \rightarrow N$



Yes: $\nu\bar{\nu}\beta\beta$ decay

 β decay

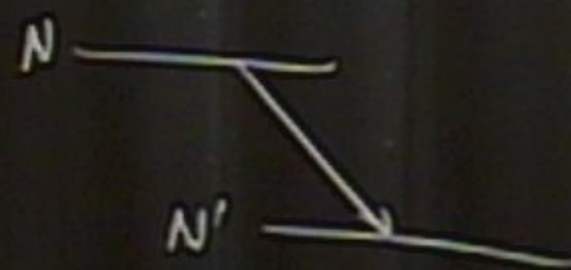
$N \rightarrow N$



Yes: $0\nu\beta\beta$ decay would imply L broken.

β decay

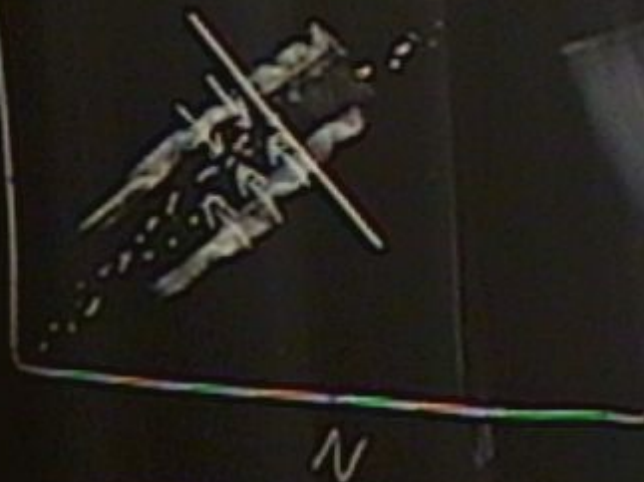
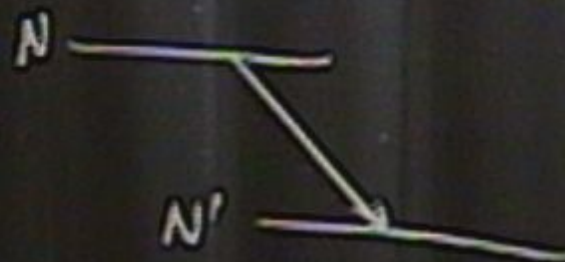
$e^- \bar{\nu}_e$



2

Yes: $0\nu\beta\beta$ decay would imply L broken.

β decay $N \rightarrow N' e^- \bar{\nu}_e$



$\exists$ nuclei for which

es: $0\nu\beta\beta$ decay would imply L broken.

β decay

N

$\bar{\nu}_e$

N

N'

$\exists$

nuclei for which

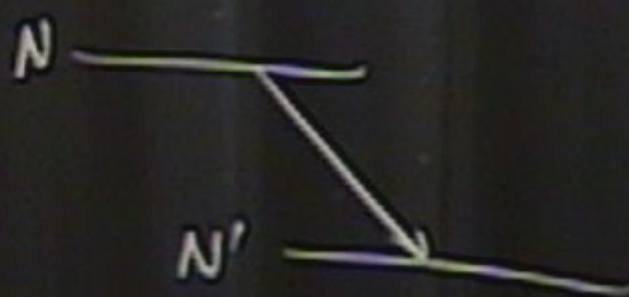
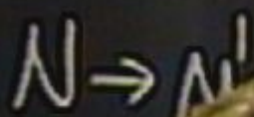
Z, N

$Z+1, N-1$

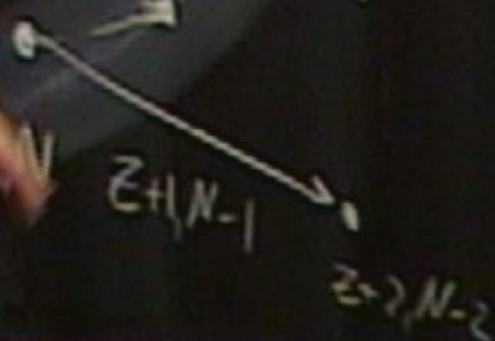
$Z+2, N-2$

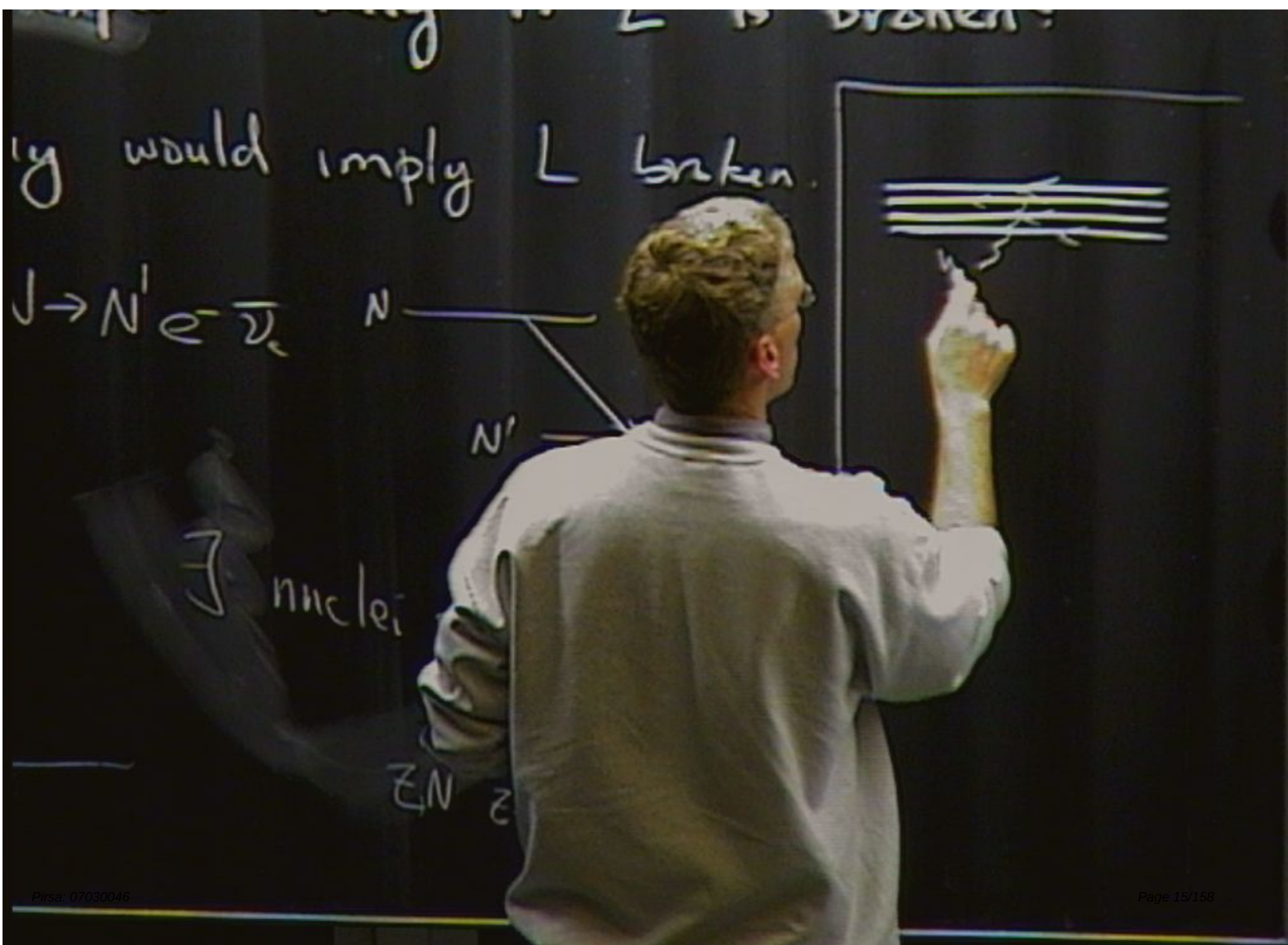
es: $0\nu\beta\beta$ decay would imply L broken.

β decay



nuclei for which

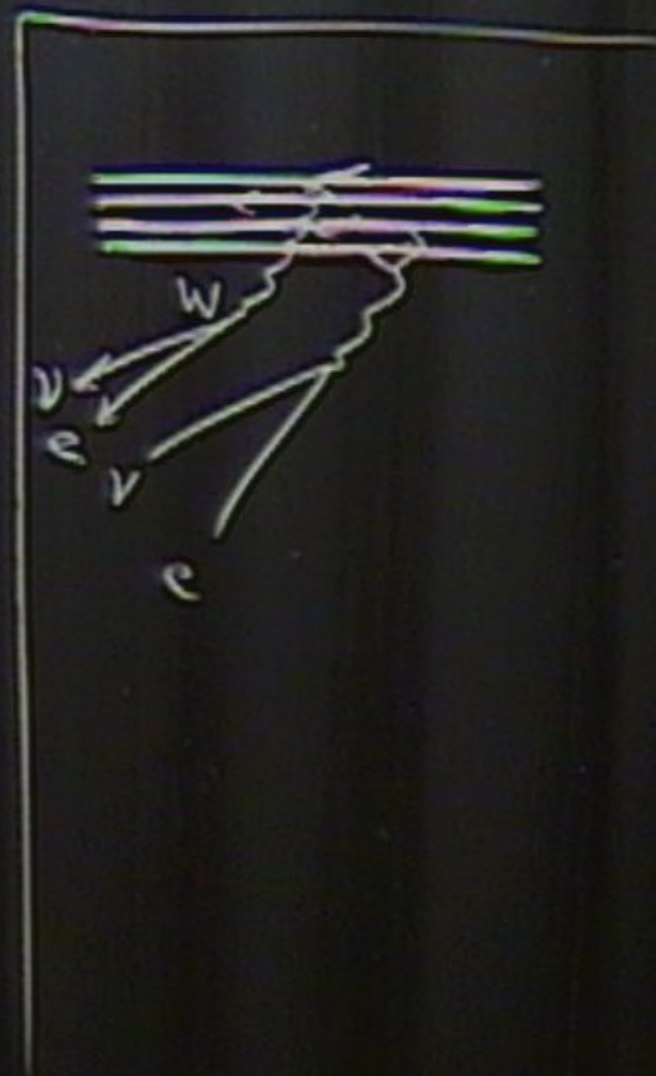




... would imply L broken.

... would imply L broken.

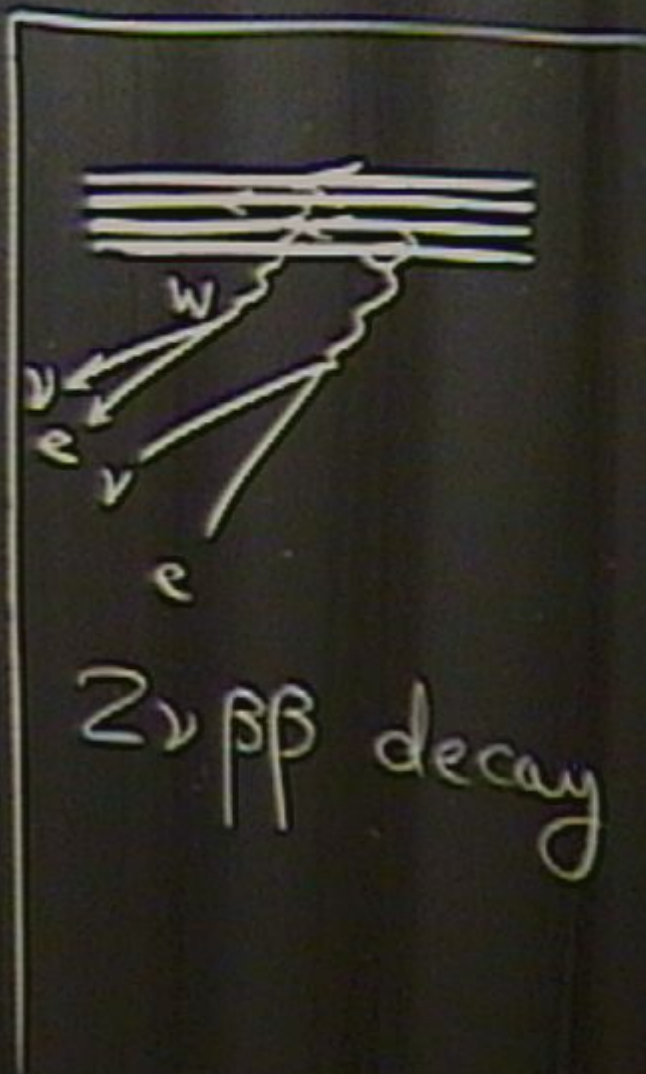
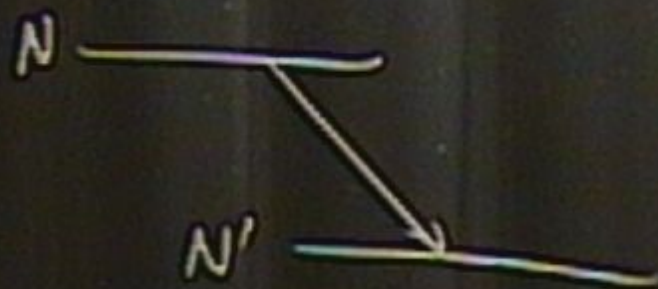
$$J \rightarrow N' e^- \bar{\nu}_e$$



... L is broken:

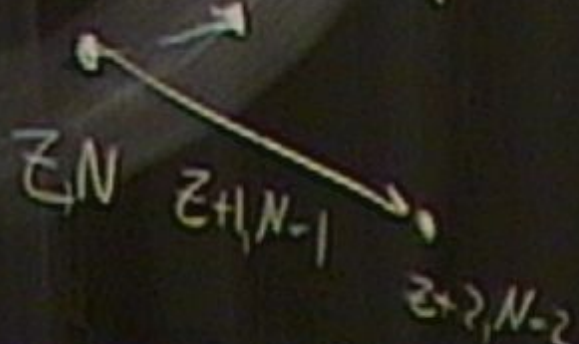
... would imply L broken.

$e^- \bar{\nu}_e$

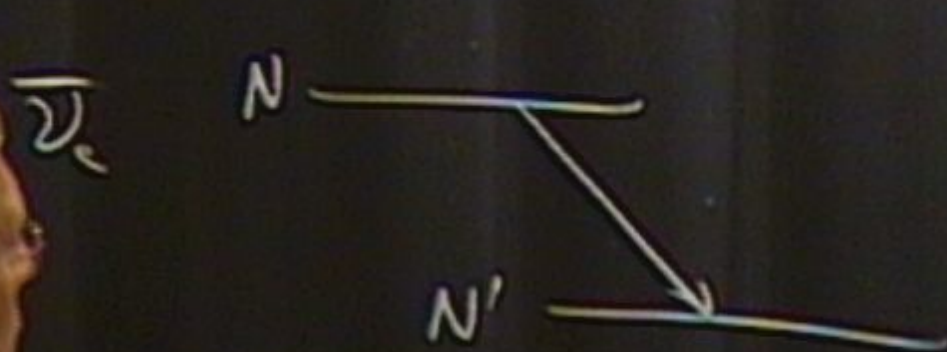


$Z^0 \beta\beta$ decay

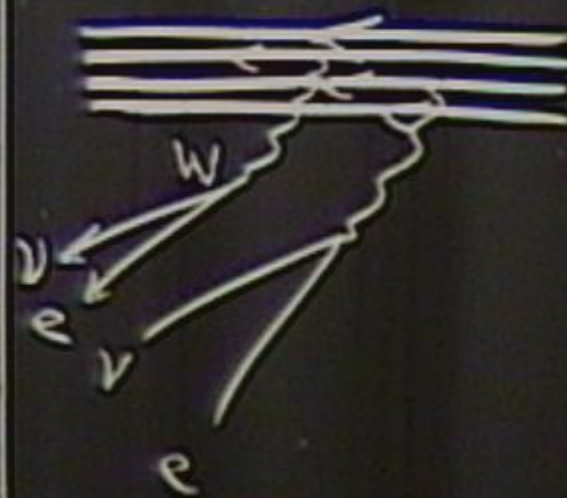
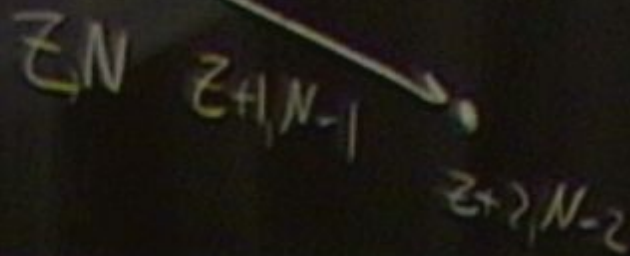
I nuclei for which



would imply L broken.



nuclei for which



$2\nu\beta\beta$ decay

$\tau \gg T_{\text{universe}}$

broken?

$E_e + E_\nu$

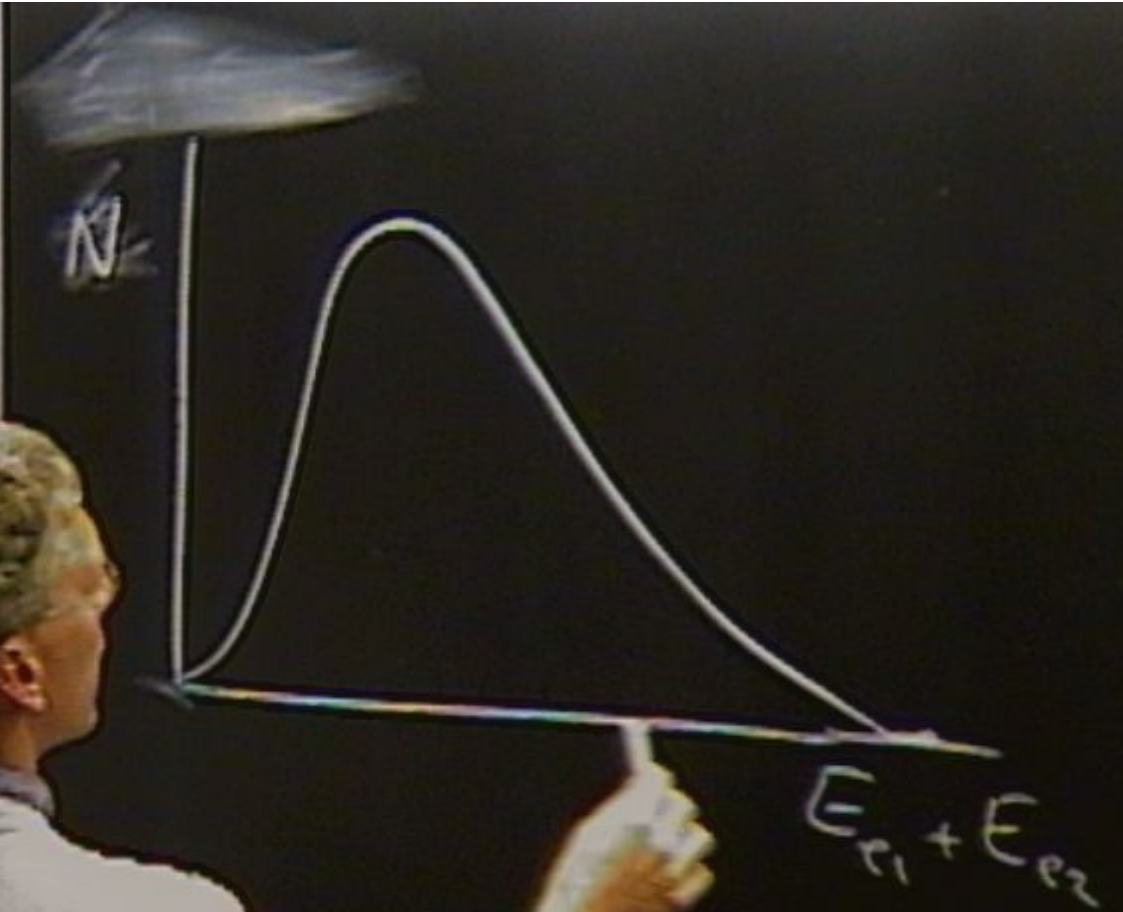


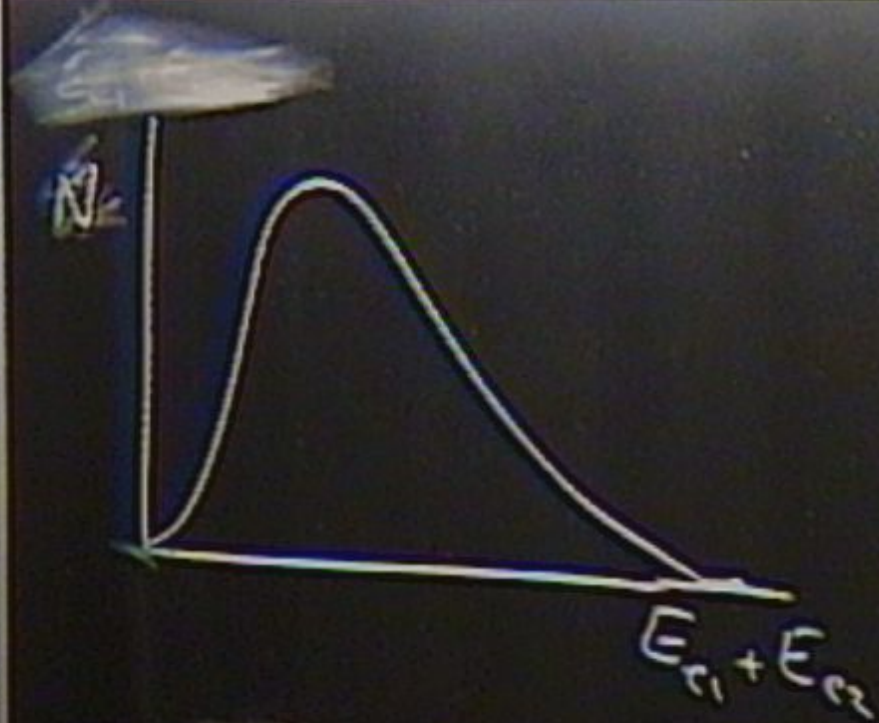
broken?



$2\nu\beta\beta$

$\tau \gg$

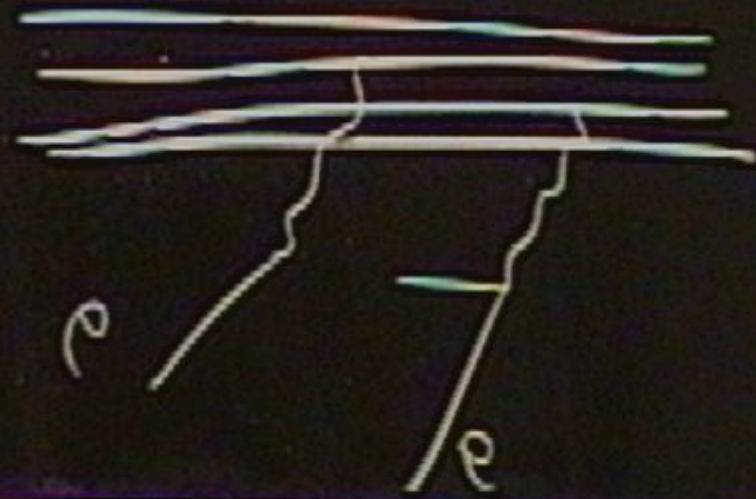




If ν and $\bar{\nu}$ were not distinguishable (L violated, mass)

$$E_{e1} + E_{e2}$$

If ν and $\bar{\nu}$ were not dis

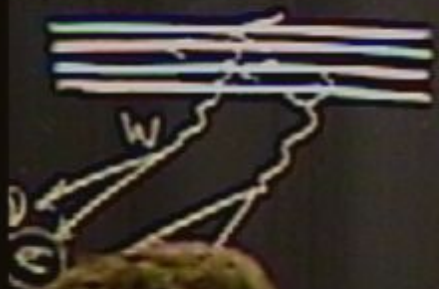


$$E_{e1} + E_{e2}$$

- If ν and $\bar{\nu}$ were not distinguishable (eg: L violated) an
is possible: $0\nu\beta\beta$ decay.

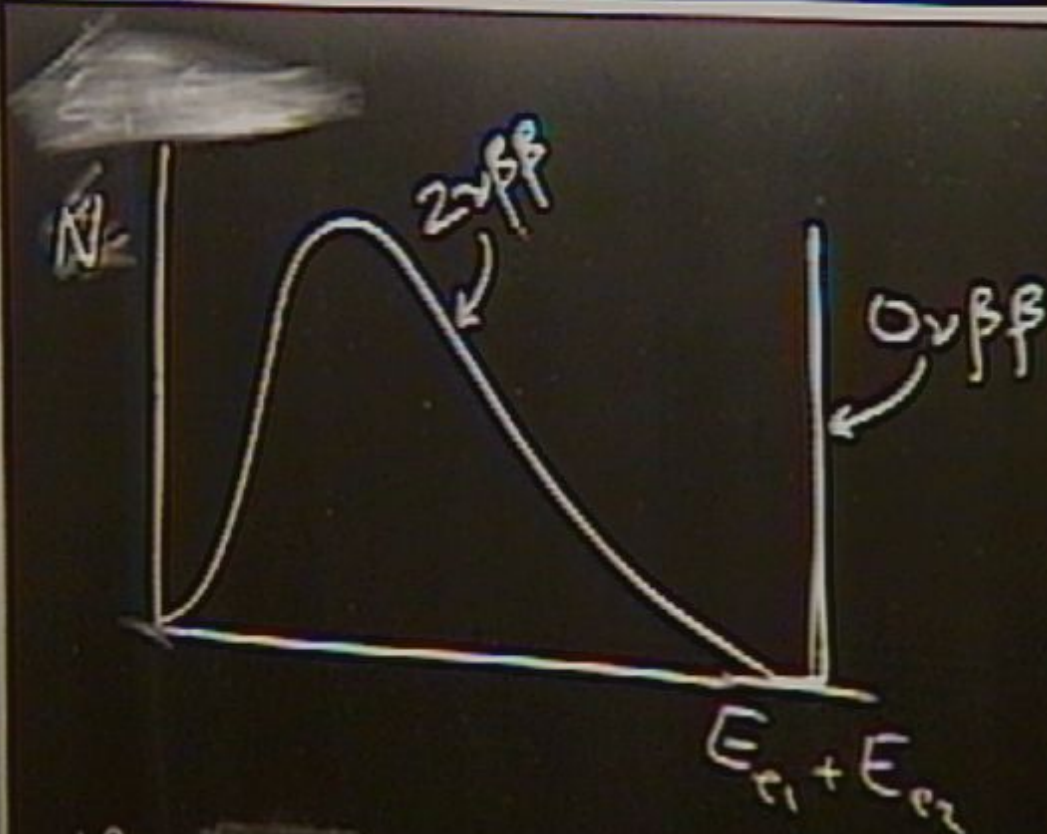


broken?



decay

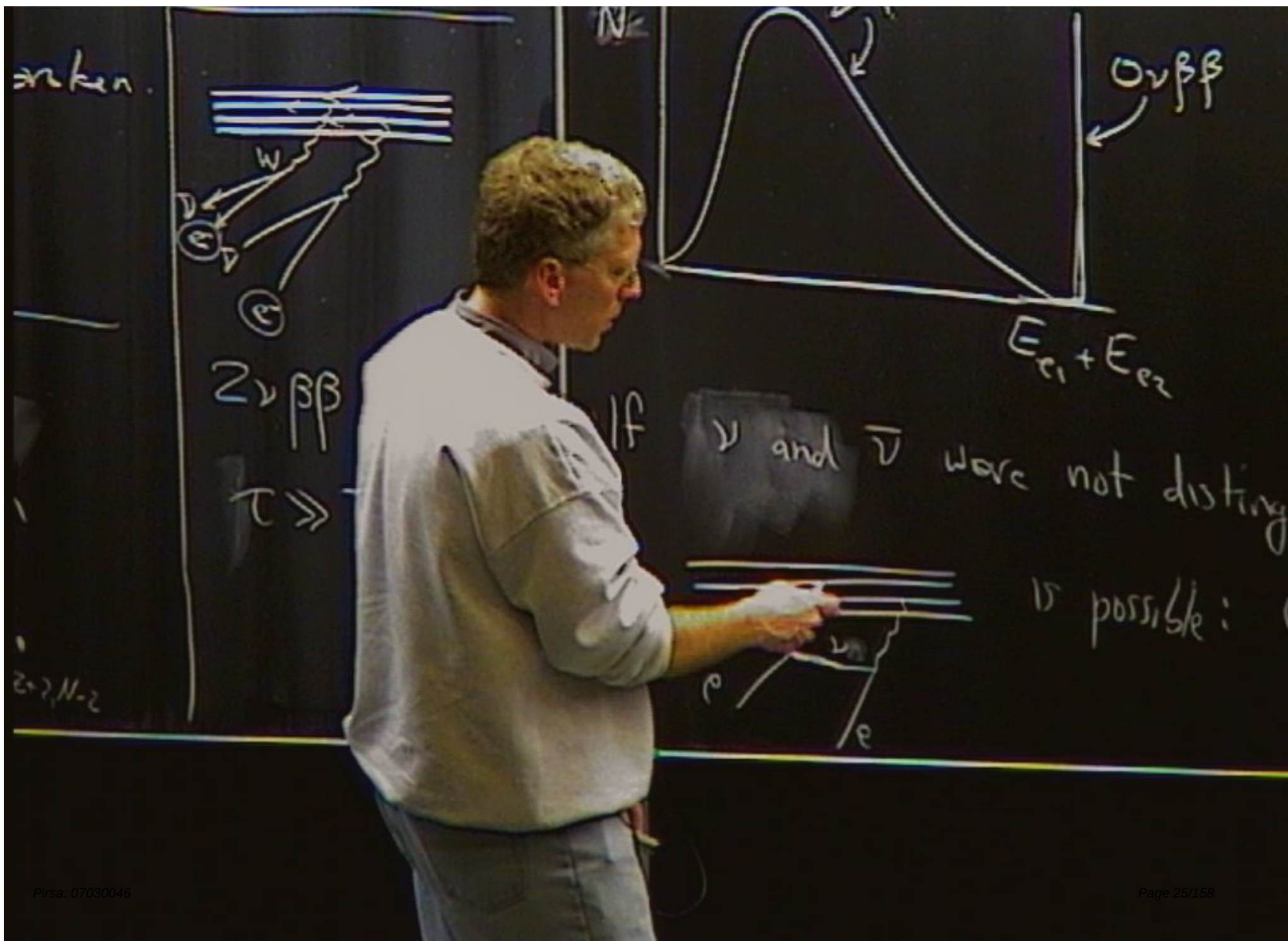
T_{universe}

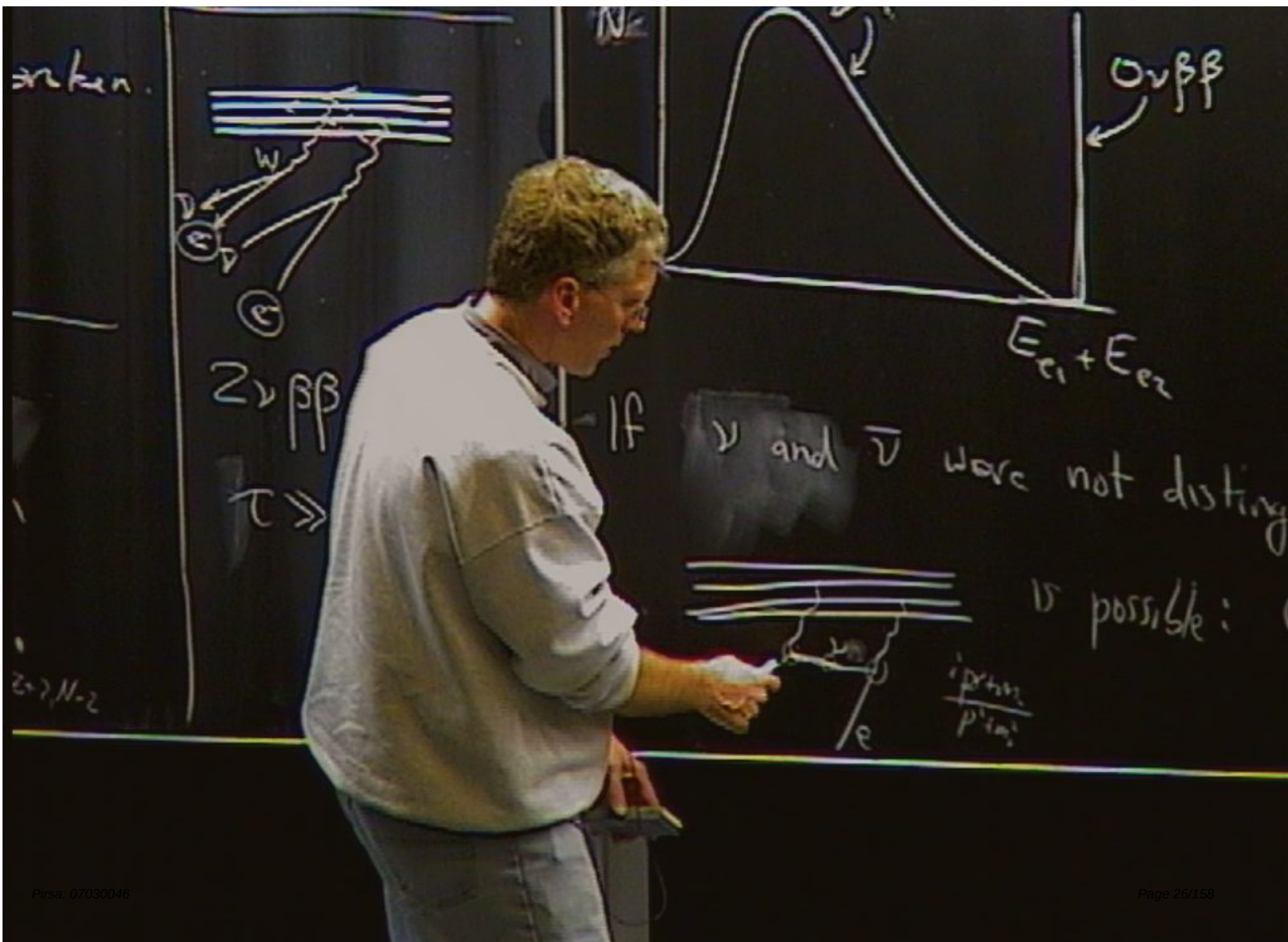


If ν and $\bar{\nu}$ were not distinguishable



is possible: $0\nu\beta\beta, c$





$$E_{e_1} + E_{e_2}$$

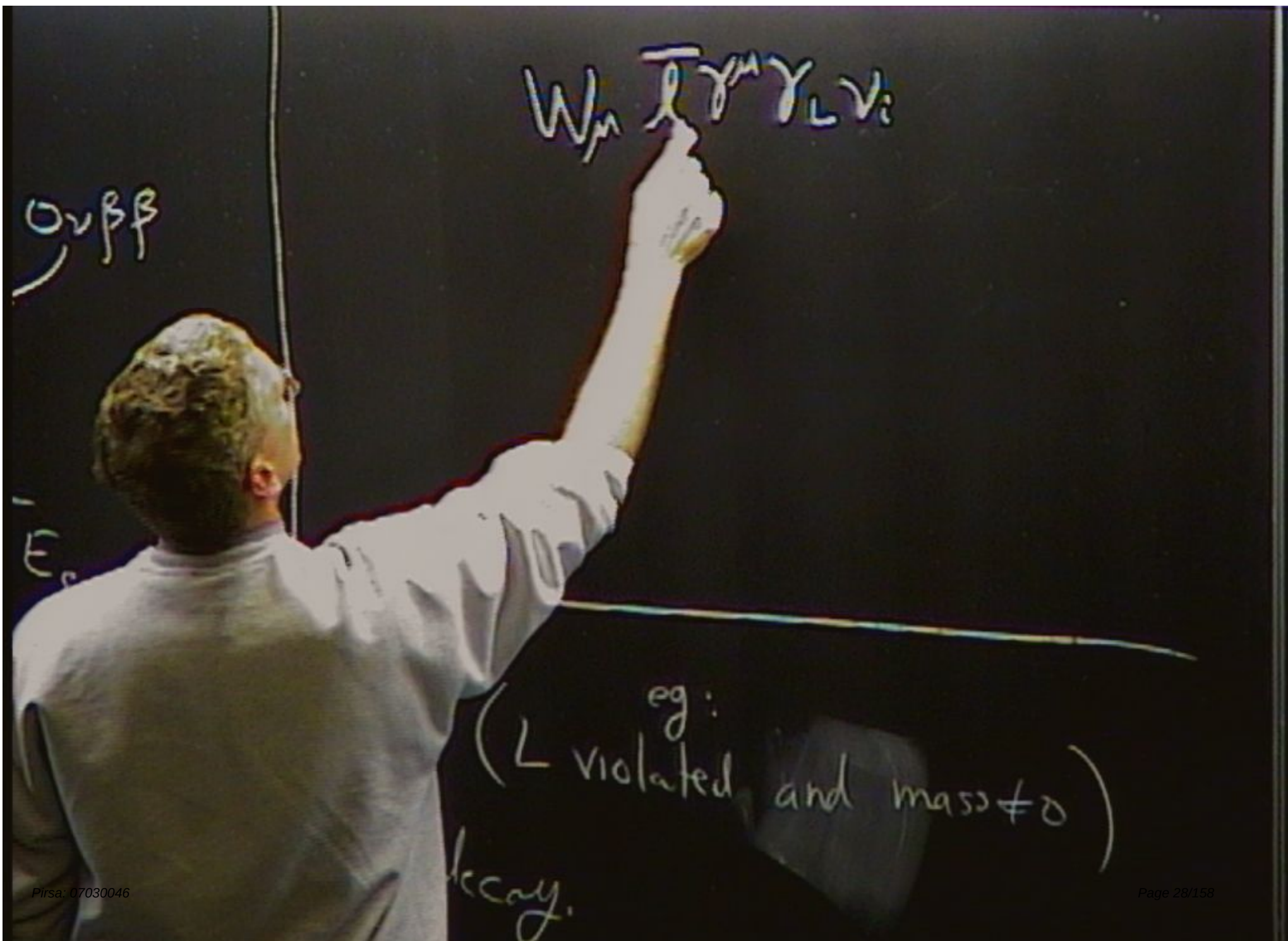
and $\bar{\nu}$ are

not distinguishable (eg: L violated and ν)

possible: $0\nu\beta\beta$ decay.

if $m_\nu \ll 100 \text{ MeV}$ Amplitude $\approx m_\nu f(\dots)$

$$\frac{A^2 m_\nu}{p^2 + m_\nu^2}$$



$$V_\mu W_\mu \bar{\ell}_a \gamma^\mu \gamma_L \nu_i$$

$$\text{Amplitude} \approx \sum m_i V_{ai} V_{\mu i}$$

$\nu\beta\beta$

ϵ_2

not distinguishable

possible: $\nu\beta\beta$, etc.

$\neq 0$

$$V_e W_\mu \bar{\ell}_L \gamma^\mu \gamma_L \nu_i$$

$$\text{Amplitude} \approx \sum m_i V_{ei} V_{\mu i}$$

$\nu \beta \beta$

$\bar{\ell}_e$

not distinguishable

possible: $\nu \beta \beta$, etc.

if $m_\mu \ll 100 \text{ MeV}$ Amplitude

$$V_e W_\mu \bar{l}_\mu \gamma^\mu \gamma_L \nu_i$$

$$\text{Amplitude} \approx \sum_i m_i V_{ei} V_{\mu i}$$

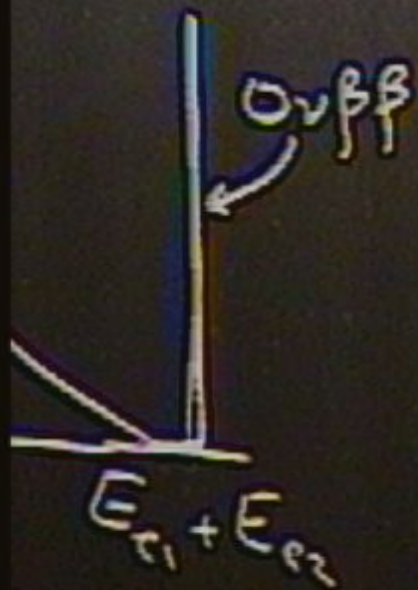
$$= m_{\text{eff}}$$

$$= m_{ee}$$

not distinguishable (eg: L violated and $m_{\nu} \neq 0$)

possible: $0\nu\beta\beta$ decay.

if $m_\nu \ll 100 \text{ MeV}$ Amplitude $\approx m_\nu f(\dots)$



$$V_e W_p \bar{L} \gamma^\mu L \nu_i$$

$$\text{Amplitude} \approx \sum_i m_i V_e V_p$$

$$= m_{eff}$$

$$= m_{ee}$$

$$|m_{ee}| \leq 1 \text{ eV}$$

are not distinguishable (eg: L violated and mass $\neq 0$)

is possible: $0\nu\beta\beta$ decay.

if $m_\nu \ll 100 \text{ MeV}$ Amplitude $\approx m_\nu f(\dots)$

$\frac{X_{f_1 f_2}}{P^2 + m_i^2}$

Neutrino Oscillations

$$V_{ei} V_{ei}$$

$$m_{\nu} \neq 0$$

Neutrino Oscillations

Unitary gauge $H = \begin{pmatrix} 0 \\ 0 \\ v \end{pmatrix}$ $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} +$

Neutrino Oscillations

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\mathcal{L} = \mathcal{L}_m + (\underline{m}_{\nu\bar{\nu}} \bar{\nu}_L \gamma_L \nu_L + \text{c.c.})$

$$H = \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\mathcal{L} = \mathcal{L}_{SM} + (\underline{m_{ab}} \bar{\nu}_a \gamma_L \nu_b + c.c.)$$

$$m_{ab} = \frac{g_{ab}}{M} v^2$$

$$= y_{ai} M^{-1}_{ij} y_{bj} v^2$$

$$H = \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m}_{\text{ab}} \bar{\nu}_a \gamma_L \nu_b + \text{c.c.})$$

$$m_{ab} = \left\{ \begin{array}{l} \frac{g_{ab}}{M} v^2 \\ + y_{ai} M^{-1}_{ij} y_{bj} v^2 \end{array} \right.$$

$$m_i, V_{ei}, V_{ei}$$

m_{eff}

m_{ee}

nd mass $\neq 0$)

Unitary gauge $H = ($

Realize ν masses:

$\rightarrow U_{ab}$

$$m_i, V_{ei}, V_{ei}$$

$$m_{\text{eff}}$$

$$m_{ee}$$

nd

Unitary gauge $H = ($

Diagonalize ν masses:

$$\gamma_L \nu_a \rightarrow U_{ab} \gamma_L \nu_b$$

$$m_i V_{ei} V_{ei}$$

$$m_{\text{eff}}$$

$$m_{ee}$$

nd

Unitary gauge $H = ($

Diagonalize ν masses:

$$\gamma_L \nu_a \rightarrow U_{ab} \gamma_L \nu_b$$

$$\gamma_L l_a \rightarrow W_{ab} \gamma_L l_b$$

V_{ei}

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$

$\mathcal{L}_{\text{eff}} = 0$

Diagonalize masses:

χ, χ_c

$$U^\dagger U = 1$$

$$W^\dagger W = 1$$

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \dots$

Diagonalize ν masses:

$$\gamma_L \nu_a \rightarrow U_{ab} \gamma_L \nu_b$$

$$U^\dagger U = 1$$

(preserve)
 $\bar{\nu}_a \not\propto \nu_a$

$$\gamma_L \ell_a \rightarrow W_{ab} \gamma_L \ell_b$$

$$W^\dagger W = 1$$

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} +$

diagonalize ν masses:

$$\gamma_L \nu_a \rightarrow U_{ab} \gamma_L \nu_b$$

$$U^\dagger U = 1$$

$$\gamma_L l_a \rightarrow W_{ab} \gamma_L l_b$$

$$W^\dagger W = 1$$

(preserve $\bar{\nu}_a \gamma \nu_a$)

$$= \gamma^\mu (g_V + g_A \gamma_5) \nu_a$$

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} +$

Diagonalize ν masses:

$$\gamma_L \nu_a \rightarrow U_{ab} \gamma_L \nu_b$$

$$\gamma_L \ell_a \rightarrow W_{ab} \gamma_L \ell_b$$

$$U^\dagger U = 1$$

$$W^\dagger W = 1$$

(preserve $\bar{\nu}_a \gamma \nu_a$)

$$\sum_A \bar{\nu}_i \gamma^A (g_V + g_A \gamma_5) \nu_j$$

Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$ $\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} +$

Diagonalize ν masses:

$$\chi_L \nu_a \rightarrow U_{ab} \chi_L \nu_b$$

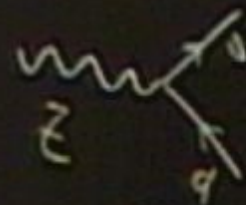
$$\chi_L l_a \rightarrow W_{ab} \chi_L l_b$$

$$U^\dagger U = 1$$

$$W^\dagger W = 1$$

(preserve $\bar{\nu}_a \not\partial \nu_a$)

$$\sum_i \bar{\nu}_i \gamma^\mu (g_\nu + g_A \gamma_5) \nu_i$$



Unitary gauge $H = \begin{pmatrix} 0 \\ v \end{pmatrix}$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_m + (m_{\nu} \bar{\nu}_L \gamma_L \nu_L)$$

Diagonalize ν masses:

$$\gamma_L \nu_L \rightarrow U_{ab} \gamma_L \nu_b$$

$$U^\dagger U = 1$$

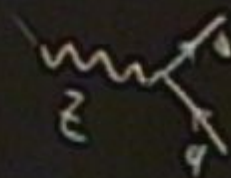
$$\gamma_L \ell_L \rightarrow W_{ab} \gamma_L \ell_b$$

$$W^\dagger W = 1$$

(preserve $\bar{\nu}_L \partial \nu_L$)

$$m_{\nu} = \begin{cases} \frac{g_{\nu} v}{M} v^2 \\ y_{\nu} M \end{cases}$$

$$\mathcal{L}_\nu = \bar{\nu}_L \gamma^\mu (g_V + g_A \gamma_5) \nu_L$$

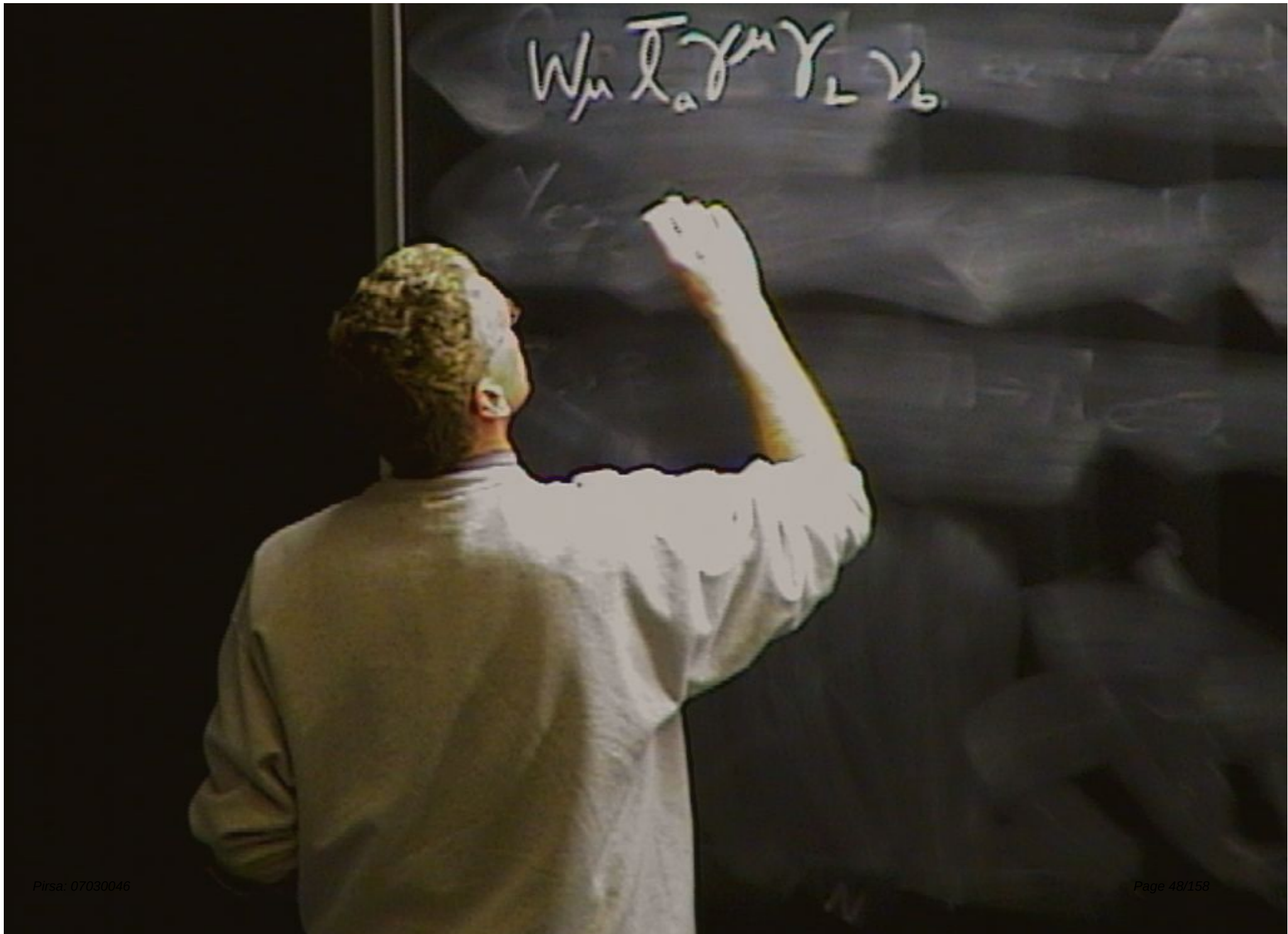


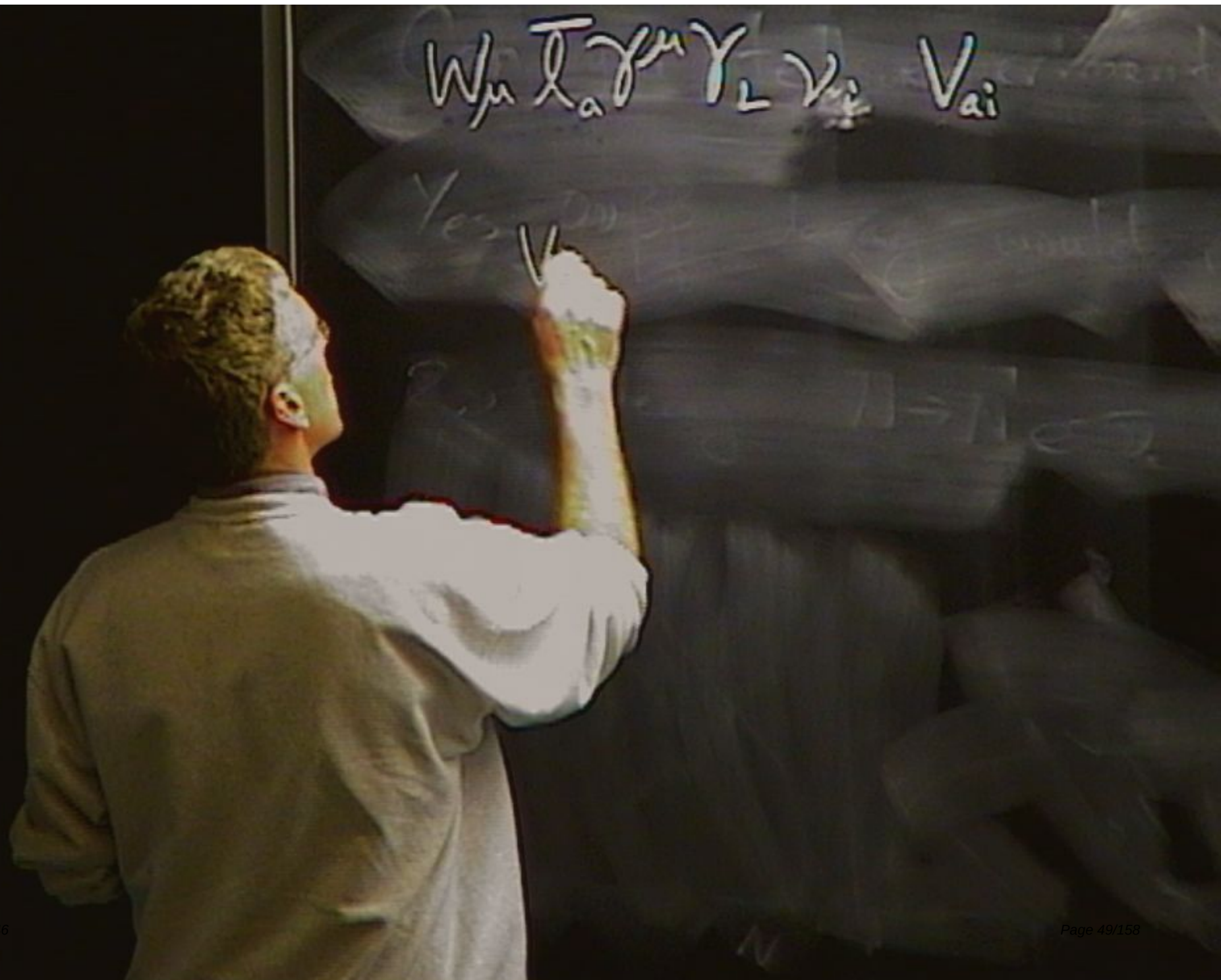
$$m_{ab} = \begin{cases} \frac{g_{ab}}{M} v^2 \\ y_{ai} M^{-1} y_{bj} v^2 \end{cases}$$

(preserve
 $\bar{\nu}_a \not\partial \nu_a$)

~~$K \rightarrow \mu^+ \mu^-$~~

$Z \rightarrow e^+ \mu^-$





$$W_{\mu} \gamma^{\mu} \gamma_5 V_{ai}$$

$$V = W^{\dagger} U \rightarrow V^{\dagger} V = 1$$

$$W_{\mu} \gamma_{\mu} \gamma_L v_i \quad V_{ai}$$

Yes. Do look

$$V = W^{\dagger} U \Rightarrow V^{\dagger} V = 1$$

$$W_\mu \bar{\ell}_a \gamma^\mu \gamma_L \nu_i V_{ai}$$

Yes, Dirac

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$

$$e^- \quad \nu_i$$

V

$$W_\mu \bar{\ell}_a \gamma^\mu \gamma_L \nu_i V_{ai}$$

Yes, Dirac

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$



$$W_\mu \bar{\psi}_L \gamma^\mu \gamma_5 \psi_L = V_{ai}$$

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$



$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$

ν_i

μ^+

Amplitude (hat creation

V^*

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$

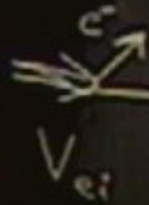
ν_i



Amplitude (l_i at creation; l_L at detection) $\approx \sum_i V_{\mu i} V_{L i}^* f(m_i, \dots)$

$$W_\mu \bar{\ell}_a \gamma^\mu \gamma_L \nu_{\ell b} V_{ai}$$

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$

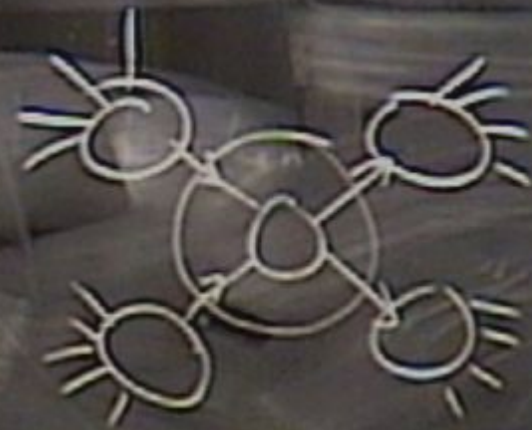


Amplitude (that cross)

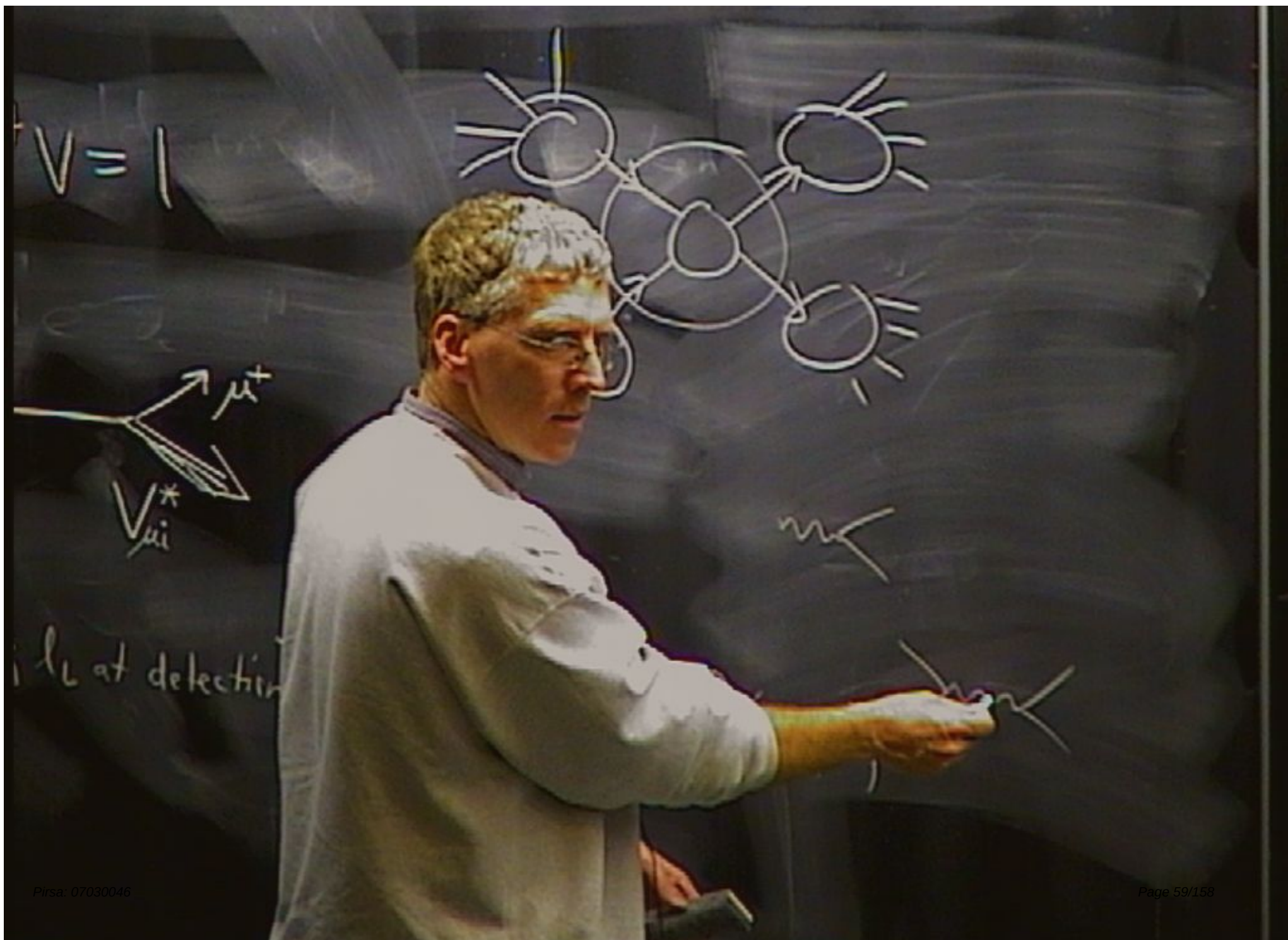
$$V_{\ell i} V_{\ell j}^* f(m_{\ell}, \dots)$$

$$W_\mu \bar{\ell}_a \gamma^\mu \gamma_L \nu_{\ell b} V_{ai}$$

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$



Amplitude (ν_i at detection) $\approx \sum_i V_{\ell i} V_{\ell i}^* f(m_i, \dots)$



$$L \quad V_{\mu i} \quad V_{\nu i}$$

$$U \Rightarrow V^\dagger V = 1$$

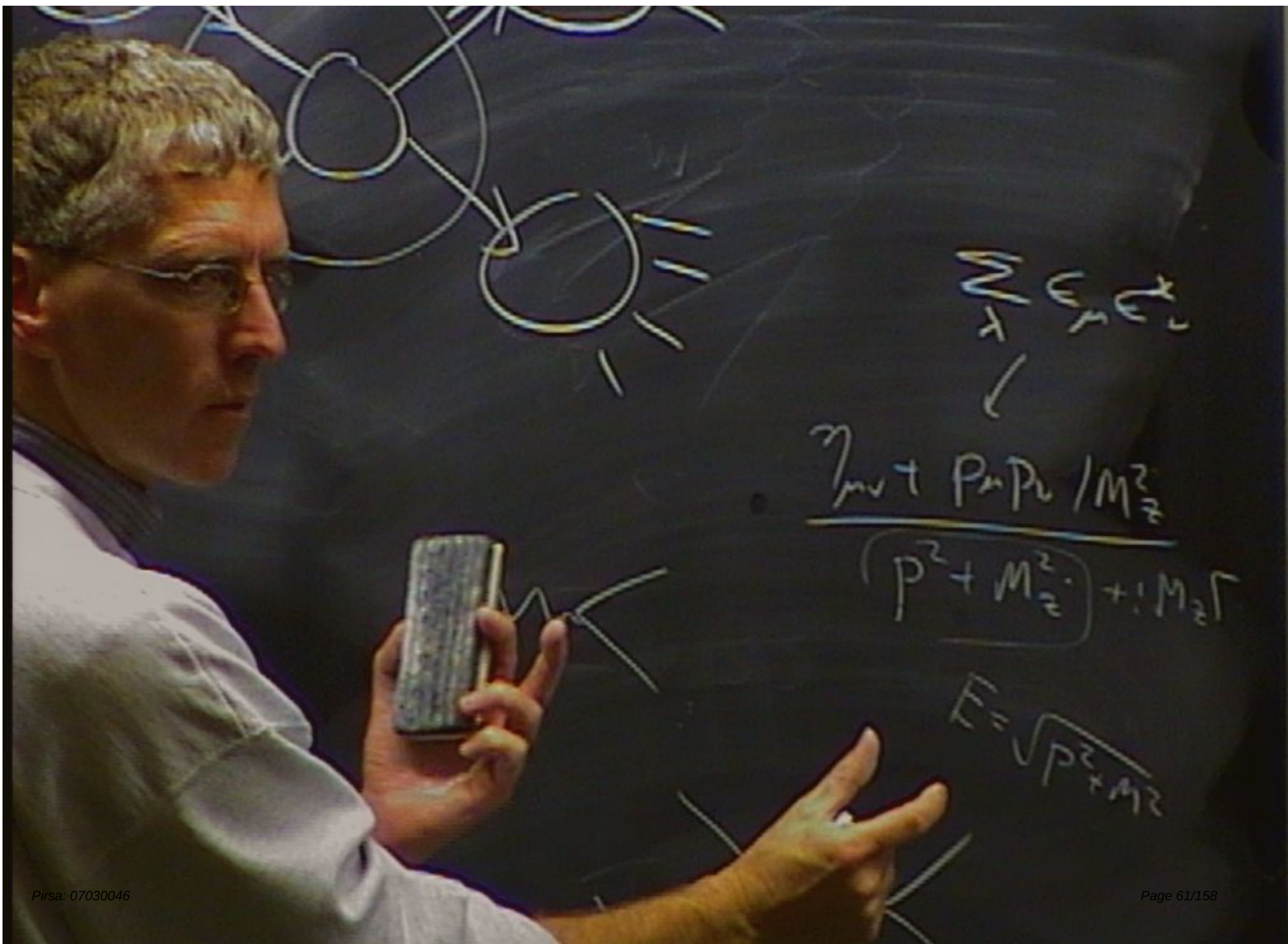


(l_i at creation; l_L at detection) $\approx$



$$\frac{\eta_{\mu\tau} P_\mu P_\tau / M^2}{P^2}$$

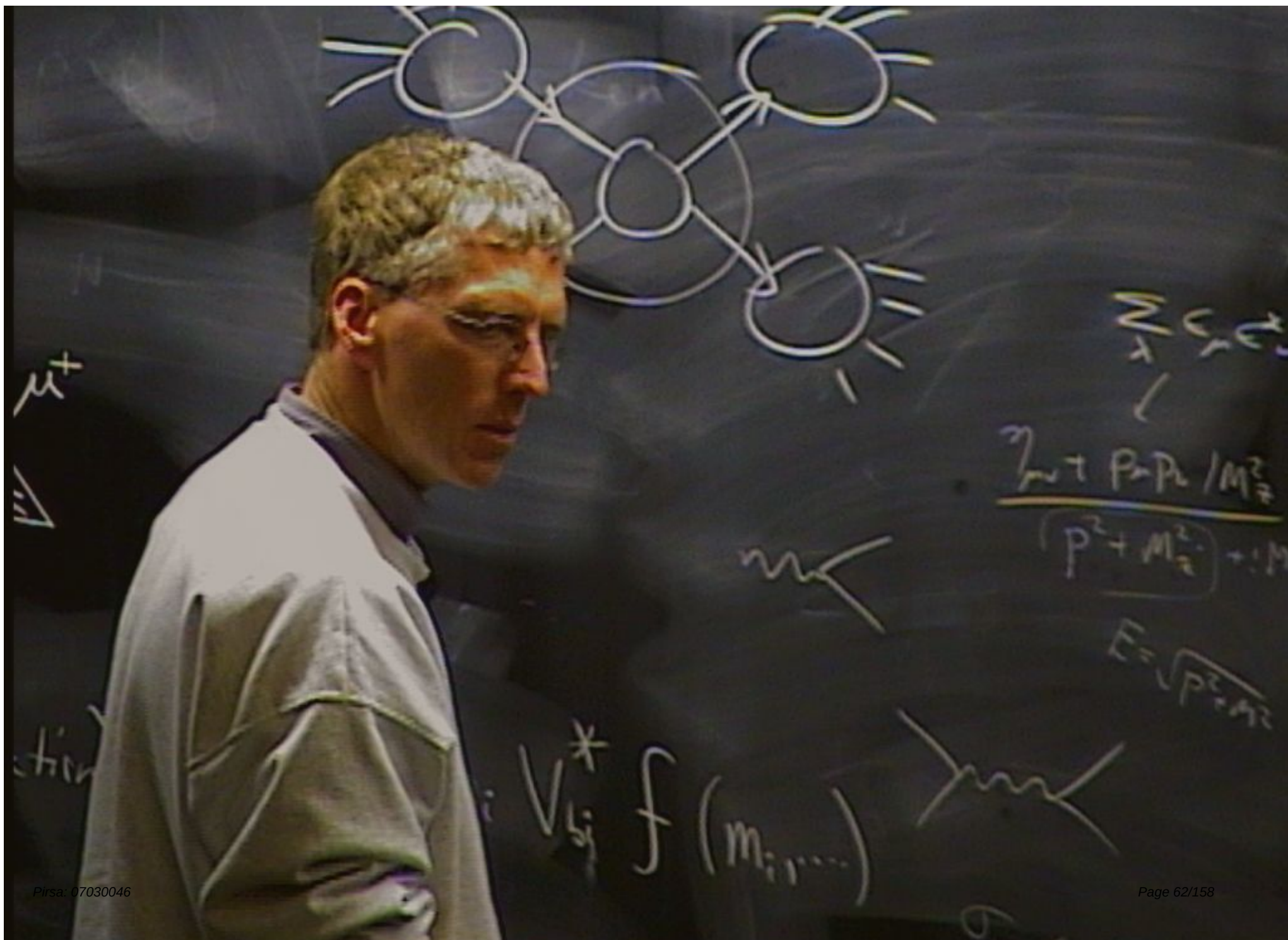
$$\begin{aligned} & \eta_{\mu\tau} (p_\mu p_\tau / M^2) \\ &= \eta_{\mu\tau} (p_\mu p_\tau / M^2) \delta(p_\mu p_\tau) \end{aligned}$$

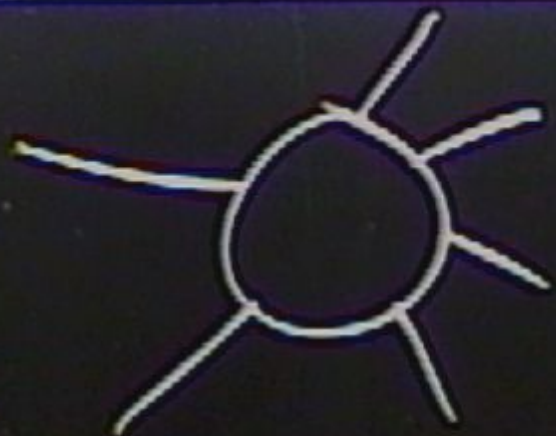


$$\sum_k \epsilon_\mu \epsilon_\nu$$

$$\frac{\gamma_{\mu\nu} + p_\mu p_\nu / M_Z^2}{(p^2 + M_Z^2) + i M_Z \Gamma}$$

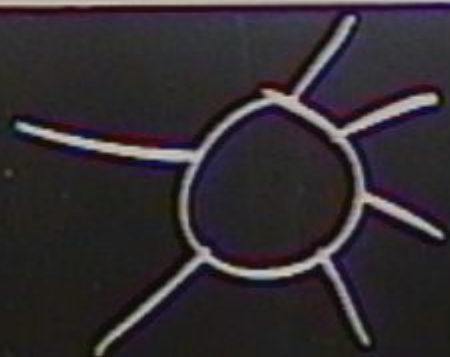
$$E = \sqrt{p^2 + M_Z^2}$$





$$\langle dT [b(x)] \dots$$

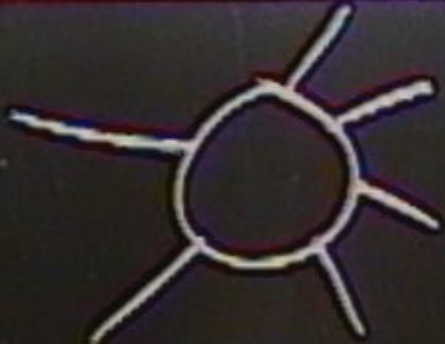
$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m_{ab}} \bar{\nu}_a \gamma_L \nu_b +$$



$$\langle 0 | T [\psi(x) \dots \phi(x)] | 0 \rangle$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m_{ab}} \psi_a \psi_b + \text{c.c.})$$

$$m_{ab} = \begin{cases} g_{ab} \\ \dots \end{cases}$$



$$\int d^4x \langle 0 | T [\psi(x) \dots \phi(x)] | 0 \rangle e^{ipx}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m_{ab}} \bar{\nu}_a \gamma_L \nu_b + \text{c.c.})$$

G^2



$$\sum_{\text{Feynman}} A(\dots) \int d^4x \langle 0 | T [\psi(x) \dots \phi(x)] | 0 \rangle e^{i p x}$$

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m_{\nu}} \bar{\nu}_L \gamma_5 \nu_L + \text{c.c.})$$

$$m_{\nu} = \begin{cases} \frac{g_{\nu}^2}{M} v^2 \\ y_{\nu i} M^{-1}_{ij} y_{\nu j} v^2 \end{cases}$$

$$U^\dagger U = 1$$

$$\begin{pmatrix} \text{preserve} \\ \bar{\nu}_L \gamma_5 \nu_L \end{pmatrix}$$

$$W^\dagger W = 1$$



$$\int_{\sum_{\text{Feynman}} A(\dots)} \langle 0 | T [\phi(x) \dots \phi(x)] | 0 \rangle e^{i p x}$$

$$\begin{pmatrix} 0 \\ \nu \end{pmatrix}$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (\underline{m_{\nu b}} \bar{\nu}_L \gamma_L \nu_b + \text{c.c.})$$

$$m_{\nu b} = \begin{cases} \frac{g_{\nu b}}{M} v^2 \end{cases}$$



$$\left\{ \begin{array}{l} y_{\nu i} M^{-1}_{ij} y_{\nu j} v^2 \end{array} \right.$$

$$U^\dagger U = 1$$

(preserve)
 $\bar{\nu}_L \not{\partial} \nu_L$

$$W^\dagger W = 1$$

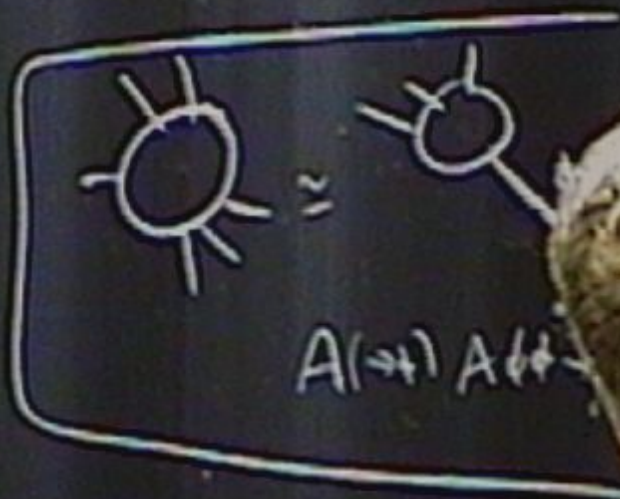
$$\underline{\underline{\eta_{ab} \bar{\nu}_a \gamma_L \nu_b + c.c.})}$$

$$g_{ab} = \frac{g_{ab}}{M} v^2$$

$$+ y_{ai} M^{-1}_{ij} y_{bj} v^2$$



$$V_a \gamma_L V_b + c.c.)$$



$$\frac{a_k}{M} \psi^2$$

$$y_{ai} M^{-1}_{ij} y_{bj} \psi^2$$

$$(\bar{\nu}_a \gamma_L \nu_b + \text{c.c.})$$



$$\frac{a_6}{M} \psi^2$$

$$y_{ai} M^{-1}_{ij} y_{bj} \psi^2$$

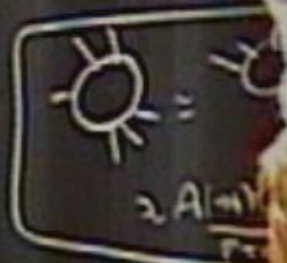


$$\int d^4x \langle \alpha T [\frac{1}{\sum_{p=1}^n A(p...)}] \rangle e^{ipx}$$

$$= \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + (m_{ab} \bar{\nu}_a \gamma_L \nu_b + c.c.)$$

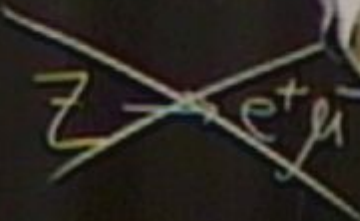
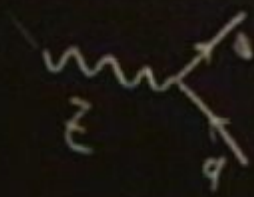
$$m_{ab} = \begin{cases} \frac{g_{ab}}{M} v^2 \\ y_{ij} M^{-1} y_{lj} v \end{cases}$$



$$U^\dagger U = 1$$

(preserve $\bar{\nu}_a \gamma_L \nu_a$)

$$W^\dagger W = 1$$



$$+ \mathcal{L}_{SM} + (\underline{m_{ab}} \bar{\nu}_a \gamma_L \nu_b + c.c.)$$

$$m_{ab} = \begin{cases} \frac{g_{ab}}{M} v^2 \\ y_{ai} M^{-1}_{ij} y_{bj} v^2 \end{cases}$$

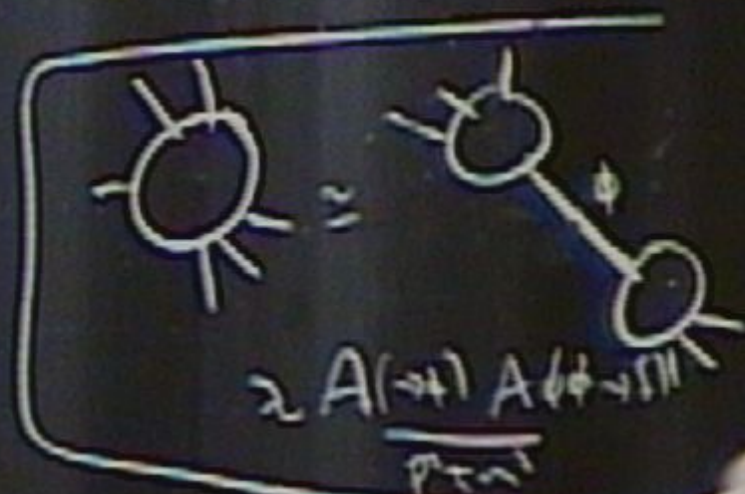


$$\left(\begin{array}{c} \text{reference} \\ \bar{\nu}_a \phi \nu_b \end{array} \right)$$

$$i f \mathcal{L}_{SM} + (\underline{m_{ab}} \bar{\nu}_a \gamma_L \nu_b + c.c.)$$

$$m_{ab} = \left\{ \frac{g_{ab}}{M} v^2 \right.$$

$$\left. + y_{ai} M^{-1}_{ij} y_{bj} v^2 \right.$$



reference
 $\bar{\nu}_a \gamma_L \nu_b$

$$W_\mu \bar{\ell}_L \gamma^\mu \gamma_5 \nu_L V_{\ell i} V_{\ell i}$$

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$



Amplitude (ℓ_i at creation; ℓ_j at detection) $\approx \sum_i V_{\ell i} V_{\ell j}^* f(m_i, \dots)$

$$W_\mu \bar{\chi}_a \gamma^\mu \gamma_5 \chi_b V_{ab}$$

$$V = W^\dagger U \Rightarrow V^\dagger V = 1$$

$$V_{ei}$$

Amplitude (h)

$$\sum_i V_{ei} V_{\mu i}^* f(m_i, \dots)$$



$$\begin{aligned}
 I_{\text{L at detection}} &\approx \sum_i V_{ai} V_{bi}^* f(m_1, \dots) \\
 &= \sum_i \text{Amp}(i \rightarrow \nu_i, t_i) e^{-iE_i(t_f - t_i)} A(\nu_i \rightarrow f, t_f)
 \end{aligned}$$

- If ν and $\bar{\nu}$

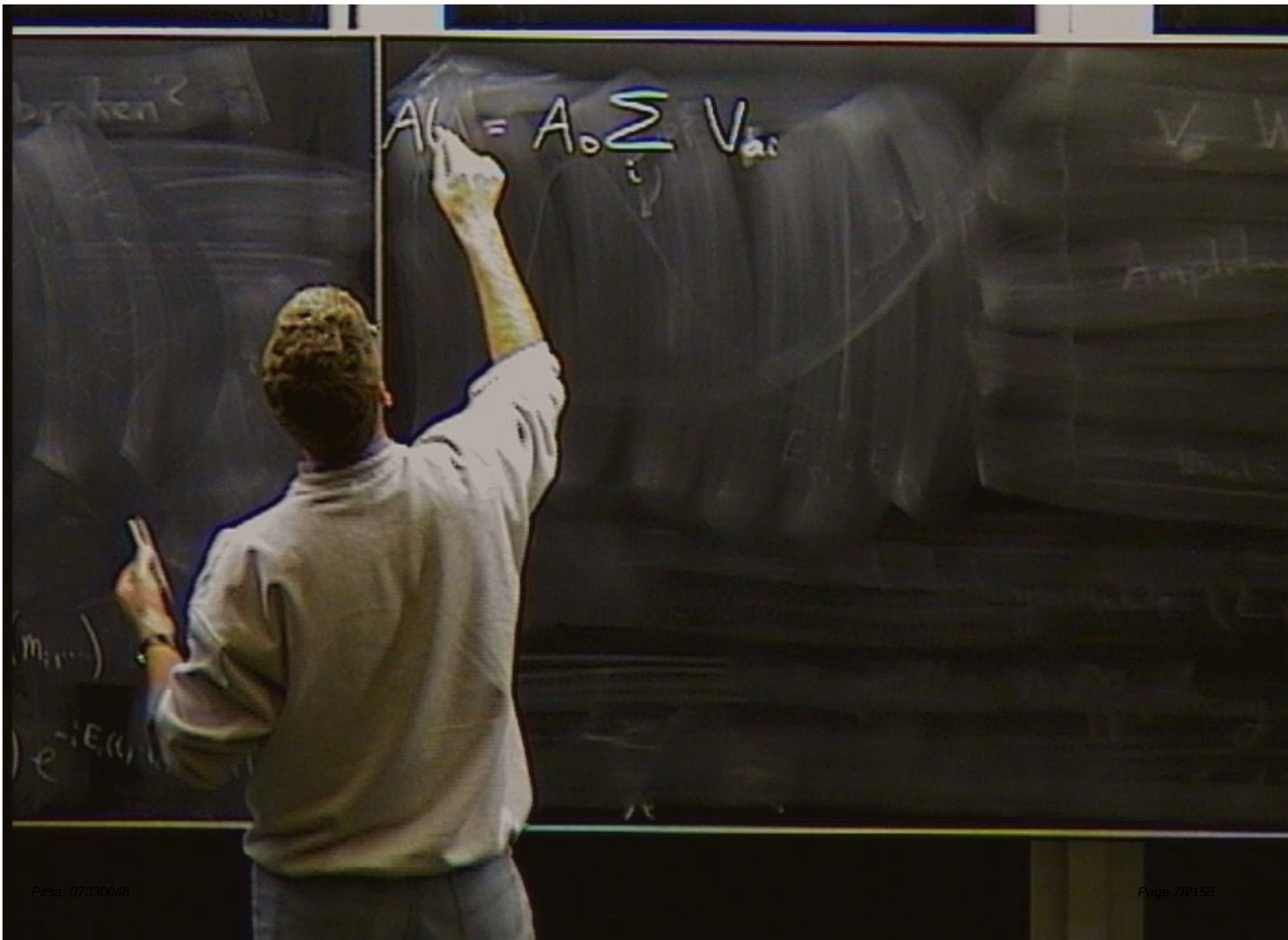


$$A = A_0$$

$$V = W \cdot \overline{C} \cdot \gamma \cdot \gamma_0$$

$$\text{Amplitude} = \sum m_i V$$

$$A(v, \vec{m})$$



$$A(p, t_f) = A_0 \sum_i V_{oi} V_{bi}^* e^{-iE_i t_f}$$

$$(m_1, \dots)$$

$$e^{-iE_i(t_f - t_i)} A(v_i, t_f)$$

$$\tau = t_f - t_i$$

$$A(\mathbf{r}, t) = A_0 \sum_i V_{ai} V_{bi}^* e^{-iE_i \tau}$$

$$\tau = t_f - t_i$$

$$A(l_a; l_b) = A_0 \sum_i V_{ai} V_{bi}^* e^{-iE_i \tau}$$

$$P(l_a; l_b) = P_0$$

$$\tau = t_f - t_i$$

$$A(l_a; l_b) = A_0 \sum_i V_{ai} V_{bi}^* e^{-iE_i \tau}$$

$$P(l_a; l_b) = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{ai}^* V_{bj} e^{-i(E_i - E_j) \tau}$$

$$\tau = t_f - t_i$$

$$A(t_i; t_f) = A_0 \sum_i V_{ai} V_{bi}^* e^{-iE_i \tau}$$

$$P(t_i; t_f) = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

If there had been two V 's

$$\sum_{ij} (\dots) =$$

$$\tau = t_f - t_i$$

$$A_0 \sum_i V_{ai} V_{bi}^* e^{-iE_i \tau}$$

$$E = \sqrt{p^2 + m^2} \approx p + \frac{m^2}{2p}$$

$$\langle a_i; b_i \rangle = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

there had been two V_i 's:

$$\sum_{ij} (\dots) = \sum_i |V_{ai}|^2 |V_{bi}|^2$$

$$E = \sqrt{p^2 + m^2} \approx p + \frac{m^2}{2p}$$

$$e^{-i(E_i - E_j)\tau}$$

$$(E_i - E_j)\tau \approx \frac{m_i^2 - m_j^2}{2p} \tau$$

$$\Rightarrow V^\dagger V = 1$$

$$\tau \approx L/v$$

at cr

$$A_{fi} \approx \sum_i V_{fi} V_{ii}^* f(m_i, \dots)$$

$$Amp(i \rightarrow \nu_i, t_i) e^{-iE_i(t_i)} A$$

$$A(l, t) = A_0 \sum_i V_{li} V_{li}^* e^{-iE_i t}$$

$$P(l_i; l_j) = P_0 \sum_{ij} V_{li} V_{li}^* V_{lj}^* V_{lj} e^{-i(E_i - E_j)\tau}$$

If there had been +

$$\sum_{ij}$$

$$V_{li} =$$

$$(E_i - E_j)\tau \approx \frac{m_i^2 - m_j^2}{2E} \tau$$

$$\approx \frac{\Delta m^2 L}{2E}$$

$$\sum_{ij} V_{li} V_{li}^* V_{lj}^* V_{lj} e^{-i \frac{\Delta m^2 L}{2E}}$$

$$A(l_1; l_2) = A_0 \sum_i V_{\mu i} V_{\mu i}^* e^{-iE_i l_1}$$

$$P(l_1; l_2) = P_0 \sum_{ij} V_{\mu i} V_{\mu i}^* V_{\mu j}^* V_{\mu j} e^{-i(E_i - E_j)l_2}$$

If had been two ν_μ 's: $V_{\mu i} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$

$$P(l_1; l_2) = \sum_i |V_{\mu i}|^2 |V_{\mu i}|^2 + \sum_{i \neq j} V_{\mu i} V_{\mu i}^* V_{\mu j}^* V_{\mu j} e^{-i(E_i - E_j)l_2}$$

$$P(l_a; l_b) = P_0 \sum_i V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

If there are two ν_i 's: $V_{ai} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$ $(E_i - E_j)\tau \approx \frac{m_i^2 - m_j^2}{2E} \tau$

$$\sum_i |V_{ai}|^2 |V_{bi}|^2 + \sum_{i \neq j} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i \frac{\Delta m^2 L}{2E}}$$

$$P(l_a; l_b) = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

If there had been two states: $V_{ai} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$

$$(E_i - E_j)\tau \approx \frac{m_i^2 - m_j^2}{2p} \tau \approx \frac{\Delta m^2 L}{2E}$$

$$\sum_i |V_{bi}|^2 + \sum_{i \neq j} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i \Delta m^2 L / 2E}$$

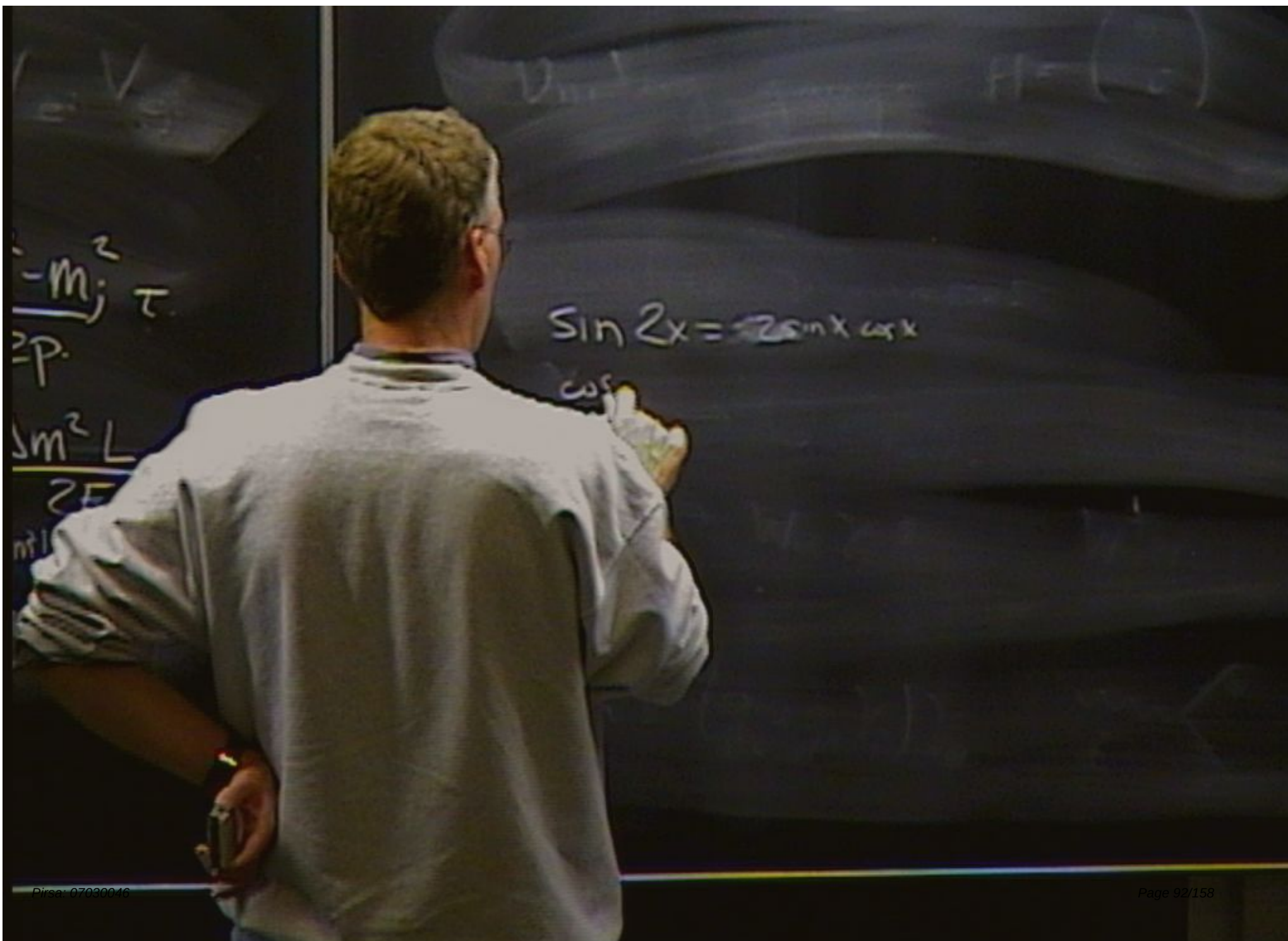
$$\frac{P(e \rightarrow \nu)}{P_0}$$

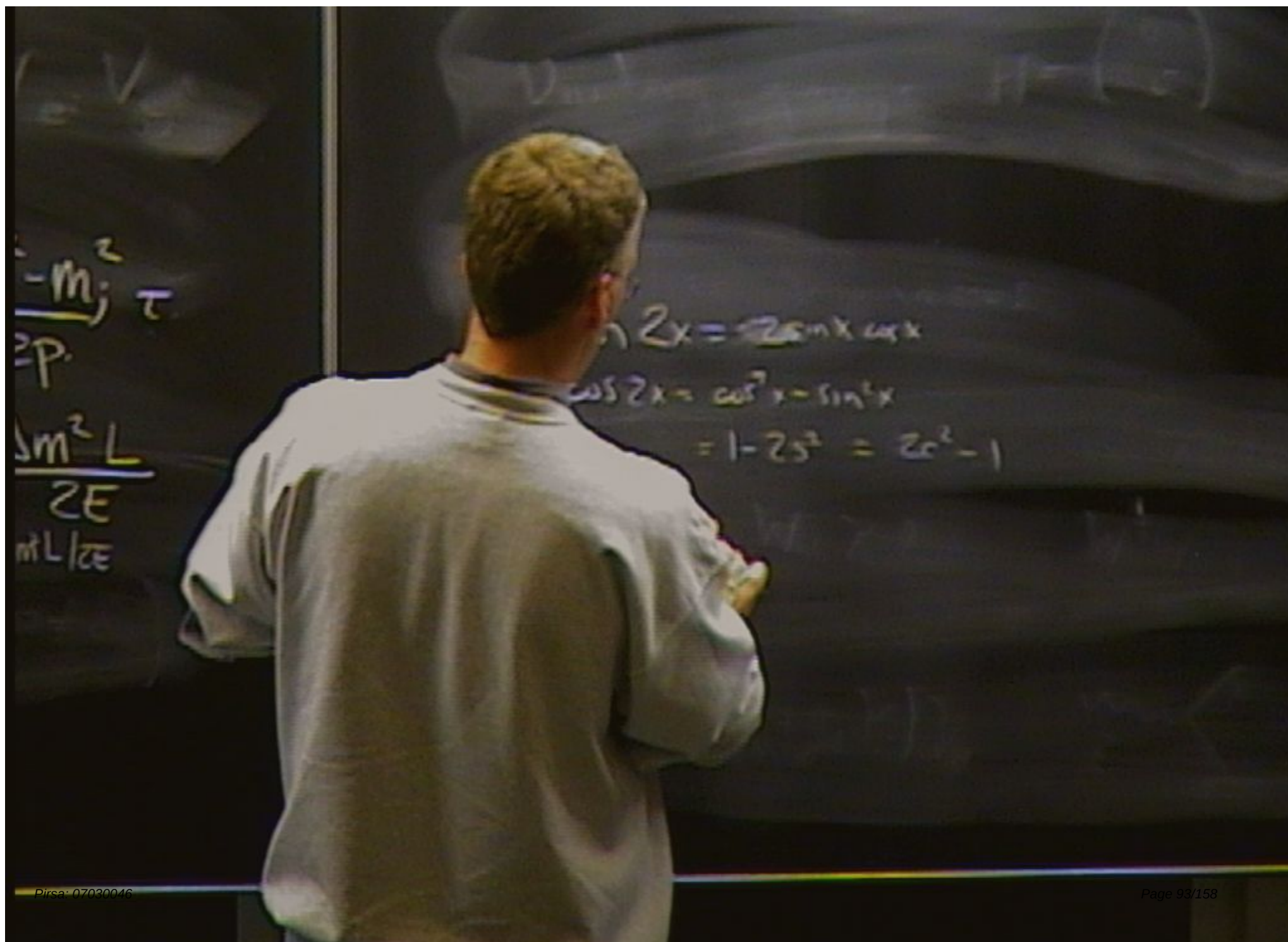
$$P(l_e; l_e) = P_0 \sum_{ij} V_{ei} V_{ei}^* V_{ej}^* V_{ej} e^{-i(E_i - E_j)\tau}$$

If there are two ν_i 's: $V_{ei} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$ $(E_i - E_j)\tau \approx \frac{m_i^2 - m_j^2}{2E} \tau \approx \frac{\Delta m^2 L}{2E}$

$$= \sum_i |V_{ei}|^2 |V_{ei}|^2 + \sum_{i \neq j} V_{ei} V_{ei}^* V_{ej}^* V_{ej} e^{-i \Delta m^2 L / 2E}$$

$$= \cos^2\theta \sin^2\theta + 2 \cos\theta (-\sin\theta) \sin\theta \cos\theta \cos\left(\frac{\Delta m^2 L}{2E}\right)$$





$$P(l_a; l_b) = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

If there had been V_{ij} 's: $V_{ai} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$ $(E_i - E_j)\tau \approx \frac{m^2 L}{2E}$

$$\sum |V_{ai}|^2 |V_{bi}|^2 + \sum_{i \neq j} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

$P(e)$

$$2\cos^2\theta$$

$$\cos\left(\frac{\Delta m^2 L}{2E}\right)$$

$$P(l_a; l_b) = P_0 \sum_{ij} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

If there had been V_{ij} : $V_{ai} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$ $(E_i - E_j)\tau \approx \frac{m^2 L}{2E}$

$$\sum_i |V_{ai}|^2 |V_{bi}|^2 + \sum_{i \neq j} V_{ai} V_{bi}^* V_{aj}^* V_{bj} e^{-i(E_i - E_j)\tau}$$

$$-2 \cos^2 \theta \sin^2 \theta$$

$$\cos\left(\frac{\Delta m^2 L}{2E}\right)$$

$$P(l_e; l_e) = P_0 \sum_{ij} V_{ei} V_{ei}^* V_{ej}^* V_{ej} e^{-i(E_i - E_j)\tau}$$

If there had been two ν_e 's: $V_{ei} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$ $(E_i - E_j)\tau \approx \frac{\Delta m^2 L}{2E}$

$$\sum_{ij} (\dots) = \sum_i |V_{ei}|^2 |V_{ei}|^2 + \sum_{i \neq j} V_{ei} V_{ei}^* V_{ej}^* V_{ej} e^{-i(E_i - E_j)\tau}$$

$$P(e \rightarrow \mu) = 2 \cos^2 \theta \sin^2 \theta - 2 \cos^2 \theta \sin^2 \theta \cos\left(\frac{\Delta m^2 L}{2E}\right)$$

$$= (\sin^2 2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

$$E^2 = p^2 + \frac{m^2}{2p} \dots$$

For atmospheric
neutrinos

$$\frac{h^2}{\tau}$$

$$\frac{L}{E} \approx \frac{1}{\tau}$$

For atmospheric
neutrinos

$\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$E = p + \frac{m^2}{2p}$$

For atmospheric
neutrinos
 $\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$E \approx p + \frac{m^2}{2p}$$

For atmospheric
neutrinos

$\approx (\nu_\mu - \nu_e)$ oscillations

$$\Delta m^2 \approx$$

$$E \approx p + \frac{m^2}{2p}$$

For atmospheric
neutrinos

$\approx (\nu_\mu - \nu_e)$ oscillations

$$\Delta m^2 \approx 3 \times 10^{-3} \text{ eV}^2$$

$\sin$

neutrinos

$\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$\Delta m^2 \simeq 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \simeq 1$$

$$\frac{m_i^2 - m_j^2}{2p} \tau$$

$$\simeq \Delta$$

$$\simeq \Delta$$

$$\simeq \Delta$$

neutrinos

$\approx (\nu_\mu - \nu_\tau)$ oscillations

$$\Delta m^2 \approx 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \approx 1$$

For solar neutrino oscillations

$$\nu_e - (\nu_\mu, \nu_\tau)$$

$$\Delta m^2 \approx$$

$$\frac{m_i^2 - m_j^2}{2p} \tau$$

$$\approx \frac{\Delta m^2 L}{2E}$$

$-i \Delta m^2 L / 2E$

e

neutrinos

$\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$\Delta m^2 \simeq 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \simeq 1$$

For solar neutrino oscillations

$$\nu_e = (\nu_\mu, \nu_\tau)$$

$$\Delta m^2 \simeq 8 \times 10^{-5} \text{ eV}^2$$

$$\sin^2 2\theta \simeq$$

neutrinos

$\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$\Delta m^2 \simeq 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \simeq 1$$

For solar neutrino oscillations

$$\nu_e = (\nu_\mu, \nu_\tau)$$

$$\Delta m^2 \simeq 8 \times 10^{-5} \text{ eV}^2$$

$$0.4 < \tan^2 \theta < 0.5$$

For atmospheric
neutrinos

$\simeq (\nu_\mu - \nu_e)$ oscillations

$$\Delta m^2 \simeq 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \simeq 1 \quad \leftarrow$$

For solar neutrino oscillati

$$\nu_e = (\nu_\mu, \nu_e)$$

$$\Delta m^2 \simeq 8 \times 10^{-5} \text{ eV}^2$$

$$\delta^4 \tan^2 \theta$$

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + (m_{\text{eff}} \bar{\nu} \nu)$$

$$m_{\text{eff}} = \left\{ \begin{array}{l} g_{\mu} \\ g_{\tau} \end{array} \right\}$$

For atmospheric
neutrinos

$\simeq (\nu_\mu - \nu_\tau)$ oscillations

$$\Delta m^2 \simeq 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \simeq 1 \quad \leftarrow$$

very different
from quarks.

For solar neutrino oscillations

$$\nu_e = (\nu_\mu, \nu_\tau)$$

$$\Delta m^2 \simeq 8 \times 10^{-5} \text{ eV}^2$$

$$0.4 < \tan^2 \theta < 0.5$$

For atmospheric
neutrinos

$\nu_\mu - \nu_\tau$ oscillations

$$\Delta m^2 \approx 3 \times 10^{-3} \text{ eV}^2$$

$$\sin^2 2\theta \approx 1 \leftarrow$$

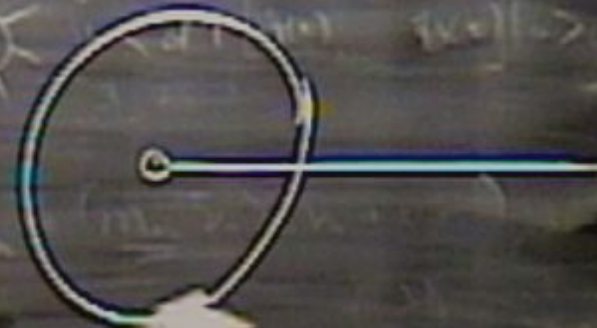
very different

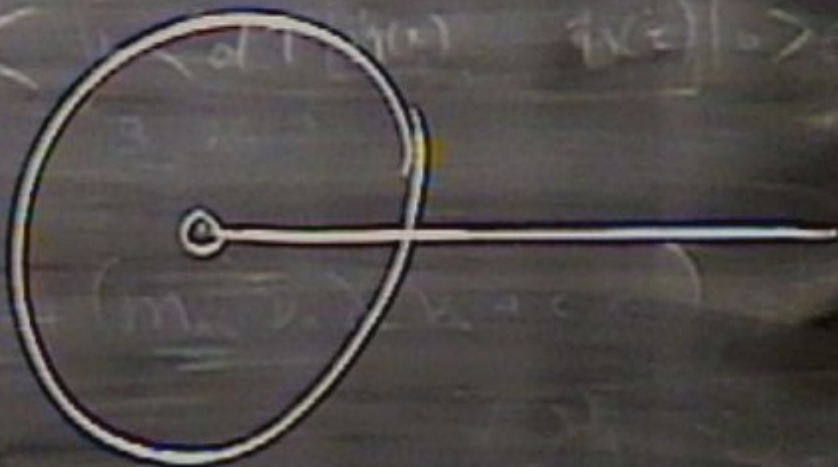
For solar neutrino oscillations

$$\nu_e - (\nu_\mu, \nu_\tau)$$

$$\Delta m^2 \approx 8 \times 10^{-5} \text{ eV}^2$$

$$\tan^2 \theta < 0.5$$



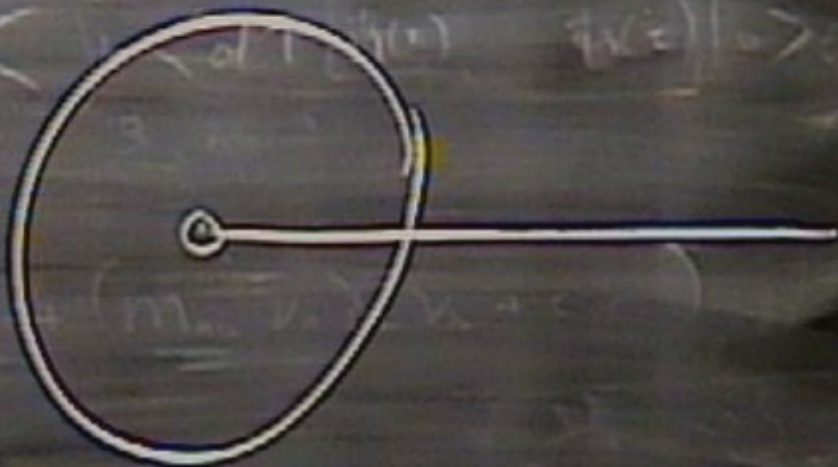


$$L_{\text{int}} \approx \frac{G_F}{\sqrt{2}} (\bar{e} \gamma^\mu \gamma_5 e) (\bar{\nu}_i \gamma_\mu \gamma_5 \nu_j)$$

very different

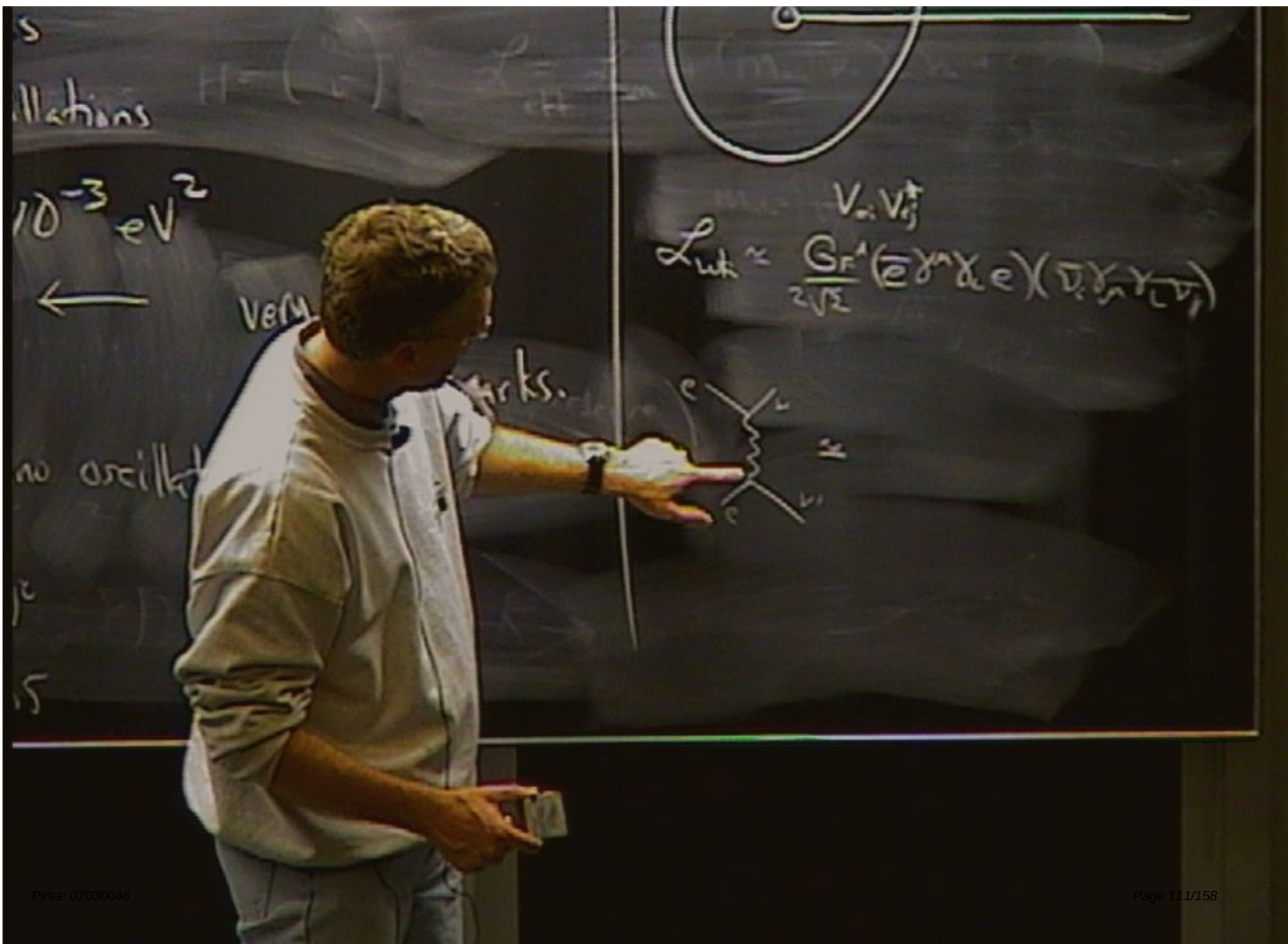
links.

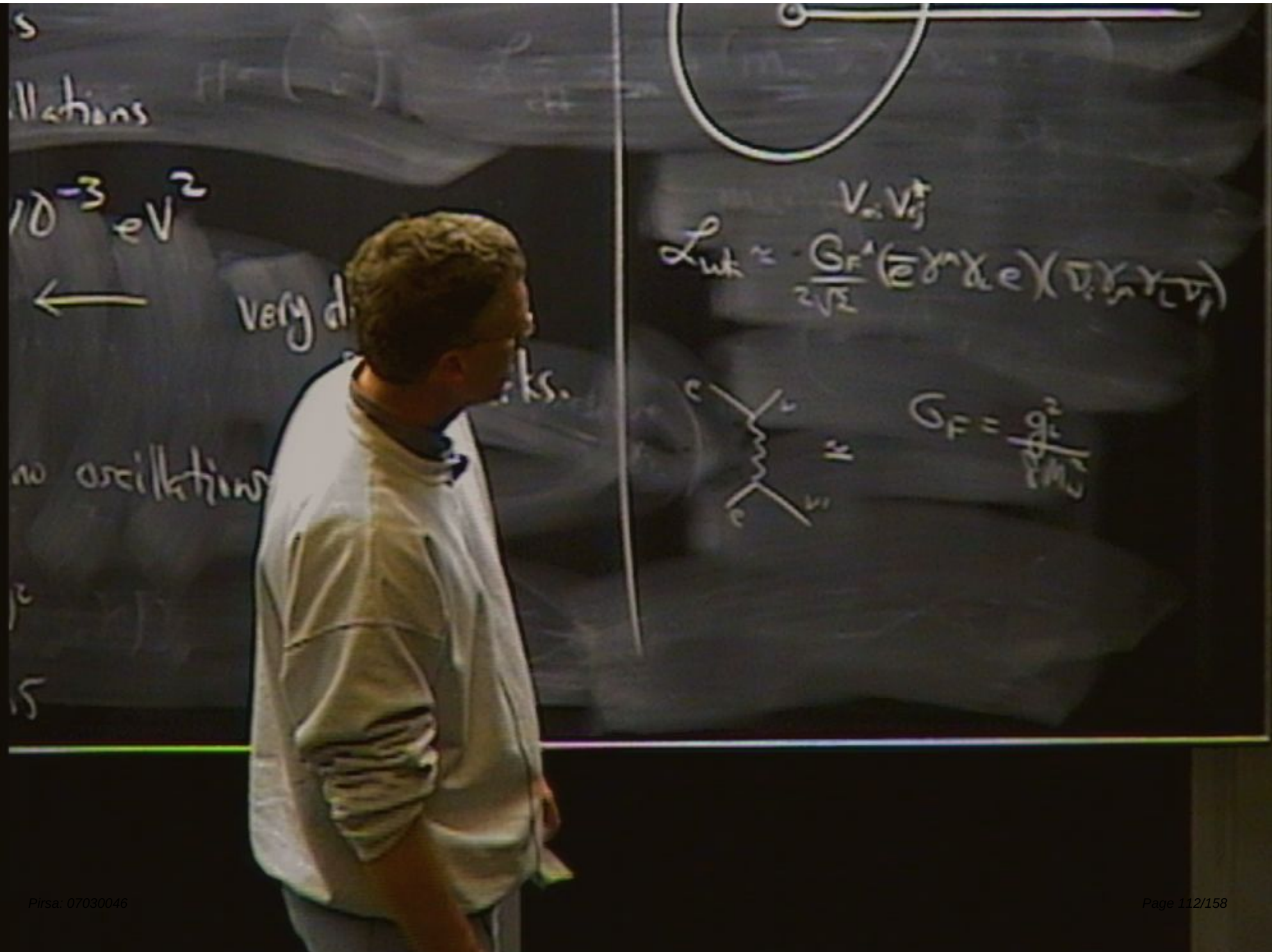
time

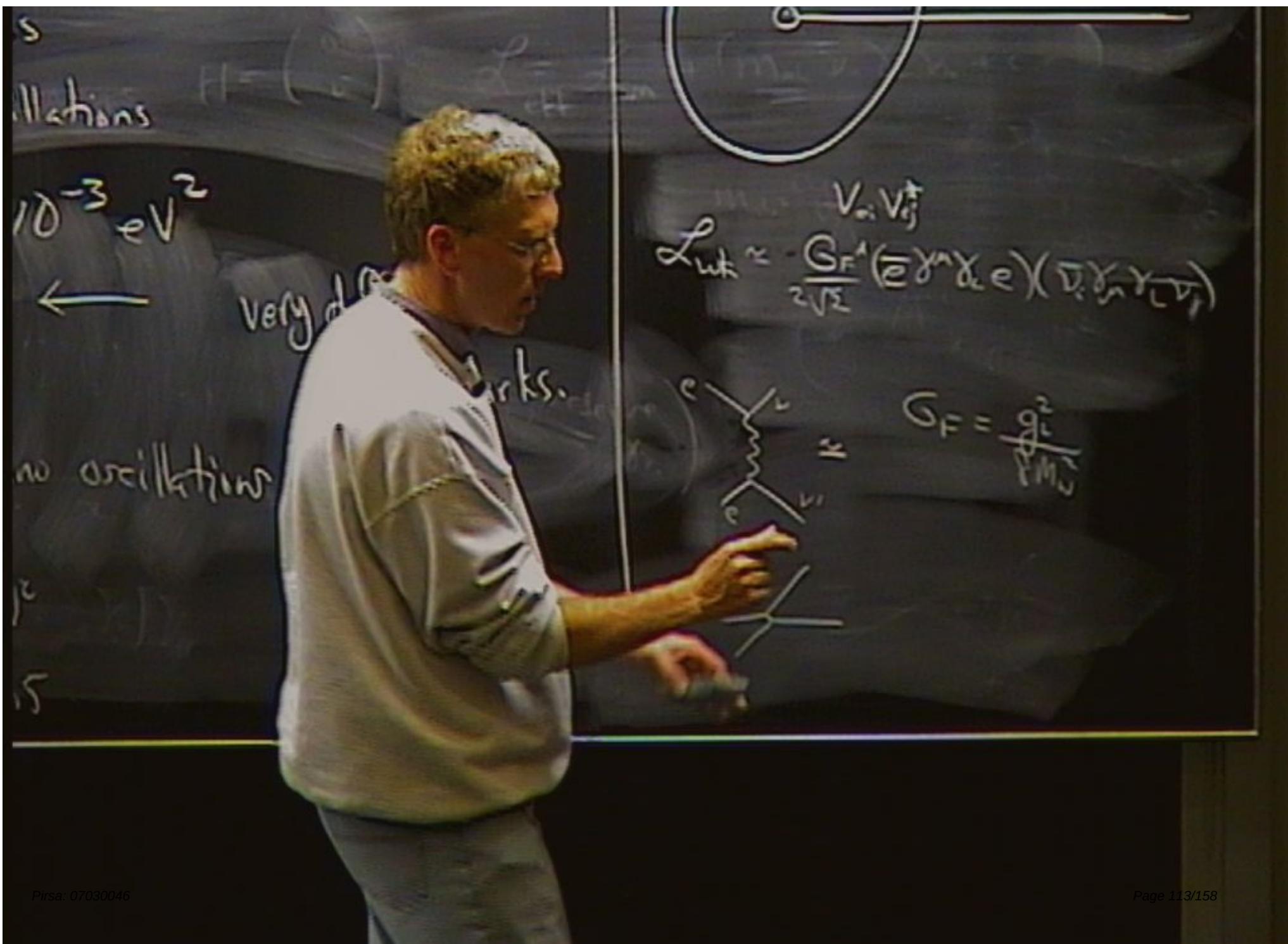


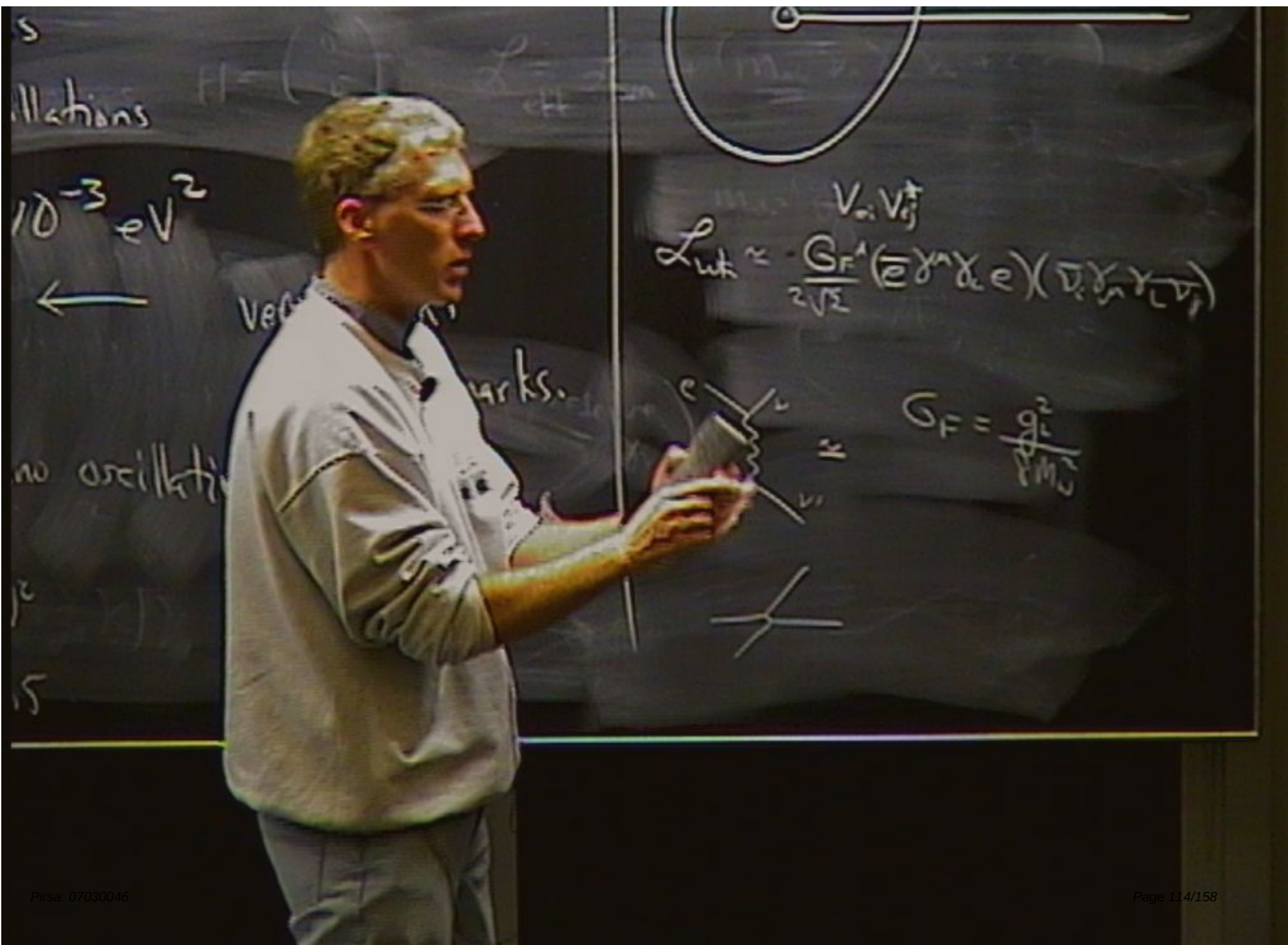
$$\mathcal{L}_{\text{int}} \approx \frac{G_F}{\sqrt{2}} V_{ei} V_{ej}^* (\bar{e} \gamma^\mu \gamma_5 e) (\bar{\nu}_i \gamma_\mu \gamma_5 \nu_j)$$











s
collisions

$$H = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$L = \frac{1}{2} m \dot{\phi}^2$$



$$-3 eV^2$$

very different
from quarks.

$$L_{\text{int}} \approx \frac{G_F}{\sqrt{2}} (\bar{e} \gamma^\mu \chi_e) (\bar{\nu}_i \gamma_\mu \chi_{\nu_i})$$



$$G_F = \frac{g^2}{8M_W^2}$$



In the hydrodynamic limit:

In the hydrodynamic limit: effective γ interaction with

e^-k

hydrodynamic limit effective ν interaction with
 e^- 's in n :

$$\frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \gamma_L e \rangle \bar{\nu}_i \gamma_\mu \gamma_L \nu_j V_{ei} V_{ej}^*$$

hydrodynamic limit: effective ν interaction with
 e^- 's in the sun:

$$\mathcal{L}_{\text{eff}} = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \gamma_L e \rangle \bar{\nu}_i \gamma_\mu \gamma_L \nu_j V_{ei} V_{ej}^*$$

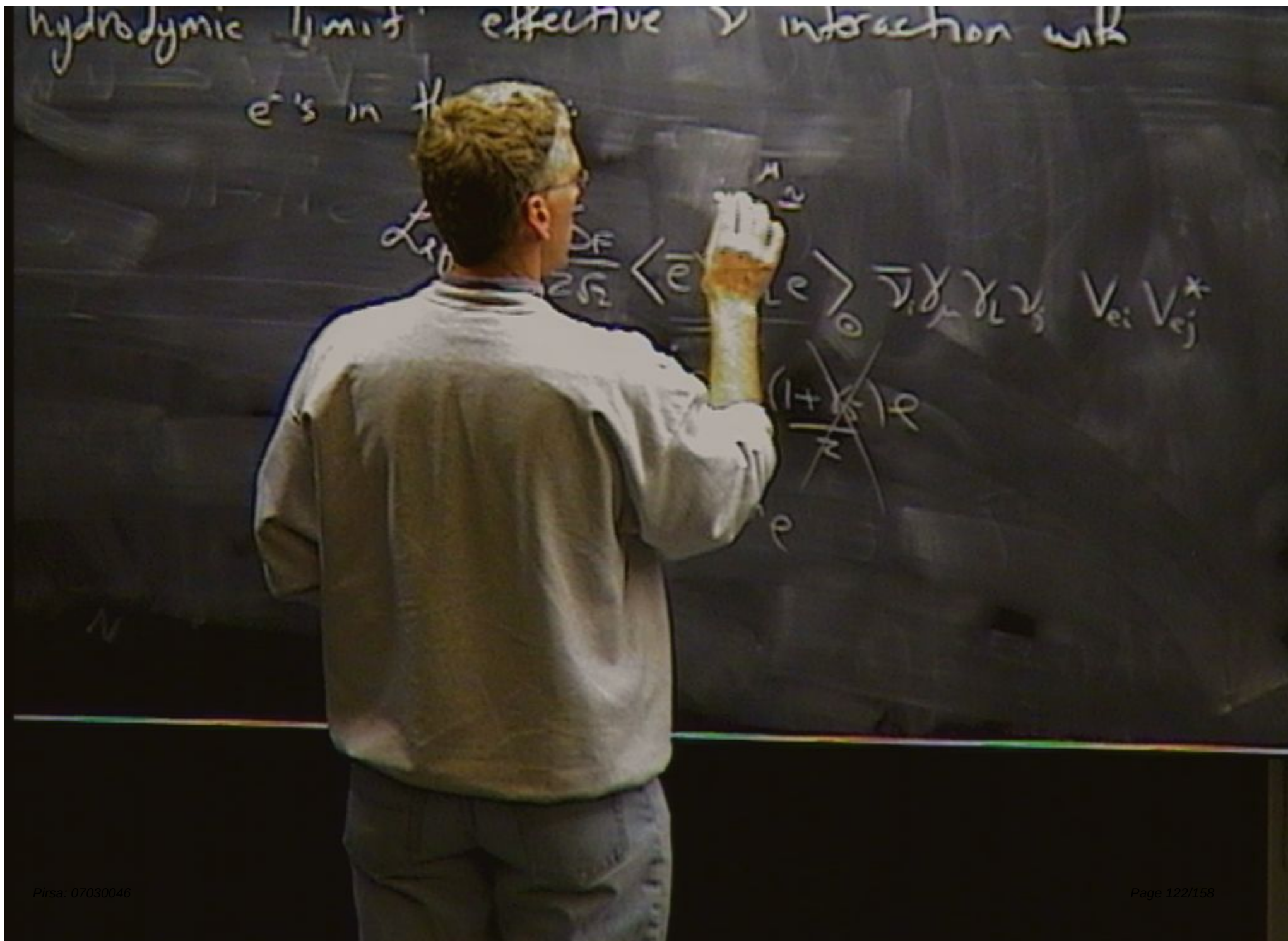
hydrodynamic limit: effective ν interaction with
 e^- 's in the sun:

$$i = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \chi_L e \rangle_0 \bar{\nu}_i \gamma_\mu \chi_L \nu_j V_{ei} V_{ej}^*$$
~~$$\bar{e} \gamma^\mu (1 + \gamma_5) e$$~~

hydrodynamic limit: effective ν interaction with
 e^- 's in the sun:

$$L_{\text{eff}} = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \chi_L e \rangle_0 \overline{\nu_i} \gamma_\mu \chi_L \nu_j V_{ei} V_{ej}^*$$

~~$\bar{e} \gamma^\mu (1 + \gamma_5) e$~~
 $\bar{e} \gamma^\mu e$



hydrodynamic limit: effective ν interaction with
 e^- 's in the Sun:

$$n_e \delta_0^{\mu} = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^{\mu} \gamma_L e \rangle_0 \bar{\nu}_i \gamma_{\mu} \gamma_L \nu_j V_{ei} V_{ej}^*$$

~~$\bar{e} \gamma^{\mu} (1 + \gamma_5) e$~~
 $\bar{e} \gamma^{\mu} e$

hydrodynamic limit: effective ν interaction with
 e^- 's in the sun:

$$H = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \chi_L e \rangle_0 \bar{\nu}_i \gamma_\mu \chi_L \nu_j V_{ei} V_{ej}^*$$

$$\bar{e} \gamma^\mu (1 + \cancel{\frac{\not{k}}{2}}) e$$

$$\bar{e} \gamma^\mu e$$

$$\approx \frac{G_F n_e}{2\sqrt{2}} V_{ei} V_{ej}^* (\bar{\nu}_i \gamma_\mu \chi_L \nu_j)$$

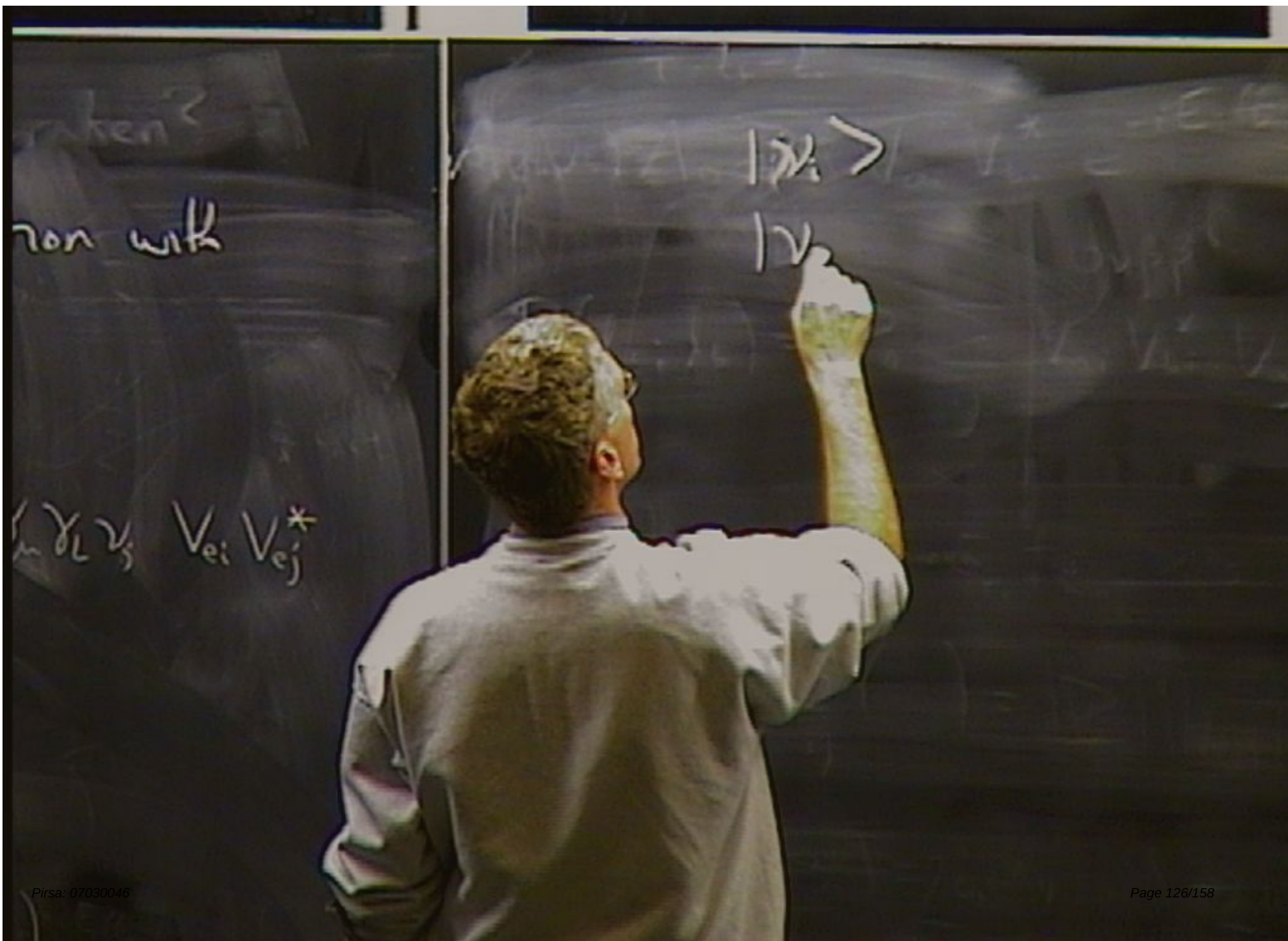
hydrodynamic limit: effective ν interaction with
 e^- 's in the sun:

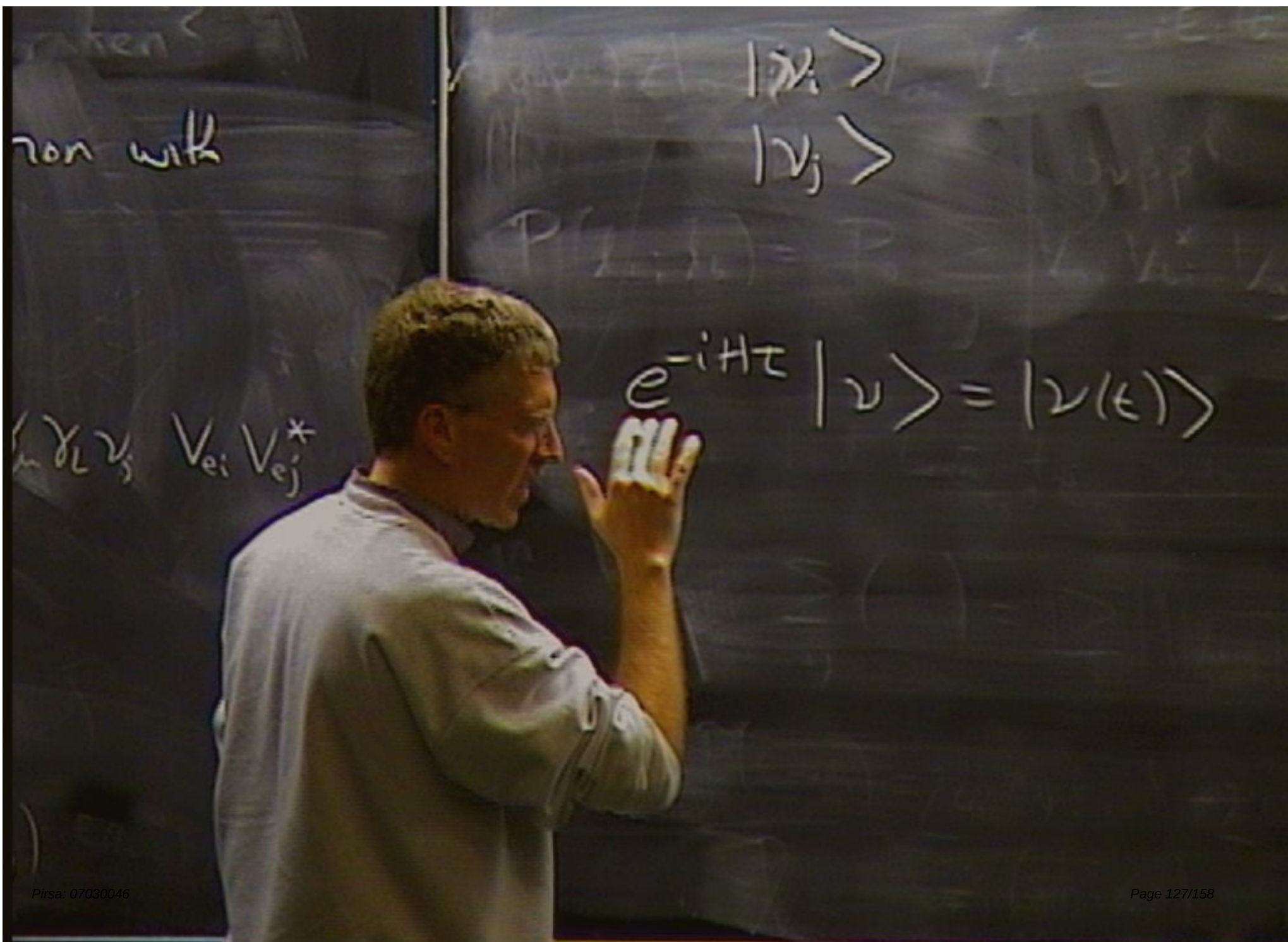
$$\rho = \frac{G_F}{2\sqrt{2}} \langle \bar{e} \gamma^\mu \chi_L e \rangle_0 \bar{\nu}_i \gamma_\mu \chi_L \nu_j V_{ei} V_{ej}^*$$

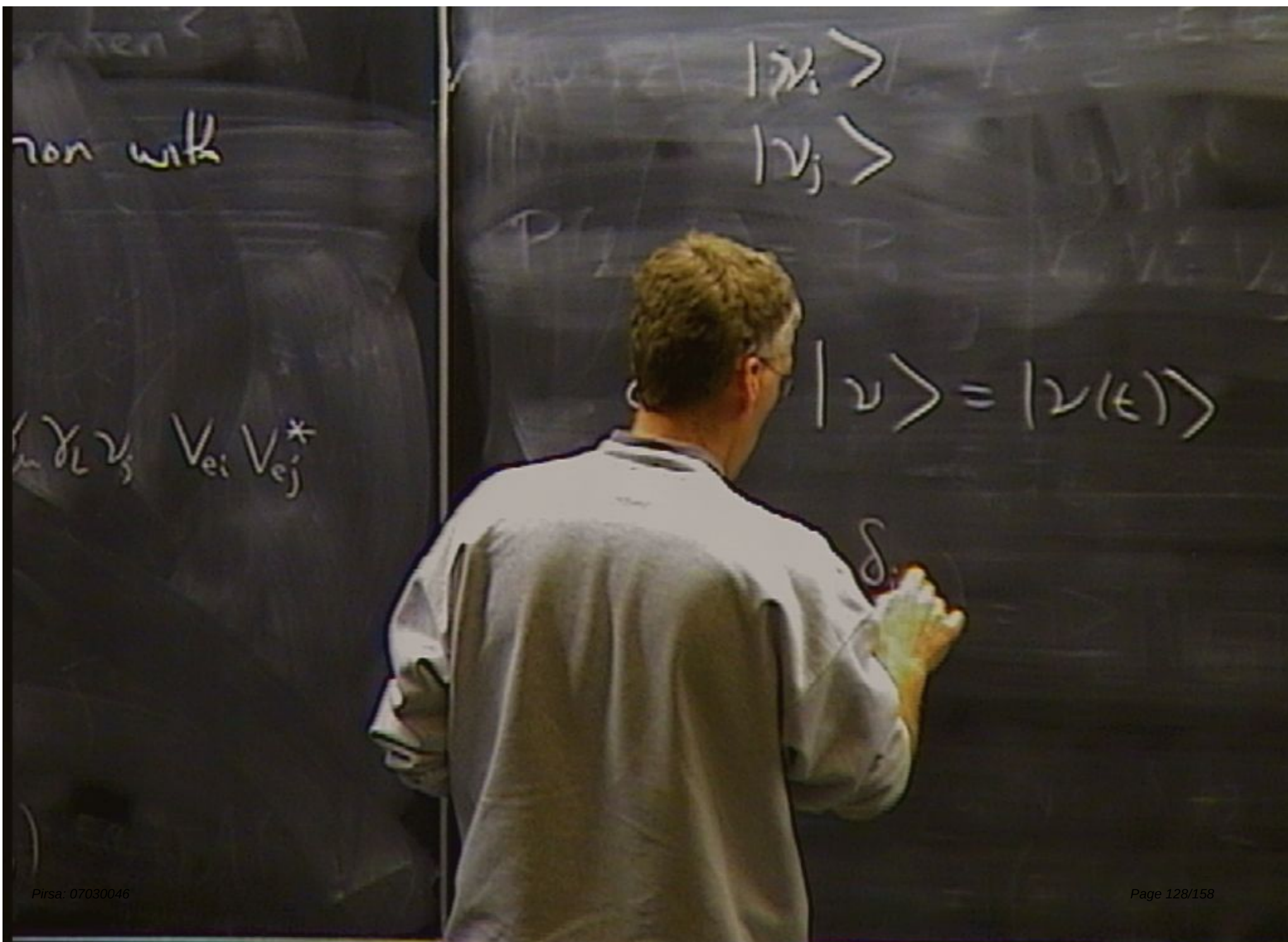
~~$$\bar{e} \gamma^\mu (1 + \frac{\gamma_5}{2}) e$$~~

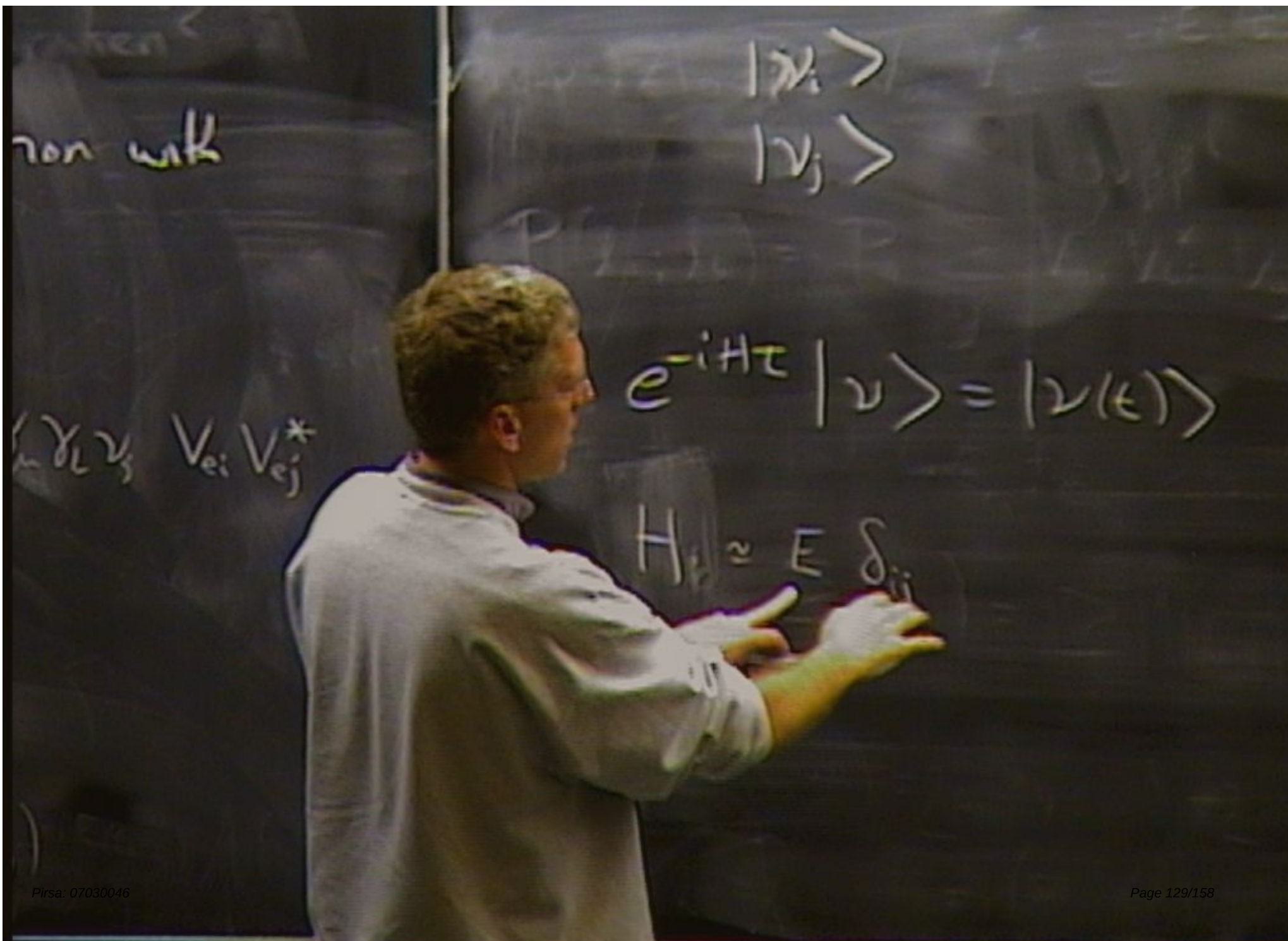
$$\bar{e} \gamma^\mu e$$

$$\approx \frac{G_F n_e}{2\sqrt{2}} V_{ei} V_{ej}^* (\bar{\nu}_i \gamma_0 \chi_L \nu_j)$$









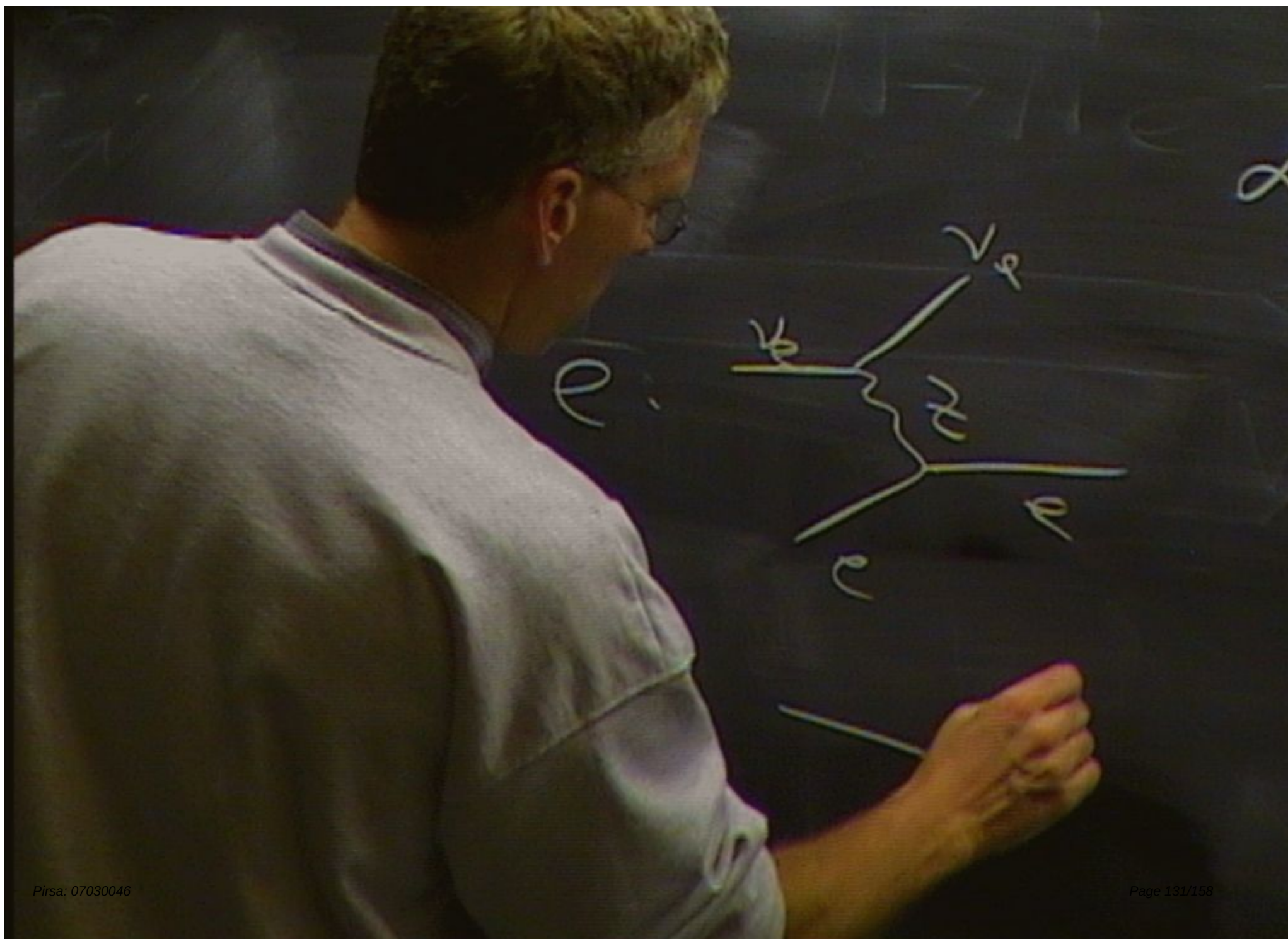
$$|v_i\rangle$$

$$|v_j\rangle$$

$$P(v_i, v_j) = P_{ij}$$

$$e^{-iH\tau} |v\rangle = |v(\tau)\rangle$$

$$E_{ij} = \delta_{ij} + m_{ij}$$



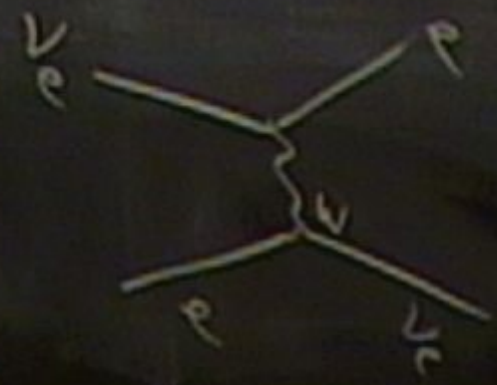
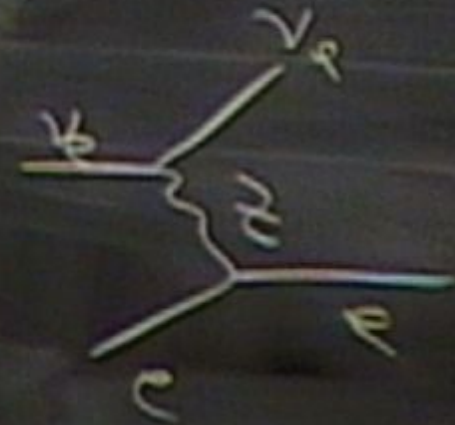
e^- 's in the sun

Left =

ν_e

ν_e

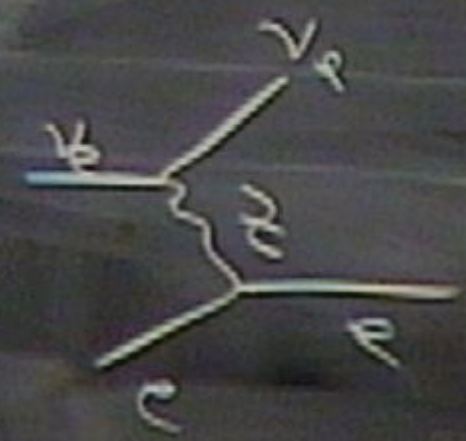
e^-



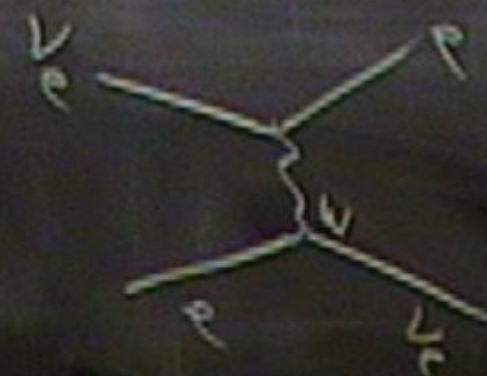
e's in the

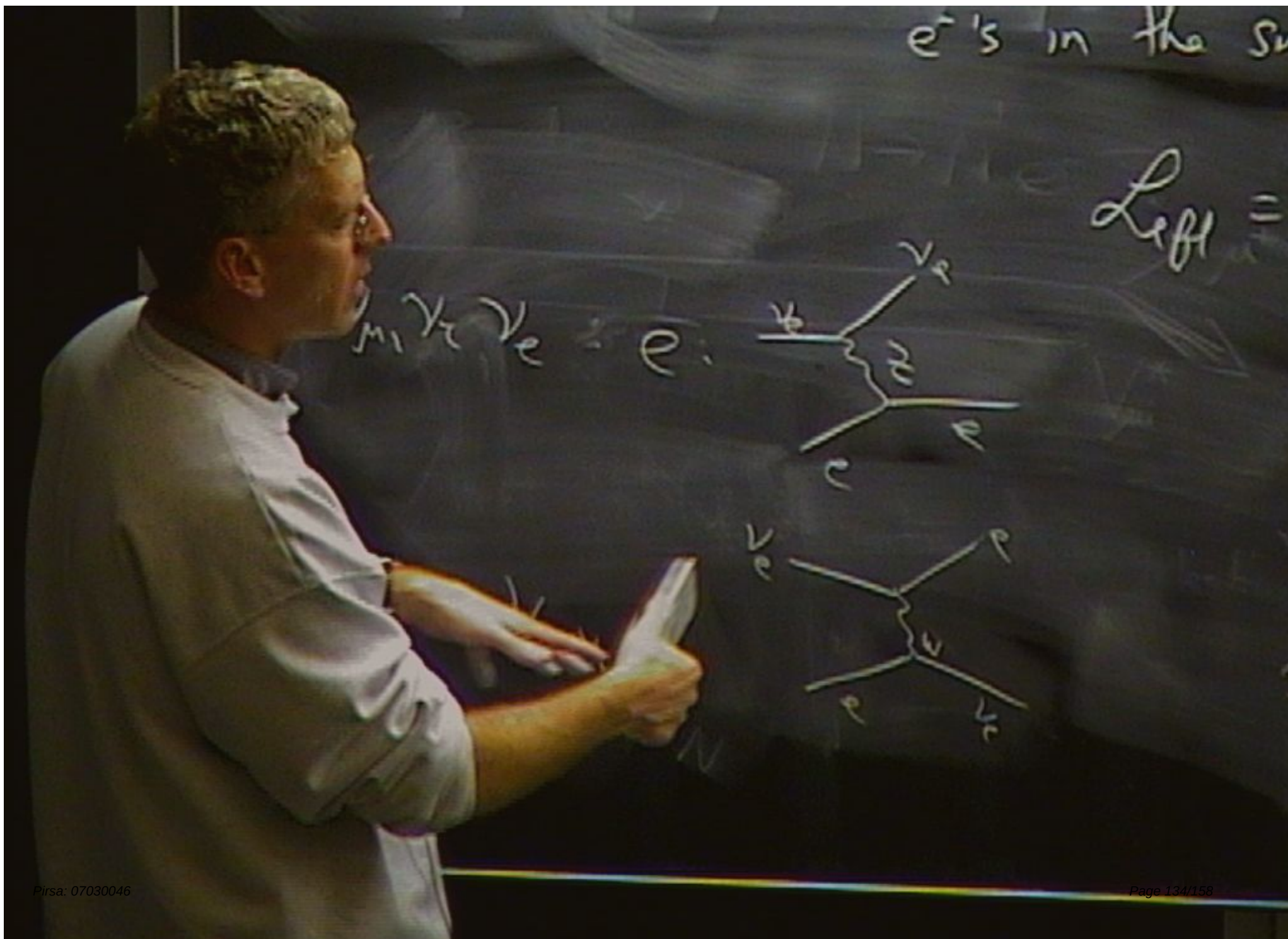
Left

$$\nu_{\mu}, \nu_{\tau}, \nu_e = e.$$



ν_e only.





$$|v_i\rangle$$

$$|v_j\rangle$$

$$P(\nu_i, \nu_j) = P_{ij} = V_{\nu_i} V_{\nu_j}^* = V_{\nu_j}^* V_{\nu_i}$$

$$e^{-iH\tau} |v\rangle = |\nu(\tau)\rangle$$

$$H_{ij} \approx H_0 \delta_{ij} + m_{ij} + \begin{pmatrix} \frac{m_e}{2} & 0 \\ 0 & 0 \end{pmatrix} \text{ in basis } |\nu_e\rangle$$

$$| \nu_e \rangle$$

$$| \nu_\mu \rangle$$

$$e^{-iH\tau} | \nu_e \rangle = | \nu(\tau) \rangle$$

$$H_f \approx H$$

$$m_{ij} + \begin{pmatrix} m_e & 0 \\ 0 & 0 \end{pmatrix} \text{ in basis } | \nu_e \rangle | \nu_\mu \rangle$$

the presence of matter is important in finding the propagation eigenstates.

$$| \nu_e \rangle$$

$$| \nu_\mu \rangle$$

$$| \nu \rangle = | \nu(t) \rangle$$

$$H_0 \delta_{ij} + m_{ij} + \begin{pmatrix} \frac{m_e}{2} & 0 \\ 0 & 0 \end{pmatrix} \text{ in basis } | \nu_e \rangle | \nu_\mu \rangle$$

$\Delta m^2 \sim 1 \text{ eV}^2$ the presence of matter is important in finding the propagation eigenstates.

atmospheric

neutrinos

oscillations

$$3 \times 10^{-3} \text{ eV}^2$$

$$\theta \approx 1 \leftarrow$$

neutrino oscillations

$$2 \nu_e$$

$$10^{-5} \text{ eV}^2$$

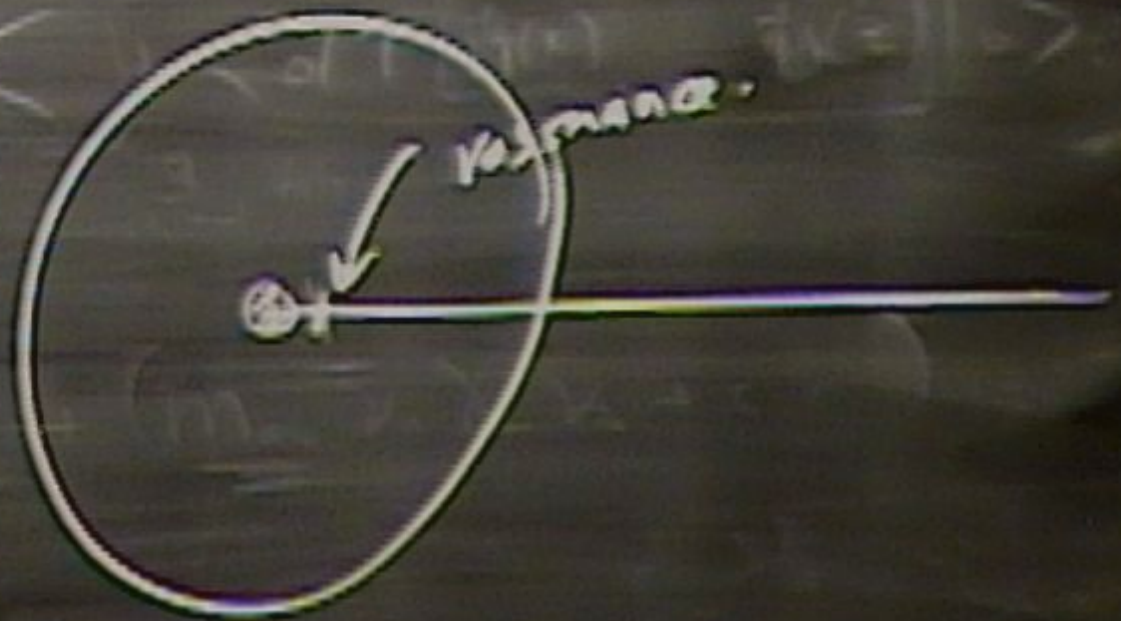
$$\theta < 0.5$$

very different
from quarks.



$$L_{\text{int}} \propto \frac{Q}{2\sqrt{2}}$$

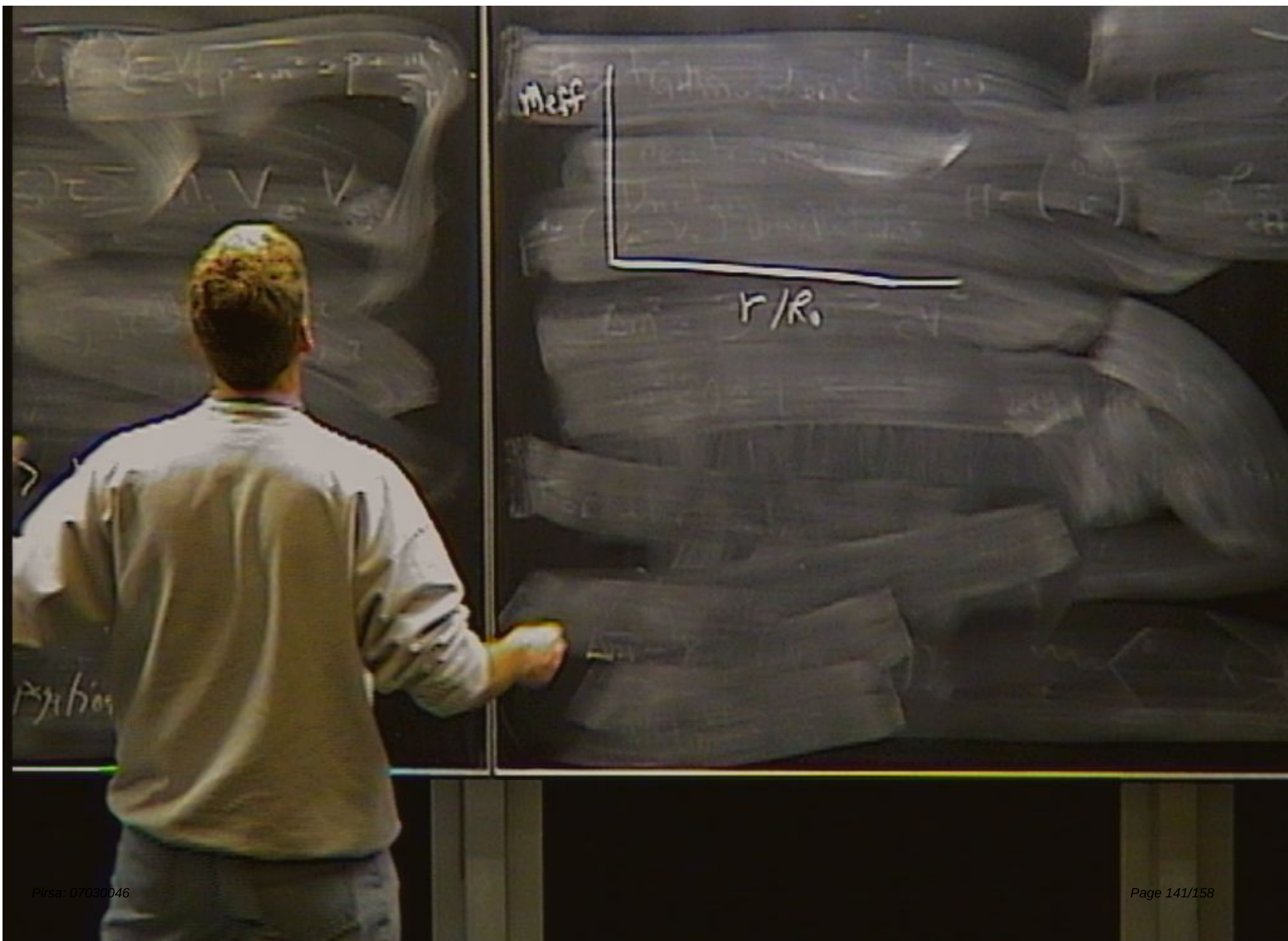




$$V_{ei} V_{ej}^*$$

$$\mathcal{L}_{\text{int}} \approx - \frac{G_F}{2\sqrt{2}} (\bar{e} \gamma^\mu \gamma_L e) (\bar{\nu}_i \gamma_\mu \gamma_L \nu_j)$$

y different
from quarks.



important in finding the
position eigenstates.

1. Trichomonas vaginalis
 2. Neisseria gonorrhoeae
 3. Chlamydia trachomatis

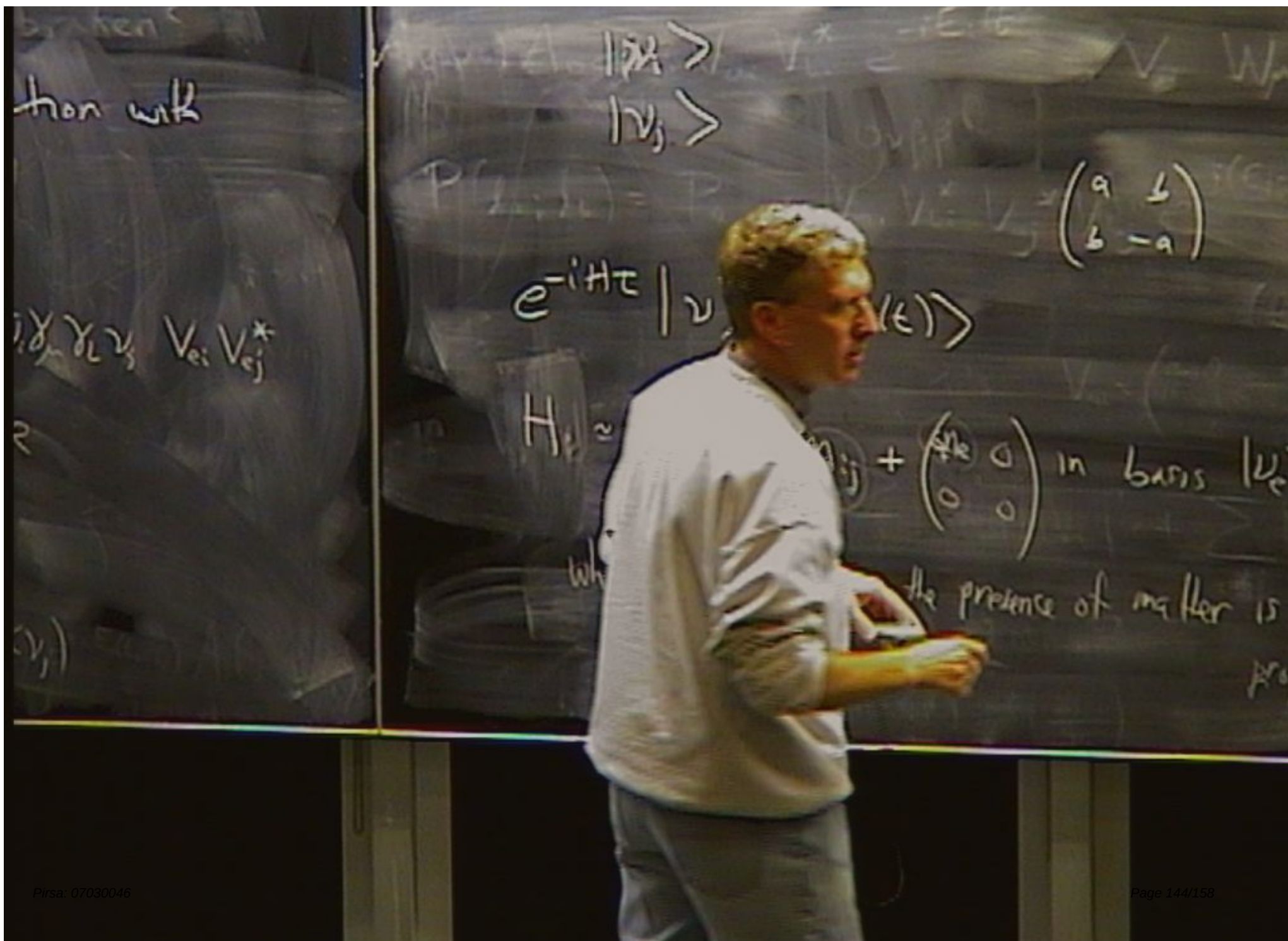
Y/R.

important in finding the
position eigenstates.

Highly magnified from
nearby rocks

Unit 2 - H
1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 - 11 - 12 - 13 - 14 - 15 - 16 - 17 - 18 - 19 - 20 - 21 - 22 - 23 - 24 - 25 - 26 - 27 - 28 - 29 - 30 - 31 - 32 - 33 - 34 - 35 - 36 - 37 - 38 - 39 - 40 - 41 - 42 - 43 - 44 - 45 - 46 - 47 - 48 - 49 - 50 - 51 - 52 - 53 - 54 - 55 - 56 - 57 - 58 - 59 - 60 - 61 - 62 - 63 - 64 - 65 - 66 - 67 - 68 - 69 - 70 - 71 - 72 - 73 - 74 - 75 - 76 - 77 - 78 - 79 - 80 - 81 - 82 - 83 - 84 - 85 - 86 - 87 - 88 - 89 - 90 - 91 - 92 - 93 - 94 - 95 - 96 - 97 - 98 - 99 - 100 - 101 - 102 - 103 - 104 - 105 - 106 - 107 - 108 - 109 - 110 - 111 - 112 - 113 - 114 - 115 - 116 - 117 - 118 - 119 - 120 - 121 - 122 - 123 - 124 - 125 - 126 - 127 - 128 - 129 - 130 - 131 - 132 - 133 - 134 - 135 - 136 - 137 - 138 - 139 - 140 - 141 - 142 - 143 - 144 - 145 - 146 - 147 - 148 - 149 - 150 - 151 - 152 - 153 - 154 - 155 - 156 - 157 - 158 - 159 - 160 - 161 - 162 - 163 - 164 - 165 - 166 - 167 - 168 - 169 - 170 - 171 - 172 - 173 - 174 - 175 - 176 - 177 - 178 - 179 - 180 - 181 - 182 - 183 - 184 - 185 - 186 - 187 - 188 - 189 - 190 - 191 - 192 - 193 - 194 - 195 - 196 - 197 - 198 - 199 - 200 - 201 - 202 - 203 - 204 - 205 - 206 - 207 - 208 - 209 - 210 - 211 - 212 - 213 - 214 - 215 - 216 - 217 - 218 - 219 - 220 - 221 - 222 - 223 - 224 - 225 - 226 - 227 - 228 - 229 - 230 - 231 - 232 - 233 - 234 - 235 - 236 - 237 - 238 - 239 - 240 - 241 - 242 - 243 - 244 - 245 - 246 - 247 - 248 - 249 - 250 - 251 - 252 - 253 - 254 - 255 - 256 - 257 - 258 - 259 - 260 - 261 - 262 - 263 - 264 - 265 - 266 - 267 - 268 - 269 - 270 - 271 - 272 - 273 - 274 - 275 - 276 - 277 - 278 - 279 - 280 - 281 - 282 - 283 - 284 - 285 - 286 - 287 - 288 - 289 - 290 - 291 - 292 - 293 - 294 - 295 - 296 - 297 - 298 - 299 - 300 - 301 - 302 - 303 - 304 - 305 - 306 - 307 - 308 - 309 - 310 - 311 - 312 - 313 - 314 - 315 - 316 - 317 - 318 - 319 - 320 - 321 - 322 - 323 - 324 - 325 - 326 - 327 - 328 - 329 - 330 - 331 - 332 - 333 - 334 - 335 - 336 - 337 - 338 - 339 - 340 - 341 - 342 - 343 - 344 - 345 - 346 - 347 - 348 - 349 - 350 - 351 - 352 - 353 - 354 - 355 - 356 - 357 - 358 - 359 - 360 - 361 - 362 - 363 - 364 - 365 - 366 - 367 - 368 - 369 - 370 - 371 - 372 - 373 - 374 - 375 - 376 - 377 - 378 - 379 - 380 - 381 - 382 - 383 - 384 - 385 - 386 - 387 - 388 - 389 - 390 - 391 - 392 - 393 - 394 - 395 - 396 - 397 - 398 - 399 - 400 - 401 - 402 - 403 - 404 - 405 - 406 - 407 - 408 - 409 - 410 - 411 - 412 - 413 - 414 - 415 - 416 - 417 - 418 - 419 - 420 - 421 - 422 - 423 - 424 - 425 - 426 - 427 - 428 - 429 - 430 - 431 - 432 - 433 - 434 - 435 - 436 - 437 - 438 - 439 - 440 - 441 - 442 - 443 - 444 - 445 - 446 - 447 - 448 - 449 - 450 - 451 - 452 - 453 - 454 - 455 - 456 - 457 - 458 - 459 - 460 - 461 - 462 - 463 - 464 - 465 - 466 - 467 - 468 - 469 - 470 - 471 - 472 - 473 - 474 - 475 - 476 - 477 - 478 - 479 - 480 - 481 - 482 - 483 - 484 - 485 - 486 - 487 - 488 - 489 - 490 - 491 - 492 - 493 - 494 - 495 - 496 - 497 - 498 - 499 - 500 - 501 - 502 - 503 - 504 - 505 - 506 - 507 - 508 - 509 - 510 - 511 - 512 - 513 - 514 - 515 - 516 - 517 - 518 - 519 - 520 - 521 - 522 - 523 - 524 - 525 - 526 - 527 - 528 - 529 - 530 - 531 - 532 - 533 - 534 - 535 - 536 - 537 - 538 - 539 - 540 - 541 - 542 - 543 - 544 - 545 - 546 - 547 - 548 - 549 - 550 - 551 - 552 - 553 - 554 - 555 - 556 - 557 - 558 - 559 - 560 - 561 - 562 - 563 - 564 - 565 - 566 - 567 - 568 - 569 - 570 - 571 - 572 - 573 - 574 - 575 - 576 - 577 - 578 - 579 - 580 - 581 - 582 - 583 - 584 - 585 - 586 - 587 - 588 - 589 - 590 - 591 - 592 - 593 - 594 - 595 - 596 - 597 - 598 - 599 - 600 - 601 - 602 - 603 - 604 - 605 - 606 - 607 - 608 - 609 - 610 - 611 - 612 - 613 - 614 - 615 - 616 - 617 - 618 - 619 - 620 - 621 - 622 - 623 - 624 - 625 - 626 - 627 - 628 - 629 - 630 - 631 - 632 - 633 - 634 - 635 - 636 - 637 - 638 - 639 - 640 - 641 - 642 - 643 - 644 - 645 - 646 - 647 - 648 - 649 - 650 - 651 - 652 - 653 - 654 - 655 - 656 - 657 - 658 - 659 - 660 - 661 - 662 - 663 - 664 - 665 - 666 - 667 - 668 - 669 - 670 - 671 - 672 - 673 - 674 - 675 - 676 - 677 - 678 - 679 - 680 - 681 - 682 - 683 - 684 - 685 - 686 - 687 - 688 - 689 - 690 - 691 - 692 - 693 - 694 - 695 - 696 - 697 - 698 - 699 - 700 - 701 - 702 - 703 - 704 - 705 - 706 - 707 - 708 - 709 - 710 - 711 - 712 - 713 - 714 - 715 - 716 - 717 - 718 - 719 - 720 - 721 - 722 - 723 - 724 - 725 - 726 - 727 - 728 - 729 - 730 - 731 - 732 - 733 - 734 - 735 - 736 - 737 - 738 - 739 - 740 - 741 - 742 - 743 - 744 - 745 - 746 - 747 - 748 - 749 - 750 - 751 - 752 - 753 - 754 - 755 - 756 - 757 - 758 - 759 - 760 - 761 - 762 - 763 - 764 - 765 - 766 - 767 - 768 - 769 - 770 - 771 - 772 - 773 - 774 - 775 - 776 - 777 - 778 - 779 - 780 - 781 - 782 - 783 - 784 - 785 - 786 - 787 - 788 - 789 - 790 - 791 - 792 - 793 - 794 - 795 - 796 - 797 - 798 - 799 - 800 - 801 - 802 - 803 - 804 - 805 - 806 - 807 - 808 - 809 - 810 - 811 - 812 - 813 - 814 - 815 - 816 - 817 - 818 - 819 - 820 - 821 - 822 - 823 - 824 - 825 - 826 - 827 - 828 - 829 - 830 - 831 - 832 - 833 - 834 - 835 - 836

Y/R.



tion with

$$i\gamma_L \gamma_L v_j V_{ei} V_{ej}^*$$

$$v_j)$$

$$|v_i\rangle \quad |v_j\rangle$$

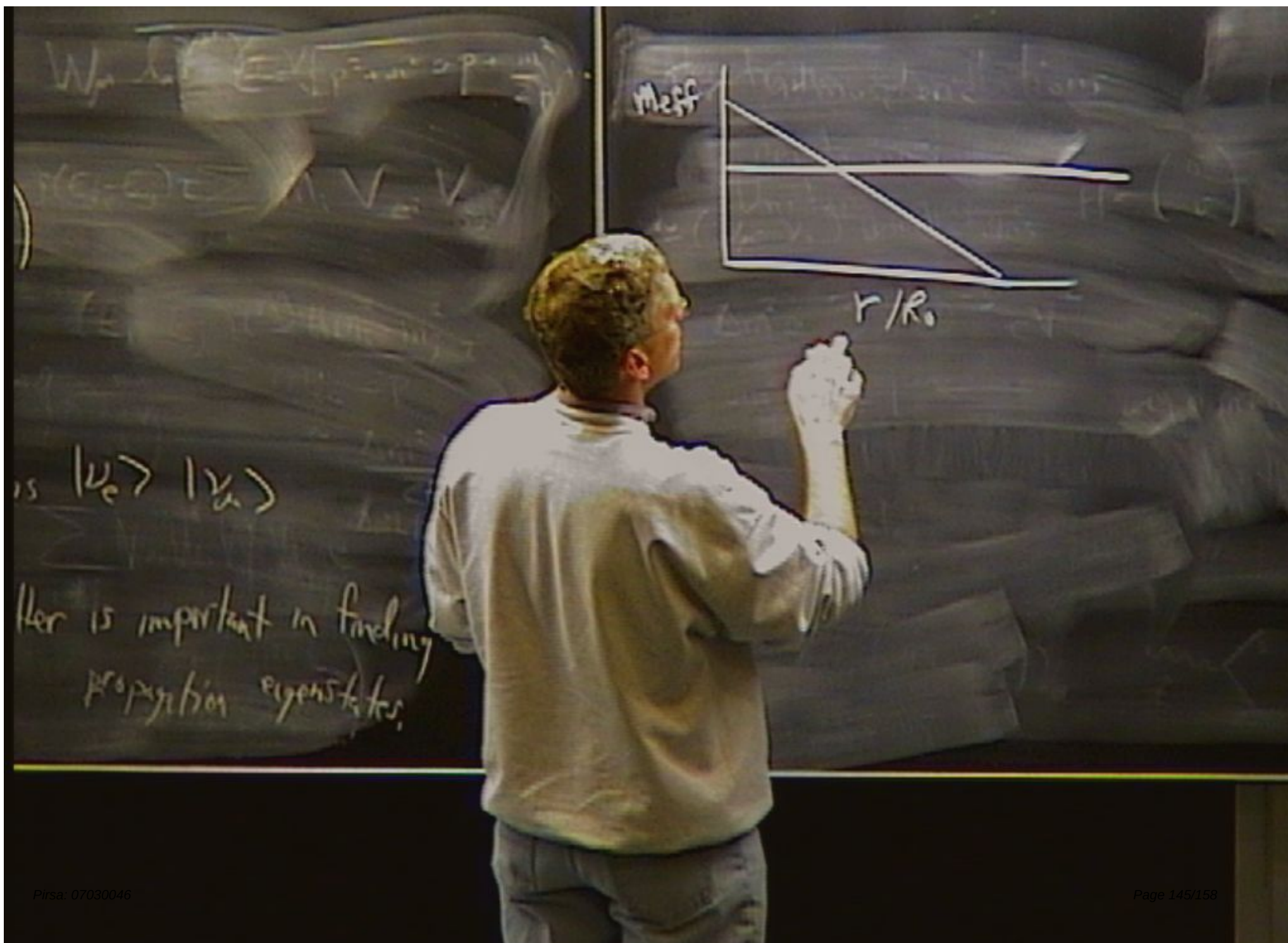
$$P(v_i, v_j) = P_0 \quad V_{ei} V_{ej}^* = \begin{pmatrix} a & b \\ b & -a \end{pmatrix}$$

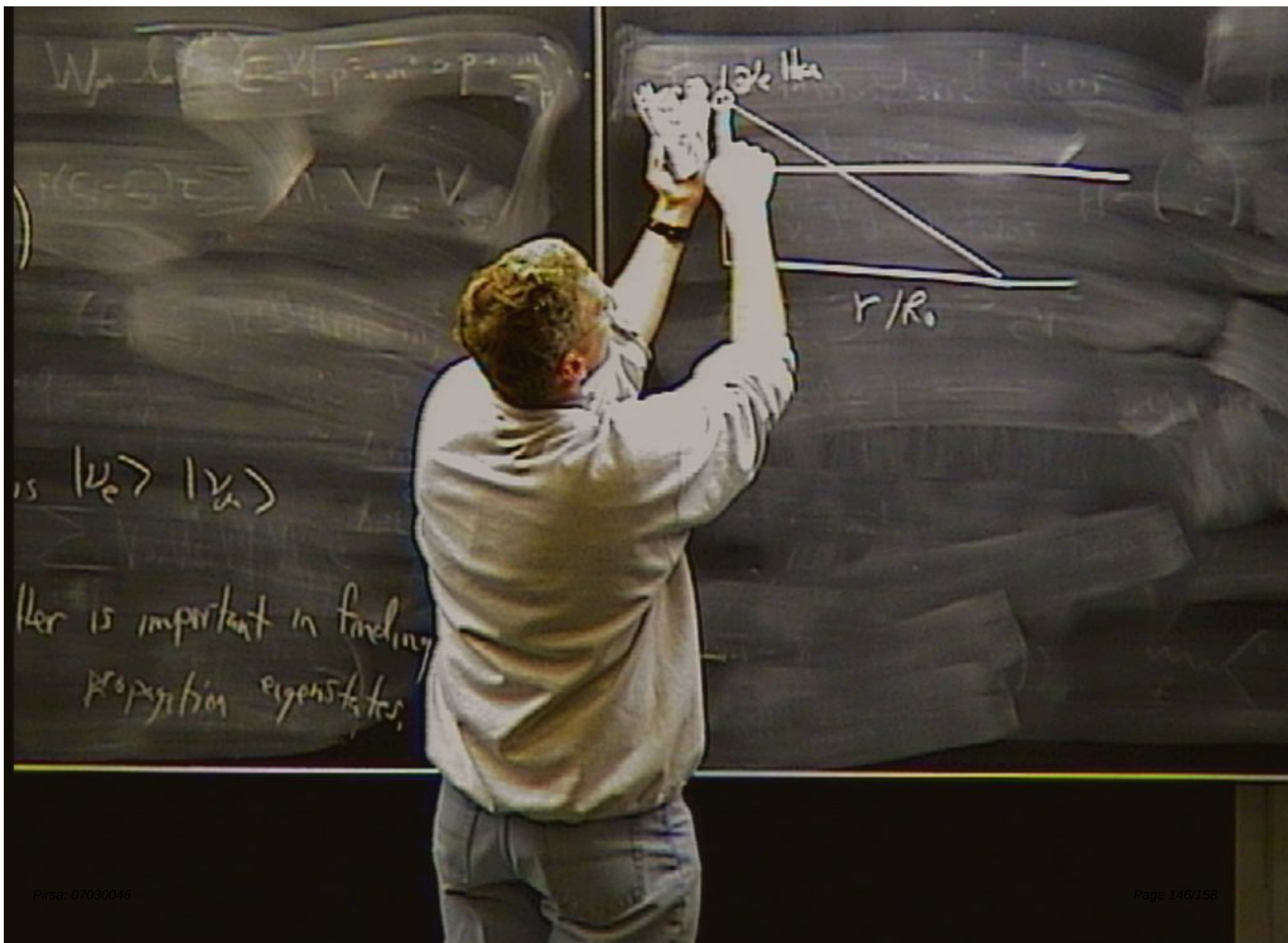
$$e^{-iH\tau} |v_i(t)\rangle$$

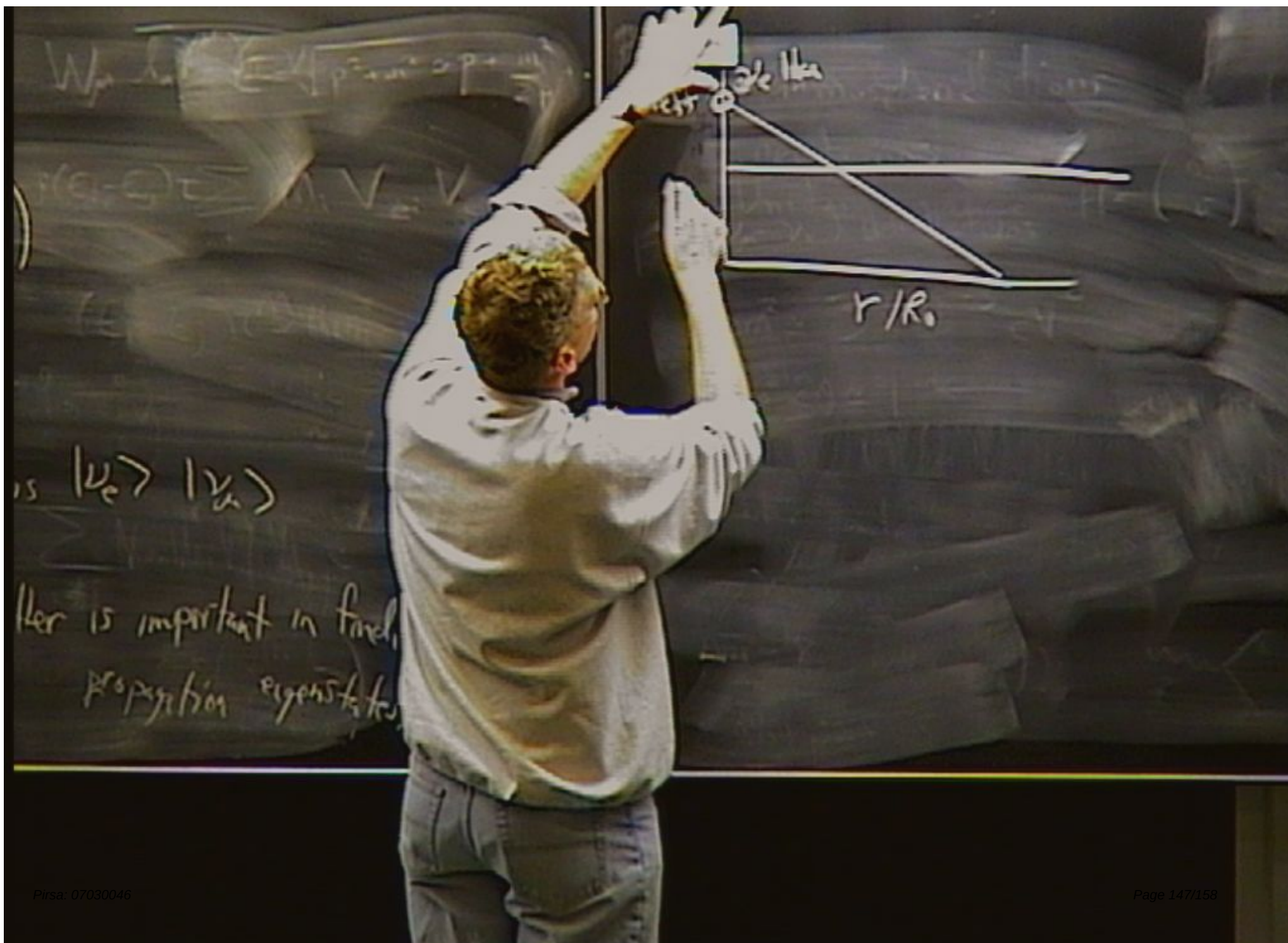
$$H_{eff} \approx$$

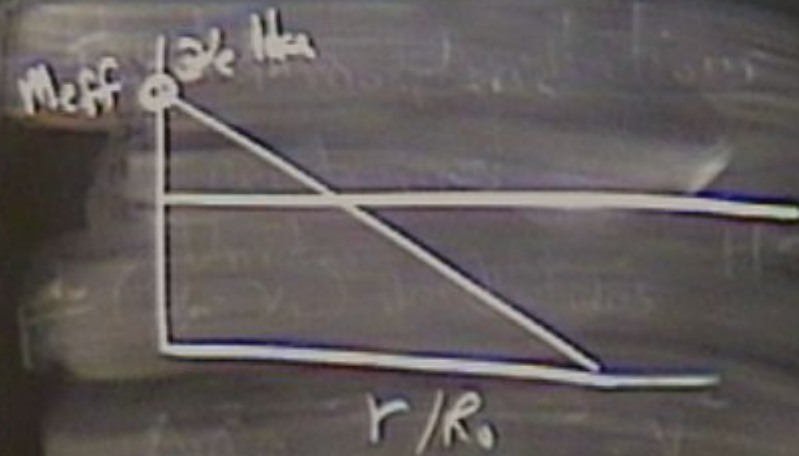
$$+ \begin{pmatrix} \frac{g}{2} & 0 \\ 0 & 0 \end{pmatrix} \text{ in basis } |v_i\rangle$$

the presence of matter is





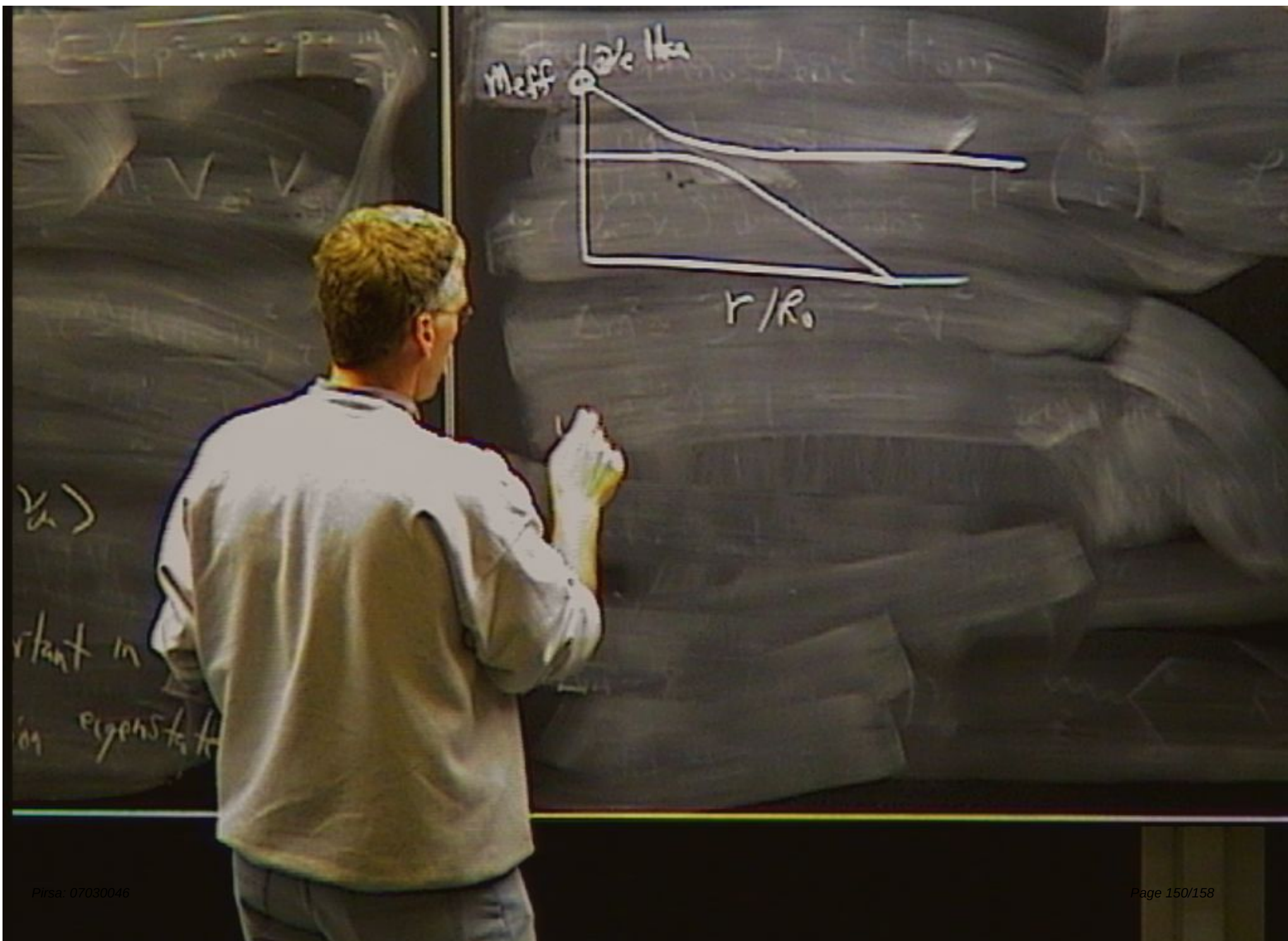


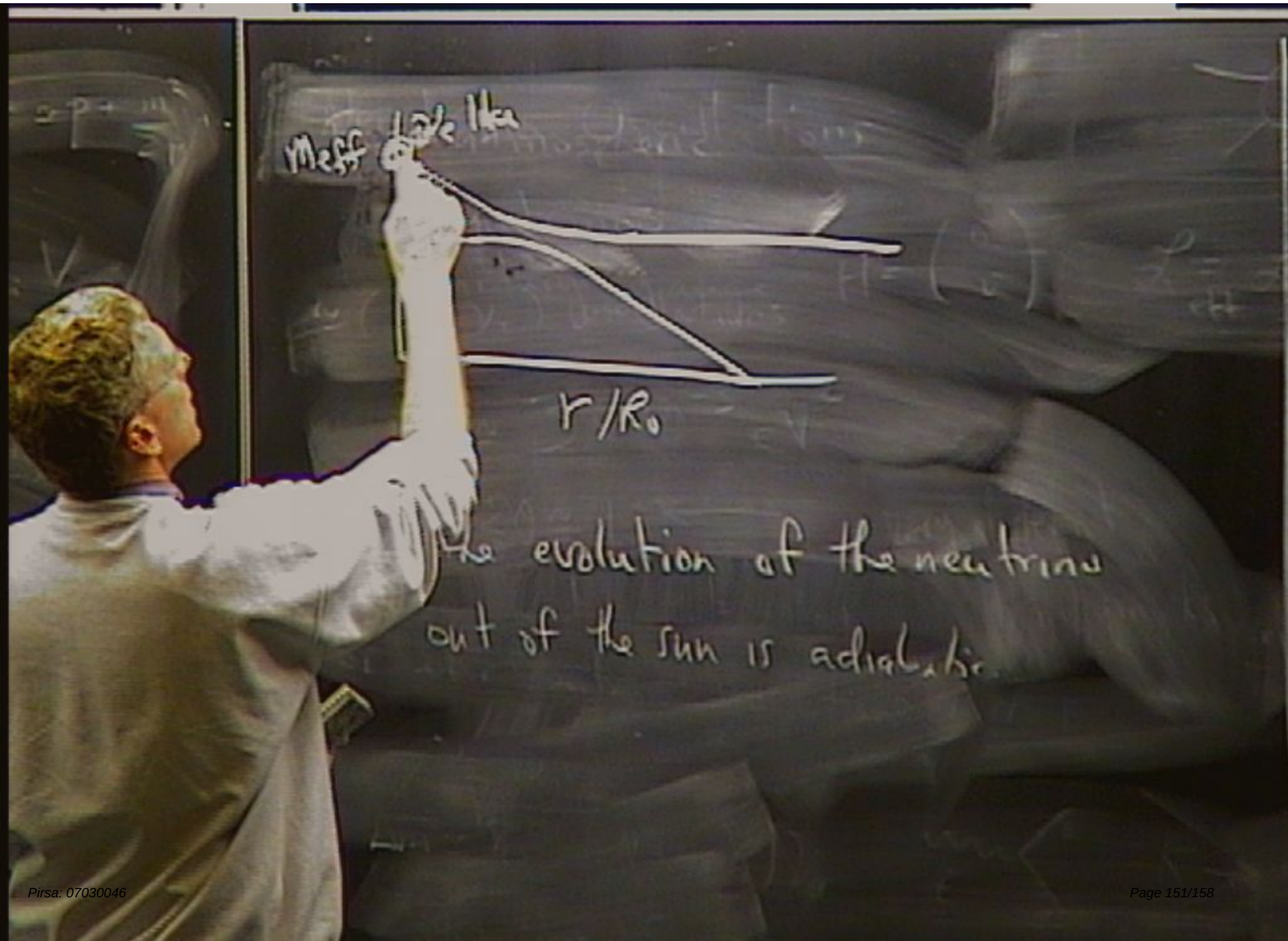


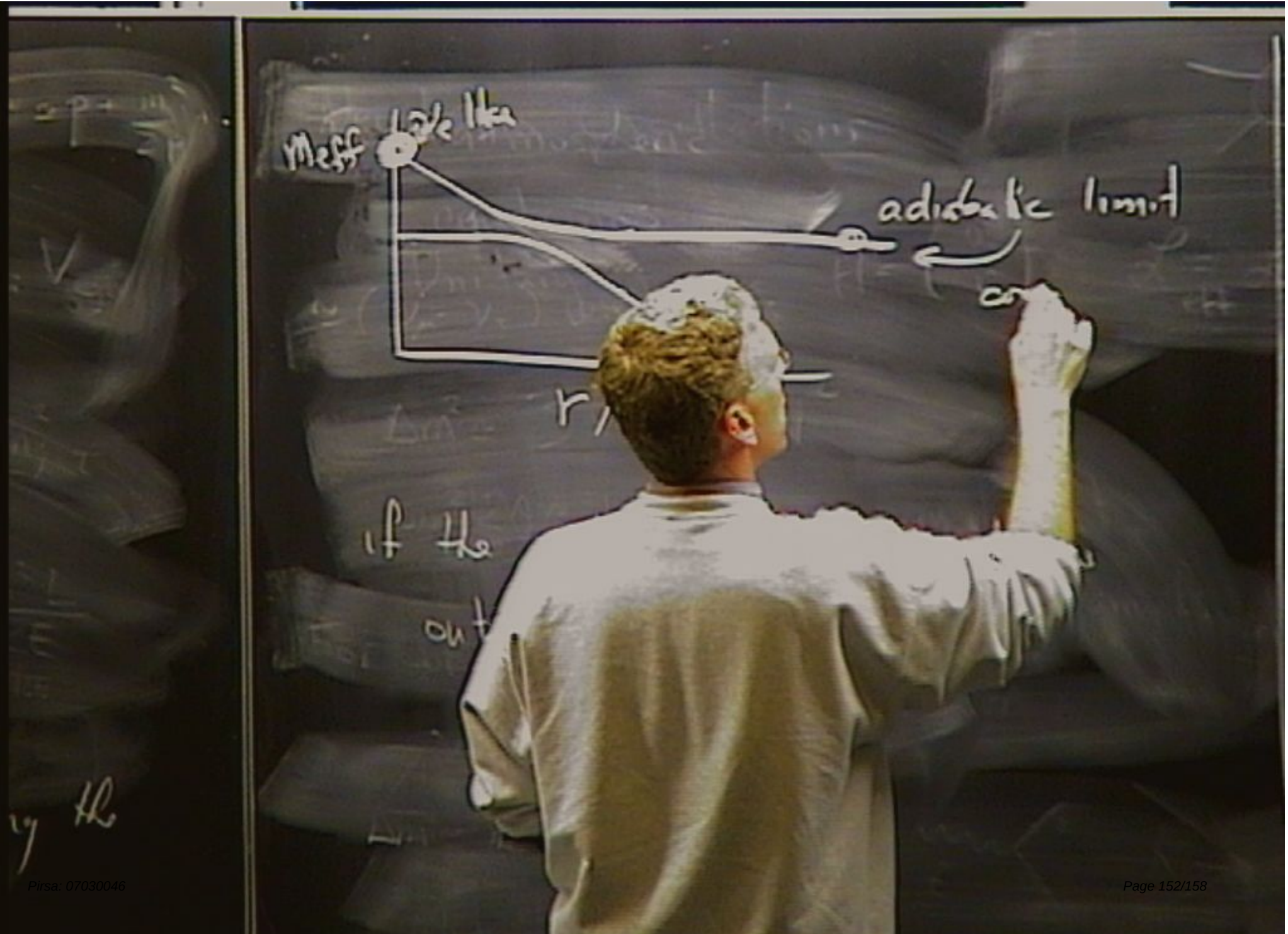
$m_{eff} \propto \frac{1}{2} \frac{1}{k_a}$

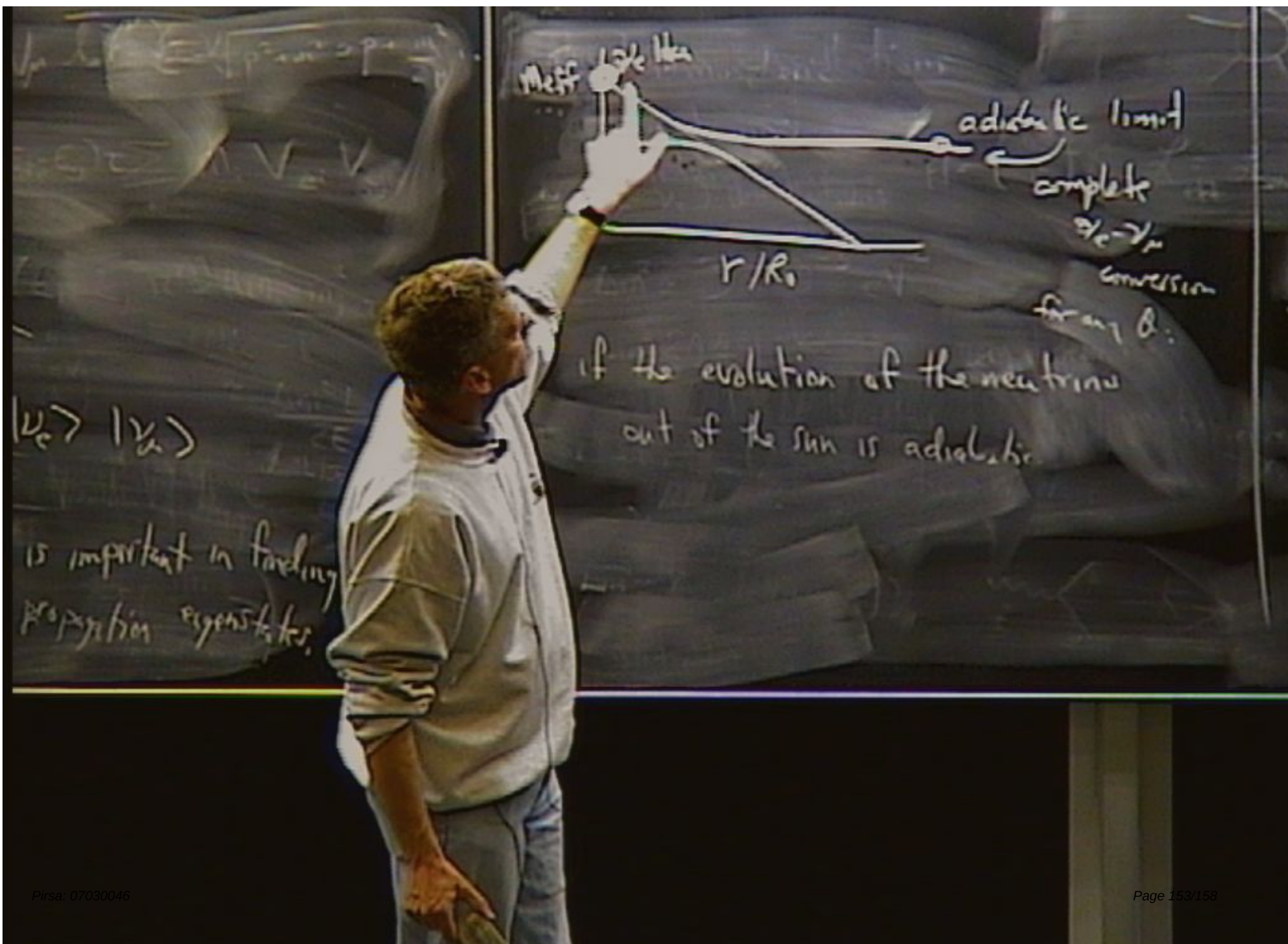


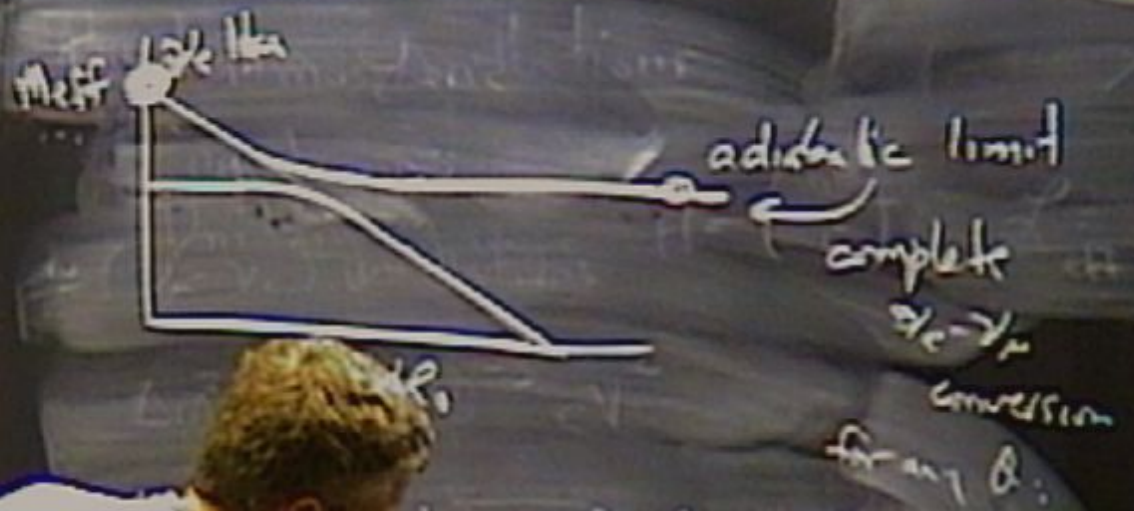
r/R_0







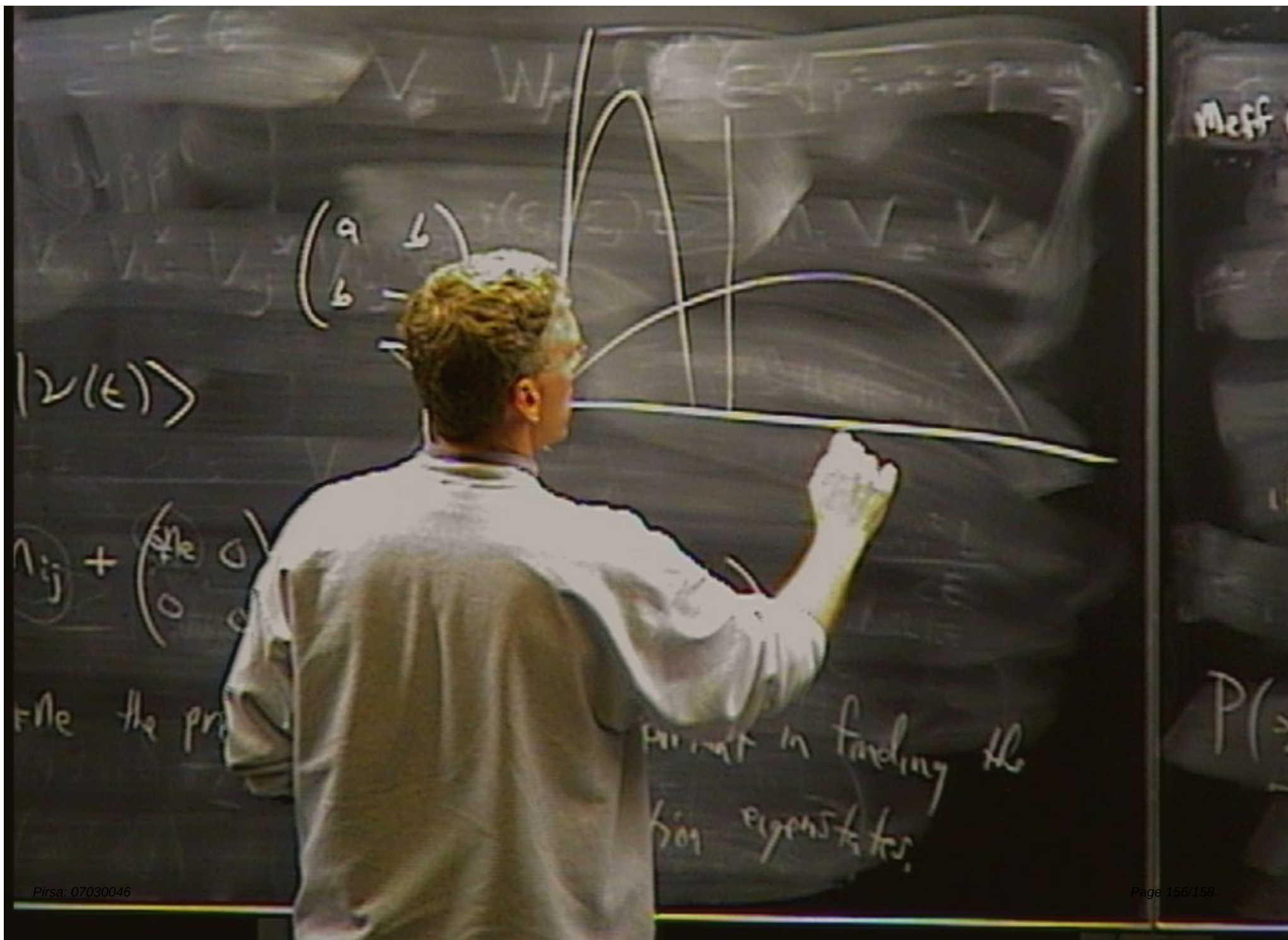


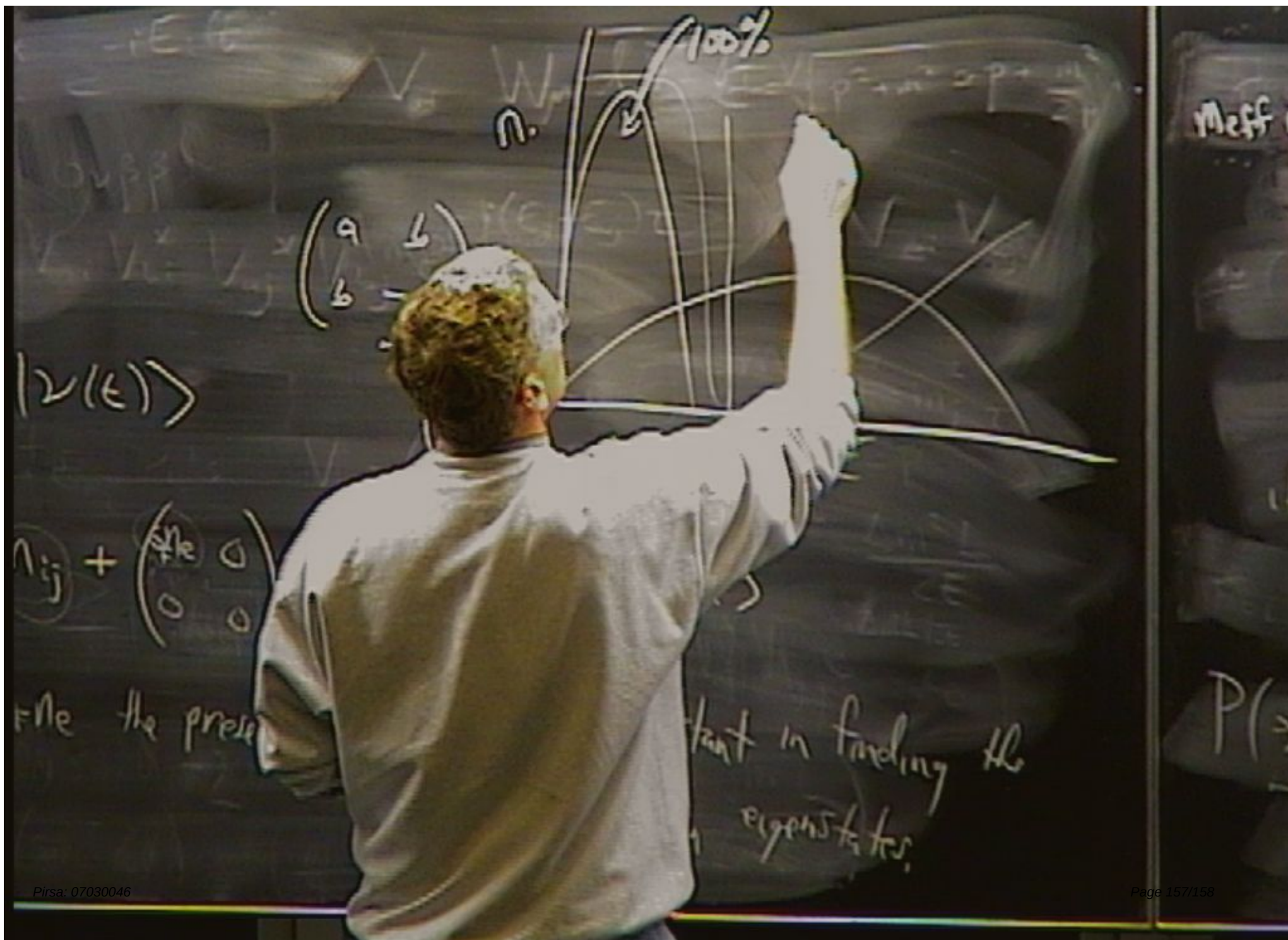


evolution of the neutrinos
of the sun is adiabatic.

147 148

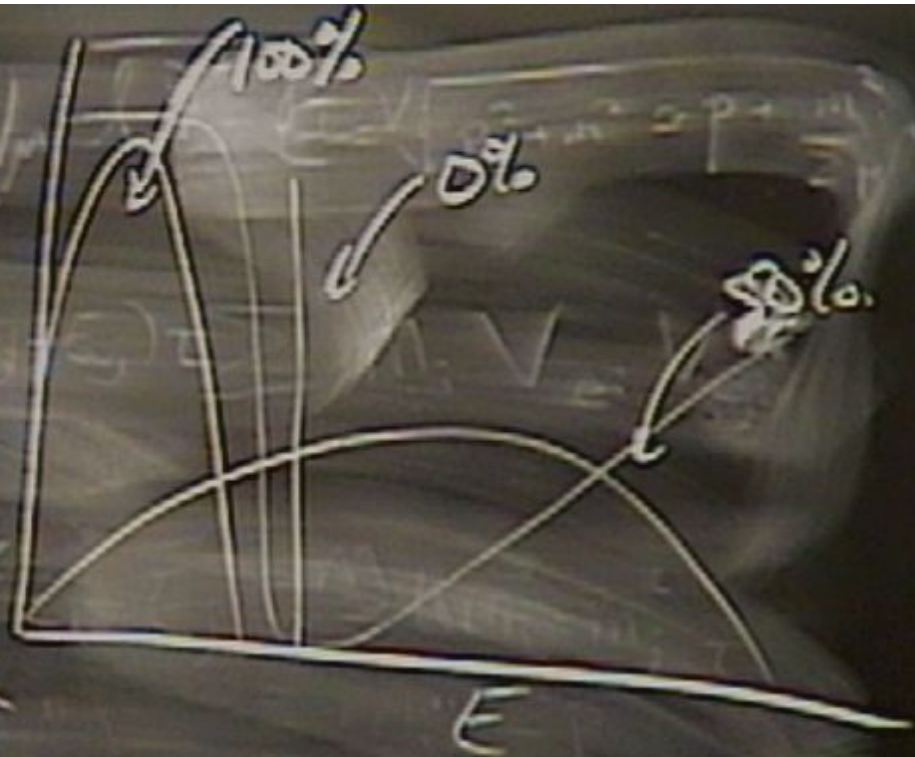
is important in finding the
propagation constants.





$$\begin{pmatrix} a & b \\ b & -a \end{pmatrix}$$

$|\nu(t)\rangle$



$n_{ij} + \begin{pmatrix} n_{ee} & 0 \\ 0 & 0 \end{pmatrix}$ in basis $|\nu_e\rangle |\nu_\mu\rangle$

the presence of matter is important in finding the propagation eigenstates.