

Title: 12/13 PSI - Standard Model Review Lecture 6

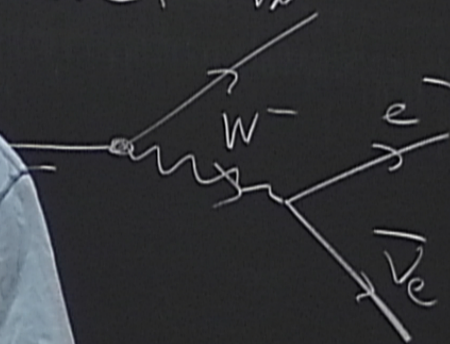
Date: Jan 14, 2013 09:00 AM

URL: <http://pirsa.org/13010031>

Abstract:

# Standard Model

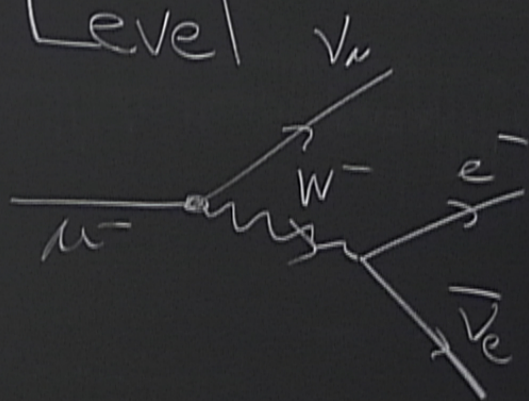
DT Level  $\nu_\mu$



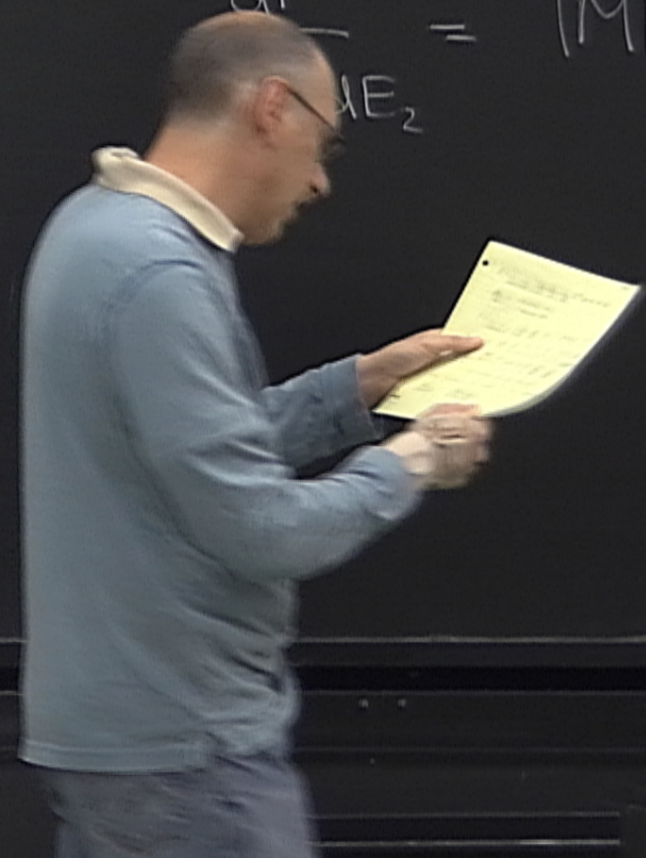


# Standard Model

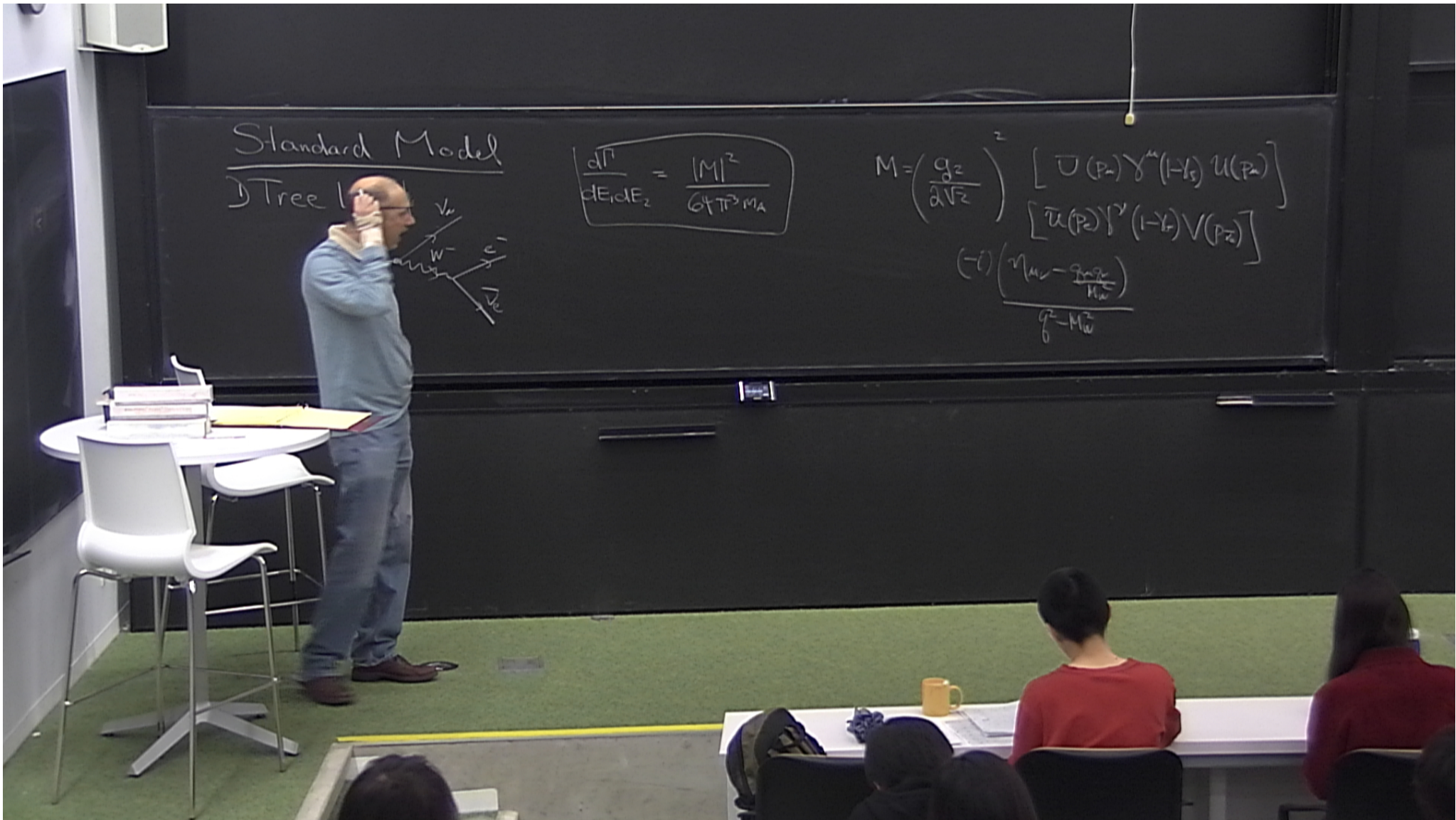
Tree Level



$$\frac{d\Gamma}{dE_2} = |M|^2$$



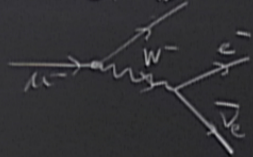






# Standard Model

Tree Level  $\nu_\mu$

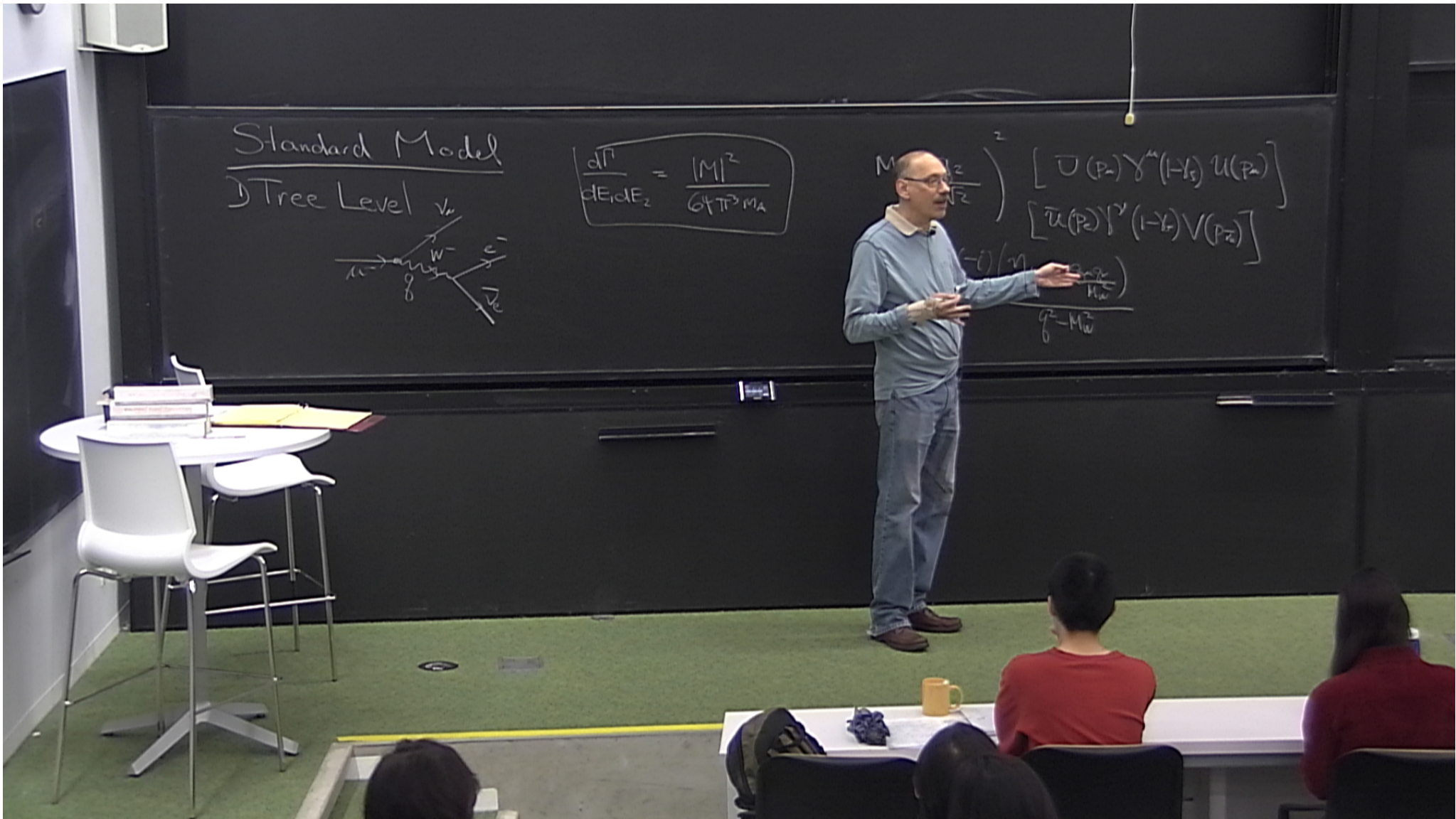


$$\frac{d\Gamma}{dE_1 dE_2} = \frac{|M|^2}{64\pi^3 M_A}$$

$$M = \left( \frac{g_2}{2\sqrt{2}} \right)^2 \frac{[\bar{U}(p_2) \gamma^\mu (1-\gamma_5) U(p_1)] [\bar{U}(p_2) \gamma^\nu (1-\gamma_5) V(p_2)]}{q^2 - M_W^2} (-i) \left( \eta_{\mu\nu} - \frac{q_\mu q_\nu}{M_W^2} \right)$$

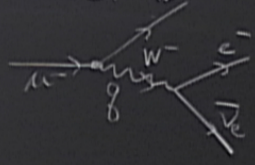






Standard Model

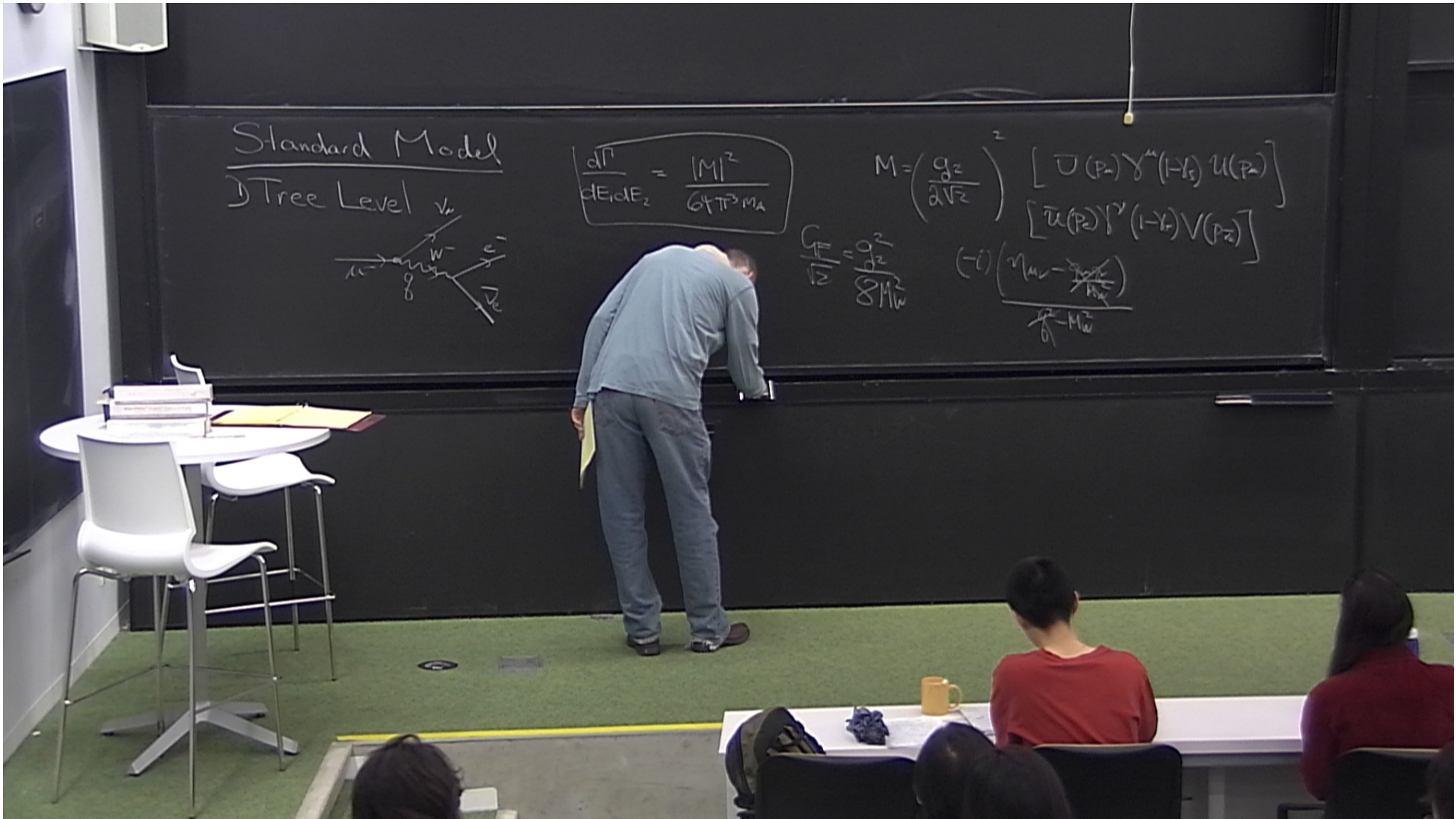
Tree Level



$$\frac{d\Gamma}{dE_1 dE_2} = \frac{|M|^2}{64\pi^3 M_A}$$

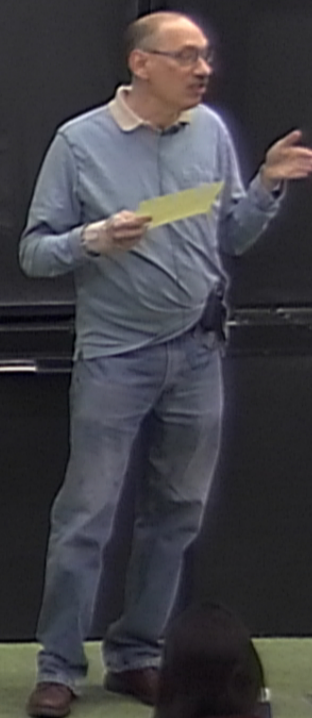
$$M = \frac{g^2}{8M_W^2} \left( \frac{1}{2} \right)^2 \left[ \bar{U}(p_2) \gamma^\mu (1-\gamma_5) U(p_1) \right] \left[ \bar{V}(p_3) \gamma^\nu (1-\gamma_5) V(p_4) \right] \frac{(-i)(\eta_{\mu\nu} - \frac{q_\mu q_\nu}{M_W^2})}{q^2 - M_W^2}$$







$$\begin{aligned} \frac{1}{2} \sum_{\text{spins}} |M|^2 &= \frac{G_F^2}{4} \frac{\text{Tr} [\not{\epsilon}_\mu \gamma^\mu (1-\gamma_5) (\not{p}_n + m_n) \not{\epsilon}_\nu (1-\gamma_5)]}{\text{Tr} [\not{p}_e \gamma^\mu (1-\gamma_5) \not{p}_n \gamma^\mu (1-\gamma_5)]} \\ &= 32 G_F^2 \left[ 2 m_n^2 E_e E_\nu - (E_e + E_\nu)^2 M_n^2 + \frac{M_n^2}{2} (E_e + E_\nu) \right] \end{aligned}$$





$$\frac{1}{2} \sum_{\text{spins}} |M|^2 = \frac{G_F^2}{4} \text{Tr} \left[ \not{\epsilon}_{\nu_n} \gamma^\mu (1-\gamma_5) (\not{p}_n + m_n) \not{\epsilon}_\mu (1-\gamma_5) \right] \\ \text{Tr} [\not{p}_e \gamma^\mu (1-\gamma_5) \not{p}_n \gamma^\mu (1-\gamma_5)] \\ = 32 G_F^2 \left[ 2 m_n^2 E_e E_{\nu_n} - (E_e + E_{\nu_n})^2 M_n^2 + \frac{M_n^2}{2} (E_e + E_{\nu_n}) \right]$$

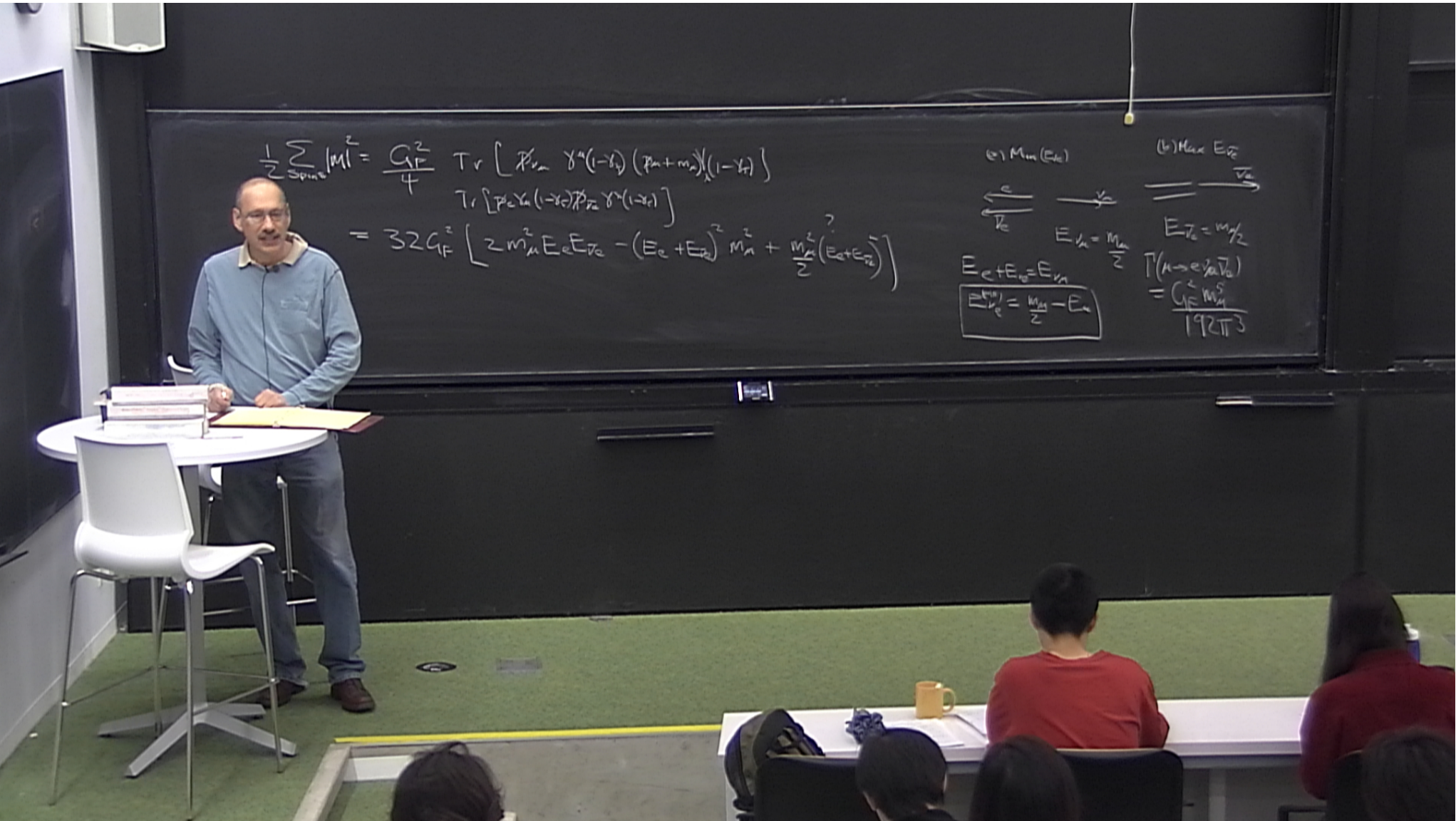
(c)  $M_{\mu\nu}(E_e)$

$$\begin{array}{c} \xleftarrow{e} \quad \xrightarrow{\nu_n} \\ \xleftarrow{p_e} \quad \xrightarrow{p_n} \end{array} \quad E_{\nu_n} = \frac{M_n}{2}$$

$$E_e + E_{\nu_n} = E_{\nu_n}$$

$$E_{\nu_n} = \frac{M_n}{2} - E_e$$







$$\frac{1}{2} \sum_{\text{spins}} |M|^2 = \frac{G_F^2}{4} \text{Tr} \left[ \not{p}_\nu \gamma^\mu (1-\gamma_5) (\not{p}_\mu + m_\mu) \not{p}_e (1-\gamma_5) \right] \\ \text{Tr} [\not{p}_e \gamma^\mu (1-\gamma_5) \not{p}_\mu \gamma^\nu (1-\gamma_5)] \\ = 32 G_F^2 \left[ 2 m_\mu^2 E_e E_\nu - (E_e + E_\nu)^2 M_\mu^2 + \frac{M_\mu^2}{2} (E_e + E_\nu)^2 \right]$$

(a) Min  $E_\nu$

$$\begin{array}{c} \leftarrow e \quad \rightarrow \nu \\ \leftarrow \bar{e} \quad \rightarrow \bar{\nu} \end{array} \quad E_\mu = \frac{M_\mu}{2}$$

$$E_e + E_\nu = E_\mu$$

$$E_\nu^{\text{min}} = \frac{M_\mu}{2} - E_e$$

(b) Max  $E_\nu$

$$\begin{array}{c} \rightarrow \nu \\ \rightarrow \bar{\nu} \end{array} \quad E_\nu = m_\mu/2$$

$$\Gamma(\mu \rightarrow e \bar{\nu}_\mu \nu_e) = \frac{G_F^2 M_\mu^5}{192}$$

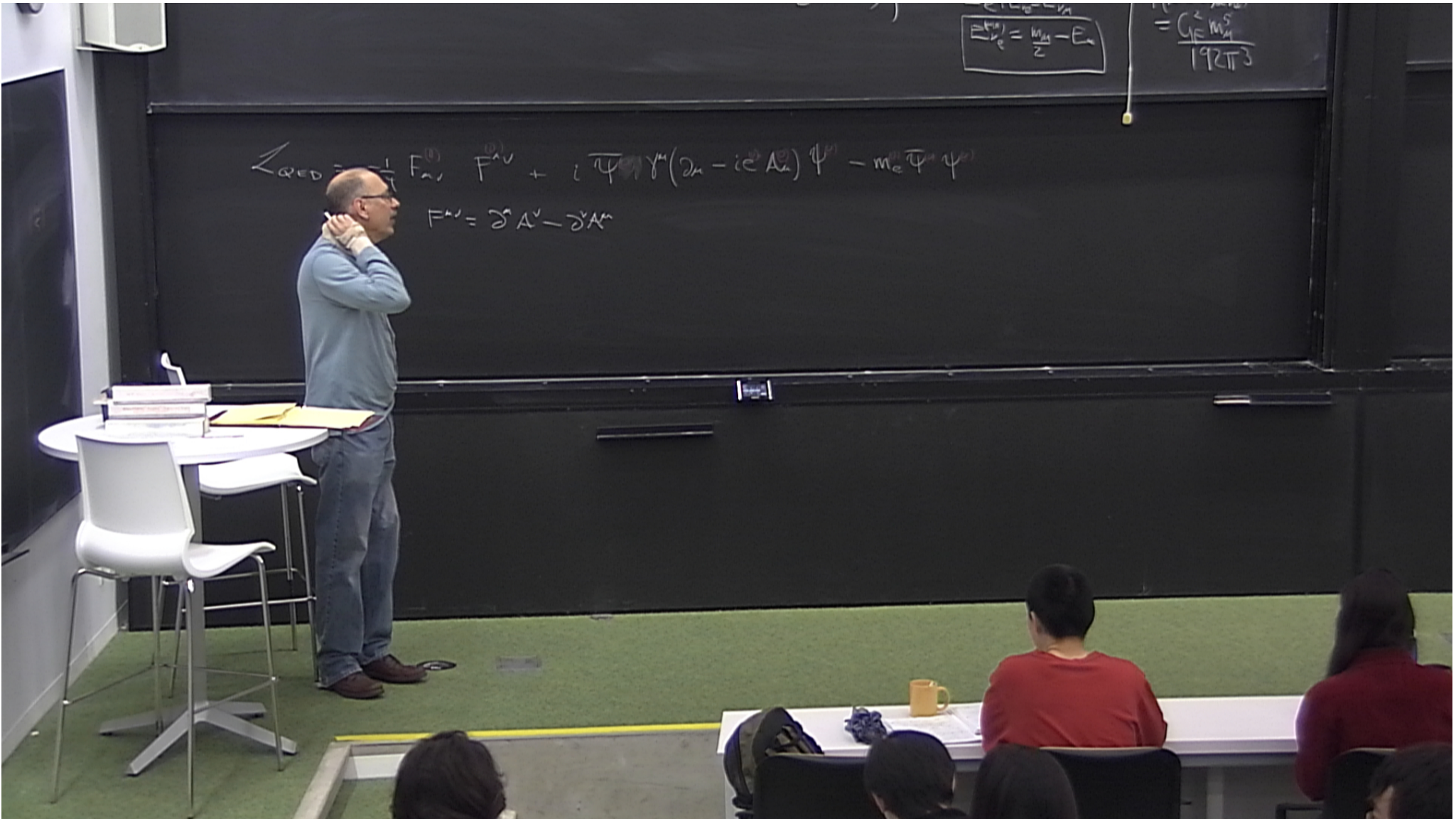


$$\mathcal{L}_{QED} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\Psi} \gamma^\mu (\partial_\mu - ie A_\mu) \Psi - m_e \bar{\Psi} \Psi$$

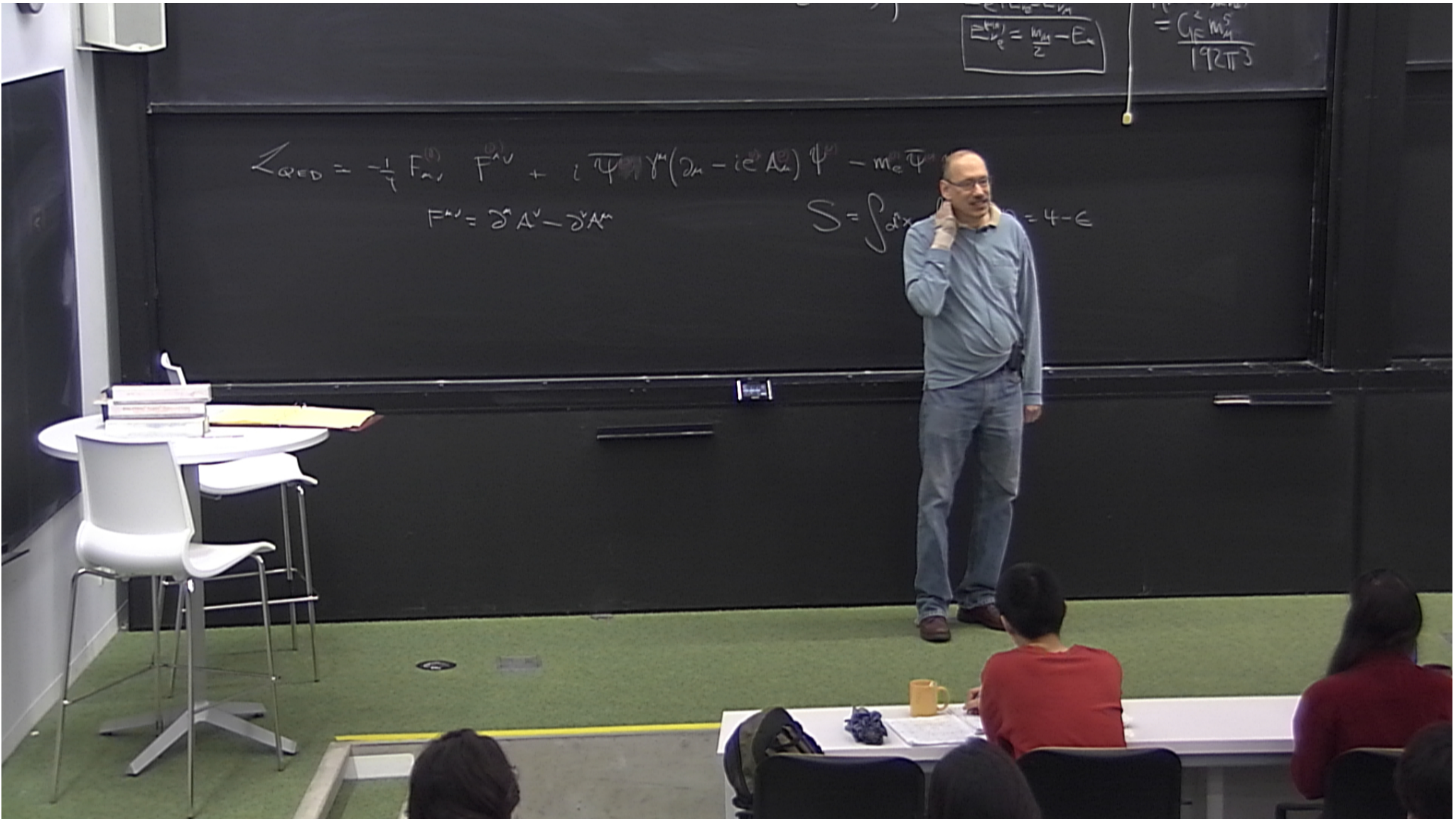
$$\frac{E_{\nu_e}}{E_e} = \frac{m_M}{2} - E_e$$

$$= \frac{G_F^2 m_M^2}{192\pi^3}$$

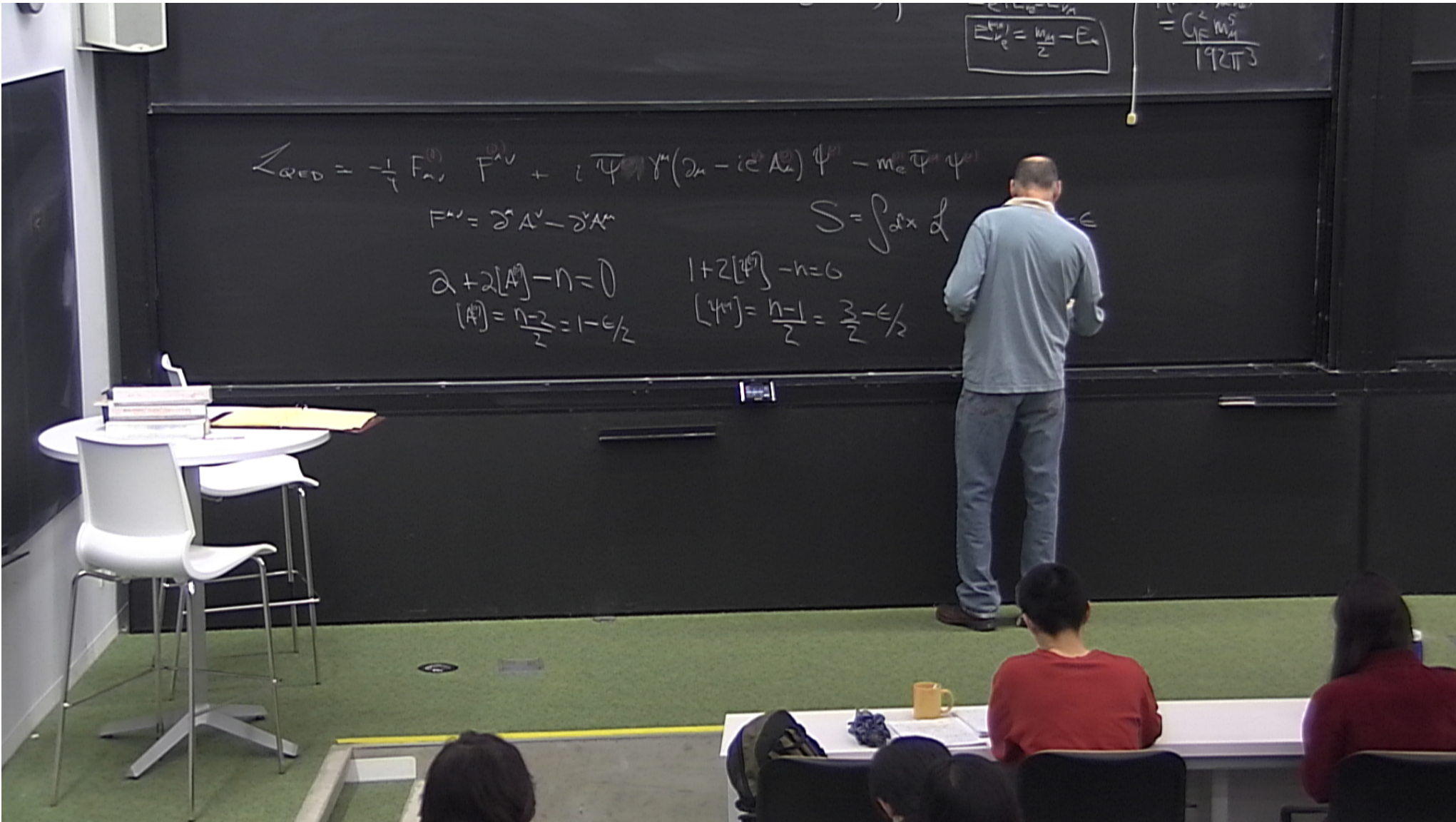














$$\Delta_n = \frac{1}{\sqrt{Z_n}} \Delta_n^{(e)}$$

$$\psi = \frac{1}{\sqrt{Z_\psi}} \psi^{(e)}$$

$$e = \frac{1}{Z_e} \psi^{(e)}$$



$$\Delta_n = \frac{1}{\sqrt{Z_\Delta}} \Delta_n^{(c)}$$

$$\psi = \frac{1}{\sqrt{Z_\psi}} \psi^{(c)}$$

$$e = \frac{1}{Z_e} \mu^{\frac{1}{2}} e^{(c)}$$

[ $\mu$ ] = 1

dimension  
ESS



$$\Delta_n = \frac{1}{\sqrt{Z_n}} \Delta_n^{(c)}$$

$$\psi = \frac{1}{\sqrt{Z_\psi}} \psi^{(c)}$$

$$e = \frac{1}{Z} \mu^{\text{th}}$$

dimension  
ESS



$$A_\mu = \frac{1}{\sqrt{Z_A}} A_\mu^{(c)}$$

$$\psi = \frac{1}{\sqrt{Z_\psi}} \psi^{(c)}$$

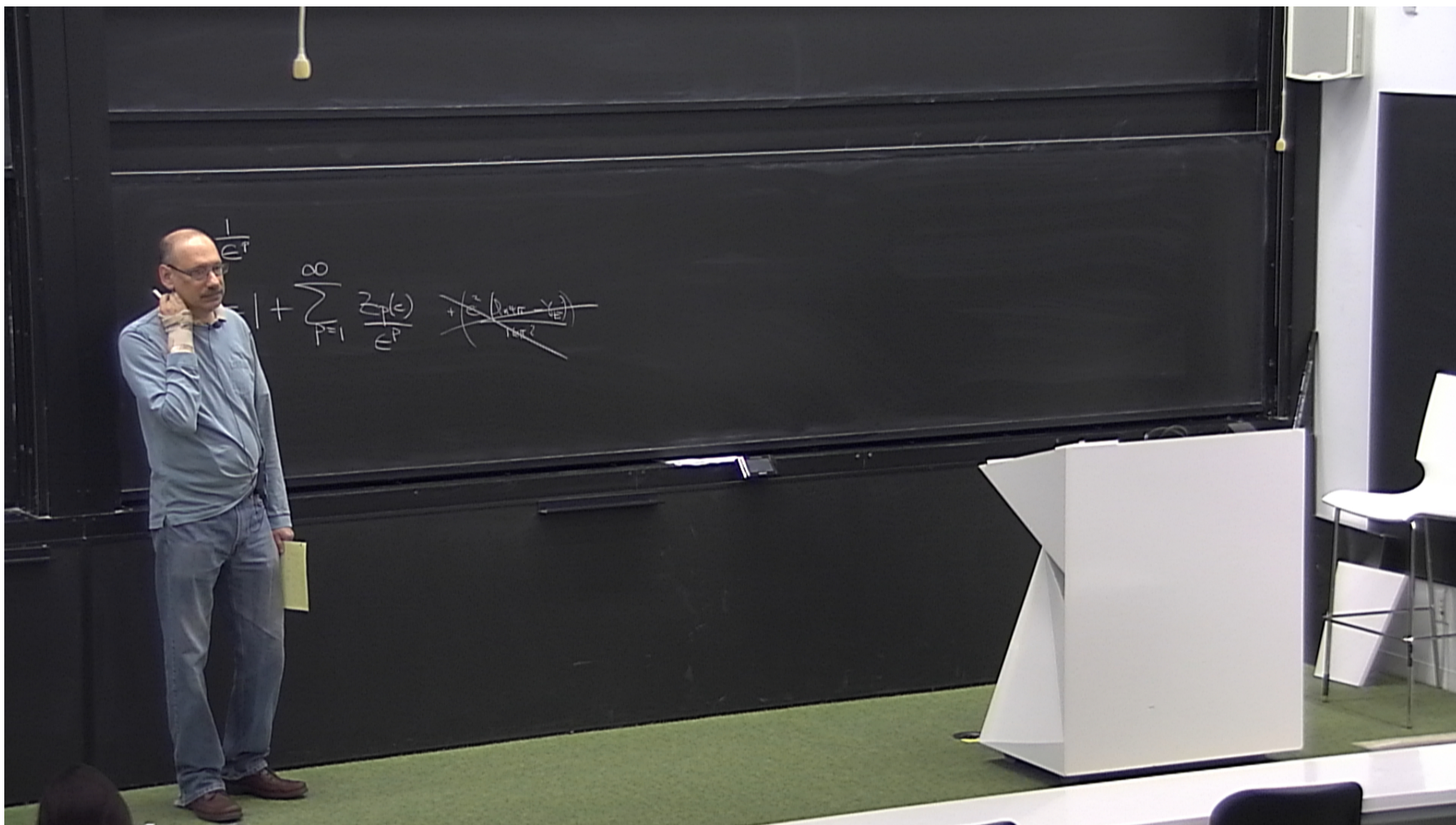
$$e = \frac{1}{Z_e} \mu^{1/2} e^{(c)} \quad [e] = 1$$

dynamical CSJ

$\mu$  is called subtraction point

$$\begin{cases} \mathcal{L} = -\frac{1}{4} Z_A F_{\mu\nu} F^{\mu\nu} + i Z_\psi \bar{\psi} \gamma^\mu (\partial_\mu - (i\mu^{1/2} Z_e \sqrt{Z_A} e A_\mu) - Z_m Z_\psi m) \psi \\ \quad - F^{\mu\nu} + i \bar{\psi} \gamma^\mu (\partial_\mu - (i\mu^{1/2} A_\mu) \psi - m_e \bar{\psi} \psi + \text{counter terms} \end{cases}$$





$$\frac{1}{\epsilon^r} = 1 + \sum_{p=1}^{\infty} \frac{Z_p(\epsilon)}{\epsilon^p} + \left( \frac{\epsilon^2 (D_{\text{eff}}^2 - \epsilon^2)}{1 - \epsilon^2} \right)$$



$$\frac{1}{\epsilon^r}$$

$$Z = 1 + \sum_{p=1}^{\infty} \frac{Z_p(\epsilon)}{\epsilon^p} + \left( \frac{\epsilon^2 (0.4\pi - \gamma(\epsilon))}{1.6\pi^2} \right)$$



